NAAC Criterion VII	Institutional Values and Best Practices
Key Indicator: 7.3	Institutional Distinctiveness
Metric: 7.3	University Excellence in the Mitigation of Climate Change Leading to Innovation of Technology

7.3: Institutional Distinctiveness:-

University Excellence in the Mitigation of Climate Change Leading to Innovation of Technology

Content

Project completion report

on

“High Energy Density Thermal Energy Storage for Concentrated Solar Plant”

HIGH ENERGY DENSITY THERMAL ENERGY STORAGE FOR CONCENTRATED SOLAR PLANT

(File No. 15/12/2014-15/ST dated 21 July 2015)

Project Completion Report

PI: Dr V K Sethi,
Vice Chancellor RKDF University

RKDF UNIVERSITY

Airport Bypass Road, Gandhi Nagar, Bhopal (M.P.)
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Annexure XVII

Performa for Project Completion Report (PCR)

15 nos. each of the physical (bound) and electronic (CD) copies of the Project Completion Report (PCR) should be sent within one month of the completion or termination of the project. The cover page should include the title of the project; file number, names and addresses of the PI and grantee institution / organization.

1. **Title of the project**: **High Energy Density Thermal Energy Storage for Concentrated Solar Plant**

   i. **Principal Investigator(s)** : Dr. V.K Sethi Vice Chancellor, Ram Krishna Dharmarth Foundation (RKDF) University
   Co-Investigator(s): Dr. Partha S. Dutta, Deputy Director, Rensselaer Polytechnic Institute (RPI), NY, USA

   ii. **Implementing Institution(s) and other collaborating Institution(s)**: Ram Krishna Dharmarth Foundation (RKDF) University, Bhopal, M.P
   Collaborating Institution: Rensselaer Polytechnic Institute, NY, USA

4. **Date of commencement of Project**: 6th September, 2015

5. **Approved date of completion**: 6th March, 2017

6. **Actual date of completion**: 18th Marach,2017

7. **Objectives of the Project**: The goal of this project is to demonstrate a solar thermal storage system with 1 kW capacity of volumetric energy density exceeding 300 kWh/m^3, capable of operating at high temperatures up to 1000^{O}C in comparison, the volumetric energy storage density for water is typically around 80 kWh/m^3 and 200 kWh/m^3 for molten salts used in solar thermal plants.

8. **Output of the Project**:
   - Design and construction of a prototype 1kW capacity solar thermal energy storage system with volumetric energy density exceeding 300 kWh/m^3, capable of operating at high temperatures up to 1000^{O}C
   - The unique aspects of this system are the selection of an alkali halide salt with high melting temperature and a corrosion-resistant, low-cost ceramic container material. The thermal storage unit is coupled with a high solar concentrator system (1000 – 10,000 Xs).In this project, we have proposed to develop and demonstrate an affordable, high Energy density thermal storage system that can store heat at temperatures around 1000 ^{O}C.

- Field data on energy storage capacity and energy losses of the prototype system.
- Economic analysis of the solar thermal energy storage system.
- Joint IPR from the research.
- Research papers on the final system design and field testing data.

(Achieved vis-à-vis. originally planned in respect of:

i) Nature of Output: Material/Process/Product/Equipment/ Pilot scale demonstration/Any other (Please Specify) : **PILOT SCALE DEMONSTRATION**

ii) Performance specifications : Purity of materials, process details, product specifications (capacity, rating, efficiency, test results) Equipment (performance features, capacity, bill of materials), Pilot production (capacity, through put, yield, test results):

Details as per ENCL: 08

iii) Details of engineering designs/ drawings (plans and sections) and prototype/ pilot/ full scale, specifications, etc.

(Refer PLATE: 1, 2 and 3& Assembly as per Figures 2&3 below)

9. Summary of the Project work, especially with respect to the project objectives and proposed Output.

The project is being conducted with the following objectives:

i. Design and construction of a prototype 1kW capacity solar thermal energy storage system with volumetric energy density exceeding 300 kWh/m^3, capable of operating at high temperatures up to 1000^{O}C
ii. Field data on energy storage capacity and energy losses of the prototype system.
iii. Economic analysis of the solar thermal energy storage system.
iv. Joint IPR from the research.
v. Research papers on the final system design and field testing data.

The task (a) has been completed. Tasks (b) and (c) are underway. Tasks (d) and (e) will be accomplished after tasks (b) and (c) are accomplished at the completion of this project. Below is a summary of the milestones achieved in this project to-date:

9.1 The Solar thermal Unit with Tracker auto operation and associated software has been installed. This unit is currently operational in semi-manual mode.

(ENCL: 01- A view of the Pilot Plant)

9.2 The energy storage core assembly with heat exchanger boiler feed pump, piping etc has been erected and commissioned.

9.3 The temperature achieved at the tip of solar focal point was about 1400^{O}C. The temperature at the core mid-point was found to be of the order of 310 ^{O}C which may be sufficient to generate steam for heat transfer studies.

(ENCL: 02- Steam Generation from the Core)

9.4 Engineered composition of energy storage material (salt crystals) was grown at RPI which has the melting point, specific heat capacity and density to enable high energy storage density excess of 300 kWh/m^3 and operating temperature around 1000^{O}C.

9.5 Approximately 240 lbs (110 kg) of high quality crystals were synthesized and grown at RPI. The salt crystals were shipped to RKDF and used in the field unit.

9.6 The salt crystal has been tested for its resistance to moisture and humidity unlike pure NaCl crystals. Materials left in a storage unit throughout the rainy season in Bhopal (covered with simple metal container or plastic bags) did not capture moisture.

(ENCL: 03- Heating of the Salt Crystals)

9.7 The economic calculation for the laboratory scale synthesis of the engineered salt crystals has been performed. The cost of this storage material is calculated as $1.9/kWh and the energy stored per unit mass is 140 Watt hr./ kg

(140 Wh/kg x2200 kg / m^3 = 308,000 Wh/m^3 = 308 kWh/m^3 say, 300 kWh/m^3)

9.8 The temperature necessary to achieve a thermal energy density of 300kWh/m^3 has been calculated to be 565 ^{o}C based on the properties of the salt crystals. Hence heating it higher than 565 ^{o}C will help in reducing the size (volume) of the storage unit.

(ENCL: 04- Thermal Energy Density Calculation for Salt Crystals)

9.9 A specific formulation of SiC nanoparticle based high temperature corrosion resistance coating has been developed at RPI. A quantity of 3 liters of the SiC-polymeric nano-composite was delivered to RKDF University and was used for coating the interior metallic surfaces of the thermal storage unit.

9.10 We have achieved a drop in temperature at the middle of core to the tune of 2-2.5 ^{O}C per hour in 15 hours from 310 ^{O}C to 278 ^{O}C.

9.11 Direct steam generation by heating the water directly at the focal point of the lens has been demonstrated.

9.12 To transport heat efficiently from the focal point of the lens to the salt core, the thermal properties of the following materials have been compared: copper, cast iron, aluminium, cast copper alloy (C90500; gun metal). Based on the analysis, cast iron and copper heat transfer rods and cage has been fabricated and tested.

9.13 While copper provides better heat conduction compared to cast iron, it is significantly more expensive than cast iron. At the same time, it has been observed that there are no significant benefits in using copper over cast iron rod due to following reason (next point).

9.14 The energy loss due to radiative heat (emission) from the tip of the metal rod at the focal point of the lens has been found to be extremely high due to which the energy transfer to the salt core has been impeded.

9.15 Experiments are underway to reduce the radiative heat losses at the focal point of the lens by a variety of methods involving geometric configuration of the metal receiver.

9.16 To enable better heat transport in the salt, a variety of trials are underway using different salt crystal sizes, mixing salt crystals with metal fillers, etc.

9.17 Alterations in the experimental configuration is being planned to directly heat the salt crystals using radiation instead of using a metal receiver.

9.18 Experiments at RPI are underway for advanced heat transport from the hot surfaces to a thermal reservoir without molten salt carrier fluid that is used in solar thermal plants. This will avoid high cost of operation and maintenance related to molten fluid transport. Any promising approaches will be immediately translated to the field unit at RKDF.

9.19 Efforts at RKDF are underway to generate steam from the heat stored in the salt core. This will be possible once effective ways to transport heat from the focal point to the salt reservoir has been accomplished and suitable insulation has been provided to store the heat.

9.20 Due diligence has been conducted to benchmark existing global CSP plants and the CSP plants under construction in India. The capital cost and electricity selling cost (tariffs) has been compared with PV installations. This is necessary for further advancing the engineering design of the system being experimented in this project and economic feasibility for a large scale adoption in the future.

9.21 Initial calculation for the solar thermal technology using the current distributed storage with Fresnel lens approach (instead of reflecting mirrors) has been conducted. The economic analysis is being compared with existing field installations including the CSP plants under construction in India.

9.22 Economic analysis indicates a strong case for integrating the current system with existing large steam turbines such as used in coal fired plants (exceeding 50 MWe capacity). Standalone units of lower turbine capacity might suffer from higher electricity generation cost due to lower efficiency of steam turbines (lower capacity).

9.23 Direct generation of hot water, other fluids and steam using this stand-alone approach can be made economically feasible using this approach.

(ENCL: 05- Transfer of Technology Efforts by RKDF University at RPI, New York, USA)

9.24 Conventionally Molten Salt is being used as Thermal Storage Material however in view of experience of Co-PI of this project Dr. Dutta of RPI, USA as consultant of DoE, USA Solid Pathway has been used.

(Details as per ENCL: 06)

10. **Detailed progress report giving relevant information on work carried out, experimental work, detailed analysis of indicating contributions made towards increasing the state of knowledge in the subject**:

Performa for Submission of Progress Report of The Project

10.1 Project Title :- **High Energy Density Thermal Energy Storage for Concentrated Solar Plant**

10.2 MNRE Sanction order No &date: - **15/12/2014-15/ST& date 21st July, 2015.**

10.3 Name and complete address of PI: - **Dr. V.K. Sethi, Vice Chancellor,**
Ram Krishna Dharmarth Foundation (RKDF) University, Bhopal

10.4 Name and complete address of Co-PI from other participating Institution **Dr. Partha S. Dutta, Deputy Director, Rensselaer Polytechnic Institute, NY, USA (RPI)**

10.5 Date of start of the project and Scheduled completion date **6th September 2015 - 18th March 2017**

10.6 Approved project budget **Rs.36,00,000 (MNRE) + 5,00,000 (RPI)**

10.7 Total funds released by MNRE:

Sl. No.	Sanction No.	Date	Amount (Rs.)
1.	**15/12/2014-15/ST**	**21st July, 2015**	**20,00,000/-**
2.	**15/12/2014-15/ST**	**15th March 2016**	**6,00,000/-**
3.	**15/12/2014-15/ST**	**30th August, 2016**	**9,00,000/-**
Total:			**35,00,000/-**

10.8 **Actual expenditure as on date enclosing SoE and UC**: **Rs. 34,98,943.51**

10.9 **Approved Objectives of the Project**

- Design and construction of a prototype 1kW capacity solar thermal energy storage system with volumetric energy density exceeding 300 kWh/m^3, capable of operating at high temperatures up to 1000^{O}C
- Field data on energy storage capacity and energy losses of the prototype system.
- Economic analysis of the solar thermal energy storage system.
- Joint IPR from the research.

- Research papers on the final system design and field testing data.

10.10 THE GOAL OF THE PROJECT

- The goal of this project is to demonstrate a solar thermal storage system with 1 kW capacity of volumetric energy density, exceeding 300 kWh/m^3 and capable of operating at high temperatures up to 1000 C. In comparison, the volumetric energy storage density for water is typically around 80 kWh/m^3 and 200 kWh/m^3 for molten salts used in solar thermal plants.

- The unique aspects of this system are the selection of an alkali halide salt with high melting temperature and a corrosion-resistant, low-cost ceramic container material. The thermal storage unit is coupled with a high solar concentrator system (1000 – 10,000 Xs).In this project, we propose to develop and demonstrate an affordable, high energy density thermal storage system that can store heat at temperatures around 1000 ^{O}C.

10.11 Output of the Approved project

- The Solar thermal Unit with Tracker auto operation and associated software has been installed. The core assembly with heat exchanger boiler feed pump, piping etc. has been erected & commissioned along with MS, Copper & Cast Iron core for heat transfer..
  The temperature achieved at the tip of solar focal point about 1400^{O}C. The temperature at the core mid-point was found to be of the order of 310 ^{O}C which is sufficient to generate steam for heat transfer studies.

10.12 Summary of the Progress reported (September 2015 to March 2017): BACKGROUND

- Energy storage in form of heat offers a potential pathway for small (local) and large (utility power plants) scale applications. Thermal storage systems provide a unique opportunity to store energy locally in the form of heat that cannot be transported over long distances. Current thermal storage systems are still in its infancy. The most common ones are large, water-heating storage tanks and molten salt-based systems at solar power plants. These systems have been designed based on the economics of water and salt, the heat capacity of water, and the latent heat of salts. Research on a large host of sensible heat storage and phase-change materials have been conducted over the past two decades. The materials parameters that are relevant for this application are: melting point, boiling point, vapor pressure, density, heat capacity, thermal conductivity, latent heat of fusion and chemical reactivity.

- While it is intuitive that increasing the temperature of storage could pack in more energy, barriers to the development and deployment of high energy density storage remain, including handling materials at high temperatures, associated systems costs, and operating costs. Thus sensible thermal storage systems are cost prohibitive. Phase change materials (PCM) do provide a viable economical solution for higher energy storage density. However, operation temperatures limit current PCM systems; higher temperatures cause chemical instability and reactivity with containers. Development of affordable high-density thermal storage system will only be possible by utilizing low cost earth abundant thermal storage materials in conjunction with suitable thermally insulating container materials.

- Current heat storage systems utilize either sensible heat storage (i.e. water in storage tanks) or latent heat storage (i.e. phase-change materials such as molten salts). The relatively low operating temperatures of these systems limit their capacity to store thermal energy; storage systems with higher temperatures would be more economical. In this project, we are developing an affordable high energy density thermal storage system that can store heat at temperature around 1000 ^{O}C. The unique aspects of this system are the selection of an alkali halide salt with high melting temperature and a corrosion resistant cheap ceramic container material. The thermal storage unit will be coupled with a high solar concentrator system (1000 – 10,000 x).

PROGRESS SUMMARY

- As a part of an on-going project funded by MNRE, the RPI group has developed flux grown crystals of high melting temperature (700 – 1500 ^{O}C) mixed alkali halide compounds doped with metallic impurities to enhance thermal conductivity. The trade-off between material density, specific heat capacity, thermal conductivity and cost of raw material has been evaluated to develop a material system that could meet the system's specification at cost of energy storage lower than current electrochemical systems (batteries). In addition, a SiC based composite polymeric coating solution has been developed to avoid corrosion of steel containers used for the thermal storage unit. These materials have been shipped to RKDF and incorporated into the field unit (test-bed).

- Since the inception of this project in September 2015, the engineering design phase was completed by November 2015. Dr. Dutta visited RKDF University and the sponsor (MNRE, New Delhi) in December 2015 to jump start the fabrication and installation of the field unit. Significant progress has been made since then. The field unit (test-bed) was fully installed by May 14th, 2016. Currently, solar heating and overnight cooling cycles are being collected on an hourly basis. A series of temperature profiling experiments inside the thermal storage unit for benchmarking with other earth abundant materials such as iron filings, sand, used vegetable oil, fly ash from coal power splants; rocks, etc. have been performed till August 2016.

- The test-bed at RKDF comprises of a thermal storage unit, Fresnel lens based solar tracking unit to focus sunlight into the thermal storage media and a steam generation unit (for future electricity generation using a steam turbine). **Figure 2** shows the field site of the thermal storage power generation system at RKDF University in Bhopal. **Figures 3-4** shows show the installation and initial evaluation activities of the solar thermal storage unit at RKDF University.

- The Co-PI Dr. Partha. S. Dutta from RPI, USA, has experimentally measured the Crystals were grown in his lab at RPI to have high energy density in excess of 300 kWh/m^3 with operating temperature around 1000^{O}C. Approximately 240 lbs of high quality crystals were synthesized and grown. These crystals were shipped to RKDF and used in this proto type unit. Further experiments at RPI, USA are on for enhancing energy density of crystals.

- During 3 days of trial run from 11 May to 14th May 2016, we have achieved a drop in temperature at the middle of core to the tune of 2 to 2.5 ^{O}C per hour in 15 hours from 310 ^{O}C to 278 ^{O}C. The trial operations will continue for about 6 month to get study steam flow at highest possible temperature and pressure to run the steam turbine for Power generation to the tune of 300 W electric (1000W thermal).

- The temperature achieved at the tip of solar focal point about 1400^{O}C. The temperature at the core mid-point was found to be of the order of 310 ^{O}C which may be sufficient to generate steam for heat transfer studies.

Figure: 1. Flux grown crystals of mixed alkali halide compounds doped with metallic impurities.

Figure: 2. Installation of the solar thermal storage and solar tracker unit at RKDF university

Figure:3. Demonstration of the solar thermal storage unit

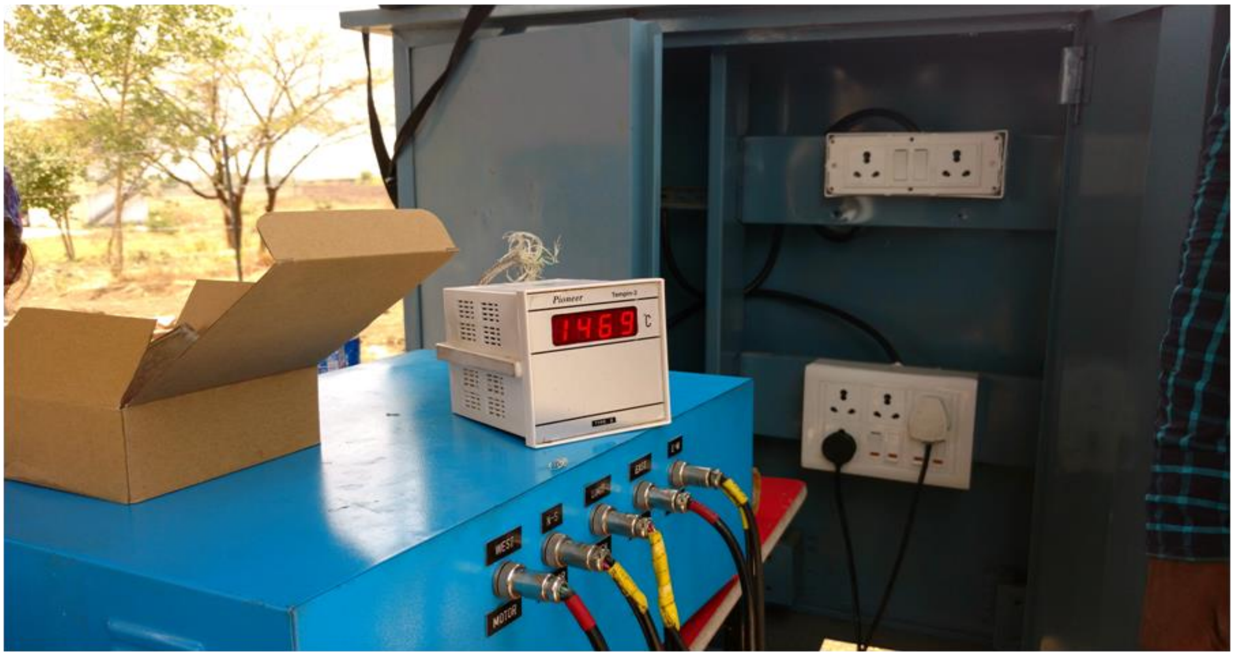


Figure:4 . Temperature measured at the collection point of the solar thermal storage unit

10.13 Other achievements and Publications etc.:

Ph. D students working on the subject/ topic covered under the project : **02 Nos.**	Technical Personnel trained: **07 Nos. Students of the University working on the project**	Research Publications arising out of the present project: **04 Nos.**

List of Publications from the Project Work (including title, author(s), journals & year(s)

i) Papers published in International Journals: b**y CO-PI (02)**
ii) Papers published in Conference Proceedings: b**y PI (01)**
iii) Papers published in National/ other Journals etc.: b**y PI**(**01**)
iv) Patents filed/ to be filed (if any): **In progress**
v) Confidential Data (if any):NA

10.14 Status of Equipment Procurement:

Sl. No.	**Sanctioned items of equipment**	**Procurement status**	**Working (Yes/ No)**	**Remarks (Give reasons for negative response)**
1	**Solar Tracker Unit + Lens**	Received, Erected, Commissioned and tested.	**Yes.**	--
2	**Heat Transfer Unit**	Received, Erected, Commissioned and tested	**Yes**	---
3	**Salt Crystals for Core Assembly from RPI USA**	Received, Erected, Commissioned and tested	Working, performance testing will be done using revised core in high solar flux period of April / May 2017	The procurement of revised core is being done for improved steam generation using Cast Iron Crucible design

10.15 Status of Manpower:

S No	Sanctioned List	In position (Yes/ No)	Scale	Remarks (Give reasons for negative response)
1.	**Research Scholars-7 Nos.**	**Yes**	**2000 PM each**	**-**
2.	**Accountant**	**Yes**	**2000 PM**	**-**

10.16 New observations: **Plant trial run completed, performance testing scheduled in March to May 2017**

- ➢ The temperature achieved at the tip of solar focal point about 1400^{O}C. The temperature at the core mid-point was found to be of the order of 310 ^{O}C which may be sufficient to generate steam for heat transfer studies.
- ➢ During 3 days of trial run from 11 May to 14th May 2016, we have achieved a drop in temperature at the middle of core to the tune of 2 to 2.5 ^{O}C per hour in 15 hours from 310 ^{O}C to 278 ^{O}C.

10.17 Innovations:

Temperature up to 1485 ^{O}C achieved at focal point and the temperature loss of the Salt Core is less than 2.5 ^{O}C per hour in the night.

10.18 Application Potential:

Long term
i) Medium term } **As per Para 10.12- Background**
ii) Short term

10.19 Research / technology development work remaining to be done under the project and Work Plan for next six months.

The trial operations will continue for about 3 month till May 2017 to get steady Steam flow using revised cast iron core at highest possible temperature and pressure suitable to run the steam turbine for Power generation to the tune of 300 W electric (1000W thermal) and residual heat for producing power through TPV.

10.20 Status of Financial year wise UC and SoE: **Up to date SoE and UC are attached**

24.1.17

(Dr. V K Sethi, PI)

Vice Chancellor
RKDF University
Airport Bypass Road, Gandhi Nagar
BHOPAL (M.P.) 462033

11. S&T benefits accrued:

i) Patents taken, if any: No

ii) List of Research publications (a copy of the papers should be attached):

Sl. No	Authors	Title of paper*	Name of the Journal	Volume	Pages	Year
1.	Dr. V.K. Sethi	An Innovative Approach for Carbon Capture & Sequestration on a Thermal Power Plant through Conversion to Multi-Purpose Fuels – A Feasibility Study in Indian Context	ScienceDirect	-	9	2017
2.	Dr. Partha S Dutta	Books related to TE & TPV devices for Power generation through Thermal Energy as under*	-	-	-	2016

iii) List of Technical Documents prepared (a copy of the documents should be attached):

Proceeding & Recommendations of Seminars conducted & details of Coursework on "Optoelectronics & Solid State Physics" attached at ENCL: 07

*P.S. Dutta, *Optoelectronics and Photonics Engineering*, Textbook for senior level undergraduate and entry level graduate students, Publisher: Springer, New York (*2016*)

*P.S. Dutta, *Applied Solid State Physics*, Textbook for senior level undergraduate and entry level graduate students, Publisher: Springer, New York (*2016*)

iv) **Manpower trained under the project**:

a) Research Scientists/ Research Associates: 07 Nos. **As per details at Para 16 Below**

b) No. of Ph.D. (s) produced: 02

c) Other Technical Personnel trained: NO

v) Awareness, training camps, etc. organized:

(1) **National Seminar on R&D Efforts in Energy Sector towards Mitigation of Climate Change**
November 3, 2015

(2) **International Seminar on "New Dimensions of Solar Thermal Technology"**
December 2, 2015

(3) **Short Term Courses in Collaboration with RPI, USA on Solid State Physics & Opto-Electronics by Dr. Partha S Dutta**
24th-27th Oct, 2016

(4) **International Seminar on**
"Solar Thermal for Coal Substitution for Mitigation of Climate Change"-
Sponsored by EPCO, Bhopal under the aegis of MNRE Project
28th-29th Oct, 2016

(Some Glimpses of the Seminar and Short term course are given in ENCL: 07)

12. Details of work which could not be completed (if any):

In order to improve the steam generation performance suitable for production of power the core is being revised as 100 kg Cast-Iron crucible design core and further performance testing will be done in the high solar flux period of April and May, 2017.

Further a TE device will also be incorporated to generate electricity using residual heat from the core.

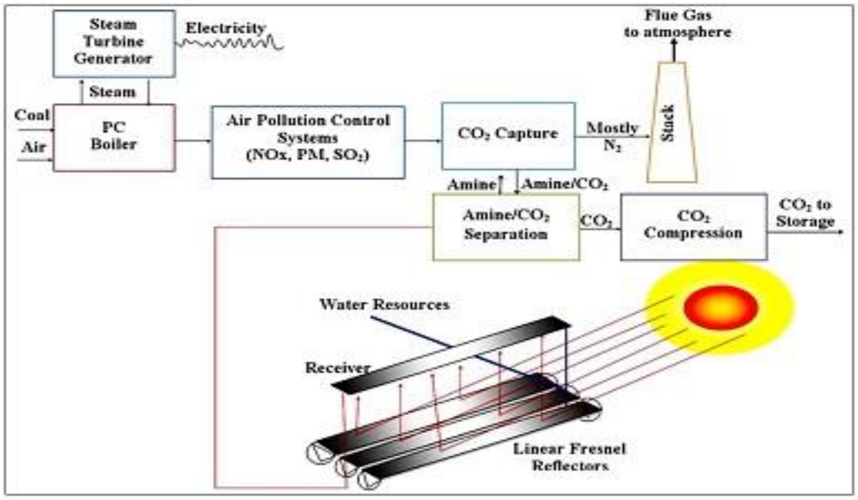
13. Suggestions on further work on the subject of research:

Based on this research, the following is a list of identified components that will be necessary to be developed within India at ultra-low cost by technology licensing and manufacturing technology transfer approaches by commercial entities (from abroad) to translate the existing technology for large scale adoption:

- Large area high optical quality Fresnel lens manufacturing with low cost
- High thermal storage density material manufacturing
- Corrosion resistance nano-coating process
- Ultra-low cost solar trackers
- Energy efficient, low maintenance cost thermal transport systems.
- Selection of economic Power Gen Options – Steam Turbine / Thermo-Photo-Voltaic (TPV)

In view of the above the Long Term Perspective of this Project would be as under:-

- The long term goal of this project is develop the necessary technology know-how to enable the manufacturing process in India for large scale MW systems. While the entire system integration and construction has to be done in India at the location where it will operate in the field, there are key components that must be imported in the near term. In the future, these components can also be developed and manufactured by a commercial entity by technology licensing or marketing from abroad. An Underground Solar Thermal Unit would be more appropriate from heat loss reduction point of view
- Based on preliminary economic analysis, auxiliary heating system for steam in coal thermal power plants or for applications in direct heat utilization in industry, Steam Substitution, CCS processes, etc. seems more feasible than stand-alone CSP system using the distributed storage type system (that's being developed and demonstrated in this project). This is primarily due to lower efficiency of steam turbines for lower capacity.
- A typical scheme of Steam Generation through Solar Thermal Storage Application in Carbon Capture and Sequestration (CCS) is shown below:



14. Project Expenditure: **Audited UC and SoE enclosed**

No	Financial Position/ Budget Head	Amount Sanctioned	Actual Expenditure	Deviation if any	% of Total cost
1.	Equipment	10,00,000	11,93,490.85	(+)1,93,490.85*	(+)19%*
2.	Consumables	2,00,000	1,79,700	(-)20,300	(-)10.15%
3.	Manpower	2,40,000	85,800	(-)1,54,200**	(-) 64.25%**
4.	Travel	60,000	83,498	(+)23,498	(+)39.16%
5.	Contingencies	1,00,000	1,01,327.54	(+)1,327.54	(+)1.33%
6.	Others, (Consultancy to RPI,USA)	20,00,000	18,55,127.12	(-)1,44,872.88#	(-)7.24#
7.	Overhead Expenses	Absorbed By RKDF University			
	Total	36,00,000	34,98,943.51	-	-

Includes the cost of* ***Consumable Core* *of MS and Copper*

Only Under-Graduate Students were involved in the project at a nominal honorarium of Rs.* ***2000 per month

#Part Consultancy to RPI,USA was paid through ***Seminar fund****.*

15. Equipment Status:

Sl. No	Name of Equipment	Year of Purchase	Make/ Model	Cost (FE/ Rs)	Date of Installation	Utilization Rate (%)	Remarks regarding Maintenance/ Breakdown
1.	**Solar Tracker Unit**			**7,04,175.00**	**23rd Jan,2016**	100%	Control System Components Replaced
2.	**Heat Transfer Unit (Boiler Feed Pump & Piping & Core of MS and Copper)**		D4#23P SR NO: CE-5606 Dosing Metering Pump	**1,19,914.85**	**26th Mar,2016**	75%	Piping work was revised for better steam generation and the Core is under revision to Cast-Iron crucible design for improving steam parameters.
3.	**Core Material from RPI USA**			**3,38,401.00**	**7th May,2016**	75%	Size of Crystal revised
4.	**Fresnel Lens**	2015	**HS 71171900000** Focal length 1300mm 1100mm Dia.	**31,000.00**	**23rd Jan,2016**	100%	-

16. Manpower:

Sl. No.	Sanctioned List	In position at the time of project completion (Yes/ No)	Pay Scale/ Emoluments
1.	**List of 07 Students of B.E & Diploma(Mechanical & Electrical)** i. Sourabh Kumar ii. Sandeep Dutta iii. Neelam Sharma iv. Aniket Shyam Singh v. Shubham Kumar vi. Wasim Akram vii. Jai Kishan Sharma	Yes	Stipend @ Rs. 2000 per Month/Student
2.	Mr. Kailash Dodkey (Accountant)	Yes	Rs. 2000 per Month

Dr V.K. SETHI

Name and Signature

Date: 24-01-2017

Vice Chancellor
RKDF University
Airport Bypass Road, Gandhi Nagar
BHOPAL (M.P.) 462033

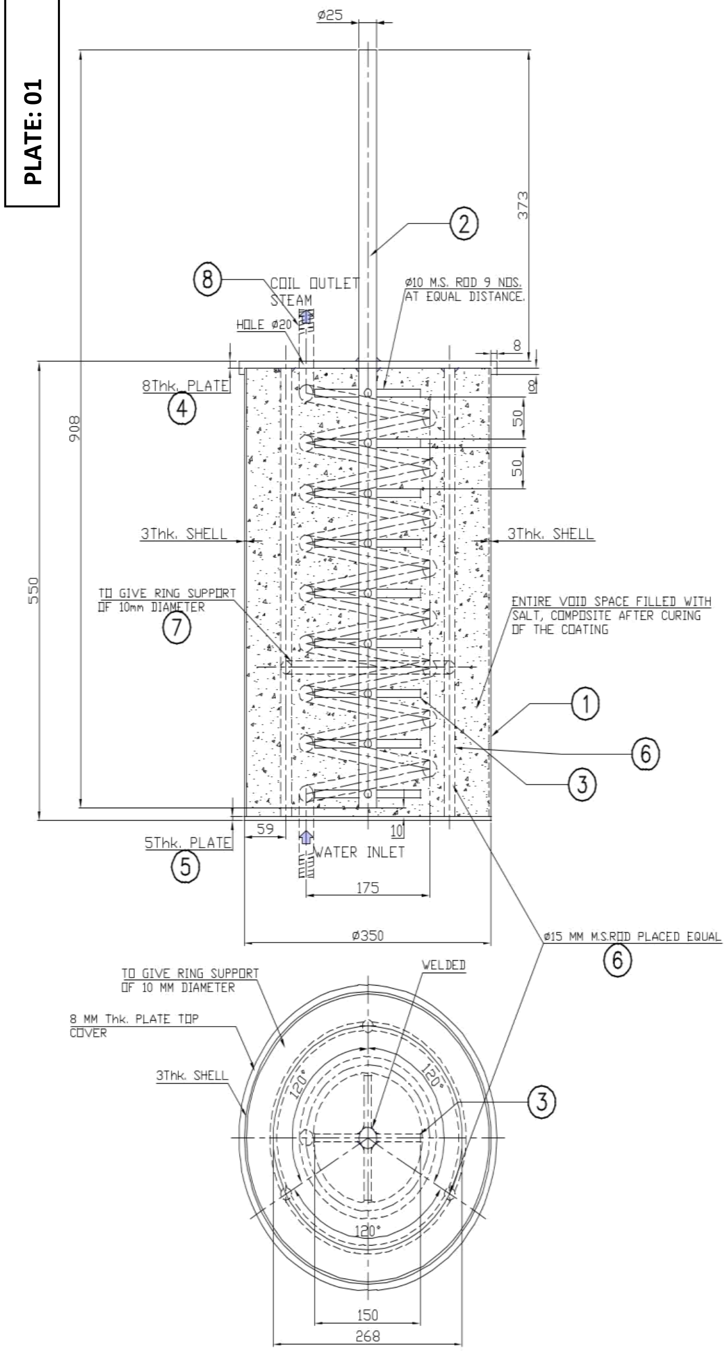
Vinod k Sethi

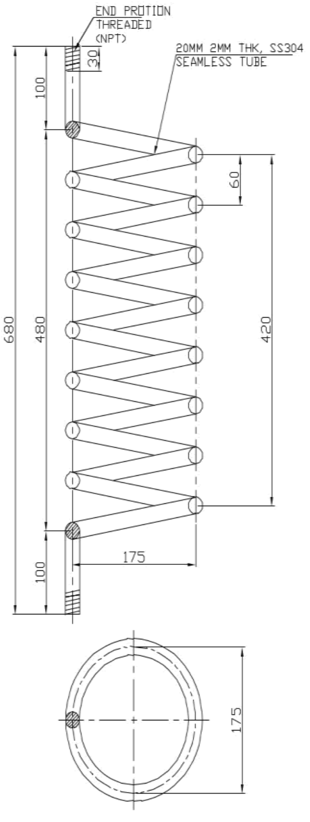
(Principal Investigator)

(Head of grantee organization)

Registrar
RKDF University

PLATE: 01





TUBE COIL FOR
SALT CORE

NOTES:-

1) ALL DIMENSION ARE IN MM.

2) INNER SURFACE SHALL BE COATED WITH ANTI-CORROSION PAINT.

IT. NO.	DESCRIPTION	SIZE (L X B X THK.)	QTY.	MATERIAL	REMARKS
08	TUBE COIL	ø20 X 2 X 6000	01	SS 304 SEAMLESS	
07	SUPPORT RING.10 OD.	842 LG.	01	IS 2062 GR B	
06	SUP. RODS 15 OD.	537 LG.	03	IS 2062 GR B	
05	BOTTOM PLATE	350 OD x 5	01	IS 2062 GR B	
04	TOP PLATE	400 OD. X 8	01	IS 2062 GR B	
03	CENT. EX. FINS. 10 OD.	63 LG.	36	IS 2062 GR B	
02	CENTRE ROD 25 OD.	908 LG.	01	IS 2062 GR B	
01	SHELL DIA 350MM	1109 x 537 x 3	01	IS 2062 GR B	

CUSTOMER/PROJECT : -MNRE SOLAR THERMAL PROJECT
CUSTOMER PO.NO. : - 8392/VC/RKDF/MNRE PROJ./2016-17
CUST. DRG. NO.
-

LAXMI ENGG. IND. (BHOPAL) PVT. LTD.
72 A&B, Sector-I, Ind. Area, Govindpura
Bhopal - 462 023.
Heat Transfer Solutions

	NAME	SIGN.	DATE
DRN.	MP		22/04/16
CHD.	AM		22/04/16
APPD	AM		22/04/16

PROJ.	SCALE	WEIGHT IN KG.	REF. TO ASSY./CUST. DRG.	MO. NO.
	N.T.S.	42 Kg.(APPROX.)	-	1816

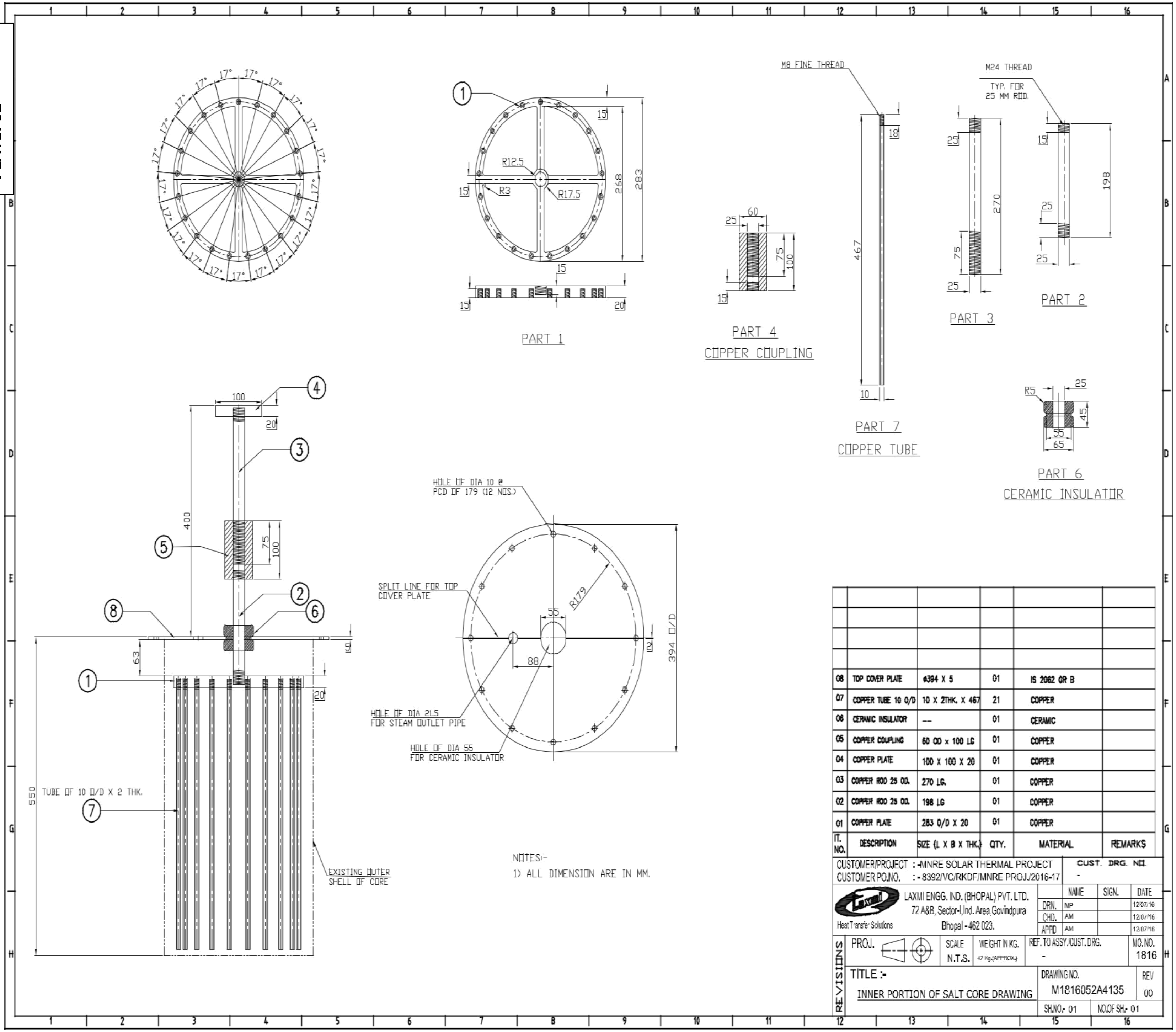
REVISIONS

TITLE :-

SALT CORE DRAWING

DRAWING NO. M1816052A4134
REV 00
SH.NO.- 01
NO.OF SH.- 01

PLATE: 02



NOTES:-

1) ALL DIMENSION ARE IN MM.

IT. NO.	DESCRIPTION	SIZE (L X B X THK.)	QTY.	MATERIAL	REMARKS
08	TOP COVER PLATE	ø394 X 5	01	IS 2062 GR B	
07	COPPER TUBE 10 O/D	10 X 2THK. X 467	21	COPPER	
06	CERAMIC INSULATOR	--	01	CERAMIC	
05	COPPER COUPLING	60 OD x 100 LG	01	COPPER	
04	COPPER PLATE	100 X 100 X 20	01	COPPER	
03	COPPER ROD 25 OD.	270 LG.	01	COPPER	
02	COPPER ROD 25 OD.	198 LG	01	COPPER	
01	COPPER PLATE	283 O/D X 20	01	COPPER	

CUSTOMER/PROJECT : -MNRE SOLAR THERMAL PROJECT
CUSTOMER PO.NO. : - 8392/VC/RKDF/MNRE PROJ./2016-17
CUST. DRG. NO.
-

LAXMI ENGG. IND. (BHOPAL) PVT. LTD.
72 A&B, Sector-I, Ind. Area, Govindpura
Bhopal - 462 023.
Heat Transfer Solutions

	NAME	SIGN.	DATE
DRN.	MP		12/07/16
CHD.	AM		12/07/16
APPD	AM		12/07/16

REVISIONS

PROJ.

SCALE N.T.S.

WEIGHT IN KG. 47 Kg.(APPROX.)

REF. TO ASSY./CUST. DRG. -

MO. NO. 1816

TITLE :- INNER PORTION OF SALT CORE DRAWING

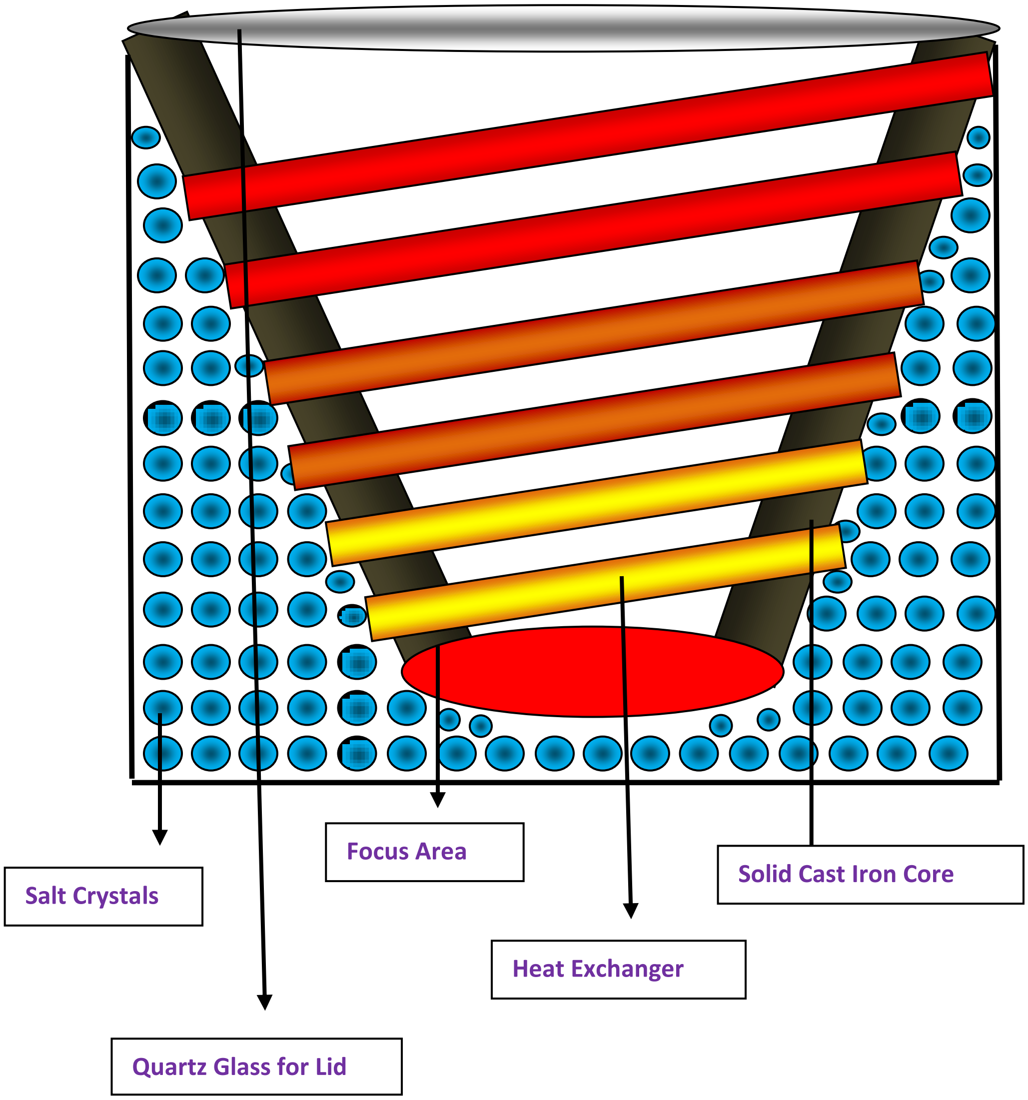
DRAWING NO. M1816052A4135

REV 00

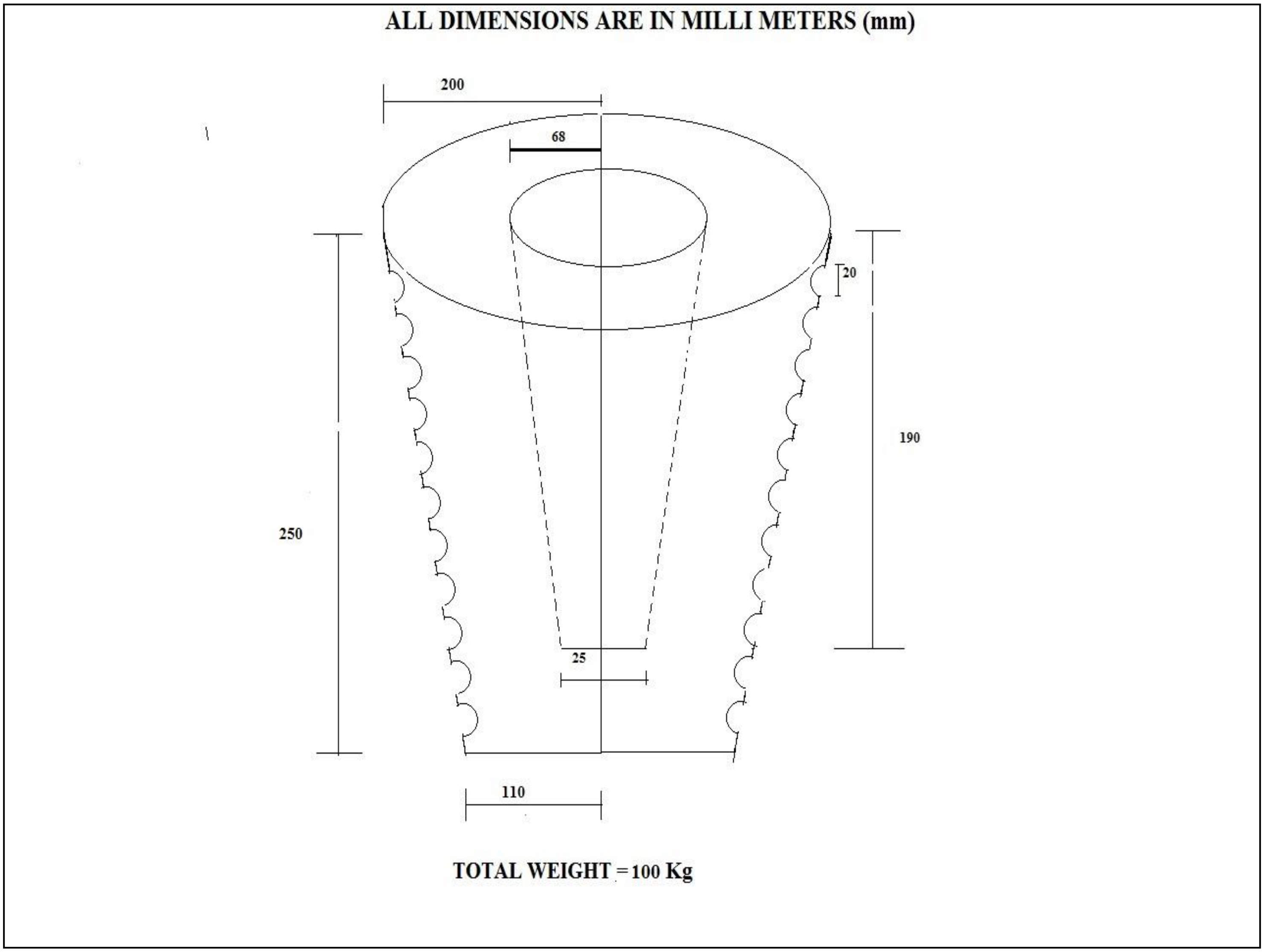
SH.NO.- 01

NO.OF SH.- 01

CORE ASSEMBLY



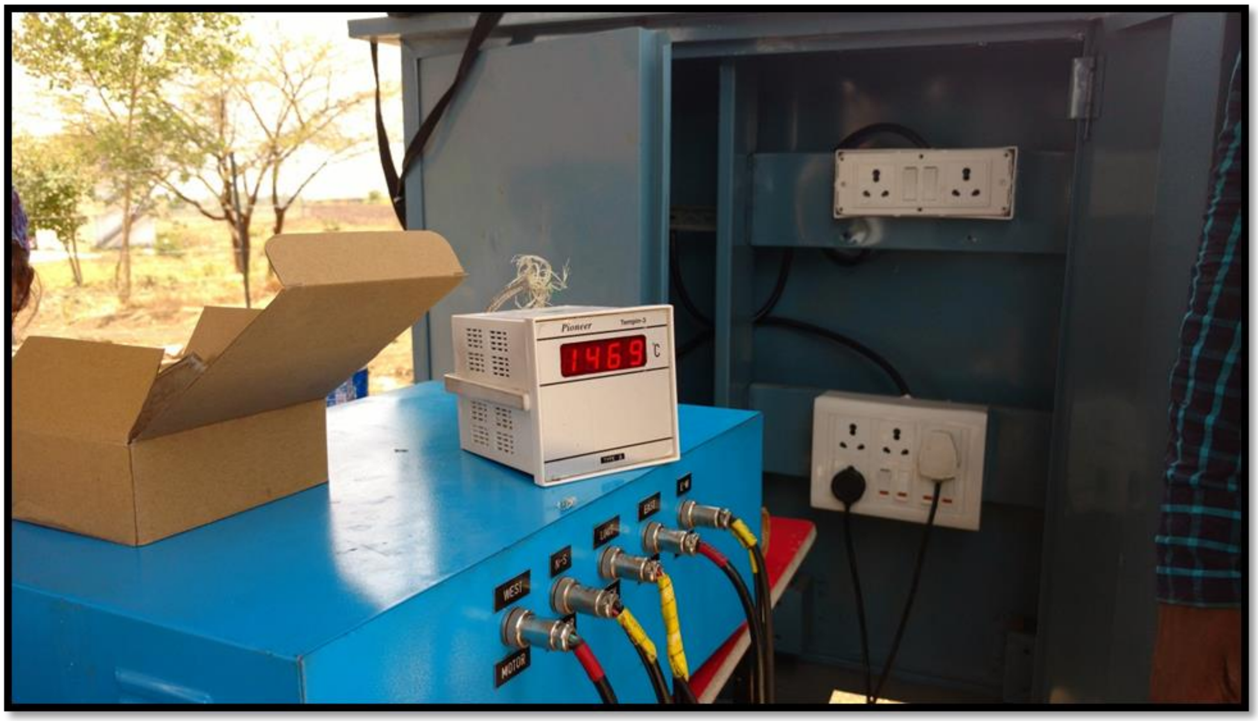
Cast-Iron Core Crucible Design



ENCLOSURES 01-05

ENCL: 01- A VIEW OF THE PILOT PLANT

ENCL: 02- STEAM GENERATION FROM THE CORE



ENCL: 03- HEATING OF THE SALT CRYSTALS

Salt Heating and Cooling Cycle

After 6 hours

3.5 hours to reach 708 C with the tip of copper receiver at 1100 C at RPI, USA

Insulation placed on the copper rod after heating

ENCL:04

Thermal Energy Density Calculation for Salt Crystals

Thermal energy stored in a solid mass (sensible heat) by raising its temperature can be calculated as follows:

The heat or energy storage is given by:

$Q = V \rho c_p dt$

where,

Q = *sensible heat stored in the material (J)*
V = *volume of substance* (m^3)
ρ = *density of substance* (kg/m^3)
c_p = *specific heat of the substance* ($J/kg\ {}^oC$)
dt = *temperature change* (${}^oC$)

Temperature necessary to stored 300 KWh in 1 m^3 of Salt Crystals (Thermal Energy Density: 300 KWh/m^3)

$dt = Q/ (V \rho c_p)$

Q (in KWh) = Q (in KJ) /3600 (second/hour)

Q *(in KJ)* $= 3600 \times 300 = 1.08 \times 10^6$ *KJ*

$Q = 1.08 \times 10^9\ J$

$V = 1\ m^3$

$\rho = 2200\ kg/m^3$

$c_p = 870\ J/kg\ {}^oC$

Using the above values, we get:

$dt = 565\ {}^oC$

Hence we need the core temperature to rise up to 565 ${}^oC$ *to capture and store 300 KWh/*m^3 *of* ***thermal energy density****.*

ENCL: 05

"A write up on technology transfer details of Solar Thermal Project- June 2016"

1.	Project Title :-	**High Energy Density Thermal Energy Storage for Concentrated Solar Plant**
2.	MNRE Sanction order No &date: -	**15/12/2014-15/ST& date 21st July, 2015.**
3.	Name and complete address of PI :-	**Dr. V.K. Sethi, Vice Chancellor, Ram Krishna Dharmarth Foundation (RKDF) University, Bhopal**
4.	Name and complete address of Co-PI from other participating Institution	**Dr. Partha S. Dutta, Deputy Director, Rensselaer Polytechnic Institute, NY, USA (RPI)**
5.	Date of start of the project and Scheduled completion date	6th **September 2015 & 18th March, 2017**
6.	Approved project budget	**Rs.36, 00,000 (MNRE), Rs. 5, 00,000 (RPI)**

7 TECHNOLOGY TRANSFER REPORT (14 to 22 June 2016)

Undersigned visited Rensselaer Polytechnic Institute –RPI, Troy, New York from 14th to 22nd June 2016 during my personal visit to Seattle, USA. The RPI is about 200 year old Center of learning in US in Engineering and Technology which was established in 1824. The New York State Center for future Energy systems and Smart Lighting Engineering Research Center were the focus areas of my study of Technology Transfer in Solar Thermal and Thermo Electrics jointly with Co-PI of the Project Dr. Partha S Dutta. There are three categories of research and development activities that were undertaken by the RPI team for this project and technology transfer deliverables made. A brief summary of each topic is included below.

7.1 Low cost high efficiency thermal storage material development

A host of metals, insulators and semiconductor materials were tested for its sensible heat storage capabilities. These include: aluminum, copper, stainless steel, iron, brass, silicon, silica, alumina, zinc oxide, iron oxide, silicon carbide, sand and gravel, mineral oil (Dowtherm Oil), salts (LiCl, KCl, NaCl and their mixtures). The goal was to select high melting point (close to 1000 ^{o}C) and with high heat capacity and low density. At the same time, the cost of the material required to fill the entire volume of the storage container played a deciding role in the final selection of the material. Composites of the metal-insulator-semiconductor were also evaluated. Eventually, a new composites developed at RPI was found to meet the criteria for the project. The 300 KWh/m^3 of thermal energy density storage with the lowest cost and material operability of 1000 ^{o}C were met by a novel composition of NaCl-Fe_2O_3 composite. Crystals of 240 pounds (lbs) were synthesized and shipped to RKDF for this project. The photos of these crystals are presented in the appendix of this report.

This composite provide the necessary 300 KWh/m^3 of thermal energy density storage when heated to 565 ^oC based on analysis performed with the specific heat capacity and density as shown below. This material has been successfully heated in air up to 1400 ^oC for short period without any melting observed. Also the material is resistant to moisture and humidity unlike pure NaCl crystals (table salt). At laboratory scale synthesis process, the cost of this storage material is calculated as \$1.9/kWh. The energy stored per unit mass is 140 watts/kg.
Thermal energy stored in a solid mass (sensible heat) by raising its temperature was calculated as follows:

The heat or energy storage is given by:

$Q = V \rho c_p dt$

Q = *sensible heat stored in the material (J)*
V = *volume of substance* (m^3)
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$Q = 1.08 \times 10^9\ J$

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$\rho = 2200\ kg/m^3$

$c_p = 870\ J/kg\ ^oC$

Using the above values, we get:

$dt = 565\ ^oC$

Hence we need the core temperature to rise up to 565 ^oC *to capture and store 300 kWh/m*^{3} *of* ***thermal energy density****.*

For comparison, the properties of some common materials are shown below for the design of Core heat transfer device.

Cast copper alloy C90500 (Gun Metal)
Chemical composition: Sn=10.0%, Zn=2.0%, Cu=88%
Density: 8720 kg/m³
Specific heat capacity: 377 J/(kg*K)
Thermal conductivity: 74.8 W/(m*K)
Melting temperature: 999 ºC
Softening temperature: 854 ºC

Copper:
Density: 8960 kg/m³
Specific heat capacity: 383 J/(kg*K)
Thermal conductivity: 385 W/(m*K)
Melting point: 1084 ºC

Cast Iron:
Density: 7900 kg/m³
Specific heat capacity: 837 J/(kg*K)
Thermal conductivity: 50-80 W/(m*K)
Melting point: 1200 ºC

Aluminum:
Density: 2700 kg/m³
Specific heat capacity: 900 J/(kg*K)
Thermal conductivity: 204 W/(m*K)
Melting point: 659 ºC

New design of Core was prepared at RPI during stay of Undersigned using copper; the same will be manufactured at Bhopal in July 2016.

7.2 High temperature corrosion resistance coating

Corrosion of metal walls and embedded water/steam pipes used in thermal storage tanks using salt at high temperature is a major issue. To avoid long term degradation, protective coating is necessary. Coating materials such as CVD deposited SiC or metal oxides such as alumina, zirconia, etc. are very expensive and only used for niche applications. One the other hand polymeric coatings such as polyurethane mixed with nanoparticles or similar nanocomposites can only sustain low operating temperatures (below 400 ^{o}C). Based on research at RPI over the last 2 decades on high temperature corrosion resistance coating, a specific formulation was developed for this project. Synthesis of SiC nanocomposite paint (black in color) was conducted using carbon containing precursor such as Apiezon W wax dissolved in xylene and silicon containing precursor such a tetraethylsilane or tetraethyl orthosilicate. These precursors were mixed using hydrogen carrier gas and injected into a furnace in the temperature range of 850-1100 ^{o}C. The SiC particles formed were found to be embedded in a carbon-rich and silicon-rich phases exhibiting polymeric properties. The reacted mixture of the SiC nanoparticles with the multi-phase material was dispersed in petroleum oil (kerosene or gasoline) prior to application on any metal surface. After drying these coatings were found to be resistant to any corrosive environment. A quantity of 2-3 liters of the SiC-polymeric nano-composite was delivered to RKDF University and was used for coating the interior metallic surfaces of the thermal storage unit. Photos of the precursors and final nano-composite are shown in the appendix.

7.3 Conceptual System design

The conceptual system designs of the entire thermal storage configuration including sketches with dimensions were finalized during the period of stay (now being transmitted to associated industry partners). The designs of the salt core, heat transfer pathways and solar tracker designs were revised as discussed in previous Para. The goal of these designs exercise was to enable low cost manufacturing of the entire unit in India using locally available raw material and labor resources.

8 Details of "Indigenous design of CSP and thermal storage based on imported components and designs”

Discussions were held with Co-PI Dr. Partha on the long term goal of this project is develop the necessary technology know-how to enable the manufacturing process in India for large scale MW systems. While the entire system integration and construction has to be done in India at the location where it will operate in the field, there are key components that must be imported in the near term. In the future, these components can also be developed and manufactured by a commercial entity by technology licensing or marketing from abroad. **The following is the list of components that will be imported for future Mega Watt Scale Project:**

i. Fresnel lens:

High optical quality large area Fresnel lens in not manufactured in India. The necessary lens is available in large quantities from China or USA. The cost of this lens is within the range necessary for the economic feasibility of the entire system.

ii. Thermal storage material:

High quality salt crystals are key to the performance of the energy storage system. These materials are not available commercially in India. The RPI team has conducted toll production analysis with a suitable commercial vendor in USA. Materials necessary in large quantities can be supplied for large power plants in India. The manufacturing of these advanced materials would require significant infrastructure investment in India. This will be evaluated in the future. The cost of storage materials manufactured in USA is within the range necessary for the economic feasibility of the entire system.

iii. Corrosion resistant nano-coating:

The corrosion resistant coating is a unique formulation developed by RPI. The synthesis of the polymeric nano composite requires special chemical and high temperature processes that are not available in India. Due to low volume requirement, the RPI team will synthesize this material in the laboratory at RPI. In the future, when large volume is necessary, it can be toll manufactured by a US chemical manufacturer and supplied directly for projects in India.

iv. Solar tracker design:

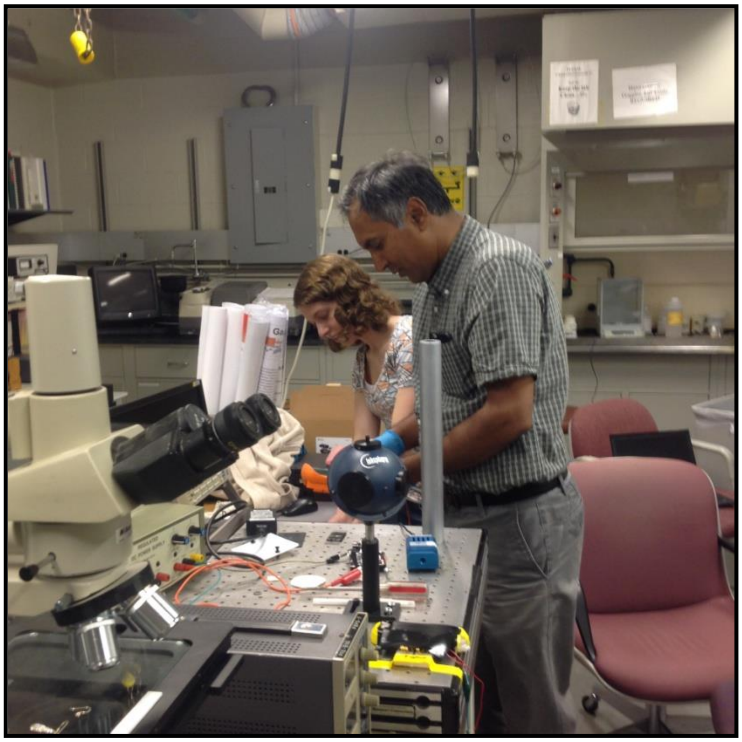
While there are numerous commercially available solar trackers available in India, there are two issues: 1. These trackers are not suitable for integrating with the thermal storage core unit at the ground level or underground. 2. The costs of various tracker configurations are significantly high to adopt for this application. The RPI team in conjunction with a commercial vendor in USA has developed low cost solar tracker that can be easily integrated and automated with thermal storage unit. The design of suitable trackers along with the list of components will be provided to a local Indian manufacturer/workshop where it could be built.

v. Heat transfer element and core insulation designs:

Heat transport from the focal point of the lens to the salt core is a crucial part of the system and dictates the system storage efficiency. The RPI team based on experiments and thermal simulation will provide the necessary designs for this project. Some of the components like insulation material, coils and rods for heat transport, etc. will be selected by the RPI team based on thermal modeling. These components will be acquired from US commercial vendors and shipped to India.

Some Glimpses of the Technology Transfer Process and Labs is as under

PI Dr. V.K. Sethi at Rensselaer Polytechnic Institute (RPI), USA, 14 to 22 June 2016



Co-PI Dr. Partha S. Dutta at Technology Incubation Center

Co-PI Dr. Partha S. Dutta at Technology Incubation Center

Thermal Test Rig at Technology Incubation Center

Corrosion Resistant Nano Technology Lab at LESA Technology Incubation Center

Thermo Photo voltaic Lab at LESA Technology Incubation Center

Underground Solar Thermal plant of Megawatt size

(Dr. V.K. Sethi)
PI

ENCL: 06

SOLID PATHWAY

Conventionally Molten Salt is being used as Thermal Storage Material however in view of experience of Co-PI of this project Dr. Dutta of RPI, USA as consultant of DOE, USA the Solid Pathway has been used in this project.

The U.S. Department of Energy (DOE) launched the *SunShot Initiative* in 2011 with the goal of making solar electricity cost-competitive with conventionally generated electricity by 2020. The CSP SunShot Program set aggressive targets to achieve lower component costs and higher system efficiencies. Over the course of 5 years, the program's portfolio of research has developed sub-system technologies potentially capable of efficient operation at higher temperatures, and hold promise to be reliable and cost effective.

Within the CSP SunShot research portfolio, the three technology pathways which hold promise for achieving these temperatures can be categorized by the phases of matter of the materials used: liquid, solid, and gaseous.

- A liquid pathway is considered to look much like today's molten salt two tank tower configuration, but using a suitable high temperature and cost effective HTF / TES.
- Solid pathways involve solid inert media which absorbs solar radiation and stores that energy as heat. When electric power is needed, the turbine working fluid is heated by the solid media.
- Gaseous pathways use an inert gas flowing through a receiver to absorb the solar energy and then transfer the thermal energy to a storage system and / or the turbine working fluid. The distinctive characteristic of inert gas systems is that the thermal energy is stored in a media that is not the fluid flowing in the receiver.

Solid Particle Pathway:

SunShot-funded R&D has identified sand-like particles for high temperature HTF and TES as a possible solid pathway for Gen 3 CSP at temperatures above 700 °C. A key benefit of this pathway is the ability to transport heat via low-cost particles which are chemically inert.

ENCL: 07

National Seminar on R&D Efforts in Energy Sector towards Mitigation of Climate Change
November 3, 2015

International Seminar on
"New Dimensions of Solar Thermal Technology"
December 2, 2015

Short Term Courses on Solid State Physics & Opto-Electronics

Seminar on "Solar Thermal for Coal Substitution for Mitigation of Climate Change"

Round Table on R&D Efforts in Energy Sector towards Mitigation of Climate Change

Nov. 3, 2015

In association with EPCO & CDM Agency, Bhopal

Proceedings & Recommendations

Round Table Meeting on "**R&D Efforts in Energy Sector towards Mitigation of Climate Change**" was held at RKDF University, Airport Road Bhopal on Nov. 3, 2015. The knowledge partners were EPCO & CDM Agency, Bhopal, Urja Vikas Nigam, Institution of Engineers & AISECT University, who participated in Panel discussions and Invited Talks. Dr Awasthi, Er. Vajpai presented curtain raiser talks.

The Chief Guest in the Inaugural Session was Er. P.P. Agarwal, IAS, Council Member of Institution of Engineer Calcutta HQ and the key Note address was given by Dr V K Sethi, VC, RKDF University,

In the Round Table meeting, Engineers from Urja Vikas Nigam and EPCO, MANIT & Institution of Engineers (India) participated.

The event was coordinated by Er. Aditya Gupta

Round Table Session- Recommendations

- Energy Security- Action Plan was drawn for "Self- dependent villages with Energy Security & Net metering in Urban areas"
- Skill Development- Involvement of Private Universities in Skill development programs like SURYAMITA of MNRE, New Delhi.
- Clean India Mission- Dealing with Solid waste & Plastic waste
- Green Transportation- Electric vehicles: Electric cars for public transport & Bio-fuels for Mass transportation
- Mandatory Initiatives for Energy Conservation & Energy efficiency.
- Augmenting Hydro & Solar Thermal
- New Technology Concepts- Thermo photo voltaic (TPV) & Concentrated photo voltaic (CPV), Coal substitution by Solar Thermal, Vertical axis wind turbines to penetrate low wind region, Energy storage device to replace lead acid batteries, Organic solar cells, etc.
- Smart cities plan to integrate ideas of smart green building with appropriate RE technologies.

Solar Thermal for Coal substitution towards Mitigation of Climate Change

(Sponsored by EPCO, Bhopal)

Oct 28-29, 2016

28th October 2016

Registration: 11:00 – 1130 hrs.

Inauguration of Solar Thermal Storage Unit: 11:30 hrs.

Main Session: 11:30 to 13:30 hrs

Venue: Seminar Hall, RKDF University, Airport bypass Road, Gandhi Nagar, Bhopal

Welcome of Guests	Floral Welcome , Lighting of Lamp
Welcome Address “Theme Paper : Solar Thermal for Coal Substitution Towards Mitigation of Climate Change”	Dr. V.K. Sethi, VC, RKDF University
Expert Lecture on “Solar Thermal Generation & Storage- an Unique Opportunity”	Prof. Partha S Dutta, Rensselaer Poly. Institute (RPI), New York USA
Expert Lecture on “Climate Change Agenda Post COP21 and CO2 Sequestration' ”	Dr. Malti Goel (Emeritus Scientist, JNU, DST & INSA)
Green Building Concept: A way out for Energy Conservation and Sustainable Development	Sri Anoop Srivastava, CE, EPCO
Climate Change – Issues before COP 22 to be held in Nov 2016	Sri Lokendra Thakkar, General Manager, CDM, EPCO
Address by Chairman / Chancellor/MD	Hon’ble Chairman / Chancellor RKDF/MD, RKDF
Address by Chief Guest	Dr. Ashish Dongre, Director Tech. Education, GoMP
Vote of Thanks	Shri. Aditya Gupta, Director (T&P), RKDF
Lunch :	**13:30 to 14:15**

Venue: Seminar Hall, RKDF University, Airport bypass Road, Gandhi Nagar, Bhopal

Technical Session: 15:00 – 17:00 hrs.

Net Metering & Solar Policy in MP	Er. Surendra Vajpaye & Er. Sanjay Verma, MPUVNL
Energy- Environment Synergy for Sustainability	Dr. V.K. Sethi, VC, RKDF University
Student’s Presentations on Solar Thermal & Innovative approaches	RKDF Students
Tea:	**1700 hrs.**

29th October 2016

Round Table Session 10:30 to 13:00

Venue: Board Room

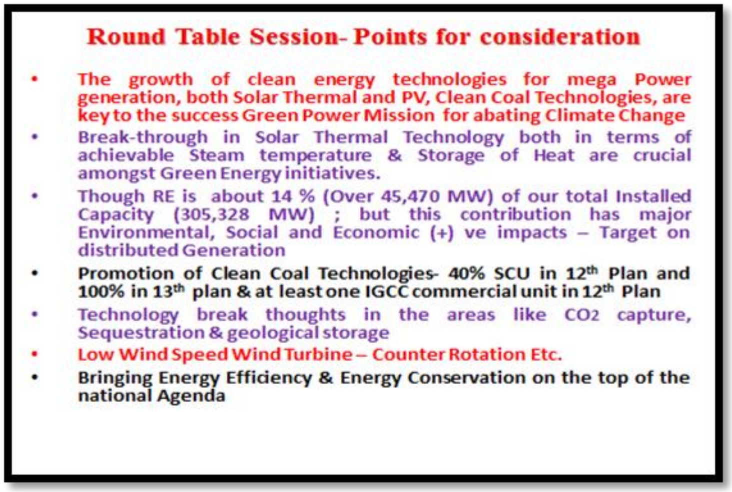
Chair	Prof. Partha S Dutta, Rensselaer Poly. Institute (RPI), New York USA
Co-Chair	Ms. Supaporn Chaungchid, Executive Secretary, AUAP
Discussion by Panellists:	Participating Organizations: EPCO, BHEL RGPV (EEM) , MPUVNL, MANIT, Institution of Engineers (IEI) & Faculty of RKDF Group
Vote of Thanks	Dr. B.N. Singh, Registrar, RKDF University
Lunch & Interaction:	**13:00 – 14:00 hrs.**

Seminar
on
"Solar Thermal for Coal Substitution Towards Mitigation of Climate Change"
Sponsored by: Environmental Planning & Coordination Organization (EPCO) Bhopal

Knowledge Partner : Association of Universities of Asia & Pacific (AUAP) Thailand

28- 29 October 2016

RECOMMENDATIONS

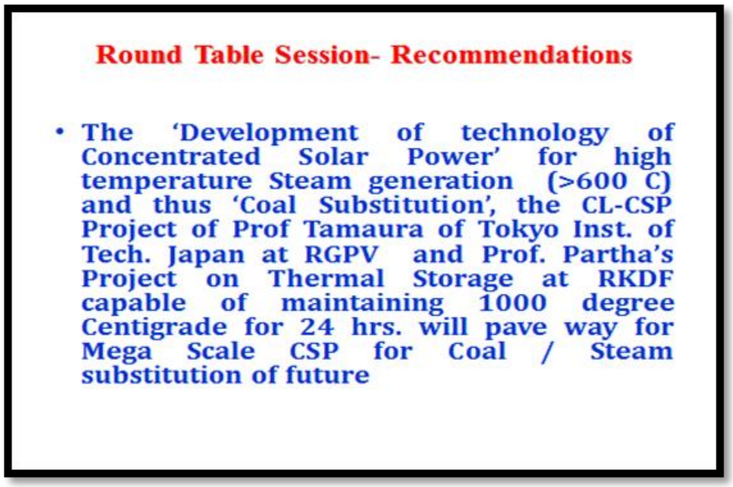


Round Table Session- Points for consideration

- The growth of clean energy technologies for mega Power generation, both Solar Thermal and PV, Clean Coal Technologies, are key to the success Green Power Mission for abating Climate Change
- Break-through in Solar Thermal Technology both in terms of achievable Steam temperature & Storage of Heat are crucial amongst Green Energy initiatives.
- Though RE is about 14 % (Over 45,470 MW) of our total Installed Capacity (305,328 MW) ; but this contribution has major Environmental, Social and Economic (+) ve impacts – Target on distributed Generation
- Promotion of Clean Coal Technologies- 40% SCU in 12th Plan and 100% in 13th plan & at least one IGCC commercial unit in 12th Plan
- Technology break thoughts in the areas like CO_2 capture, Sequestration & geological storage
- Low Wind Speed Wind Turbine – Counter Rotation Etc.
- Bringing Energy Efficiency & Energy Conservation on the top of the national Agenda

Round Table Session- Recommendations
Green Technologies

- Green Technologies should be viewed in a wider spectrum. Climate change should be addressed by various sustainable technological options Not only REs need thrust but also Clean Coal technologies options should be targeted for energy security & environmental sustainability.
- Applied and fundamental research is needed in frontal areas of green power such as supercritical , Integrated coal gasification combined cycle, carbon capture & sequestration and newer renewable energy technologies likes Hybrid fuel cell power plant .



Round Table Session- Recommendations

- The 'Development of technology of Concentrated Solar Power' for high temperature Steam generation (>600 C) and thus 'Coal Substitution', the CL-CSP Project of Prof Tamaura of Tokyo Inst. of Tech. Japan at RGPV and Prof. Partha's Project on Thermal Storage at RKDF capable of maintaining 1000 degree Centigrade for 24 hrs. will pave way for Mega Scale CSP for Coal / Steam substitution of future

Round Table Session- Recommendations
Energy Security

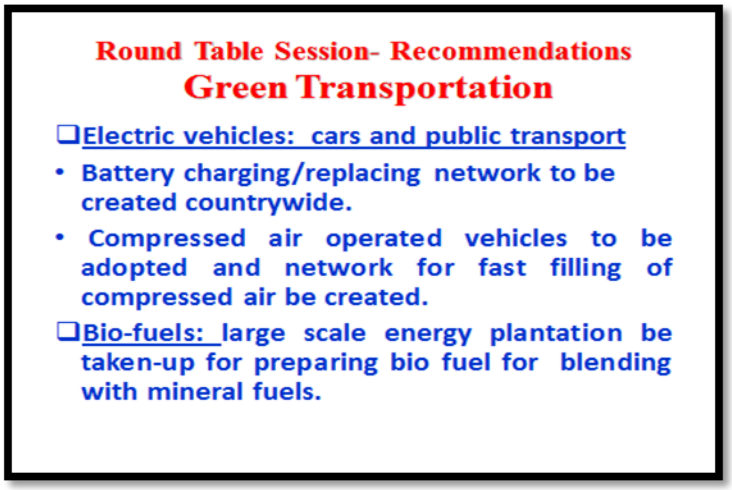
- Self-dependent villages with Energy Security
  - Renewable Energy based power generation using local resources like animal waste, agriculture waste etc. need to be adopted in rural areas. The operation and maintenance will be managed by the local bodies by employing rural human resource
  - Incentives for accelerating the pace of RE system installation through CDM, RPOS & Green Certificates
  - Micro grids should be adopted at village level. Start can be made from the villages not having grid connectivity.
- Net metering :
- Net metering policy for MP has been announced recently.
  In order to make solar photovoltaic system economically viable,
  Some sizes need to be standardized to facilitate cost reduction, spares, O&M etc. Efforts should be made to see that standard design (BIS) are made for cost reduction.

Round Table Session- Recommendations
Skill Development

- There is an urgent need of skill development in Renewable Energy with a focus on Solar PV, micro-grid etc. The rural youths need to develop skill in biomass, biogas, Solar PV, mini/micro hydro, micro-grid etc. as per local needs. In order to meet large scale urgent requirement of skilled manpower, it is necessary to actively involve private educational institutions, industries, NGOs etc. besides government/semi-government bodies in the schemes like Surya Mitra.

Round Table Session- Recommendations
Clean India Mission

- Plastic to oil: This is an established technology in India to convert plastic waste into synthetic oil which has superior lubricating and knocking characteristics and is suitable for use in industry and transport sector. This technology accepts all kinds of plastic. To start with, such plants need to be established in each district which will be a great initiative towards "Clean India Mission".
- Municipal Solid Waste to electricity: Municipal solid waste (MSW) based power generation plants should be installed in the cities having daily MSW above 200 t/day. This will be a novel step towards "Clean India Mission".



Round Table Session- Recommendations
Green Transportation

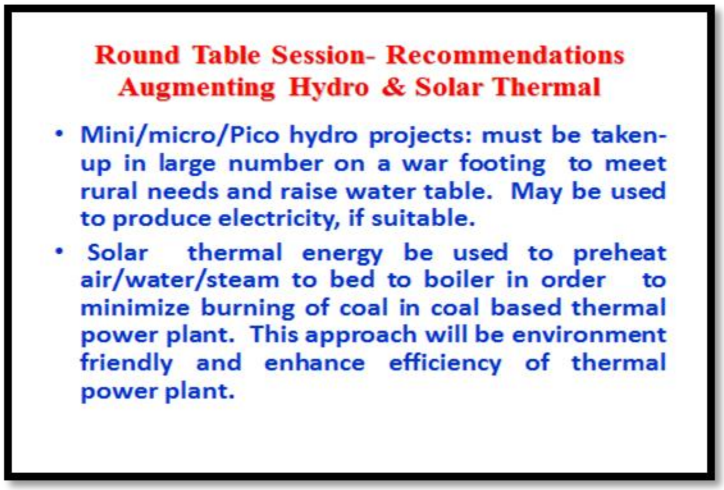
☐ Electric vehicles: cars and public transport

- Battery charging/replacing network to be created countrywide.
- Compressed air operated vehicles to be adopted and network for fast filling of compressed air be created.

☐ Bio-fuels: large scale energy plantation be taken-up for preparing bio fuel for blending with mineral fuels.

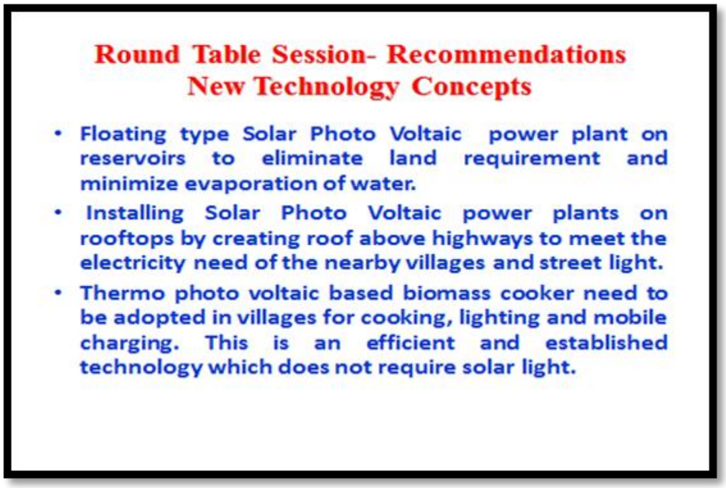
Round Table Session- Recommendations
Mandatory Initiatives

- Air conditioner : Minimum temperature setting limit to be raised to say 25° C.
- No grid power be allowed for advertisement and exterior lighting in hotels, malls etc. having connected load above 500 kW.
- Manufacture of electrical appliances below 4 star rating must be banned.
- Taxation on 5 star products (BEE) be reduced to make them cost effective.
- Provision of release of controlled water toilet from flush tank. It may be achieved by providing two button flush tanks for toilet.



Round Table Session- Recommendations
Augmenting Hydro & Solar Thermal

- Mini/micro/Pico hydro projects: must be taken-up in large number on a war footing to meet rural needs and raise water table. May be used to produce electricity, if suitable.
- Solar thermal energy be used to preheat air/water/steam to bed to boiler in order to minimize burning of coal in coal based thermal power plant. This approach will be environment friendly and enhance efficiency of thermal power plant.



Round Table Session- Recommendations
New Technology Concepts

- Floating type Solar Photo Voltaic power plant on reservoirs to eliminate land requirement and minimize evaporation of water.
- Installing Solar Photo Voltaic power plants on rooftops by creating roof above highways to meet the electricity need of the nearby villages and street light.
- Thermo photo voltaic based biomass cooker need to be adopted in villages for cooking, lighting and mobile charging. This is an efficient and established technology which does not require solar light.

Round Table Session- Recommendations
New Technology Concepts... Contd.

☐ Thermo photo voltaic(TPV) /Concentrated photo voltaic (CPV) is also a new technology in which these is no need of solar light, instead solar heat (infrared Rays) are need to produce power. This appears to be an appropriate Technology for rural application in conjunction with heat of biomass.

☐ Solar Thermal plants should integrated with conventional and fired plants for coal substitution by producing steam all appropriate parameters. Multi-fuel thermal based small level power generation at agricultural site for harnessing the available potential of solar, biomass and other heat generating sources

☐ Domestic CSP sterling engine based power generation at rooftop should be encouraged due to their high efficiency (30-40%) when compared to PV Technology (15-20%)

Short Course on Optoelectronics & Solid State Physics
October 24-27, 2016
RKDF University, Bhopal, India

Course Information

Instructor:
Prof. Partha Dutta
Professor, Electrical, Computer & Systems Engineering (ECSE)
Rensselaer Polytechnic Institute, Troy, NY
E-mail: duttap@rpi.edu

Course Schedule:

Date	Morning Session (11 am - 1 pm) Optoelectronics	Afternoon Session (2 pm - 4 pm) Solid State Physics
October 24	Introduction, Light Emission (LEDs & Laser Diodes)	Introduction, Electrical Transport in Metals & Semiconductors
October 25	Light Detection (Photoconductor, Photodiode, APD)	Semiconductors Physics, Thermal Transport
October 26	Power Generation (Solar Cell & TPV Cells) & Light Modulation	Magnets & Superconductors
October 27	Optoelectronic Systems (Fiber Optic Communication)	Atomic Scale Structures (Atomic Bonding & Crystal Lattice)

ENCL 08

List of Equipments and their Specifications:

1. Fresnel Lens : - 1100mm(dia.) x 5mm(thick); MMA Polymer; Focal Length of 1300mm

2. Tracker Unit Assembly complete with Micro-Controller with Computer Interfacing Facility and full auto operation throughout the year and data logging system.

3. Boiler Feed Pump:- Plunger Type Positive Return Metering; 0-50 LPH with discharge pressure $11kg/cm^2$; Flooded suction ; Pump speed – 145 RPM; All material SS 316 ; Plunger – Hard Chrome Plated

4. Thermocouple R-Type ; 360mm Long; 0-1500o C range ; Compensating Cable SS braided and Digital Meter along with accessories.

5. Thermo-Electric Device duly designed and fabricated at Micro-and nano Fabrication Clean Room (MNCR), RPI, USA. Conversion Efficiency more than 5%.

6. Core Assemblies of Mild Steel, Copper and Cast-Iron as per drawing in Plate 1-3.

7. Thermal Storage Salt for Research developed at the RPI Lab, USA and imported vide invoice dated 25th April, 2016- having high “Energy Density” exceeding $300kWh/m^3$ and Density $2200kg/m^3$.

   Appendix I gives the Composition, Synthesis methodology of Salt and procedure for its production in India for future Thermal Storage application

Guidelines for preparing the Manuscript of the Report:

i) Manuscripts should be neatly written/ printed (with single spacing) in the enclosed format for direct reproduction by Xerox/ photo offset process. Any corrections should be redone on a separate slip & then pasted neatly. Don’t erase or retype. Don’t cut/ cross.

ii) Matter should be first preferably typed on A4 size paper within the prescribed space leaving the same margin as in the enclosed format and then retyped cleanly after careful correction/ changes.

iii) Manuscript should not exceed five pages in any case and should be in the enclosed format.

iv) Scanned photographs, diagrams, tables & graphs should be accommodated within the space provided for the text for direct reproduction.

v) Designs & drawings of larger size also need to be scanned and electronic copy sent along with the physical copy.

Physical as well as electronic (CD) copy of the report need to be sent

Annexure-XVIII

Final Statement of Expenditure (S.O.E.)

Subject: **SOE of the MNRE Project "High Energy Density Thermal Energy Storage for Concentrated Solar Plant" at RKDF University, Bhopal**

1. MNRE Sanction Letter/ Order No and date of sanctioning the project : **15/12/2014-15/ST Dated 21 July 2015.**
2. Total Project Cost (Sanctioned/ Revised Project Cost, if applicable) : **Sanctioned Rs. 36,00,000 (MNRE Share)**
3. Date of Commencement of Project : **17 September 2016**
4. Date of Completion of Project : **15 March 2017**
5. Grant received in each year (financial year):

Sr.No.	Year	Amount Received (Rs.)	Interest Accrued (Rs.)	Total Amount (Rs.)
1.	1st year **(1st Installment)** **(2nd Installment)**	**20,00,000** **6,00,000**	**NIL (1)**	**26,00,000**
2.	2nd year	**9,00,000**	**NIL (1)**	**9,00,000**
	Grand Total	**35,00,000**	**NIL**	**35,00,000**

Note: (1) **Current A/c No: 586701010050119**
UBI, RGPV Branch, Bhopal

(2) **Additional fund deposited in the above account for conducting seminar and through collection of Registration fee of the Delegates:**

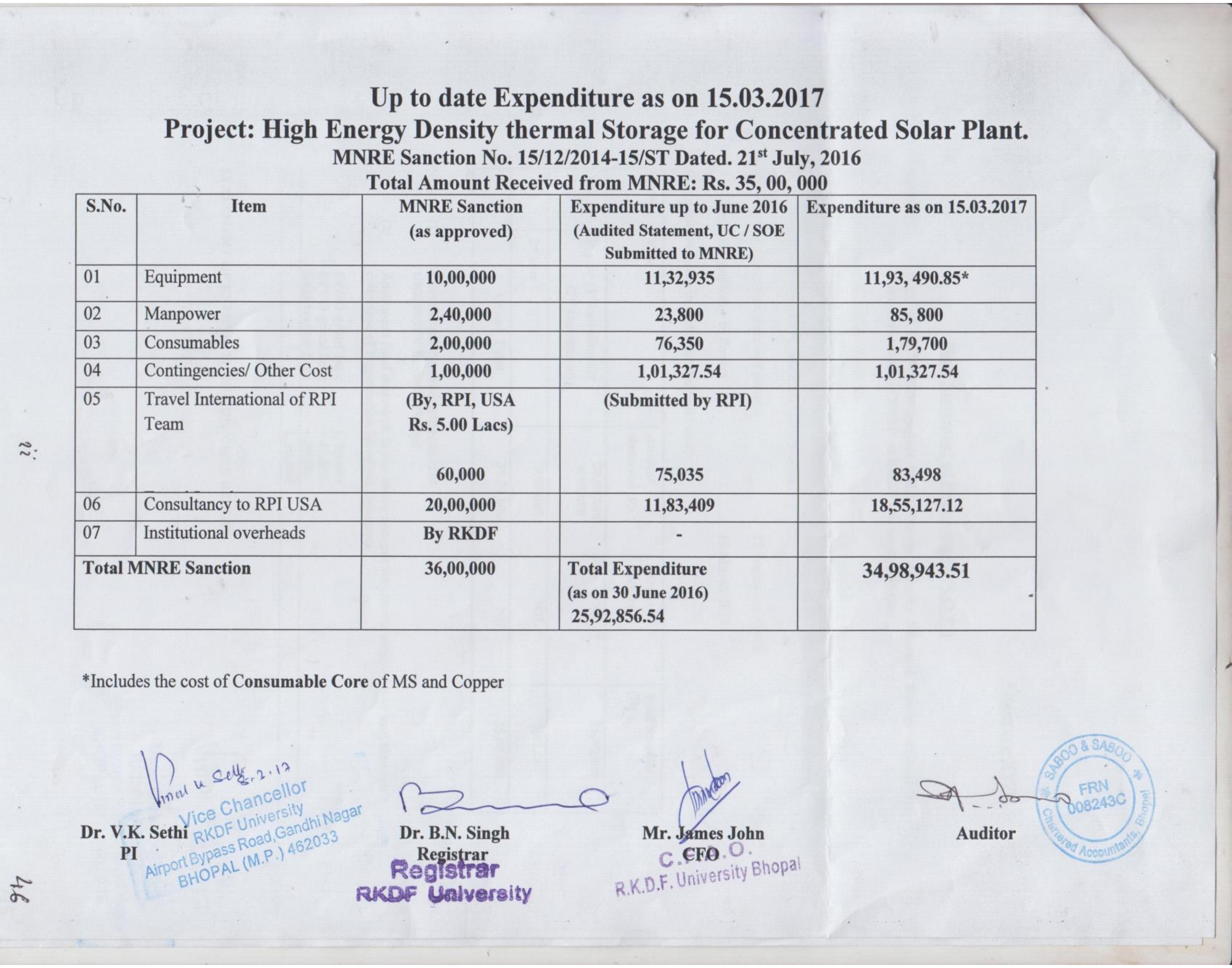
EPCO grant 1st :	**1, 25,000**
EPCO grant 2nd:	**+ 47,500**
Registration Fee :	**+ 20,000**
	1, 92,500

STATEMENT OF EXPENDITURE ATTACHED BELOW

Vinod k
8.3.17

P.I

Vice Chancellor
RKDF University
Airport Bypass Road, Gandhi Nagar
BHOPAL (M.P.) 462033



Up to date Expenditure as on 15.03.2017

Project: High Energy Density thermal Storage for Concentrated Solar Plant.

MNRE Sanction No. 15/12/2014-15/ST Dated. 21st July, 2016

Total Amount Received from MNRE: Rs. 35, 00, 000

S.No.	Item	MNRE Sanction (as approved)	Expenditure up to June 2016 (Audited Statement, UC / SOE Submitted to MNRE)	Expenditure as on 15.03.2017
01	Equipment	**10,00,000**	**11,32,935**	**11,93, 490.85***
02	Manpower	**2,40,000**	**23,800**	**85, 800**
03	Consumables	**2,00,000**	**76,350**	**1,79,700**
04	Contingencies/ Other Cost	**1,00,000**	**1,01,327.54**	**1,01,327.54**
05	Travel International of RPI Team	**(By, RPI, USA Rs. 5.00 Lacs)** **60,000**	**(Submitted by RPI)** **75,035**	**83,498**
06	Consultancy to RPI USA	**20,00,000**	**11,83,409**	**18,55,127.12**
07	Institutional overheads	**By RKDF**	**-**	
Total MNRE Sanction		**36,00,000**	**Total Expenditure (as on 30 June 2016) 25,92,856.54**	**34,98,943.51**

*Includes the cost of **Consumable Core** of MS and Copper

Vimal u Sethi 8.2.17

Vice Chancellor
RKDF University
Airport Bypass Road, Gandhi Nagar
BHOPAL (M.P.) 462033

Dr. V.K. Sethi
PI

Dr. B.N. Singh
Registrar

Registrar
RKDF University

Mr. James John
CFO

C.F.O.
R.K.D.F. University Bhopal

Auditor

SABOO & SABOO
FRN 008243C

Annexure-X

Performa for Utilization Certificate (U.C.) for the Financial Year 2016-17 (ending March 2017)

1. Title of the Project/ Scheme: **High Energy Density Thermal Energy Storage for Concentrated Solar Plant**

2. Name of the Institution: **Ram Krishna Dharmarth Foundation (RKDF) University, Bhopal**

3. Principal Investigator: **Dr. V.K. Sethi, Vice Chancellor, RKDF University**

4. MNRE Sanction order No & date of sanctioning the Project: **15/12/2014-15/ST , date 21st July, 2015.**

5. Amount brought forward from the previous month Financial year, if any:
   - i. Amount: **Rs. 6,25, 508.96**
   - ii. Sanction Letter No.: **15/12/2014-15/ST**
   - iii. Date: **21-07-2015 & 15-03-2016**

6. Amount received during the financial year:
   - i. Amount: **Rs. 9,00,000**
   - ii. Sanction Letter No.: **15/12/2014-15/ST**
   - iii. Date: **30 August 2016**

7. Total amount that was available for expenditure (excluding commitments) during the financial year (Sr. No. 5+6): **Rs. 15,25,508.96**

8. Actual Expenditure (excluding commitments)

   Incurred during the financial year (up to 31 March): **Rs. 15,24,452.47**

9. Balance amount available at the end of financial year: **Rs. 1056.49**

10. Unspent balance refunded, if any (please give details of ECS/ crossed Demand Draft etc.): NA

11. Amount to be carried forward to the next financial year (if applicable): **Rs. 1056.49 + Rs1,00,000 (balance of sanctioned grant to be received from MNRE)**

12. **Certificate:**

(a) Certified that out of **Rs. 9,00,000** of grants-in-aid sanctioned during the year **2016-17** in favor of Ram Krishna Dharmarth Foundation (RKDF) University, Bhopal under this Ministry/ Department letter/ order no. **15/12/2014-15/ST dated 30 August 2016** and **Rs. 6, 25, 508.96** on account of unspent balance of the previous year, a sum of **Rs.15, 25,508.96** has been utilized for the purpose of Solar Thermal Project Execution for which it was sanctioned and that the balance of **Rs. 1,056.49** remaining unutilized at the end of year has been surrendered to Government (vide ECS/Crossed Demand Draft No…….dated……. / will be adjusted towards the grant-in-aid payable during next year i.e. **2017-18 for Performance Testing of the Pilot Plant.**

Signature of PI

Vice Chancellor
RKDF University
Airport Bypass Road, Gandhi Nagar
BHOPAL (M.P.) 462033

Date 08.02.18

Signature of Registrar/ Signature of Head

Registrar
RKDF University

Seal

Date

Accounts Officer

Seal

C.F.A.O.
R.K.D.F. University Bhopal

Date

(b) Certified that I have satisfied that the conditions on which the grants-in-aid was sanctioned have been fulfilled/ are being fulfilled and that I have exercised the following checks to see that the amount was actually utilized for the purpose for which it was sanctioned:-

Kinds of checks exercised:

1. **Quotations were invited for area development & minor equipment of the project.**
2. **Imported equipment was procured on proprietary basis.**

3. **Only qualified erectors and agencies were deployed for civil construction and E&M works.**
4. **Before starting the project at the design stage two seminars were conducted… National: Nov 03, 2015 and International: Dec. 02, 2015 and during Project execution an International Conference on "Solar Thermal" was conducted on 28-29 October 2017.**
5. **During the project execution an International Seminar on "Solar Thermal for Coal Substitution for Mitigation of Climate Change" was organized in collaboration with EPCO, Bhopal, the funding from the same including Registration fee was Rs. 1,92, 500**
6. **Design and Engineering work at RPI, USA was closely monitored though regular correspondence by mail and the Co-PI from USA was invited at the time of International Conference for explaining the various details.**
7. **The PI visited RPI, USA for Technology Transfer of Salt synthesis, TE / TPV and Core design**

Date: 8.3.17

Principal Investigator:
Signature:

Vice Chancellor
RKDF University
Airport Bypass Road,Gandhi Naga
BHOPAL (M.P.) 462033

Designation:
of Organization/

Head
Administration: Registrar
Signature RKDF University

Date:

Designation:
Seal C.F.A.O.
R.K.D.F. University Bhopal

SABOO & SABOO
FRN 008243C
Chartered Accountants, Bhopal

Composition, Synthesis methodology of Salt and procedure for its production in India for future Thermal Storage application

1. Composition of Thermal Storage Salt:

- Salt Material:
  Flux grown crystals of mixed alkali halide compounds doped with metallic impurities.
- Salt density: 2200 kg / m^3
- Energy Density at 565 degree Centigrade: 300 kWh / m^3 = 140 wh /kg

2. Heating experiment in controlled condition at RPI USA:

The salt core reached (20 cm deep from the tip) the temperature around 700^{o} C. The rate of cooling is around 12 ^{o}C/ hr., but more insulation will make it better. The salt was crystals plus powder mixed. The results are shown below


Salt Heating and Cooling Cycle

3.5 hours to reach 708 C with the tip of copper receiver at 1100 C

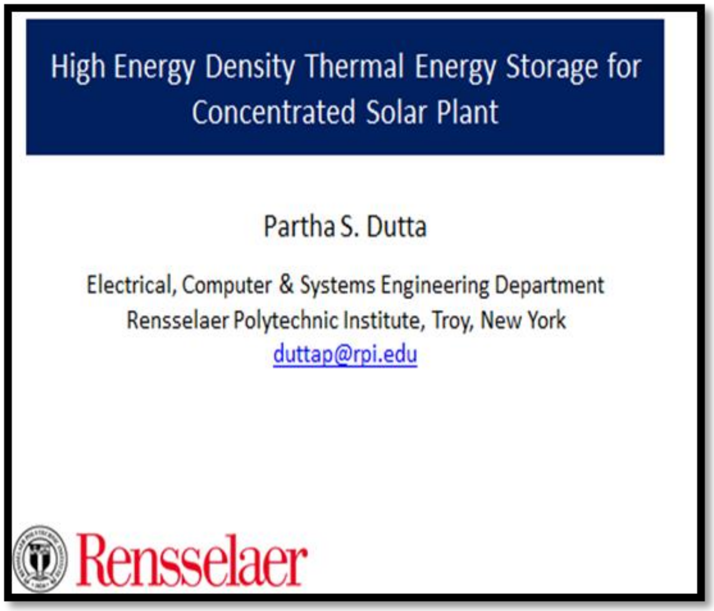
Insulation placed on the copper rod after heating

3. Process of Production of Salt in Indian Labs – equipments needed

Refer ENCL: 05

4. Process of Cooling of Salt:

In summary, profile#2 given below clearly shows that thermal storage under lab conditions is possible to retain heat in the salt for about 5-6 days to reach about 100 degree centigrade.

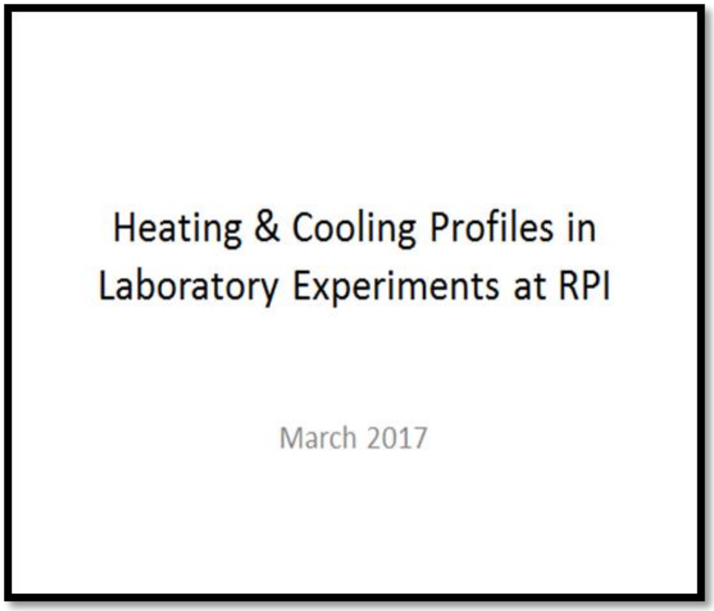


High Energy Density Thermal Energy Storage for Concentrated Solar Plant

Partha S. Dutta

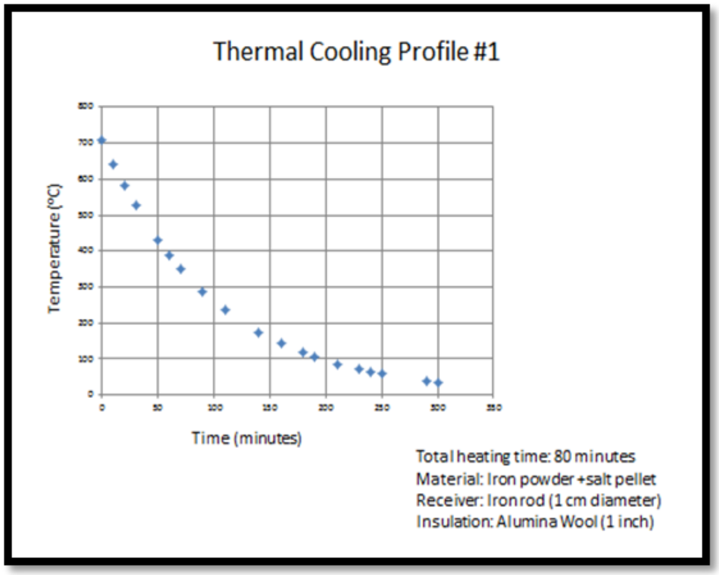
Electrical, Computer & Systems Engineering Department
Rensselaer Polytechnic Institute, Troy, New York
duttap@rpi.edu

Rensselaer



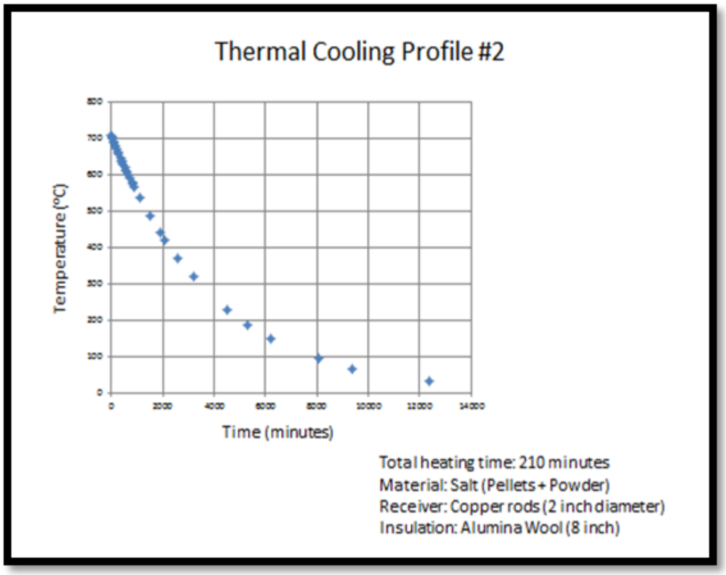
Heating & Cooling Profiles in Laboratory Experiments at RPI

March 2017



Thermal Cooling Profile #1

Total heating time: 80 minutes
Material: Iron powder + salt pellet
Receiver: Iron rod (1 cm diameter)
Insulation: Alumina Wool (1 inch)



Thermal Cooling Profile #2

Total heating time: 210 minutes
Material: Salt (Pellets + Powder)
Receiver: Copper rods (2 inch diameter)
Insulation: Alumina Wool (8 inch)

Project completion report

on

“System Design, Erection, Testing & Commissioning of 40 kWth and 10 kWe pilot plant aiming at the Feasibility Study of MWe Scale Concentrated Solar Thermal Plant integrated with 24 x 7 Thermal Energy Storage”

Speed Post

15/01/2018-19/ST

भारत सरकार/ **Government of India**

नवीन और नवीकरणीय ऊर्जा मंत्रालय / **Ministry of New & Renewable Energy**

(सौर अनुसंधान और विकास प्रभाग / (Solar R&D Division)

***

Block No. 14, CGO Complex,
Lodi Road, New Delhi - 10003.
Dated: 29th March, 2019

Sub: Sanction & Release for implementation of a R&D project entitled "System Design, Erection, Testing & Commissioning of 40 kWth and 10 kWe pilot plant aiming at the Feasibility Study of MWe Scale Concentrated Solar Thermal Plant integrated with 24 x 7 Thermal Energy Storage" by Dr. V K Sethi, Ram Krishna Dharmarth Foundation University, Bhopal and RPI USA, along with the release of Rs.10,00,000/- towards Creation of Capital Assets.

Sanction of the President is hereby accorded to the approval of the project entitled "System Design, Erection, Testing & Commissioning of 40 kWth and 10 kWe pilot plant aiming at the Feasibility Study of MWe Scale Concentrated Solar Thermal Plant integrated with 24 x 7 Thermal Energy Storage" by Dr. V K Sethi, Ram Krishna Dharmarth Foundation University, Bhopal and RPI USA, at a total cost of Rs. 81.50 Lakhs (Rs Eighty One Lakhs and Fifty Thousand only) with Ministry's financial support of Rs. 39.00 Lakhs for a duration of 18 months.

2. The sanction of the President is also accorded to the release of Rs.**10,00,000/- (Rs. Ten Lakh only)** as first instalment of grant under "Creation of Capital Assets" for implementation of the above mentioned project to Ram Krishna Dharmarth Foundation University, Bhopal.

3. The details of the previous release/s is given as under:

Sl. No.	Sanction No. & Date	Amount
1.	Nil	Nil

4. The above sanction will be on the following terms and conditions:-

4.1	Project Title	System Design, Erection, Testing & Commissioning of 40 kWth and 10 kWe pilot plant aiming at the Feasibility Study of MWe Scale Concentrated Solar Thermal Plant integrated with 24 x 7 Thermal Energy Storage
4.2	Principal Investigator	Dr. V K Sethi Vice Chancellor Ram Krishna Dharmarth Foundation , University Gandhi Naga, Bhopal 462033

	Co- Principal Investigator	Dr. Partha S. Dutta Professor, Electrical, Computer and Systems Engineering Department Rensselaer Polytechnic Institute, Troy, New York
4.3	Objectives	• To conduct a comprehensive economic feasibility analysis of a MW e (electrical) scale concentrated solar thermal power (CSP) plant integrated with 24x7 thermal energy storage and • Engineering design, installation and testing of a pilot plant with 40 kWth (thermal) capacity integrated with 24x7 Thermal Energy Storage (TES).
4.4	Time Schedule	18 months
4.5	Budget	

Sl. No.	Items	Cost (in Rs.)		
		1st Year	6 Months	Sharing Cost
1.	Equipment	31,00,000	-	MNRE
2.	Manpower	6,00,000	-	MNRE
3.	Consumables	1,00,000	-	MNRE
4.	Contingency RKDF Land	2,00,000	-	RKDF
5.	Travel	Int. (4,00,000)	-	RKDF
		Local (1,00,000)		MNRE
6.	Consultancy	20,00,000	-	RPI, USA
		9,00,000		RKDF
7.	Overhead (Custom duty + (10% Shipping etc.)	7,50,000	Performance Monitoring	RKDF
Total		**81,50,000**		

4.6	Cost Sharing	RKDF share - Rs.22.50 lakhs RPI (USA) share - Rs. 20.00 lakhs MNRE share - Rs.39.00 lakhs (Equipment-Rs.31 lakh + manpower-Rs. 6 lakh + consumables-Rs. 1 lakh + local travel - Rs. 1 lakh) Total cost - Rs.81.50 lakh
4.7	Deliverables	• Design and Economic Feasibility Analysis of a 1MWe capacity solar thermal energy storage system with volumetric energy density exceeding 300 kWh/m3, capable of operating at high temperatures up to 1000 o C. • Commissioning and field data on energy storage capacity, energy losses, steam generation and electrical power generation (using steam turbine) of a pilot plant with 40 kW_{th}. • Joint IPR from the research. • Research papers on the final pilot plant and field testing data.

5. This sanction is subject to the condition that the grantee organization will furnish to the Ministry of New and Renewable Energy, financial year wise Utilization Certificate (UC) in the prescribed format of GFR-12(A) and audited statement of expenditure (ASoE) duly

reflecting the interest accrued on the grants received/unspent balance under the project along with up to detailed progress report periodically as prescribed under the guidelines. The interest accrued, if any, on the released amount/unspent balance shall be treated as the part of grant.

6. The grantee organization shall ensure that the final statement. of expenditure, utilization certificate and project completion report are furnished within one year from the scheduled date of completion of the project.

7. The grantee organization/institution shall be responsible for timely execution of the project as per the Provisions contained in the guidelines and within the allocated budget. Any request for extension of the project duration or for change in budget allocation, for valid reason, shall be placed before the duly constituted Committee for their recommendation before the expiry of the approved period of the project.

8. In terms of Rule 230 (1) of GFR, the grantee organization/institute will certify that it has not obtained or applied for grants for the same purpose or activity from any other Ministry or Department of the Government of India or State Government.

9. As per the Provision contained in Rule 230 of GFR, the Grants-in-Aid will be sanctioned to the grantee to meet the bonafide expenditure incurred not earlier than two years prior to the date of issue of the sanction. The grantee organization/institute shall ensure that the claims furnished by them are not exceeding the sanctioned components within the approved grant.

10. Procurement of capital equipment should be completed in the year mentioned in the sanctioned or in the succeeding financial year if circumstances so warrant. In no case procurement would be allowed beyond the next succeeding year.

11. In terms of Rule 230 (7) of GFR 2017 and instructions of DoE the Programme Implementing Agency shall record the receipt of grant and the expenditure there from in the EAT module of PFMS. Subsequent release would be contingent upon updation in the EAT module and the actual unspent balance recorded therein.

12. The grantee organization/institution shall be liable for recovery of the whole or part amount of the grant/subsidy, with applicable Penal interest, in case of non-compliance of the guidelines of the scheme/sanction.

13. The sanction of the project is subject to the condition that

(a) A transparent procurement procedure in line with Provisions of GFR, 2017 and Manual for Procurement of Goods-2017 will be followed by the Institute/Organization and /or under the appropriate Rules of the grantee organization while procuring capital assets sanctioned for the above mentioned project and a certificate to this effect will be submitted by the Grantee organization immediately on receipt of the grant:

(b) While furnishing the Utilization Certificate/Statement of Expenditure, the organization has to ensure submission of supporting documents with regard to purchase of equipment/capital assets as per the provisions of GFR-2017.

(c) The PI will follow the norms strictly as guidelines for Renewable Energy Research and Technology Development Programme vide OM No. 223/90/2017 - R&D dated 21st Feb, 2019.

(d) The PI will follow the norms strictly as per the Guidelines for Renewable Energy Research and Technology Development Programme issued by the Ministry vide OM No. 223/90/2017 - R&D dated 21st Feb, 2019.

(e) For implementation of the project, the temporary manpower i.e SRF, JRF and RA etc. shall be hired in the R&D project based on their expertise/professional qualification in RE field depending upon availability. The hiring of the manpower will be purely on temporary basis with a condition that there will be no liability of such staff for confirmation by government. The staff services shall discontinue immediately after the project duration expires.

(f) The projects as such do not involve hiring of consultants as the projects are implemented by experts in the respective areas, hence hiring of consultants under the project will not be allowed.

(g) The funds released towards equipment to be utilized in first year itself.

15. In terms of provisions contained in Rule 233 of GFR, 2017, the Ministry reserves its rights on the assets created out of grants. Assets acquired wholly or substantially out of government grant, shall not be disposed of without prior approval of the Ministry. Further, if the assets are to be sold, the proceeds there from shall be credited to the account of the Ministry. If the assets are allowed to be retained by the institution/organization, the implementing agency shall include the assets at the book value in their own account.

16. In terms of provisions contained in Rule 236(i) of GFR, 2017, the account of the grantee organization shall be open to inspection by the sanctioning authority and audit (both by C&AG of India and Internal Audit by the Principal Accounts office of the MNRE), whenever the organization is called upon to do so.

17. Due acknowledgement of technical support/financial assistance resulting from this project grant should mandatorily be made by the grantee organization in bold letters in all publications/media releases as well as in the opening paragraphs of their Annual Reports during and after the completion of the projects.

18. The expenditure involved is debatable to Demand No., Ministry of New and Renewable energy for the year 2018-19, as per following details

Demand No.67, Ministry of New & Renewable Energy, Major Head:2810-New & Renewable Energy, 00.104-Research, Design and Development in Renewable Energy, 06-Research and Development-(Sub Head), 00-Research and Development Activities, **35-Creation of Capital Assets (2810.00.104.06.00.35) during the year 2018-19 (Plan).**

19. The amount of **Rs.10,00,000 (Rs. Ten Lakh only)** will be drawn by the Drawing and Disbursing Officer, MNRE and will be disbursed to RKDF UNIVERSITY PROJECT ACCOUNT. The bank details for electronic transfer of funds through RTGS are given below:-

Name of Account Holder	RKDF UNIVERSITY PROJECT ACCOUNT
Name of Bank	UNION BANK OF INDIA
Name of Branch	RGPV BRANCH, BHOPAL 0755-2676760
Account Number	586701010050119
Account Type	Current
MICR Code	462026016
IFSC/RTGS Code	UBIN0558672

20. As per Rule 234 of GFR-2017, this sanction has been entered at S. No. 6 & Page No. 11 in the Register of grants for the year 2017-18

21. This issues in exercise of the delegated powers conferred on the Ministry and in consultation of IFD Vide their Dy. No 651 dated 28.03.2019.

24/3/2019

Anil Kumar)
Scientist-C, Solar (R&D)
Tel: 011-24360707 Extn:1034

To

The Pay and Accounts Officer,
Ministry of New & Renewable Energy,
New Delhi.

Copy for information and necessary action to:-

1. The Director of Audit, CW&M-II (Science Audit) DACR Building, I.P. Estate, New Delhi 110 002.
2. Dr.V K Sethi, Ram Krishna Dharmarth Foundation , University, Gandhi Nagar, Bhopal 462033.
3. JS (GKG)/ US/ (F)
4. Cash Section (2 copies).
5. Sanction Folder.

24/3/2019

Anil Kumar)
Scientist-C, Solar (R&D)
Tel: 011-24360707 Extn:1034

GENERAL TERMS & CONDITIONS OF THE GRANT FOR R&D TECHNOLOGY DEVELOPMENT PROJECT

1. Approval of the R&D/ technology development project and the grant being released is for the specific project sanctioned and should be exclusively spent on the project within the approved time duration. The grantee organization is not permitted to seek or utilize funds from any other organization (government, semi-government, autonomous and private bodies) for this research project, unless specifically approved for joint funding. Any un-spent balance out of the amount sanctioned must be surrendered to the Government of India through an ECS/ crossed Demand Draft drawn in favour of Drawing & Disbursing Officer, MNRE payable at New Delhi.
2. Full infrastructure facilities by way of accommodation, water, electricity, communication etc. for smooth implementation of the project shall be given by the grantee organization(s) at their cost.
3. For permanent, semi-permanent assets acquired solely or mainly out of the project grants, an audited record in the form of a register in the prescribed format (Annexure-XIII of 'R&D Formats' on home page of www.mnre.gov.in) shall be maintained by the grantee organization. The term "Assets" include (a) the immovable property acquired out of the grant; and (b) movable property of capital nature where the value exceeds Rs. 50,000/-. The grantee organization is required to send to the MNRE a list of assets acquired from the grant. The grant shall not be utilized for construction of any building unless specific provision is made for that purpose.
4. Assets acquired in the project shall be shared proportionately between Government of India and grantee organization(s) in accordance with the cost sharing pattern of the project. The assets should not be disposed off or encumbered or utilized for purpose other than those for which the grant had been sanctioned, without the prior permission of this Ministry.
5. On conclusion/ termination of a project, the Government of India will be free to sell or otherwise dispose off its share of the assets, which are the property of the government. The grantee organization shall render to the Government of India necessary facilities for arranging the sale of these assets. The Government of India has the discretion to gift its share of assets to the grantee organization or transfer them to any other organization if it is considered appropriate.
6. The grantee organization/ PI will furnish Progress Report of the work carried out under the project on six monthly basis in the months of April and October during the project implementation period in a prescribed format given at Annexure-VIII of 'R&D Formats' on home page of www.mnre.gov.in.
7. Officer(s) of MNRE and MNRE designated Scientist/ Specialist/ Expert Panel/Committee may visit the organization periodically to review the progress of the work being carried out and to suggest suitable measures to ensure realization of the objectives of the project. During implementation of the project, the grantee organization will provide facilities to such visitors in the form of accommodation, site visits, etc.
8. On completion of the project, final consolidated 'Project Completion Report' on the work done on the project will be prepared after incorporating suggestions, if any, from the reviewers of the project and 10 copies of the same will be submitted to the MNRE in the prescribed format given at Annexure-XVII of 'R&D Formats' on home page of www.mnre.gov.in, in physical as well as electronic forms.

9. The 'Project Completion Report' must include all relevant technical details/specifications, working drawings for designing of the systems/equipment, and an inventory of materials required, etc.
10. At the time of seeking further installment of grant and closure/ termination of the project, the grantee organization / PI has to furnish the following documents:
    a. Utilization Certificate (U.C) for MNRE grant and 'Statement of Expenditure' (S.O.E.) for the total expenditure for the previous financial year (in original or copy if sent earlier) in enclosed formats given at Annexure-IX, X and XI (of 'R&D Formats' on home page of www.mnre.gov.in).
    b. Latest authenticated 'Statement of Expenditure' including Committed Expenditure, for the expenditure on the project including cost shared by any other organization since 1st April of that financial year till the previous month; and
    c. Technical Progress Report, if not sent earlier.
11. The Comptroller & Auditor General of India, at his discretion, shall have the right of access to the books and accounts of the grantee organization maintained in respect of the grant received from the Government of India.
12. The grantee organization will maintain separate accounts for the project in a Bank. If it is found expedient to keep a part or whole of the grant in a bank account earning interest, the interest thus earned should be reported to the MNRE and should be reflected in the 'Statement of Expenditure'. The interest thus earned will be treated as a credit to the Institute to be adjusted towards further installment of grant.
13. The grantee organization will neither entrust the implementation of the work for which the grant is sanctioned to another institution nor will it divert the grant receipts to other institute as assistance. In case the grantee organization is not in a position to implement or complete the project, it should, forthwith, refund to this Ministry the entire grant or the balance received by it at the earliest.
14. All the personnel including Research personnel appointed under the project, for the full/ part duration of the project, are to be treated as project personnel on contract to the organization and will be governed by the Administrative rules/ service conditions (for leave, TA/DA etc.) of the implementing Institute. They are not to be treated as employees of the Government of India under any circumstances and the MNRE will have no liability, whatsoever, for the project personnel after completion of the project duration.
15. For the expeditious implementation of the research project, the PI will take the assistance of the grantee organization in the process of selection and appointment of staff and payment to them in accordance with the guidelines given at Annexure-VII of 'R&D Formats' on home page of www.mnre.gov.in. Scale and emoluments for the posts not covered in the said guidelines are to be governed by the norms prevalent in the grantee organization or as decided in consultation with MNRE. Deviations from these guidelines, generally, shall be considered only in consortium projects or projects taken up by an industry on 50:50 cost sharing basis.
16. The Ministry reserves the right to terminate the project at any stage if it is convinced that the grant has not been properly utilized or sufficient progress has not been reported under the project or sufficient efforts have not been devoted.
17. The project becomes operative with immediate effect or within a maximum of one month from the date on which the ECS/ Draft/ Cheque is received by the implementing Institution. This date should be intimated by the grantee authorities/ Principal Investigator to this Ministry.
18. The grantee organization shall associate a co-PI with the project, if not already part of the project team. The co-PI shall function as PI in the absence of PI and should be

totally in knowledge of the activities of the project to avoid loss to the project in case PI leaves the project / organization.

19. If the PI to whom a grant for a project has been sanctioned wishes to leave the grantee organization where the project is sanctioned, the grantee organization/ PI will inform the same to the Ministry and in consultation with MNRE, evolve steps to ensure successful completion of the project through co-PI, before relieving the PI or appoint another Scientist as PI.
20. If the results of research are to be legally protected under IPR, the results should not be published without action being taken to secure legal protection for the research results.
21. Investigator(s) wishing to publish technical/ scientific papers based on the research work done under the project should acknowledge the assistance received from MNRE, indicating the project sanction no. under which grant has been given to the grantee organization. The PI will submit a copy of the paper to the Ministry as soon as it is published.
22. If the results of the work carried out under the grant require preparation of a technical booklet/ guides/ software/ CD etc. in such cases the grantee organization will publish/ prepare sufficient copies (number of copies to be decided in consultation with MNRE) and keep a portion for their use/ dissemination and submit the remaining copies to the Ministry for their use and distribution.
23. If the result is in the form of a survey report / product performance evaluation or other such activities which have commercial implications, the grantee organization will not publish the results without specific written approval of this Ministry.
24. The grantee institution/ PI should provide a copy of the 'Full Text Document' of the Patent/ PI within one month of its publication.
25. The grantee organization(s)/ Inventor(s) are required to seek protection of Intellectual Property Rights for the results/ output of the sanctioned RD&D projects and shall share royalty/ proceeds of sale of IPR in accordance with the guidelines given below:

i. The Government shall have a royalty-free license/ marching right for the use of the Intellectual Property for the purposes of the Government of India and this Ministry reserves the right to require the institution and the industry to license others and that anyone exclusively licensed to market the innovation in India, must manufacture the product in India.

ii. In case MNRE files patents (when grantee organization is unable to file a patent) any earnings accruing from transfer and commercialization shall be shared equally by this Ministry with the Institution and the generator of the Intellectual Property. However, wherever the expected earnings are above Rs.10 lakh, the proportion of sharing can be 40% for the institution, 40% for this Ministry and 20% to the generator of Intellectual Property.

iii. The grantee organization(s) is permitted to retain the benefits arising out of the IPR. In case of more than one institution, IPR generated through joint research can be owned jointly by them as may be mutually agreed to by them through a written agreement.

iv. The institution and industry may transfer the technology to another industry for commercialization, on terms and conditions as may be mutually agreed upon, on non-exclusive basis under intimation to MNRE. Any earnings accruing from such a transfer and commercialization shall be shared between the institution and the industry as may be mutually agreed to. The details of the agreement, amounts-received, annual sales turnover of the product shall be intimated periodically to this Ministry.

v. In case of projects supported solely to industry, any earnings arising out of sale/transfer of IPR generated through the MNRE supported project shall be shared between the MNRE and the industry in the ratio of their individual shares of the project cost.

vi. Other terms and conditions regarding IPR issues shall be in accordance with the guidelines contained in the DST circular issued with the concurrence of Ministry of Finance, Department of Expenditure vide their O.M. No.33 (5)PF- II99, dated 22nd February, 2000 or subsequent circulars which may be issued by DST/ MOF on the subject (Annexure-XV of 'R&D Formats' on home page of the Ministry (www.mnre.gov.in).

26. In case of any dispute the decision of Secretary, Ministry of New and Renewable Energy shall be final.

***

Project completion report

on

“Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant Feasibility Study”

RKDF UNIVERSITY

The CPRI (RSOP) Sponsored Project to RKDF University, Bhopal

“Post Combustion Carbon Capture & Sequestration (CCS) Plant on a Coal Fired Power Plant - Feasibility Study”

Sanctioned vide: CPRI/R&D/TC/Thermal/ 2019 Dated 06-02-2019

Period of Project: April 2019 – June 2021

Collaborator: RGPV, Bhopal & RPI, USA

PROJECT COMPLETION REPORT

TECHNICAL REPORT

SUBMITTED BY: DR. VINOD KRISHNA SETHI, DG (Research) RKDF University

Principal Investigator

Executing Organization: Ram Krishna Dharmarth Foundation (RKDF) University, Airport Bypass Road, Gandhi Nagar Bhopal, MP 462033

RKDF UNIVERSITY

The CPRI (RSOP) Sponsored Project to RKDF University, Bhopal

“Post Combustion Carbon Capture & Sequestration (CCS) Plant on a Coal Fired Power Plant - Feasibility Study”

TECHNICAL REPORT

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Executing Organization: Ram Krishna Dharmarth Foundation (RKDF)
University, Airport Bypass Road, Gandhi Nagar Bhopal, MP 462033

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- **Captured CO2 for EOR**
- **Other NOVEL Options of Sequestration**

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Chapter - 5.3: **Energy Penalty optimization in regeneration of Solvent through Steam from Solar Thermal Plant**

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CHAPTER – 1

INTRODUCTION

CHAPTER – 1.1

PREAMBLE

CHAPTER – 1 INTRODUCTION

1.1 : PREAMBLE – The Project & the 'Technical Report'

1.1.1 Genesis of the Study

1.1.2 Salient Features of the Project – Specs. , Results & Analysis

1.1.3 Executive Summary

1.1 Preamble – The Project & the Technical Report

A. THE PROJECT: Sponsored by CPRI under RSOP scheme vide Sanction letter no. CPRI/R&D/ TC/ Thermal / 2019 Dated 06-02-2019 (Period: April 2019 to June 2021)

Project Title:

"Post Combustion Carbon Capture & Sequestration (CCS) Plant on a Coal Fired Power Plant - Feasibility Study"

Total Outlay:

- CPRI Funding: Rs. 35.00 Lacs
- CPRI Monitoring : Rs. 3.50 Lacs (To CPRI Thermal R&D Division)
- RKDF Equity: Rs. 15.00 Lacs: For Scheffler Discs of Solar Thermal , a Coal fired Steam Boiler , Foundations , Manpower, Testing Commissioning & Contingency

PI: **Dr. Vinod Krishna Sethi,** DG (Research), RKDF University, Ex. VC RKDF & Ex. Pro-VC RGPV & Ex. Director MOP/ CEA

CO- PIs: **Dr. Sunil K Gupta**, VC, RGPV – State Tech. University of MP State &
Dr. Savita Vyas, Professor, RGPV

EPC Contractor: **M/S SUNRISE CSP (I) Private Ltd. Baroda**

Executing Organization: Ram Krishna Dharmarth Foundation **(RKDF) University**, Airport Bypass Road, Gandhi Nagar Bhopal, MP 462033

Executives of RKDF University:

- **Dr. Sunil Kapoor, Hon'ble Chairman RKDF Group**
- **Dr. Sadhna Kapoor, Hon'ble Chancellor**
- **Dr. Sudesh K Sohani, Hon'ble VC**
- **Mr. Siddharth Kapoor, MD,**
- **Dr. B N Singh, DG(Management)**
- **Dr. Sunil Patil, Director**
- **Mr. Suresh K Rathore, Controller of Finance**
- **Dr. Ravi Kumar Singh Pippal, PDF Fellow & Professor**

Project Location: Sir J C Bose Interdisciplinary Technology Park, RKDF, University, Bhopal

B. THE TECHNICAL REPORT

Chapter- wise summary of each of the Chapters of this ‘Technical Report’ is given here under:

CHAPTER – 1: INTRODUCTION

In addition to the Preamble, this chapter covers the ‘Genesis of present R&D Project’ and salient features of the pilot project covering specification analysis of test results and a one page ‘Executive summary’.

Detailed Literature survey giving ‘Gaps’ in the understanding of the Research subject, International Perspective, State of Art of Technology, Policy aspects, Opportunities and Economic implications of CCS Projects in Indian Context are given in the sub-sections of this chapter. Research Papers on Solar Integrated CCS are given due emphasis in this Chapter.

Full text of the ‘References & Papers’ selected for study are given at **ENCL: 01** for information.

Chapter- 2 & 3: OBJECITVES, SCOPE OF THE STUDY & DELIVERABLES

These Chapters give a summary table of how the Objectives of the Sponsored project have been achieved through various out-come results and deliverables.

Chapter - 4: EXPERIMENTAL PROCEDURE

The chapter covers the Specifications and Pilot Plant Design parameters, its integration with Solar Thermal for regeneration of Solvent and details of Coal fired boiler for Steam & Flue Gas generation. Thirty days continuous testing trial Run Data Sheet also forms the part of this chapter.

Chapter – 5: RESULTS, DISCUSSION & ANALYSIS – PRIME OUTPUT THE STUDY

This Chapter covers analysis of out-put of study and various Sequestration Options like; Production of Hydrogen, Pilot study of production of Bio-diesel through Algae Route and sequestration options like use of Captured CO2 to depleted Coal mines etc.

A SCADA / DATA Acquisition System (DAS) is under installation but its commissioning is under hold due to lock-down and severe Pandemic condition. As such full report on this will be submitted as the situation improves as a ‘Supplementary Report’. As such, the Energy Penalty optimization in regeneration of Solvent through Steam from Solar Thermal Plant has been determined and results presented through simulation software **ASPEN Plus.**

Chapter -6: CONCLUSIONS

Main Conclusions of the R&D Pilot Project together with Future Perspective covering Sustainable development aspects and Issues in implementation in Industry & Academia are presented

Chapter -7: TECHNOLOGY KNOW-HOW REPORT

This chapter is devoted to Scaling up of CO2 Capture Plant on a 500 MW Coal fired Thermal Unit at ANPARA B TPS -2x500 MW Unit no. 4 of 500 MW. The water, Power and Land requirement as well as project authority's perspective towards deployment of this technology in their power plants are presented. The Heat / Energy Balances, HBD/ PI diagrams of the 500 MW Unit at ANPARA TPS are also presented.

Chapter -8: PROGRESS REPORTS, SOE & UC SUBMITTED TO CPRI

A summary of latest progress report submitted to CPRI has been presented here and full details will be found in the "Folder" on Progress Reports / SOE **/ UC (ENCL: 02)**

Chapter - 9: PUBLICATIONS & PATENTS

A compiled list of publications and book chapters emerged through the CPRI sponsored RSOP project has been given in this chapter, while the full text of these publications will be found in **ENCL: 03**. The patent application entitled "A reactor for reducing energy penalty in a solar thermal integrated Carbon capture plant with 24x7 energy storage" has been submitted as detailed in **ENCL: 03.**

Chapter - 10: PFMS SUMMARY & EQUITY

This Chapter is devoted to Summary of Payments through PFMS of the CPRI Grant and Equity participation by RKDF University on Civil works, procurement of Coal fired Boiler & Solar Thermal Plant and Testing & Commissioning expenses.

1.1.1 Genesis of the Study

The commercial success of Post Combustion Carbon Capture (PCCC) is mostly technology driven. At present, there is lack of large scale demonstration capabilities for any technology other than those based on amine and ammonia absorption in thermal power plants. Most of the adsorption and membrane based technological options are still in early R&D stage and a credible estimate of their success or failure is difficult to provide at the current stage of development. This trend emphasizes the need to intensify parallel R&D efforts on other potential alternatives based on super adsorbents and novel membranes and undertake pilot and semi-commercial level scale-up initiatives on fast track.

As far as economic factors are concerned, in the case of amine based PCCC technologies, fairly good confidence has been generated in recent years to continuously bring down the unit cost of CO_2. In all other cases, the cost figures are yet to reach commercially viable levels.

At the outset, it may be mentioned that the challenges associated with the commercial use of CCS in India are identified and listed as under.

- ***Potential areas of R&D:*** Along with its research phase, potential estimation of conversion of CO2 into multi-purpose fuels or either its geo sequestration (potential site estimation) plays an important role. The comprehensive geological assessment for CO2 storage potential is yet to be studied in India.

- ***Lack of financing and inflow of foreign direct investment (FDI):*** Implementation of costly CCS technologies require financial incentives from local and central governments in India and good governance politiesenabling to attract foreign FDI for the same.

- ***Environmental and legal concerns:*** Like land acquisition, ground water contamination, fear of CO2 leakage.

- ***Energy penalty:*** CCS requires additional energy input and India's power requirement and economy is not in a position to tolerate this increased cost of generation. Thus, energy penalty plays as barrier in India. **Integration of Solar Thermal with or without Thermal Energy storage require mammoth R&D efforts and to this end the present project has been sponsored by CPRI to RKDF University** together with RGPV, the State owned technology University of MP where the initial trials were performed by the same PI in 2008-2012 under a DST sponsored pilot study.

Policy aspects of CCS projects in Indian Context are based on opportunities of the Post Combustion CCS in India on coal fired power plants, Economic Implications of CO2 Capture & CCS Policy Perspectives of the Government as detailed further in the literature survey.

Key Policy Initiatives for CCS Implementation in India includes introduction of ‘Clean Energy Tax’ on imported and domestic coal in 2010, which goes to go into the National Clean Energy Fund. In 2012, National Action Plan on Climate Change (NAPCC) was expanded to include clean coal and clean carbon technology to minimize CO2 emissions. India’s Twelfth Five Year

Plan (2012-17) highlighted the need to invest in R&D of ultra-supercritical (USC) units. Accordingly Ultra Mega Power Projects (UMPP) came up based on Supercritical technology. These are Sasan Power Limited, Sasan UMPP, Madhya Pradesh; Coastal Gujarat Power Limited, Mundra UMPP; Gujarat; Andhra Power Ltd., Krishnapatnam UMPP, Andhra Pradesh Jharkhand Integrated Power Ltd., Tilaiya UMPP, Jharkhand.

The Renovation, modernization (RM) and Life Extension (LE) activities for 72 Coal power plants totaling to 16532 MW has been done. Institute of Reservoir Studies is carrying out CO2 capture and EOR field studies in Gujarat, while National Geological Research Institute (NGRI) Hyderabad is testing the feasibility of storing CO2 in basalt formations.

India has declared its policy on Carbon Dioxide (CO_2) abatement by the announcement and adoption of the 'National Action Plan on Climate Change'. It has also made voluntary commitment at the UNFCCCs Paris Summit that the country shall decrease its Carbon Intensity by 30-33% by 2030. The path chosen makes it imperative that the CO_2 which forms 95% of the GHG emissions be reduced. Out of total annual emission of about 2100 Million Tons per annum (MTPA), CO_2 emitted by the Coal based thermal power plants of capacity over 180 GW amounts to about over 55%. The reduction of 33% intensity as promised by India at COP-21: Paris; would translate to a decrease of CO_2 emissions to a level of 0.58 kg/kWh by 2030. This decrease is possible by a combination of abatement and recycling measures like augmentation of Low Carbon Technologies (LCT) such as Renewable and Clean Coal Technologies (CCT) and Carbon Capture & Sequestration (CCS) on our Fossil Fuel based thermal power plants. However, as regards post combustion CCS plants on coal fired units, the CO_2 capture by an amine system of 30% CO_2 capture would mean an energy penalty of about 25- 35% including a minimum of 10-20% for compression and pumping to deep reserves like mineral rocks, gas hydrates and ocean. In any case, the energy penalty in Indian context, when CO_2 sequestration for production of multi-purpose fuels is considered a far more appropriate option than CO_2 storage. the energy penalty still remains at level of 15-25%. This can be further reduced to a level of 5% if solar thermal device is used for production of steam for an amine solvent regeneration and stripping of CO_2. The same can be demonstrated only after establishment of pilot plant of CO_2 Capture and Sequestration plant integrated with Concentrated Solar Power (CSP) for carrying out system optimization studies, having variable fluid dynamic configuration.

The challenges associated with the commercial use of CCS in India are many as discussed above, but at the top of all is the need for reduction in 'Energy Penalty. This is the origin and source of inspiration to submit the present proposal to CPRI, pointing towards the Genesis of taking up this project. Parallel projects on Solar Thermal Storage are underway at the RKDF University & RGPV sponsored by MNRE, GOI under the same Principal Investigator, since 2014, which will supplement our efforts in CPRI (RSOP) project on Solar Integrated CCS.

1.1.2 Salient Features of the Project – Specs. , Results & Analysis

The set Objectives of the project have been fulfilled through:

1. Installation of Solar Integrates Carbon Capture Pilot Plant of Capacity 45 kg/hr. of CO2 (250 kg/hr. Flue Gas from the associated Coal Fired Boiler installed for the purpose).

2. Feasibility Study of Installation of Retrofit Post Combustion Carbon Capture Plant on 500 MW Unit of ANPARA B TPS – 2x500 MW in Singrauli region of MP.

[1] The Solar Integrated CCS pilot Plant of Capacity 45 kg/hr. CO2 - Specifications:

- The flue gas is being tapped-off @ 6 tons per day or 250 kg/hr. (i.e. CO_2@ 18% about 45 kg per hour) running in 8 hr. shift and regeneration in 2 shifts with solar steam having 6 hours additional thermal storage capacity using high energy density Halide salt (in excess of 300 kWh/m^3).
- Steam production @ 50 kg/hr. by 10 Scheffler Solar Thermal reflectors @ 5 kg/hr. each
- Additional water requirement is 70 kg per hour - for Steam generation@ 40 kg per hour; Water- gas-shift reaction@ 18 kg per hour and balance for Boiler auxiliaries
- Auxiliary Power requirement of 100 kW has been worked out for the entire CCS plant integrated with 'Solar thermal' system including Solar Trackers, Boiler auxiliaries etc.

Summary bullet-points of Test Results on the Pilot Plant

The project has met its goal during intense testing. The CCS plant has achieved following:-

- CO2 Capture efficiency of 87-90% has been achieved
- CO2 release from Reactor is of the order of 18-23% with steam from Solar Plant for solvent regeneration
- The Energy Penalty in re-generation of Solvent has come down to a level of 2.18 MJ/ ton of CO2 from standard value achieved elsewhere of 4.2 MJ/ Ton of CO2 using Steam from Solar as discussed in the Chapter 5.3 on simulation study using ASPEN Plus Software
- ALGAL BIO-DIESEL PILOT STUDY**:** Dry mass of algae *Scenedesmus obliquus*- Before release of CO2: 5.24 gm. & after release of the CO2: 14.22 gm. Similarly Dry mass of algae *Monoraphidium minutum*- Before release of CO2: 4.71 gm. & after release of the CO2: 11.17 gm. Thus the 'Growth' of selected micro algae has been found to be increased by 2.4 to 2.7 times by weight with CO2 injection
- H2 formation was evaluated to the extent of 1.43%-1.79% by weight equivalent to H2 by volume 17.44% to 21.83% creating the opportunity to the production of multipurpose fuels from captured CO2
- The study conducted for CO2 capture from flue gases & release has revalidated the Amine absorption system for the CO2 application for conversion to fuel molecules through pilot studies for algal Bio-diesel & Hydrogen production.

[2] THE SCALED-UP CCS PLANT ON A 500 MW UNIT:

In this project the scaling-up has been envisaged to 30% CO_2 Capture & Sequestration to produce multi-purpose fuels on a 500 MW Unit at selected thermal plant in Singrauli region. Efforts have been made with UPRVUNL in collaboration with TOSHIBA Corp. the EPC contractor & supplier of the Anpara B TPS for establishment of CCS plant on one of the pit head unit no. 4 of 500 MW at ANPARA in SINGRAULI Region of UP and MP border.

Since a 500 MW unit emits about 8000 tons of CO_2 per day (about 330 tons per hour), the scaled-up carbon capture and sequestration plant will be of capacity 100 tons per hour. No compression and storage of CO_2 is presently envisaged.

The strategy of scaling-up of the pilot plant of the proposal is briefly given below:

- Optimization of scale of carbon capture (range 30% to 100%)
- Algae plant stage of implementation for species to grow.
- Feasibility study of power plant modification required for production of multi-purpose fuels like H2 , CH4 etc.
- Analysis to utilization of CCS Plant produced H2 in fuel cell for lighting application
- CO recycling option to boiler – short flame burner design
- Energy penalty reduction through various option of solar thermal- technologies
- Sequestration to coal seams of depleted mines

BREIF SPECIFICATIONS:

- Incorporation Solar thermal plant of capacity 70 tons per hour for steam production both for MEA solvent regeneration and WGS reaction with a make-up water consumption of 4.5%, i.e. 3 tons/hr.

- Land Area between Stack-area Slab (now being used for De-sulfurization) & Fuel Oil corridor in front of the stack: … 70 mx125 m, with reactors at 2 levels

- Additional Water requirement … 4-5 tons per hour as make-up & for gasification

- Additional Power requirement … 4 MW, that increases auxiliary power consumption by 0.8 %

- Production of Algal Bio-mass @55 tons per hour using selected species of Algae viz. Scenedesmus obliquus, Monoraphidium minutum and Clorola Velgaris in the specially designed bio-reactor for culture preparation and algal pond. These varieties have been tested to have growth in the Ash decantation water also. Bio-diesel shall be produced using trans-stratification process.

- Production of CO from CO_2 using gasifier and thereby producing Hydrogen using water-gas shift (WGS) reactors. Performance of WGS catalysts under wide range of CO-to-Steam ratios will be investigated for an optimum level.

- Our feasibility study shows that for 500 MW Unit No.4 of ANPARA B TPS -2x500 MW (EPC by Toshiba Corp, Japan) the best solution would be:
    - Initially use depleted Kakri coal field for sequestration
    - Next use Bina coal seam for CO2 sequestration
    - The pipeline cost will be minimum via Anpara Shaktinagar road side
    - The old Warf wall of Kakri mine shall be used for CO2 pumping station

The following are presently considered as items which have been demonstrated /verified at the CO_2 Capture Demo Plant, as discussed in various sections of this TECHNICAL REPORTusing SCADA / DAS under execution**.**

Performance Issues

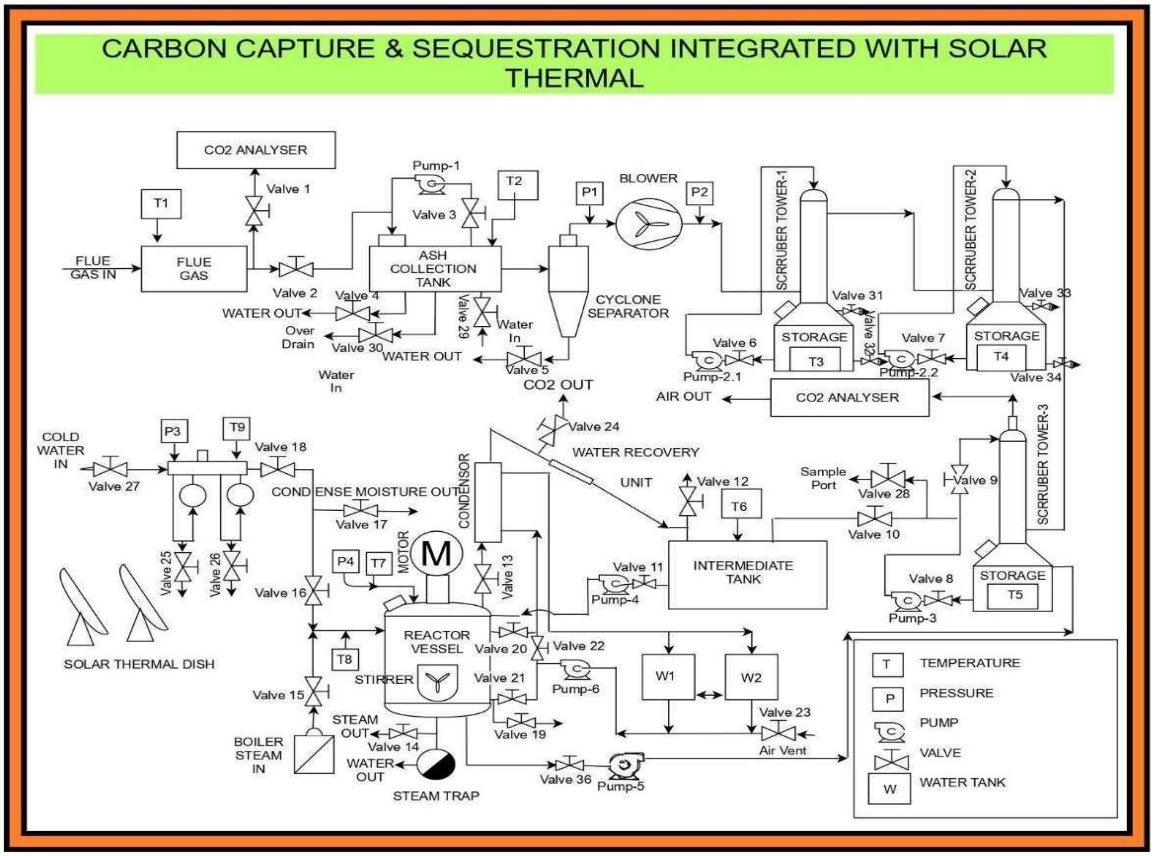
- CO_2 Capture mass flow
- CO_2 Capture rate
- Energy required to capture CO_2
- Overall effect on performance of the power plantequipped with CO_2 capture facility

Operability Issues

- Effects of flue gas property (including Coal properties)
- Effects of CO_2 capture rate setting
- Effects of heat inputs to CO_2 capture
- Start-up, shut-down, transient operations
- Part load, part capture operability

HEAT BALANCE DIAGRAM: ANP-B – FIG 01 PROVIDES DETAILS OF CCS PLANT SCHEME INTEGRATED WITH THE 500 MW ANPARA – B UNIT # 4.

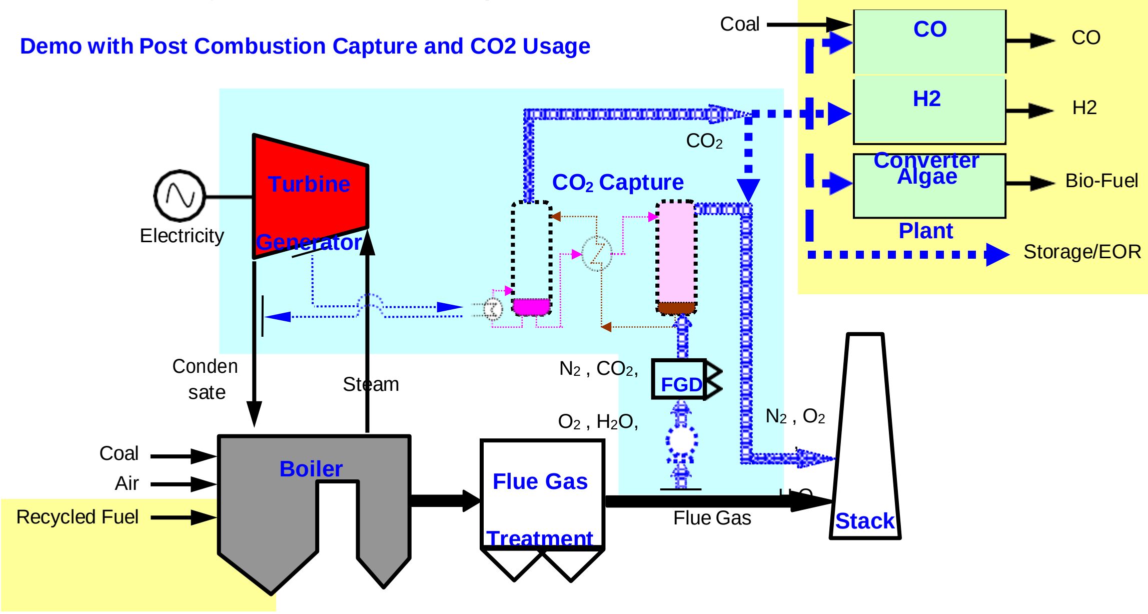
BOTH {1} PILOT PLANT AND {2} SCALED UP PROPOSED PROJECTS ARE SCHEMATICALLY SHOWN BELOW:


CARBON CAPTURE & SEQUESTRATION INTEGRATED WITH SOLAR THERMAL

Scaled-up Project on A Mega Power Plant

Retrofit of existing 500 MW Thermal Power plant of ANPARA B TPS.

Demo with Post Combustion Capture and CO2 Usage

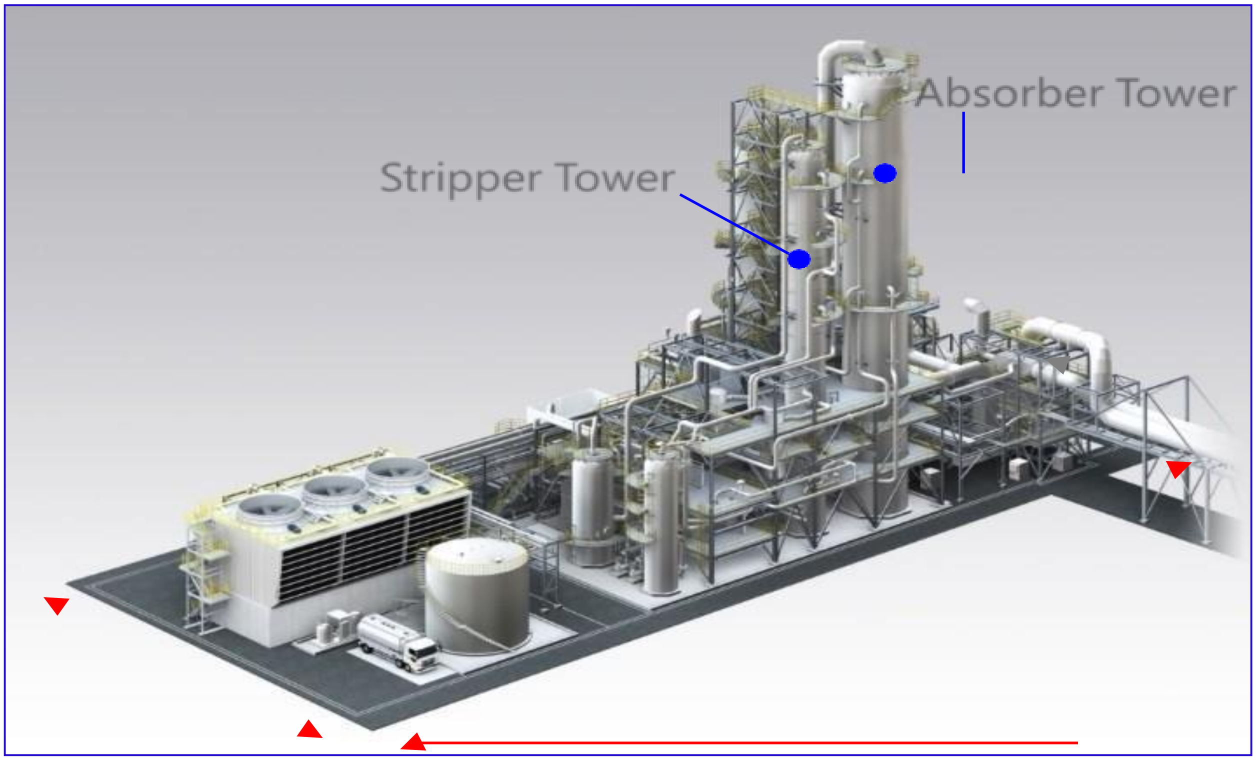


🟦 *Toshiba engineers construction or modification*

🟨 *RKDF / RGPV specifies requirements – Industry partner (ANPARA B TPS) engineer's construction or modification*

THE PILOT PLANT AT RKDF UNIBERSITY

CCS PLANT AT ANPARA 'B' TPS 2x500 MW – EPC BY TOSHIBA (Proposed)



CPRI- RSOP Project Title: "Post Combustion Carbon Capture & Sequestration (CCS) Plant on a Coal Fired Power Plant - Feasibility Study"

1.1.3 Executive Summary

The Prime Objectives of the R&D Project are to provide a potential ground under aegis of CPRI: MOP for developing and demonstrating feasibility of Sustainable Clean Coal Thermal Power Plants equipped with Carbon Capture & Sequestration Technology & Exploring options for reducing energy penalty through solar thermal and other options like process optimization etc.

These Objectives have been fulfilled through the Installation of Carbon Capture Pilot Plant of 45 kg/hr. of CO2 capture Capacity using a Coal Fired Boiler installed for the purpose and integration with Solar Thermal Plant for steam production. The Feasibility Study of Installation of Retrofit Post Combustion Carbon Capture Plant on 500 MW ANPARA B TPS – 2x500 MW in Singrauli region of MP has been carried out and detailed specifications of mega scale CCS plant have been worked out.

A Pilot Study of Production of Multi-purpose Fuels like Hydrogen and Bio-diesel through Algae route has also been carried out on the table-top set-up. The feasibility study on ANPARA B TPS –Unit # 4 of 500 MW has examined various options like application of Captured CO2 to depleted Coal mines of NCL, Singrauli region.

The pilot plant has achieved CO2 capture efficiency of 87-90% and use of solar generated steam for regeneration of solvent in the reactor (re-boiler) has reduced energy penalty from a level of about 4 MJ/ton CO2 to 2.18 MJ/ton CO2.

The study conducted for CO2 capture from flue gases & release has revalidated the Amine absorption system for the CO2 application for conversion to fuel molecules through pilot studies for algal Bio-diesel & Hydrogen production

The Feasibility Study of Installation of Retrofit Post Combustion Carbon Capture Plant on 500 MW ANPARA B TPS – 2x500 MW in Singrauli region of MP has demonstrated that the scaled-up plant would require incorporation of Solar thermal plant of capacity 70 tons per hour for steam production both for MEA solvent regeneration and WGS reaction with a make-up water consumption of 4.5%, i.e. about 3 tons/hr. Additional power requirement will increases auxiliary power consumption by 0.8 %.The production of Algal Bio-mass will be of the order of @55 tons per hour using selected species of Algae like Scenedesmus obliquus, Monoraphidium minutum and Clorola Velgaris in the algal pond. These varieties have been tested to have growth in the Ash decantation water also.

Production of CO from CO_2 using gasifier and thereby producing Hydrogen using water-gas shift (WGS) reactors has been put forward together with estimation of energy saving through CO recycling to boiler. Performance of WGS catalysts under wide range of CO-to-Steam ratios will be investigated for an optimum level. Our feasibility demonstrated a variety of applications of sequestered CO2 and optimized Heat / Energy Balance of the retrofitted CCS plant to the selected 500 MW pit head power plant Unit in Singrauli coal field region, having ample space for Solar Thermal plant installation.

CHAPTER – 1.2

LITERATURE SURVEY

Chapter -1.2: LITERATURE SURVEY

1.2.1 Gaps in the understanding of the Research subject

1.2.2 CCS Projects – International Perspective: State of Art of Technology

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- **Opportunities of Post Combustion CCS in India**
- **Economic Implications of CO_2 Capture & CCS Policy Perspectives**

1.2.4 Techno-economics of CO_2 Capture in Indian Context
1.2.5 Solar Integrated CCS

1.2.1 Gaps in the understanding of the Research Subject

The commercial success of PCCC is mostly technology driven. At present, there is lack of large scale demonstration capabilities for any technology other than those based on amine and ammonia absorption in thermal power plants. Most of the adsorption and membrane based technological options are still in early R&D stage and a credible estimate of their success or failure is difficult to provide at the current stage of development. Even in the case of amine and ammonia based PCCC technologies, several commercial and semi-commercial ventures which were found to be successful initially, their use declined by more than 50 % after more than a decade of deployment at coal fired power plants due to insurmountable techno economic factors. This trend emphasizes the need to intensify parallel R&D efforts on other potential alternatives based on super adsorbents and novel membranes and undertake pilot and semi-commercial level scale-up initiatives on fast track. Special attention has to be given to hybrid absorption-adsorption/membrane separation systems that can provide highly impressive CO_2 capture efficiency and selectivity. Past experiences have shown that adsorption-diffusion processes have a strong influence on the pace of innovation and enhance the prospects for cost effective PCCC technologies.

As far as economic factors are concerned, in the case of amine based PCCC technologies, fairly good confidence has been generated in recent years to continuously bring down the unit cost of CO_2. In all other cases, the cost figures are yet to reach commercially viable levels.

The challenges associated with the commercial use of CCS in India are identified and listed below.

- *Lack of R&D effort:* Along with its research phase, its potential estimation of conversion into fuel or either its
  geo sequestration (potential site estimation) plays an important role.
- *Need for comprehensive national study on Geological storage:* The comprehensive geological assessment for CO2 storage potential is yet to be studied in India.
- *Lack of financing and inflow of foreign direct investment (FDI):* Implementation of costly CCS technologies require financial incentives from local and central governments in India and good governance polities enabling to attract foreign FDI for the same.
- *Environmental and legal concerns:* Like land acquisition, ground water contamination, fear of CO2 leakage.
- *Cost scenario:* Even after development for over 30 years, CCS technology is still proven costly to developing countries like India.
- ***Energy penalty:* CCS requires additional energy input and India's power requirement is yet to be fulfilled. Thus, energy penalty plays as barrier in India. Integration of Solar Thermal with & without Thermal Energy storage require mammoth R&D efforts and to this end the present project has been sponsored by CPRI to RKDF University together with RGPV where the initial trials were performed in 2008-2012 by the same PI.**

1.2.2 CCS Projects – International Perspective: State of Art of Technology

i. Carbon Capture and Sequestration worldwide Project Database

Power Plant CCS Projects

These are large scale, over 60 MW, CCS projects from which the CO_2 is sourced from power plants. The database summary table contains information on the project name, the main leader of the project, feedstock, size, capture process, CO_2 fate, proposed start-up date and the project's location. All of these projects are currently active in planning and execution of their CCS plans. When a project is unfortunately cancelled or placed on hold, we change the start-date to indicate the status of the project. After a period of inactivity the project is removed from the database.

A list of abbreviations used in the table is provided at the bottom of the page.

Non-Power CCS Projects

This database contains all other CCS projects from which the CO_2 is not sourced from power plants. This includes industrial and natural sources. The summary table provides information on the project's leader, location, CO_2 source, size, CO_2 sink and proposed start date. These projects include the US DOE Regional Partnership projects which, although some of them are small, they are important as they have all received US Government funding.

A list of abbreviations used in the table is provided at the bottom of the page.

Commercial EOR Projects using Anthropogenic CO2

These Commercial EOR projects are projects which capture almost a pure stream of CO_2 and use it commercially for CO2-EOR. These large scale projects include project information on the general project parameters, but also include additional information on the EOR site, the length of pipeline from the capture site to the injection site, the type of reservoir, its depth and where information is available; the additional recovery rate achieved using the CO2-EOR.

Pilot Power Plant CCS Projects

These pilot CCS projects are smaller scale projects ranging from 1 MW to 50 MW and are dedicated to the advancement of research in CCS and its larger scale deployment. They include all types of CCS pilot projects from both power and industrial projects. The summary table contains information on the pilot project's main leader, its size, capture type, current status and its announced start date

Announced Projects

There are many CCS projects being announced worldwide. This page is to give the basic information about these projects without saturating the main database. This database also contains dormant projects; those which have had no news on for multiple years but which have not been publicly cancelled.

Cancelled and Inactive Projects

These are projects which have been cancelled, postponed (On Hold), or have had no news or any activity for an extended amount of time (Dormant).

Regional CCS Financing Summaries

These summary sheets are designed to give a quick overview of the region's CCS financial background and there are links to different project funding sources for more detailed information. These summaries can also be found by clicking on the country's name in the CCS database table headings. Currently we have summary policies on: USA, Canada, UK and Australia which is being presented in this Chapter: Literature Survey

Power Plant Carbon Dioxide Capture and Storage Projects

<table>
<tr><th colspan="8">Large scale Power Plant CCS Projects Worldwide</th></tr>
<tr><td colspan="8">USA</td></tr>
<tr><td>Project Name</td><td>Leader</td><td>Location</td><td>Feedstock</td><td>Size MW</td><td>Capture Process</td><td>CO2 Fate</td><td>Status</td></tr>
<tr><td>Kemper County</td><td>Southern</td><td>Mississippi</td><td>Coal</td><td>582</td><td>Pre</td><td>EOR</td><td>Operational</td></tr>
<tr><td>Petra Nova WA Parish</td><td>NRG Energy JX Nippon</td><td>Texas</td><td>Coal</td><td>240</td><td>Post</td><td>EOR</td><td>Operational</td></tr>
<tr><td>TCEP</td><td>Summit Power</td><td>Texas</td><td>Coal</td><td>400</td><td>Pre</td><td>EOR</td><td>Planning</td></tr>
<tr><td colspan="8">Canada</td></tr>
<tr><td>Project Name</td><td>Leader</td><td>Location</td><td>Feedstock</td><td>Size MW</td><td>Capture Process</td><td>CO2 Fate</td><td>Status</td></tr>
<tr><td>Boundary Dam</td><td>SaskPower</td><td>Saskatchewan</td><td>Coal</td><td>110</td><td>Post</td><td>EOR</td><td>Operational since October 2014</td></tr>
<tr><td colspan="8">European Union</td></tr>
<tr><td>Project Name</td><td>Leader</td><td>Location</td><td>Feedstock</td><td>Size MW</td><td>Capture Process</td><td>CO2 Fate</td><td>Status</td></tr>
<tr><td>Peterhead</td><td>Shell and SSE</td><td>UK</td><td>Gas</td><td>385</td><td>Post</td><td>Depleted Gas</td><td>Operational</td></tr>
<tr><td>Don Valley Power Project</td><td>2Co Energy</td><td>UK</td><td>Coal</td><td>900</td><td>Pre</td><td>Saline</td><td>Operational</td></tr>
<tr><td>Captain/ Clean Energy Project</td><td>Summit Power</td><td>UK</td><td>Coal</td><td>570</td><td>Post</td><td>Saline</td><td>Operational</td></tr>
</table>

White Rose	Capture Power	UK	Coal	426	Oxy	Saline	Planning
Rest of the World							
Project Name	**Leader**	**Location**	**Feedstock**	**Size MW**	**Capture Process**	**CO2 Fate**	**Status**
Daqing	Alstom & Datang	China	Coal	350	Oxy	EOR	Planning
Dongguan	Dongguan Taiyangzhou Power Corporation	China	Coal	800	Pre	EOR	Planning
Shengli Oil Field EOR	Sinopec	China	Coal	40-250	Post	EOR	Pilot Operating 2007
GreenGen	GreenGen	China	Coal	100-400	Pre	EOR	Planning
Lianyungang	Lianyungang Clean Energy	China	Coal	1200	Pre	Saline or EOR	Planning
Korea CCS	KCRC	Korea	Coal	300/500	Oxy	Saline	Planning
Taweelah	Masdar	UAE	Gas	2 Mt/yr	Post	EOR	Planning

Announced Carbon Dioxide Capture and Storage Projects

The following projects have been announced but very little detail is known about them. When the projects are further defined a project page will be created.

Project Name	**Location**	**Leader**	**Size**	**Further information**
CarbonNet	Australia	Victorian Government	Network	Research project on the potential to develop a large scale CCS network in Victoria, Australia
South West Hub	Australia	Western Australian Dep. Mines and Petroleum	2.5 Mt/yr	CO2 capture from various industrial sources, including fertilizer and power generation for onshore EOR.
Shanxi	China	Shanxi Energy Group	350 MW	New build Super critical Power plant with 2-3 Mt/yr with potential for CCS
YiHe Coal plant	China	China Energy & Seamwell	1000 MW	$1.5 billion clean coal plant to be built in Inner Mongolia (June 2011)

Ledvice	Czech Republic	CEZ	660 MW	Retrofit post combustion plant. Financing proposed
Hodonin	Czech Republic	CEZ	660 MW	Considering 2 sites for pilot plants
Hassyan Clean Coal	Dubai	DEWA	1200 MW	Dubai Electricity and Water Authority (DEWA) has competition to select developer for 49% of its new clean coal power plant. Commissioned by 2020
Gundih project	Indonesia	Kyoto University C-PIER	N/A	Carbon sequestration in Indonesia enters pilot phase with ADB funding (May 2016)
Gulf Cryo	Kuwait	Equate Petrochemical Company	280t/day	Kuwait's first CO2 plant officially opened
Kurashiki	Japan	Nippon Ekitan Corp.	283 t/day	MHI receives order for CO2-capture unit for Nippon Ekitan's Mizushima Plant
Nord	France	Total	N/A	The French Environment and Energy Management Agency (ADEME) selects the project for E54M
Eemshaven RWE	Netherlands	RWE	0.19 Mt/yr	RWE project web-page
Turceni	Romania	Turceni	1.5 Mt/yr	GCCSI awards Romania project $2.55 (October 2010) Project is on hold as more funding is secured for FEED and storage appraisal
CO2 solutions and EERC	USA	CO2 Solutions and EERC	N/A	CO2 Solutions Announces Testing Program with Energy & Environmental Research Center (EERC) (September 2014)
Medicine Bow	USA	Sinopec	2.5 Mt/yr	Medicine Bowl Project presentation (2011) Coal to liquids facility with CO2 for EOR. Start 2018
Quintana	USA	Great Northern Power Development	2.1 Mt/yr	Quintana South Heart Project 2.1 MT/Yr, IGCC pre-combustion capture. New Build. Start in 2018

Power Plant Carbon Dioxide Capture and Storage Projects

Pilot CCS Projects- Completed							
Project Name	**Leader**	**Location**	**Feedstock**	**Size MW**	**Capture Process**	**CO2 Fate**	**Status**
K12-B	GDF Suez	Netherlands	Gas Processing	0.2 Mt/yr	Depleted Gas	2004	Operated 2004-2006
Ketzin	GFZ	Germany	H2 Production	0.06 Mt/yr	Post	Saline	Operated 2008-2013
Schwarze Pumpe	Vattenfall	Germany	Coal	30	Oxy	Depleted Gas	Operated 2008-2014
ECO2 Burger	Powerspan	OH, USA	Coal	1	Post	Vented	Operated 2008-2010
Pleasant Prairie	Alstom	WI, USA	Coal	5	Post	Vented	Operated 2008-2009
Otway	CO2CRC	Australia	Natural Deposit	0.065 Mt/yr	Natural Deposit	Depleted Gas	Operated 2008-2011
AEP Mountaineer	AEP	WV, USA	Coal	30	Post	Saline	Operated 2009-2011
Karlshamn	E.ON	Sweden	Oil	5	Post	Vented	Operated 2009-2010
Compostilla	ENDESA	Spain	Coal	30	Oxy	Saline	Operated 2009-2012
Puertollano	ELCOGAS	Spain	Coal	14	Pre	Recycled	Operated 2010-2011
Lacq	Total	France	Oil	35	Oxy	Depleted Gas	Operated 2010-2013
Buggenum	Vattenfall	Netherlands	Coal	20	Pre	Vented	Operated 2011-2013
Brindisi	Enel &Eni	Italy	Coal	48	Post	EOR	Tested March 2011

Ferrybridge CCSPilot100 +	SSE	UK	Coal	5	Post	Vented	Operated 2012-2013
Aberthaw	RWE	Wales, UK	Coal	3	Post	N/A	Operational 2013-2014
Polk	Tampa Electric	FL, USA	Coal	0.3 Mt/yr	Pre	Saline	Tested 2014
Callide-A Oxy Fuel	CS Energy	Australia	Coal	30	Oxy	Saline	Operated 2012-2015
Pikes Peak	Husky Energy	SA, Canada	Coal	15 t/day	Post	EOR	Operated 2015
E.W. Brown	Univeristy of Kentucky	KY, USA	Coal	2 MW	Post	N/A	Completed

Pilot CCS Projects- Operating

Project Name	**Leader**	**Location**	**Feedstock**	**Size**	**Capture Process**	**CO2 Fate**	**Status**
Zama	Apache & PCOR	Alberta	Gas Processing	0.026 Mt/yr	Gas Production	EOR	Operational July 2006
Snohvit	StatoilHydro	Norway	LNG Processing	0.7 Mt/yr	Post	Saline	Operational October 2007
Shidongkou	Huaneng	China	Coal	0.1 Mt/Yr	Post	Commercial Use	Operational 2009
Jilin	PetroChina	China	Nat. Gas Processing	0.2 Mt/yr	Post	EOR	Operational 2009
Ordos	Shenhua group	China	Liquefaction	0.1	Post	EOR / Saline	Operational 2011
Shengli	Sinopec	China	Coal	0.04 Mt/yr	Post	EOR	Operational 2007
Wilhelmshaven	E.ON	Germany	Coal	3.5 MW	Post	Vented	Operational October 2012
Mongstad	Statoil	Norway	Gas	0.1 Mt/y	Post	Saline	Operational May

				r			2012
Plant Barry	Southern Energy	AL, USA	Coal	25 MW	Post	Saline	Operational 2011
Jingbian	Yanchang	China	Chemicals	40 Kt/yr	N/A	EOR	Operational 2012
Lula	Petrobas	Brazil	Gas Production	0.7 Mt/yr	Gas Production	EOR	Operational 2013
Boryeong Station	KEPCO	South Korea	Coal	10 MW	Post	Vented	Operational May 2013
Shand	SaskPower	Canada	Coal	43 kt/yr	Post	Vented	Operational June 2015
Tomakomai	JCCS	Japan	Hydrogen Production	0.1 Mt/yr	Post	Saline	Operational March 2016
NET Power	NET Power	TX, USA	Natural Gas	50 MW	Oxy	EOR	Planning

Abbreviations:

Oxy = Oxyfuel Combustion Capture
Pre = Pre Combustion Capture
Post = Post Combustion Capture
EOR = Enhanced Oil Recovery
EGR = Enhanced Gas Recovery
Saline = Saline Formation
Depleted Gas = Depleted Gas Reservoir
Depleted Oil = Depleted Oil Reservoir
TBD = To Be Decided

Kemper County IGCC Fact Sheet: Carbon Dioxide Capture and Storage Project

Company/Alliance: Mississippi Power, Southern Energy, KBR

Location: Kemper County, Mississippi

Feedstock: Coal: Mississippi lignite

Size: 582 MW: about 3 Mt of CO2 captured annually

Capture Technology: Pre-combustion IGCC plant using TRIG™ technology (65% capture)

CO2 Fate: Pipeline for onshore EOR

Timing: Construction started June 2010. Originally the Kemper was to start in May 2014. After many delays the Project started full operation by 2016

Petra Nova W.A. Parish Fact Sheet: Carbon Dioxide Capture and Storage Project

Company/Alliance: Petra Nova Holdings: a 50/50 partnership between NRG Energy and JX Nippon Oil & Gas Exploration Corp.

Location: Unit 8, W.A. Parish plant, Thompsons, 60KM from Houston, Texas, USA

Feedstock: Coal

Size: 240 MW slip stream from 610 MW unit.

Capture: 1.4 Mt of CO2 captured annually (90% capture)

Capture Technology: Post-combustion: KM-CDR amine scrubbing CO2 developed by MHI and KEPCO

CO2 Fate: 82 mile pipeline for onshore EOR in Hilcorp's West Ranch Oil Field in Jackson County, Texas

Timing: Project started at the end of 2016

Boundary Dam Fact Sheet: Carbon Dioxide Capture and Storage Project

Company/Alliance: SaskPower

Location: Unit #3, Boundary Dam Power Station, Estevan, Saskatchewan, Canada

Feedstock: Coal

Size: Original 139 MW gross upgraded to 160 MW gross; Net after CO2 capture retrofit (1Mt/yr) is 110 MW net

Capture Technology: Post-combustion amine

CO2 Fate: EOR in Weyburn field (90% of CO2). Transportation is via 66 km pipeline built by Cenovus. Any CO2 not used for EOR is to be used at the Aquistore project 2 km away

Start Date: Started in October 2014. Fully operational since 2016

Texas Clean Energy Project (TCEP) Fact Sheet: Carbon Dioxide Capture and Storage Project

Company/Alliance: Summit Power Group Inc, Siemens, Fluor, Linde, R.W. Beck, Blue Source and Texas Bureau of Economic Geology

Location: Penwell, Ector County, Texas, USA

Feedstock: Coal

Size: 400 MW Gross, 245 MW Commercial output (2 Mt/yr captured) New Build

Capture Technology: Pre-Combustion: Siemens IGCC technology and Linde Rectisol acid-gas capture technology (90% CO2 capture)

CO2 Fate: EOR in the Permian Basin

Start: Started (2019)

Don Valley Power Project Fact Sheet: Carbon Dioxide Capture and Storage Project

**Formally known as Hatfield*

Company/Alliance: Sargas Power (sold in 2014 by 2Co Energy Ltd)

Location: Stainforth, South Yorkshire, UK

Feedstock: Coal

Size: New build 900 MW gross, 650 MW net: 4.5 Mt/yr (90% capture)

Capture Technology: IGCC: Pre-combustion

CO2 Fate: 175 Km onshore to offshore pipeline for sequestration in offshore deep saline formations

Timing: Started in 2020.

Korea CCS 1&2 Project Fact Sheet: Carbon Dioxide Capture and Storage Project

Company/Alliance: Korea Carbon Capture and Sequestration R&D Center (KCRC)

Location: Korea

Feedstock: Coal

Size: 500 MW (oxyfuel) or 300 MW (IGCC)

Capture Technology: Oxyfuel or Post-combustion

CO2 Fate: Offshore deep saline aquifers: Ulleung deep saline formation or the Gorae gas reservoir

Timing: Start: Plant 1 (2016) Plant 2 (2018)

Motivation/Economics: Total Budget: 172 billion KRW

E.W. Brown Fact Sheet: Carbon Dioxide Capture and Storage Project

Company/Alliance: University of Kentucky Centre for Applied Energy Research (UKCAER)

Location: Kentucky Utilities Company's E.W. Brown Generating Station, near Harrodsburg, Kentucky, USA

Feedstock: Coal

Size: 2 MW

Capture Technology: Post-combustion

Timing: Construction started (2014) Complete construction (end 2014)

Cost: $19.5 million (Rs. 140 Cr.)

ii. CCS Project Recent Updates

The CCS project database is constantly being updated as shown at APPENDIX- I

iii. CCS Project worldwide – Status of Technology

UK Perspective:

Ref-01: "The prospects for coal-fired power plants with carbon capture and storage: A UK perspective" by Geoffrey P. Hammond, Jack Spargo, Current carbon capture and storage (CCS) technologies

In the UK for CO2 capture there are three main methods for capturing the carbon dioxide from coal-fired power stations that are currently in development: post-combustion capture, pre-combustion capture, and oxy-fuel combustion capture [1, 2]. These three generic 'routes' all involve the process of removing CO2 from point-source gas streams, and this can be done in a number of ways. Technical and cost data associated with these routes have been described in the Intergovernmental Panel on Climate Change (IPCC) Special Report on CCS (SRCC) [3]. The drivers for and barriers to the deployment of currently available CCS technologies in the UK were discussed by Hammond et al. [1]. They suggested that around 90% of operational carbon emissions can be captured; albeit with an energy penalty of about 16% and rises by some 140% in 'cost of electricity' (COE) compared with a Pulverised Coal reference plant [1]. Kleijn et al. [4] have also recently found that power plant CCS are substantially more metal intensive than existing electricity generators. There are five main technologies to remove CO2 from a gas stream that are available for use in CCS, and the pressure, temperature and concentration of CO2 in the flue gas stream will determine which is best suited to a given process [2]. The five technologies are: (i) Chemical Solvents; (ii) Physical Solvents; (iii) Adsorption/Desorption; (iv) Membrane Separation; and (v) Cryogenic Separation. The method of post-combustion capture (or 'flue gas scrubbing') is currently the most developed and popular technique employed in industry for capturing CO2 from the exhaust gases of fossil fuel combustion [1, 2, 3]. It can be retrofitted at relatively low cost to existing power stations [2] and allows the combustion process to be kept relatively unchanged. The coal is burnt in a conventional combustion chamber, and then the exhaust gases are passed through a particle removal chamber that separates out ash and smoke particles. After a sulphur removal stage, the flue gas is transferred into a CO2 absorption unit where a solvent absorbs the CO2. The solvent would react adversely (or be consumed at a fast rate) if the ash, sulphur and other major impurities had not previously been filtered. A CO2 rich, (typically) amine-based solvent, like mono-ethanol amine (MEA) [1, 2], is subsequently heated in a CO2 stripper, where it releases the pure CO2 that can be recycled to absorb more CO2. The CO2 that is collected by the stripper is then compressed and stored locally before being piped or shipped directly to its final storage location. Amine-scrubbing is a proven process that is currently used in CO2 removal for industrial applications [2]. It does however carry an added energy penalty because of gas compression and solvent cooling and heating requirements. This is typically amounts to around 16% [1, 2], and therefore more coal needs to be burnt to achieve the same level of electrical output.

The UK Government in their 2007 Energy White Paper (EWP accepted that Britain should put itself on a path to achieve a goal by adopting various low-carbon options, principally energy efficiency measures, renewable energy sources, and next generation nuclear power plants. Carbon capture and storage (CCS) facilities coupled to coal-fired power plants provide a climate change mitigation strategy that potentially permits the continued use of fossil fuels whilst reducing the carbon dioxide (CO2) emissions. The 2007 EWP also identified CCS as an important element in any energy RD&D programme. Potential routes for the capture, transport and storage of CO2 from UK power plants, such as the Kings north and Lon gannet sites, were examined. Storage for the British Isles is likely to be in geological formations, such as depleted oil and gas fields under the North Sea or saline aquifers. Both currently available and novel CCS technologies were evaluated. Due to lower operating efficiencies, the CCS plants showed a longer energy payback period and a lower energy gain ratio than conventional plant. The CO2 that was emitted per unit of electricity generated from the assessed CCS power station is found to be only 0.12 kgCO2 per kWh [in contrast to 0.96 kgCO2 per kWh for a non-CCS plant]. A complementary economic analysis of the

CCS power plants found them to be relatively expensive. However, cycle improvements and the introduction of a ‘floor price’ for carbon under, for example, the EU ‘Emissions Trading Scheme’ might make CCS economically viable in the future. The undiscounted cost of CO2 avoided is shown to be $35.30/tonne (€26.62 or £23.11/ tCO2). That represented roughly a median value between the earlier techno-economic studies of various CCS power plants by Hammond et al. [1]. The UK Government stated in their 2009 UK Low Carbon Transition Plan that they intended to support the construction of up to four CCS demonstrators linked to coal-fired power stations by 2014–2015. In addition, it proposed to place a requirement on any new coal power stations to demonstrate this technology. They noted that the uncertain-ties over full-scale power plant CCS technical performance and costs may only become clearer when the first demonstrators are operational in perhaps five years’ time. The study has attempted to reduce these uncertainties by way of indicative estimates of the techno-economic performance of both modern and advanced UK power plant/CCS chain options over their whole chain: from power stations to typical storage reservoir. In addition to carbon mitigation on the supply-side, it is clearly important to reduce energy demand in the UK and elsewhere. This could be achieved, in part, by the array of methods available to improve the efficiency with which energy is produced and consumed [1]. That would mitigate against climate change and enhance energy security [6].

[1] Hammond GP, Ondo Akwe SS, Williams S. Techno-economic appraisal of fossil-fuelled power generation systems with carbon dioxide capture and storage. Energy 2011;36(2):975–84.

[2] Spigarelli BP, Kawatra SK. Opportunities and challenges in carbon dioxide capture. J CO_2 Utilization 2013;1:69–87.

[3] Intergovernmental Panel on Climate Change [IPCC]. IPCC special report on carbon dioxide and storage. Cambridge: Cambridge University Press; 2005 [Prepared by Working Group III of the IPCC].

[4] Hammond GP, Ondo Akwe SS. Thermodynamic and related analysis of natural gas combined cycle power plants with and without carbon sequestration. Int J Energy Res 2007;31(12):1180–201.

[5] Kleijn R, van der Voet E, Kramer GJ, van Oers L, van der Giesen C. Metal requirements of low-carbon generation. Energy 2011;36(9):5640–8.

[6] Advanced Power Generation Technology Forum [APGTF]. A technology strategy for carbon capture & storage, London, UK: APGTF; 2009.

USA - DOE Perspective:

Ref-02: “Advances in CO2 capture technology—The U.S. Department of Energy’s Carbon Sequestration Program” by Jose´ D. Figueroa a,, Timothy Fout a, Sean Plasynski a, Howard McIlvried b, Rameshwar D. Srivastava b*

There is growing concern in the US that anthropogenic carbon dioxide (CO_2) emissions are contributing to global climate change. Therefore, it is critical to develop technologies to mitigate this problem. One very promising approach to reducing CO_2 emissions is CO_2 capture at a power plant, transport to an injection site, and sequestration for long-term storage in any of a variety of suitable geologic formations. However, if the promise of this approach is to come to fruition, capture costs will have to be reduced. The Department of Energy’s Carbon Sequestration Program is actively pursuing this goal. CO_2 capture from coal-derived power generation can be achieved by various approaches: post-combustion capture, pre-combustion capture, and oxy-combustion. All three of these pathways are under investigation, some at an early stage of development. A wide variety of separation techniques is being pursued, including gas phase separation, absorption into a liquid, and adsorption on a solid, as well as hybrid processes, such as adsorption/membrane systems. Current efforts cover not only improvements to state-of-the-art technologies but also development of several innovative concepts, such as metal organic frameworks, ionic liquids, and enzyme-based systems.

CO2 capture and separation from large point sources, such as power plants, can be achieved through continued research, development, and demonstration. Worldwide research is being performed to abate global climate change, which a consensus of the scientific community indicates is due, at least in part, to anthropogenic GHG emissions (IPCC, 2007). Research to develop technologies and processes that increase the efficiency of capture systems while reducing overall cost is critical to creating a feasible GHG control implementation plan, covering not only power plants and industrial facilities but also the infrastructure required to support that implementation.

The DOE Carbon Sequestration Program is developing a project portfolio associated with carbon capture and separation technologies that can significantly impact the level of CO2 emissions from fossil-fuelled power generation plants. These technologies, while focused on the power sector due to the volume of its CO2 emissions, are also applicable to other sectors. The programmatic timeline is to demonstrate a series of cost effective CO2 capture and separation technologies at pilot scale by 2012, with deployment leading to substantial market penetration beyond 2012. The Sequestration Program has identified performance and cost targets which are necessary to reduce the impact associated with capture and separation of CO2 not only on the power sector but also on supporting industries.

Research and development is driven by a commercialization focus to satisfy the requirements of identified market segments and to substantially improve performance with a significant cost reduction. Wide deployment of these technologies, in addition to energy efficiency and demand management approaches, is necessary to mitigate GHG emissions and ultimately achieve stabilization.

LIST OF ON-GOING PROJECTS UNDER AGEIS OF DOE WILL BE FOUND IN THE DATA BASE ABOVE APPENDIX I

CANADA PERSPECTIVE:

***Ref-03: "Implementing a second generation CCS facility on a coal fired power station – results of a feasibility study to retrofit SaskPower's Shand power station with CCS"* by Stavroula Giannaris, Corwyn Bruce, Brent Jacobs, Wayuta Srisang and Dominika Janowczyk, The International CCS Knowledge Centre, Regina, Saskatchewan, Canada**

Thermal integration and minimizing the output penalty

Energy, usually supplied by steam, is required for amine regeneration when utilizing a solvent-based post combustion CO_2 capture system. Steam can be sourced by integrating directly with the power station's steam cycle (as was done with the BD3 project) or by constructing a purpose-built auxiliary steam generator (as was done with the Petra Nova project). Option one induces a parasitic loss in generation output for the power station during CCS operations while option two produces additional CO_2 emissions (which hinders overall CO_2 emissions reduction) while also requiring adequate natural gas infrastructure to support such a facility. The integrated design was chosen for Shand. Heat integration strategies to reduce the parasitic lose would include:

- Utilizing flue gas waste heat for low pressure condensate preheating by means of a flue gas cooler and condensate preheater and,
- Utilizing energy in the condensate returning from the capture facility for feed water preheating.
- Replacing the DEA to facilitate a higher pressure steam bleed therefore maximizing the use of rejected flue gas heat and energy in the returning condensate for LP condensate preheating and,
- Adding bypass drains to remove FWH4 from service during CCS operations rather than incurring costs associated with replacing a costly high pressure FWH, as the increased operating pressure and

These integration strategies would maximize waste heat utilization while reducing the parasitic load, which was determined to be 22.2% with these strategies.

The overall cost for Shand CCS was determined to be approximately $45 USD/tonne of CO_2. Costs have been attributed to four major cost categories : capture facility capital costs, OM&A and consumable costs, cost of electricity lost, and cost of limestone.

Note that this value does not consider a CO_2 sale.

iv. Fact sheet on Carbon Dioxide Capture and Storage (CCS)-European Union (EU)

Policy Context

The European Community and its Member States are signatories to the United Nations Framework Convention on Climate Change (UNFCCC). A key aim of the treaty (Article 2) is: "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". The EU Council of Ministers has agreed that a mean 2ºC rise in global temperature represents the limit which should not be exceeded. The Council has stated that, in line with that limit, reductions in developed country greenhouse gas emissions of between 15 and 30% below 1990 levels will likely be required by 2020, while the Environment Council noted the probable need for a global reduction of up to 50%in greenhouse gas emissions by 2050.

The European Community and its Member States have also ratified the Kyoto Protocol under the UNFCCC, requiring reductions in greenhouse gas emissions in the period 2008-2012. As one mechanism for meeting this target, the EU Emissions Trading Scheme (EU ETS) was established in 2005 for thousands of installations in Europe, for instance steel factories, refineries, and power plants larger than 20 Megawatts in size. The EU ETS covers about 45% of all EU CO_2 emissions (the other 55% of emissions are from other industrial sectors, transport and households). The second phase of the EU ETS will run from 2008-2012, concurrent with the 'first commitment period' of the Kyoto Protocol, and the system is designed to continue beyond 2012.

Overview of Concepts and Technologies behind CCS

There are four major possible storage sites for the captured CO2: i) depleted oil and gas reservoirs; ii) still operational oil and gas fields with the CO2 being used for enhanced oil (or gas) recovery; iii) saline formations, which are porous rocks that currently contain very salty water; and iv) un-mineable coal beds, in which the CO2 attaches via a chemical reaction to the coal's surface. The first three types of storage can be located onshore or offshore. Coal beds are more commonly onshore.

The capacity of potential reservoirs globally is not known with any degree of accuracy but is likely to be sufficient to allow CCS to play a major role in reducing CO2 emissions in many countries. For example, in the UK the storage sites examined in detail have a large enough capacity that they can store all of the CO2 arising from electricity generation (at present levels) for at least the next 50 years. For Norway and the Netherlands, similar numbers have been published.

Much work is underway on assessing the risks arising from potential leakage of CO2 from the geological storage sites. Such risks are site-specific and detailed risk assessment on a site-by-site basis will be necessary. Natural gas and CO2 have remained trapped in geological formations for millions of years, so there are good reasons for believing that storage sites can be chosen that would hold CO2 for the very long timescales required for climate change mitigation purposes. Questions remain regarding the integrity of existing borehole seals and more research will be required to better understand the risks. An appropriate regulatory regime will include site-specific requirements for monitoring during and probably also following injection. Very minor leakage might be tolerated both in terms of local environmental impacts and global climate change impacts, but this depends on the careful assessment of risks to human health and safety and ecosystems arising from leakage from sites.

Costs

It is nearly always more expensive to use CCS than to allow the CO2 to escape to the atmosphere. This is because the capture of the CO2 requires a large installation and uses up energy – a so- called ‘energy penalty’ - for the separation and compression of the CO2. The only reason to implement most applications of CCS therefore is to reduce CO2 emissions to limit climate change. The capture installation can remove 85 to 95% of the CO2 from the flue gas. Taking into account the energy penalty of 10 - 40%, this varies greatly depending upon the CO2 capture method, the power plant design and age conditions etc., the CO2 reduction drops to 80 to 90% per unit of the output. A summary of the costs of CCS is provided in Table below. Expressed as the cost of avoiding a ton of CO2 emissions, the additional costs for most of these CCS technologies are in the same order of magnitude as many renewables and new nuclear build. The cost of electricity with CCS would increase by approximately 2 to 3 cents per kWh. Depending on the price paid by the end-consumer, this represents an increase in price of between 20 and 80%.

Table: Range of total costs for CO_2 capture, transport and geological storage based on current technology for new power plants (in € 2002) - Source IPCC

Power plant with capture and storage	Pulverised coal power plant	Natural gas combined cycle plant	Integrated coal gasification combined cycle plant
Cost of electricity ***without*** CCS per MWh (in €)	43-52	31-50	41-61
Cost of electricity per MWh ***with*** CCS (in €)	63-99	43-77	55-91
Electricity cost increase per MWh (in €)	19-47	12-29	10-32
% increase in costs with CCS	43-91%	37-85%	21-78%
Cost per tonne CO_2 avoided (in €)	30-71	38-91	14-53

Incentives

Because electricity generation with CCS always costs more than equivalent generation without it CCS will only take place if there are specific financial incentives. The one exception to this is where cheap CO_2 capture can be combined with Enhanced Oil Recovery, though this is likely to be limited to a relatively few locations. Furthermore many companies will require financial incentives which take account of the relatively high business risk associated with the implementation of CCS due to, e.g., technological, market and policy uncertainties. The EU Emissions Trading Scheme is one such incentive scheme but the price it gives for a ton of CO_2 abatement (between 10 and 30 euros per ton CO_2) is lower than the (current) real cost of CCS per ton of CO_2 especially when there is no guarantee that those prices will be as high over the entire lifetime of the CCS project. Hence some further incentive is likely to be required. The following incentive mechanisms have been proposed.

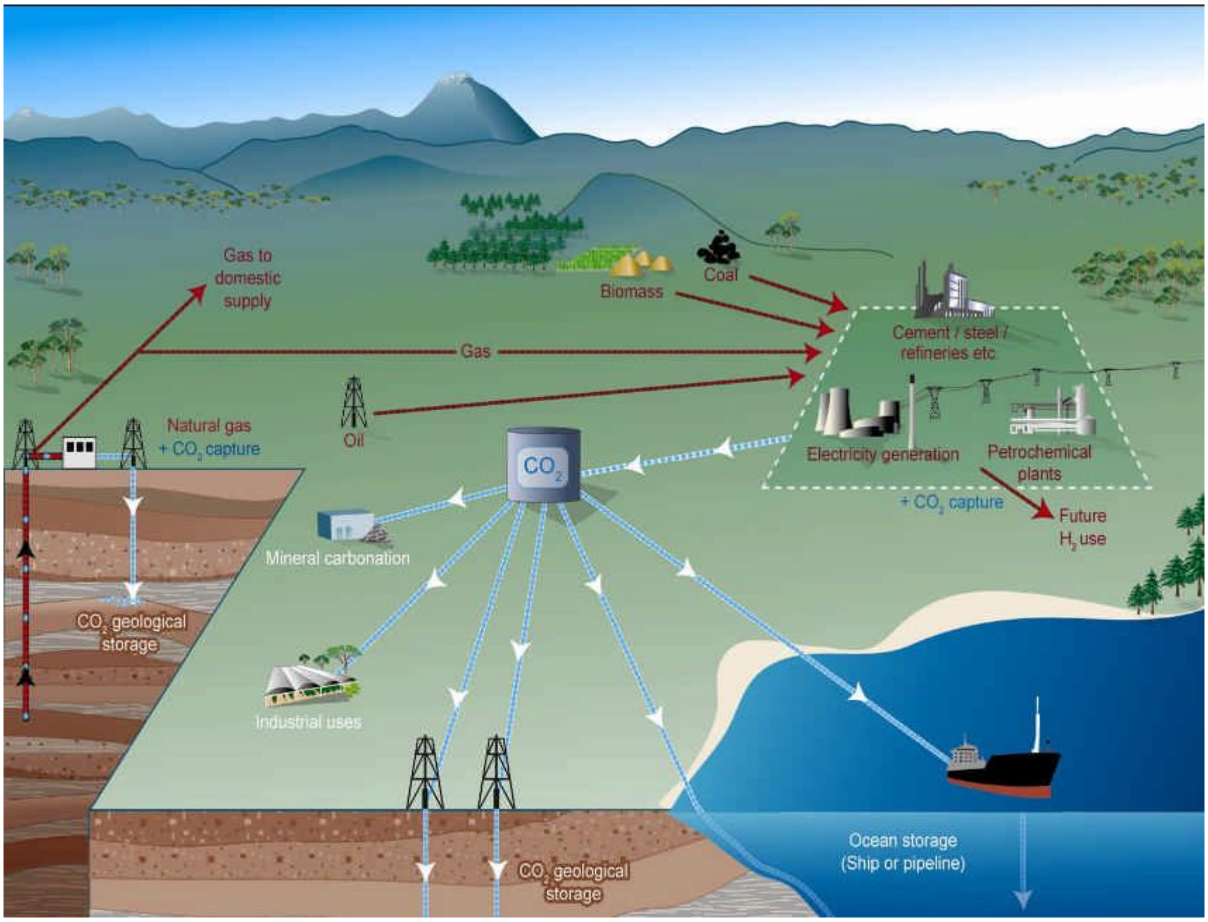
a) A subsidy scheme whereby producers of electricity using CCS are provided with the additional cost of CCS from public finances (e.g. through a guaranteed feed-in tariff for electricity generated with CCS which reflects the real costs of implementing CCS).

b) A requirement or obligation scheme whereby electricity producers are required to produce a certain proportion of their electricity using CCS (comparable to Renewable Portfolio Standards or a Renewables Obligation) or a similar requirement, but without specifying the low- or zero-carbon electricity source.
c) A capital subsidy support scheme, whereby public finance is used to subsidize the initial capital costs of a CCS project.
d) An economy-wide carbon tax, whereby end-users of carbon-based fuels and electricity pay a tax per unit of CO_2 emitted. This would mean that domestic, commercial and industrial users of gas, electricity and petroleum-derived fuels would pay a tax based upon the carbon content of the fuel so providing an incentive for the development of low- or zero-carbon sources of energy such as CCS.
e) An extension of the EU Emissions Trading Scheme with tighter emission caps: the EU ETS could be extended beyond 2012 and tighter national emissions quotas could be negotiated, so pushing up the permit price of a tonne of CO_2. The EU ETS could also be extended to all energy users, not just medium- to large- energy producers.
f) Public support for Research, Development and Demonstration projects.

Legal Issues

The London Convention regulates the dumping of wastes at sea. OSPAR is a regional treaty for the North East Atlantic and similar to the London Convention. Dumping is defined widely to include any deliberate disposal or storage at sea of wastes or other matter. No dumping of wastes is permitted except for those listed and CO_2 is not presently included on the list. Exceptions are permitted such as placement of wastes rather than disposal and disposal related to seabedmineral exploitation. Amendment of the London Convention and OSPAR treaties is probably necessary before CO_2 storage in saline aquifers and oil and gas fields can take place offshore and this could take several years, especially as little is known about the impact of leaks of CO_2 into the marine environment. Clarification and modification of the legal framework will be necessary before CCS can become an established carbon abatement technology. Companies are unlikely to initiate major investments in CCS technology where there are potential conflicts with the provisions of the London and OSPAR Conventions. A process is now underway to modify the London Convention and a proposed amendment is to add CO2 to the annex so allowing it to be dumped provided: that it is stored in sub-seabed formations (not in the water column); that it is overwhelmingly CO2 and does not contain additional wastes.

Figure: Pectoral Representation of CO2 Capture and Storage is given below to describe various technology options of CCS in EU.


Gas to domestic supply
Biomass
Coal
Gas
Cement / steel / refineries etc
Oil
Natural gas
+ CO_2 capture
CO_2
Electricity generation
Petrochemical plants
+ CO_2 capture
Future H_2 use
Mineral carbonation
CO_2 geological storage
Industrial uses
CO_2 geological storage
Ocean storage
(Ship or pipeline)

1.2.3 CCS Project – Policy aspects in Indian Context are based on:

i. Opportunities of Post Combustion CCS in India

ii. Economic Implications of CO2 Capture

& CCS Policy Perspectives

The summary of various International / National papers are briefly discussed here so as to arrive at CCS Policy Perspective for India.

i. OPPORTUNITIES – POLICY SCENARIO:

Ref-4: "Economic Implications of CO_2 Capture from the Existing as well asProposed Coal-fired Power Plants in India under Various Policy Scenarios" -Udayan Singh[a], Anand B. Rao[b,*], Munish K. Chandel[c]

India is a country with rising energy needs. Much of the energy demand is met by coal and there are dynamic links between coal consumption and economic growth. However, the increasing coal use is likely to result in increasing carbon dioxide emissions. India's power sector contributes to about half of the all-India CO_2 emissions. As a result, end-of-the-pipe abatement of CO_2 in the power sector may be one of the prominent mechanisms to reduce India's greenhouse gas (GHG) emissions. Carbon capture and storage (CCS) technology may provide such a means in the Indian coal-fired power plants. This paper initially makes an effort to assess the economic implications of this technology on existing Indian coal-fired power plants. Some characteristic features of Indian power plants are identified with special reference towards CCS deployment. The importance of proximity of coal linkage and sink location from the power plant is established using the studied examples. General trends on the estimates of cost of electricity (COE), emission factor and net plant efficiency are evaluated. Subsequently, the trends in costs are projected for the next three decades for the upcoming plants using CCS. In these predictions, three scenarios of CCS deployment are considered, with varying carbon price range. In a high carbon price scenario (C price of US$ 80/t-CO_2 in 2030), CCS is firmly established as a useful technology for the Indian coal-fired power plants by the year 2050. India is a major developing economy with a Gross Domestic Product (GDP) of more than US$ 2 trillion. Although, the per-capita CO_2 emissions of India are quite low (1.66 tonnes, compared to the world average of 4.94 tonnes), it contributes to almost 6% of the global CO2 emissions and is the third largest CO_2 emitter after China and the USA [1]. Furthermore, the MAPLECROFT Climate Change vulnerability index 2015 ranked India as the 13th most vulnerable country with regards to climate change impacts [2]. The above facts necessitate effective climate policyon part of India. More than 50% of India's CO_2 emissions within the organized sectors (industry and transport sectors) come from thermal power generation [3],

There may be several mechanisms to ensure higher energy consumption without an increase in GHG emissions, which include improvement in energy efficiency, and use of low-carbon substitutes to the conventional fossil fuels. However, no single technology is likely to play a principal role in mitigation of GHG emissions [4]. Thus, it is important to analyze every aspect of each mitigating technology. Carbon Capture and Storage (CCS) is an important technology, which is believed to have a significant potential compared to other sizeable carbon mitigation options at a reasonable cost. Carbon Capture and Storage involves CO_2 capture from large point sources. As a result, it allows an easy way to properly manage CO_2 reductions. Furthermore, as coal happens to be India's main source of energy, CCS will be a form of energy security for India [5].

Estimating the economic penalty of CCS would help in policy-framing in regards to the share this technology could have in climate mitigation. CCS is expected to result in large increase in cost of electricity (COE). This will go against the large-scale electrification efforts – especially designed and implemented to improve the access, availability, quality and affordability – targeting the rural households. Currently, there is a lack of accurate costs of CCS as a mitigation option with reference to India [6]. Several macro-modeling studies have used generalized international costs. However, Indian plants are quite different from their western counterparts as they are often characterized by much lower efficiency, capital costs and varying fuel quality [7, 8].

With ambitious electrification and climate targets, the Government of India has committed to increase the installed solar and wind capacity up to 160 GW by 2022, as a part of the INDCs submitted as per the Paris Climate Agreement. Nevertheless, coal-fired power plants are expected to remain key to India's energy security at least up to 2050 [5, 9]. Therefore, for mitigation to meet the 2ºC targets[1], either CO_2 capture and storage (CCS) or a strong reliance on renewable and nuclear energy will be needed. Shukla et al [10] have suggested that if conventional carbon mitigation strategies such as imposition of carbon taxes are utilized, CCS will have a higher role in mitigation. In such a scenario, they predict that the national CO_2 intensity of energy supply would drop tenfold from the current 771 g-CO_2/kWh to 66 g-CO_2/kWh by 2050. This establishes a strong inter-linkage of CCS, India's all India emissions and the power sector, and therefore necessitates the study of CCS in the Indian power sector.

A systematic economic analysis for coal-fired power plants with CCS in India has been carried out. Initially, seven existing units of the state-owned NTPC have been considered and the impact of retrofitting of CO_2 capture units on their performance, costs and emissions has been estimated. Unlike the previous economic studies for CCS in India, the advanced amine based capture and the losses due to sorbent regeneration have been considered. As a result, the energy penalty for the eight units ranges from 34% to 53%, while the cost of CO_2 avoidance is US$ 66-109/t-CO_2. Some suitable features of various plants are annotated which are likely to act as enablers towards CCS implementation in India. For instance, units close to coal-bearing areas can have a lower CO_2 capture and sequestration chain cost because of low transportation investments for coal as well as CO_2. This has been established by the case of the Talcher power plant.

Subsequently, an analysis for upcoming power plants in India has been carried out and the cost and environmental benefits of implementing carbon prices have been suggested in various scenarios. For instance, in a low carbon price scenario, CCS fails to become economically competitive against the currently established coal-fired power generating units. At high carbon prices and with active deployment of ultra-supercritical units, a cost reduction of almost 24-35% with use of CCS is expected during 2020-2050.

While high carbon prices shall make the CCS more favorable, the overall cost of electricity will be driven high. If these costs can come down with indigenous development of collectors as well as learning, they shall become comparable to the costs of coal-based power with CCS. As a result, CCS will face stiff competition from the renewable sector. Therefore, a significant degree of learning is also required in the CO_2 capture systems to drive down overall cost of electricity.

Advanced coal technologies (ACTs) are the need of the hour. The Government of India has clearly indicated a great deal of support for ACT. However, for CCS to develop, it is necessary that the perspective towards CCS is as an important ACT rather than as an expensive and 'foreign' technology. It is expected that the costing results obtained in this study shall be useful in modeling and planning of the Indian energy system and further studies shall be undertaken to strengthen the research base in this area.

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OPPORTUNITIES – COMPREHENSIVE POLICY REVIEW:

*Ref-5: “Carbon capture and sequestration potential in India: Acomprehensive review by Abhishek Gupta, Akshoy Paul***

The paper focuses on Challenges in CCS Implementation in India, which are:

Key Policy Initiatives for CCS Implementation in India includes introduction of ‘Clean Energy Tax’ on imported and domestic coal 2010, which goes to go into the National Clean Energy Fund. In 2012, National Action Plan on Climate Change (NAPCC) was expanded to include clean coal and clean carbon technology to minimize CO2 emissions. India’s Twelfth Five Year Plan (2012-17) highlighted the need to invest in R&D of ultra-supercritical (USC) units. The Renovation, modernization (RM) and Life Extension (LE) activities for 72 Coal power plants totaling to 16532 MW are currently underway. Institute of Reservoir Studies is carrying out CO2 capture and EOR field studies in Gujarat, while National Geological Research Institute (NGRI) Hyderabad is testing the feasibility of storing CO2 in basalt formations. The challenges associated with the commercial use of CCS in India are identified and listed below.

- *Lack of R&D effort:* Along with its research phase, its potential estimation of conversion into fuel or either its geo sequestration (potential site estimation) plays an important role.
- *Need for comprehensive national study on Geological storage:* The comprehensive geological assessment for CO2 storage potential is yet to be studied in India.
- *Energy penalty:* CCS requires additional energy input and India's power requirement is yet to be fulfilled. Thus, energy penalty plays as barrier in India.
- *Lack of financing and inflow of foreign direct investment (FDI):* Implementation of costly CCS technologies require financial incentives from local and central governments in India and good governance politiesenabling to attract foreign FDI for the same.
- *Environmental and legal concerns:* Like land acquisition, ground water contamination, fear of CO2 leakage.
- *Cost scenario:* Even after development for over 30 years, CCS technology is still proven costly to developingcountries like India.

ii. ECONOMIC IMPLICATIONS – COST RELATED POLICY REVIEW:

Ref-6: "UNDERSTANDING THE COST OF CO₂ CAPTURE AND STORAGE FOR FOSSIL FUEL POWER PLANTS" by Edward S. Rubin, Anand B. Rao and Chao Chen, Department of Engineering and Public Policy; Carnegie Mellon University Pittsburgh, PA 15213

Cost related 'Results' for a New PC Plant in India

To quantify the costs and uncertainties of CO_2 capture and storage we first analyze a new pulverized coal (PC) power plant with an amine (MEA-based) CO_2 capture system, representing current commercial technology. Table 1 lists the key power plant parameters and assumed uncertainty distributions, while Tables 2 and 3 show the performance and cost parameters, respectively, for the CO_2 capture and storage system. The nominal case assumes geologic storage of CO_2 at a net cost to the plant owner, while the uncertainty (variability) case includes the sale of CO_2 for enhanced oil recovery (EOR).

TABLE: 1

Design Parameter		**Value**	**Parameter**	**Value**
Gross plant size (MW)		500	Emission standards	2000 NSPS
Gross plant heat rate (kJ/kWh)		9600[a]	NO_x Controls	LNB[e] +SCR[f]
Plant capacity factor (%)		75[b]	Particulate Control	ESP
Coal characteristics			SO_2 Control	FGD
Coal	Low-S	High-S	CO_2 Control	MEA[i]
HHV (kJ/kg)	19,346	25,300	CO_2 capture efficiency (%)	90
% S	0.48	3.25	CO_2 product pressure (kPa)	13,790[j]
% C	47.85	61.2	Distance to storage (km)	165
Mine-mouth cost ($/tonne)	13.73	32.24	Cost year basis (constant $)	2000
Delivered cost ($/tonne)	23.19	41.37	Fixed charge factor	0.15[k]

TABLE: 2

AMINE SYSTEM PERFORMANCE MODEL PARAMETERS AND UNCERTAINTIES

Performance Parameter	**Units**	**Data (Range)**	**Nominal Value**	**Unc. Representation (Distribution Function)**
CO_2 removal efficiency	%	Mostly 90	90	-
SO_2 removal efficiency	%	Almost 100	99.5	Uniform (99,100)
NO_2 removal efficiency	%	20-30	25	Uniform (20,30)
HCl removal efficiency	%	90-95	95	Uniform (90,95)
Particulate removal eff.	%	50	50	Uniform (40,60)
MEA concentration	wt%	15-50	30	-
Lean solvent CO_2 loading	mol CO_2/mol MEA	0.15-0.30	0.22	Triangular (0.17,0.22,0.25)
Nominal MEA make-up	kg MEA/tonne CO_2	0.5-3.1	1.5	Triangular (0.5,1.5,3.1)
MEA loss (SO_2)	mol MEA/mol SO_2	2	2	-
MEA loss (NO_2)	mol MEA/mol NO_2	2	2	-
MEA loss (HCl)	mol MEA/mol HCl	1	1	-
MEA loss (exhaust gas)	ppm	1-4	2	Uniform (1,4)
NH_3 generation	molNH_3/molMEA ox	1	1	-
Caustic for MEA reclaimer	kg NaOH/tonneCO_2	0.13	0.13	-
Cooling water makeup	M^3/tonne CO_2	0.5-1.8	0.8	Triangular (135,200,480)

Solvent pumping head	kPa	35-250	207	Triangular (150,207,250)
Pump efficiency	%	70-75	75	Uniform (70,75)
Gas-phase pressure drop	kPa	14-30	26	Triangular (14,26,30)
Fan efficiency	%	70-75	75	Uniform (70,75)
Equiv. elec. requirement	% regeneration heat	9-19	14[a]	Uniform (9,19)
CO_2 product purity	wt%	99-99.8	99.5	Uniform (99,99.8)
CO_2 product pressure	MPa	5.86-15.16	13.79	Triangular (5.86,13.79,15.16)
Compressor efficiency	%	75-85	80	Uniform (75,85)

TABLE: 3

MEA COST MODEL PARAMETERS AND NOMINAL VALUES

Capital Cost Elements	Nom. Value*	O&M Cost Elements	Nom. Value*
Process Area Costs (9 areas)[a]		**Fixed O&M Costs (FOM)**	
Total Process Facilities Cost	PFC	Total Maintenance Cost	2.5 % TPC[J]
Engineering and Home Office	7 % PFC	Maintenance cost allocated to labor	40 % of total maint. cost
General Facilities	10 % PFC		
Project Contingency	15 % PFC	Admin. & support labor	30 % of total labor
Process Contingency	5 % PFC	Operating Labor	2 jobs/shift
Total Plant Cost (TPC) = sum of	above	**Variable O&M Costs (VOM)**	
Interest During Construction	calculated	Reagent (MEA) Cost	\$1250/tonne MEA
Royalty Fees	0.5 % PFC	Water Cost	\$0.2/m^{3}
Pre-production Costs	1 month VOM & FOM	CO_2 Transport Cost	\$0.02/tonne CO_2/km
Inventory (startup) Cost	0.5 % TPC	CO_2 storage/disposal cost	\$5/tonne CO_2[n]
Total Capital Reqmt (TCR) = sum of above		Solid waste disposal cost	\$175/tonne waste

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Table 4, below summarizes the mean, median, and range of the overall distributions for COE and cost of CO_2 avoided for several cases involving plants burning either a low-sulfur or high-sulfur coal, with and without CCS. Across all these cases, the mean and median values of the cost of CO_2 avoided lie in the range of roughly \$ 45 to \$53/ tonne CO_2. When uncertainty and variability assumptions are taken into account the range widens considerably. With uncertainties only in the CCS system, the 95% probability interval varies by approximately a factor of three, from \$28 to \$74/ tonne CO_2. The most significant variables here were the lean solvent CO_2 loading of the amine system (which determines the regeneration heat requirements), the efficiency of heat integration (in terms of net power loss), and the CO_2 storage/disposal cost. Adding variability in plant parameters has a measurable effect on COE, but a small impact on avoidance cost because the reference plant and capture plant employ the same assumptions. Otherwise, the impact on avoidance cost could be large. Results for the two different coal types show that fuel choice assumptions also can have a large effect on COE but a much smaller effect on avoided cost relative to the same plant without CCS.

TABLE: 4

COST RESULTS FOR CO_2 CAPTURE PLANTS (UNC. = Uncertainty)

Case	COE (\$/MWh)			Avoidance Cost (\$/tonne CO_2 av.)		
	Mean	**Median**	**Range**	**Mean**	**Median**	**Range**
Low-S coal*						
Unc. in CCS only	89.3	89.0	63-118	49.4	49.0	16-87
+unc. plant parameters						
(both ref & capture plant)	86.1	85.8	52-127	48.4	48.0	14-87
High-S coal**						
Unc in CCS only	99.3	99.3	76-133	53.3	53.1	24-99
+unc. plant parameters						
(both ref & capture plant)	95.8	94.6	63-149	52.2	51.9	20-110

* Reference plant COE: mean = \$48/MWh; range = \$34-63/MWh.

** Reference plant COE: mean = \$54/MWh; range = \$40-69/MWh.

As part of the USDOE's Carbon Sequestration Program, authors have developed an integrated modelling framework to evaluate the performance and costs of alternative CO_2 capture and storage technologies for fossil-fuelled power plants, in the context of multi-pollutant control requirements. This model (called the IECM-CS) allows for explicit characterization of the uncertainty or variability in any or all model input parameters. This paper reviews the major sources of uncertainty or variability in CO_2 cost estimates, then uses the IECM-CS to analyse CO_2 mitigation costs and uncertainties for currently available CO_2 capture technologies applicable to coal-based power plants in Indian context.

The analysis methods illustrated in this paper can be extended to other types of power generation systems and CCS technologies to develop a more comprehensive framework in which to assess alternative options. Such options would include advanced technologies that offer the promise of lower costs and/or improved performance relative to current systems. The probabilistic framework also can be used to quantify the likely impacts of technology innovation on future cost reductions, an important application for evaluating the expected benefits of R&D. Such applications would complement retrospective analyses of technological innovation and learning being conducted in other on-going research by Rubin, E.S., Taylor M.R., Yeh S. and D.A. Hounshell (2002), in their work on "Experience Curves for Environmental Technology and Their Relationship to Government Actions." This Paper was presented at the GHGT-6 Sixth International Conference on Greenhouse Gas Control Technologies, October 1-4, 2002, Kyoto, Japan.

Ref-7: "Advances in Carbon Capture and Storage in Coal based Power Generating Units in Indian Context"by Anoop Kumar Shukla , Zoheb Ahmad , Meeta Sharma Gaurav Dwivedi , Tikendra Nath Verma , Siddharth Jain, Puneet Verma and Ali Zare

India is a nation with a diverse economy that requires tremendous resources to completely meet the desires of its compatriots in various sectors. In terms of energy resources and requirements, coal-based power plants can fulfill the bulk of these electricity needs. India is very reliant on coal, which is used in power plants as a primary energy source. However, the usage of coal energy at a higher level continuously pollutes the atmosphere. The Indian power market alone accounts for half of the country's CO_2 emissions, which implies that significant action is needed to contain environmental pollution. Carbon Capture and Storage (CCS) is a bridging technique and feasible alternative for the carbon fired plant processing of CO_2. However, the application of CCS in coal-fired power stations is still uncommon in the nation. At the UNFCCC Paris Summit, India committed to reduce its carbon emission intensity by approximately 30–33% by 2030. In this work, several CCS systems, possible CO_2 origins, and emission levels in India are discussed. Various advanced methods for CO_2 capture and separation are also highlighted. Furthermore, the current work discusses CCS situations and the applications of CCS in India along with its manifold challenges. CCS ventures are currently operating worldwide at a variety of commercial sizes, but the deployment of CCS is difficult and faces many barriers in India. Currently, a method for collecting CO2 at a lower rate from various processing industries is being sought. CCS, in this case, is important to developing countries such as India for viable resources, despite its higher costs and is the world's most beneficial technique to reduce GHG pollution. Nonetheless, many factors, such as storage capacity, expenses, technological advancements, and skilled workers, are involved in the implementation of CCS.

CCS Status in India

Industrialization is rapid in India and is very dependent on coal, which is considered a critical fuel. Thus, the nation finds it very difficult to sever its reliance on coal, which will ultimately increase the supply of global coal-based energy technology by 2040. The Indian CO_2 Sequestrations Advanced Research (ICOSAR) network was established by the Department of Science and Technology (DST) to organize CCS research and development activities in 2007. Given the estimated capacity of around 280,000 MW needed for thermal energy production by 2030, many researchers have sought to achieve these possible CO_2 ejection estimates by broadly focusing on potential carbon gases accumulated at aggregation height in India. In India, the National Thermal Power Corporation (NTPC) together with Bharat Heavy

Electricals Limited (also known as BHEL) are making many experimental efforts to improve these factors, which is the only solution. BHEL also performed an oxy-fuel check inthe year 2010 at the Fuel Evaluation Test Facility (FETF). At the beginning of 2011, many scale-up studies were planned to be carried out in a Solid Fuel Burning Test Facility (SFBTF) to build a boiler of 211/251 MW by March 2013. India’s largest supplier of gas and energy (ONGC) is also exploring the usage of CO2 to improve oil retrieval or EOR at the Ankleshwar petroleum farm. In addition to the above CCS initiatives at the domestic level, India is involved in many foreign programs and networks, such as the CSLF and the U.S. System Protocol. However, scientists concentrate primarily on the increasing expenses of introducing the CCS within carbon-fired plants. This research suggested possibilities and obstacles for introducing CCS in India to handle CO_2 reduction. The current carbon prices for CCS implementation in India are not attractive in this sector. The development of scrubbing systems in CCS integrated power plants requires tremendous energy and thus contributes to losses in plant effectiveness. India has a tremendous capacity in its solar thermal power plants, and, in combination with this capacity, energy-intensive scrubbing can be realized. The implementation of CCS in coal-based power plants increases the cost of energy, which is not favorable for the end user. Therefore, CCS needs a maximum economic model that supports integration with coal-based power generating units to reduce GHG eissions through SOLAR THERMAL ***as discussed further at PARA 1.2.5.***

1.2.4 TECHNO-ECONOMICS OF CCS IN INDIA

Ref-8: ***“Techno-economic aspects of the post-combustion CO_2 capture processes by S Sai Prasad* & K V Raghavan; CSIR-Indian Institute of Chemical Technology, Uppal Road, Hyderabad 500 007, India***

• Economic aspects of CO_2 capture

Given the worldwide interest in CCS as a potential option for climate change mitigation, the likely cost of various alternative technologies will be of great interest to policy makers. Most of the recently reported financial studies of CO_2 capture have been based on some of the currently developed technologies. The real challenge lies in assessing the cost components of potential future improvements, which will influence the long term competitiveness of CO_2 capture systems.

Finkenrath [1] has reviewed and analysed the cost factors of post-, pre- and oxy-combustion based CO_2 capture from coal fired, IGCC and natural gas combined cycle power sources. The present and projected future costs, their sensitivity and uncertainty were examined across a very diverse set of CO_2 capture Installations in OECD countries during 2005-09. A snapshot of the emerging economic scenario for CO_2 capture from power generation plants is presented in Table below. With the application of potential PCCC options, the cost of CO_2 avoided may come down to around USD 40-50 per tonne by 2030.

From economic considerations, the following are relevant:

- Amongst the feed stocks, coal based power plants provide the best CO_2 capture economics due to superior efficiencies inherent with their higher CO_2 content.

- Early demonstration projects would cost between USD 80-120 per tonne CO_2 abated due to their small scale, lower efficiency and commercially non-optimized nature.

- Retrofit carbon capture systems will be costlier than the newly built coal based power installations.

- Currently, the differences in cost between various CO_2 capture options are relatively small to create scope for their pilot and semi-commercial level testing on parallel mode for the next 4-5 years.

- Achieving 0.4 Giga tons of CO_2 abatement/annum may require installation of 80-120 large scale CCS projects which would typically consist of newly built power plants adjacent to retrofits and other industrial CO_2 capture plants, all connected to a common transport and storage network.

Rubin *et al*. [2] employed the learning rate approach to project the future cost of power plants with PCCC based on historical rates of change for similar technologies. The future cost trends in post combustion CO_2 capture technologies are evaluated in the cases of pulverized coal (PC), and natural gas combined cycle (NGCC) plants. The evaluation is also carried out for pre-combustion CO_2 capture technology in the case of coal based IGCC plants and oxy-fuel CO_2 capture process for coal fired power plants. The results of this study when projected at 100 GW installed capacity indicates the following:

- A 3-5 % decrease in electricity cost for each doubling of capacity.
- The largest reduction of 18 % in electricity cost is seen in IGCC system and the smallest of 10 % for the oxy-fuel system on doubling the installed capacities.

For fixing an appropriate time scale for technology development as well as demonstration components, the time frame normally required for each of the following activities need to be identified as: TD1: Bench scale proving (component wise); TD2: Pilot level scale-up (component wise); TD3: Semi-commercial technology demonstration (semi-integrated); TD4: Full scale commercial deployment (integrated). It is also necessary to identify parallel and sequential process options based on the current and medium term R&D outcomes. In the highly research intensive area of CO_2 capture, several parallel development activities may have to be pursued with provision for intensifying technology scale up and demonstration.

Such a schedule will facilitate demonstration of PCCC technologies from 2022 onwards for setting up large scale commercial installations.

Table8 – A snapshot of CO_2 capture economics

Item	**Without CO_2 capture**	**With CO_2 capture**	**Increase (+) or Decrease (-) (%)**
Capital cost (USD/KW)	**1899**	**3135**	**+65.0**
Power output (MW)	**582**	**545**	**-6.4**
Power generation efficiency (%)	**41.4**	**30.9**	**-25.4**
Cost of electricity (USD/MWH)	**66**	**107 (102)**	**+62.0**
Cost of CO_2 avoided (USD/tCO_2)	**--**	**58.0 (80)**	--

Note: Numbers in parenthesis indicate the average figures for natural gas based power plants

References:

1. **Finkenrath M,** ***Cost and Performance of CO_2 Capture from Power Generation,*** **Working Paper (International Energy Agency Paris, France), 2011.**

2. **Rubin E S,** ***Estimating Future Costs of CO_2 Capture Systems Using Historical Experience Curves, Proc 8 Int Conf Greenhouse Gas Control Technologies,*** **Norway, 2006, pp. 1-6.**

Ref-9: ***"Opportunities in India for Carbon Capture and Storage as a form ofclimate change mitigation" by Rudra V. Kapila[a], R. Stuart Haszeldine[a,] GHGT -9***

• CCS Opportunities in India - options

Considering the industrial point sources of CO_2 and the relevant geological sites with storage potential in India, it may seem that there are only a limited number of opportunities for implementing CCS technology. There are however, a few options that one could consider, and the case studies for this study will focus on 4 possible options that may well be a starting point for demonstrating the technology in India.

These are:

- *Capture of pure CO_2 streams in industry* – it may be easiest to apply capture technology to industry where processes already produce pure streams of CO_2, e.g. the gas and fertilizer industries. However, a study by Shackley & Verma [1] found that there is actually a shortage of CO_2 at many Indian fertilizer plants because they tend to use all the CO_2 that is generated from ammonia production in neighboring urea plants. In fact, it was found in some cases that extra CO_2 generating units had been constructed at various facilities in order to supplement the supply of CO_2 for urea manufacture [11]. Supplying waste CO_2 could displace this generation.

- *Enhanced Oil Recovery (EOR) offshore & onshore* – the Indian government has already started developing plans for using CO_2 from an offshore sour gas facility at Hazira, Gujarat for EOR at an onshore site 70 km away. An estimated 1200 tonnes of captured CO_2 would be transported to this oil field on a daily basis (0.36 Mt CO_2 /yr) and be used to maintain pressure in the field, rather than decrease the viscosity of the oil remaining in the field[1]. This results in a large percentage of the CO_2 remaining in the pore space and not returning to the atmosphere [1]. Furthermore, the assessment by the IEAGHG indicates that there is potential for CO_2 storage in the offshore basins around Gujarat, such as the Cambay, which are in close proximity to the Hazira industrial belt.

- *CCS technology with coal & power sector* – Carbon abatement in the coal and power sector could start with efficient generation technologies, such as advanced supercritical steam conditions. **In addition, it may be possible to design the new generation of power plants in India, such as the UMPPs, to be 'capture-ready', an approach implying "low upfront costs and unimpaired performance", enabling a future retrofit of CCS "when the necessary regulatory or economic drivers are in place"** [2].

- *Export of CO_2 for foreign EOR activities* – One option may be to capture the CO_2 emissions from large industrial areas in India and export them to be used for EOR purposes in other countries, essentially the Middle East. Some of the planned UMPP projects are going to be based on the coast, where it is anticipated that large shipping terminals will form an integral part of the project. These UMPP projects, such as Mundra, are particularly designed for imported coal. It may be also possible to capture CO_2 from such large power plants and ship this to countries for EOR activities. States such as Qatar are dominant gas producers with established LPG tanker traffic, and so these tankers could be converted to take return loads of CO_2 for injection into depleted gas or heavy oil fields [3].

• India’s storage potential

CO_2 storage is an integral part of the CCS chain, and therefore it is important to quantify the storage potential of geological sites such as coal fields, oil and gas fields, and deep saline water-bearing reservoir rocks. Presently, there is a lack of knowledge in this area due to a general dearth of essential data required to characterize these sites. Nonetheless, some attempts have been made at evaluating the storage potential in India, initially by Singh et al. [4] who estimated that roughly 5 Gt CO_2 could be stored in un-mineable coal seams, 7 Gt CO_2 in depleted oil and gas reservoirs, 360 Gt CO_2 in offshore and onshore deep saline aquifers, and 200 Gt CO_2 via mineralization in basalt rocks. The latter refers to laboratory experiments conducted by McGrail et al. [5] that demonstrated a relatively rapid chemical reaction of CO_2-saturated pore water with basalts to form stable carbonate minerals. This could be quite an appealing opportunity for India as a very extensive portion of the central peninsula consists of one of the world’s largest basalt lava flows known as the Deccan trap formation. However, this concept is still in the experimental phase and can only be considered a possibility if the basalt is adequately permeable to the CO_2 and can be demonstrated to be safe and secure [5]. A more recent study conducted for the IEA Greenhouse Gas R&D Program [IEAGHG] has revised down the estimates first made by Singh et al. [4].

This new assessment predicts that the storage in coal seams is likely to be constrained due to the fact that these coal reserves can be easily mined and used as fuel. Therefore, they calculate the storage potential countrywide to be more of the order of 345 Mt CO2 in the major coalfields, where none have the capacity to store more than 100 Mt CO2, and only eight of the fields can store more than 10 Mt CO2. For oil and gas reservoirs, the authors calculate the total storage capacity to be between 3.7 and 4.6 Gt CO2. In addition, the authors note that only a few fields, such as the Bombay High field, offshore Mumbai, are thought to have ample storage for the lifetime emissions of a medium sized coal-fired power plant. None of the fields, it would seem, are large enough to store the lifetime emissions of India’s planned UMPPs (currently estimated at 28-29 Mt CO2/year for a period of 35 years, or 1 Gt CO2 roughly). However, the authors do believe that there may be significant CO2 storage potential “in the oil and gas-bearing sedimentary basins around the margins of the peninsula, especially in the offshore basins, but also onshore in the states of Gujarat and Rajasthan”. Yet, these potential storage sites are not well placed in respect to major CO2 sources occurring in the central parts of the peninsula. Some areas in the northeast, such as Assam, are thought to have possible CO2 storage, though this region is quite distant from the main emission sources, requiring thousands of kilometers worth of pipeline infrastructure, particularly if they were not to cross Bangladesh. Their study concludes that more realistic storage capacities for saline aquifers need to be quantified, most likely with the aid of oil and gas exploration information, such as seismic and well data.

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Ref-10: ***"CCS prospects in India: results from an expert stakeholder survey" by Rudra V. Kapila1,a, Hannah Chalmers, Stuart Haszeldine, Matt Leachc***

It is expected that coal will play a significant role in many large industrial applications (including electricity generation) in India until 2050, at least, despite measures to significantly increase the role of other energy sources. Although CCS is not currently seen as an immediate domestic priority for the Indian Government or industry, stakeholders participating in a research survey do expect it to become more important in the future, particularly for industry. Thus, it is appropriate to consider whether CCS is a technically feasible option for India and, if so, if and when it should be used.

STAKEHOLDER'S VIEWS ARE SUMMARIZED BELOW:

Question: If India is planning to invest in a low-carbon and energy secure future, then which technologies will be given investment priority for development by the Indian Government/private sector industry in India, and how might this change in the future? Please identify the three most important technologies and rank them (where 1 is 'likely to be given highest priority')

Reply by Stake-holders

	Indian Government			***Private Sector Industry in India***		
Rank	**Now**	**2030**	**2050**	**Now**	**2030**	**2050**
1	Nuclear & Hydro	Solar	Solar & Nuclear	Solar & Wind	Solar & CCS	CCS
2	Wind	Nuclear	Hydro	Hydro	Wind & Hydro	Solar
3	Solar	CCS & Hydro	CCS	Micro-gen	Microgen	Nuclear

Coal is likely to dominate India's energy landscape for several decades, despite the increasing contributions to the energy mix from other sources. Although there are some significant challenges, it seems likely that introducing CO_2 capture at Indian power plants could be feasible, especially if it is considered appropriate to apply 'capture ready' concepts for new build plants. Identifying both suitable storage sites and routes for transporting captured CO_2 safely to these sites also requires careful consideration. With regards to timing the views are:

In particular, survey respondents emphasized that it is necessary for developed countries to demonstrate CCS at commercial scale before any commercial-scale CCS projects in India are considered. Most survey respondents suggested that any consideration of deployment of CCS in India should be within an appropriate international framework, including measures for knowledge sharing and technology transfer that consider local conditions carefully. The stakeholders also highlighted the importance of establishing methods for early engagement on CCS between India and developed countries. It was also suggested that developed country governments should contribute to financing of both initial projects and wider deployment of CCS in India. This could partly be through international finance institutions such as the World Bank, the International Monetary Fund and the Asian Development Bank.

Ref-11: Techno-economic assessment of CO_2 capture retrofit to existing power plants by Jon Gibbins[1*,a], Hannah Chalmers[a], Mathieu Lucquiaud[a], Jia Li[b], Niall McGlashan[b], Xi Liang[c], John Davison[d]

- **RETROFITTING OPTION FOR INDIA**

Technical factors that must be considered in retrofitting CO_2 capture to an existing plant include:

(a) Access to suitable CO_2 storage;
(b) Space on site for additional equipment associated with capture;
(c) Gas cleaning including FGD (flue gas desulphurisation) performance;
(d) Cooling requirements including identifying space on site for cooling in some cases, waterconsumption and achievable temperatures;
(e) Meeting the additional electricity and heat needs for the capture-related equipment,including integrating with the main power plant where appropriate; and
(f) Identifying a strategy for coping with reduced power output from the site, or maintaining orincreasing the exported power

It may be noted that there is a sound theoretical basis for CCS retrofits to existing power plants to be considered as a complement, and in some cases as an alternative, to new build power plants with CCS.

Six rules for effective thermodynamic integration of post-combustion capture and CO2 compression

Number	**Description**
1	For new build projects, add heat to the steam cycle at as high a temperature as possible (i.e. be prepared to use best available steam conditions if commercially justified). For retrofits to existing plants, though, the penalty per tonne of CO_2 emissions avoided is independent of the steam conditions.
2	Reject heat from the steam cycle, in the steam extracted for solvent regeneration, at a temperature as close as possible to the temperature of regeneration of the solvent. Optimise solvent temperature of regeneration to minimise the sum of the overall electricity output of the capture system and the CO_2 compression system.
3	Produce as much electricity as reasonably possible from the power cycle (i.e. be prepared to use additional turbines for retrofit projects if commercially justified) and from any additional fuel used, consistent with rejecting heat at the required temperature for solvent regeneration.
4	Make use of waste heat from CO_2 capture and compression in the steam cycle.
5	Anticipate the use of the latest solvent developments throughout the whole operating life of the plant.
6	Exploit the inherent flexibility of post-combustion capture (e.g. to shift the financial penalty of capture from high to low operating profit periods of time and/or to accelerate ramp rate during transient operation if necessary.

A viable retrofit project will have to satisfy a range of requirements in the separate, although interlinked, areas, these are:

- The ability to add CO_2 capture on the power plant site (or at a linked site in some cases);
- Access to secure CO_2 storage; and Economic and social viability, including meeting all legalrequirements and gaining public acceptance

A general rejection of retrofitting on grounds such as the age or lower efficiency of existing plants is not justified. The reduced capture costs for new build CCS plants can often be offset by the much higher capital cost of the base power plant itself compared to a retrofit, even if some level of refurbishment to the base power plant is required to achieve an adequate retrofit project life. More specifically CCS retrofits need to be assessed on a site-specific basis, but the numbers of relevant power plant sites is relatively small. Applying CCR principles when building new plants obviously increases the probability that they can be retrofitted successfully and this work suggests that the option of retrofitting these could well be exercised in the future.

A wide range of options exist for effective integration of CO_2 capture equipment with the steam cycles of existing coal and gas power plants, allowing electricity output penalties per tonne of CO_2 captured to be achieved that are close to those for new build plants using the same capture technology. If the electricity output of the plant is to be maintained on-site then additional fuel should be used in ways that deliver as much electricity as possible (i.e. natural gas turbine combined cycle or high-pressure steam coal CHP plants). Unless a large increase in power output is required it is most effective to combine this with some steam extraction from the main steam turbine.

IMPACT OF COAL QUALITY

Ref-12: "Impact of Coal Quality on Post-Combustion CO2 Capture in Indian Coal Power Plants" Pranav C. Phadke, Anand B. Rao, and Munish K. Chandel

The objective of this study is to investigate the impact of coal quality while implementing post-combustion carbon capture system and oxy-fuel carbon capture system in the new supercritical coal fired power plants in India. Pre-combustion CO2 capture in IGCC plant using the Indian coal is a challenge, and hence not included as an option in this analysis. This study focuses on post-combustion CO2 capture and oxy-fuel carbon capture system which seems a promising option in Indian context, considering the large existing pulverized coal (PC) fleet that is available in the country and the ease with which it can be retrofitted. Also, there has been large scale post combustion CCS based demonstration projects in Canada and U.S. with more upcoming projects planned globally. The cost of coal, which is determined based on the coal quality, plays a significant role in implementation of CCS. India has levied cess on coal, lignite and peat produced and imported into India.

Coal selection for power generation plays a critical role towards achieving high plant efficiency, selection of appropriate emission control technologies, maximizing net electricity generation and minimizing the cost of electricity generation. The study presented here helps us to understand the impact of coal quality while implementing carbon capture (CC) system in the new supercritical coal fired power plants in India. The suitability of Indian coal and imported coal for implementation of CCS in the country was assessed in terms of net capacity, flue gas volume, boiler efficiency, net plant efficiency, CO2 emission rate, LCOE and cost of CO2 avoided. It can be seen that flue gas volume and cost of coal governs the economics of CCS.

Oxyfuel-CC seems cheaper option in Indian context compared to Amine based CCS systems. This could be because Indian coals have lower calorific value requiring high coal flow rate which results in higher flue gas volumes. Flue gas volume significantly impacts the Amine-CC system.

Coal with high C/O ratio and low ash and moisture content, found in West Bengal and Jharkhand generates higher flue gas volume and thereby more CO2 emissions however; installing Amine-CC system in plants using these coals will further drastically reduce their NET generation and efficiency. However, since these coals have low $/GJ value, Oxyfuel-CC seems a more economical option for these plants.

Implementing carbon capture in plants using coal having medium C/O ratio, medium $/GJ value, medium ash and moisture content like Talcher seems most cost effective but, these plants are already efficient in terms of CO2 emissions as they generate least amount of CO2 emissions per MWh of electricity production. Furthermore, although efficient, implementation of carbon capture in these plants will reduce their efficiencies by about 7 to 11 percentage points.

Implementing Amine-CC in plants using imported coal provides the best advantage in terms of net energy generation due to their high calorific value and low ash content, however, their fluctuating prices will impact feasibility of such projects. Plants using low calorific value, high ash coal like Rajmahal and Bilaspur have higher energy consumption by emission control devices and lower boiler efficiencies which affect their overall efficiency. Thus, before implementation of carbon capture, quality of coal along with plant characteristics should be carefully analysed. Currently, this clean energy cess stands at Rs. 400/tonne [CIL- DATA]. With implementation of clean energy cess, the cost of CCS will increase substantially. Without certain policy initiatives such as exemption of clean energy cess for plants with CCS or enforcement of suitable carbon tax, implementation of CCS in Indian power plants seems an uphill task.

1.2.5 SOLAR THERMAL INTEGRATION IN CCS

Pollution and increasing fuel prices are the main focus for governments today. The main cause of pollution is existing electricity power plants that use huge quantities of fossil fuel. A new strategy should be applied in the coming decades based **on the integration of existing power plants with renewable energy sources, such as solar and wind energy**. Hybridization of existing power plants with solar energy is one proven option to overcome the problems of pollution and increasing fuel prices. The focus on hybrid solar conventional power plants includes: the review of studies of hybrid solar–steam cycle power plants, integrated solar combined-cycle systems (ISCCS) and hybrid solar–gas turbine power plants, while for hybrid solarnon-conventional power plants the focus of study is hybrid solar–geothermal power plants. The most successful option is ISCCS due to their advantages and the plans for implementation at various power plants in the world like in Tunisia, Egypt, Spain, and Iran. **The energy penalty reduction in regeneration of MEA solvent is the Pilot Plant at RKDF University is the prime focus of the following papers by the PI of this CPRI sponsored CCS project at the University.**

Ref-13A: An Innovative Approach for Carbon Capture & Sequestration on a Thermal Power Plant through Conversion to Multi-Purpose Fuels –A Feasibility Study in Indian Context by Vinod Krishna Sethi, Savita Vyas – GHGT-13

Government of India has declared its policy on Carbon Dioxide (CO_2) abatement by the announcement and adoption of the 'National Action Plan on Climate Change'. It has also made voluntary commitment at the UNFCCCs Paris Summit that the country shall decrease its Carbon Intensity by 30-33% by 2030. The path chosen makes it imperative that the CO_2 which forms 95% of the GHG emissions be reduced. Out of total annual emission of about 1700 Million Tons per annum (MTPA), CO_2 emitted by the Coal based thermal power plants of capacity over 180GW amounts to about 860 MTPA. For EPA regulations to be implemented there have to be a road map asto how this can be done without major impact on the cost or efficiency of power generation. The thermal plants in India have a thermal efficiency of about 35% and an emission ratio of 0.90 kg/kWh of CO_2 emissions as published by Central Electricity Authority (CEA). The reduction of 33% intensity as promised by India at COP-21: Paris; would translate to a decrease of CO_2 emissions to a level of 0.58 kg/kWh by 2030. This decrease is possible by a combination of abatement and recycling measures like augmentation of Low Carbon Technologies (LCT) such as Renewable and Clean Coal Technologies (CCT) and Carbon Capture & Sequestration (CCS) on our Fossil Fuel based thermal power plants. However, as regards post combustion CCS plants on coal fired units, the CO_2 capture by an amine system of 30% CO_2 capture would mean an energy penalty of about 25% including a minimum of 10% for compression and pumping to deep reserves like mineral rocks, gas hydrates and ocean. In any case, the energy penalty in Indian context, when CO_2 sequestration is considered a far more appropriate option than CO_2 storage the energy penalty still remains at level of 15%. This can be further reduced to a level of 4-5% if solar thermal device is used for production of steam for an amine solvent regeneration and stripping of CO_2. The same can be demonstrated only after establishment of pilot plant of CO_2 Capture and Sequestration plant integrated with Concentrated Solar Power (CSP) for carrying out system optimization studies, having variable fluid dynamic configuration.

The paper covers description and test results of Post Combustion Carbon Capture & Sequestration Pilot Plant installed at the Rajiv Gandhi Proudyogiki Vishwavidyalya (RGPV), Bhopal in Central India, for CO_2 capture and conversion into fuel molecules like H_2 and CH_4 from associated Oil fired Boiler and a Biomass gasifier. A feasibility study of installation of CCS on a

500MW unit together with integration of solar concentrator for steam generation for reducing energy penalty in regeneration is also presented.

In house CCS technology development require R&D efforts under the aegis of Department of Science & Technology and the Ministry of Power, nevertheless it would be useful to estimate the economic implications of implementing CCS in the existing coal plants, as a potential carbon mitigation measure through pilot studies etc. The Pilot plant has revalidated the Amine process of CO_2 Capture at an optimized molar strength of MEA. Further the Pilot plant has provided opportunity for feasibility study of installation of CCS Plant on a 500 MW unit using MATLAB simulation tool. Interfacing of Solar for Steam generation for solvent regeneration is a newer dimension of the feasibility study.

The CCS option towards sustainability covered in this paper may lead to an opportunity for course- correctionin line of thinking of our Engineers & Scientists working in the arena of Green Power.

Ref-13B: "A Pilot Study of Post Combustion Carbon Capture & Sequestration Pilot Plant aimed at Feasibility Analysis of Installation of a Carbon Capture, Utilization and Sequestration (CCUS) Plant on a Large Thermal Unit in India" by Dr. Vinod Krishna Sethi, Dr. Savita Vyas , Dr. Partha S Dutta – GHGT 14

CO_2 Capture, Sequestration and Production of Multi-purpose fuels – Hydrogen, Methane and Biodiesel through Algae route through Post combustion CCS on a fossil fuel fired Plant has been successfully demonstrated at the DST sponsored CO_2 sequestration Pilot Plant at the State Technological University of MP, the 'RGPV' at Bhopal in Central India. A CO_2 Capture efficiency of over 93% has been achieved using MEA solvent of 18 % concentration and the required heat for stripping captured CO_2 in the regeneration tower has been worked out at the level of 3.88 MJ per kg of recovered carbon dioxide, which is provided by the low pressure steam of about 150°C and 2 bar pressure @ 1.5-1.6 tons of steam per ton of CO_2. Exergy analysis was carried out to optimize this regeneration energy requirement with multiple fuels including bituminous coal, fuel oil and also bio-mass aiming towards negative emission strategy. Production of multipurpose fuels like hydrogen and bio-diesel have been demonstrated in the pilot plant through lignite gasifier via CO and Algae routes respectively. Hydrogen to the tune of 21.92% by volume has been produced, while selected species of Algae grown in open pond with CO_2 and Solar flux input provided Algal oil by using Soxhlet extraction process using petroleum ether. Parallel efforts are made in a Solar Thermal Pilot Unit, a MNRE sponsored project, in collaboration with Rensselaer Polytechnic Institute (RPI), NY, USA at the State Private University, RKDF in near vicinity of RGPV's CCS pilot plant under joint collaboration.

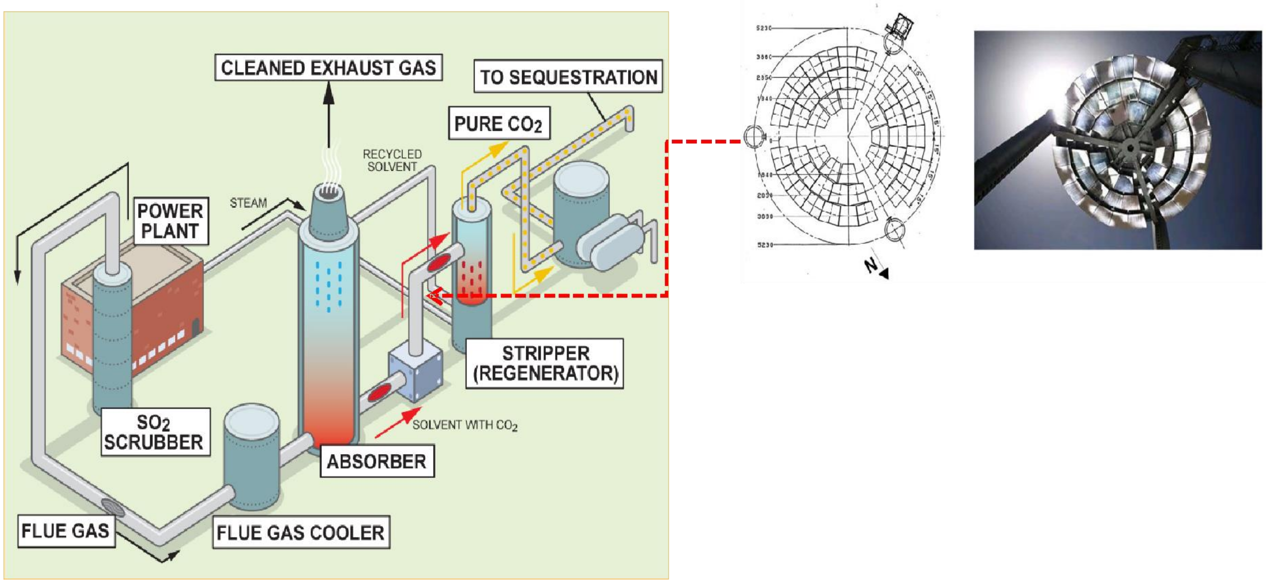
Based on above two pilot studies a feasibility analysis is carried out for installation of Carbon Capture, Utilization & Storage plant on a 500 MW Anpara Thermal Power Plant in Northern Coal Fields of India. The Feasibility Study has revealed that it is possible to implement Carbon Utilization by growing selected species of Algae culture in the Ash pond of the plant for almost doubling the Algae growth for bio-diesel production. The feasibility analysis has further revealed that energy penalty for a 30% CO_2 capture for a 500 MW Unit would be around 25% including 10% for compression and pumping in an Enhanced Coal Bed Methane (ECBM) technique in proximity to the CO_2 source. In any case, the energy penalty in Indian context, when our power planners are targeting at no-storage options for CCS like Carbon sequestration for conversion to multi-purpose fuels rather than CO_2 storage, the energy penalty still remains at level of 15-20%. This can be further reduced to a level of 5-10 % if solar thermal device is used for production of steam for solvent regeneration and stripping of CO2. A specially designed Alkali Halide Salt developed by RPI, USA is used as 24x7 heat storage- materials in the pilot plant and the same is integrated with the CCS pilot plant for solvent regeneration and stripping of CO2. Test results of Solar Thermal pilot plant for Steam production with thermal storage, using solid pathway is given which may pave way for development of the technology of Post Combustion Carbon Capture with least energy penalty in regeneration of solvents used in the CCS process. The paper also covers a novel approach for reducing energy penalty in regeneration of solvent as well as production of useful multipurpose fuels through Solar Assisted Post Combustion Carbon Capture (SPCC) on a 500 MW Thermal Power Plant.

- **Solar Integration Perspective in Australia & Malaysia:**

Ref-14: "Integration of solar energy in coal-fired power plants retrofitted with carbon capture: A review" by ForoughParvareh, ManishSharma, [a]AbdulQadir, [a]DiaMilani, [a]RajabKhalil pour, [a]Matte, Chiesa[b], AliAbbas[a]

This paper reviews the utilization of solar thermal energy technology in assisting coal-fired power plants retrofitted with post-combustion carbon capture (PCC) in Australia. The focus is on compensating the so-called 'energy penalty' imposed on the power plant output by the introduction of PCC plant operations. The integration of solar thermal energy can offset the power plant output reduction due to the PCC installation by totally, or partially providing the energy requirement of the carbon capture plant. The main process integration approaches proposed in this regard are reviewed; their advantages and drawbacks are discussed considering technical and climatic factors. The paper also discusses the merits of this hybridization of power, capture and solar plants as a transition solution for future low-carbon power generation.

SOLAR ASSISTED POST COMBUSTION CARBON CAPURE PLANT



CONCLUSIONS

- **Solar-assisted Post-combustion Carbon Capture (SPCC) is not feasible at current carbon price (it is feasible when a 5% per annum increase in price is assumed OR if REC are allowed)**
- **Non-concentrating evacuated tube collectors are most feasible for a plant with heat integration.**
- **Parabolic trough collectors most feasible without heat integration.**
- **Renewable Energy Certificates (REC) provide highest benefit.**
  - **– Policy proposed to allow REC for SPCC plants**
- **Direct regeneration of solvent through solar thermal energy is more economically feasible than SPCC.**

Ref-15: Advances in the integration of solar thermal energy with conventional and non-conventional power plants" by M.S. Jamel, A. Abd Rahman, A.H. Shamsuddin n, MALAYSIA

A review of conventional and non-conventional hybrid solar– thermal power plants was carried out on the studies and published papers for the last three decades. It is clear that there has been the intention to search for and study such technologies in the last decades. The main cause has been increasing fuel prices and growth awareness about climate global warning, in addition to the technical and economic advantages of hybridization. Many methods were used by the authors to analyze the hybrid cycles, some of them using compact software tools like TRANSYS, the most used tool in analyzing and simulating STS, while the others used classical programming analysis methods based on the first and second laws of thermodynamics. The most useful analyzing method used by the authors is based on exergy principles. Also, many methods of optimizing these hybrid systems where used by the authors for optimized synthesis, operation and design of these new systems. Compared with SCR and other types of STS, PTCs are the most interesting type of solar collecting system used by the authors for integration purposes due to their proven technology and commercialized use in many operations over the years through deployment of many such solar type plants around the world. TSS is used to a limited extent due to its high cost and is still subject to modification. In addition, compared with other types of hybrid system, ISCCS is more interesting due to its technical and economic advantages over other types and also the recent plans to deploy such power plants in many regions in the world, such as Spain, Tunisia, Egypt, and Iran.

In the end, the hybrid solar-thermal–fossil-fuel power plant concept can offer huge advantages, especially for existing power plants. Also, more studies are needed to overcome the technical and commercial problems and to apply advanced optimization methods for a more economic and reliable technology.

Ref-16: "Experimental study of solar assisted post-combustion carbon capture" by Fu Wang, Jun Zhao, Hao Li, Hailong Li, Li Zhao, Jinyue Yan

Solar-assisted post-combustion carbon capture system is studied to compensate the energy penalty of coal-fired plant due to absorbent regeneration. The system is highly integrated with the amine-based carbon capture process coupled with solar thermal sub-system. The dynamic performance is largely affected by the variations of parameters and the fluctuations in solar collectors. An experimental facility of solar-assisted chemical absorption pilot with two types of collectors (parabolic trough and linear Fresnel) was constructed in this study. The impacts on the absorbent regeneration performance were studied on the dynamic variation of the solar heat and the operating temperature of the re-boiler. The results show that an optimum ratio of liquid-to-gas of 2.5-3.0 was determined at the lowest of the required regeneration energy. The study suggests that a better understanding of the key parameters associated with both capture process as well as the solar assisted sub-system if of importance for the overall operation and control.

L/G ratio has significant impact on specific regeneration energy, the minimal required energy demand for solvent regeneration for 30 wt.% MEA in the pilot test at given flue gas flow rate was approximately 4.0 MJ/kg CO2, and the optimal L/G ratio was gained at 2.5-3.0 kg/kg.

Ref-17: "Solar-Assisted Post-Combustion Carbon Capture Feasibility Study" by Marwan Mokhtar, Muhammad Tauha Ali, Rajab Khalilpour, Ali Abbas, Nilay Shah, Ahmed Al Hajaj, Peter Armstrong, Matteo Chiesa[1], Sgouris Sgouridis

This paper proposes a novel hybridization of solar thermal concentrators and solvent-based post-combustion capture (PCC) of carbon dioxide from the flue gas of fossil-fuel power plants. The rationale for a solar-assisted PCC (SPCC) is based on the fact that solvent regeneration requires thermal energy of lower quality that can be provided relatively cost-effectively by a solar thermal plant thus leaving the higher quality steam to be used more efficiently for electricity generation. Furthermore, we hypothesized that since this mitigation of the Output Energy Penalty (OEP) coincides with times when wholesale electricity prices peak thus resulting in increased plant revenues, a positive argument can be made for such a hybrid SPCC.

Authors have developed a feasibility assessment methodology to evaluate the relative performance of combinations of solar field size and thermal energy storage under different cost and carbon price assumptions in Australian climatic and electricity market conditions. The case study plant was a typical 300 MW_e pulverized coal-fired power plant with installed carbon capture equipment with a PCC facility using (30 wt. %) mono-ethanolamine (MEA) solvent. The collector field used in the simulation was a Fresnel collector field. This type of concentrating solar collector is capable of generating adequate temperatures for solvent regeneration and is currently commercially available.

Since the temperature needed in this application is around 120°C, less expensive non concentrating collectors or smaller and cheaper trough collectors might be available to provide these temperatures. The authors did not have enough information on the availability, technical performance or prices of these collectors and that is why different prices of solar collectors were shown in the results. The feasibility of the proposed system is expected to improve if we use non-concentrating collectors or low-concentration collectors (e.g. CPC), which are optimized for the required operating temperature.

Further, they assumed an ON/OFF control scheme for providing the re-boiler energy either from the solar circuit or the steam turbine circuit. This choice might not be the optimal choice and higher utilization of the solar field might be achieved by combining both circuits in a more sophisticated control scheme.

In principle, solar-assisted post-combustion carbon capture is one of the most appealing points of integrating solar power into the power system; the relatively low operating temperature may allow for the use of cheaper collectors optimized for these temperatures. Through a consistent assessment of such an integrated system in the specific conditions of NSW Australia, it was found that only very low collector costs would make the system feasible at current conditions despite its environmental and energy generation benefits. As a result, broader acceptance of such a system is sensitive to the boundary conditions such as electricity prices, carbon taxes, financing conditions, cost of equipment, life time, energy PCC penalty etc. Since the assumption of PCC in any case is expected to raise electricity prices based on the opportunity cost of the avoided carbon emissions, the cost advantage of this technology will increase at higher electricity prices and higher carbon prices on a system-wide assessment.

Ref-18: "Feasibility of integrating solar energy into a power plant with amine-based chemical absorption for CO_2 capture" by HailongLi JinyueYan Pietro E.Campana

Solar thermal energy has the potential to supply the thermal demand of stripper reboiler in the power plant with amine-based post combustion CO_2 capture. The performance of a power plant integrated with solar assisted post combustion CO_2 capture (SCC) is largely affected by the local climatic conditions, such as solar irradiation, sunshine hours and ambient temperature, the type of solar thermal collector and CO_2 recovery ratio. The feasibility evaluation results about such a power plant show that the cost of electricity (COE) and cost of CO_2 avoidance (COA) are mainly determined by the local climatic conditions. For the locations having higher solar irradiation, longer sunshine hours and higher ambient temperature, the power plant with SCC has lower COE and COA. COE and COA are sensitive to the prices of solar thermal collectors. In order to achieve lower COE and COA compared to the power plant integrated with non-solar assisted post combustion capture, the price of solar thermal collector has to be lower than 150 USD/m^2 and 90 USD/m^2 for the solar trough and vacuum tube, respectively.

Solar thermal energy can supply the thermal demand of the stripper re-boiler in CO_2 chemical absorption. The integration of solar thermal energy can reduce the electrical efficiency penalty to 4–6% of fuel LHV. The integration of solar thermal energy may not reduce COE and COA at the current solar thermal collector prices.

Ref-19: "Utilizing Solar Thermal Energy for Post-Combustion CO_2 Capture" by Stuart M. Cohen , Michael E. Webber , Gary T. Rochelle

There is broad scientific agreement that anthropogenic greenhouse gases are contributing to global climate change and that carbon dioxide (CO_2) is the primary contributor. Coal-based electricity generation produces over 30% of U.S. CO_2 emissions; however, coal is also an available, secure, and low cost fuel that currently provides roughly half of U.S. electricity. As the world transitions from the existing fossil fuel-based energy infrastructure to a sustainable energy system, carbon dioxide capture and sequestration (CCS) will be a critical technology to allow continued use of coal-based electricity in an environmentally acceptable manner. Post-combustion amine absorption and stripping is one leading CO_2 capture technology that is relatively mature, available for retrofit, and amenable to flexible operation. However, standard system designs have high capital costs and can reduce plant output by approximately 30% due to energy requirements for solvent regeneration (stripping) and CO_2 compression. A typical design extracts steam from the power cycle to provide CO_2 capture energy, reducing net power output by 11–40%. One way to reduce the CO_2 capture energy penalty while developing renewable energy **technologies;** is to provide some or all CO_2 capture energy with a solar thermal energy system. Doing so would allow greater power plant output when electricity demand and prices are the highest. This study presents an initial review of solar thermal technologies for supplying energy for CO_2 capture with a focus on high temperature solar thermal systems. Parabolic trough and central receiver (power tower) technology appear technically able to supply superheated steam for CO_2 compression or saturated steam for solvent stripping, but steam requirements depend strongly on power plant and CO_2 capture system design. Evacuated tube and compound parabolic collectors could feasibly supply heat for solvent stripping. A parabolic trough system supplying the energy for CO_2 compression and solvent stripping at a gross 500 megawatt-electrical coal-fired power plant using 7 molal MEA-based CO_2 capture would require a total aperture area on the order of 2 km^2 or more if sized for an average direct normal solar insolation of 561 W/m^2. The solar system's capital costs would be roughly half that of the base coal-fired plant with CO_2 capture. This analysis finds that irrespective of capital costs, relatively high electricity prices are required for additional electricity sales to offset the operating and maintenance costs of the solar thermal system, and desirable operational periods will be further limited by the availability of sunlight and thermal storage. At CO_2 prices near 50 dollars per metric ton of CO_2, bypassing CO_2 capture yields similar operating economics as using solar energy for CO_2 capture with lower capital cost. Even at high CO_2 prices, any operating profit improvement from using solar energy for CO_2 capture is unlikely to offset system capital costs. For high temperature solar systems such as power towers and parabolic troughs, direct electricity generation is likely a more efficient way to use solar energy to replace output lost to CO_2 capture energy. However, low temperature solar systems might integrate more seamlessly with solvent stripping equipment, and more rigorous plant design analysis is required to definitively assess the technical and economic feasibility of using solar energy for CO_2 capture.

Post-combustion amine absorption and stripping can remove 90% of the CO_2 from power plant flue gas, but systems can reduce electrical output by approximately 30% due to energy requirements for stripping CO_2 from solvent and CO_2 compression. The CO_2 capture energy penalty can be reduced while developing renewable energy technologies by meeting CO_2 capture energy requirements with a solar thermal energy system, particularly when electricity demand and prices are the highest. This study presents an initial review of solar thermal technologies for supplying CO_2 capture energy, with a focus on high temperature systems. Parabolic troughs and central receivers are technically able to provide energy for CO_2 capture. However, the solar system's capital costs would be roughly half that of the base coal-fired plant with CO_2 capture, and high electricity prices are required to offset the costs of operating the solar thermal system. For high temperature solar thermal systems, direct electricity generation is likely a more efficient way to use solar energy to replace output lost to CO_2 capture energy. However, low temperature solar thermal systems might integrate better with solvent stripping equipment, and more rigorous analysis is required to definitively assess the feasibility of using solar energy for CO_2 capture.

Using solar thermal energy for CO_2 capture appears technically feasible, but significant capital and operating cost reductions are required to offer an economic improvement over steam extraction. A more realistic approach might use solar energy for just a fraction of the stripping heat requirement. However, size and cost calculations reported here are preliminary; detailed plant design analysis and dynamic simulation is required for an accurate assessment of the technical and economic feasibility of using solar energy to meet CO_2 capture energy requirements.

Ref-20: "Preliminary experimental study of post-combustion carbon capture integrated with solar thermal collectors" l Fu Wang Jun Zhao Hailing Li Shuai Deng Jinyue Yan

The amine-based chemical absorption for CO_2 capture normally needs to extract steam from the steam turbine cycle for solvent regeneration. Integrating solar thermal energy enables the reduction of steam extraction and therefore, can reduce the energy penalty caused by CO_2 capture. In this paper, a pilot system of the solar thermal energy assisted chemical absorption was built to investigate the system performance. Two types of solar thermal energy collectors, parabolic trough and linear Fresnel reflector, were tested. It was found that the values of operation parameters can meet the requirements of designed setting parameters, and the solar collectors can provide the thermal energy required by the reboiler, while its contribution was mainly determined by solar irradiation. The solvent regeneration was investigated by varying the heat input. The results show that the response time of the re-boiler heat duty is longer than those of the re-boiler temperature and de-absorber pressure. This work provides a better understanding about the overall operation and control of the system.

Ref-21: "Feasibility Study of CO2 Mitigation from Coal Power Plants via CCS with Auxiliary Solar Thermal and Biogas" by Pranav C Phadke, Munish K Chandel, Anand B Rao

CCS is a major transition technology which can effectively help us in containing the global warming below 2°C and such studies along with pilot projects needs to be executed to achieve zero-carbon energy scenario

The feasibility of using auxiliary natural gas boiler, biogas boiler and solar thermal was evaluated. Also, a perspective on viability of CCS with regard to new stricter emission control standards was provided. It is seen that retrofitting reference plants with CCS unit, SO2 polisher and low NOx burners effectively controls all the emissions including CO2 emissions well below revised standards, thus making plants future-proof. Auxiliary natural gas boiler can effectively be used year round for amine regeneration thereby reducing the burden on CCS plant at a lower capital cost. But, this increases the LCOE by 11% and CO2 avoidance cost by about 64% and also increases the CO2 emissions when compared to CCS plant without auxiliary boiler. Using crude biogas auxiliary heat, produced using wood waste at the plant location itself can effectively reduce CO2 emissions and also reduce the burden on CCS plant. It has lower CO2 avoidance cost of 99.78$/tonne of CO2 compared to natural gas but, being poor quality fuel, increases the capital cost and LCOE.

Results of CCS + CSP cannot be directly compared with other technologies but, using solar for auxiliary heat, results in maximum reduction in CO2 emissions with least CO2 avoidance cost and competitive LCOE but, requires huge capital investment. Also, even with storage, due to seasonal variations and varying solar intensity, CSP cannot continuously provide auxiliary heat and a storage of higher capacity or a backup source would be required for this purpose which would increase emissions, capital costs, LCOE & CO2 avoidance cost. Alternatively, CCS unit can be run partially, only when auxiliary heat from solar is available to get optimum benefits.

Ref.-22: Carbon Capture and Storage Using Renewable Energy Sources: A Review by: S Ragul hari et al

The world is undergoing a population explosion; urbanization has also taken giant leaps with higher standards of people. It is noted that the supply and the demand for energy have not been in correlation with one another, as around. When the supply of energy is scaled up, there will large amounts of emissions released from the power plants. Therefore, it is important to focus on capturing and storage of harmful greenhouse gas emissions, using renewable energy resources, so that emission mitigation can be made in an efficient and economically feasible way. The pragmatic analysis of solar-assisted post-combustion carbon capture (SPCC) has been reviewed upon, where the energy compensation of a coal-fired plant due to regeneration of absorbent has been scrutinized. It is also been compared with the integration of geothermal energy (GTCC) for carbon capture. In the adsorption process, various techno-economic analysis of Carbon Capture and Storage (CCS) integrating solar-assisted temperature swing adsorption has been reported along with the effect of absorbent material in pressure-temperature swing adsorption for CO2 capture. Assessment of solar-assisted CCS are also been accomplished by adopting pliable thinking on the energy system. Finally, the integration with solar thermal power plant using novel Sodium Carbonate as a solvent is discussed. Thus, several parts of the CCS system have been construed with renewable energy towards the goal of zero-emission power generation, which seems highly impossible, can be harnessed by 2050.

The idea behind the study is to provide with a basic strive of stressing the fact that the application of SPCC and GPCC in a power plant would enhance in obtaining improved power output thereby reducing CO2 emission, Adsorption has also been discussed owing to the fact that this technology will be in the mere future. The main motive of zero additional carbon emission SPCC is achieved by including the fact that it is high on demand and an abundant available source comparatively with other renewable or traditional energy resources. Depending on the data considered from several areas the final statement on the techno–economical aspects is that the cost of electricity produced at the power plant as a result of Solar assisted post carbon capture arrangement is higher than the cost of electricity of a power plant without solar input. In order for the solar energy addition to be practically applicable and economically feasible, incentives such as carbon tax, discount rates and subsidies are required. Based on the country's policy on solar and carbon capture technologies, specific cost rate the feasibility of SPCC arrangement may be varied. Thus, the thirteenth sustainable development goal formulated by the United Nations of having zero emission fuels by the year 2050 can be only be fulfilled using renewable energy resources.

Ref.-23: OPEN SOURCE INTEC OPEN PAPER BY THE PI IS GIVEN HERE BELOW TO GIVE COMPREHENSIVE REVIEW OF PAPERS ON SOLAR INTEGRATION IN CCS (Chapter :6)

An Innovative Approach in Post Combustion Carbon Capture and Sequestration towards Reduction of Energy Penalty in Regeneration of Solvent

Vinod Krishna Sethi and Partha S. Dutta

Abstract

India as a fast growing economy is pursuing strategic knowledge mission for focused research in the area of climate change. Our R&D in Carbon Capture & Sequestration (CCS) will be initially focused on post combustion carbon capture on coal fired power plants. India is 3rd largest emitter of world after China and US with a share of 6.9% in global emission of CO_2, however, India's per capita GHG emission is only 1.6 MT per annum (MTPA) which is well below the world average 7.5 MTPA. National Mission on Strategic Knowledge for Climate Change aims to develop a better understanding of Climate Science impacts and challenges. The planning commission has announced the Government's interest in adding a ninth mission i.e. 'Clean Coal Technologies mission' that would include Carbon Capture & Sequestration. As regards Carbon Capture & Sequestration (CCS) on coal fired power plants in India is concerned, an innovative concept of integrating solar thermal for steam produc- tion will pave way for reducing energy penalty in regeneration of solvents from a level of over 15% to around 05%. This chapter deals with an innovative approach of CCS in which the major issues of energy penalty reduction have been taken care of through use of Solar Steam Generation, through concentrated solar plant (CSP) with 24 × 7 thermal energy storage (TES).

Keywords: carbon capture, sequestration, amine solvent, post combustion carbon capture, concentrated solar plant, MEA solvent, energy penalty, oil fired boiler, thermal energy storage (TES), halide salt

1. Introduction: current climate change policies in India and targets

India is rich in coal and is third largest coal producer in the world with estimated coal reserves of the order of 257 billion tons [1]. Coal continues to be the dominating energy source and meets nearly 58% of total requirement of commercial energy, but it accounts for over 50% of the gross emissions. Out of total annual emission of about 2100 million tons per annum (MTPA), CO_2 emitted by the coal based thermal power plants amounts to about over 1000 MTPA. With the developmental activities using fossil fuels on the anvil, the aggregate emission in the country would increase. The coal-based power plants totaling to 192 GW out of total installed capacity of 330 GW would remain main stay of India's power sector for at least 2–3 decades. India, though has lower contribution to the historical GHG accumulation, it holds a large potential for options like cost effective CCS to tackle the adverse effects of climate change [2]. Coal fired power plants in India account for more than half of the energy production in the country annually and about 52% of the total GHG emissions of the country [3, 4]. With a large number of new coal power plants, sub and supercritical, being installed, the problem of GHG emissions is likely to increase.

India has world's largest sedimentary basins. Ganga Basin and adjoining Rajasthan and Vindhya Basins offer a potential site for CO_2 storage [5].

India has made a voluntary commitment at Paris agreement; COP-21, that it would decrease its carbon intensity by 30–33% by 2030 from 2005 level. To address the threat of climate change, India has further declared in UNFCC's Conference of Parties (COP21) at Paris, that it will augment 175 GW of renewable energy, out of which 100 GW would be solar PV and solar thermal. Carbon sequestration of the order of 2.5–3.0 billion tons of CO_2 through additional forest is also aimed at in the perspective five year plans and focus on adaptation in agricul- ture, forest, water and livelihood would be accelerated [1, 7].

The path chosen makes it imperative that the CO_2, which forms 95% of the GHG emissions, be reduced. The reduction of 33% intensity as promised by India at COP-21: Paris; would translate to a decrease of CO_2 emissions from our coal plants from 0.9 kg/kWh to a level of 0.58 kg/kWh by 2030. This decrease is possible by a combination of adaptation and mitigation measures like acceleration of present pace of Low Carbon Technologies (LCT) particularly and Clean Coal Technologies (CCT) and setting up of Carbon Capture & Sequestration (CCS) plants primarily for post combustion carbon capture on our fossil fuel based sub and super- critical thermal power plants.

The Indian Power Ministry and the Department of Science & Technology have considered CO_2 capture and its sequestration through options like conversion to fuels as a far economical option than storage in sedimentary basins by [6, 7]. As per the Global Assessment Report, there is limited geological storage capacity [8], however a better potential will be found, if the concept of CO_2 storage in Basalt formations can be advanced into a matured option through focused R&D [9, 10]. Expected benefits for the environment and society at large due to the CCS implementation plan are:

- Adoption and implementation of Low Carbon Technologies will pave way for sustainable Society prepared to meet the challenges of climate change.

- CO_2 sequestration is a multi-dimensional aspect involving capture of carbon from atmosphere followed by transportation, injection into favorable sites and post-injection monitoring. The favorable sites for storage of CO_2 must be reliable in the sense that CO_2 will be stored there permanently at least for 1000 years and no leakage is preferable. In this backdrop, the most suitable storage sites where CO_2 could be fixed permanently by chemical absorption and reaction respectively are depleted coal beds and saline aquifers [7].

- Carbon Capture & Sequestration would play an important role in reducing GHG emis- sions at the same time enabling low carbon electricity generation from Power plants. Considering a CCS integrated 500 MW unit, which emits over 3 million tons of CO_2 per annum, would be equivalent to: (a) planting over 60 million trees and maintaining them to grow for 10 years; (b) avoiding energy related emission of about 0.3 million houses [7].

R&D efforts under the aegis of various Ministries of Government of India including Department of Science & Technology would be required to estimate the economic implica- tions of implementing CCS in the existing coal Fired plants [11]. Nine national missions for managing climate change have been set up by the Planning Commission, which include Clean Coal Technologies and CCS as a prime mitigation measure.

It has been recommended at several forums of Ministry of Power that a better option could be carbon capture and sequestration (CCS) through the technologies of conversion of CO_2 into multipurpose fuels including biodiesel through Algae route. In post combustion amine based CCS Plant the Energy Penalty in regeneration of solvent has been identified as main issues in CCS deployment; as such India is taking conscious steps in the area of CCS as under following stage wise program:

- Stage-1 (1–5 years): CO_2 sequestration to selected species of Algae in ash pond in the plant Area.

- Stage-2 (5–10 years): sequestration to depleted coal mines for pit-head coal based power stations.

- Stage 3A (10–15 years): sequestration to basalt rocks, saline aquifers & EOR as per site specific options.

- Stage-3B (10–15 years): for costal power stations: CO_2 hydrate formation in seabed sediments.

Innovative concept of energy penalty reduction through integration with the solar thermal could also be an option for India and other countries between tropic of cancer & Capricorn viz. under International Solar Alliance launched recently with India in lead role. The CCS option towards sustainability may lead to an opportunity for course-correction in line of thinking of our Planners, Engineers & Scientists working in the arena of Green Power technology and its development. The time appears to be ripe for implementation of CCS on an actual thermal power plant.

2. Detailed methodology of post combustion CCS on a thermal power plant: a pilot study

A pilot plant of CCS having rated capacity of curbing carbon dioxide of 500 kg/day was installed at RGPV University, Bhopal in Central India in the year 2008. The source of carbon dioxide was a baby boiler of rated capacity of producing 100 kg/h of steam. Desired amount of steam is extracted for catalytic conversion and other heating processes. Another source of flue gases is a biomass gasifier fired engine of capacity 10 kWe, which is also coupled with the system. Scrubbing of flue gas is done using solution of $NaHCO_3$, NaOH and lime for removal of SOx and Nox; and for capturing carbon dioxide from flue gas an aqueous solvent of 1–2 M monoethanolamine is used. The strip of CO_2 is sent to the three MEA solvent tanks where the MEA solvent in the three tanks absorb the CO_2 up to their saturation point. The saturated MEA containing CO_2, from the three MEA solvent tanks are sent to the saturated MEA tank. In order to remove CO_2 from the MEA saturated solvent, a striping tank is pro- vided. The CO_2 is released from the MEA solvent in striping tank with the help of steam generated from the diesel-fired boiler. Data are recorded by combustion gas analyzer, which was customized to record data as per requirement [12]. The scheme diagram of the plant is shown at **Figure 1**. Catalytic converters/reduction units for methane, hydrogen and CO are installed for this pilot unit.

The long term "Objectives" behind setting up of a pilot plant are to provide ground for 'Feasibility study' on large thermal units of future having CCS facility with least energy penalty. To this end, the development of Concentrated Solar Power for Steam generation for Regeneration of CO_2 captured MEA Solvent & System optimization studies are on the anvil.

The pilot plant will also provide a study and prove the viability of sequestration of CO_2 to selected species of Algae for getting optimum lipid content from the increased growth of species.

The pilot plant together with the combustion gas analyzer & data acquisition system has been used for 4000 h. Trail run for 'Uncertainty Analysis' in the experimentation. CO_2 capture level of 90–93% was achieved for the above post combustion CO_2 sources viz. a boiler and a gasifier. It was seen that H_2 formation to the extent of 21% by volume was also achieved.

The pilot plant (**Figure 2**) was utilized for variety of application during trial run of 4000 h for process stabilization such as: the study of CO_2 capture in mono ethanol amine (MEA) ranging from 1 molar to 5 molar strength; sequestration of CO_2 released from the stripper unit to vari- ety of algae and development of lipid content for bio-diesel production. The pilot plant is also being used for development of low cost catalysts for production of fuel elements like CH_4 [13].

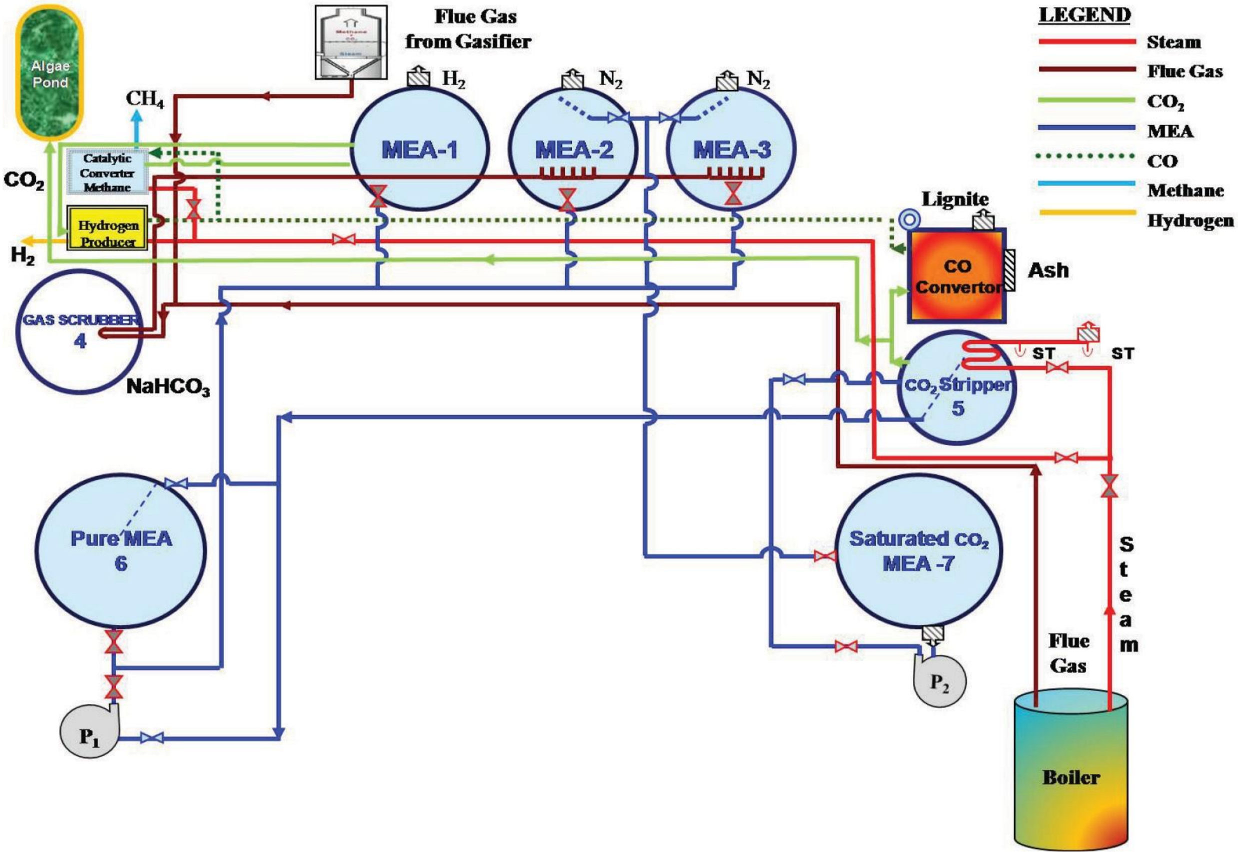


Figure 1. Scheme diagram of CO_2 capture & sequestration pilot plant

Figure- 2 CO_2 capture & sequestration plant (CO_2 & steam source—oil fired baby boiler).

A need was established soon after the 4000 h trail runs of this pilot plant to explore:

- **i.** Optimum value of molar strength of MEA solvent for highest efficiency of capture with minimum cost penalty of regeneration.
- **ii.** Optimum value of carbon dioxide recycling for conversion to CO to attain heat gain up to the calculated theoretical limit of 21.88%.

Simulation studies were carried out and a 1.5 molar strength was found to be optimum for CO_2 capture to the level over 90%. Further, using lignite Gasifier the carbon monoxide of the order of 20% was produced for recycling to the boiler using short-flame burners, which is close to the theoretical limit of 21.88%. The pilot plant was also used for the feasibility study of installation of CCS plant on a 500 MW thermal power plant as discussed further.

The objective of this pilot project is also to carry out feasibility study, prototype design & development of a 30% CO_2 capture & sequestration unit for installation on a 500 MW coal-fired thermal power plant as per the broad scheme given below (**Figure 3**). The project proposal also provides details of plant modification to be done by plant engineers for steam tapping from turbine extractions, as well as design and consultancy scope, etc. A full-scale plant on a 500 MW Pulverized Coal Fired Unit would require a plant of 510 tonnes/h capacity. This interdisciplinary project is expected to resolve certain frontline issues in CO_2 sequestration such as energy intensive process optimization in terms of cost of generation and development of effective catalyst for methane, hydrogen and biodiesel recovery through Algae route. This

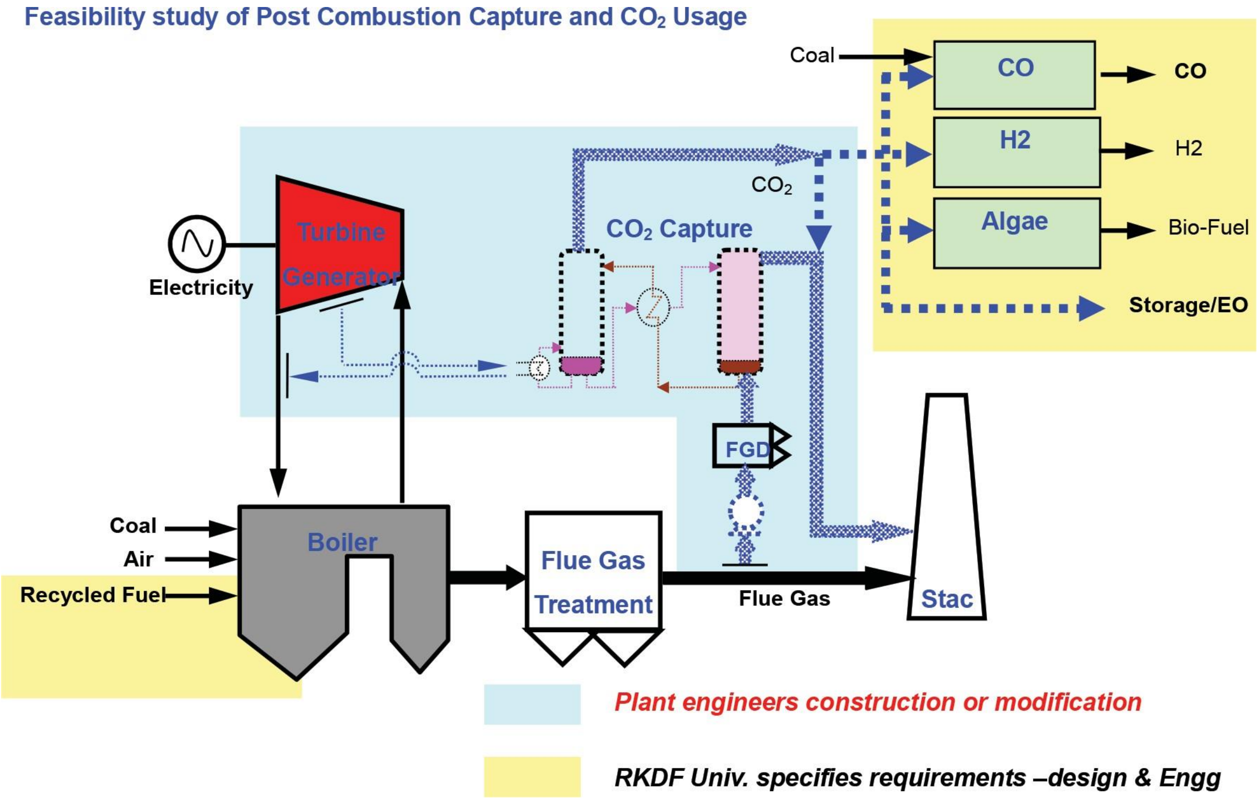


Figure 3. Conceptual diagram of a power project with CCS

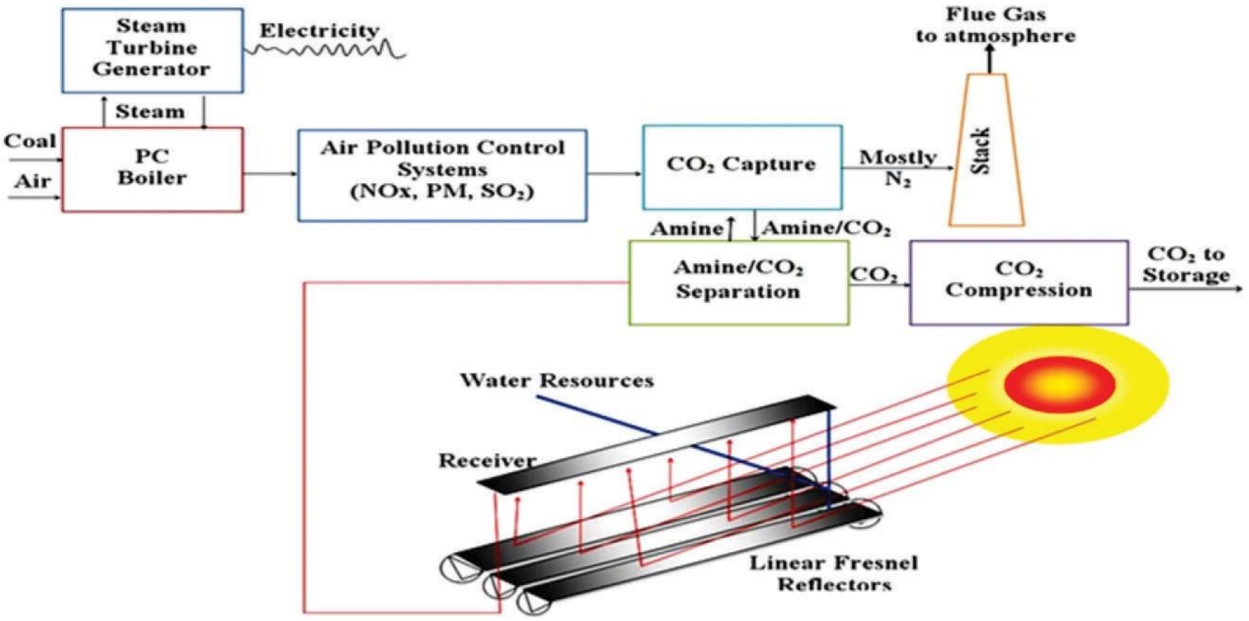


Figure 4. Scheme of implementation of CCS plant through integration with solar thermal

scheme of retrofitting of existing 500 MW unit with CO_2 capture & recycling of CO is being discussed with power utilities like NTPC, TOSHIBA and BHEL and the broad outline of the same are given at **Figure 3**.

The methodology of implementation of CCS plant on a 500 MW unit is broadly shown in this figure. The scheme also shows steam turbine extractions for providing steam for regeneration of solvent which will cause energy penalty of the order of 15%. The same can be reduced to 4–5% level by combination of solar thermal generated steam coupled with thermal energy storage using a concentrated solar plant (CSP) as shown below in the conceptual **Figure 4**. The incorporation of solar thermal with CCS will pave way for reduction of energy penalty in regeneration of solvents [1, 7].

An amine solvent based plant with 30% CO_2 capture would mean an energy penalty of about 25% including about 15% for sequestration to mineral rocks, gas hydrates and ocean. In any case the energy penalty in our case when we are going for CO_2 conversion to multipurpose fuels the energy penalty still remains at level of 12–15% [1, 7]. The reduction to about 10% has been calculated using MATLAB simulation and shall be verified after establishment of pilot scale CO_2 capture and sequestration plant integrated with Concentrated Solar Power (CSP) for carrying out system optimization studies (**Figure 4**).

3. Solar thermal technology application in post combustion CCS on a thermal power plant

Concentrated Solar Plant (CSP) is presently a matured technology in which several ther- mal energy storage options are being deployed. Energy storage in form of heat offers a potential pathway for small (local) and large (utility power plants) scale applications. Thermal storage systems provide a unique opportunity to store energy locally in the form of heat that cannot be transported over long distances. Current thermal storage systems are still in its infancy. The most common ones are large, water-heating storage tanks and molten salt-based systems at solar power plants. These systems have been designed based on the economics of water and salt, the heat capacity of water, and the latent heat of salts. Research on a large host of sensible heat storage and phase-change materials have been conducted over the past two decades. The materials parameters that are relevant for this application are: melting point, boiling point, vapor pressure, density, heat capacity, thermal conductivity, latent heat of fusion and chemical reactivity. While it is intuitive that increasing the temperature of storage could pack in more energy, barriers to the development and deployment of high energy density storage remain, including handling materials at high temperatures, associated systems costs, and operating costs. Thus sensible thermal storage systems are cost prohibitive. Phase change materials (PCM) do provide a viable economical solution for higher energy storage density. However, operation temperatures limit current PCM systems; higher temperatures cause chemical instability and reactivity with containers. Development of affordable high-density thermal storage system will only be possible by utilizing low cost earth abundant thermal storage materials in conjunction with suitable thermally insulating container materials. Current heat storage systems utilize either sensible heat storage (i.e. water in storage tanks) or latent heat storage (i.e. phase-change materials such as molten salts). The relatively low operating temperatures of these systems limit their capacity to store thermal energy; storage systems with higher temperatures would be more economical.

The technologies which hold promise for achieving temperatures in the range of 150–600°C and beyond can be categorized by the phases of matter of the materials used: liquid, gaseous, solid, as under:

- A liquid pathway is considered to look much like today's molten salt two tank tower configuration, but using a suitable high temperature and cost effective HTF/TES.
- Gaseous pathways use an inert gas flowing through a receiver to absorb the solar energy and then transfer the thermal energy to a storage system and/or the turbine working fluid.
- Solid pathways involve solid inert media which absorbs solar radiation and stores that energy as heat. When electric power is needed, the turbine working fluid is heated by the solid media.

In this CCS integrated with CSP project we examined several options of 'Solid Pathway' such as cast iron core of Mount Abu 1 MW solar plant used for steam generation, CL-CSP plant at the State technological University of MP, RGPV, in Central India in which pebbles/rock storage has been proposed for energy storage for heating air in primary cycle and steam in secondary cycle.

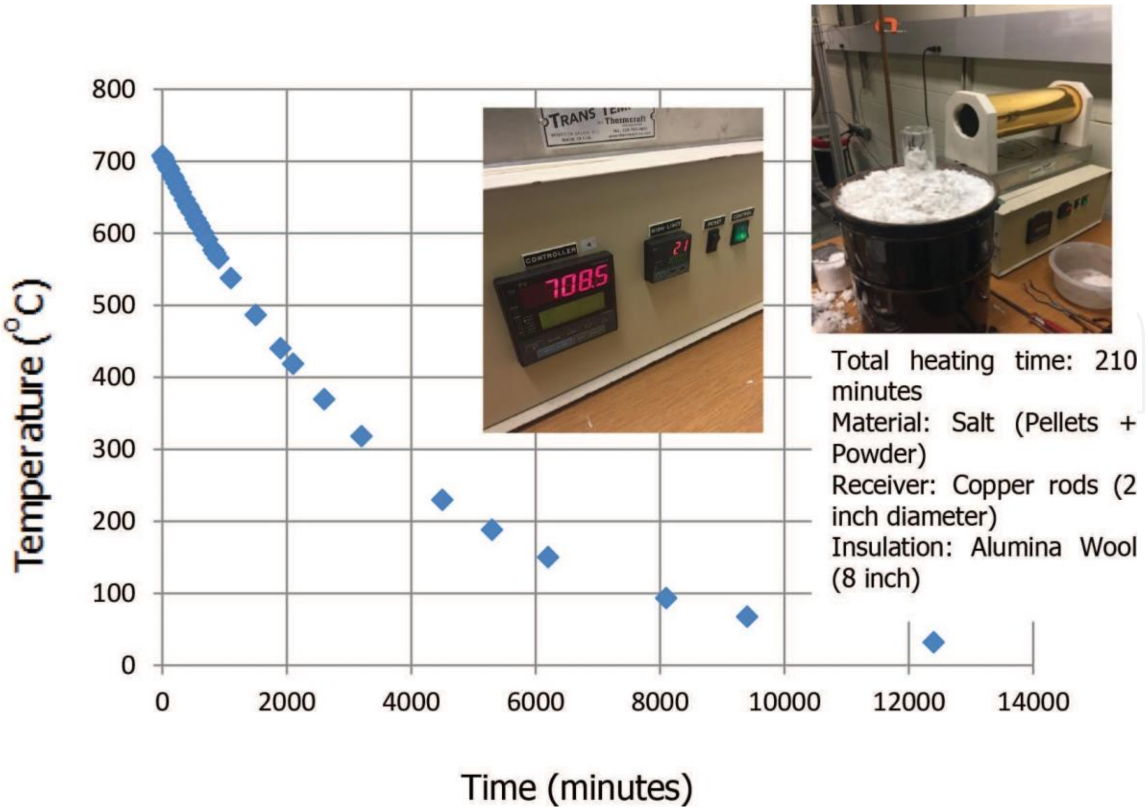
In this CSP to CCS integration project, we are developing an affordable high energy density (in excess of 300 kWh/m^3) thermal storage system, that can store heat at temperature around

1000°C [14, 15]. The unique aspects of this system are the selection of an alkali halide salt with high melting temperature and a corrosion resistant cheap ceramic container material. The thermal storage unit will be coupled with a high solar concentrator system (1000–10,000×). As a part of an on-going project at RKDF University in near vicinity of RGPV, funded by MNRE, the project collaborator in Solar thermal, the Rensselaer Polytechnic Institute of USA has developed flux grown crystals of high melting temperature (700–1500°C) mixed alkali halide compounds doped with metallic impurities to enhance thermal conductivity. The trade-off between material density, specific heat capacity, thermal conductivity and cost of raw material has been evaluated to develop a material system that could meet the system's specification at cost of energy storage lower than current electrochemical systems (batteries). In addition, a SiC based composite polymeric coating solution has been developed to avoid corrosion of steel containers used for the thermal storage unit [16]. These materials have been shipped to RKDF University and incorporated into the field unit (test-bed). The test-bed at RKDF comprises of a thermal storage unit, Fresnel lens based solar tracking unit to focus sun- light into the thermal storage media and a steam generation unit (for future electricity genera- tion using a steam turbine). **Figure 5** shows the installation and initial evaluation activities of the solar thermal storage unit at RKDF University.

The expected physical outcomes of the project of CSP integration with CCS as discussed above are in terms of establishment of the pilot plant of CO_2 capture and sequestration on an actual thermal power station for future development of technology of CCS in India and countries between tropic of cancer & capricorn bestowed with high solar DNI [1, 7].

Test results have shown that the innovative halide salt used as thermal storage material stores heat to such an extent that it retains heat for over 5 days to be able to produce steam (**Figure 6**). This innovative halide salt was also tested in the pilot plant shown at **Figure 5**. The biggest challenge in this project is, however, the development of Alkali Halide Salt indigenously for which efforts are under way at RKDF University to procure some of the key components for growing crystals with high energy density, capable of retaining heat. Also efforts are underway towards indigenous development of Heliostats, Fresnel lens and low cost trackers.

Figure 5. Solar thermal storage unit at RKDF University



Total heating time: 210 minutes
Material: Salt (Pellets + Powder)
Receiver: Copper rods (2 inch diameter)
Insulation: Alumina Wool (8 inch)

Figure 6. Thermal cooling profile testing of the halide salt at RPI, USA

4. Conclusion & way forward

Low Carbon Technology Vision for India together with strategies, challenges & opportunities in Green Power for energy security environmental sustainability are put forward in this paper covering Carbon Capture & Sequestration as a key factor. While there is growing trend of carbon dioxide emissions by energy sector since coal continue to play role in primary energy consumption, the urgency of CCS deployment in countries where coal is the main stay is very important. A pilot plant has been developed at RGPV University, for capture of CO_2 and converting the same into useful fuel like hydrogen for fuel cell application, methane for multiple applications and bio-diesel production through algae route. MATLAB simulations have shown that the recycling of CO back to the boiler will provide heat gain up to theoretical limit of 21.88%. Further, the energy penalty in regeneration of solvent using steam produced by solar thermal plant with an innovative Halide salt as thermal energy storage material will reduce by about 10%.

Climate change has already been experienced in many parts of the world therefore state policies need to support practices that successfully keep carbon in the ground, prevent deforestation, support agricultural practice that sequesters carbon and promote sustainable land use practices that reduce emissions. Policies should push especially the more prosperous communities towards less carbon intensive lifestyles, either through taxes or incentives or both. In addition, the path to zero-emissions must be progressive and in line with the progress of new and renewable technologies of hydro, solar and wind. The first step towards in this progressive path should be CCS.

Indigenous development of critical components of solar thermal plants for integration with CCS is nevertheless important. The following is a list of identified components that will be necessary to be developed within India at ultra-low cost by technology licensing and manufacturing technology transfer approaches by commercial entities (from abroad) to translate the existing technology for large scale adoption:

1. Large area high optical quality Fresnel lens/Heliostats/Fresnel Reflectors manufacturing with low cost.
2. High thermal storage density material development for 24 × 7 heat storage.
3. Corrosion resistance nano-coating process.
4. Ultra-low cost solar trackers.
5. Energy efficient, low maintenance cost thermal transport systems for heat exchange.

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CHAPTER – 2

OBJECTIVES & SCOPE

Chapter-2: Objectives and Scope of the study:

2.1The objectives of the study:

The Objectives are:

2.1.1 To provide a potential ground under aegis of MOP for developing and demonstrating feasibility of Sustainable Clean Coal Thermal Power Plants equipped with Carbon Capture & Sequestration Technology.

2.1.2 Exploring options for reducing energy penalty through solar thermal & other options

a. Process optimization leading to improve design of MEA Solvent reactors, System optimization studies.
b. Design & Engineering - Data Acquisition System & Instrumentation
c. Pilot study of CO_2 sequestration to a simulated coal seam in the used coal mines
d. Pilot study of CO_2 Sequestration to Algae pond for production of Bio-diesel

The Objectives have been achieved as under:

Item No.	Description	Action taken report (brief)	Ref. Chapter no.	Remarks
2.1.1	**The feasibility Study of Sustainable Clean Coal Thermal Power Plants equipped with Carbon Capture & Sequestration Technology.**	**Refer Chapters on:** **The feasibility study of Scaling up of CO2 Carbon Capture & Sequestration Plant on 500 MW ANPAR B TPS in Singrauli Region has been carried out**	**Ch. No.** **7.1 & 7.2**	**Water, Power, Land requirement and project authority's perspective** **+** **Heat / Energy Balances, HBD/ PI DIAGRAMS for a 500 MW Unit given**
2.1.2 (a)	**Process optimization leading to improve design of MEA Solvent reactors, System optimization studies**	**Refer Chapter on:** **Energy Penalty optimization in regeneration of Solvent through Steam from Solar Thermal Plant**	**Ch. No.** **5.2**	**Energy Penalty reduced from a level of 4,2 MJ per kg CO2 to 2.18 MJ per kg of CO2**

2.1.2 (b)	**Design & Engineering - Data Acquisition System & Instrumentation**	**Ref: Chapter on:** **EXPERIMENTAL PROCEDURE** **Pilot Plant Design - Integration with Solar Thermal for regeneration of Solvent and Coal fired boiler for Steam & Flue Gas generation &** **&** **Trial Run of 30 days**	**Ch. No. - 4**	**Compiled reports on:** **(1) Designs & Drawings** **(2) Operation Manual** **& (3) Data Book attached at Appendix I,II, & III**
2.1.2 (c) & (d)	**Pilot study of CO_2 sequestration to a simulated coal seam in the used coal mines** **&** **Pilot study of CO_2 Sequestration to Algae pond for production of Bio-diesel**	**Refer Chapter on:** **SEQUESTRATION OPTIONS** • **Production of Hydrogen** • **Production of Bio-diesel through Algae route** • **CO2 to depleted coal mines** • **EOR & other novel options**	**Ch. – 5.1**	**Chapter on feasibility stidy of Coal seams of KAKRI Mine and pilot study of production of Multi purpose fuels given in this chapter**

2.2 Scope of the work

The Scope of Work includes:

Attached enclosures (ENCL: 1 to ENCL: 3) in the form of compiled document folders provide a deep insight into the Scope of Work which mainly covers:

1. **Installation of Solar Integrates Carbon Capture Pilot Plant of Capacity 45 kg/hr. of CO2 (250 kg/hr. Flue Gas from the associated Coal Fired Boiler installed for the purpose).**

2. **Feasibility Study of Installation of Retrofit Post Combustion Carbon Capture Plant on 500 MW ANPARA B TPS – 2x500 MW in Singrauli region of MP**

3. **Pilot Study of Production of Multi-purpose Fuels**

2.2.1 Establishment of the Pilot plant of CO_2 capture and sequestration for future development of Technology as to provide formidable support to the Govt. of India in the 'Climate Change Mission'. This has been achieved through Erection Testing, Commissioning of a Pilot plant retrofitted with Solar Thermal plant for steam generation and elaborate instrumentation & software for optimized configuration. The Pilot Plant details are given in Chapter 1 below:

CHAPTER -1: PREAMBE
1.1.1 Genesis of Study
1.1.2 Executive Summary
1.1.3 Salient Features of the Project

2.2.2 The feasibility study has examined various options (in Chapter 5.1) like:

- **Production of Hydrogen**
- **Bio-diesel through Algae Route**
- **Captured CO_2 to depleted Coal mines**
- **Captured CO_2 for EOR**
- **Other NOVEL Options of Sequestration**

2.2.3 The latest Technology based Solar Thermal Plant to produce steam for integration with CCS plant for regeneration of CO2 saturated MEA has been experimented , so as to reduce energy penalty to about 5%from a level of 15% as inferred from reduction of regeneration energy by about 48% (4.2 MJ/kg CO2 to 2.18 MJ/kg CO2).

ALSO REFER CHAPTER -6: Main Conclusions & Future Prospects

CHAPTER – 3

DELIVERABLES

Chapter-3: Deliverables:

3.1 The expected deliverables & Achievements of the Research Study are

3.1.1 Process and product development

TARGET: The Process and product development will lead to technological solutions matured enough for achieving high level of CO_2 capture at the same time reducing energy penalty in the process through Solar Energy supplement and various optimization techniques.

ACHIEVEMENT:

Solar Integrated Carbon Capture Pilot Plant associated with a Coal Fired Boiler has been installed, commissioned and tested as per following broad specifications:

A CCS Plant Capacity 45 kg/hr. CO2 as per following broad calculations:

The plant for Carbon Capture & Sequestration is indeed a Carbon Capture & Utilization Plant (CCU) which is in Sir J C Bose Interdisciplinary Research Park at RKDF University, Gandhi Nagar Campus Bhopal in the area of 15 x 25 meter. Fig: 01 blow gives glimpses of the plant.

The Plant has been tested by supplying steam for regeneration of MEA Solvent both from Boiler and 8 Nos. Solar Thermal Scheffler Units as shown below:

The plant is installed on a concrete foundation in which MEA Tanks, Gasifier, Water-gas-shift (WGS) reactor, pumps and piping etc. are installed in single-tier structural frame-work. The flue gas is being tapped-off @ 6 tons per day or 250 kg/hr. (i.e. CO_2@ 18% about 45 kg per hour) running in a 8 hr. shift and regeneration in 2 shifts with solar steam having 4-8 hr. additional thermal storage capacity. Adjacent Solar Thermal Plant with thermal storage has been installed on ground. The size reduction of the land area requirement is due to the following reasons:

- **Use of high density (in excess of 300 kWh/m^3) Halide salt in the Solar Thermal Unit for production of steam for MEA solvent regeneration & WGS reaction**
- **Optimized design of reactors and the gasifier through CFD modeling**
- **Steam requirement will be met by 8 parabolic discs of 5 kg/hr. capacity along with up to 16 hr. thermal storage of Halide salts supplied by RPI USA. Additionally 2 Scheffler units have been provided for meeting steam requirement in case of lower solar flux in cloudy days.**

Other Specifications are:

Additional water requirement is 70 kg per hour for:

- **Steam generation: 40 kg per hour**
- **Water-gas-shift reaction: 18 kg per hour**
- **Fluidized bed gasification process: 10 kg per hour**
- **Chamber cooling : 2kg per hour**

Additional Power Requirement of the system is as under

Auxiliary Power requirement of 100 kW has been worked out as under for the entire CCS integrated with 'Solar thermal' system

- **Pumps, Boiler etc.: 40 kW**
- **Solar Tracker motor for 2 axis tracking: 30 kW**
- **Gasifier fluidized blower: 20 kW**
- **DAS Monitoring: 10 kW**

3.1.2 Contribution towards improvements in issues concerning System operation

TARGET: The 30% CO_2 capture will reduce the CO_2 emission level from 0.9 kg/kWh to 0.7 kg/kWh. For a 500 MW unit the co_2 reduction will be of the order of 20% which translate into 0.7 million tonnes of co_2 reduction in a year. The energy penalty will be of the order of 5% which is considered least in today's scenario. The environmental benefits thus out ways the energy penalty

ACHIEVEMENT THROUGH INNOVATION:

OBJECT OF THE INNOVATION:

- The principle objective e of the innovation is to bring down the Energy requirement in the regeneration of MEA Solvent from a level of 4 Mega Jules (MJ) per ton of CO2 captured to below 2.2 MJ /Ton and the same time continue the process of Solvent regeneration by Solar Steam drawn from the Thermal Storage System, consisting of Halide Salt.

- The present innovation related to a Carbon Capture & Sequestration Plant on a Fossil fuel-fired Power Plant faces a big issue of Energy penalty in the regeneration of Solvent such as MEA. The Energy for regeneration is to be drawn from the power plant itself causing an energy penalty on the cost of generation by over 25%. In the Solar Thermal integrated Carbon Capture Plant the steam for regeneration will be given by 8 Scheffler units of 5 kW each. Since the CCS Plant is to be run 24x7, the Solar Thermal plant is being provided with a thermal storage unit.

- Design of the reactor in which the solvent is heated by the steam coming from Solar Thermal Plant integrated with Thermal storage, steam remains in the jacket while the flue gas also contributes in heating by passing through the coils as shown in figure 2 given below.

- Accordingly a pilot plant has been designed and developed as shown below at Figures 2. The novelty lies in design of Reactor for which the patent has also been sought. The heat exchange process is unique in which solar steam jacket heats the solvent and additional heat is supplied from the flue gas of the boiler itself as heat recovery unit.

PLANT OPERATION:

1. Flue gas is subjected to water flow which traps all particulates with water and cools down the temperature of flue gas.
2. Gas is sent to Scrubbing tower where it enters the scrubber from the bottom
3. Soda solution (Sodium Carbonate solution of 10% is sprinkled from top of the pickings, causing Ammonia, SOx gas and NOx gases to convert into their respective salts like Sodium sulphate, Ammonium Sulphate and Sodium Nitrate.
4. After this, the gases are subjected to another identical tower so that any traces of these impurities get absorbed and does not come in to contact with MEA solution (mono-ethanol-amine). Reaction with MEA solution can result in the formation of complex salts.
5. Flue gases from second scrubber tower are free from the impurity of Ammonia, SOx and NOx.

6. These gases are now subjected to counter-current of MEA solution of 30% in the third tower. Here it forms a bond with CO_2 gas to form MEA-CO_2 mixture solution. MEA solution of 30% has been found to absorb up to 90% of CO2
7. MEA-CO2, the solution is sent to a reactor vessel where the mixture is heated by means of the coil which carries hot fuel gases at about 150-degree centigrade. The outer jacket can be heated by steam supplied by a solar thermal system.
8. At 120 degree centigrade, CO2 will start releasing from the mixture of MEA-CO2 This happens because of the physical property of MEA that has the tendency to release CO2 when heated. (Note: The boiling point of MEA is 170 degrees centigrade. To prevent losses of MEA, max temp of MEA-CO2 mixture is restricted to 155 degrees centigrade)

BRIEF DESCRIPTION OF THE DRAWING

Figure 2A - Schematic design of the working of the processing .
Figure 2 B- Reactor Vessel
Figure 2C- Cross-section of the reactor

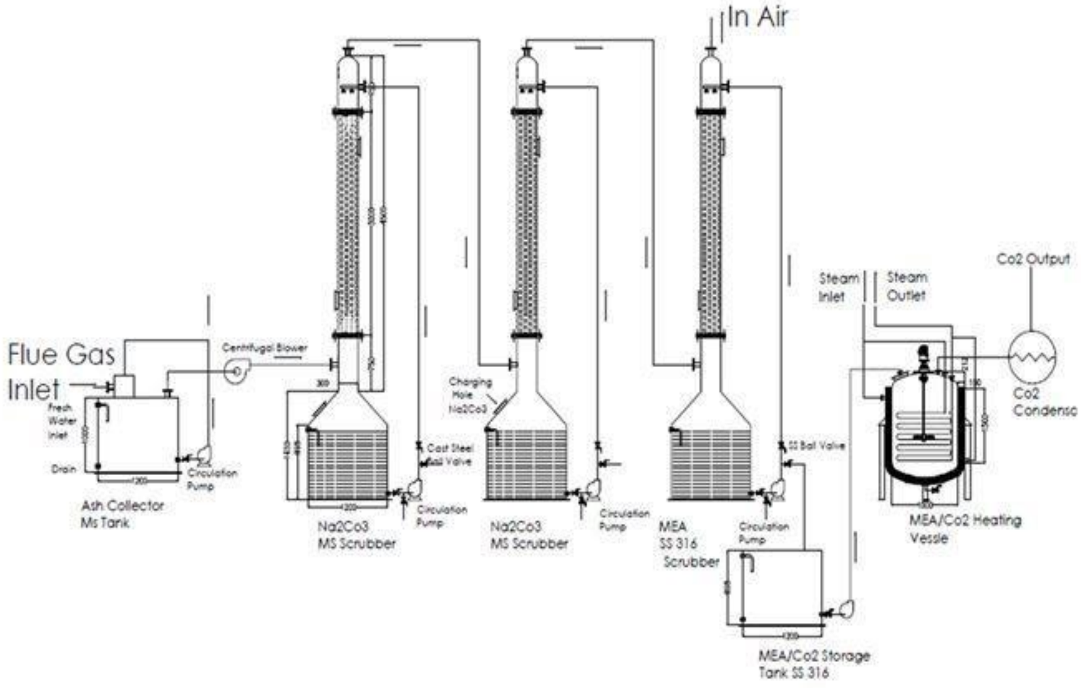

Figure 2 A: OVERALL SCHEME OF THE PLANT

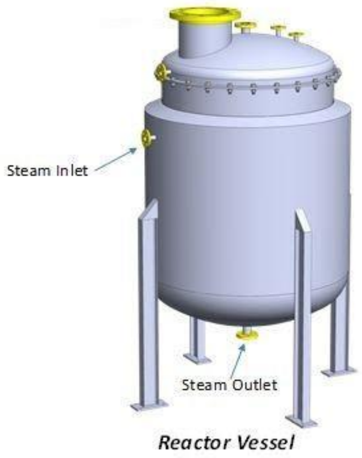

Fig.2B - Reactor Vessel

Fig. 2C - Cross Sections of the Reactor Vessel

A reactor for reducing energy penalty in a solar thermal integrated carbon capture plant in any Carbon Capture & Sequestration Plant on a Fossil fuel-fired Power Plant faces a big issue of Energy penalty in the regeneration of Solvent such as MEA. The Energy for regeneration is to be drawn from the power plant itself causing an energy penalty on the cost of generation by over 25%. In the Solar Thermal integrated Carbon Capture Plant the steam for regeneration will be given by 8 Scheffler units of 5 kW each. Since the Plant is to be run 24x7, the Solar Thermal plant is being provided with a thermal storage unit.

The design of the reactor in which the solvent is heated by the steam coming from Solar Thermal Plant integrated with Thermal storage. The reactor in which steam remains in the jacket while the flue gas also contributes to heating by passing through the coils as shown in the figures.

3.1.3 Value addition

CCS involves the capture of carbon dioxide (CO_2), the principal GHG, from concentrated emission sources, and then transporting it to and storing it perpetually in underground geological formations, used oil wells, or other secure locations. However, several challenges must be overcome before large-scale CCS deployment becomes practical, including establishing the technical feasibility of long-term geological CO_2 storage, assessing the economics of capture, transport and storage of CO_2, sensitizing the Government, industry, and the common man to the potential of this technology, etc.
Accordingly, eight national missions for managing climate change have been set up:

1. National Solar Mission
2. National Mission for Enhanced Energy Efficiency
3. National Mission on Sustainable Habitat
4. National Water Mission
5. National Mission for Sustaining the Himalayan Ecosystem
6. National Mission for a "Green India"
7. National Mission for Sustainable Agriculture
8. National Mission on Strategic Knowledge for Climate Change

The Principal Scientific Advisor has announced the Government’s interest in adding a ninth ‘Clean Coal Technologies’ mission that would include CCS. The value addition shall be in terms of Mitigation of Climate Change in line with National Clean Coal Technology Mission which includes CCS.

3.1.4 Research publications & Patent

TARGET: A minimum of 4-6 International papers with good impact factor will be produced in the execution period of this project

ACHIEVEMENT: List of 11 Publications & one Patent Application will be found in Chapter 9. At least 1 PDF, 2 Ph. Ds and about 15 M. Tech. thesis will also be contributed in this research period.

3.1.5 *Benefits / returns from the project work (indicate likely benefits to Indian Power Sector / Indian Utility / Manufacturer / Society)*

Ministries: MOP, MNRE, MoEF
Power Utilities: NTPC, GENCOs, BERGEN, SUNRISE CSP India Pvt. Ltd.
Power Plants: Anpara Thermal Power Station, Renusagar Power Station, Shaktinagar Thermal Power Station, Panipat thermal Power Station

Universities: RGPV, DTU, PDPU, IIT/D, IIT/B

3.2The present day needs of the Power Sector – relevance & importance

3.2.1 Preamble:

Despite the fact that we in India have taken a giant leap forward in increasing the installed capacity from a mere 1713 MW in 1950 to over 3, 79.13 MW as on date, the renewable energy sources however contribute over 25.4% with total capacity of over 91,150 MW. But this contribution has a major social and economic impact on rural and remote area population. The growth of clean energy technologies for mega Power generation, such as the Solar Mega Power under Jawaharlal Nehru Solar Mission, both Solar Thermal and PV, Clean Coal Technologies, CCTs, i.e. Supercritical power plants, Integrated Gasification Combined Cycle (IGCC) , Carbon Capture & Sequestration (CCS) and fluidized bed combustion (FBC) are key to the success Green Power Mission for India

An important portion of the National Action Plan for Climate Change (NAPCC) deals with GHG mitigation in India's power sector which contributes over 56% in our total annual CO_2 emission of 2500 Million Tons. It points out that various measures for reducing GHG emissions from power plants, such as increasing the efficiency of existing power plants, using clean coal technologies, and switching to fuels other than coal where possible, must be viewed as being complementary and not mutually exclusive. CCS is regarded as one of the frontier CCT. Unless a CCS plant is installed on an actual Plant as per product development plan submitted herewith the vision of Climate Change mitigation will not be fulfilled.

3.2.2 The feasibility study of installation of this Mega Scale CCS Plant:

The feasibility study of installation of CCS Plant on 500 MW ANPARA B TPS 2x500 MW has been detailed in subsequent chapters 7.1 & 7.2. A brief summary of the same is under:

In this project the scaling-up has been envisaged to 30% CO_2 Capture & Sequestration to produce multi-purpose fuels on a 500 MW Unit at selected thermal plant in Singrauli region. Since a 500 MW unit emits about 8000 tons of CO_2 per day (about 330 tons per hour), the scaled-up carbon capture and sequestration plant will be of capacity 100 tons per hour. No compression and storage of CO_2 is presently envisaged.
The sequestration options covered in the project are related to CCU:

- Production of Algal Bio-mass @55 tons per hour using selected species of Algae viz. Scenedesmus obliquus, Monoraphidium minutum and ClorolaVelgaris in the specially designed bio-reactor for culture preparation and algal pond. These varieties have been tested to have growth in the Ash decantation water also. Bio-diesel shall be produced using trans-stratification process.

- Production of CO from CO_2 using gasifier and thereby producing Hydrogen using water-gas shift (WGS) reactors. Performance of WGS catalysts under wide range of CO-to-Steam ratios will be investigated for an optimum level.

Incorporation Solar thermal plant of capacity 70 tons per hour for steam production both for MEA solvent regeneration and WGS reaction with a make-up water consumption of 4.5%, i.e. 3 tons/hr.

This novel concept of using Renewable Energy will reduce energy penalty from a level of 15-17% to about 4-5% {ref. Energy Procedia 114 (2017) 1288 – 1296}

- Corresponding to above the estimated quantities of in-puts required are:
    - ➢ Land Area between Stack-area Slab (now being used for De-sulfurization) & Fuel Oil corridor in front of the stack: … 70 mx125 m, with reactors at 2 levels
    - ➢ Additional Water requirement … 4-5 tons per hour as make-up & gasification
    - ➢ Additional Power requirement … 4 MW, that increases auxiliary power consumption by 0.8 %
- The CCS units are designed to run at base load in safe and efficient manner through a Microprocessor based Distributed Digital Control and Monitoring Information System (DCS). The units are expected to display lowest possible Turbine heat rate of the order of 1950 kCal/ kWh and Unit Heat Rate of the order of 2300 kcal/kWh even after CS installation
- Heat balance diagrams in various operating conditions at various CW inlet temperature conditions shall be provided at the time of detailed engineering. The overall Power Cycle envisaged in the Heat balance and Optimization study shall be as per diagram as per chapter 7.2 mentioned above.

Once successful of an actual power plant of 500 MW and on 660 MW Supercritical Units of over 4000 MW capacity UMPP being installed in the country with an acceptance of providing CCS plants from the very beginning as discussed in the chapter 2 on Literature Survey”.

CHAPTER – 4

EXPERIMENTAL PROCEDURE

RKDF UNIVERSITY

The CPRI Sponsored Project to RKDF University, Bhopal under RSOP Scheme

Project Title:

“Post Combustion Carbon Capture & Sequestration (CCS) Plant on a Coal Fired Power Plant - Feasibility Study”

Sanctioned vide: CPRI/R&D/TC/Thermal/ 2019 Dated 06-02-2019

Period of Project: April 2019 – June 2021

Collaborator: RPI, USA & RGPV, Bhopal

CHAPTER-4: EXPERIMENTAL PROCEDURE

PROJECT REPORT

PROJECT COMPLETION REPORT

Sir J C Bose Interdisciplinary Technology Park

Executing Organization: Ram Krishna Dharmarth Foundation (RKDF) University, Airport Bypass Road, Gandhi Nagar Bhopal, MP 462033

RKDF UNIVERSITY

SUNRISE CSP
CONCENTRATED SOLAR POWER

Project Submission Report

2019-2021

Carbon Capture & Sequestration Integrated with Solar Thermal Technologies

Sunrise CSP India Pvt. Ltd.
Muni Seva Ashram, Goraj, Waghodia, Vadodara-391760
www.sunrisecsp.in www.greenashram.org
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SUNRISE CSP
CONCENTRATED SOLAR POWER

ABOUT

Sunrise CSP Pvt. Ltd. develops, supplies and supports world leading Concentrated Solar Power (CSP) technology for the development of cost-competitive, utility-scale electricity generation and high temperature industrial process heat systems.

Our core technology is the Big Dish solar concentrator and its complementary technologies such as Scheffler and Carbon Capture and Sequestration. These technologies can be deployed in stand-alone or grid-integrated solar power projects, with or without storage, or hybridised with gas, oil or other fuels to deliver cost-competitive dispatchable power generation systems.

They may also be deployed to provide thermal energy for a diverse range of high temperature industrial processes such as desalination, enhanced oil recovery, minerals processing, the production of hydrogen and solar enhanced fuels.

.

Project Funding Organization

*Funded by a **CPRI (Central Power Research Institute)** of Bangalore RKDF University has placed order for CCS project with sunrise not just to supply 2 Scheffler Concentrators of 16 m2 each but also CO2 absorption system. Co2 from flue gases would be absorbed in MEA Solution in the scrubber in/of the CO2 absorption system and would be released by solar generated steam by Scheffler Concentrator*

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Abstract

The proliferation in the production sector encourage to produce more and more energy to support the national growth and development of the country. The coal serve as a major role and become backbone for the country. The massive use of coal leads to global warming and various environmental problem. To overcome such issue is very critical and required major attention to scrap out from the environment. There are two ways to have negative carbon emission one by Afforestation such as Bhutan and another is CCS. To take step forward the Carbon Capture and Sequestration is a solution in this direction. This absorbed CO2 from the atmosphere or carbon emission from Stack of chimney to absorb the unburnt carbon into the MEA and store it permanently in deep sea, old oil mines, in some salt or convert into some by-products such as hydrogen, methane or Bio-Diesel.

Introduction

Introduction

1.1 INTRODUCTION

The mathematics of climate change are unforgiving. It reduces to a deceptively simple equation which when solved, leads to a clear conclusion that net-zero emissions energy and industry is necessary to meet climate targets. Despite more than two decades of international negotiations and trillions of dollars spent on research and subsidies, unabated fossil fuels still provide about 80% of primary energy and global emissions of CO2 continue to grow. The gap between what is required to stabilise the global climate and what is required to maintain and grow modern economies has never been wider. Demand for energy, cement, steel, fertilizer, plastics and many other materials and chemicals that form the building blocks of modernity will be higher in 2050 than today. That demand is driven by two billion extra people to feed, clothe, house, transport and entertain, hundreds of millions of which will have become sufficiently affluent to consume these emission intense goods and services for the first time.

Figure 1: CCS Plant at RKDF University

It is time to recognize that a more progressive approach to climate change is necessary. The old thinking, rooted in the belief that the two silver bullets of renewable energy and energy efficiency would deliver rapid emission reductions must be replaced with new thinking that embraces every feasible option and sets a path to net-zero emissions. The concept of a circular economy with its “three Rs” of “**Reduce, Reuse and Recycle”**, works well in describing an approach to sustainability considering the efficient utilization of resources and wastes, but has proven manifestly inadequate as a framework for defining climate action. To be effective, a fourth R must be added; “**Remove”**, creating a new concept – the Circular Carbon Economy (CCE). The CCE provides for the removal of carbon dioxide from the atmosphere (Carbon Direct Removal or CDR) and the prevention of carbon dioxide, once produced, from entering the atmosphere using carbon capture & sequestration (CCS). The CCE establishes a framework that respects the analysis of the Intergovernmental Panel on Climate Change (IPCC) and many others, that all conclude that CCS and CDR, alongside all other options, are essential to achieve climate targets.

CCS describes a family of technologies that capture CO2 from large point sources such as industrial facilities or power stations, compresses the CO2 to a supercritical fluid, and injects it into suitable geological structures 800 meters or more beneath the earth’s surface for permanent storage. At those depths, the CO2 remains a supercritical fluid, with a density similar to water.

These technologies are not new. The first CO2 capture processes were commercialized in natural gas processing almost 90 years ago. Geological storage of CO2, in the course of Enhanced Oil Recovery, commenced almost 50 years ago. Continuous dedicated geological storage of CO2 commenced more than 20 years ago. Today, 21 commercial CCS facilities with a total capacity of 40Mtpa CO2 are operating, three more are in construction, 16 are in advanced development and approximately another 20 are in early development. Each of these facilities is or will permanently store hundreds of thousands of tonnes of CO2 per year, and several store more than one million tonnes of CO2 each year, captured from power and industrial facilities. To date, approximately 260Mt of anthropogenic carbon dioxide has been safely and permanently stored in geological formations.

They also continue to improve, as expected for any industrial technology. The cost of capturing CO2 from power stations has halved over the past decade and the next generation of capture technologies offer further reductions in cost. The lowest cost opportunities for CCS can deliver multi-million tonne CO2 abatement at a single facility, at a cost of less than USD20 per tonne.

In addition to capturing CO2 at its source, CO2 must be removed from the atmosphere to achieve climate targets. The capture of CO2 from the utilization of biomass, and directly from the atmosphere followed by permanent geological storage (BECCS and Direct Air Capture with storage: DACS) are important negative emission technologies offering higher security and greater flexibility than nature-based solutions, which are also essential.

CCS encompasses a versatile suite of technologies that can be applied to almost any source of carbon dioxide. It is this versatility that underpins its enormous carbon management potential. The IPCC’s Special Report on Global Warming of 1.5 Degrees Celsius published in 2019 reviewed 90 scenarios, almost all of which required CCS to limit global warming to 1.5 degrees Celsius. The average mass of CO2 permanently stored in the year 2050 across all scenarios reviewed by the IPCC report was 10Gt. The IPCC constructed four illustrative pathways to represent the range of 1.5 degree scenarios in the models it reviewed. Three of the four illustrative pathways required CCS with cumulative CO2 storage to the year 2100 of between 348Gt and 1,218Gt. The fourth illustrative pathway required final energy demand to reduce by one third by 2050 compared to 2010. The lowest risk pathway probably lies somewhere in the middle. In any case, it is clear that CCS has a carbon management potential this century of hundreds to thousands of billions of tonnes of carbon dioxide.

However, like renewable energy, nuclear power and many other essential technologies, CCS is not being deployed at the rate and scale necessary to achieve climate targets. The reason is that the incentive for investment in CCS is generally insufficient to mobilize the requisite capital. There are several market failures across the CCS value chain that directly affect the business case for CCS. For a potential capture plant developer, the main impediment to investment is the lack of a sufficient value on emissions reductions. Without this, there is no incentive for a developer to incur the costs of constructing and operating the capture plant, even though it may be beneficial from a broader societal perspective in helping to meet climate targets cost effectively. In economic terms, CO2 emissions are an externality.

1.2 The Challenge of Achieving Net-Zero Emissions

Preventing dangerous interference with the global climate system will require anthropogenic greenhouse gas emissions to reach net-zero in the second half of this century. This means arriving at a steady state equilibrium in carbon cycles by either having no more anthropogenic emissions, or having any emissions balanced by corresponding removals of greenhouse gases from the atmosphere by enhanced sinks. This must occur against the backdrop of a rising human population and increasing affluence, especially in developing economies which are delivering a rapid rise in Gross Domestic Product (GDP) per capita. In summary, there will be more people with a significantly greater average economic capacity to consume goods and services.

The Japanese economist Yoichi Kaya describes the relationship between CO2 emissions, population, energy use and GDP in his famous equation known as the Kaya identity.

$$F = P.\frac{G}{P}.\frac{E}{G}.\frac{F}{E}$$

Where:

F = global CO_2 emissions from human use of energy
P = global population
G = global GDP
E = global consumption of energy

The identity shows that CO2 emissions are proportional to population (P), GDP per capita (G/P), the energy intensity of the global economy (E/G) and the emissions intensity of the global energy system (F/E). Adopting assumptions used by the International Energy Agency, global population will grow from 7.6 billion in 2018 to 9.2 billion by 2040, global GDP will grow at a compound average annual rate of 3.4% to 2040 and energy efficiency (E/G) will improve by 2.3% per year. Substituting these values into the Kaya Identity shows that global anthropogenic emissions could be 51% higher in 2040 compared to 2018 if the emissions intensity of energy remains unchanged. This demonstrates the criticality of developing a near-zero emissions global energy system as the emissions intensity of energy is the only variable left to proactive intervention. Whilst the emissions intensity of the global energy system is already falling, it will not achieve near-zero status without strong policy action that takes advantage of every opportunity to reduce emissions.

1.3 A More Progressive Approach is Necessary

The Circular Economy is effective in describing an approach to sustainability considering the efficient utilization of resources and wastes however it is not sufficient to describe a wholistic approach to mitigating carbon dioxide emissions. This is because it does not explicitly make provision for the removal of carbon dioxide from the atmosphere (Carbon Direct Removal or CDR) or the prevention of carbon dioxide, once produced, from entering the atmosphere using carbon capture & sequestration (CCS). Rigorous analysis by the Intergovernmental Panel on Climate Change, the International Energy Agency, and many others all conclude that CCS and CDR are essential to achieve climate targets.

An approach that is more progressive than the Circular Economy is required for climate action. To that end, the Circular Carbon Economy adds a fourth “R” to the “three Rs” of the Circular Economy; Remove. Remove includes measures which remove CO2 from atmosphere or prevent it from entering the atmosphere after it has been produced such as carbon capture & sequestration (CCS) at industrial and energy facilities, bioenergy with CCS (BECCS), Direct Air Capture (DAC) with geological storage, and afforestation.

Measures taken under the Remove dimension of the Circular Carbon Economy contribute to climate mitigation by storing carbon dioxide in the geosphere (CCS or DAC with geological storage) or in the biosphere (nature-based solutions such as afforestation). However, CO_2 stored in the biosphere via nature-based solutions may be susceptible to release due to natural phenomena such as fires, droughts or disease (of plants). Technology-based solutions such as CCS and DAC with geological storage offer extremely secure and permanent storage of CO_2, which is not susceptible to disruption from fire or weather, as well as requiring very little land for facilities with a capacity to provide multi mega-tonne per annum abatement.

Both nature-based and technology-based solutions are essential elements of a comprehensive approach to driving CO_2 emissions towards net-zero. The critical requirement for success in achieving climate targets is that both technology-based and nature-based solutions under the Remove dimension, along with all other options under the other “three Rs” of the Circular Carbon Economy, are available for selection and that incentives for investment enable deployment of the best option in each circumstance, whatever that may be.

1.4 CURRENT STATUS OF CCS

1.4.1 Introduction to Carbon capture & sequestration

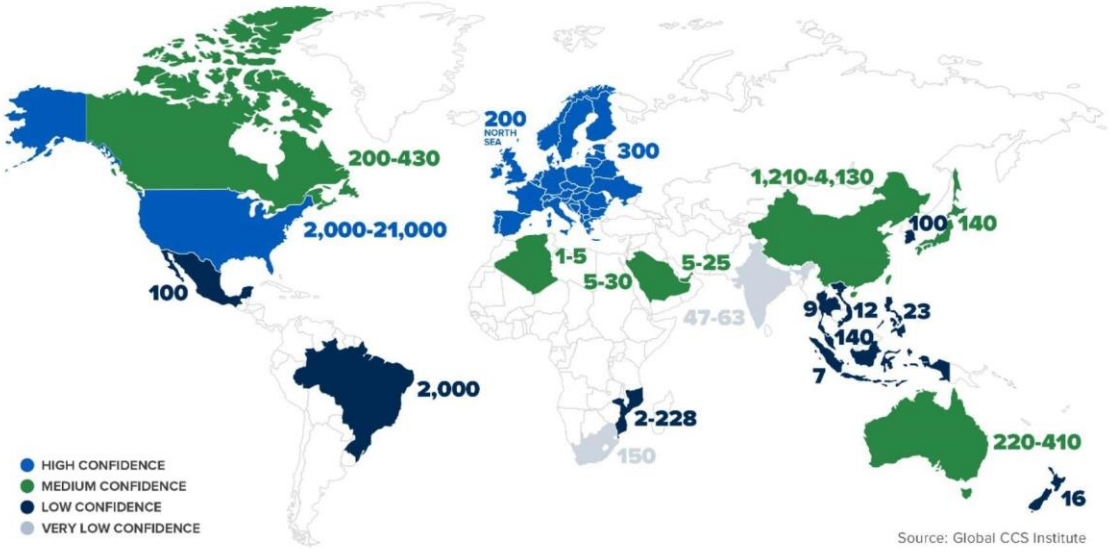
CCS describes a family of technologies that capture CO_2 from large point sources such as industrial facilities or power stations, compresses the CO_2 to a supercritical fluid, and injects it into suitable geological structures 800 meters or more beneath the Earth’s surface for permanent storage. At those depths, the CO_2 will remain a supercritical fluid, with a density similar to water.

The capture of CO_2 from gas streams is not new. CO_2 capture technologies based on chemical solvents (amines) were first commercially deployed in the 1930s to separate CO_2 and other acid gases from methane in natural gas production. Prior to 1972, all CO_2 captured was vented to atmosphere except a small proportion used or sold for other purposes such as urea production or beverage carbonation.

The first commercial CCS facility commenced operation in 1972 at the Val Verde Natural Gas Plant in west Texas USA. This facility is still operating as the Terrell gas processing facility. CO_2 captured from natural gas processing at Terrell is transported via a pipeline to oil fields where it is injected for Enhanced Oil Recovery (EOR). In EOR, the injected CO_2 mixes with the oil reducing its viscosity resulting in greater recovery of oil in place. Generally, approximately half of each tonne of CO_2 injected becomes permanently trapped in the pore space originally occupied by the oil and the other half is produced with the oil. At the surface it is separated from the oil and then re-injected, together with additional CO_2 to make up the difference for that which has become permanently stored. Ultimately, all the CO_2 injected becomes permanently trapped in the pore space previously occupied by the oil.

More generally, any rock formation of sufficient size and depth with adequate porosity and permeability is a potential CO_2 storage reservoir if migration of CO_2 to the surface is prevented by other impermeable rock formations. Geological storage of CO_2 utilises the same forces and processes that have trapped oil, gas and other hydrocarbons in the subsurface for millions of years. Global geological storage capacity is conservatively estimated to exceed 4000 billion tonnes of CO_2, which is more than sufficient for CCS to play its full role in emission mitigation under any scenario. The overwhelming majority of that potential storage capacity is not associated with oil or gas production, but rather with formations currently saturated with saline water.

The behaviour of fluids like CO_2 in the subsurface is very well understood courtesy of more than a century of experience in the oil and gas industry and a large body of more recent academic research and monitoring. The probability of leakage of CO_2 to the atmosphere from an appropriately selected and operated geological storage reservoir is diminishingly small. For example, in an article published in Nature Communications in 2018, Alcade et al concluded that there was 50% probability that more than 98% of CO_2 injected would remain trapped after 10,000 years for a well-regulated CCS industry. Alcade also considered an unrealistic scenario where regulation was inadequate and injection was conducted in a region with a high risk of leakage and improperly closed abandoned wells. Even under these worst-case conditions, Alcade concluded that more than 78% of the CO_2 injected would remain trapped in the subsurface over 10,000 years. To date, approximately 260Mt of anthropogenic carbon dioxide has been safely and permanently stored in geological formations.



Source: Global CCS Institute

Figure 2: Estimated CO_2 Geological storage capacity – billions of tonnes.

1.4.2 CCS in Industry

CCS is essential to achieve deep emission reductions in industry which produces about 8 billion tonnes of direct CO2 emissions annually. If indirect emissions are considered, then industry accounts for almost 40% of global anthropogenic CO2 emissions.

Approximately 1.9 billion tonnes of annual CO2 emissions from industry are process emissions where carbon dioxide is produced as a bi-product of chemical reactions inherent to the production process. These emissions cannot be avoided by changing the energy source. The only feasible option for their mitigation in many cases is to remove the CO2 after production using CCS. For example, 65% of emissions from the production of cement arise from the chemical reaction in which calcium carbonate (limestone) is converted to calcium oxide (lime). It is not possible to avoid the production of CO2 in cement production.

Other examples of industrial processes with significant CO2 emissions are natural gas processing, iron and steel production, ammonia/urea production, biofuel production, and various petrochemical processes that produce chemicals, plastics and fibers.

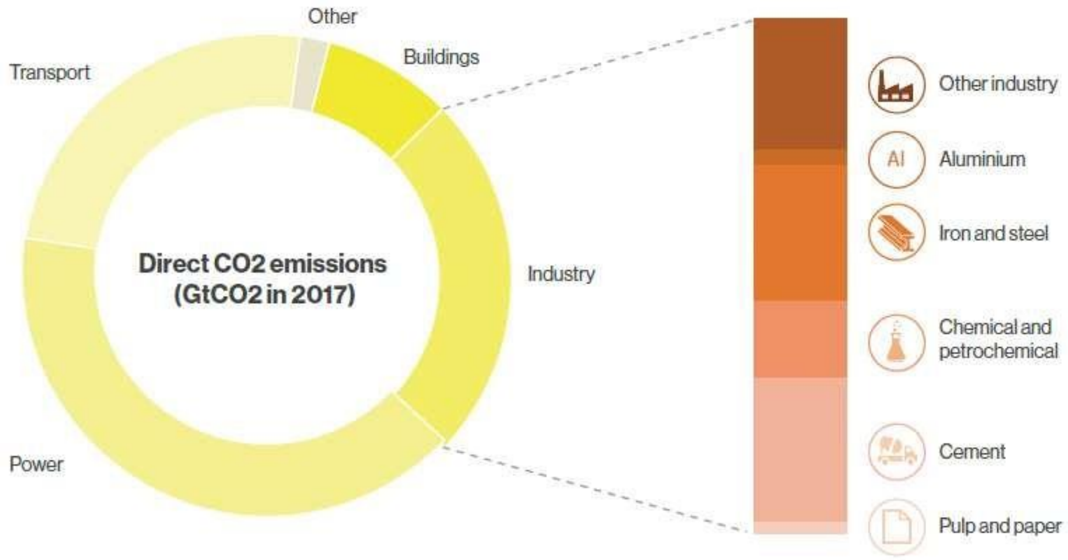


Figure 3: Global Direct CO2 Emissions by Sector

Demand for these industrial products will grow at least through the middle of this century driven by an additional 2 billion people to feed, clothe, house, transport and entertain. Demand growth will also be driven by growing affluence particularly in developing economies where hundreds of millions of people will be able to afford to purchase goods and services, requiring these inputs, for the first time.

Experience over the last decade is informative. Steel production capacity increased by 18% between 2010 and 2018.37 Clinker (for cement) production capacity increased by 19% between 2010 and 2019. In both cases, capacity additions were dominated by developing countries, particularly China and India.

1.5 CCS and Clean Hydrogen Production

Near-zero emissions hydrogen has the potential to make a significant contribution to emissions reduction in the power generation, transportation, and industrial sectors. Hydrogen can be burned in turbines or used in fuel cells to generate electricity, can be used in fuel cells to power electric vehicles, as a source of domestic and industrial heat, and as a feedstock for industrial processes. The virtue of hydrogen is that it produces zero carbon emissions at the point of use.

In 2018, around 70Mt per annum of pure hydrogen was used, almost entirely for refining (38Mt) and the production of ammonia (31Mt). Less than 0.01Mt of pure hydrogen was used in fuel cell electric vehicles. In addition to pure hydrogen, an additional 48Mt of hydrogen mixed with other gases (mostly carbon monoxide in the form of syngas) was used for industrial heat (26Mt), methanol production (12Mt), and Direct Reduction Iron production (4Mt). Currently, 98 per cent of global hydrogen production is from unabated fossil fuels, around three quarters from reforming of natural gas and the rest from gasification of coal. The remaining 2% of hydrogen is produced using electrolysis.40 Current hydrogen production is emissions intense, emitting around 830Mtpa.

For hydrogen to make a meaningful contribution to global greenhouse gas emission reductions, very large quantities of hydrogen will need to be produced to displace a significant proportion of current unabated fossil fuel use. Annual demand for hydrogen could grow to 530Mt by 2050, reducing annual CO2 emissions by up to 6 billion tonnes.42 However that abatement benefit requires that hydrogen is produced using near zero emission processes such as electrolysis powered by nuclear or renewable electricity or from gas, coal or biomass with CCS. Currently, less than 0.7% of hydrogen production is from renewable energy (via electrolysis) and fossil fuel plants equipped with CCS.

The ability to rapidly scale up clean hydrogen production is a critical success factor. In this respect, scaling up production of clean hydrogen from fossil fuels with CCS is relatively simple. Coal, methane and pore space for CO2 storage are plentiful and the technology is proven at large scale. Hydrogen has been produced through gas reforming or coal gasification with CCS for decades. For example, the Great Plains Syn-fuel Plant in North Dakota, US, commenced operation in the year 2000 and produces approximately 1,300 tonnes of hydrogen (in the form of hydrogen rich syngas) per day, from brown coal. In comparison, the largest operating renewable powered electrolyser in Fukushima Japan can produce around 2.4 tonnes of hydrogen per day. There are five low-carbon hydrogen production facilities with CCS operating and one under construction, with a total annual production capacity of 1.5 million tonnes of hydrogen.

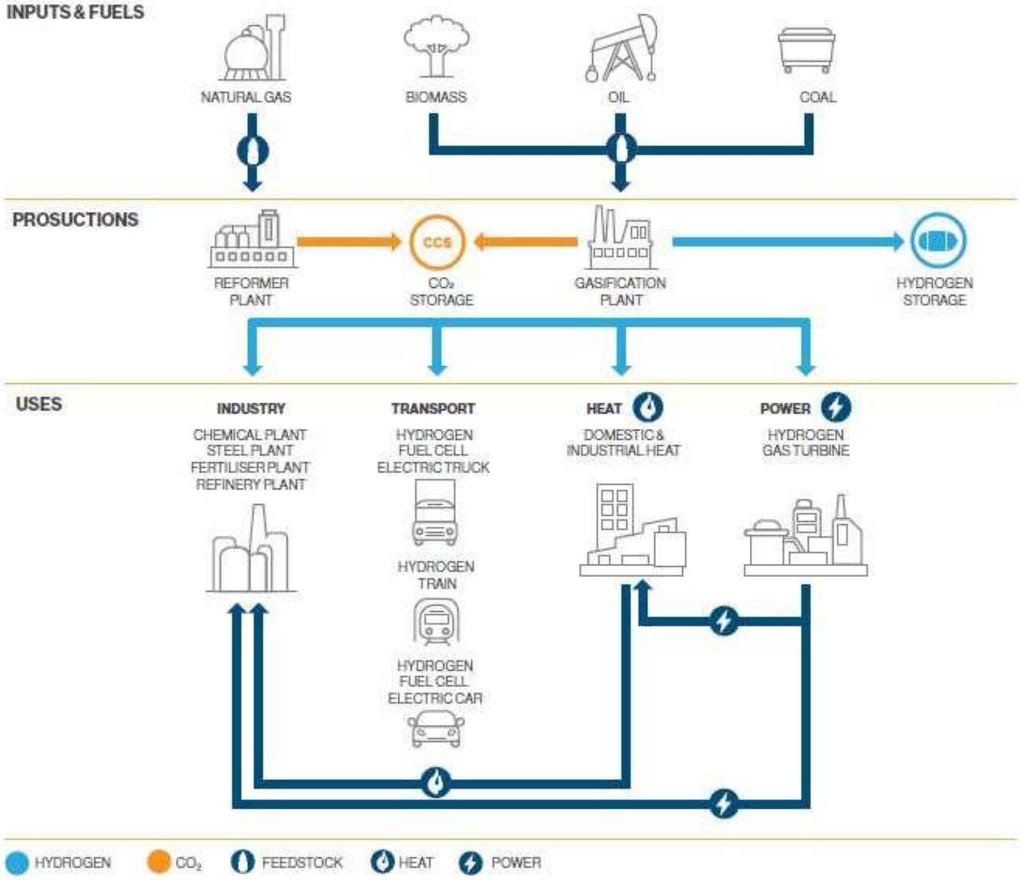


Figure 4:. Hydrogen in the low emissions economy.

Table 1: Hydrogen production facilities with CCS

Facility	H_2 Production Capacity	H_2 Production Process	Operational Commencement
Enid Fertiliser	200 tonnes per day of H_2 in syngas	Methane reformation	1982
Great Plains Synfuel	1,300 tonnes per day of H_2 in syngas	Coal gasification	2000
Air Products	500 tonnes H_2 per day	Methane reformation	2013
Coffeyville	200 tonnes H_2 per day	Petroleum coke gasification	2013
Quest	900 tonnes H_2 per day	Methane reformation	2015
Alberta Carbon Trunk Line - Sturgeon	240 tonnes H_2 per day	Asphaltene residue gasification	2020
Alberta Carbon Trunk Line - Agrium	800 tonnes H_2 per day	Methane reformation	2020
Sinopec Qilu	100 tonnes H_2 per day (estimated)	Coal/Coke gasification	Expected 2021

There is a large range of costs of production of clean hydrogen for both fossil fuels/biomass with CCS and renewable powered electrolysis. Key determining factors of cost are the price of coal, gas or biomass and the quality of the CO2 storage resource for fossil/biomass hydrogen with CCS, and the quality of the renewable energy resource (which impacts electricity price & capacity factor of the elctrolysers) for renewable hydrogen. Overall, hydrogen produced from coal or gas with CCS is the lowest cost clean hydrogen today and is expected to remain so at least until 2030.

However there will be locations with oustanding renewable energy resources and where there is no opportunity for that renewable electricity to displace unabated fossil generation, where production of renewable hydrogen using electrolysis will be competitive. In these circumstances renewable hydrogen can make an important contribution and must be pursued. However, achieving meaningful scale in renewable hydrogen is challenged by the fundamental physics of this process. To illustrate, meeting potential future global clean hydrogen demand of 530 million tonnes per year using electrolysis would require more than 26,000 TWh47 of electricity, which is approximately equal to the total electricity generated by all sources combined in 2018.

1.6 BARRIERS

Carbon capture & sequestration technologies are commercially available and have been proven at large scale over the past five decades. Geological storage resources are more than sufficient to meet CO2 storage requirements under any scenario to achieve ambitious climate targets. In summary, there are no technological or resource barriers to broad scale deployment of CCS. Yet CCS is not being deployed at the rate necessary to stabilize the global climate. The same can be said of renewable energy, nuclear power, electric vehicles, and a myriad of other low emissions and energy efficiency technologies.

The reason that these essential technologies including CCS are not being deployed at the necessary rate is that the incentive for investment is insufficient to mobilize the requisite capital. There are several market failures across the CCS value chain that directly affect the business case for CCS, as summarized in Figure 25.

For a potential capture plant developer, the main impediment to investment is the lack of a sufficient value on emissions reductions. Without this, there is no incentive for a developer to incur the costs of constructing and operating the capture plant, even though it may be beneficial from a broader societal perspective in helping to meet climate targets cost effectively. In economic terms, CO2 emissions are an externality.

Whilst capture technologies are well developed and proven, their application in most industries has been very limited and investment to date, for the most part, has been by first movers. First movers incur additional costs through the application of conservative engineering to ensure the successful integration of the capture plant with the host plant. The developers of the Boundary Dam and Petra Nova CCS facilities have both stated that the capital cost of building their plant again could be reduced by at least 20% simply by applying what was learned the first time. In fact, an approximate 20% reduction in capital cost per unit CO2 capture capacity was observed between Boundary Dam in 2014 and Petra Nova in 2017.

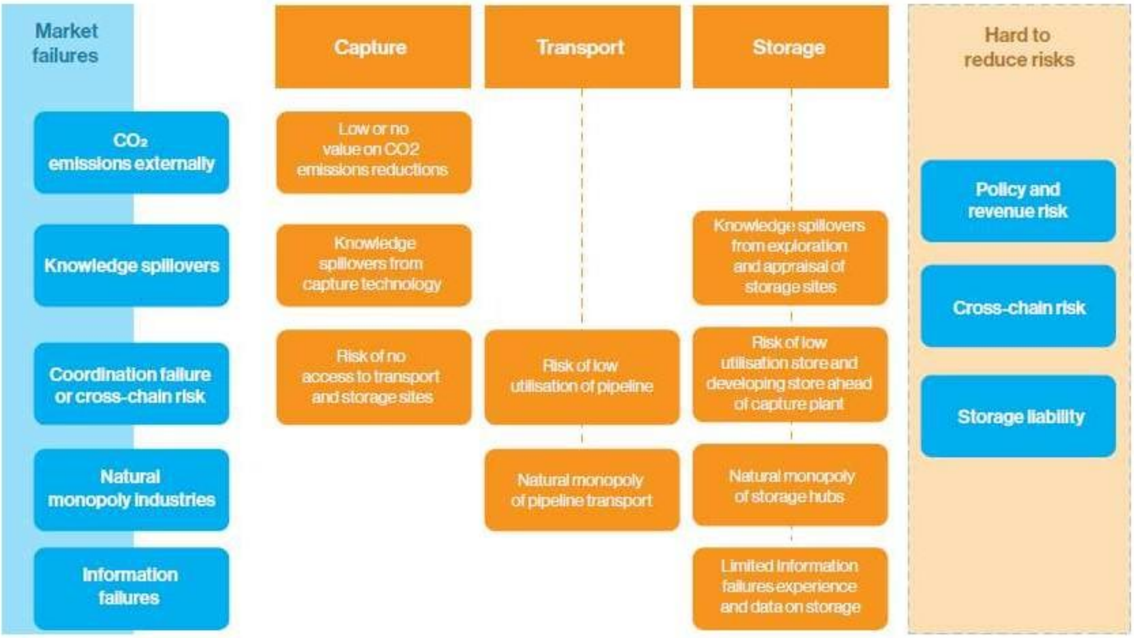


Figure 5: Market Failures across the CCS value chain

First movers are also the first to test business models and regulations, especially if the project is in a jurisdiction in which CCS has not previously been undertaken. This particularly applies to geological storage resource operators who must navigate geological storage regulations or find a way to manage access to pore space, compliance and liability risk if the regulation is absent or unclear. The second operator in a jurisdiction will have the benefit of precedent and a more informed and confident regulator not enjoyed by the first. Fast followers can take advantage of the learnings for which first movers have paid. These knowledge spillovers create an incentive to delay investment in CCS projects until there is greater experience on which to base business decisions.

The CCS value chain requires a broad range of skills and knowledge. Perhaps with the exception of natural gas separation, competencies required for the handling and transport of dense phase gases or the appraisal and operation of geological storage facilities are beyond the capture plant operator. Similarly, CO2 separation and capture is often well beyond the competence of the host plant operator. For example, a cement manufacturer has no expertise in CO2 capture, transport or geological storage. Thus in most circumstances, the most efficient value chain will involve multiple parties each specializing in one component of the value chain and the CCS project will require coordination of multiple investment decisions which all have long lead times. Once the CCS project is operating, the interdependency between value chain actors remains. The storage operator relies upon the capture operator to supply CO2 and vice versa. If any element of the chain fails, the whole chain fails. This creates cross-chain risk.

The transport and storage elements of a CCS value chain will in many if not most cases be natural monopolies which creates a risk of price gouging for the services they offer. In the absence of competitors, they are able to set their price at the highest level that their customers can bear, eroding the business case for investing in a capture project.

There are also information failures arising from the limited experience in developing and operating CCS value chains. One example relates to geological storage of CO2. Whilst geological storage of CO2 is well understood and has been proven through decades of experience and a massive body of scientific study, there is still only a very small pool of commercial operational data compared to other industries. This translates to an increased perception of risk amongst financiers and investors.

Capital intensive investments like CCS are exposed to many classes of risk. Most of these risks are best managed by the value chain actors. Project operators are best placed to manage operational and safety risks for example, as is the case across mature heavy industries. There are also ‘hard to manage’ risks that the private sector is unwilling or unable to take on. These risks are usually managed through government policy and regulation. For example, corporate law provides a general framework for undertaking business that significantly reduces the risk of undetected dishonest behavior by counterparties. For CCS, which is an immature industry, there are three specific hard to manage risks:

- Policy and revenue risk
- Cross chain risk
- CO2 storage liability risk

The policy and revenue risk arises because there is no natural market for the storage of CO2. Policy or regulation is required to correct the CO2 externality to support revenue generation (or the avoidance of costs) essential to the business case for investment. The cross-chain risk is linked to the immaturity of the CCS industry and the lack of confidence that exists in business models and between counterparties compared to mature industries. The CO2 storage liability risk is related to potential perpetual liability for regulatory enforcement action, exposure to future carbon pricing and civil claims for damages arising from leakage of CO2 from geological storage facilities. Whilst the probability of leakage from an appropriately selected and operated geological storage facility is diminishingly small, it is not zero. Taken together, these ‘hard to manage risks’ can be insurmountable barriers to investment. The difference in the cost of capital (debt and equity) between an investments that is perceived to have low risk versus an investment that is perceived to have high risk can be 10% or more. That risk premium can add several tens of millions of dollars to the annual cost of servicing debt for a CCS project, impairing the investability of the project.

Overall, the well-established and familiar business models, structures and practices that exist in mature industries and play a significant role in reducing perceived investment risk have generally not yet developed for CCS. In the large majority of cases, the market does not provide sufficient reward for CCS to achieve required rates of return on investment – and the required rate of return is usually elevated due to the perceived risk associated with the investment making financing difficult.

All things considered, it is clear that the primary barrier to the deployment of CCS at the rate and scale necessary to achieve climate targets is the difficulty in developing a project that delivers a sufficiently high risk-weighted return on investment to attract private industries.

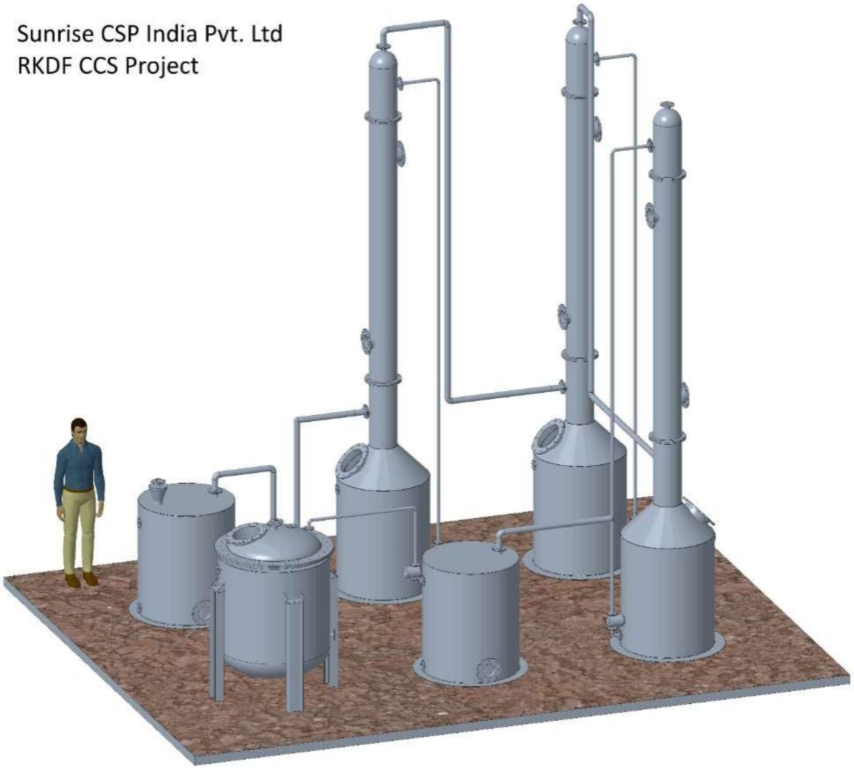


Figure 6: Depicts the setup for the CCS plant.

KNOW REQUIREMENT & FINDINGS

KNOW REQUIREMENT & FINDINGS FOR CCS

The project has various aspects of carbon capture and sequestration unit. The testing plant is designed to take pulverized coal in boiler for combustion. The project is again modified to seam coal based boiler of 5Kg/hr.

2.1 THE OBJECTIVES OF PROJECTS

- To provide a potential ground under the aegis of Ministry of Power for developing and demonstrating feasibility of future sustainable Clean Coal Power Plant equipped with Carbon Capture & Sequestration studies.
- Exploring options for reducing energy penalty through solar thermal & other options.
    1. Process optimization leading to improve design of MEA Solvent reactors, System optimization studies.
    2. Design & Engineering-Instrumentation
    3. Pilot study of CO2 sequestration to a simulated Coal seam in the used Coal Mines.
    4. Pilot Study of CO2 Sequestration to Algae Pond for production of Bio-Diesel.

2.2 CONSTRAINTS

- 10 meter piping is considered in the cost from the tapped-off point of chimney to the CCS pant. Steam pipeline considered is also 20 meters from Solar system to CCS system.

- The proposed pilot for Carbon Capture & Sequestration is indeed a Carbon Capture & Utilisation Plant (CCU) which is proposed to be built at selected TPS in the area of 15×25 meter shadow free area available during the whole day in the space available between free area available Fuel Oil-Steam corridors. The plant shall be in two tier formation in which MEA Tanks Gasifier. Water - gas-shift (WGS) reactor. Pumps and piping etc. Shell be installed in 2- tier structural frame work.

- The flue gas will be tapped-off the sampling port of 2 diameter @ 6 tons per day or 250 kg/hr. (i.e. CO2 @ 18% about 45kg per hour) running in a 8 hr. Shift and regeneration in 2 shift with solar steam having 8 hr. additional thermal storage capacity.

- Adjacent solar. Thermal Plant with thermal storage will be installed on ground in shade free area near the stack of the power plant.

- Cost of Thermal Plant with thermal storage will be installed on included in above and will be tendered separately.

2.3 Basic Calculation

2.3.1 SAMPLING PORT CALCULATION

CO_2 - 1 ton/hr flue gas

2 shift – 16 – 18 ton/hr

A proposed CCS plant of 30% capacity of 18 ton/hr= $18 \times 0.3 \;= 6\; ton/day$

Therefore flow rate = $\frac{6 \times 1000}{24}$ = 250 kg/hr

Percentage of CO_2 – 12% to 18%

12% is Pulverized Coal combustion flue gas

Table 2: The various gas release at combustion of fuels

Gasses	Pulv. coal combustion flue gas	Waste incineration flue gas	Coal gasification fuel gas	Coal-fired IGCC flue gas	Natural gas Groningen	Gas-fired CC flue gas
$O_2\% - V$	~ 6	7 – 14		~ 12		~ 14
$N_2\% - V$	~ 76	Balance	~ 4/ ~ 1	~ 66	~ 14	~ 76
$CO_2\% - V$	~ 11	6 – 12	~ 4/ ~ 13	~ 7	~ 1	~ 3
$H_2O\% - V$	~ 6	10 – 18	~ 4/ ~ 1	~ 14		~ 6
$CO\% - V$		0.001 – 0.06	~ 58/ ~ 40			
$H_2\% - V$			~ 30/ ~ 29			
$Ar\% - V$	~ 1	~ 1	~ 1	~ 1		~ 1
SO_2 ppmw		200 – 1500		10 – 200		
H_2S ppmw			1000 – 4000			
NO_x ppmw	500 – 800	200 – 500		10 – 100		10 - 300
NH_3 ppmw			300 – 800			
HCN ppmw			40 – 150			
HCl ppmw		400 – 3000	500 – 600			
HF ppmw		2 – 100	150 – 250			
Dioxine ppb	< < 1	1 – 10				
CH_4%-V					~ 81	
$C_nH_m\% — V$		< 0.002			~ 4	
Hg ppmw	0.1 – 1	0.1 – 1	0.01 – 0.1			
Cd ppmw	0.01 – 1	0.1 – 0.5	0.01 – 0.2			
Other heavy metal ppmw	0.5 – 2	1 – 5	~ 20			
Dust g/m^3	5 – 20	0.2 – 15	~ 17/ ~ 18	< < 0.02		

ABSORBED CO_2

% CO_2	12%	18%
Flow rate of absorbed CO_2/hr	$=250\times 0.12$ =30 kg/hr	$= 250\times 0.12$ =45 kg/hr

Sampling port dia. as per PO = 1 – 2 inch
Connected port using reducer is 1- inch

2.3.2 DESIGN OF SCRUBBER TOWER

Flow rate of flue gas = 250 kg/hr
Air flow rate through port-

$Q_a = 60\,\pi\upsilon\,(\frac{d}{2})^2$ (1inch= $0.0254m$)

$15 = 60\,\pi\upsilon\,(\frac{0.0254}{2})^2$

$\upsilon = 493.38$ m/s

Table 3: Amount of gasses and dust particles in per Shift.

Gasses	Percent	Calculation
$O_2\% - V$	~ 6	60 gm= (60/100)× 1000
$N_2\% - V$	~ 76	760
$CO_2\% - V$	~ 11	110
$H_2O\% - V$	~ 6	60
$CO\% - V$		
$H_2\% - V$		
$Ar\% - V$	~ 1	10
SO_2 ppmw		
H_2S ppmw		
NO_x ppmw	500 – 800	0.8 gm= $(\frac{0.8}{10000} \times \frac{1}{100}) \times 1000$
NH_3 ppmw		
HCN ppmw		
HCl ppmw		
HF ppmw		
Dioxine ppb	<< 1	$1 \times 10^6 gm = (\frac{0.8}{10000} \times \frac{1}{100}) \times 1000$
CH_4%-V		
$C_nH_m\% - V$		
Hg ppmw	0.1 – 1	0.001
Cd ppmw	0.01 – 1	0.001
Other heavy metal ppmw	0.5 – 2	0.002
Dust g/m^3	5 – 20	20 gm
		$\sum = 1020.804\ gms$

2.3.3 Estimation of Fly ash in Ash Collection Tank

1 kg = 1000gm

∑ = 1.020804

% of fly ash = $\frac{0.02}{1.020804}$

= 0.019592399

$= 0.02\ (Approx.)$

Per hr fly ash = 250×0.02

$= 5\ kg/hr$

CCS SYSTEM

CCS SYSTEM

3.1 DIFFERENT PART OF CCS PLANT (Refer Appendix A)

3.1.1 Scheffler Dish

3.1.1.1 About the Scheffler dish Technology

Scheffler dish is a small lateral section of a paraboloid, which concentrates sun's radiation over a fixed focus, with an automatic single axis tracking.

3.1.1.2 Underlying principle

Scheffler dish is made of number of flat shaped mirrors or reflective films which are mounted on a structural frame. The dish rotates about north-south axis parallel to earth's axis to track the sun's movement. The axis of rotation passes through the center of gravity of the reflector and that's how the reflector alwaysmaintainsitsgravitationalequilibrium.Theschefflerreflectoralsoperforms change in inclination angle while staying directed to sun, in order to obtain sharp focal point. Focus is fixed at distance of focal length of the paraboloid along the axis of the paraboloid. Receiver at a fixed location captures the concentrated heat and transfers it to water/thermic fluid to generate hot water/hot thermic fluid or high pressure steam.

3.1.1.3 *Key components of* Scheffler dish

Key components of Scheffler dish based system can be classified on the basis of their individual functions:

3.1.1.4 SCHEFFLER Reflector

1. Reflector dish
2. Receiver
3. Dish stand
4. Tracking System

3.1.1.5 BALANCE OF SYSTEM

- Piping and Insulation
- Instrumentation and Safety Mechanism
- Heat Storage System

3.1.1.6 Key design variants

Scheffler dish is currently available in two design variants, namely

1. 16 m^2 Scheffler Dish
2. 32 m^2 Scheffler Dish

Figure 7: Scheffler Dish at RKDF University

The important characteristics of these designs are as follows

Table 4: Scheffler Parameters

Parameter	16 m^2
Average Aperture Area	*11.65 m^2*
Shadow Free Area	*35 m^2*
Thermic medium	*Steam, hot water, thermic fluid*
Delivery capacity	*Up to 12 bar pressure, Up to 180^0C temperature*
Weight	*Minimum 400 Kg*

3.2 End-use application

Scheffler dish is used for the low-medium process heat applications. This dish can attain the temperature up to 150-200°C as per the specific requirements in industries, commercial & residential complexes, religious places, etc. A typical 16 m^2 Scheffler Dish has thermal capacity equivalent to 30,000 Kcal/ day to 35,000 Kcal/day depending on the manufacturing precision and DNI on a clear sunny day.

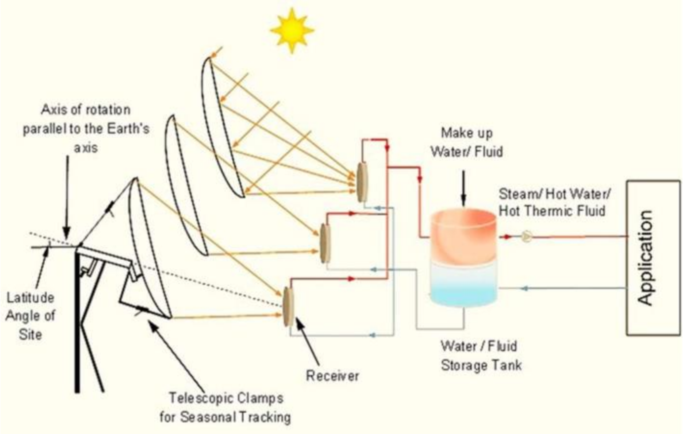


Figure 8: *Schematic diagram of CST based System with Scheffler Dishes*

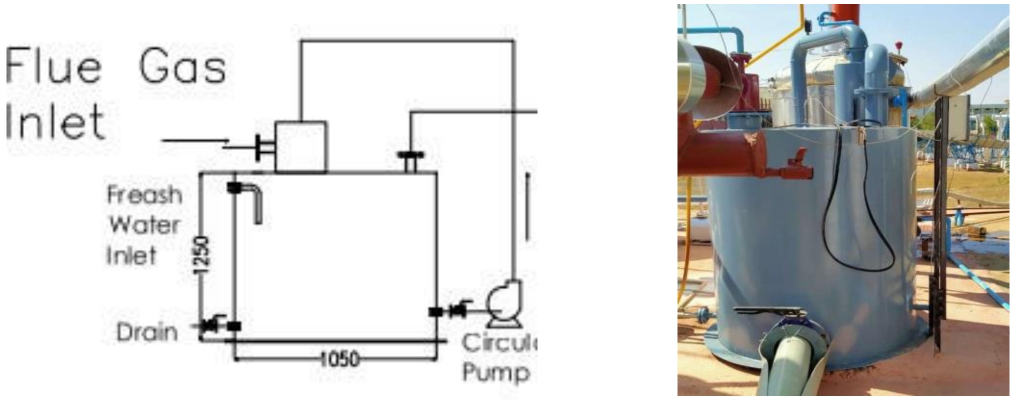
Some of the typical application areas of Scheffler dish are:

- Food processing
- Community cooking
- Solar-assisted comfort cooling
- Laundry
- Pharmaceutical
- Drying and dying
- CO2 Regeneration

The design configuration of an industrial process heat solar system depends on the specific application. It may consist of one or more number of Scheffler dishes in a system. Scheffler dishes have been installed in various thermal applications across the industries including laundry in hotels, cooking in religious and educational institutions, comfort cooling in offices, boiler feed water heating in chemical process industries amongst others.

3.3 Ash collection Tank

The ash collection tank consist of 890 liters of water tank and a pump connected in a loop. The Pump developed high pressure in venture. The venture create a vacuum at the suction end of the flue gas which increase the flow and increase the dissolve efficiency of heavy particle into water. Therefore on gasses passes through the system and moves towards the Cyclone separator.



a. Working of Ash Collection Tank
b. Ash collection Tank at RKDF

Figure 9: Ash Collection Tank

3.4 Cyclone Separator

The cyclone separator takes the gas and moisture coming out of ash collection tank and start rotating a high speed. Due to centrifugal forces the moisture and few heavy dust particle stick to the surface of cyclone and collected in the bottom of it. From the bottom the valve is open and it is drained out.

Figure 9: cyclone Separator

3.5 Blower

The flue gas coming from the cyclone separator goes through it which create a positive pressure in discharge direction and negative pressure in suction side.

The negative pressure is approximately -2.5 Kg/cm^2 to -3Kg/cm^2.

Figure 10: Blower

Table 5: Blower Specification

Specification	
HP	2
Pressure	400 MMWG
Type	Centrifugal Blower
RPM	2880
MFR	United Engineering CO.
CFM	280

3.6 Scrubber Tower

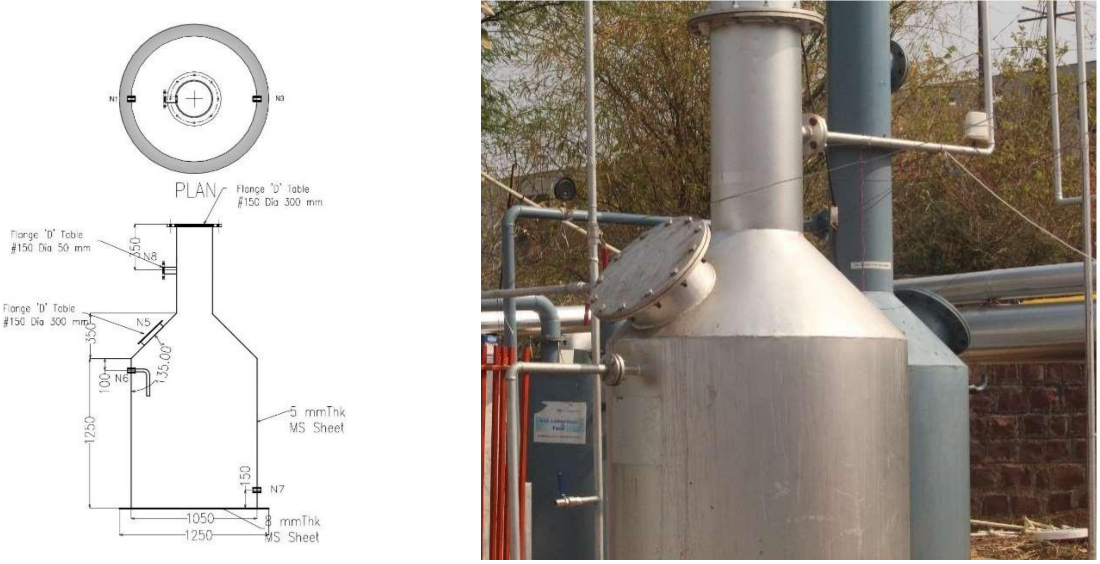
The scrubber tower is filled with "Paul Ring" of SS-304 and SS-316. In Scrubber Tower 1and 2 the SS-304 Paul ring is filled. In scrubber tower 3 the SS-316 in filled with the support of metal mesh plat. The Paul ring is filled to increase the surface area of fluid into tower to increase the efficiency of the scrubbing.

Scrubber Tower at RKDF Paul Ring Scrubber Tower

Figure 11: Scrubber Tower

3.7 Storage Tank

The storage tank 1 and Tank 2 consist of Na_2CO_3 of 900 liters. The Storage Tank 3 has 800 liters of MEA (MonoEthyleAmine). The storage tank is serve as a pool of chemical from where motor pump the chemical to scrubber tower and from scrubber it is again collected in storage tank due to gravity.



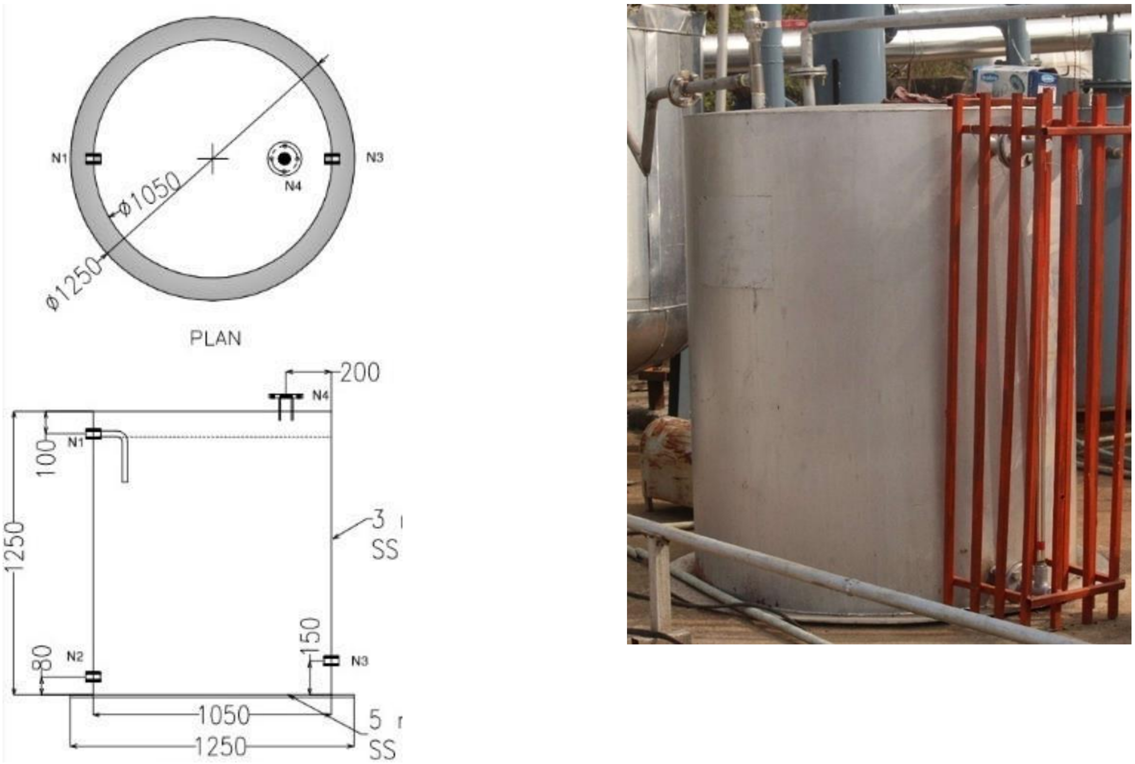
Storage Tank Diagram

Storage Tank

Figure 12: Storage Tank

3.8 Intermediate Tank

The intermediate tank serve as two purpose one is to hold the charged MEA till it is required for the next process and second is to recover the condensed MEA and moisture during the time of regeneration.



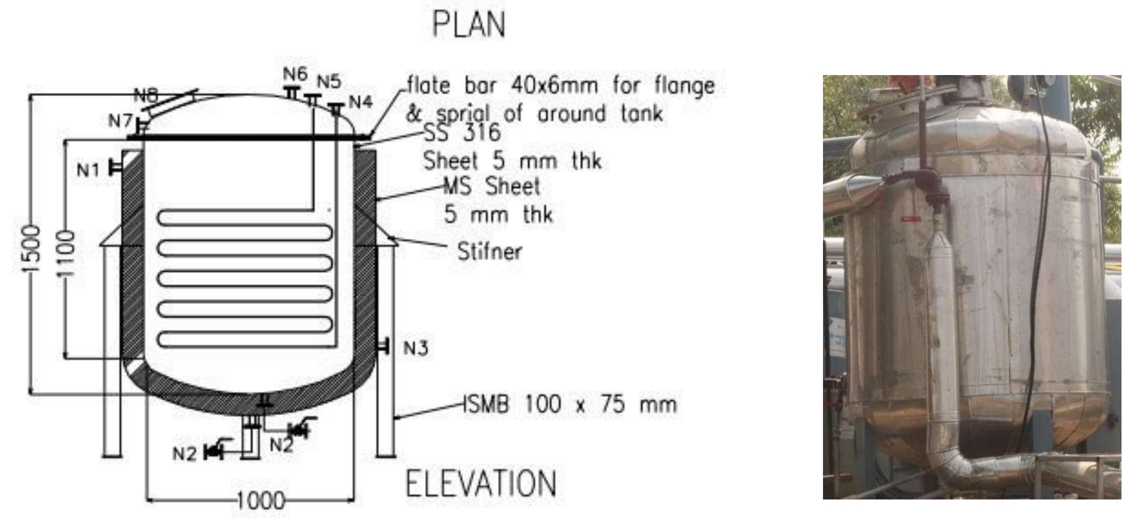
Intermediate Tank Diagram

Intermediate Tank at RKDF

Figure 13: Intermediate Tank

3.9 Reactor

The reactor is the heart of system. The regeneration of CO2 take place in it. The reactor has two stem inlet one is from the scheffler (10 Kg/hr) and another is from the boiler (5Kg/hr). The combine steam is used to heat the MEA from atmospheric condition to 155°C. The pressure of 7-8 Kg/cm2 is developed inside the vessel. The stirrer is also fitted into it for the uniform heating and cooling of the reactor to restrict from the thermal cracks or buckling failure. Thus it releases the CO2 molecules which is further used in byproduct process. The use of solar heat from solar thermal dish make it unique. The reactor is also equipped with the internal cooling system so that the chemical can be stored for longer duration without releasing CO2 in ambient Condition.



Reactor diagram Reactor

Figure 14: Reactor

3.10 Condenser and Chemical Recovery Unit

A 7 tons of condenser is used to recover the evaporated MEA solution. The coil runs the MEA+ CO2+ H2O and water cooled by the help of the pump. The MEA+H2O condensed bellow 100°C and get liquefied. The remaining CO2 is passed from the CCS unit to other process as per the byproducts.

The Chemical recovery Unit has a V bend to restrict the flow of CO2 in intermediate tank and only allows the MEA+H2O into the intermediate tank. This is achieved by varying the height of the liquid.

Figure 15:Condenser

3.11 Pumps

3.12 CRI Pumps

3.11.1.1 Overview of product

Self-priming and non-self-priming mono-block pumps volute chamber and impeller to deliver optimum hydraulic efficiency and suction. Mechanics IL carbon and ceramic is fitted over the shaft which is machined to close tolerance. These models are provided with built-in check valve on the suction side which requires no foot valve. Non self-priming mono-block pump require good quality foot valve with strainer pumps are powered with to Pol San motor enclosed construction with cooling fan and suitable for continuous working stator is made of silicon Steel lamination to ensure low watt loss dynamically balance rotor insurance vibration and noise free operation. Ending are of high grade enameled copper wire and are impregnated construction of motor frames and uses of quality materials result in high performance and low temperature rise thereby increasing the life cycle of the motor overload protector is incorporated in all single phase Motors.

3.11.1.2 Operating condition

The pump shall work continuously under the following conditions

- The pumps are suitable only to pump clean, cold, non-aggressive, non-explosive, water without abrasives, particles or fibers.
- Maximum ambient temperature degree Celsius
- Maximum water temperature 33 degree Celsius
- Maximum Suction lift up to 8 meters
- duty type S1 continuous
- direction of rotation clockwise from driving end
- Voltage and frequency in accordance with the nominal value indicated in the nameplate

3.11.1.3 Installation procedure

- Install the pump in horizontal position and near the force of water on a platform with proper Foundation bolts
- The location of the pump should be such that it is free from dust, fumes, moisture stall in ventilator area, protected against weather and it must be easily accessible for regular inspection
- Types with related supports to avoid transmitting stress to the pump body lead to premature failure of and other pump parts
- Tighten the pipes are Union couplings to the extent sufficient to ensure a tight sale and do not apply access a torque which may lead to damage on the pump

- The pipe diameter bend smaller than the pump connection number of bands and air tight joints total elected suction pipe length should not be more than 8 metres
- Self-priming regenerative pumps have an inbuilt check valve on the suction side and therefore no need to use footwall fit a strainer at the suction Pipe and to avoid the entry of foreign particles into the pump
- Maintain sufficient clearance of minimum 1 feet in between the suction pipe bottom and water tank bottom and both side each time the pump must be switched off water level goes below the suction pipe

3.11.1.4 Electrical connection

- Electrical connection should be carried out by technically qualified personal complying with local rules and regulations and follow safety 4 doubts
- Pump should be connected to a single phase heart AC supply with the voltage ranging between 220 to 240 volts
- Connecting war toys should be of appropriate size and quality of copper cable wire should be as per the standard if the voltage variation is more than Plus do not operate the pump
- Switch on the supply and check for the direction of rotation of the motor and it should be in the direction specified by an arrow on the cooling fan cover
- Before starting the form it is necessary to fill water in to the pump casing once during the installation and when the priming screw are priming plug tightly

3.11.1.5 Maintenance

- Disconnect electrical power before carrying out any maintenance work
- The pump idle for longer periods shaft in order to ensure the free NEF if this does not solve the problem remove the pump casing by unscrewing the Bolt and clean the pump trolley until the pump shaft rotates freely by hand
- Ensure that the pump casing is filled adequately with water before starting if the pump is ideal for a long duration
- Ensure that the clogging does not take place in a strainer clean the strainer regularly.
- CRI Pumps do not required day-to-day maintenance under normal operating condition however it is mandatory to check the pumping system at regular intervals with regard to current drawn in each lead what is water discharge and drawdown water level starter panel wiring earthing and electrical connections.

3.13 CHL (SS-316)

3.11.2.1 Applications and conditions

CHL /CHL-f /CHL-ft or non-self-priming light horizontal centrifugal pump pump in the following they are official low noise little tolerance compact structure good looking small volume lightweight etc

3.11.2.2 Operation conditions

- liquid temperature normal temperature type 15 degree Celsius third degree Celsius hot water type 15 degree Celsius 110 degree Celsius
- Slow range 0.5 28 meter cube per hour
- Max pressure 10 bar
- Liquid pH range 8529
- Max ambient temperature + 40 degree Celsius
- The max suction pressure is limited by Max operating pressure
- Minimum inlet pressure referred to npsh curve

Caution: when pumping liquids with the density and for viscosity higher than that of Water used motor with corresponding Li higher output if required

3.11.2.3 Installation and connection

3.11.2.3.1 Installation

- Pump should be seated in a well-ventilated but for first free prediction in pump with motor and other objects should be at least 150 mm in order to call the motor by fan with an affair
- To reduce the inlet pressure of inlet as list as possible the inlet pipe shall be as short as possible
- Ensure the check valve is installed in pipeline system before the pump installation to prevent liquid from returning
- Pump should be fixed in ground or fixed on the brackets on wall from should be safely fixed and stable pay attention not to let the weight of pipe system on pump to prevent pump from damage
- Before pump installation the inlet pipe line shall be cleaned if there is impurities in the pipe it is necessary to install a strainer at 0.52 1 mm in front of the pump inlet
- The air pockets shall be provided when installing the inlet pipe Line 3 Figure 2
- It is necessary to fit a pressure meter to observe and control operation of pump
- when the height of composition is higher than liquid level in the suction range of pump of foot valve should be installed in the inlet Pipe and feet of water pouring screw hole in the drainage pipe it is used for pouring water in before starting pump

3.11.2.3.2 Electrical connection

- The electrical connection should be carried out by qualified electrician.
- To make sure the motor is suitable for the power supply cables of the motor must be connected to power supply according to the figure on the term Terminal box and the motor nameplate
- Motorcycle with connected beta fast and effective motor starter to ensure that the motor will not be changed by lack of phase unstable voltage or overload the motor Shelby birthday reliably

Caution: before taking apart The Terminal box cover or dismantle pump makes sure that the power supply is switched off.

3.11.2.4 Startup operation and maintenance

Caution: it is prohibited to run without liquid which will damage and sliding bearing

Do not start the pump until it has been filled with water or liquid fully.

- Fill water in sump in inverse pouring system: Close the pump outlet Wall release air vent screw on the pump head and open the inlet valve slowly until stable water from the air vent screw The Fast and the screw.
- Fill water in pump when liquid level is lower than pump: Before installing pump and pipes must be filled with liquid fully and air vented.

3.11.2.4 .1 Check the Rotary direction

Switch on the power supply and will the Rotary direction by weaving the motor fan from the motor and pump shall run counterclockwise.

3.11.2.4 .2 Check before pump start up

- Check whether the pump is fixed security
- Whether pump is filled with water fully and check whether liquid can flow freely
- whether the voltage of power supply is stable
- check whether it turns correctly
- to make sure all pipe lines are connected tightly and can supply water normally
- the wall in the inlet pipe line are completely opened
- The outlet valve shall be opened slowly after the pump is started up

- Check the operation pressure if pressure meter is installed
- All the controls for normal operation if the pump is controlled by pressure switch check and adjust the starting pressure and stopping pressure the full load current to make sure it will not exceed the max allowed current.

3.11.2.4 .3 Frequency off pump starts

- Pump should not be started to frequently it is suggested pump shall not be started more than hundred times per hour.
- The application of pump should according to the range of performance curve to avoid motor overload.
- There should be no noise when pump running if there is something wrong stop pump and check it and repair.

3.11.2.4 .4 Trust protecting

Pump can be used in the system with anti-frogen major if the pump is installed in a project environment suitable antifreeze cell be added to the transferring liquid to prevent pump from being damaged is not used pump shall not be used during periods of first pump should be drained when stop using.

3.11.2.4 .5 The following should be checked regularly for pump

- Pump working and operating pressure.
- Possible leakage
- Possible motor overheat
- Placement of all strainer set
- The switch off time of motor overload
- Frequency of starts and stops
- All control operation

Note:-If find fault check system according to fault finding and solution chart

- Pump shall be cleaned and kept approximately when it is not used for a long time
- Pump shall be prevented from being corrupted and damaged in storage

Table 6: Pump, Blower and Stirrer Specification and Mounting

CRI	Power:0.5HP RPM: 1400 rpm Operating voltage:230V Efficiency:85.10 Pumping Head:8m Discharge:1 m3/hr Type: 2-Phase induction motor	In Condenser line
CHL	Power:1HP RPM: 2830rpm Operating voltage:415V Efficiency:81.30 Pumping Head:31m Discharge:4 m3/hr Pressure: 10 bar Type: 3-Phase induction motor	1. Ash collection tank 2. Scrubber-1/2/3 3. Intermediate Tank 4. Reactor
Blower	Power:2HP RPM: 2830rpm Operating voltage:415V Efficiency:81.30 Type: 3-Phase induction motor	In between cyclone separator and scrubber tower-1
Stirrer	Power:2HP RPM: 1400rpm Operating voltage:415V Efficiency:81.30 Type: 3-Phase induction motor	At top of reactor

Measurement Devices

Measurement Devices

4.1 CO2 Analyzer (FM 2000 FLUE ANALYSER)

EFM 2000 FLUE ANALYSER

Figure 16: CO2 Analyzer

4.1.1 SPECIAL FEATURES:

- Portable, compact & rugged state of art design
- Complete automatic operation.
- Automatic calibration possible on atmospheric air; also manual calibration with spangas.
- 16 character, 2line alphanumeric LCD display.
- Standard 20 fuels with their parameters preprogrammed.
- Eight keys to operate the complete instrument.
- Calculates CO_2, excess air, combustion efficiency.
- Displays two parameters at a time.
- Reading can be stored and replayed later.
- Battery status is indicated during every sampling or LOBAT is indicated
- Built-in NiCad battery can be fully recharged in 15hours.
- Can be built to include up to six gas channels like CO, SO_2,NO,HC, NO_2.
- Long life maintenance free electrochemical sensor.
- RS-232forcomputerorprinterinterfaceisoptional.

- SS Sampling probe standard 1 ft.; for high temperature sampling use 1 m (OPTIONAL) within built K-typet/cto measure temperature of flue gas along with filter mechanism to remove particulates, moisture.
- Built-inpumptodrawsampletoactagainstnegativepressureupto-200mmHg. Higher suction pump for large negative pressure (OPTIONAL).

4.1.2 APPLICATION:

- Fuel efficiency of Internal combustion Engines.
- Energy audits and Environmental Monitoring.
- Stack and exhaust Gas Analysis in Boilers.
- Ambient and Emission Monitoring.
- Heat treatment and annealing.
- Power and Industrial Plants.
- Quality control Labs.
- Process Analysis.
- Metal processing.
- Furnaces.

4.1.3 DESCRIPTION:

The EFM2000 offers convenient portability while providing complete combustion efficiency and pollution emission capabilities. All boiler and furnace users can significantly reduce total fuel bills merely by ensuring that their burner is using the fuel efficiently. The EFM2000 gives the operator a continuous feedback to adjust the burner controls to achieve the right fuel / air ratio with combustion optimization you win both ways, you get the maximum energy for your money and have the bonus of a cleaner and pollution free environment through reduced carbon monoxide and emission Combustion efficiency is determined by the oxygen content and temperature of flue gas. An excess air condition reduces the efficiency as it carries the heat while efficient air produces an in complete combustion with consequent higher costs and increased pollution emissions.

4.1.4 Technical Specification:

Table 7: Basic instruments measures and calculates the following

PARAMETER	***SENSOR***	***RANGE***	***RESOLUTION***	***ACCURACY***
O_2	Electrochemical	0-25%	0.1%	± 0.5%
CO	Electrochemical	0-5000ppm	1ppm 10ppm	±5%±1ppm
CO	Electrochemical	0-5%	0.1%	+5%±10ppm
CO_2	Calculated	0-MaxCO_2	1^0C	± 0.5%
Ambient temp	Semiconductor K-	0-99^0C	1^0C	±0.5%
Stack temp	type T/C	0-1200^0C	1%	±1%
Excess Air	Calculated	0-250%	0.1%	
Efficiency	Calculated	0-100%	sic	
Optional gas c	Channel that can be	added to above ba	instruments	
SO_2	Electrochemical	0-2000ppm	1ppm	±5%+1ppm
NO	Electrochemical	0-1000ppm	1ppm1ppm	±5%+1ppm
NO_2	Electrochemical	0-100ppm	0.001%	±5%+1ppm
HC (CH_4)	NDIR	0-5%		±2%

Power supply : Internal Ni-Cd battery pack. Fuse :1A(20mm) fast acting fuse.

Charge time : 15 hours with instrument switched off. Ambient temp : 0-50^0C.

Dimension : (220\92\230) mm. Weight : @1.5Kg.

Standard probe : 300mm rigid SS316 with taper plug & 2.5 m flexible hose (0-600^0C)

Optional probe : 1000mm rigid Inconel alloy. (0-1150^0C)

Optional leaf : To measure surface temperature for radiation loss probe(0-200^0C)

calculation 300mm rigid and 1m cable

4.2 Temperature Sensor

Table 8: Thermocouple Devices

Thermocouple	Qty	Description	Image
K-Type Simplex	3	Temperature measuring point: Pick shell / insulation / dew point. Thread: 1/4, 5/16, M8, M6, M12. Temperature range: -50°C~950°C.	
J-Type	1	• Size: Can be customized. Temperature measurement • point: Pick shell, insulation, dew • Point. Thread: 1/4, 5/16, M8, M16, M12. • Pipe diameter: 1.0-Φ8.0 • Pipe: 316L/34 etc. • Lead: String, Glass fiber, PVC, Teflon, Silica gel. • Temperature range: -50°C~950°C.	
LM35	4	• Minimum and Maximum Input Voltage is 35V and -2V respectively. • Typically 5V. Can measure temperature ranging from -55°C to 150°C Output voltage is directly proportional (Linear) to temperature (i.e.) there will be a rise of 10mV (0.01V) for every 1°C rise in temperature. • ±0.5°C Accuracy • Drain current is less than 60uA • Low cost temperature sensor • Small and hence suitable for remote applications • Available in TO-92, TO-220, TO-CAN and SOIC package	

4.3 Pressure Sensor

Pressure gauges and switches are among the most often used instruments in a plant. But because of their great numbers, attention to maintenance--and reliability--can be compromised. As a consequence, it is not uncommon in older plants to see many gauges and switches out of service. This is unfortunate because, if a plant is operated with a failed pressure switch, the safety of the plant may be compromised. Conversely, if a plant can operate safely while a gauge is defective, it shows that the gauge was not needed in the first place. Therefore, one goal of good process instrumentation design is to install fewer but more useful and more reliable pressure gauges and switches.

Figure 17: Pressure Gauges

One way to reduce the number of gauges in a plant is to stop installing them on the basis of habit (such as placing a pressure gauge on the discharge of every pump). Instead, review the need for each device individually. During the review one should ask: "What will I do with the reading of this gauge?" and install one only if there is a logical answer to the question. If a gauge only indicates that a pump is running, it is not needed, since one can hear and see that. If the gauge indicates the pressure (or pressure drop) in the process, that information is valuable only if one can do something about it (like cleaning a filter); otherwise it is useless. If one approaches the specification of pressure gauges with this mentality, the number of gauges used will be reduced. If a plant uses fewer, better gauges, reliability will increase.

4.3.1 Pressure Gauge Designs

Two common reasons for gauge (and switch) failure are pipe vibration and water condensation, which in colder climates can freeze and damage the gauge housing. Figure 1 illustrates the design of both a traditional and a more reliable, "filled" pressure gauge. The delicate links, pivots, and pinions of a traditional gauge are sensitive to both condensation and vibration. The life of the filled gauge is longer, not only because it has fewer moving parts, but because its housing is filled with a viscous oil. This oil filling is beneficial not only because it dampens pointer vibration, but also because it leaves no room for humid ambient air to enter. As a result, water cannot condense and accumulate. Available gauge features include illuminated dials and digital readouts for better visibility, temperature compensation to correct for ambient temperature variation, differential gauges for differential pressures, and duplex gauges for dual pressure indication on the same dial. Pressure gauges are classified according to their precision, from grade 4A (permissible error of 0.1% of span) to grade D (5% error).

4.3.2 Protective Accessories

The most obvious gauge accessory is a shutoff valve between it and the process, which allows blocking while removing or performing maintenance. A second valve is often added for one of two reasons: draining of condensate in vapor service (such as steam), or, for higher accuracy applications, to allow calibration against an external pressure source.

Other accessories include pipe coils or siphons (Figure 5-2A), which in steam service protect the gauge from temperature damage, and snubbers or pulsation dampeners (Figure 5-2B), which can both absorb pressure shocks and average out pressure fluctuations. If freeze protection is needed, the gauge should be heated by steam or electric tracing. Chemical seals protect the gauge from plugging up in viscous or slurry service, and prevent corrosive, noxious or poisonous process materials from reaching the sensor. They also keep the process fluid from freezing or gelling in a dead-ended sensor cavity. The seal protects the gauge by placing a diaphragm between the process and the gauge. The cavity between the gauge and the diaphragm is filled with a stable, low thermal expansion, low viscosity and non-corrosive fluid. For high temperature applications, a sodium-potassium eutectic often is used; at ambient temperatures, a mixture of glycerine and water; and at low temperatures, ethyl alcohol, toluene, or silicon oil.

The pressure gauge can be located for better operator visibility if the chemical seal is connected to the gauge by a capillary tube. To maintain accuracy, capillary tubes should not be exposed to excessive temperatures and should not exceed 25 feet (7.5 m) in length. The chemical seal itself can be of four designs: off line, "flow-through" type self-cleaning, extended seal elements, or wafer elements that fit between flanges.

The spring rate of the diaphragm in the chemical seal can cause measurement errors when detecting low pressures (under 50 psig, 350 kPa) and in vacuum service (because gas bubbles dissolved in the filling fluid might come out of solution). For these reasons, pressure repeaters often are preferred to seals in such service. Pressure repeaters are available with 0.1% to 1% of span accuracy and with absolute pressure ranges from 0-5 mm Hg to 0-50 psia (0-0.7 to 0-350 kPa).

4.4 Vacuum Gauge

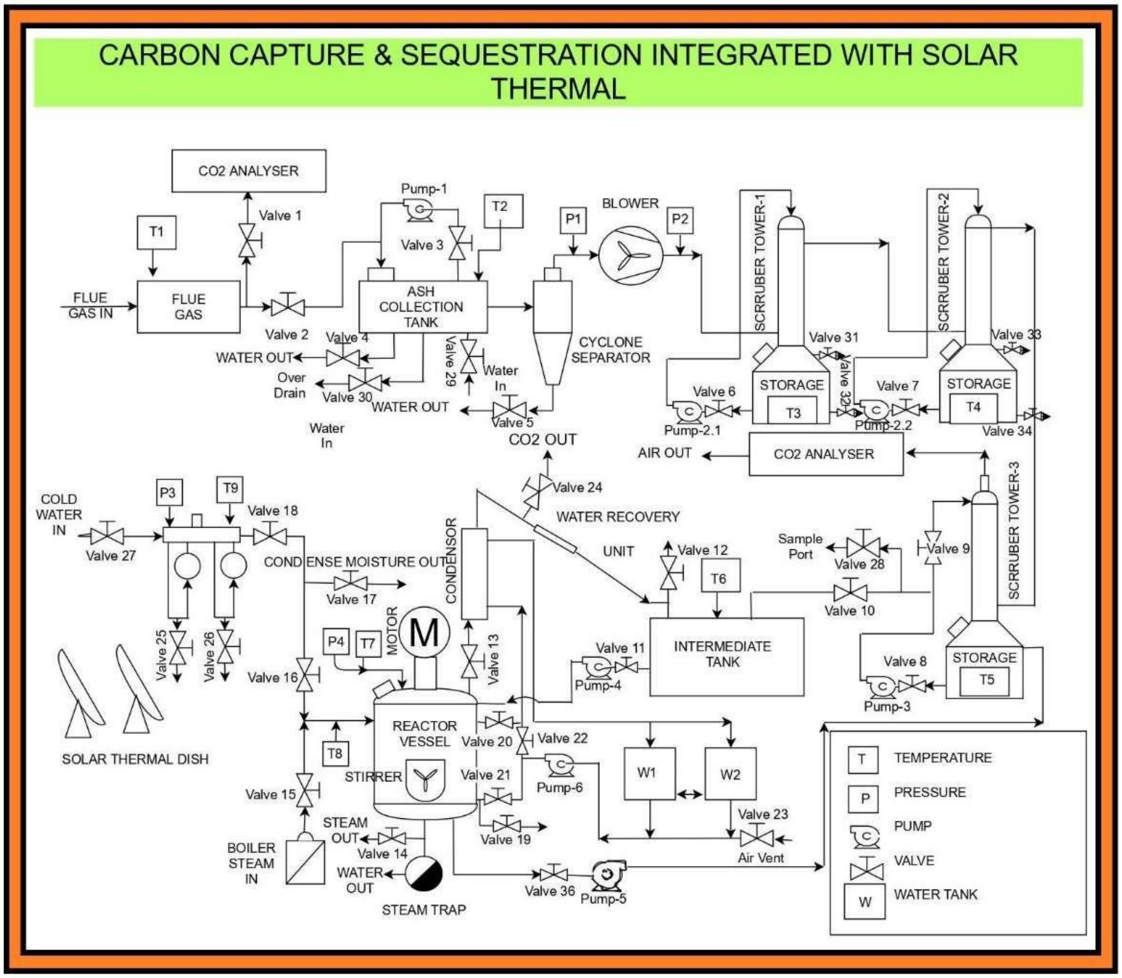
Measures vacuum (below atmospheric pressure). Enter the range from lowest vacuum to highest vacuum (e.g., from 0 to 30 inches of Hg VAC).

Figure 18: Vacuum Gauge

WORKING & OPERATION PROCEDURE

WORKING & OPERATION PROCEDURE

5.1 PLANT LAYOUT



5.2 CARBON CAPTURE & SEQUESTRATION- SETUP & PROCEDURE

Flue gas generally contains 14% CO_2. It contains SO_K, NO_K gases as well as some Ammonia gases and some dust particles such as Ash and Carbon particles.

The process is as follows,

1. Flue gas is subjected to water flow which will trap all particulates with water and it will also cool down the temperature of flue gas.
2. Then the gas will be sent to Tower A, shown in the fig.2. Flue gas will enter scrubber from bottom.
3. Soda solution (Sodium Carbonate solution of 10% will be sprinkled from top of the packing and because of packing, contact area will increase, so Ammonia, SO_K gas and NO_K gases will come in to contact with soda solution and will be converted to their respective salts like Sodium Sulphate, Ammonium Sulphate and Sodium Nitrate.
4. After this the gases are subjected to Tower-B (identical to Tower A) so that any traces of these impurities get observed and does not come in to contact with MEA solution, as reaction with MEA solution can result in formation of complex salts.
5. Flue gases from scrubber of Tower B are free from impurity of Ammonia, SO_K andNO_K.The gases are now subject with counter current of MEA solution of 30%. Here it forms bond with CO_2 gas to form mixture of MEA - CO_2 mixture solution. MEA solution of 30% can combine with 1 kg of CO_2.
6. MEA - CO_2 solution is sent to Tower C which is a 1000Ltr SS316 reactor with wall thickness of 8 mm thickness and bottom of 8mm thickness jacketed with MS jacket and have steam jacket SS316 coil. All contact parts with MEA solution are of SS316, as MEA is very corrosive with MS.
7. SS Reactor also has vertical condenser which will act as a reflux and will stop losses of MEA and water vapour and will allow only pure CO_2 to go out so there will not be any impurity of MEA in CO_2 gas.’\
8. This is not a chemical reaction but it is a physical property of MEA which has tendency to absorb CO_2 gas and CO_2 gas gets released when heated above 130° . As boiling point of MEA is 170°C, to prevent losses of MEA max temp of MEA - CO_2 mixture is to be restricted to stay below 155°C.

The system will have an input of 250 kg/ hr of flue gasses and will be able to extract 45 kg/hr (18%) of carbon dioxide. Thermal energy is required to heat the MEA - CO_2 solution in Tower C to extract out the carbon dioxide. To provide this heat, the plant will rely on Solar Thermal technology provided by Sunrise CSP India Pvt. Ltd. The company has a 520m^2 solar concentrator as its main IP, but for the CCS plant, the company will provide 8 scheffler dishes of 16 m^2 each. The solar system will provide 50 kg/hr of steam during sunshine for re-generation of MEA solvent.

5.3 OPERATING PROCEDURE

Table 9: Operating Steps to Start the CCS Plant

VALVE NO.	STEP NO.	START		REMARKS
		CCS Absorption Unit	CCS Regeneration Unit	
1	3	ON	-	
2	11	ON	-	After Co2 Analysis, BLOWER IS ON
3	4	ON	-	Pump 1 is ON
4		OFF	-	EMPTY AFTER EVERY 2SHIFT
5	5	OFF	-	OPEN TO DRAIN THE IMPURTIES AND THEN CLOSED
6	6	ON	-	On 30mins before start of the plant: PUMP 2-ON
7	7	ON	-	On 30mins before start of the plant: PUMP 2-ON
8	8	ON	-	
9	9	ON	-	Pump 3-ON
10	12	OFF	-	CLOSE VALVE 9 AND SHUT DOWN THE PLANT FOR 15 MIN, START PUMP 3 ONLY.
11	13	OFF	ON	
12	14	OFF	ON	TO RELEASE THE AIR FROM THE INTERMEDIATE TANK, TO PUT BACK THE MEA SAMPLE
13	15	ON	OFF	IT MUST BE OPEN AFTER TEMPERATURE REACHES TO 135C
14	16	OFF	ON	PARTIALLY OPEN
15	17	OFF	ON	IN WINTER THE SCHEFFLER PRODUCE STEAM AT 12pm
16	18	OFF	ON	EITHER 15 OR 16 SHOULD BE OPENED IF STEAM ATTAINS THE TEMPERATURE ABOVE 140C
17	19	OFF	OFF	IT MUST BE ON TILL CONDENSED WATER IS REMOVED FROM THE CHARGED PIPE
18	20	OFF	ON	WHEN REQUIRED FROM THE SCHEFFLER
19	22	OFF	ON	TO DRAIN ALL WATER FROM COIL
20	23	OFF	OFF	
21	24	OFF	ON	
22	25	OFF	ON	
23	21	OFF	OFF	
24	26	OFF	ON	
25		OFF	OFF	ONLY OPEN AT TIME OF CLEANING
26		OFF	OFF	ONLY OPEN AT TIME OF CLEANING
27		OFF	-	Only ON at time of feeding cold water.
28	10	OFF	-	Sample is collected before Pump Start
29		OFF	-	
30	12	OFF	-	Drain valve used at time of filling to stop water entering into cyclone separator.
31	27	OFF	-	TO TAKE SAMPLE
32	28	OFF	-	TO PUT BACK THE SAMPLE
33	29	OFF	-	TO TAKE SAMPLE
34	30	OFF	-	TO PUT BACK THE SAMPLE
35	2	OFF	-	For removing Excess Steam or for Safety of Boiler
36	1	ON	-	
37	31	-	ON	AT TIME OF TRANSFER FROM REACTOR TO STORAGE TANK 3

***Please flow the order provided in the list for the smooth operation of the plant.**

5.4 Time of Shut Down

PART-A

1. OFF- the Blower
2. ON- Valve 30
3. OFF-VALVE-2
4. OFF- VALVE 35
5. SWITCH OFF PUMP-1, PUMP-2,PUMP-3
6. THEN CLOSE ALL VALVE
7. ON VALVE-4
8. ON VALVE-29 (AFTER VALVE 4 IS CLOSED)

PART-B

1. OFF-VALVE 19
2. OFF-VALVE 22
3. ON- VALVE 21
4. ON- VALVE 20

THIS PROCESS IS ON UNTILL 40°C TEPERATURE IS OT ACHIEVED IN REACTOR.

5. OFF-STIRRER
6. OFF-ALL VALVE
7. VALVE 13 OPEN PARTIALLY TILL AMBIENT TEMPERATURE IS NOT MEET.
8. OFF-VALVE 12
9. OFF-VALVE 24
10. OFF-PUMP-6

5.6 SAFETY

5.6.1 HAZARD SUMMARY

- **Mono-Ethylamine** can affect you when breathed in and by passing through your skin.
- Contact can severely irritate and burn the skin and eyes with possible eye damage.
- Breathing **Mono-Ethylamine** can irritate the nose, throat and lungs causing coughing, wheezing and/or shortness of breath.
- Repeated exposure can affect the eyes causing blurred vision and seeing halos around lights, and may lead to permanent damage.
- **Mono-Ethylamine** is a HIGHLY FLAMMABLE LIQUID or GAS and a DANGEROUS FIRE HAZARD.

5.6.2 WORK PRACTICES

- Workers whose clothing has been contaminated by **Mono-Ethylamine** should change into clean clothing promptly.

- Contaminated work clothes should be laundered by individuals who have been informed of the hazards of exposure to **Mono-Ethylamine**.

- Eye wash fountains should be provided in the immediate work area for emergency use.

- If there is the possibility of skin exposure, emergency shower facilities should be provided.

- On skin contact with **Mono-Ethylamine**, immediately wash or shower to remove the chemical. At the end of the work shift, wash any areas of the body that may have contacted **Mono-Ethylamine**, whether or not known skin contact has occurred.

- Do not eat, smoke, or drink where **Mono-Ethylamine** is handled, processed, or stored, since the chemical can be swallowed. Wash hands carefully before eating, drinking, smoking, or using the toilet.

5.6.3 Clothing

- Avoid skin contact with **Mono-Ethylamine**. Wear protective gloves and clothing. Safety equipment suppliers/ manufacturers can provide recommendations on the most protective glove/clothing material for your operation.

- All protective clothing (suits, gloves, footwear, headgear) should be clean, available each day, and put on before work.

5.6.4 Eye Protection

- Wear indirect-vent, impact and splash resistant goggles when working with liquids.
- Wear non-vented, impact resistant goggles when working with fumes, gases, or vapors.
- Wear a face shield along with goggles when working with corrosive, highly irritating or toxic substances.
- Contact lenses should not be worn when working with this substance.

RESULT

RESULT

6.1 OBSERVATION TABLE

Table 10: Parameter measured at various section of CCS Plant

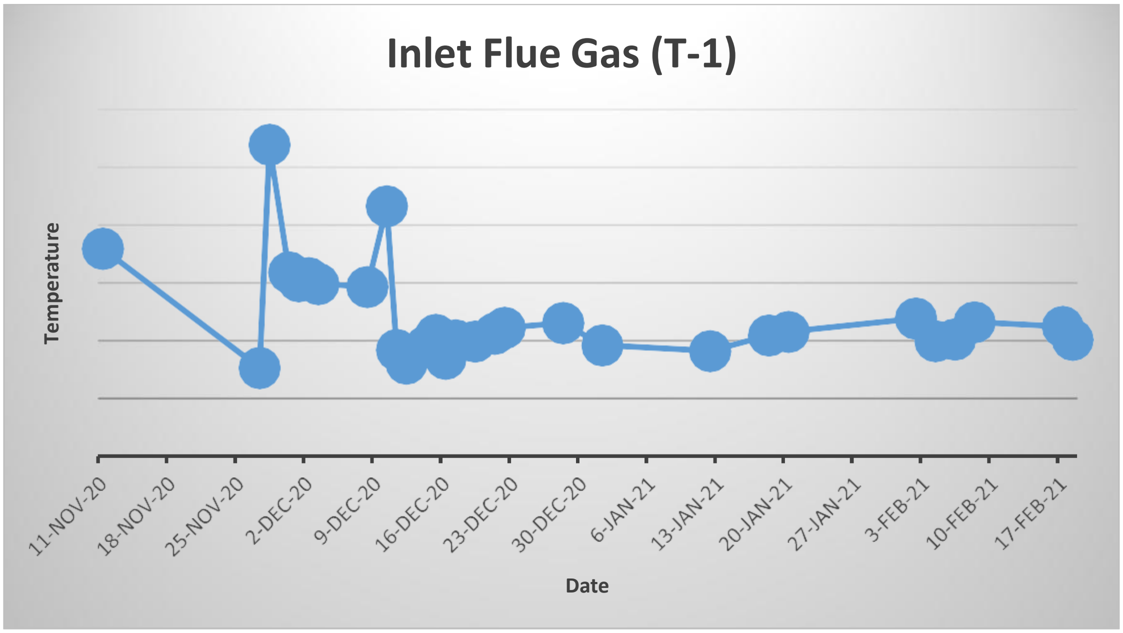
Part	Result	Measured	Instruments
1. Ash Collection Tank	• Flue inlet Condition • Removal of Moisture • Water Temperature	• CO2 % • °C • °C	Gas analyzer Thermocouple Thermocouple
2. Scrubber Tower-1	• Temperature • SOx • NOx	• °C	Thermocouple
3. Scrubber Tower-1	• Temperature • SOx • NOx	• °C	Thermocouple
4. Scrubber Tower-3	• CO2 • Temperature	• CO2 % • °C	Gas analyzer Thermocouple
5. Intermediate Tank	• Stored qty of MEA sol • Recoverd MEA Sol	• Liters • liters	
6. Reactor	• Reactor Condition with Mixing and without Mixing • CO2 Release Condition 1. Temperature 2. CO2	• Inlet- °C • Inlet- Kg/cm2 1. CO2-°C 2. CO2%	Thermocouple Pressure Gauge Thermocouple Gas analyzer
7. Scheffler Solar Dish	1. Steam Condition	• Steam-°C • Kg/cm2	Thermocouple Pressure Gauge
8. Boiler	1. Boiler	• Steam- °C • Kg/cm2	Thermocouple Pressure Gauge

Table 11: Monthly operation Reading at various section of CCS Plant

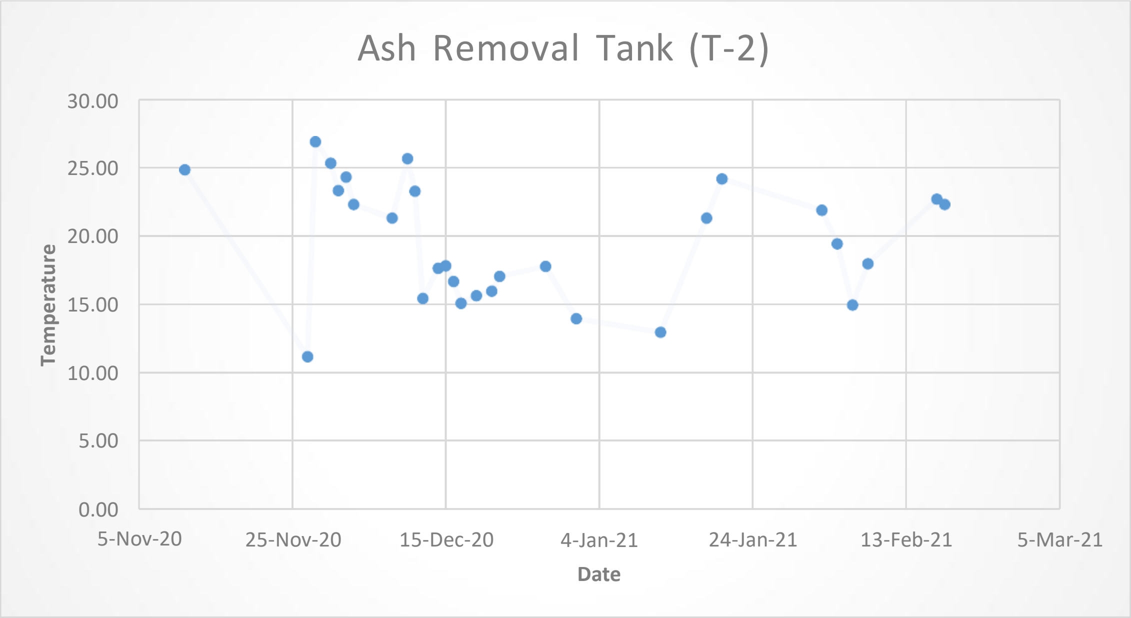
Date	Inlet Flue Gas	Ash Removal Tank	Scrubber Tower-1	Scrubber Tower-2	Scrubber Tower-3	Intermediate Tank	Reactor Vessel	Stem Inlet Temperature	Solar Thermal Dish	Cyclone Separator		Solar Thermal Dish	Reactor Vessel	Inlet CO2%	EXIT CO2 %	Efficiency	CO2 Release
	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	P-1	P-2	P-3	P-4	%	%	η	%
11-Nov-20	71.87	24.83	24.36	24.06	27.53	19.03	29.96	NA	161.83	2.49	-2.50	8.35	1.00	11.73	10.12	13.72	-
27-Nov-20	30.61	11.17	11.96	12.01	14.24	10.06	20.74	NA	82.04	1.30	-1.30	3.85	0.52	16.20	13.13	20.14	-
28-Nov-20	107.70	26.87	25.26	24.96	28.42	19.92	46.35	NA	157.83	2.49	-2.50	8.18	1.00	13.90	11.77	15.34	-
30-Nov-20	63.61	25.30	25.83	25.50	28.97	20.47	45.13	NA	144.39	2.49	-2.50	5.95	1.00	11.75	9.07	23.33	-
1-Dec-20	60.61	23.30	23.87	23.54	27.01	18.51	48.13	NA	149.39	2.49	-2.50	6.70	1.00	12.90	9.43	27.20	-
2-Dec-20	61.61	24.30	23.92	23.59	27.06	18.56	47.13	NA	148.00	2.49	-2.50	6.65	1.00	8.77	6.55	25.28	-
3-Dec-20	59.61	22.30	24.20	23.87	27.34	18.84	49.13	NA	144.74	2.49	-2.50	6.17	1.00	12.85	8.57	33.25	-
8-Dec-20	58.61	21.30	25.83	25.50	28.97	20.47	45.13	NA	147.74	2.49	-2.50	6.65	1.00	17.62	10.28	41.59	-
10-Dec-20	86.48	25.65	23.97	23.60	27.14	18.29	43.00	NA	135.70	2.49	-2.50	4.87	1.00	17.45	10.33	40.73	-
11-Dec-20	36.83	23.26	24.18	23.85	27.32	18.82	24.96	NA	48.43	2.49	-2.50	2.00	1.00	13.28	6.80	48.66	-
12-Dec-20	32.17	15.43	18.85	18.59	21.55	14.56	23.43	NA	31.30	1.96	-1.96	1.63	0.78	11.50	6.30	45.72	-
14-Dec-20	38.18	17.65	19.94	19.94	29.35	17.47	24.06	NA	35.00	2.59	-2.59	2.25	1.00	13.34	7.06	47.73	-
15-Dec-20	42.04	17.83	22.91	23.41	23.42	18.26	35.22	NA	34.13	2.49	-2.50	2.25	1.00	18.37	3.63	80.88	-
16-Dec-20	33.81	16.67	22.06	20.00	20.89	19.02	24.22	NA	41.09	2.93	-2.93	2.64	1.00	8.88	2.38	74.58	-
17-Dec-20	40.20	15.08	23.81	24.20	24.16	24.36	55.24	NA	106.40	2.36	-2.36	4.61	1.00	11.92	2.87	76.38	-
19-Dec-20	39.78	15.63	24.98	27.40	23.62	25.28	19.67	NA	132.96	2.19	-2.19	6.33	2.67	11.10	2.85	74.55	3.17
21-Dec-20	42.44	15.96	25.66	27.90	25.12	28.57	93.22	113.56	146.11	2.72	-2.72	6.92	2.48	12.51	3.19	74.09	3.40
22-Dec-20	44.48	17.04	26.88	29.16	26.41	29.91	93.74	111.74	151.44	3.09	-2.31	8.11	3.09	15.71	6.53	69.78	6.71
28-Dec-20	46.07	17.78	26.89	29.14	26.35	29.81	98.11	114.44	138.89	2.72	-2.72	5.91	2.46	14.17	3.47	75.06	3.80
1-Jan-21	38.44	13.96	24.55	26.79	24.01	27.46	103.44	117.96	131.11	2.72	-2.72	5.31	2.46	11.70	2.33	79.62	4.96

12-Jan-21	36.44	12.96	24.79	27.03	24.25	27.70	99.70	109.96	136.11	2.72	-2.72	6.46	2.33	11.10	2.34	78.54	8.45
18-Jan-21	41.82	21.29	31.42	31.39	29.35	32.44	68.65	103.24	76.82	3.00	-3.00	0.00	1.24	13.22	2.98	77.39	3.50
20-Jan-21	43.11	24.16	36.88	35.91	28.76	30.65	68.16	111.05	131.84	2.66	-2.68	3.21	1.16	12.98	3.14	75.79	0.00
2-Feb-21	47.67	21.87	36.25	36.13	32.72	36.59	80.80	119.73	133.33	2.50	-2.50	3.68	1.07	13.10	3.42	74.03	0.00
4-Feb-21	39.86	19.43	26.41	27.95	25.74	28.13	93.57	124.19	104.76	2.98	-2.98	2.10	2.19	11.75	2.62	78.76	6.62
6-Feb-21	40.44	14.96	24.95	27.20	24.41	27.87	84.93	110.56	137.52	2.72	-2.72	6.46	2.33	13.47	3.51	73.71	13.37
8-Feb-21	46.44	17.96	26.89	29.13	26.35	29.80	43.48	122.56	139.00	2.72	-2.72	6.57	3.33	14.20	3.41	76.03	14.65
17-Feb-21	44.87	22.70	28.66	29.31	34.13	25.99	101.83	97.61	117.57	2.74	-2.96	2.24	0.11	13.65	3.58	73.64	13.83
18-Feb-21	40.41	22.30	28.95	29.19	33.24	23.00	103.04	106.30	115.00	2.69	-2.69	2.70	2.46	12.90	3.82	71.65	16.97

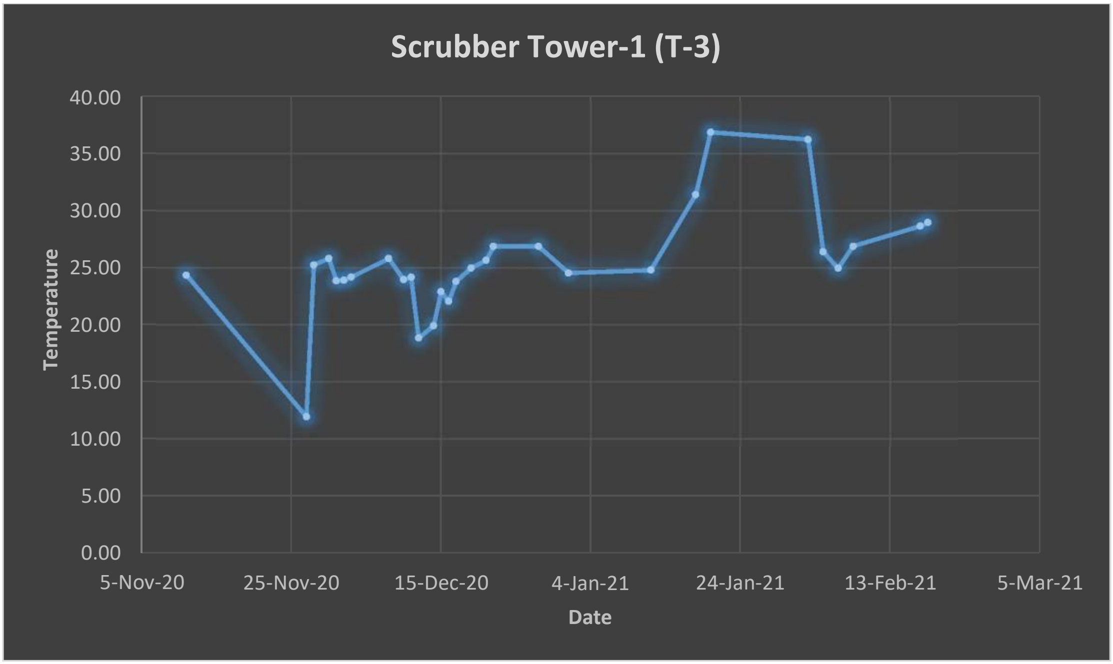
6.2 RESULTS



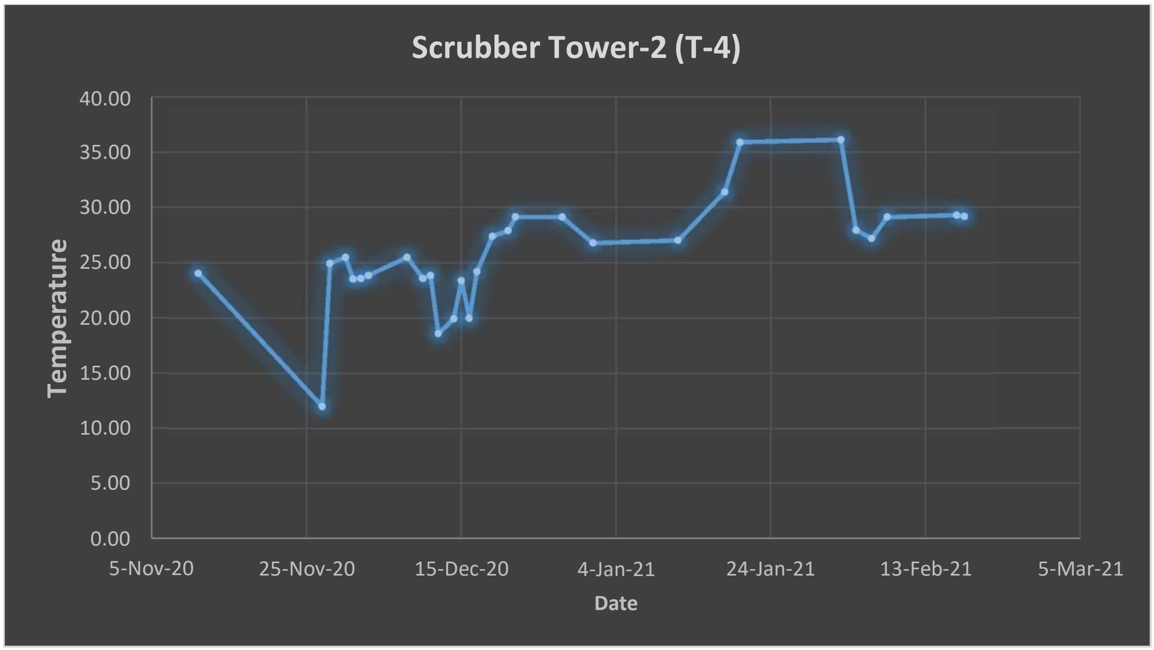
Graph 1: one Month Trial run result of temperature of Flue Gas



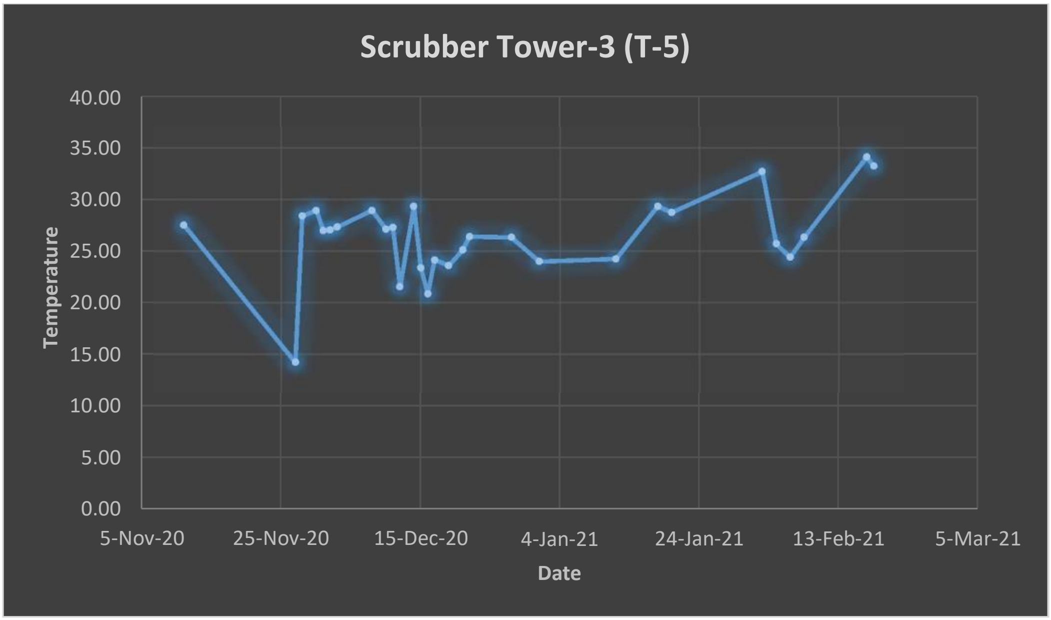
Graph 2: one Month Trial run result of temperature of water in Ash Collection Tank



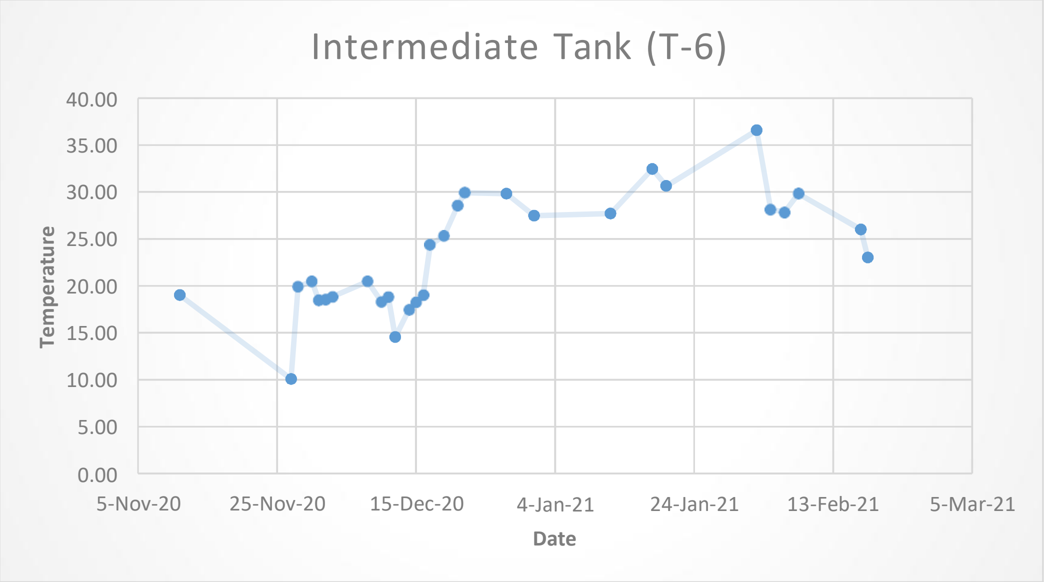
Graph 3: one Month Trial run result of temperature of water in Scrubber Tower-1



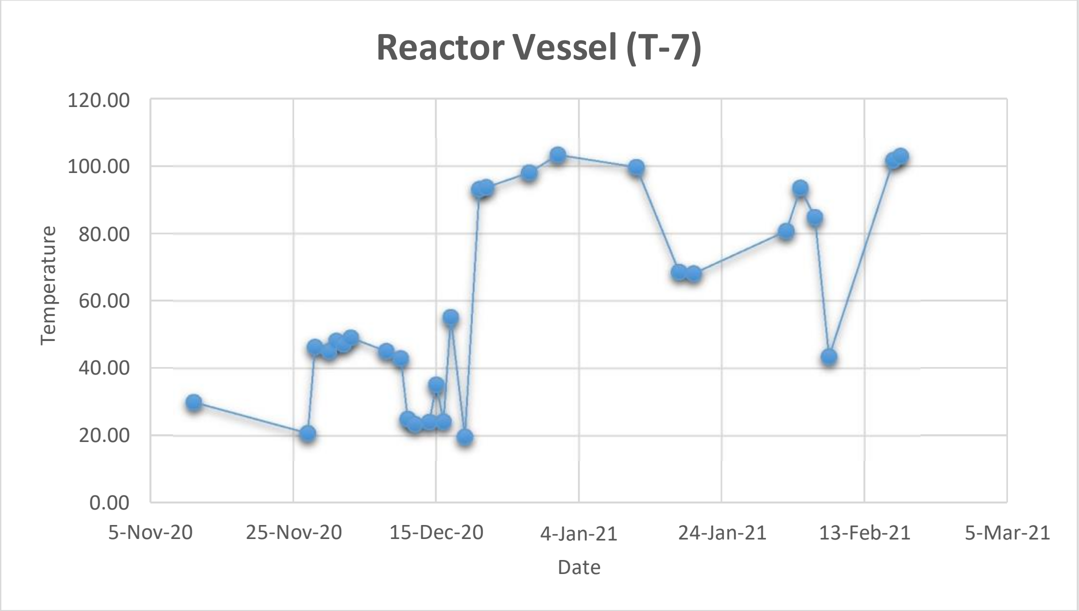
Graph 4: one Month Trial run result of temperature of water in Scrubber Tower-2



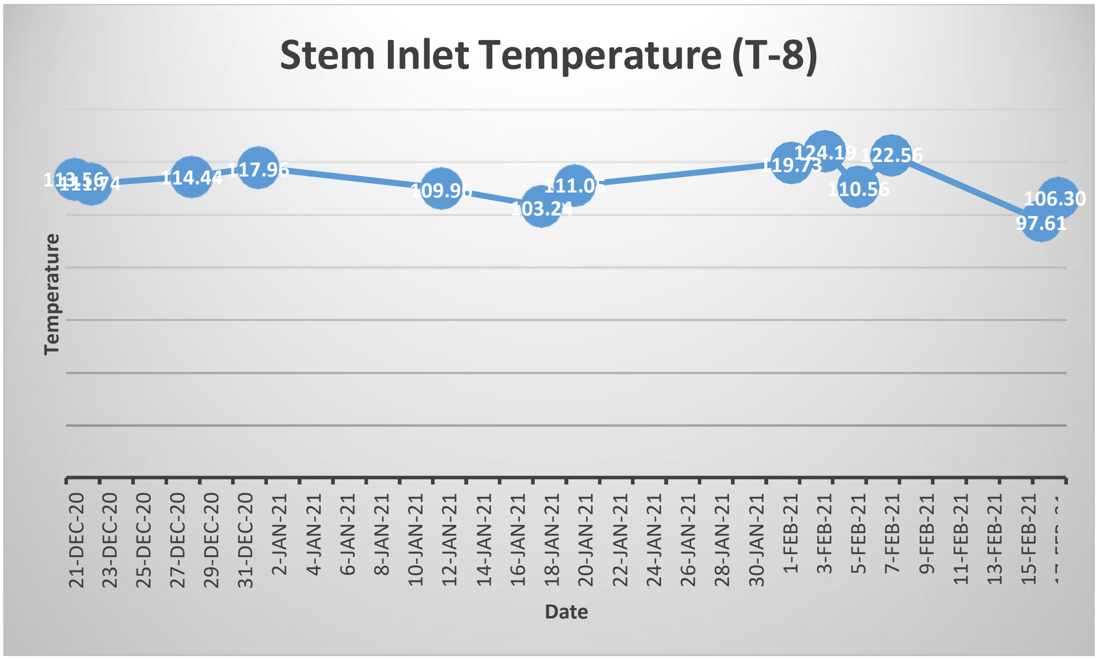
Graph 5: one Month Trial run result of temperature of water in Scrubber Tower-3



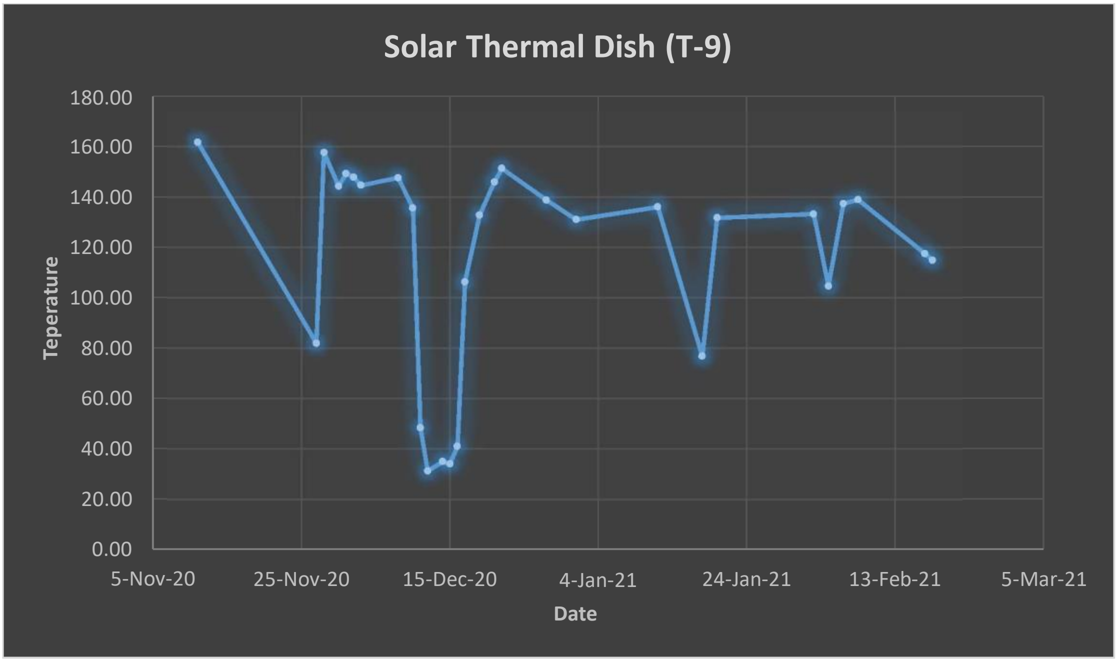
Graph 6: one Month Trial run result of temperature of charged MEA in Intermediate Tank



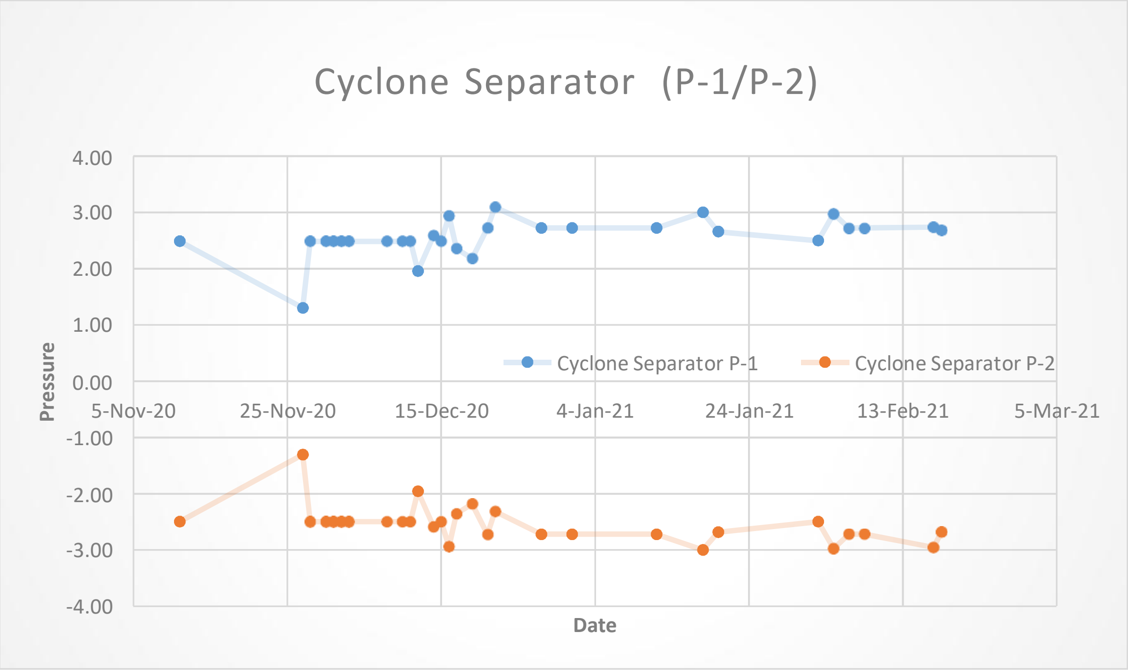
Graph 7: one Month Trial run result of temperature of charged MEA in Intermediate Tank



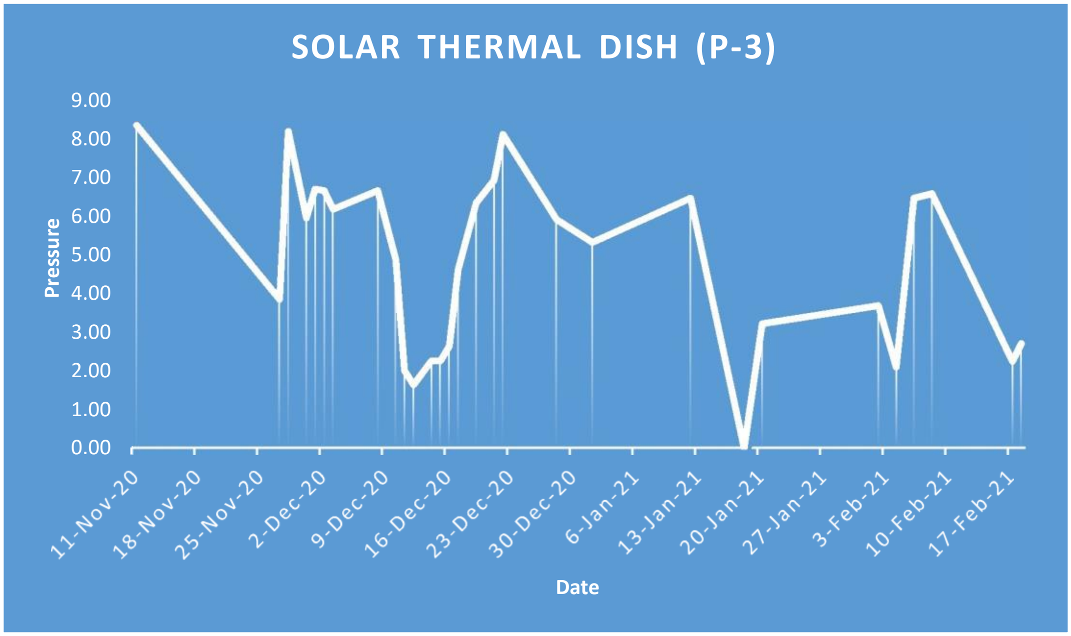
Graph 8: one Month Trial run result of temperature of Inlet Steam in Reactor



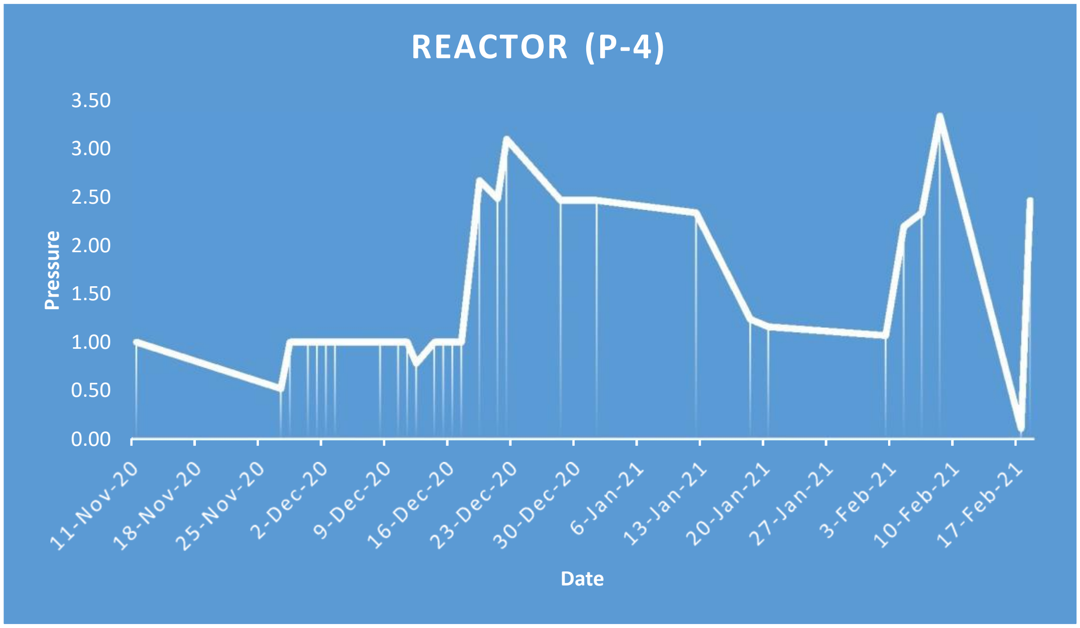
Graph 9: one Month Trial run result of temperature of Solar Thermal Dish



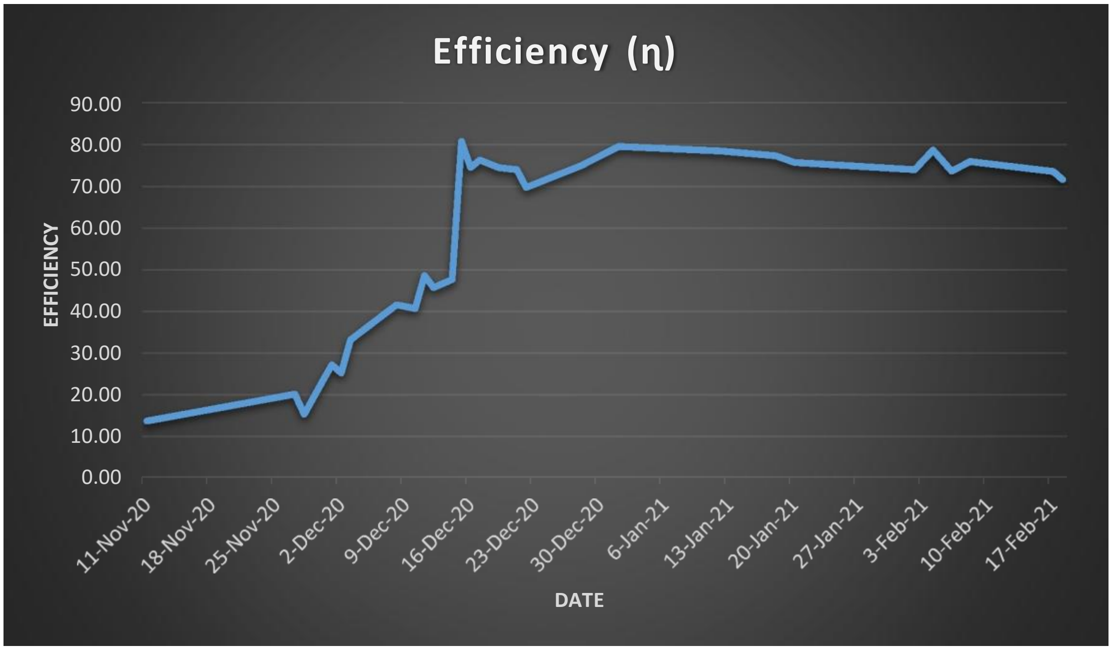
Graph 10: one Month Trial run result of pressure before and after Cyclone Separator



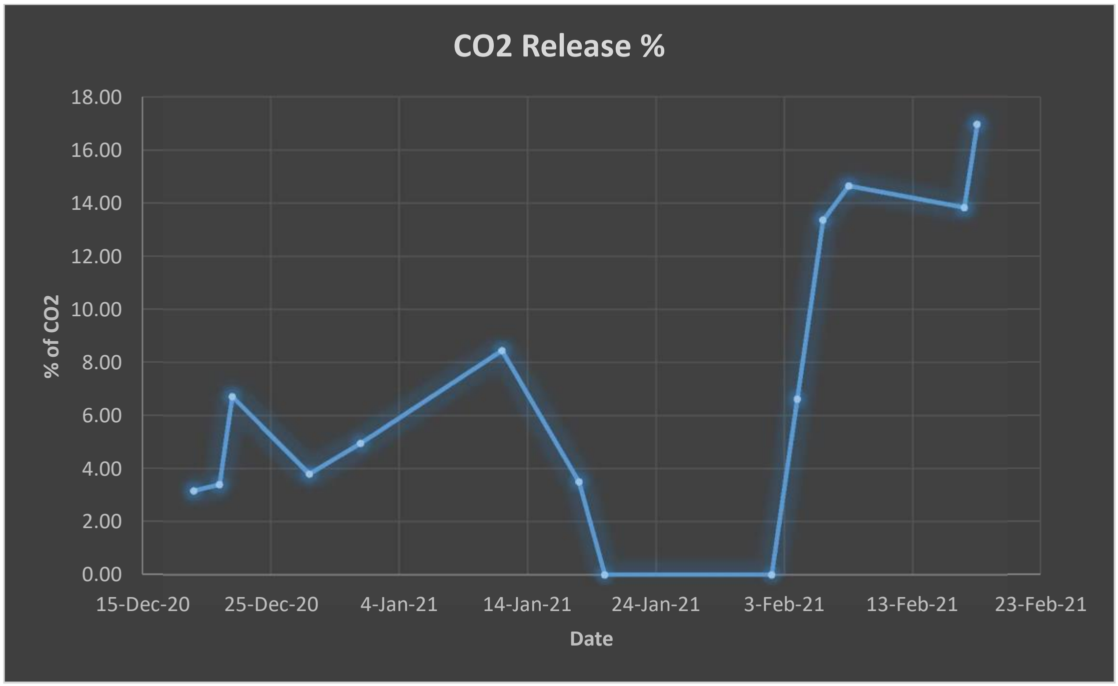
Graph 11: one Month Trial run result of pressure Scheffler Dish



Graph 12: one Month Trial run result of pressure in Reactor



Graph 13: one Month Trial run result of CO2 Absorption Efficiency



Graph 14: one Month Trial run result of Regeneration of CO2

6.3 CONCLUSION

The project has met its all goal and intense testing is performed. The CCS plant has achieved following:-

- The average inlet flue gas temperature is 45.82℃ .
- The average temperature of ash collection tank is 19.25℃ .
- The average temperature of Scrubber Tower-1, Scrubber Tower-2 & Scrubber Tower-3 is 25.89, 26.52 & 26.74 respectively.
- The average temperature of intermediate tank is 24.38.
- The average temperature of reactor when it start release of CO_2 is 115℃ with 2.3% of CO_2 & increase to 18.5% at 159℃ .
- The maximum steam inlet temperature in Boiler & Scheffler is 169℃ & 174℃ respectively. The average temperature of steam at inlet is 111.77℃ .
- The maximum achieved temperature is 174℃ at 11 kg/cm^2 pressure and overall average temperature of Solar thermal dish is 112.70℃ & average pressure of 4.51 kg/cm^2.
- The average suction vacuum is - 2.60 kg/cm^2& discharge pressure is 2.62 kg/cm^2, after the treatment of flue gas.
- The maximum temperature & pressure achieved in reactor is 159℃ & 8 kg/cm^2. The average temperature & pressure throughout the trial run is 62.73℃ & 1.60 kg/cm^2.
- The overall average at time of trial run the CO_2entering the system & exit of system is 13.14% 4.89% of CO_2 - which is twice as per pre set goal of capturing 30% of CO_2.
- The average CO_2 released from the reactor vessel is 8.13%.
- The water tank of 4000 Liter is used to condense the MEA solution & recollected in intermediate tank.

6.4 SUGGESTIONS

- The tapping port of 1” is not sufficient to tap off and required 4” of Port.
- The Cooling tower for recovery of water is required at time of regeneration of CO2
- The hot condensed water from the steam trap could be used in scheffler to increase its efficiency.
- For testing 20kg/hr boiler is required instead of 7Kg/hr.
- The pulverized coal boiler is required to use (originally) instead seam coal boiler.

CHAPTER – 4.1

PILOT PLANT DESIGN

RKDF UNIVERSITY

The CPRI Sponsored Project to RKDF University, Bhopal under RSOP Scheme

Project Title:

"Post Combustion Carbon Capture & Sequestration (CCS) Plant on a Coal Fired Power Plant - Feasibility Study"

Sanctioned vide: CPRI/R&D/TC/Thermal/ 2019 Dated 06-02-2019

Period of Project: April 2019 – June 2021

Collaborator: RPI, USA & RGPV, Bhopal

CHAPTER-4: EXPERIMENTAL PROCEDURE

OPERATION MANUAL

PROJECT COMPLETION REPORT

Sir J C Bose Interdisciplinary Technology Park

Executing Organization: Ram Krishna Dharmarth Foundation (RKDF) University, Airport Bypass Road, Gandhi Nagar Bhopal, MP 462033

RKDF UNIVERSITY

SUNRISE CSP
CONCENTRATED SOLAR POWER

OPERATION MANUAL

Carbon Capture & Sequestration Integrated with Solar Thermal Technologies

ABOUT

Sunrise CSP Pvt. Ltd. develops, supplies and supports world leading Concentrated Solar Power (CSP) technology for the development of cost-competitive, utility-scale electricity generation and high temperature industrial process heat systems.

Our core technology is the Big Dish solar concentrator and its complementary technologies such as Scheffler and Carbon Capture and Sequestration. These technologies can be deployed in stand-alone or grid-integrated solar power projects, with or without storage, or hybridised with gas, oil or other fuels to deliver cost-competitive dispatchable power generation systems.

They may also be deployed to provide thermal energy for a diverse range of high temperature industrial processes such as desalination, enhanced oil recovery, minerals processing, the production of hydrogen and solar enhanced fuels.

.

Projected Funded by:

Funded by a **CPRI (Central Power Research Institute)** of Bangalore RKDF University has placed order for CCS project with sunrise not just to supply 2 Scheffler Concentrators of 16 m2 each but also CO2 absorption system. Co2 from flue gases would be absorbed in MEA Solution in the scrubber in/of the CO2 absorption system and would be released by solar generated steam by Scheffler Concentrator

TABLE OF CONTENT

INTRODUCTION

CO_2 capture and storage of CCS is the removal of carbon dioxide from the emissions arising from power plants or from other large 'point sources' of CO_2 such as cement works, Steel plants or as in this case, Thermal power plants. The CO_2 compressed and transported as a liquid for storage in a suitable geological structure. The following figure represents CO_2 Capture and Storage.

CCS can, in theory, be applied to all using fossil fuels (coal, gas and oil) and Biomass. It can therefore be said to permit the continued use of fossil fuels while still limiting CO_2 emissions into the atmosphere. CCS is most after discussed in combination with coal. The amount of carbon contained in known coal reserves far exceeds the quantity which can be safely released into the atmosphere if dangerous level of climate change are to be avoided. In addition to generating electricity from coal, liquid fuels such as hydrogen can be created from coal. Such coal - derived fuels could be used not only in transportation but also in meeting domestic heating and cooling demands. Because their manufacturer from fossil fuels in energy - extensive, however, such new fuels would end up contributing to human- induced climate change and unless CCS is employed.

Figure 1: CCS Plant at RKDF University

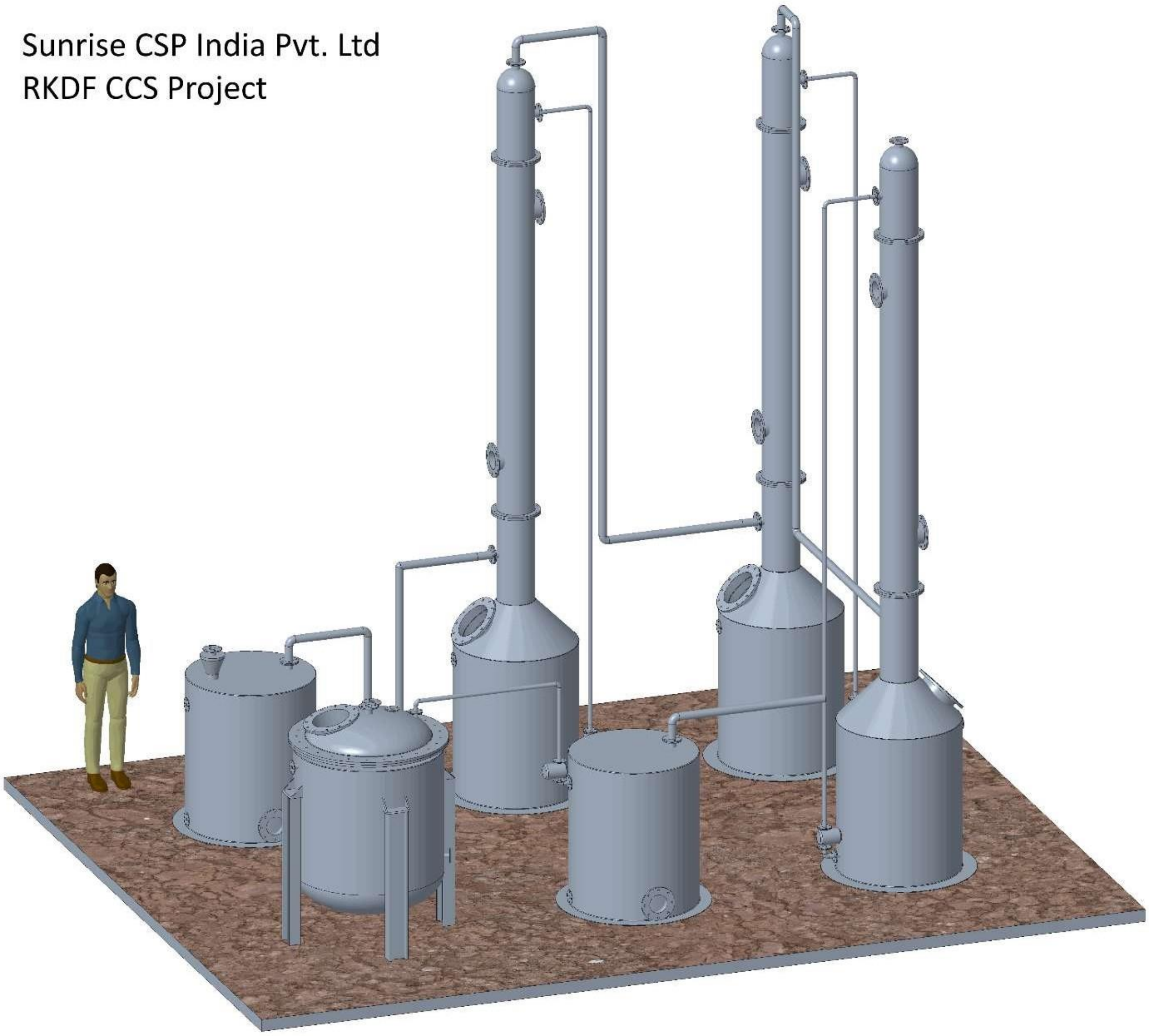
CARBON CAPTURE AND STORAGE- SETUP & PROCEDURE

Flue gas generally contains 14% CO_2. It contains SO_K, NO_K gases as well as some Ammonia gases and some dust particles such as Ash and Carbon particles.

The process is as follows,

1. Flue gas is subjected to water flow which will trap all particulates with water and it will also cool down the temperature of flue gas.
2. Then the gas will be sent to Tower A, shown in the fig.2. Flue gas will enter scrubber from bottom.
3. Soda solution (Sodium Carbonate solution of 10% will be sprinkled from top of the packing and because of packing, contact area will increase, so Ammonia, SO_K gas and NO_K gases will come in to contact with soda solution and will be converted to their respective salts like Sodium Sulphate, Ammonium Sulphate and Sodium Nitrate.
4. After this the gases are subjected to Tower-B (identical to Tower A) so that any traces of these impurities get observed and does not come in to contact with MEA solution, as reaction with MEA solution can result in formation of complex salts.
5. Flue gases from scrubber of Tower B are free from impurity of Ammonia, SO_K and $NO_{K.}$ The gases are now subject with counter current of MEA solution of 30%. Here it forms bond with CO_2 gas to form mixture of MEA - CO_2 mixture solution. MEA solution of 30% can combine with 1 kg of CO_2.
6. MEA - CO_2 solution is sent to Tower C which is a 1000Ltr SS316 reactor with wall thickness of 8 mm thickness and bottom of 8mm thickness jacketed with MS jacket and have steam jacket SS316 coil. All contact parts with MEA solution are of SS316, as MEA is very corrosive with MS.
7. SS Reactor also has vertical condenser which will act as a reflux and will stop losses of MEA and water vapour and will allow only pure CO_2 to go out so there will not be any impurity of MEA in CO_2 gas.'\
8. This is not a chemical reaction but it is a physical property of MEA which has tendency to absorb CO_2 gas and CO_2 gas gets released when heated above 130° . As boiling point of MEAis 170°C, to prevent losses of MEA max temp of MEA - CO_2 mixture is to be restricted to stay below 155°C.

The system will have an input of 250 kg/ hr of flue gasses and will be able to extract 45 kg/hr (18%) of carbon dioxide. Thermal energy is required to heat the MEA - CO_2 solution in Tower C to extract out the carbon dioxide. To provide this heat, the plant will rely on Solar Thermal technology provided by Sunrise CSP India Pvt. Ltd. The company has a 520 m^2 solar concentrator as its main IP, but for the CCS plant, the company will provide 8 scheffler dishes of 16 m^2 each. The solar system will provide 50 kg/hr of steam during sunshine for re-generation of MEA solvent.



Depicts the setup for the CCS plant.

DIFFERENT PART OF CCS PLANT

1. Scheffler Dish

About the Scheffler dish Technology

Scheffler dish is a small lateral section of a paraboloid, which concentrates sun’s radiation over a fixed focus, with an automatic single axis tracking.

Underlying principle

Scheffler dish is made of number of flat shaped mirrors or reflective films which are mounted on a structural frame. The dish rotates about north-south axis parallel to earth’s axis to track the sun’s movement. The axis of rotation passes through the center of gravity of the reflector and that’s how the reflector al- ways maintains its gravitational equilibrium. The scheffler reflector also performs change in inclination angle while staying directed to sun, in order to obtain sharp focal point. Focus is fixed at distance of focal length of the paraboloid along the axis of the paraboloid. Receiver at a fixed location captures the concentrated heat and transfers it to water/thermic fluid to generate hot water/hot thermic fluid or high pressure steam.

Key components of Scheffler dish

Key components of Scheffler dish based system can be classified on the basis of their individual functions:

SCHEFFLER Reflector

2. Reflector dish
3. Receiver
4. Dish stand
5. Tracking System

BALANCE OF SYSTEM

- Piping and Insulation
- Instrumentation and Safety Mechanism
- Heat Storage System

Key design variants

Scheffler dish is currently available in two design variants, namely

1. 16 m^2 Scheffler Dish
2. 32 m^2 Scheffler Dish

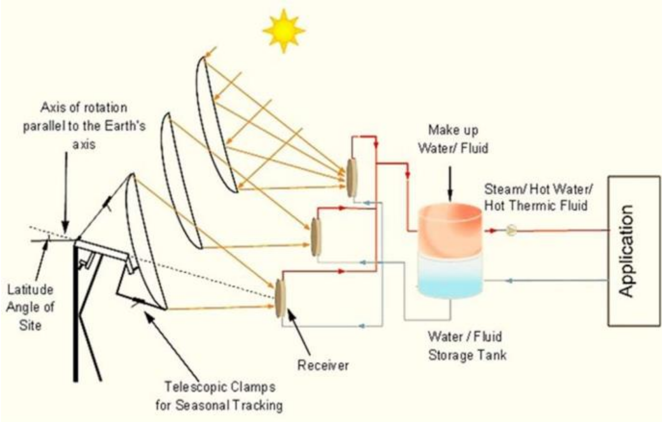
Scheffler Dish at RKDF University

The important characteristics of these designs are as follows

Parameter	16 m^2	32 m^2
Average Aperture Area	*11.65 m^2*	*23.3 m^2*
Shadow Free Area	*35 m^2*	*60 m^2*
Thermic medium	*Steam, hot water, thermic fluid*	*Steam, hot water, thermic fluid*
Delivery capacity	*Up to 12 bar pressure, Up to 180^0C temperature*	*Up to 12 bar pressure, Up to 200^0C temperature*
Weight	*Minimum 400 Kg*	*Minimum 800 Kg*

End-use application

Scheffler dish is used for the low-medium process heat applications. This dish can attain the temperature up to 150-200°C as per the specific requirements in industries, commercial & residential complexes, religious places, etc. A typical 16 m^2 Scheffler Dish has thermal capacity equivalent to 30,000 Kcal/ day to 35,000 Kcal/day depending on the manufacturing precision and DNI on a clear sunny day.



Schematic diagram of CST based System with Scheffler Dishes

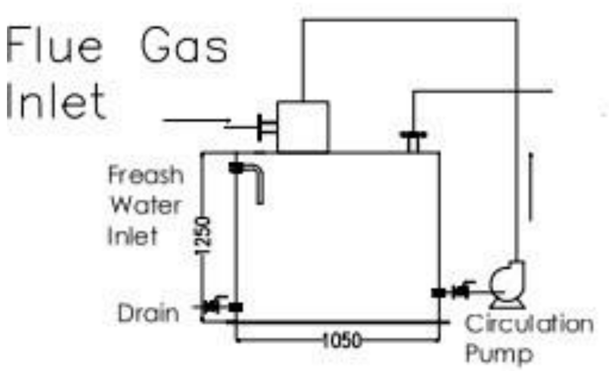
Some of the typical application areas of Scheffler dish are:

- Food processing
- Community cooking
- Solar-assisted comfort cooling
- Laundry
- Pharmaceutical
- Drying and dying
- CO2 Regeneration

The design configuration of an industrial process heat solar system depends on the specific application. It may consist of one or more number of Scheffler dishes in a system. Scheffler dishes have been installed in various thermal applications across the industries including laundry in hotels, cooking in religious and educational institutions, comfort cooling in offices, boiler feed water heating in chemical process industries amongst others.

2. Ash collection Tank

The ash collection tank consist of 890 liters of water tank and a pump connected in a loop. The Pump developed high pressure in venture. The venture create a vacuum at the suction end of the flue gas which increase the flow and increase the dissolve efficiency of heavy particle into water. Therefore on gasses passes through the system and moves towards the Cyclone separator.

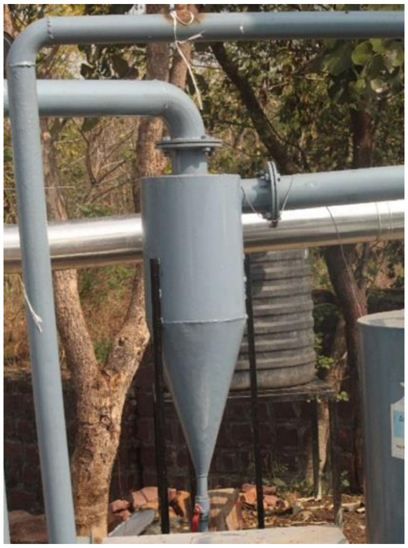


a. Working of Ash Collection Tank

b. Ash collection Tank at RKDF

3. Cyclone Separator

The cyclone separator takes the gas and moisture coming out of ash collection tank and start rotating a high speed. Due to centrifugal forces the moisture and few heavy dust particle stick to the surface of cyclone and collected in the bottom of it. From the bottom the valve is open and it is drained out.



Cyclone Separator

4. Blower

The flue gas coming from the cyclone separator goes through it which create a positive pressure in discharge direction and negative pressure in suction side.

The negative pressure is approximately -2.5 Kg/cm^2 to -3Kg/cm^2.

Blower

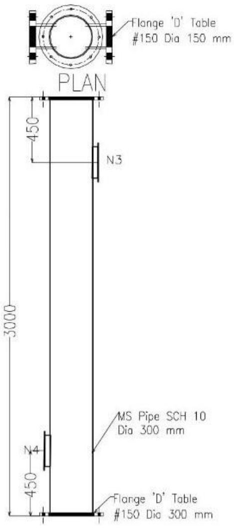
<u>Specification</u>	
HP	**2**
Pressure	**400 MMWG**
Type	**Centrifugal Blower**
RPM	**2880**
MFR	**United Engineering CO.**
CFM	**280**

5. Scrubber Tower

The scrubber tower is filled with “Paul Ring” of SS-304 and SS-316. In Scrubber Tower 1and 2 the SS-304 Paul ring is filled. In scrubber tower 3 the SS-316 in filled with the support of metal mesh plat. The Paul ring is filled to increase the surface area of fluid into tower to increase the efficiency of the scrubbing.


Scrubber Tower at RKDF

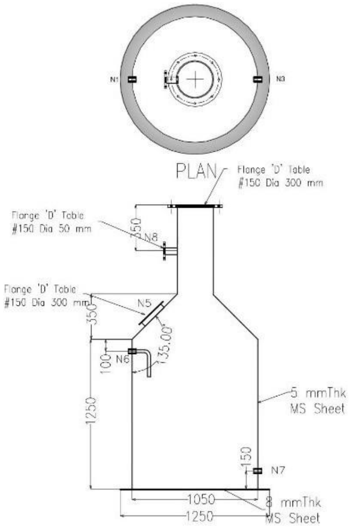

Paul Ring



Scrubber Tower

6. Storage Tank

The storage tank 1 and Tank 2 consist of Na2CO3 of 900 liters. The Storage Tank 3 has 800 liters of MEA (MonoEthyleAmine). The storage tank is serve as a pool of chemical from where motor pump the chemical to scrubber tower and from scrubber it is again collected in storage tank due to gravity.

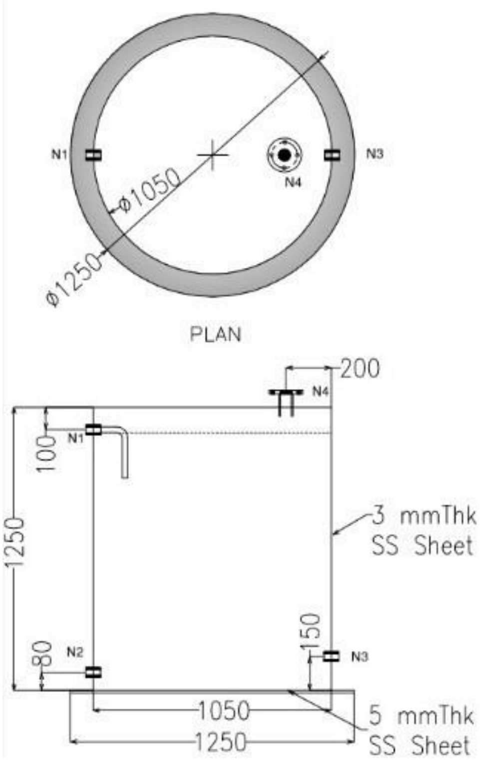


Storage Tank Diagram


Storage Tank

7. Intermediate Tank

The intermediate tank serve as two purpose one is to hold the charged MEA till it is required for the next process and second is to recover the condensed MEA and moisture during the time of regeneration.

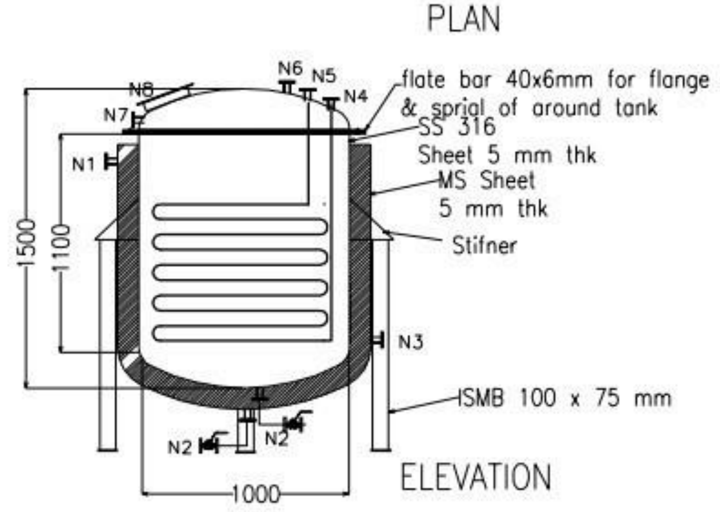


Intermediate Tank Diagram

Intermediate Tank at RKDF

8. Reactor

The reactor is the heart of system. The regeneration of CO2 take place in it. The reactor has two stem inlet one is from the scheffler (10 Kg/hr) and another is from the boiler (5Kg/hr). The combine steam is used to heat the MEA from atmospheric condition to 155℃. The pressure of 7-8 Kg/cm2 is developed inside the vessel. The stirrer is also fitted into it for the uniform heating and cooling of the reactor to restrict from the thermal cracks or buckling failure. Thus it releases the CO2 molecules which is further used in byproduct process. The use of solar heat from solar thermal dish make it unique. The reactor is also equipped with the internal cooling system so that the chemical can be stored for longer duration without releasing CO2 in ambient Condition.



Reactor diagram

Reactor

9. Condenser and Chemical Recovery Unit

A 7 tons of condenser is used to recover the evaporated MEA solution. The coil runs the MEA+ CO2+ H2O and water cooled by the help of the pump. The MEA+H2O condensed bellow 100℃ and get liqiffied. The remaining CO2 is passed from the CCS unit to other process as per the byproducts.

The Chemical recovery Unit has a V bend to restrict the flow of CO2 in intermediate tank and only allows the MEA+H2O into the intermediate tank. This is achieved by varying the height of the liquid.

Condenser

10. Pumps

(1) CRI Pumps

Overview of product

Self-priming and non-self-priming monoblock pumps volute chamber and impeller to deliver optimum hydraulic efficiency and suction. Mechanics IL carbon and ceramic is fitted over the shaft which is machined to close tolerance. These models are provided with built-in check valve on the suction side which requires no foot valve. Non self-priming monoblock pump require good quality foot valve with strainer pumps are powered with to Pol San motor enclosed construction with cooling fan and suitable for continuous working stator is made of silicon Steel lamination to ensure low watt loss dynamically balance rotor insurance vibration and noise free operation. Ending are of high grade enameled copper wire and are impregnated construction of motor frames and uses of quality materials result in high performance and low temperature rise thereby increasing the life cycle of the motor overload protector is incorporated in all single phase Motors.

Operating condition

The pump shall work continuously under the following conditions

- The pumps are suitable only to pump clean, cold, non-aggressive, non-explosive, water without abrasives, particles or fibers.
- Maximum ambient temperature degree Celsius
- Maximum water temperature 33 degree Celsius
- Maximum Suction lift up to 8 meters
- duty type S1 continuous
- direction of rotation clockwise from driving end
- Voltage and frequency in accordance with the nominal value indicated in the nameplate

Installation procedure

- Install the pump in horizontal position and near the force of water on a platform with proper Foundation bolts
- The location of the pump should be such that it is free from dust, fumes, moisture stall in ventilator area, protected against weather and it must be easily accessible for regular inspection
- Types with related supports to avoid transmitting stress to the pump body lead to premature failure of and other pump parts
- Tighten the pipes are Union couplings to the extent sufficient to ensure a tight sale and do not apply access a torque which may lead to damage on the pump
- The pipe diameter bend smaller than the pump connection number of bands and air tight joints total elected suction pipe length should not be more than 8 metres
- Self-priming regenerative pumps have an inbuilt check valve on the suction side and therefore no need to use footwall fit a strainer at the suction Pipe and to avoid the entry of foreign particles into the pump
- Maintain sufficient clearance of minimum 1 feet in between the suction pipe bottom and water tank bottom and both side each time the pump must be switched off water level goes below the suction pipe

Electrical connection

- Electrical connection should be carried out by technically qualified personal complying with local rules and regulations and follow safety 4 doubts

- Pump should be connected to a single phase heart AC supply with the voltage ranging between 220 to 240 volts
- Connecting war toys should be of appropriate size and quality of copper cable wire should be as per the standard if the voltage variation is more than Plus do not operate the pump
- Switch on the supply and check for the direction of rotation of the motor and it should be in the direction specified by an arrow on the cooling fan cover
- Before starting the form it is necessary to fill water in to the pump casing once during the installation and when the priming screw are priming plug tightly

Maintenance

- Disconnect electrical power before carrying out any maintenance work
- The pump idle for longer periods shaft in order to ensure the free NEF if this does not solve the problem remove the pump casing by unscrewing the Bolt and clean the pump trolley until the pump shaft rotates freely by hand
- Ensure that the pump casing is filled adequately with water before starting if the pump is ideal for a long duration
- Ensure that the clogging does not take place in a strainer clean the strainer regularly.
- CRI Pumps do not required day-to-day maintenance under normal operating condition however it is mandatory to check the pumping system at regular intervals with regard to current drawn in each lead what is water discharge and drawdown water level starter panel wiring earthing and electrical connections.

(2) CHL (SS-316)

Applications and conditions

CHL /CHL-f /CHL-ft or non-self-priming light horizontal centrifugal pump pump in the following they are official low noise little tolerance compact structure good looking small volume lightweight etc

1. Operation conditions

- liquid temperature normal temperature type 15 degree Celsius third degree Celsius hot water type 15 degree Celsius 110 degree Celsius
- Slow range 0.5 28 meter cube per hour
- Max pressure 10 bar
- Liquid pH range 8529
- Max ambient temperature + 40 degree Celsius
- The max suction pressure is limited by Max operating pressure
- Minimum inlet pressure referred to npsh curve

Caution: when pumping liquids with the density and for viscosity higher than that of Water used motor with corresponding Li higher output if required

Installation and connection

1. Installation

- Pump should be seated in a well-ventilated but for first free prediction in pump with motor and other objects should be at least 150 mm in order to call the motor by fan with an affair
- To reduce the inlet pressure of inlet as list as possible the inlet pipe shall be as short as possible
- Ensure the check valve is installed in pipeline system before the pump installation to prevent liquid from returning
- Pump should be fixed in ground or fixed on the brackets on wall from should be safely fixed and stable pay attention not to let the weight of pipe system on pump to prevent pump from damage
- Before pump installation the inlet pipe line shall be cleaned if there is impurities in the pipe it is necessary to install a strainer at 0.52 1 mm in front of the pump inlet
- The air pockets shall be provided when installing the inlet pipe Line 3 Figure 2
- It is necessary to fit a pressure metre to observe and control operation of pump
- when the height of composition is higher than liquid level in the suction range of pump of foot valve should be installed in the inlet Pipe and and feet of water pouring screw hole in the drainage pipe it is used for pouring water in before starting pump

2. Electrical connection

- The electrical connection should be carried out by qualified electrician.
- To make sure the motor is suitable for the power supply cables of the motor must be connected to power supply according to the figure on the term Terminal box and the motor nameplate
- Motorcycle with connected beta fast and effective motor starter to ensure that the motor will not be changed by lack of phase unstable voltage or overload the motor Shelby birthday reliably

Caution: before taking apart The Terminal box cover or dismantle pump makes sure that the power supply is switched off.

Startup operation and maintenance

Caution: it is prohibited to run without liquid which will damage and sliding bearing

1. Do not start the pump until it has been filled with water or liquid fully.

- Fill water in sump in inverse pouring system: Close the pump outlet Wall release air vent screw on the pump head and open the inlet valve slowly until stable water from the air vent screw The Fast and the screw.
- Fill water in pump when liquid level is lower than pump: Before installing pump and pipes must be filled with liquid fully and air vented.

2. Check the Rotary direction

Switch on the power supply and will the Rotary direction by weaving the motor fan from the motor and pump shall run counterclockwise.

3. Check before pump start up

- Check whether the pump is fixed security
- Whether pump is filled with water fully and check whether liquid can flow freely
- whether the voltage of power supply is stable
- check whether it turns correctly
- to make sure all pipe lines are connected tightly and can supply water normally
- the wall in the inlet pipe line are completely opened
- The outlet valve shall be opened slowly after the pump is started up
- Check the operation pressure if pressure meter is installed
- All the controls for normal operation if the pump is controlled by pressure switch check and adjust the starting pressure and stopping pressure the full load current to make sure it will not exceed the max allowed current.

4. Frequency off pump starts

- Pump should not be started to frequently it is suggested pump shall not be started more than hundred times per hour.
- The application of pump should according to the range of performance curve to avoid motor overload.
- There should be no noise when pump running if there is something wrong stop pump and check it and repair.

5. Trust protecting

Pump can be used in the system with antifrogen major if the pump is installed in a project environment suitable antifreeze cell be added to the transferring liquid to prevent pump from being damaged is not used pump shall not be used during periods of first pump should be drained when stop using.

6. The following should be checked regularly for pump

- Pump working and operating pressure.
- Possible possible leakage
- Possible motor overheat
- Placement of all strainer strainer set
- The switch off time of motor overload
- Frequency of starts and stops
- All control operation

Note:- If find fault check system according to fault finding and solution chart

- Pump shall be cleaned and kept approximately when it is not used for a long time
- Pump shall be prevented from being corrupted and damaged in storage

CRI	Power:0.5HP RPM: 1400 rpm Operating voltage:230V Efficiency:85.10 Pumping Head:8m Discharge:1 m3/hr Type: 2-Phase induction motor	In Condenser line
CHL	Power:1HP RPM: 2830rpm Operating voltage:415V Efficiency:81.30 Pumping Head:31m Discharge:4 m3/hr Pressure: 10 bar Type: 3-Phase induction motor	1. Ash collection tank 2. Scrubber-1/2/3 3. Intermediate Tank 4. Reactor
Blower	Power:2HP RPM: 2830rpm Operating voltage:415V Efficiency:81.30 Type: 3-Phase induction motor	In between cyclone separator and scrubber tower-1
Stirrer	Power:2HP RPM: 1400rpm Operating voltage:415V Efficiency:81.30 Type: 3-Phase induction motor	At top of reactor

Measurement Devices

1. CO2 Analyzer (FM 2000 FLUE ANALYSER)

EFM 2000 FLUE ANALYSER

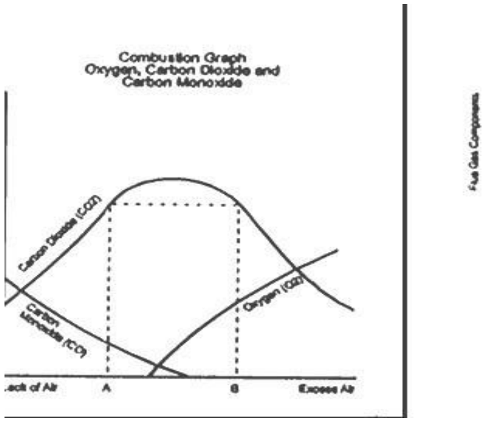
Figure: CO2 Analyzer

SPECIAL FEATURES:

- Portable, compact & rugged state of art design
- Complete automatic operation.
- Automatic calibration possible on atmospheric air; also manual calibration with span gas.
- 16 character, 2line alphanumeric LCD display.
- Standard 20 fuels with their parameters preprogrammed.
- Eight keys to operate the complete instrument.
- Calculates CO_2, excess air, combustion efficiency.
- Displays two parameters at a time.
- Reading can be stored and replayed later.
- Battery status is indicated during every sampling or LOBAT is indicated
- Built-in NiCad battery can be fully recharged in 15hours.
- Can be built to include up to six gas channels like CO, SO_2, NO,HC, NO_2.
- Long life maintenance free electrochemical sensor.
- RS-232 for computer or printer interface is optional.
- SS Sampling probe standard 1 ft.; for high temperature sampling use 1 m (OPTIONAL) with inbuilt K-type t/c to measure temperature of flue gas along with filter mechanism to remove particulates, moisture.
- Built-in pump to draw sample to act against negative pressure up to -200mm Hg. Higher suction pump for large negative pressure(OPTIONAL).

APPLICATION:

- Fuel efficiency of Internal combustion Engines.
- Energy audits and Environmental Monitoring.
- Stack and exhaust Gas Analysis in Boilers.
- Ambient and Emission Monitoring.
- Heat treatment and annealing.
- Power and Industrial Plants.
- Quality control Labs.
- Process Analysis.
- Metal processing.
- Furnaces.



DESCRIPTION:

The EFM2000 offers convenient portability while providing complete combustion efficiency and pollution emission capabilities. All boiler and furnace users can significantly reduce total fuel bills merely by ensuring that their burner is using the fuel efficiently. The EFM2000 gives the operator a continuous feedback to adjust the burner controls to achieve the right fuel / air ratio with combustion optimization you win both ways, you get the maximum energy for your money and have the bonus of a cleaner and pollution free environment through reduced carbon monoxide and soot emission Combustion efficiency is determined by the oxygen content and temperature of flue gas. An excess air condition reduces the efficiency as it carries the heat while a deficient air produces an incomplete combustion with consequent higher costs and increased pollution emissions.

Technical Specification:

Basic instruments measures and calculates the following

PARAMETER	***SENSOR***	***RANGE***	***RESOLUTION***	***ACCURACY***
O_2	Electrochemical	0-25%	0.1%	± 0.5%
CO	Electrochemical	0-5000ppm	1ppm	±5%±1ppm
CO	Electrochemical	0-5%	10ppm	±5%±10ppm
CO_2	Calculated	0-MaxCO_2	0.1%	± 0.5%
Ambient temp	Semiconductor	0-99^{0}C	1^{0}C	±0.5%
Stack temp	K-type T/C	0-1200^{0}C	1^{0}C	±1%
Excess Air	Calculated	0-250%	1%	
Efficiency	Calculated	0-100%	0.1%	
Optional gas channel that can be added to above basic instruments				
SO_2	Electrochemical	0-2000ppm	1ppm	±5%+1ppm
NO	Electrochemical	0-1000ppm	1ppm	±5%+1ppm
NO_2	Electrochemical	0-100ppm	1ppm	±5%+1ppm
HC (CH_4)	NDIR	0-5%	0.001%	±2%

Power supply : Internal Ni-Cd battery pack. Fuse : 1A (20mm) fast acting fuse.

Charge time : 15 hours with instrument switched
off. Ambient temp : 0-50^{0}C.
Dimension : (220\92\230)
mm. Weight : @1.5 Kg.
Standard probe: 300mm rigid SS316 with taper plug & 2.5m flexible
hose (0-600^{0}C)
Optional probe: 1000mm rigid Inconel
alloy. (0-1150^{0}C)
Optional leaf : To measure surface temperature for radiation
loss probe (0-200^{0}C) calculation 300mm rigid and 1m cable

2. Temperature Sensor

Thermocouple	Qty	Description	Image
K-Type Simplex	3	Temperature measuring point: Pick shell / insulation / dew point. Thread: 1/4, 5/16, M8, M6, M12. Temperature range: -50°C~950°C.	
J-Type	1	• Size: Can be customized. Temperature measurement • point: Pick shell, insulation, dew • Point. Thread: 1/4, 5/16, M8, M16, M12. • Pipe diameter: 1.0-Φ8.0 • Pipe: 316L/34 etc. • Lead: String, Glass fiber, PVC, Teflon, Silica gel. • Temperature range: -50°C~950°C.	
LM35	4	• Minimum and Maximum Input Voltage is 35V and -2V respectively. • Typically 5V. Can measure temperature ranging from -55°C to 150°C Output voltage is directly proportional (Linear) to temperature (i.e.) there will be a rise of 10mV (0.01V) for every 1°C rise in temperature. • ±0.5°C Accuracy • Drain current is less than 60uA • Low cost temperature sensor • Small and hence suitable for remote applications • Available in TO-92, TO-220, TO-CAN and SOIC package	

3. Pressure Sensor

Pressure gauges and switches are among the most often used instruments in a plant. But because of their great numbers, attention to maintenance--and reliability--can be compromised. As a consequence, it is not uncommon in older plants to see many gauges and switches out of service. This is unfortunate because, if a plant is operated with a failed pressure switch, the safety of the plant may be compromised. Conversely, if a plant can operate safely while a gauge is defective, it shows that the gauge was not needed in the first place. Therefore, one goal of good process instrumentation design is to install fewer but more useful and more reliable pressure gauges and switches.

Pressure Gauges

One way to reduce the number of gauges in a plant is to stop installing them on the basis of habit (such as placing a pressure gauge on the discharge of every pump). Instead, review the need for each device individually. During the review one should ask: "What will I do with the reading of this gauge?" and install one only if there is a logical answer to the question. If a gauge only indicates that a pump is running, it is not needed, since one can hear and see that. If the gauge indicates the pressure (or pressure drop) in the process, that information is valuable only if one can do something about it (like cleaning a filter); otherwise it is useless. If one approaches the specification of pressure gauges with this mentality, the number of gauges used will be reduced. If a plant uses fewer, better gauges, reliability will increase.

Pressure Gauge Designs

Two common reasons for gauge (and switch) failure are pipe vibration and water condensation, which in colder climates can freeze and damage the gauge housing. Figure 1 illustrates the design of both a traditional and a more reliable, "filled" pressure gauge. The delicate links, pivots, and pinions of a traditional gauge are sensitive to both condensation and vibration. The life of the filled gauge is longer, not only because it has fewer moving parts, but because its housing is filled with a viscous oil. This oil filling is beneficial not only because it dampens pointer vibration, but also because it leaves no room for humid ambient air to enter. As a result, water cannot condense and accumulate. Available gauge features include illuminated dials and digital readouts for better visibility, temperature compensation to correct for ambient temperature variation, differential gauges for differential pressures, and duplex gauges for dual pressure indication on the same dial. Pressure gauges are classified according to their precision, from grade 4A (permissible error of 0.1% of span) to grade D (5% error).

Protective Accessories

The most obvious gauge accessory is a shutoff valve between it and the process, which allows blocking while removing or performing maintenance. A second valve is often added for one of two reasons: draining of condensate in vapor service (such as steam), or, for higher accuracy applications, to allow calibration against an external pressure source.

Other accessories include pipe coils or siphons (Figure 5-2A), which in steam service protect the gauge from temperature damage, and snubbers or pulsation dampeners (Figure 5-2B), which can both absorb pressure shocks and average out pressure fluctuations. If freeze protection is needed, the gauge should be heated by steam or electric tracing. Chemical seals protect the gauge from plugging up in viscous or slurry service, and prevent corrosive, noxious or poisonous process materials from reaching the sensor. They also keep the process fluid from freezing or gelling in a dead-ended sensor cavity. The seal protects the gauge by placing a diaphragm between the process and the gauge. The cavity between the gauge and the diaphragm is filled with a stable, low thermal expansion, low viscosity and non-corrosive fluid. For high temperature applications, a sodium-potassium eutectic often is used; at ambient temperatures, a mixture of glycerine and water; and at low temperatures, ethyl alcohol, toluene, or silicon oil.

The pressure gauge can be located for better operator visibility if the chemical seal is connected to the gauge by a capillary tube. To maintain accuracy, capillary tubes should not be exposed to excessive temperatures and should not exceed 25 feet (7.5 m) in length. The chemical seal itself can be of four designs: off line, "flow-through" type self-cleaning, extended seal elements, or wafer elements that fit between flanges.

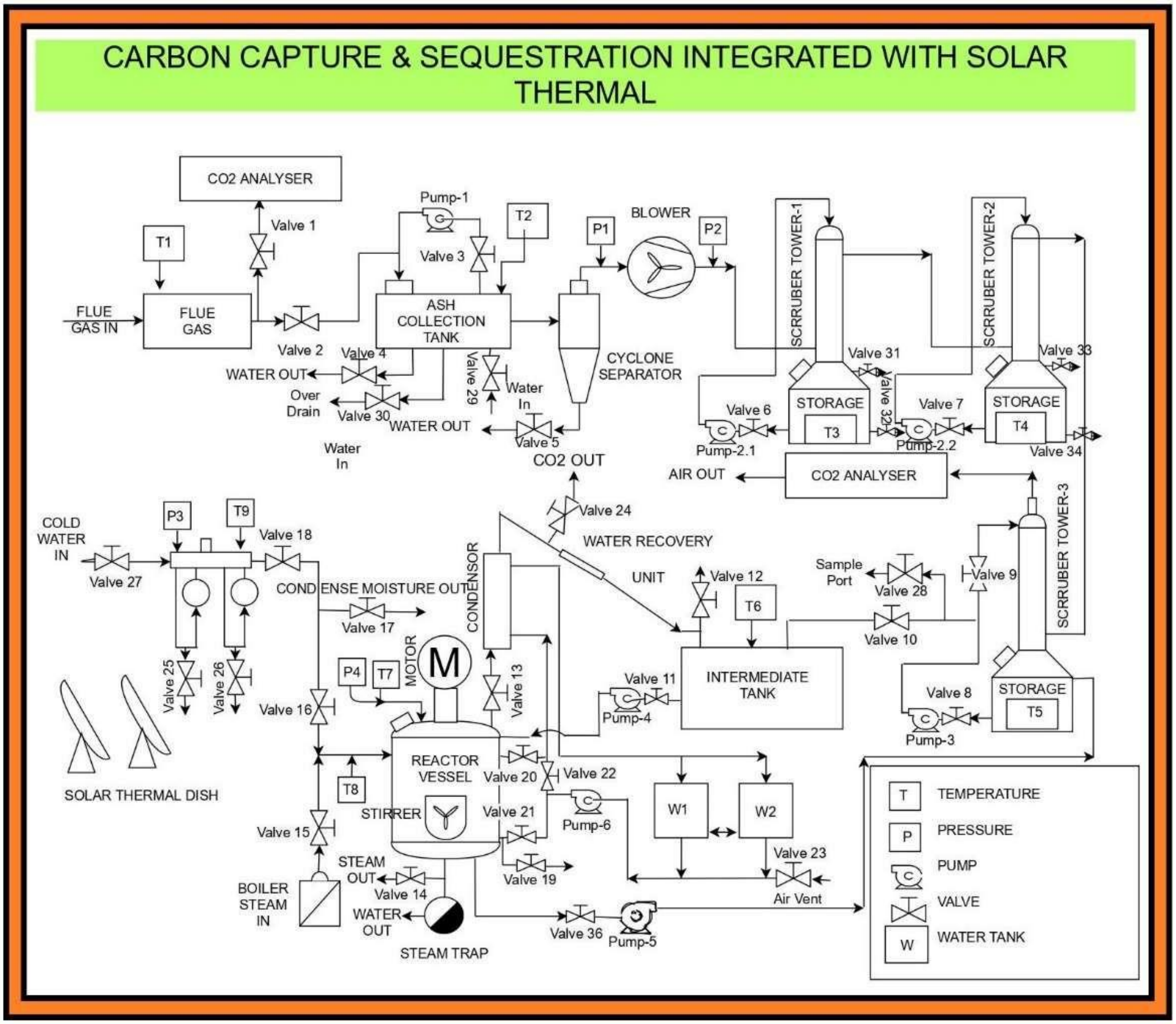
The spring rate of the diaphragm in the chemical seal can cause measurement errors when detecting low pressures (under 50 psig, 350 kPa) and in vacuum service (because gas bubbles dissolved in the filling fluid might come out of solution). For these reasons, pressure repeaters often are preferred to seals in such service. Pressure repeaters are available with 0.1% to 1% of span accuracy and with absolute pressure ranges from 0-5 mm Hg to 0-50 psia (0-0.7 to 0-350 kPa).

4. Vacuum Gauge

Measures vacuum (below atmospheric pressure). Enter the range from lowest vacuum to highest vacuum (e.g., from 0 to 30 inches of Hg VAC).

Vacuum Gauge

PLANT LAYOUT



OPERATING PROCEDURE

VALVE NO.	STEP NO.	START		REMARKS
		CCS Absorption Unit	CCS Regeneration Unit	
1	3	ON	-	
2	11	ON	-	After Co2 Analysis, BLOWER IS ON
3	4	ON	-	Pump 1 is ON
4		OFF	-	EMPTY AFTER EVERY 2SHIFT
5	5	OFF	-	OPEN TO DRAIN THE IMPURTIES AND THEN CLOSED
6	6	ON	-	On 30mins before start of the plant: PUMP 2-ON
7	7	ON	-	On 30mins before start of the plant: PUMP 2-ON
8	8	ON	-	
9	9	ON	-	Pump 3-ON
10	12	OFF	-	CLOSE VALVE 9 AND SHUT DOWN THE PLANT FOR 15 MIN START PUMP 3 ONLY.
11	13	OFF	ON	
12	14	OFF	ON	TO RELEASE THE AIR FROM THE INTERMEDIATE TANK, TO PUT BACK THE MEA SAMPLE
13	15	ON	OFF	IT MUST BE OPEN AFTER TEMPERATURE REACHES TO 135C
14	16	OFF	ON	PARTIALLY OPEN
15	17	OFF	ON	IN WINTER THE SCHEFFLER PRODUCE STEAM AT 12pm
16	18	OFF	ON	EITHER 15 OR 16 SHOULD BE OPENED IF STEAM ATTAINS THE TEMPERATURE ABOVE 140C
17	19	OFF	OFF	IT MUST BE ON TILL CONDENSED WATER IS REMOVED FROM THE CHARGED PIPE
18	20	OFF	ON	WHEN REQUIRED FROM THE SCHEFFLER
19	22	OFF	ON	TO DRAIN ALL WATER FROM COIL
20	23	OFF	OFF	
21	24	OFF	ON	
22	25	OFF	ON	
23	21	OFF	OFF	
24	26	OFF	ON	
25		OFF	OFF	ONLY OPEN AT TIME OF CLEANING
26		OFF	OFF	ONLY OPEN AT TIME OF CLEANING
27		OFF	-	Only ON at time of feeding cold water.
28	10	OFF	-	Sample is collected before Pump Start
29		OFF	-	
30	12	OFF	-	Drain valve used at time of filling to stop water entering into cyclone separator.
31	27	OFF	-	TO TAKE SAMPLE
32	28	OFF	-	TO PUT BACK THE SAMPLE
33	29	OFF	-	TO TAKE SAMPLE
34	30	OFF	-	TO PUT BACK THE SAMPLE
35	2	OFF	-	For removing Excess Steam or for Safety of Boiler
36	1	ON	-	
37	31	-	ON	AT TIME OF TRANSFER FROM REACTOR TO STORAGE TANK 3

***Please flow the order provided in the list for the smooth operation of the plant.**

Time of Shut Down

PART-A

1. OFF- the Blower
2. ON- Valve 30
3. OFF-VALVE-2
4. OFF- VALVE 35
5. SWITCH OFF PUMP-1, PUMP-2,PUMP-3
6. THEN CLOSE ALL VALVE
7. ON VALVE-4
8. ON VALVE-29 (AFTER VALVE 4 IS CLOSED)

PART-B

1. OFF-VALVE 19
2. OFF-VALVE 22
3. ON- VALVE 21
4. ON- VALVE 20

THIS PROCESS IS ON UNTILL 40℃ TEPERATURE IS OT ACHIEVED IN REACTOR.

5. OFF-STIRRER
6. OFF-ALL VALVE
7. VALVE 13 OPEN PARTIALLY TILL AMBIENT TEMPERATURE IS NOT MEET.
8. OFF-VALVE 12
9. OFF-VALVE 24
10. OFF-PUMP-6

SAFETY

HAZARD SUMMARY

- **Mono-Ethylamine** can affect you when breathed in and by passing through your skin.
- Contact can severely irritate and burn the skin and eyes with possible eye damage.
- Breathing **Mono-Ethylamine** can irritate the nose, throat and lungs causing coughing, wheezing and/or shortness of breath.
- Repeated exposure can affect the eyes causing blurred vision and seeing halos around lights, and may lead to permanent damage.
- **Mono-Ethylamine** is a HIGHLY FLAMMABLE LIQUID or GAS and a DANGEROUS FIRE HAZARD.

WORK PRACTICES

- Workers whose clothing has been contaminated by **Mono-Ethylamine** should change into clean clothing promptly.
- Contaminated work clothes should be laundered by individuals who have been informed of the hazards of exposure to **Mono-Ethylamine**.
- Eye wash fountains should be provided in the immediate work area for emergency use.
- If there is the possibility of skin exposure, emergency shower facilities should be provided.
- On skin contact with **Mono-Ethylamine**, immediately wash or shower to remove the chemical. At the end of the work shift, wash any areas of the body that may have contacted **Mono-Ethylamine**, whether or not known skin contact has occurred.
- Do not eat, smoke, or drink where **Mono-Ethylamine** is handled, processed, or stored, since the chemical can be swallowed. Wash hands carefully before eating, drinking, smoking, or using the toilet.

Clothing

- Avoid skin contact with **Mono-Ethylamine**. Wear protective gloves and clothing. Safety equipment suppliers/ manufacturers can provide recommendations on the most protective glove/clothing material for your operation.
- All protective clothing (suits, gloves, footwear, headgear) should be clean, available each day, and put on before work.

Eye Protection

- Wear indirect-vent, impact and splash resistant goggles when working with liquids.
- Wear non-vented, impact resistant goggles when working with fumes, gases, or vapors.
- Wear a face shield along with goggles when working with corrosive, highly irritating or toxic substances.
- Contact lenses should not be worn when working with this substance.

Note:-Please wear a helmet at time of operation to safeguard operator.

CHAPTER – 4.2

TRIAL RUN RESULTS

RKDF UNIVERSITY

The CPRI Sponsored Project to RKDF University, Bhopal under RSOP Scheme

Project Title:

"Post Combustion Carbon Capture & Sequestration (CCS) Plant on a Coal Fired Power Plant - Feasibility Study"

Sanctioned vide: CPRI/R&D/TC/Thermal/ 2019 Dated 06-02-2019

Period of Project: April 2019 – June 2021

Collaborator: RPI, USA & RGPV, Bhopal

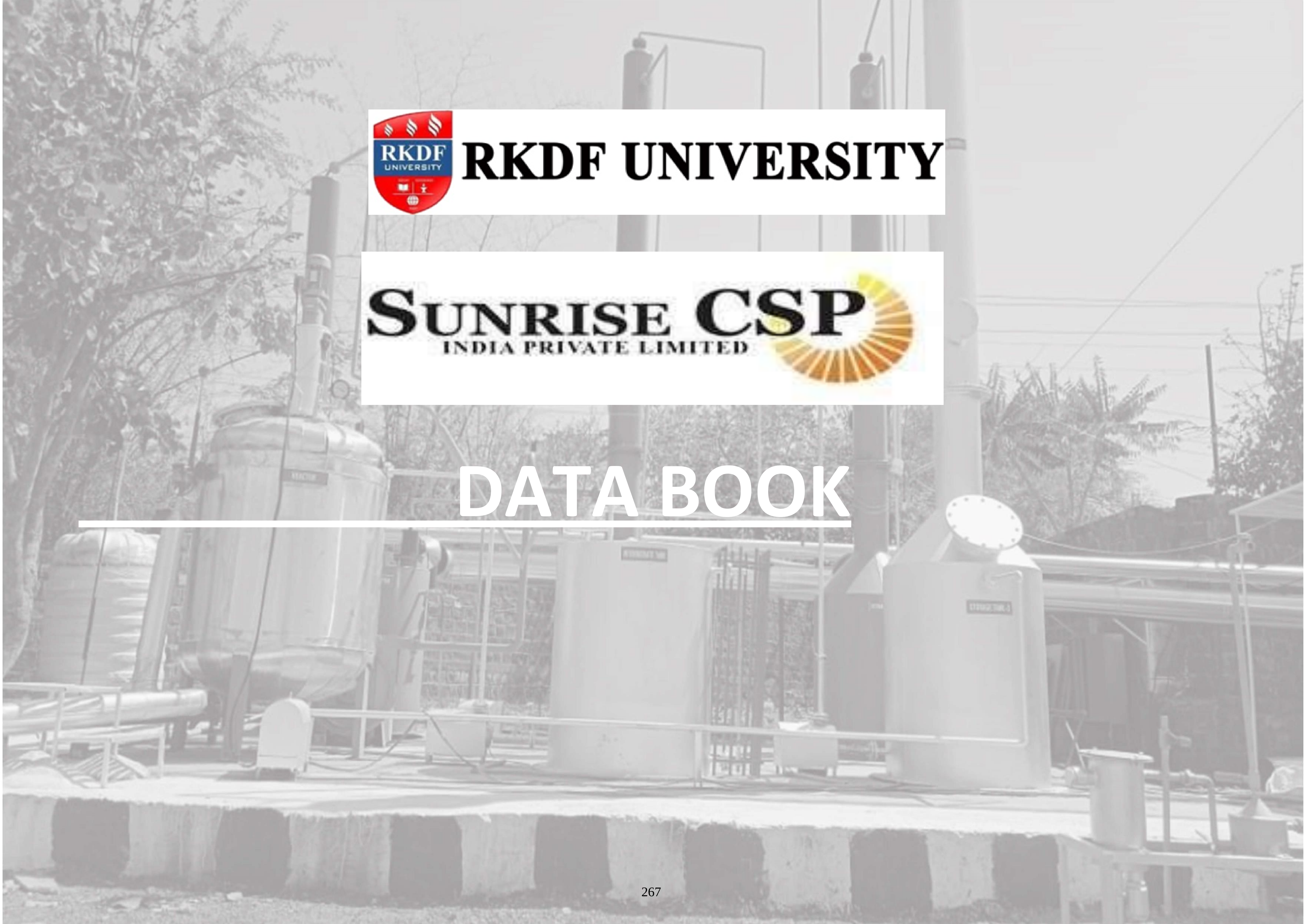
CHAPTER-4: EXPERIMENTAL PROCEDURE

DATA BOOK

PROJECT COMPLETION REPORT

Sir J C Bose Interdisciplinary Technology Park

Executing Organization: Ram Krishna Dharmarth Foundation (RKDF) University, Airport Bypass Road, Gandhi Nagar Bhopal, MP 462033



RKDF UNIVERSITY

SUNRISE CSP
INDIA PRIVATE LIMITED

DATA BOOK

S No.: 01

Date: 11/11/2020

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1	Intel Flue Gas	T				30	40	44	55	58	60	63	68	73	76	78	79	81	82	84	82	81	82	86	86	88	88	89
2	Ash Removal Tank	T				18	18	19	20	20	21	21	22	23	24	25	25	26	26	27	28	28	29	29	30	30	31	31
3	Scrubber Tower-1	T				18	19.24	20.51	22.68	22.01	21.88	24.95	22.6	29.5	23.97	22.34	24.56	24.46	27.39	23.97	27.8	26.41	29.34	25.93	26.02	25.46	25.44	25.93
4	Scrubber Tower-2	T				18.68	19.98	21.02	21.54	23.48	22.98	23	22.4	25.48	25.95	23.02	25.88	25.39	24.46	27.34	24.9	25.39	26.86	24.9	24.9	25.39	24.46	25.93
5	Scrubber Tower-3	T				19.44	22.34	24.56	25.68	24.46	27.84	28.32	29.48	34.3	29.48	30.76	27.97	28.97	29.95	28.44	26.46	26.95	25.51	30.39	27.95	27.46	27.46	28.93
6	Intermediate Tank	T				19.32	19.02	18.05	18.68	18.84	17.25	19.53	17.09	20.1	19.53	21	20.2	19.53	17.58	17.09	17.58	19.53	21	19.53	20.02	18.07	20.02	19.04
7	Reactor Vessel	T				18	21	22	25	29	31	32	33	33	36	36	33	33	33	35	35	33	30	29	28	28	28	28
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				140	152	160	170	150	170	170	160	170	160	170	160	170	155	160	170	155	160	170	155	160	165	170
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				4	6.25	7.5	9	6.25	10	10	9	10	9	10	9	10	8	9	10	6	8	10	6	7.5	8	9.5
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				13.5				11.2				9.4				13.2				11.2				11.9		
15	**EXIT CO2%**	%				11.6				9.8				8.2				11.3				9.6				10.2		
16	**Efficiency**	%				14.07				12.5				12.77				14.39				14.29				14.29		

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2

%= READING IN PERCENTAGE

S.no	Process	Time																								
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T															34	46	49	53	56	59	61	67	69	70	70	70
2	Ash Removal Tank	T															19	20	20	20	21	21	22	22	23	23	23	23
3	Scrubber Tower-1	T															18.24	19.48	20.75	22.92	22.25	22.12	25.19	22.84	29.74	24.21	22.58	24.8
4	Scrubber Tower-2	T															18.92	20.22	21.26	21.78	23.72	23.22	23.24	22.64	25.72	26.19	23.26	26.12
5	Scrubber Tower-3	T															19.68	22.58	24.8	25.92	24.7	28.08	28.56	29.72	34.54	29.72	31	28.21
6	Intermediate Tank	T															19.56	19.26	18.29	18.92	19.08	17.49	19.77	17.33	20.34	19.77	21.24	20.44
7	Reactor Vessel	T															38	38	39	39	39	40	40	41	41	41	41	40
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T															149	150	150	160	160	160	160	160	160	160	160	158
10	Cyclone Separator	P															2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P															-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P															6	6	6	7	7.5	8	8	8	8	8	8	8
13	Reactor Vessel	P															1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%																14.6				13.8				17.2		
15	**EXIT CO2%**	%																12.6				10.4				13.4		
16	**Efficiency**	%																13.7				24.64				22.09		

T= TEMPERATURE (°C)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																										
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				40	44	64	83	100	106	115	122	121	123	123	129	125	123	122	121	118	120	118	116	115	115	114
2	Ash Removal Tank	T				27	27	19	20	21	22	22	22	23	24	25	26	27	28	29	30	31	31	32	32	33	33	34
3	Scrubber Tower-1	T				18.24	19.48	21.47	23.64	22.97	22.84	25.91	23.56	30.46	24.93	23.3	25.52	25.42	28.35	24.93	28.76	27.37	30.3	26.89	26.98	26.42	26.4	26.89
4	Scrubber Tower-2	T				18.92	20.22	21.98	22.5	24.44	23.94	23.96	23.36	26.44	26.91	23.98	26.84	26.35	25.42	28.3	25.86	26.35	27.82	25.86	25.86	26.35	25.42	26.89
5	Scrubber Tower-3	T				19.68	22.58	25.52	26.64	25.42	28.8	29.28	30.44	35.26	30.44	31.72	28.93	29.93	30.91	29.4	27.42	27.91	26.47	31.35	28.91	28.42	28.42	29.89
6	Intermediate Tank	T				19.56	19.26	19.01	19.64	19.8	18.21	20.49	18.05	21.06	20.49	21.96	21.16	20.49	18.54	18.05	18.54	20.49	21.96	20.49	20.98	19.03	20.98	20
7	Reactor Vessel	T				42	41	41	38	36	35	38	43	50	52	52	52	52	52	52	52	52	52	52	52	45	43	42
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				100	115	120	130	150	155	165	170	155	165	170	170	165	170	165	170	170	175	175	170	175	165	165
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				1	2	3	3.5	6	6	8.25	10.5	7.5	9	9.5	10	9.5	10	9	10	10	11.5	11.5	10	11.5	9.5	9.5
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				15.1				13.9				14.7				13.2				12.9				13.6		
15	**EXIT CO2%**	%				12.8				11.1				12.5				11.7				10.6				11.9		
16	**Efficiency**	%				15.23				20.14				14.97				11.36				17.83				12.5		

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																								
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				32	32	36	39	42	46	49	54	57	64	67	72	74	75	78	79	80	80	81	82	81	81	82
2	Ash Removal Tank	T				20	21	21	21	22	22	22	23	23	24	24	25	26	27	27	28	28	29	29	30	30	30	30
3	Scrubber Tower-1	T				19.68	20.92	21.95	24.12	23.45	23.32	26.39	24.04	30.94	25.41	23.78	26	25.9	28.83	25.41	29.24	27.85	30.78	27.37	27.46	26.9	26.88	27.37
4	Scrubber Tower-2	T				20.12	21.42	22.46	22.98	24.92	24.42	24.44	23.84	26.92	27.39	24.46	27.32	26.83	25.9	28.78	26.34	26.83	28.3	26.34	26.34	26.83	25.9	27.37
5	Scrubber Tower-3	T				20.88	23.78	26	27.12	25.9	29.28	29.76	30.92	35.74	30.92	32.2	29.41	30.41	31.39	29.88	27.9	28.39	26.95	31.83	29.39	28.9	28.9	30.37
6	Intermediate Tank	T				20.76	20.46	19.49	20.12	20.28	18.69	20.97	18.53	21.54	20.97	22.44	21.64	20.97	19.02	18.53	19.02	20.97	22.44	20.97	21.46	19.51	21.46	20.48
7	Reactor Vessel	T				46	46	45	43	41	40	40	43	43	45	49	48	47	45	45	45	47	46	47	47	47	46	47
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				108	108	110	120	120	120	120	130	140	150	162	155	160	170	155	160	160	160	168	170	170	150	155
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				1	1.25	2	2.1	2.2	2.4	2.4	3	5	5.5	6	7.5	7.5	7.5	8	9	9	9	10	10	10	8	8.5
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				15.1				9.8				10.5				11.2				12.4				11.5		
15	**EXIT CO2%**	%				12.8				7.4				7.9				8.1				9.6				8.6		
16	**Efficiency**	%				15.23				24.49				24.76				27.68				22.58				25.22		

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																										
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				29	29	33	36	39	43	46	51	54	61	64	69	71	72	75	76	77	77	78	79	78	78	79
2	Ash Removal Tank	T				18	19	19	19	20	20	20	21	21	22	22	23	24	25	25	26	26	27	27	28	28	28	28
3	Scrubber Tower-1	T				17.72	18.96	19.99	22.16	21.49	21.36	24.43	22.08	28.98	23.45	21.82	24.04	23.94	26.87	23.45	27.28	25.89	28.82	25.41	25.5	24.94	24.92	25.41
4	Scrubber Tower-2	T				18.16	19.46	20.5	21.02	22.96	22.46	22.48	21.88	24.96	25.43	22.5	25.36	24.87	23.94	26.82	24.38	24.87	26.34	24.38	24.38	24.87	23.94	25.41
5	Scrubber Tower-3	T				18.92	21.82	24.04	25.16	23.94	27.32	27.8	28.96	33.78	28.96	30.24	27.45	28.45	29.43	27.92	25.94	26.43	24.99	29.87	27.43	26.94	26.94	28.41
6	Intermediate Tank	T				18.8	18.5	17.53	18.16	18.32	16.73	19.01	16.57	19.58	19.01	20.48	19.68	19.01	17.06	16.57	17.06	19.01	20.48	19.01	19.5	17.55	19.5	18.52
7	Reactor Vessel	T				49	49	48	46	44	43	43	46	46	48	52	51	50	48	48	48	50	49	50	50	50	49	50
8	Stem Inlet Temperature	T																										
9	Solar Thermal Dish	T				113	113	115	125	125	125	125	135	145	155	167	160	165	175	160	165	165	165	173	175	175	155	160
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				1.5	1.5	1.5	2	2	2	2	3	5	5	10	9	10	11.5	9	9.5	9.5	9.5	10.5	11.5	11.5	8	9
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				12.8				13.4				11.9				13.7				12.4				12.2		
15	**EXIT CO2%**	%				9.8				10.2				8.9				9.4				8.4				8.9		
16	**Efficiency**	%				23.44				23.88				25.21				31.39				32.26				27.05		

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																										
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				30	30	34	37	40	44	47	52	55	62	65	70	72	73	76	77	78	78	79	80	79	79	80
2	Ash Removal Tank	T				19	20	20	20	21	21	21	22	22	23	23	24	25	26	26	27	27	28	28	29	29	29	29
3	Scrubber Tower-1	T				17.77	19.01	20.04	22.21	21.54	21.41	24.48	22.13	29.03	23.5	21.87	24.09	23.99	26.92	23.5	27.33	25.94	28.87	25.46	25.55	24.99	24.97	25.46
4	Scrubber Tower-2	T				18.21	19.51	20.55	21.07	23.01	22.51	22.53	21.93	25.01	25.48	22.55	25.41	24.92	23.99	26.87	24.43	24.92	26.39	24.43	24.43	24.92	23.99	25.46
5	Scrubber Tower-3	T				18.97	21.87	24.09	25.21	23.99	27.37	27.85	29.01	33.83	29.01	30.29	27.5	28.5	29.48	27.97	25.99	26.48	25.04	29.92	27.48	26.99	26.99	28.46
6	Intermediate Tank	T				18.85	18.55	17.58	18.21	18.37	16.78	19.06	16.62	19.63	19.06	20.53	19.73	19.06	17.11	16.62	17.11	19.06	20.53	19.06	19.55	17.6	19.55	18.57
7	Reactor Vessel	T				48	48	47	45	43	42	42	45	45	47	51	50	49	47	47	47	49	48	49	49	49	48	49
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				108	118	118	118	118	128	138	148	160	153	158	168	153	158	158	158	166	168	168	148	159	165	170
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				1	2	2	2	2	3	4	6	8	6	7	10	8	9	9	9	9.5	10	10	6	8	10	11.5
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				9.6				9.8				8.8				7.4				8.1				8.9		
15	**EXIT CO2%**	%				7.5				7.4				6.2				5.7				6.1				6.4		
16	**Efficiency**	%				21.88				24.49				29.55				22.97				24.69				28.09		

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																										
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				30	30	34	37	40	44	47	52	55	62	65	70	72	73	76	77	78	78	79	80	79	79	80
2	Ash Removal Tank	T				19	20	20	20	21	21	21	22	22	23	23	24	25	26	26	27	27	28	28	29	29	29	29
3	Scrubber Tower-1	T				17.77	19.01	20.04	22.21	21.54	21.41	24.48	22.13	29.03	23.5	21.87	24.09	23.99	26.92	23.5	27.33	25.94	28.87	25.46	25.55	24.99	24.97	25.46
4	Scrubber Tower-2	T				18.21	19.51	20.55	21.07	23.01	22.51	22.53	21.93	25.01	25.48	22.55	25.41	24.92	23.99	26.87	24.43	24.92	26.39	24.43	24.43	24.92	23.99	25.46
5	Scrubber Tower-3	T				18.97	21.87	24.09	25.21	23.99	27.37	27.85	29.01	33.83	29.01	30.29	27.5	28.5	29.48	27.97	25.99	26.48	25.04	29.92	27.48	26.99	26.99	28.46
6	Intermediate Tank	T				18.85	18.55	17.58	18.21	18.37	16.78	19.06	16.62	19.63	19.06	20.53	19.73	19.06	17.11	16.62	17.11	19.06	20.53	19.06	19.55	17.6	19.55	18.57
7	Reactor Vessel	T				48	48	47	45	43	42	42	45	45	47	51	50	49	47	47	47	49	48	49	49	49	48	49
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				108	118	118	118	118	128	138	148	160	153	158	168	153	158	158	158	166	168	168	148	159	165	170
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				1	2	2	2	2	3	4	6	8	6	7	10	8	9	9	9	9.5	10	10	6	8	10	11.5
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				9.6				9.8				8.8				7.4				8.1				8.9		
15	**EXIT CO2%**	%				7.5				7.4				6.2				5.7				6.1				6.4		
16	**Efficiency**	%				21.88				24.49				29.55				22.97				24.69				28.09		

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																								
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				28	28	32	35	38	42	45	50	53	60	63	68	70	71	74	75	76	76	77	78	77	77	78
2	Ash Removal Tank	T				17	18	18	18	19	19	19	20	20	21	21	22	23	24	24	25	25	26	26	27	27	27	27
3	Scrubber Tower-1	T				18.05	19.29	20.32	22.49	21.82	21.69	24.76	22.41	29.31	23.78	22.15	24.37	24.27	27.2	23.78	27.61	26.22	29.15	25.74	25.83	25.27	25.25	25.74
4	Scrubber Tower-2	T				18.49	19.79	20.83	21.35	23.29	22.79	22.81	22.21	25.29	25.76	22.83	25.69	25.2	24.27	27.15	24.71	25.2	26.67	24.71	24.71	25.2	24.27	25.74
5	Scrubber Tower-3	T				19.25	22.15	24.37	25.49	24.27	27.65	28.13	29.29	34.11	29.29	30.57	27.78	28.78	29.76	28.25	26.27	26.76	25.32	30.2	27.76	27.27	27.27	28.74
6	Intermediate Tank	T				19.13	18.83	17.86	18.49	18.65	17.06	19.34	16.9	19.91	19.34	20.81	20.01	19.34	17.39	16.9	17.39	19.34	20.81	19.34	19.83	17.88	19.83	18.85
7	Reactor Vessel	T				50	50	49	47	45	44	44	47	47	49	53	52	51	49	49	49	51	50	51	51	51	50	51
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				112	112	110	120	120	120	120	130	140	150	162	155	160	170	155	160	160	160	168	170	170	150	155
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				1.5	1.5	1.5	2	2	2	2	3	5	5	9	8	9	10	8.5	9	9	9	10	10	10	7	8
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				13.4				12.9				13.7				11.9				12.4				12.8		
15	**EXIT CO2%**	%				9.9				7.7				8.1				8.1				8.9				8.7		
16	**Efficiency**	%				26.12				40.31				40.88				31.93				28.23				32.03		

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																										
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				27	27	31	34	37	41	44	49	52	59	62	67	69	70	73	74	75	75	76	77	76	76	77
2	Ash Removal Tank	T				16	17	17	17	18	18	18	19	19	20	20	21	22	23	23	24	24	25	25	26	26	26	26
3	Scrubber Tower-1	T				19.68	20.92	21.95	24.12	23.45	23.32	26.39	24.04	30.94	25.41	23.78	26	25.9	28.83	25.41	29.24	27.85	30.78	27.37	27.46	26.9	26.88	27.37
4	Scrubber Tower-2	T				20.12	21.42	22.46	22.98	24.92	24.42	24.44	23.84	26.92	27.39	24.46	27.32	26.83	25.9	28.78	26.34	26.83	28.3	26.34	26.34	26.83	25.9	27.37
5	Scrubber Tower-3	T				20.88	23.78	26	27.12	25.9	29.28	29.76	30.92	35.74	30.92	32.2	29.41	30.41	31.39	29.88	27.9	28.39	26.95	31.83	29.39	28.9	28.9	30.37
6	Intermediate Tank	T				20.76	20.46	19.49	20.12	20.28	18.69	20.97	18.53	21.54	20.97	22.44	21.64	20.97	19.02	18.53	19.02	20.97	22.44	20.97	21.46	19.51	21.46	20.48
7	Reactor Vessel	T				46	46	45	43	41	40	40	43	43	45	49	48	47	45	45	45	47	46	47	47	47	46	47
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				115	115	113	123	123	123	123	133	143	153	165	158	163	173	158	163	163	163	171	173	173	153	158
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				1.5	1.5	1.5	2	2	2	2	4	5	8	9.5	9	9.5	10.5	9	9.5	9	9	10	10.5	11	8	9
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				18.6				17.4				18.2				16.5				17.1				17.9		
15	**EXIT CO2%**	%				11.1				10.9				10.7				10.1				9.8				9.1		
16	**Efficiency**	%				40.32				37.36				41.21				38.79				42.69				49.16		

T= TEMPERATURE (°C)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																									
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				40	55	64	69	73	79	83	83	93	96	99	100	101	101	101	100	98	97	95	93	92	90	87
2	Ash Removal Tank	T				18	19	20	21	22	23	24	24	25	25	26	27	27	27	28	28	28	29	29	30	30	30	30
3	Scrubber Tower-1	T				18.69	19.72	21.89	21.22	21.09	24.16	21.81	28.71	23.18	21.55	23.77	23.67	26.6	23.18	27.01	25.62	28.55	25.14	25.23	24.67	24.65	25.14	26.12
4	Scrubber Tower-2	T				19.19	20.23	20.75	22.69	22.19	22.21	21.61	24.69	25.16	22.23	25.09	24.6	23.67	26.55	24.11	24.6	26.07	24.11	24.11	24.6	23.67	25.14	25.42
5	Scrubber Tower-3	T				21.55	23.77	24.89	23.67	27.05	27.53	28.69	33.51	28.69	29.97	27.18	28.18	29.16	27.65	25.67	26.16	24.72	29.6	27.16	26.67	26.67	28.14	27.99
6	Intermediate Tank	T				18.23	17.26	17.89	18.05	16.46	18.74	16.3	19.31	18.74	20.21	19.41	18.74	16.79	16.3	16.79	18.74	20.21	18.74	19.23	17.28	19.23	18.25	19.79
7	Reactor Vessel	T				37	38	38	39	39	40	40	41	41	44	47	54	56	54	50	45	45	44	40	39	37	40	41
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				90	95	100	105	110	110	115	120	130	135	140	150	155	162	162	162	160	160	160	155	155	145	145
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				1	1	1	1	2	2	2.5	3	4	4.5	5	7	7.5	8.5	8.5	8.5	7.5	7.5	7.5	6.5	6	5	5
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				18.3				16.9				18.2				17.3				16.1				17.9		
15	**EXIT CO2%**	%				10.8				10.4				10.1				10.1				9.8				10.8		
16	**Efficiency**	%				40.98				38.46				44.51				41.62				39.13				39.66		

T= TEMPERATURE (°C)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																										
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				27	40	49	54	51	49	46	44	40	38	35	33	33	32	32	32	32	31	31	30	30	29	29
2	Ash Removal Tank	T				18	21	23	23	23	23	24	24	24	24	23	24	24	24	24	24	24	24	24	23	23	23	24
3	Scrubber Tower-1	T				18.55	19.25	20.28	22.45	21.78	21.65	24.72	22.37	29.27	23.74	22.11	24.33	24.23	27.16	23.74	27.57	26.18	29.11	25.7	25.79	25.23	25.21	25.7
4	Scrubber Tower-2	T				18.99	19.75	20.79	21.31	23.25	22.75	22.77	22.17	25.25	25.72	22.79	25.65	25.16	24.23	27.11	24.67	25.16	26.63	24.67	24.67	25.16	24.23	25.7
5	Scrubber Tower-3	T				19.75	22.11	24.33	25.45	24.23	27.61	28.09	29.25	34.07	29.25	30.53	27.74	28.74	29.72	28.21	26.23	26.72	25.28	30.16	27.72	27.23	27.23	28.7
6	Intermediate Tank	T				19.63	18.79	17.82	18.45	18.61	17.02	19.3	16.86	19.87	19.3	20.77	19.97	19.3	17.35	16.86	17.35	19.3	20.77	19.3	19.79	17.84	19.79	18.81
7	Reactor Vessel	T				28	28	28	28	28	30	31	30	28	27	23	23	23	23	23	22	22	22	22	22	22	21	20
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				40	42	42	45	45	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				14.3				12.9				14.2				13.3				12.1				12.9		
15	**EXIT CO2%**	%				6.8				6.4				6.9				7.1				6.8				6.8		
16	**Efficiency**	%				52.45				50.39				51.41				46.62				43.8				47.29		

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																								
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				17	25	35	49	53	52	50	49	46	45	43	42	41	40	39	39	38	37					
2	Ash Removal Tank	T				17	17	18	18	17	17	50	17	17	18	18	18	18	18	19	19	19	20					
3	Scrubber Tower-1	T				19.13	20.16	22.33	21.66	21.53	24.6	22.25	29.15	23.62	21.99	24.21	24.11	27.04	23.62	27.45	26.06	28.99	25.58					
4	Scrubber Tower-2	T				19.63	20.67	21.19	23.13	22.63	22.65	22.05	25.13	25.6	22.67	25.53	25.04	24.11	26.99	24.55	25.04	26.51	24.55					
5	Scrubber Tower-3	T				21.99	24.21	25.33	24.11	27.49	27.97	29.13	33.95	29.13	30.41	27.62	28.62	29.6	28.09	26.11	26.6	25.16	30.04					
6	Intermediate Tank	T				18.67	17.7	18.33	18.49	16.9	19.18	16.74	19.75	19.18	20.65	19.85	19.18	17.23	16.74	17.23	19.18	20.65	19.18					
7	Reactor Vessel	T				21	21	22	23	26	26	27	27	29	32	34	35	36	38	37	37	34	34					
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40					
10	Cyclone Separator	P				2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5					
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5					
12	Solar Thermal Dish	P				2	2	2	2	2	2	2	2	2	2	2	2	2.25	2.25	2.25	2.25	2.25	2.25					
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
14	**Inlet CO2%**	%				10.4				11.3				11.7				13.4				9.7						
15	**EXIT CO2%**	%				5.7				6.2				6.7				6.4				5.5						
16	**Efficiency**	%				45.19				45.13				42.74				52.24				43.3						

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																									
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				16	20	25	31	35	59	56	56	49	45	42	39	34	37	36	35	34						
2	Ash Removal Tank	T				16	16	17	17	18	18	18	18	18	18	18	18	18	18	18	18	18						
3	Scrubber Tower-1	T				16	16	16	20	20	20	21	21	21	21	21	21	21	21	21	21	21						
4	Scrubber Tower-2	T				16	16	16	20	20	20	21	21	21	21	21	21	21	21	21	21	21						
5	Scrubber Tower-3	T				18	18	18	34	35	35	36	34	30	28	27	31	31	31	31	31	31						
6	Intermediate Tank	T				17	17	18	18	18	18	18	18	18	18	17	17	17	17	17	17	17						
7	Reactor Vessel	T				20	22	24	25	26	26	25	25	24	24	24	24	24	24	24	24	24						
8	Stem Inlet Temperature	T				Sensor Not Installed																						
9	Solar Thermal Dish	T				35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35						
10	Cyclone Separator	P				2.5	2.5	2.5	3	3	3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5						
11		P				-2.5	-2.5	-2.5	-3	-3	-3	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5						
12	Solar Thermal Dish	P				2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25						
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1						
14	**Inlet CO2%**	%				14.4				13.9				9.6				15.2				12.6						
15	**EXIT CO2%**	%				7.8				6.6				5.3				8.4				6.2						
16	**Efficiency**	%				45.83				52.52				44.79				44.74				50.79						

T= TEMPERATURE (°C)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S.no	Process	Time																									
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T				18	26	52	52	50	51	50	48	47	46	46	45	43	42	41	40	40	40	40	39	38	37	36
2	Ash Removal Tank	T				16	15	16	16	16	17	17	17	18	18	18	18	18	18	19	19	19	19	19	19	19	19	20
3	Scrubber Tower-1	T				16	16	22.95	20.6	27.5	21.97	14.65	22.46	22.46	25.39	21.97	24.9	24.41	27.34	23.93	20.02	22.46	23.44	23.93	38.09	21	22.95	22.46
4	Scrubber Tower-2	T				16	16	21	20.4	25.48	22.95	33.2	25.88	25.39	22.46	27.34	24.9	25.39	26.86	24.9	24.9	25.39	22.46	23.93	20.02	21.97	19.53	21.97
5	Scrubber Tower-3	T				18	18	28.32	21.48	34.3	21.48	30.76	21.97	21.97	22.95	23.44	22.46	22.95	20.51	25.39	22.95	22.46	22.46	23.93	22.46	23.44	25.39	21.48
6	Intermediate Tank	T				17	17	19.53	17.09	20.1	19.53	21	20.2	19.53	17.58	17.09	17.58	19.53	21	19.53	20.02	18.07	20.02	19.04	19.04	18.55	21.97	sss
7	Reactor Vessel	T				34	35	36	37	37	41	41	38	38	38	40	40	38	35	34	33	33	33	33	31	29	28	28
8	Stem Inlet Temperature	T																										
9	Solar Thermal Dish	T				30	30	30	30	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
10	Cyclone Separator	P				2.5	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P				-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P				2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
13	Reactor Vessel	P				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				18.4				17.4				20.9				17.1				17.6				17.8		
15	**EXIT CO2%**	%				2.7				3.4				3.8				3.7				3.8				3.4		
16	**Efficiency**	%				85.33				80.46				81.82				78.36				78.41				80.9		

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%= READING IN PERCENTAGE

S. No.	Process	Time																									
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T	14	15	14	17	20	27	29	41	45	44	43	43	43	41	41	41	40	39	38	40	40	38	38	37	36	36
2	Ash Removal Tank	T	15	15	15	15	15	16	16	16	16	16	16	16	17	17	17	17	18	18	18	18	18	18	18	18	18	18
3	Scrubber Tower-1	T				17.58	21	20.51	21	21.97	18.07	22.46	21.97	22.46	22.46	31.25	21.48	23.44	23.44	23.93	21.48	21.97	22.46	22.46	19.53	22.46	21.48	22.46
4	Scrubber Tower-2	T				17.58	19.53	19.53	21	20.02	18.07	17.58	19.04	21	20.48	19.04	21.97	24.9	23.44	23.44	21.97	21.97	22.95	21.97	21.97	22..46	21.48	21
5	Scrubber Tower-3	T				20.02	20.02	20.02	20.02	19.04	19.53	21	21	21	20.58	20.51	21	20.02	21.48	21.97	21	21.48	21.97	21.97	21.97	22.46	20.51	21.97
6	Intermediate Tank	T				17.59	18.55	17.58	19.04	18.55	17.58	19.04	19.04	19.04	18.55	20.02	19.04	21	19.04	19.53	19.04	20.02	19.53	19.53	19.04	19.04	20.02	18.07
7	Reactor Vessel	T	12	14	16	18	21	23	24	25	23	24	24	24	25	25	25	26	26	26	24	24	24	24	22	19	51	54
8	Stem Inlet Temperature	T																										
9	Solar Thermal Dish	T	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
10	Cyclone Separator	P	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11		P	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish	P	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
13	Reactor Vessel	P	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	**Inlet CO2%**	%				6.8				9.5				9.1				11.4				7.4				8.1		
15	**EXIT CO2%**	%				1.4				2.2				2.6				2.8				2.2				2.1		
16	**Efficiency**	%				79.412				76.842				71.429				75.439				70.27				74.074		

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S. No.	Process	Time																										
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T	15	20	34	53	52	49	47	46	45	45	44	44	44	44	46	46	41	40	40	39	38	38	44	37		
2	Ash Removal Tank	T	12	13	12	12	13	13	14	14	14	14	15	15	15	16	16	16	17	17	17	17	18	18	18	19		
3	Scrubber Tower-1	T	14.65	15.63	18.55	26.86	19.04	19.53	18.55	28.32	22.95	39.55	22.95	24.9	25.39	24.6	22.46	25.88	23.93	26.86	28.32	26.86	26.45	26.86	22.65	26.37		
4	Scrubber Tower-2	T	18.55	18.55	18.55	20.02	20.02	19.53	23.44	23.93	22.95	29.3	24.41	28.32	26.37	27.4	22.95	24.65	21.48	29.79	28.81	29.79	28.38	28.32	23.54	28.32		
5	Scrubber Tower-3	T	20.02	20.02	20.51	19.07	19.04	21.48	20.02	21	21.97	22.46	22.95	23.44	23.44	24.05	27.34	34.25	33.69	24.9	23.93	23.44	27.25	34.92	28.96	25.39		
6	Intermediate Tank	T	23.44	23.93	25.88	26.37	26.37	25.88	26.37	27.34	26.37	24.41	25.88	23.44	22.46	22.57	24.41	25.39	24.9	23.44	23.44	22.95	23.12	22.46	22.81	21.97		
7	Reactor Vessel	T	39	40	38	36	36	36	49	76	74	72	71	69	68	68	59	55	55	56	57	58	58	58	58	56		
8	Stem Inlet Temperature	T																										
9	Solar Thermal Dish	T	40	40	40	50	60	75	80	75	90	100	110	120	120	128	130	140	135	150	160	160	160	160	160	160		
10	Cyclone Separator	P	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2	2	2	2	2	2	2		
11		P	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2	-2	-2	-2	-2	-2	-2		
12	Solar Thermal Dish	P	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.5	3	3	4.5	5	7	6	7	7.5	8	9	10	10	8		
13	Reactor Vessel	P	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
14	**Inlet CO2%**	%				12.4				9.9				11.1				14.3				13.5				9.3		
15	**EXIT CO2%**	%				2.9				2.5				2.9				2.3				2.8				2.8		
16	**Efficiency**	%				76.613				74.747				73.874				83.916				79.259				69.892		

T= TEMPERATURE (°C)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S. No.	Process	Time																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	11	15	21	23	36	45	50	51	49	48	48	47	46	45	44	43	43	43	43	42	42	42	41	39	39	39	39
2	Ash Removal Tank	12	12	12	12	13	13	13	13	14	14	14	15	15	15	16	16	17	17	17	18	18	19	19	19	19	20	20
3	Scrubber Tower-1	14.65	16.11	24.9	18.59	23.44	19.04	21.97	20.02	22.95	25.88	25.39	22.95	29.3	26.37	27.83	28.32	28.81	26.37	30.76	30.76	30.27	27.83	17.09	26.86	40.04	22.46	25.39
4	Scrubber Tower-2	16.6	18.07	19.53	21.46	15.63	20.51	22.46	21.48	23.44	24.41	25.39	27.86	28.81	31.74	28.32	28.32	29.79	31.74	31.74	31.25	31.74	28.32	48.83	32.71	31.74	34.18	33.69
5	Scrubber Tower-3	18.07	20.51	18.55	19.53	20.02	22.46	22.95	22.46	22.95	23.44	23.93	23.93	24.41	24.41	23.44	25.39	23.93	24.9	25.39	25.39	25.39	26.37	24.9	25.88	26.86	25.39	26.86
6	Intermediate Tank	23.44	22.46	27.34	29.73	26.88	30.27	27.83	27.34	30.27	28.81	26.86	26.86	23.9.	22.95	23.93	25.39	26.37	26.37	25.88	25.88	25.88	24.9	27.83	25.88	25.39	24.41	23.44
7	Reactor Vessel	23	26	25	27	26	47	73	96	117	126	135	142	145	147	142	147	136	140	145	135	137	135	127	119	106	96	83
8	Stem Inlet Temperature	Sensor Not Installed																										
9	Solar Thermal Dish	45	45	50	60	70	90	110	115	125	140	150	160	160	160	160	170	160	165	170	160	165	170	150	160	160	160	160
10	Cyclone Separator	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2	2.5	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
11		-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2	-2.5	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
12	Solar Thermal Dish	2	2	2	2	2.25	2.25	2.5	2.5	3	5	7	8	10	8	10	11.5	7.5	9	10.5	7.5	9	11.5	6	7.5	7.5	7.5	7.5
13	Reactor Vessel	1	1	1	1	1	1	1	1	2	2	3	4	5	5	5	5	5	4	4	4	4	4	3	2	1	1	1
14	**Inlet CO2%**					7.6				10.2				12.7				11.6				10.7				12.8		
15	**EXIT CO2%**					2.9				2.5				2.5				2.3				2.9				3		
16	**Efficiency**	#####				61.842				75.49				80.315				80.172				72.897				76.563		
17	**CO2 Release**	**0**				**0**				**0**		**2.5**			**3.5**						**3.5**							

T= TEMPERATURE (°C)
P= PRESSURE (Kg/cm2)
%= READING IN PERCENTAGE

S. No.	**Process**	**Time**																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	19	20	27	37	47	49	50	50	49	51	50	47	46	45	45	42	40	44	45	44	44	43	41	42	43	43	43
2	Ash Removal Tank	11	11	11	12	12	13	13	13	14	15	15	15	16	16	16	17	17	18	18	18	19	19	20	20	20	21	21
3	Scrubber Tower-1	20.02	19.53	19.53	19.04	19.53	20.51	22.95	20.02	31.74	25.88	27.83	19.04	27.83	21.48	10.74	30.27	30.27	30.76	30.76	32.71	31.25	29.79	31.25	28.81	30.76	31.25	29.3
4	Scrubber Tower-2	20.51	18.55	19.04	17.58	21	18.07	22.95	23.93	28.81	27.83	27.83	28.81	29.3	27.83	31.74	31.25	31.25	32.71	31.74	33.2	33.69	32.23	30.76	30.27	34.67	34.18	33.69
5	Scrubber Tower-3	21.97	22.46	22.46	21.97	20.02	20.51	23.44	22.46	23.93	24.9	24.41	25.39	26.86	24.41	26.86	25.88	25.39	26.86	26.37	26.86	26.37	27.34	28.32	28.32	27.34	28.32	28.81
6	Intermediate Tank	32.23	32.23	31.25	30.27	32.71	30.27	29.3	30.76	31.74	31.74	27.83	29.3	26.37	25.39	26.37	26.86	27.83	28.32	27.83	27.34	27.34	26.86	26.86	26.37	26.86	25.88	25.39
7	Reactor Vessel	19	20	25	27	29	29	32	38	41	77	96	128	134	141	141	135	131	128	127	127	128	130	131	132	131	130	110
8	Stem Inlet Temperature	40	43	47	51	77	77	54	77	84	84	118	143	154	158	158	154	138	138	139	140	137	144	143	145	146	149	128
9	Solar Thermal Dish	60	70	80	100	115	130	140	150	160	170	160	165	170	160	170	155	170	160	170	160	170	170	155	155	160	160	160
10	Cyclone Separator	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3
11		-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
12	Solar Thermal Dish	2	2	2	2.25	2.5	4	5	6	7	10	7.5	9	11	8	10	7	10	8	10	7.5	9	11	6	7	7.5	7.5	8
13	Reactor Vessel	1	1	1	1	1	1	1	1	1	1	1	3	4	5	5	5	4	3	3	3	3	3	3	3	3	3	3
14	**Inlet CO2%**	10.9				11.5				17.1				9.8				13.2				12.2				12.9		
15	**EXIT CO2%**	2.3				2.8				3.2				3.1				3.1				3.6				4.2		
16	**Efficiency**	78.899				75.652				81.287				68.367				76.515				70.492				67.442		
17	**CO2 Release**	**0**				**0**				**0**				**2.5**			**3.7**	**3.6**					**3.8**					

S. No.	**Process**	**Unit**		**Time**																										
				10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T-1	Degree C	21	22	29	39	49	51	52	52	51	53	52	49	48	47	47	44	42	46	47	46	46	45	43	44	45	45	45
2	Ash Removal Tank	T-2	Degree C	12	12	12	13	13	14	14	14	15	16	16	16	17	17	17	18	18	19	19	19	20	20	21	21	21	22	22
3	Scrubber Tower-1	T-3	Degree C	21.13	20.64	20.64	20.15	20.64	21.62	24.06	21.13	32.85	26.99	28.94	20.15	28.94	22.59	11.85	31.38	31.38	31.87	31.87	33.82	32.36	30.9	32.36	29.92	31.87	32.36	30.41
4	Scrubber Tower-2	T-4	Degree C	21.62	19.66	20.15	18.69	22.11	19.18	24.06	25.04	29.92	28.94	28.94	29.92	30.41	28.94	32.85	32.36	32.36	33.82	32.85	34.31	34.8	33.34	31.87	31.38	35.78	35.29	34.8
5	Scrubber Tower-3	T-5	Degree C	23.08	23.57	23.57	23.08	21.13	21.62	24.55	23.57	25.04	26.01	25.52	26.5	27.97	25.52	27.97	26.99	26.5	27.97	27.48	27.97	27.48	28.45	29.43	29.43	28.45	29.43	29.92
6	Intermediate Tank	T-6	Degree C	33.34	33.34	32.36	31.38	33.82	31.38	30.41	31.87	32.85	32.85	28.94	30.41	27.48	26.5	27.48	27.97	28.94	29.43	28.94	28.45	28.45	27.97	27.97	27.48	27.97	26.99	26.5
7	Reactor Vessel	T-7	Degree C	21	22	26	29	29	29	32	38	41	77	96	128	134	141	141	135	131	128	127	127	128	130	131	132	131	130	110
8	Stem Inlet Temperature	T-9	Degree C	24	24	25	51	77	77	54	77	84	84	118	143	154	158	158	154	138	138	139	140	137	144	143	145	146	149	128
9	Solar Thermal Dish	T-8	Degree C	65	75	85	105	120	135	145	155	165	175	165	170	175	165	175	160	175	165	175	165	175	175	160	160	165	165	165
10	Cyclone Separator	P-1	Kg/cm2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3
11		P-2	Kg/cm2	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
12	Solar Thermal Dish	P-3	Kg/cm2	1	1	1	1	2	4	5	7	9	11.5	9.5	10	11	9	11	8	11	9.5	11	9	11	11	8	8	9	9	9.5
13	Reactor Vessel	P-4	Kg/cm2	1	1	1	1	1	1	1	1	1	1	1	2	3	4	4	3.5	4	4	4	4	4	4	4	4	5	5	1
14	**Inlet CO2%**			12.1				12.7				18.3				11				14.4				13.4				14.1		
15	**EXIT CO2%**			3.5				4				4.4				4.3				4.3				4.8				5.4		
16	**Efficiency**			71.074				68.504				75.956				60.909				70.139				64.179				61.702		
17	**CO2 Release**		**%**	**0**				**0**				**0**				**3.5**	**4.6**	**4.8**	**5.1**	**3.4**				**3.7**				**5.5**	**6.1**	

S. No.	**Process**	**Time**																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	21	22	29	39	49	53	54	54	53	55	54	51	50	49	49	46	44	48	49	48	48	47	45	46	47	47	47
2	Ash Removal Tank	12	12	12	13	13	15	15	15	16	17	17	17	18	18	18	19	19	20	20	20	21	21	22	22	22	23	23
3	Scrubber Tower-1	21.13	20.64	20.64	20.15	20.64	21.77	24.21	21.28	33	27.14	29.09	20.3	29.09	22.74	12	31.53	31.53	32.02	32.02	33.97	32.51	31.05	32.51	30.07	32.02	32.51	30.56
4	Scrubber Tower-2	21.62	19.66	20.15	18.69	22.11	19.33	24.21	25.19	30.07	29.09	29.09	30.07	30.56	29.09	33	32.51	32.51	33.97	33	34.46	34.95	33.49	32.02	31.53	35.93	35.44	34.95
5	Scrubber Tower-3	23.08	23.57	23.57	23.08	21.13	21.77	24.7	23.72	25.19	26.16	25.67	26.65	28.12	25.67	28.12	27.14	26.65	28.12	27.63	28.12	27.63	28.6	29.58	29.58	28.6	29.58	30.07
6	Intermediate Tank	33.34	33.34	32.36	31.38	33.82	31.53	30.56	32.02	33	33	29.09	30.56	27.63	26.65	27.63	28.12	29.09	29.58	29.09	28.6	28.6	28.12	28.12	27.63	28.12	27.14	26.65
7	Reactor Vessel	26	27	31	34	34	34	37	43	46	82	101	123	139	146	146	140	136	133	132	132	133	135	136	137	136	135	115
8	Stem Inlet Temperature	27	27	28	54	80	80	57	80	87	87	121	146	157	161	161	157	141	141	142	143	140	147	146	148	149	152	131
9	Solar Thermal Dish	65	75	85	105	120	120	130	140	150	160	150	155	160	150	160	145	160	150	160	150	160	160	145	145	150	150	150
10	Cyclone Separator	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3
11		-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
12	Solar Thermal Dish	1	1	1	1	2	2	4	5	7	8	7	7.5	8	7	8	7.5	8	7	8	7	8	8	6.5	7	7	8	8
13	Reactor Vessel	1	1	1	1	1	1	1	1	1	1	1	2	4	5	5	4	3	3	3	3	3	3	3.5	4	4	4	2
14	**Inlet CO2%**	12.1				13.7				18.6				11.7				14.2				14.7				14.2		
15	**EXIT CO2%**	3.5				3.1				3.5				3.4				3.4				3.9				3.5		
16	**Efficiency**	71.074				77.372				81.183				70.94				76.056				73.469				75.352		
17	**CO2 Release**	**0**				**0**				**0**				**5.5**	**5.5**		**5.7**	**3.3**	**3.3**			**3.3**				**3.8**		

T= TEMPERATURE (°C)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S. No.	Process	Time																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	15	16	23	33	43	45	46	46	45	47	46	43	42	41	41	38	36	40	41	40	40	39	37	38	39	39	39
2	Ash Removal Tank	9	9	9	10	10	11	11	11	12	13	13	13	14	14	14	15	15	16	16	16	17	17	18	18	18	19	19
3	Scrubber Tower-1	18.91	18.42	18.42	17.93	18.42	19.4	21.84	18.91	30.63	24.77	26.72	17.93	26.72	20.37	9.63	29.16	29.16	29.65	29.65	31.6	30.14	28.68	30.14	27.7	29.65	30.14	28.19
4	Scrubber Tower-2	19.4	17.44	17.93	16.47	19.89	16.96	21.84	22.82	27.7	26.72	26.72	27.7	28.19	26.72	30.63	30.14	30.14	31.6	30.63	32.09	32.58	31.12	29.65	29.16	33.56	33.07	32.58
5	Scrubber Tower-3	20.86	21.35	21.35	20.86	18.91	19.4	22.33	21.35	22.82	23.79	23.3	24.28	25.75	23.3	25.75	24.77	24.28	25.75	25.26	25.75	25.26	26.23	27.21	27.21	26.23	27.21	27.7
6	Intermediate Tank	31.12	31.12	30.14	29.16	31.6	29.16	28.19	29.65	30.63	30.63	26.72	28.19	25.26	24.28	25.26	25.75	26.72	27.21	26.72	26.23	26.23	25.75	25.75	25.26	25.75	24.77	24.28
7	Reactor Vessel	16	16	17	43	69	69	46	69	76	76	110	135	146	150	150	146	130	130	131	132	129	136	135	137	138	141	120
8	Stem Inlet Temperature	25	25	34	72	72	114	107	97	127	133	137	142	147	137	147	132	147	137	147	137	147	147	132	132	137	137	137
9	Solar Thermal Dish	45	55	65	85	100	115	125	135	145	155	145	150	155	145	155	140	155	145	155	145	155	155	140	140	145	145	145
10	Cyclone Separator	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3
11		-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
12	Solar Thermal Dish	1	1	1	1	1	2	3	4	5	7	6	7	8	7	8	6	7.5	6	7	6.5	8.5	8.5	6	6	6.5	6.5	6.5
13	Reactor Vessel	1	1	1	1	1	1	1	1	1	1	1	3	4	5	5	4.5	3	3	3	3	3	3	3	3	4	4	2
14	**Inlet CO2%**	9.7				11.3				16.1				9.2				11.7				12.2				11.7		
15	**EXIT CO2%**	2.1				2.6				2				1.9				2.2				2.5				3		
16	**Efficiency**	78.35052				76.99115				87.57764				79.34783				81.19658				79.5082				74.35897		
17	**CO2 Release**	**0**				**0**				**0**			**3.8**	**4.1**	**7.5**	**7.8**	**7.9**	**4.5**	**3**			**3**				**3**		

T= TEMPERATURE (°C)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S. No.	Process	Time																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	13	14	21	31	41	43	44	44	43	45	44	41	40	39	39	36	34	38	39	38	38	37	35	36	37	37	37
2	Ash Removal Tank	8	8	8	9	9	10	10	10	11	12	12	12	13	13	13	14	14	15	15	15	16	16	17	17	17	18	18
3	Scrubber Tower-1	19.15	18.66	18.66	18.17	18.66	19.64	22.08	19.15	30.87	25.01	26.96	18.17	26.96	20.61	9.87	29.4	29.4	29.89	29.89	31.84	30.38	28.92	30.38	27.94	29.89	30.38	28.43
4	Scrubber Tower-2	19.64	17.68	18.17	16.71	20.13	17.2	22.08	23.06	27.94	26.96	26.96	27.94	28.43	26.96	30.87	30.38	30.38	31.84	30.87	32.33	32.82	31.36	29.89	29.4	33.8	33.31	32.82
5	Scrubber Tower-3	21.1	21.59	21.59	21.1	19.15	19.64	22.57	21.59	23.06	24.03	23.54	24.52	25.99	23.54	25.99	25.01	24.52	25.99	25.5	25.99	25.5	26.47	27.45	27.45	26.47	27.45	27.94
6	Intermediate Tank	31.36	31.36	30.38	29.4	31.84	29.4	28.43	29.89	30.87	30.87	26.96	28.43	25.5	24.52	25.5	25.99	26.96	27.45	26.96	26.47	26.47	25.99	25.99	25.5	25.99	25.01	24.52
7	Reactor Vessel	13	13	14	40	66	66	43	66	73	73	107	122	133	147	147	143	127	127	128	129	126	133	132	134	135	138	117
8	Stem Inlet Temperature	17	17	26	64	64	106	99	89	119	125	129	134	139	129	139	124	139	129	139	129	139	139	124	124	129	129	129
9	Solar Thermal Dish	50	60	70	90	105	120	130	140	150	160	150	155	160	150	160	145	160	150	160	150	160	160	145	145	150	150	150
10	Cyclone Separator	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3
11		-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
12	Solar Thermal Dish	1	1	1	1	1	2	3	4	8	9	8	8.5	9	8	9	7.5	9	8	9	8	9	9	8	8	8.5	8.5	8.5
13	Reactor Vessel	1	1	1	1	1	1	1	1	1	1	1	2	3	5	5	4	3	3	3	3	3	3	3	3	3	4	2
14	**Inlet CO2%**	9.1				10.7				15.5				8.6				11.1				11.6				11.1		
15	**EXIT CO2%**	1.5				2				2.4				2.3				2.3				2.8				3.1		
16	**Efficiency**	83.516				81.308				84.516				73.256				79.279				75.862				72.072		
17	**CO2 Release**	**0**				**0**				**0**				**0**	**11.2**	**11.5**	**11.9**	**5.7**				**5.2**				**5.2**		

S. No.	Process	Time																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas											34	34	35	38	40	47	47	46	44	44	44	44	44	43	43	42	42
2	Ash Removal Tank											18	18	19	19	19	20	20	21	22	22	22	23	23	24	24	24	24
3	Scrubber Tower-1	26.37										26.37	26.86	25.39	32.71	30.76	29.79	31.74	41.99	31.25	30.27	33.69	32.23	32.71	31.25	32.23	33.2	31.74
4	Scrubber Tower-2	26.37										26.37	26.86	28.81	31.25	32.23	30.76	30.76	32.23	32.23	33.69	32.23	32.71	32.23	33.69	33.69	32.71	31.25
5	Scrubber Tower-3	25.88										25.88	25.88	28.32	29.79	28.81	30.27	26.81	28.32	29.3	29.79	28.81	29.79	31.25	30.76	32.23	31.25	31.74
6	Intermediate Tank	33.69										33.69	32.23	33.69	37.11	32.71	33.29	33.29	32.23	32.23	31.74	31.74	31.74	32.71	32.23	30.27	29.79	30.76
7	Reactor Vessel											34	35	32	30	28	29	34	36	65	77	93	103	107	111	114	121	118
8	Stem Inlet Temperature										71	33	33	32	32	32	34	123	121	120	132	142	143	141	143	143	148	132
9	Solar Thermal Dish											40	45	47	50	52	60	70	78	82	87	90	95	100	100	100	105	105
10	Cyclone Separator											3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
11												-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
12	Solar Thermal Dish	0										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	Reactor Vessel											1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
14	**Inlet CO2%**									13.5				12.6				12.9				13.7				13.4		
15	**EXIT CO2%**									2.8				3.4				2.8				2.6				3.3		
16	**Efficiency**	#####								79.259				73.016				78.295				81.022				75.373		
17	**CO2 Release**	**0**				**0**				**0**				**0**				**0**				**0**				**0**	**3.5**	

S. No.	**Process**	**Time**																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas									45	48	50	50	48	47	45	43	42	41	41	40	39	39	39	40	40	41	41
2	Ash Removal Tank									22	22	22	22	22	23	23	23	24	24	24	25	25	26	26	26	26	27	27
3	Scrubber Tower-1									28.32	26.86	27.83	28.32	29.3	55.66	0.98	24.9	49.32	69.82	31.74	84.96	37.6	33.2	29.79	32.23	43.95	32.71	33.2
4	Scrubber Tower-2									27.93	27.83	27.34	27.83	29.3	11.23	40.04	62.5	51.27	58.11	32.23	71.78	31.74	37.6	36.62	32.23	9.28	33.69	33.69
5	Scrubber Tower-3									29.79	29.3	29.3	29.3	29.3	36.13	7.81	5.37	28.32	30.27	29.79	47.36	30.76	30.76	30.76	29.79	28.32	31.74	32.23
6	Intermediate Tank									34.18	34.67	32.23	34.67	32.23	26.37	32.71	48.63	26.37	32.71	31.25	3.42	32.23	30.27	31.25	31.74	29.3	28.81	29.25
7	Reactor Vessel									37	36	34	34	34	33	56	63	83	90	98	107	108	107	116	116	117	14	12
8	Stem Inlet Temperature									37	39	39	40	40	80	135	128	135	132	139	138	140	139	150	140	145	155	159
9	Solar Thermal Dish									80	85	90	100	115	125	130	140	145	150	155	160	165	165	165	120	130	140	145
10	Cyclone Separator									3	3	3	3	3	3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
11										-3	-3	-3	-3	-3	-3	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-3	-2.5	-2.5	-2.5	-2.5
12	Solar Thermal Dish									0	0	0	0	1	1.5	2	2.5	3	4	5	6	7	7	7.5	3	3.5	4	4
13	Reactor Vessel									1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	1	1
14	**Inlet CO2%**									12.3				13.6				13.9				12.7				12.4		
15	**EXIT CO2%**									2.7				3.8				2.9				2.8				3.5		
16	**Efficiency**	#####								78.049				72.059				79.137				77.953				71.774		
17	**CO2 Release**	**0**				**0**				**0**				**0**				**0**				**0**				**0**		

S. No.	Process	Time																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas											50	51	52	55	55	52	50	47	46	45	43	42	41	42	44		
2	Ash Removal Tank											18	19	19	20	20	21	22	22	23	23	23	24	24	25	25		
3	Scrubber Tower-1											24.41	31.25	29.79	31.74	52	35.64	32.71	29.79	56.15	30.27	36.13	37.6	33.2	41.5	41.5		
4	Scrubber Tower-2											28.81	31.25	29.3	31.74	32.71	35.16	37.6	37.11	56.64	21.97	37.6	39.06	39.55	41.02	42.48		
5	Scrubber Tower-3											28.81	33.2	29.79	32.23	28.32	30.76	32.71	32.23	27.83	34.67	34.67	35.16	36.13	37.11	37.11		
6	Intermediate Tank											39.06	41.99	39.55	37.6	34.67	33.2	36.13	33.69	39.55	36.13	34.67	34.67	36.13	35.64	36.13		
7	Reactor Vessel											40	53	61	64	68	78	83	92	102	109	112	115	33	100	102		
8	Stem Inlet Temperature									37	39	39	40	40	80	135	128	135	132	139	138	140	139	150	140	145		
9	Solar Thermal Dish											75	85	95	110	120	125	130	140	145	150	155	160	165	170	175		
10	Cyclone Separator											2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5		
11												-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5		
12	Solar Thermal Dish											0	0	0	1	1.5	2	2.25	3	4	5	6	6.5	7	8	9		
13	Reactor Vessel											1	1	1	1	1	1	1	1	1	1	1	2	1	1	1		
14	**Inlet CO2%**									13.2				14.4				13.7				12.6				11.6		
15	**EXIT CO2%**									4.3				4.1				3.5				2.3				2.9		
16	**Efficiency**	#####				#####				67.424				71.528				74.453				81.746				75		
17	**CO2 Release**	**0**				**0**				**0**				**0**				**0**				**0**				**0**		

T= TEMPERATURE (°C)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S No.: 26 **Date:** 04/02/2021

S No.	Process	Time																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	23	34	45	44	43	41	42	43	43	41	41	40	39	37	39	42	41	40	39	40	40						
2	Ash Removal Tank	15	18	25	16	17	18	18	18	18	18	19	19	20	20	20	21	21	21	22	22	22						
3	Scrubber Tower-1	19.53	20.51	21	22.95	23.44	23.93	23.93	25.39	28.32	12.21	25.88	28.81	27.83	28.32	28.32	28.32	44.92	31.25	31.74	27.83	30.27						
4	Scrubber Tower-2	15.63	24.41	20.51	23.44	21.48	23.44	22.95	24.41	22.95	42.48	27.34	27.34	28.32	29.3	29.3	31.25	30.76	32.71	14.65	58.59	35.64						
5	Scrubber Tower-3	21.48	24.41	25.39	21.48	25.39	26.37	24.9	25.39	24.41	25.39	26.86	27.34	26.37	27.34	27.34	26.86	26.37	26.37	34.18	21	25.88						
6	Intermediate Tank	26.86	29.3	30.76	24.9	32.23	33.2	31.25	31.74	32.71	8.79	31.74	32.23	30.76	28.32	26.86	27.83	28.81	28.32	40.53	4.88	28.81						
7	Reactor Vessel	34	42	36	36	40	54	70	66	88	111	126	124	126	123	132	140	146	150	152	119	50						
8	Stem Inlet Temperature	40	43	47	51	146	144	143	143	143	145	146	143	143	140	143	147	156	164	164	138	79						
9	Solar Thermal Dish	40	45	50	55	60	65	70	80	85	90	100	120	125	130	140	145	150	155	160	165	170						
10	Cyclone Separator	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3-Jan	3	3	3	3						
11		-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3						
12	Solar Thermal Dish	0	0	0	0	0	0	0	0	0	0	0.5	1	1.5	2	2.5	4	5	6	6.5	7	8						
13	Reactor Vessel	1	1	1	1	1	1	1	1	1	1	2	2	3	3	3	5	5	5	5	2	1						
14	**Inlet CO2%**	9.8				13				11.4				12.6				11.9				10.8						
15	**EXIT CO2%**	2.1				2.6				2.5				2.3				2.7				2.5						
16	**Efficiency**	78.571				80				78.07				81.746				77.311				76.852				#####		
17	**CO2 Release**	**0**				**0**				**0**		**2.5**	**4.7**	**4.8**					**11.9**	**12.3**	**3.5**							

T= TEMPERATURE (℃)

P= PRESSURE (Kg/cm2)

%= READING IN PERCENTAGE

S No.	Process	Time																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	17	18	25	35	45	47	48	48	47	49	48	45	44	43	43	40	38	42	43	42	42	41	39	40	41	41	41
2	Ash Removal Tank	10	10	10	11	11	12	12	12	13	14	14	14	15	15	15	16	16	17	17	17	18	18	19	19	19	20	20
3	Scrubber Tower-1	19.15	18.66	18.66	18.17	18.66	19.64	22.08	19.15	31.1	25.24	27.19	18.4	27.19	20.84	10.1	29.63	29.63	30.12	30.12	32.07	30.61	29.15	30.61	28.17	30.12	30.61	28.66
4	Scrubber Tower-2	19.64	17.68	18.17	16.71	20.13	17.2	22.08	23.06	28.17	27.19	27.19	28.17	28.66	27.19	31.1	30.61	30.61	32.07	31.1	32.56	33.05	31.59	30.12	29.63	34.03	33.54	33.05
5	Scrubber Tower-3	21.1	21.59	21.59	21.1	19.15	19.64	22.57	21.59	23.29	24.26	23.77	24.75	26.22	23.77	26.22	25.24	24.75	26.22	25.73	26.22	25.73	26.7	27.68	27.68	26.7	27.68	28.17
6	Intermediate Tank	31.36	31.36	30.38	29.4	31.84	29.4	28.43	29.89	31.1	31.1	27.19	28.66	25.73	24.75	25.73	26.22	27.19	27.68	27.19	26.7	26.7	26.22	26.22	25.73	26.22	25.24	24.75
7	Reactor Vessel	33	34	35	31	27	27	34	42	36	36	40	54	70	66	88	111	126	124	126	123	132	140	146	150	152	155	155
8	Stem Inlet Temperature	38	41	45	49	44	42	40	43	47	51	146	144	143	143	143	145	146	143	143	140	143	147	156	164	164	168	167
9	Solar Thermal Dish	50	60	70	90	105	120	130	140	152	162	152	157	162	152	162	147	162	152	162	152	162	162	147	147	152	152	152
10	Cyclone Separator	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3
11		-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
12	Solar Thermal Dish	1	1	1	1	1	2	3	4	8	9	8	8.5	9	8	9	7.5	9	8	9	8	9	9	8	8	8.5	8.5	8.5
13	Reactor Vessel	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	3	2	3	5	6	6	6	6	6
14	**Inlet CO2%**	9.1				10.7				15				16.2				15.5				14.4				13.4		
15	**EXIT CO2%**	2.5				3				5.1				3.9				3.3				3.1				3.7		
16	**Efficiency**	72.527				71.963				66				75.926				78.71				78.472				72.388		
17	**CO2 Release**	**0**				**0**				**0**				0				0				0	11.5	12.1	12.9	13.7	14.5	15.5

T= TEMPERATURE (°C)

P= PRESSURE (Kg/cm2)

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S No.	Process	Time																										
		10:00	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	23	24	31	41	51	53	54	54	53	55	54	51	50	49	49	46	44	48	49	48	48	47	45	46	47	47	47
2	Ash Removal Tank	13	13	13	14	14	15	15	15	16	17	17	17	18	18	18	19	19	20	20	20	21	21	22	22	22	23	23
3	Scrubber Tower-1	21.25	20.76	20.76	20.27	20.76	21.74	24.18	21.25	32.97	27.11	29.06	20.27	29.06	22.71	11.97	31.5	31.5	31.99	31.99	33.94	32.48	31.02	32.48	30.04	31.99	32.48	30.53
4	Scrubber Tower-2	21.74	19.78	20.27	18.81	22.23	19.3	24.18	25.16	30.04	29.06	29.06	30.04	30.53	29.06	32.97	32.48	32.48	33.94	32.97	34.43	34.92	33.46	31.99	31.5	35.9	35.41	34.92
5	Scrubber Tower-3	23.2	23.69	23.69	23.2	21.25	21.74	24.67	23.69	25.16	26.13	25.64	26.62	28.09	25.64	28.09	27.11	26.62	28.09	27.6	28.09	27.6	28.57	29.55	29.55	28.57	29.55	30.04
6	Intermediate Tank	33.46	33.46	32.48	31.5	33.94	31.5	30.53	31.99	32.97	32.97	29.06	30.53	27.6	26.62	27.6	28.09	29.06	29.55	29.06	28.57	28.57	28.09	28.09	27.6	28.09	27.11	26.62
7	Reactor Vessel	23	26	25	27	26	47	73	96	117	126	135	142	145	147	142	147	136	140	145	147	152	155	154	148	149	141	128
8	Stem Inlet Temperature	-	25	40	27	29	73	113	134	135	143	154	162	156	168	164	164	158	159	162	168	168	168	174	171	154	158	147
9	Solar Thermal Dish	55	65	75	95	110	125	135	145	152	162	152	157	162	152	162	147	162	152	162	152	162	162	147	147	152	152	152
10	Cyclone Separator	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3
11		-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
12	Solar Thermal Dish	1	1	1	1	2	3	4	5	8	9	8	8.5	9	8	9	7.5	9	8	9	8	9	9	8	7	8.5	8.5	8.5
13	Reactor Vessel	1	1	1	1	1	1	1	1	1	2	3	4	4	4	4	5	3	4	5	5	6	6	6	6	6	5	3
14	**Inlet CO2%**	12.4				14				14.7				15.9				15.2				14.1				13.1		
15	**EXIT CO2%**	2.8				3.3				3.8				4.6				3.2				2.8				3.4		
16	**Efficiency**	77.41935				76.42857				74.1496599				71.06918				78.94737				80.14184				74.0458		
17	**CO2 Release**	**0**				**0**				**0**				**0**								**14.5**	**15.5**	**15.8**	**15.1**	**14.7**	**12.3**	

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S No.	**Process**	Time																									
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T		29	43	49	48	52	48	47	46	47	48	47	46	46	48	45	42	43	44	43	44	43	43	38		
2	Ash Removal Tank	T		19	18	19	20	20	21	21	21	22	22	22	23	24	24	24	24	25	25	25	26	26	26	26		
3	Scrubber Tower-1	T		26.37	24.9	25.39	24.9	25.39	23.44	24.9	24.9	26.86	27.34	30.75	28.81	31.25	31.25	31.74	30.27	31.74	32.23	31.74	32.23	34.18	34.67	32.23		
4	Scrubber Tower-2	T		25.88	25.39	25.88	23.44	24.41	25.88	24.90	27.83	28.81	29.3	29.79	29.3	31.25	30.27	32.71	30.27	33.2	24.67	34.18	34.18	34.67	35.64	33.20		
5	Scrubber Tower-3	T		33.79	32.32	29.88	31.83	32.32	31.83	31.43	34.76	34.27	34.76	35.25	33.33	35.25	34.76	34.27	34.27	34.76	35.74	35.74	35.74	35.74	36.23	36.71		
6	Intermediate Tank	T		24.41	24.41	24.41	24.9	22.46	25.88	25.39	24.9	25.39	25.39	26.37	24.9	24.41	24.41	24.41	25.39	27.34	26.86	26.86	26.86	28.32	27.83	26.37		
7	Reactor Vessel	T		23	26	25	27	26	47	73	96	117	126	135	142	145	147	142	147	136	140	145	135	137	135	70		
8	Stem Inlet Temperature	T		-	25	40	27	9	73	73	84	115	123	124	122	126	128	144	144	138	139	142	135	132	131	71		
9	Solar Thermal Dish	T		60	60	65	75	80	85	95	100	110	120	122	127	130	135	140	140	140	145	150	150	155	160	160		
10	Cyclone Separator	P		2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3		
11		P		-2.5	-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3		
12	Solar Thermal Dish	P		0	0	0	0	0	0	0	0	1	1.25	1.75	2	2.25	2.75	3	3	3	4	5	5	5.5	6	6		
13	Reactor Vessel	P		0	0	0	0	0	0	0	0	0	0.5	0.5	0.5	0.5	1.5	1.5	1.5	0.5	1.5	1.5	1.5	1.5	1.5	1.5		
14	**Inlet CO2%**	%				13.2				14.6				14.2				13.8				12.2				13.9		
15	**EXIT CO2%**	%				3.3				3.8				3.6				3.4				3.9				3.5		
16	**Efficiency**	%				75				73.972603				74.647887				75.3623				68.032787				74.820144		
17	**CO2 Release**		**%**	**0**				**0**				**0**		**0**			**14.4**	**14.5**	**14.6**	**15.1**		**18.8**		**5.6**		**0.0**		

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S No.	**Process**	Time																								
		T/P	10:15	10:30	10:45	11:00	11:15	11:30	11:45	12:00	12:15	12:30	12:45	1:00	1:15	1:30	1:45	2:00	2:15	2:30	2:45	3:00	3:15	3:30	3:45	4:00	4:15	4:30
1	Intel Flue Gas	T		25	28	32	34	36	38	44	49	49	47	45	48	50	52	48	46	48	48	48	48	46	47	49	44	42
2	Ash Removal Tank	T		21	21	21	21	21	22	22	22	23	23	23	24	24	25	25	26	26	26	26	26	26	27	27	27	27
3	Scrubber Tower-1	T		25.39	27.34	26.86	23.44	25.39	28.32	28.21	28.81	29.3	31.74	31.74	31.25	32.71	32.71	32.23	35.64	34.67	32.23	31.74	31.74	35.64	34.67	37.6	36.27	36.13
4	Scrubber Tower-2	T		24.41	26.86	25.39	26.86	27.83	28.32	24.16	28.9	31.25	31.74	31.67	32.23	33.69	33.16	34.67	35.16	34.67	33.64	32.18	31.71	34.18	35.06	37.6	36.62	36.13
5	Scrubber Tower-3	T		33.79	35.25	33.79	31.34	33.3	35.25	33.79	34.76	35.74	35.74	36.23	36.71	36.71	35.74	36.23	36.71	36.71	35.25	36.71	36.71	37.2	36.71	39.67	38.32	39.06
6	Intermediate Tank	T		23.44	24.41	24.41	23.93	24.41	24.9	23.93	26.37	26.37	25.39	25.39	24.41	24.41	25.88	24.41	24.41	25.39	25.39	25.88	21.97	22.46	23.93	25.88	26.37	27.34
7	Reactor Vessel	T		18	24	47	29	44	49	69	86	115	124	133	141	147	144	149	149	145	149	141	143	145	147	151	149	144
8	Stem Inlet Temperature	T		-	35	56	37	55	73	73	96	127	134	144	147	155	154	156	158	155	155	160	160	157	156	154	158	161
9	Solar Thermal Dish	T		40	45	50	65	80	95	100	110	115	120	130	135	140	145	150	155	160	160	160	160	160	155	155	160	160
10	Cyclone Separator	P		2.5	2.5	2.5	2.5	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
11		P		-2.5	-2.5	-2.5	-2.5	-2.5	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3
12	Solar Thermal Dish	P		0	0	0	0	0	0	0	1	1	1.5	2.25	2.5	3	3.5	5	6	7	7.25	6.5	4.5	3.5	3.5	4.5	5	5.5
13	Reactor Vessel	P		0	0	0	0	0	0	0	0	0	0.5	2	3	3	4.5	5	5	5	5	4.5	4.5	4.5	5	5	5	5
14	**Inlet CO2%**	%				12.1				13.4				13.5				12.9				1				11.6		
15	**EXIT CO2%**	%				3.5				4.4				3.9				3.7				1				2.6		
16	**Efficiency**	%				71.07438				67.16418				71.11111				71.31783				0				77.58621		
17	**CO2 Release**		%	**0**				**0**						**0**		**16.8**	**17.2**	**18**	**18.4**	**17.2**	**17.9**	**16**	**15.9**	**16.1**	**17.3**	**17.7**	**17.2**	**14.9**

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%= READING IN PERCENTAGE

CHAPTER – 5

RESULTS, DISCUSSION & ANALYSIS – PRIME OUTPUT

CHAPTER – 5.1

SEQUESTRATION OPTIONS

Chapter – 5.1: SEQUESTRATION OPTIONS – Preamble & Introduction

- **5.1.1 Production of Hydrogen**
- **5.1.2 Bio-diesel through Algae Route**
- **5.1.3 Captured CO2 to depleted Coal mines Captured CO2 for EOR & Other NOVEL Options of Sequestration**

Chapter – 5.1: SEQUESTRATION OPTIONS

[1] Preamble & [2] Introduction

[1] PREAMBLE

Despite the fact that we in India have taken a giant leap forward in increasing the installed capacity from a mere 1713 MW in 1950 to over 3,79.13 MW as on March2021, the renewable energy sources however contribute 24.5% with total capacity of over 91,154 MW. This contribution has a major social and economic impact on rural and remote area population and towards our commitment towards abatement of Climate Change. The growth of clean energy technologies for mega Power generation, such as the Solar Mega Power under Mission mode, Solar Thermal and PV, Clean Coal Technologies, CCTs, i.e. Supercritical power plants, Integrated Gasification Combined Cycle (IGCC) and fluidized bed combustion (FBC) are key to the success Green Power Mission for India. Carbon Capture & Sequestration (CCS) is considered as the frontier Green Energy technology.

Mitigation options for CO2 reduction which have been taken up in the Country include GHG emission reduction in power sector through adoption of Co-generation, Combined cycle, Clean Coal Technologies and Coal Beneficiation. The technology up gradation through life extension of old polluting units is also expected to increase the generating efficiency of these units thereby reducing CO2 emissions.

A major thrust on CO2 reduction on long term and sustainable basis would however come through adoption of advanced technologies of power generation like Supercritical/Ultra-supercritical power cycles, Integrated Gasification Combined Cycles (IGCC), Fluidized Bed Combustion/Gasification Technologies; all these categorized as Clean Coal Technologies (CCTs) and so on. In addition to Clean Coal Technologies, India is currently sitting on a gold mine of opportunities of adoption of CCT based Power development in the forthcoming five year plans.

The future Power sector initiatives worldwide will witness Green Power Technologies for Mega Power production through Energy efficient and environmentally benign Super-critical and IGCC technologies and the renewable energy technologies for rural and remote area applications. The country's National Power Policy will witness a strong linkage between Energy Plans and Environmental protection. Serious investment must go in to Research and Innovations in basic low- Carbon Energy Technologies, Renewables, Carbon Capture & Sequestration (CCS), energy farming and bio fuel developments.

CCS technology is however still in the demonstration phase, and it is important that India is not left behind in this area. While there is a considerable amount of work already underway domestically, there may still be a need for research collaborations and knowledge sharing and transfer. These areas of research include development of new adsorbents, better process integration of capture equipment, and conversion of CO2 to useful multipurpose fuels / products.

Various Technology options of 'Application' of CCS on a large coal fired unit – A Rationale

1) General Use of CO2
2) Chemical Application of CO2
3) Enhanced Fossil Fuel Recovery
4) Application of CO2 for Bio Use

1) General Use of CO2

i. Beverages / Dry ice / Cooling (liquid CO2) / Supercritical food application - De caffeine / remove cholesterol

ii. Neutralization of waste water

iii. Desalinated water mineralization

iv. Welding

v. Semiconductor cleaning

i) Beverages / Dry Ice

Carbon dioxide gas is used to carbonate soft drinks, beers and wine. Frozen solid carbon dioxide, in the form of Dry Ice is used for the refrigeration of foodstuffs, especially ice cream, meat products, and frozen foods. In addition, dry ice is used for the following applications:

- Dry ice pellets are used to replace sandblasting when removing paint from surfaces. It aids in reducing the cost of disposal and cleanup.
- Dry ice is mixed with moulded substances that must be kept cold. For example, dry ice is mixed with moulded rubber articles in a tumbling drum to chill them sufficiently so that the thin flash or rind becomes brittle and breaks off.
- Dry ice is used to chill aluminium rivets. These harden rapidly at room temperature, but remain soft if kept cold with dry ice.

ii) Neutralization of Waste Water

Alkaline wastewater is produced from various industries such as the iron and steel making industries, textile and dyeing industries, pulp and paper industries, and power plants. Such industries generate highly alkaline wastewater (11.4 pH average), which must be neutralized before it can be discharged or sent for further biological treatment. As an alternative neutralizing agent, CO2 offers several advantages over mineral acids;

a) CO2 is not a highly toxic material and is safer to personnel and requires no special protective equipment to handle.

b) Due to its natural buffering action, CO2 cannot reduce the pH below 5, even if over dosing occurs.

c) The neutralization process becomes environmentally friendly since CO2 does not produce residual anions such as sulphate and chloride and even friendlier if recycled CO2 from flue gases were used.

d) Replacement of an existing mineral acid neutralization system or the erection of a new CO2 system can be achieved at a lower cost.

iii) Desalinated Water Mineralization

Desalted waters or highly soft waters produced by desalination plants cannot be directly used as they are unpalatable, corrosive and unhealthy. Re-mineralization is necessary in order to overcome these problems.

One of the advanced methods of treating desalinated water is water conditioning by supplementation with salt tablets. However the use of CO2 can also be used as part of a cost-effective post treatment, resulting in chemically stable and re-mineralized water, satisfying agricultural needs and complying with the most recent WHO recommendations.

A commonly used operation in the re-mineralization process is to contact CO2 acidified desalinated water with a bed of domestic limestone. Limestone dissolution provides two essential ingredients to the water—bicarbonate alkalinity and calcium content:

$$CaCO3 + CO2 + H2O = Ca+ + 2HCO3.$$

iv) Welding

Carbon dioxide is also used in welding, where in the welding arc, it reacts to oxidize most metals. Use in the automotive industry is common where it is used as a welding gas primarily because it is much less expensive than more inert gases such as argon or helium.

When used for MIG welding, CO2 use is sometimes referred to as MAG welding, standing for Metal Active Gas; as CO2 can react at these high temperatures. It tends to produce a hotter puddle than truly inert atmospheres, improving the flow characteristics.

v) Semi-Conductor Cleaning

Semiconductor devices include the various types of transistor, solar cells, many kinds of diodes and digital and Ana log integrated circuits. Semi-conductor solar photovoltaic panels directly convert light energy into electrical energy. It is well known that semi-conductor device performance and reliability are critically affected by chemical contaminants and particulate impurities on the device surface. CFCs used to be used as a cleaning agent but are now banned due to their impact on the ozone layer.

2) Chemical Application of CO2 in Production of:

i. Urea
ii. Methanol
iii. Soda Ash
iv. DME

i) Urea Production

For use in industry, urea is produced from synthetic ammonia and carbon dioxide. Large quantities of carbon dioxide are produced during the manufacture of ammonia from coal or from hydrocarbons such as natural gas and petroleum derived raw materials. Such point sources of CO2 facilitate direct synthesis of urea. The various urea processes are characterized by the conditions under which urea formation takes place and the way in which unconverted reactants are further processed. The process consists of two main equilibrium reactions, with incomplete conversion of the reactants.

The first is an exothermic reaction of liquid ammonia with CO2 to form (H2N-COONH4):

$$2\ NH3 + CO2 \leftrightarrow H2N\text{-}COONH4$$

The second is an endothermic decomposition of ammonium carbamate into urea and water:

$$H2N\text{-}COONH4 \leftrightarrow (NH2)2CO + H2O$$

ii) Methanol Production

The largest use of methanol is mainly in making other chemicals. About 40% of methanol is converted to formaldehyde, and from there into products as diverse as plastics, plywood, paints, explosives, and permanent press textiles. Methanol is used on a limited basis to fuel internal combustion engines. Today, synthesis gas is most commonly produced from the methane component in natural gas rather than from coal. Three processes are commercially practiced. At moderate pressures of 4 MPa (40 atm) and high temperatures (around 850 °C), methane reacts with steam on a nickel catalyst to produce syngas according to the chemical equation:

$$CH4 + H2O \rightarrow CO + 3\ H2$$

This reaction, commonly called steam-methane reforming or SMR, is endothermic and the heat transfer limitations place limits on the size of and pressure in the catalytic reactors used. Methane can also undergo partial oxidation with molecular oxygen to produce syngas, as the following equation shows:

$$2\ CH_4 + O_2 \rightarrow 2\ CO + 4\ H_2$$

This reaction is exothermic and the heat given off can be used in-situ to drive the steam-methane reforming reaction. When the two processes are combined, it is referred to as auto thermal reforming. The ratio of CO and H_2 can be adjusted to some extent by the water-gas shift reaction,

$$CO + H_2O \rightarrow CO_2 + H_2$$

The carbon monoxide and hydrogen then react on a second catalyst to produce methanol. Today, the most widely used catalyst is a mixture of copper, zinc oxide, and alumina. At 5–10 MPa (50–100 atm) and 250 °C, it can catalyze the production of methanol from carbon monoxide and hydrogen with high selectivity:

$$CO + 2\ H_2 \rightarrow CH_3OH$$

iii) Soda Ash

Soda Ash (Sodium Carbonate) Sodium carbonate (also known as washing soda, soda crystals or soda ash or "Soda Carbonate"), Na_2CO_3, is a sodium salt of carbonic acid. It most commonly occurs as a crystalline heptahydrate, which readily effloresces to form a white powder, the monohydrate; and is domestically well known for its everyday use as a water softener.

The manufacture of glass is one of the most important uses of sodium carbonate. When it is combined with sand (SiO_2) and calcium carbonate ($CaCO_3$) and heated to very high temperatures, then cooled very rapidly, glass is produced. This type of glass is known as soda lime glass. Sodium carbonate is also used as a relatively strong base in various settings. Several processes exist today using CO_2 to enhance production of Soda Ash such as the Leblanc, Solvay etc. Processes

iv) Di-methyl ether (DME) production

Di-methyl ether (DME) is the organic compound with the formula CH_3OCH_3. When combusted, DME produces minimal NO_x and CO. DME can act as a clean fuel when burned in engines properly optimized for DME.

Today, DME is primarily produced by converting hydrocarbons, predominantly sourced from natural gas (and to a lesser extent via gasification of coal), to synthesis gas (syngas). Synthesis gas is then converted into methanol in the presence of catalyst (usually copper-based), with subsequent methanol dehydration in the presence of a different catalyst (for example, silica alumina) resulting in the production of DME.

3) Enhanced Fossil Fuel Recovery

i) CO2 Enhanced Oil Recovery (EOR)
ii) Enhanced Coal Bed Methane (ECBM)

i. CO2 Enhanced Oil Recovery (EOR):-

Three major categories of EOR have been found to be commercially successful to varying degrees:

- Thermal recovery, which involves the introduction of heat such as the injection of steam to lower the viscosity, or thin, the heavy viscous oil, and improve its ability to flow through the reservoir. Thermal techniques account for over 40 percent of U.S. EOR production, primarily in California.

- Gas injection, which uses gases such as natural gas, nitrogen, or carbon dioxide that expand in a reservoir to push additional oil to a production wellbore, or other gases that dissolve in the oil to lower its viscosity and improves its flow rate. Gas injection accounts for nearly 60 percent of EOR production in the United States.

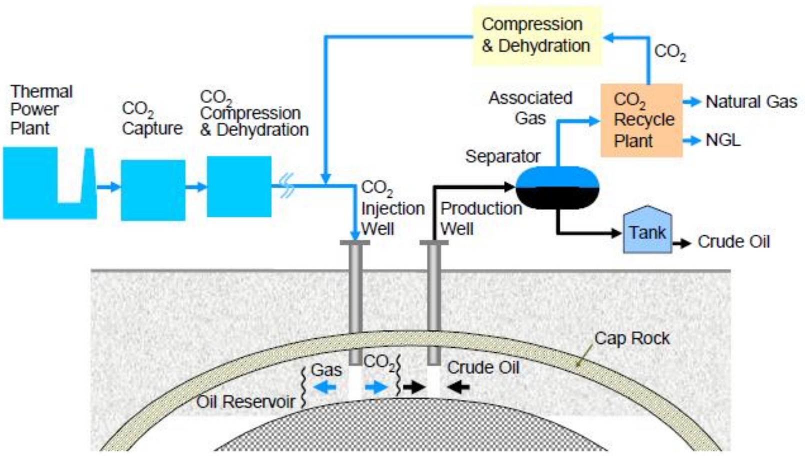
- Chemical injection, which can involve the use of long-chained molecules called polymers to increase the effectiveness of water floods, or the use of detergent-like surfactants to help lower the surface tension that often prevents oil droplets from moving through a reservoir. Chemical techniques account for about one percent of U.S. EOR production. Each of these techniques has been hampered by its relatively high cost and, in some cases, by the unpredictability of its effectiveness.

CO2 Injection Offers Considerable Potential Benefits

The EOR technique that is attracting the most new market interest is carbon dioxide (CO2)-EOR. First tried in 1972 in Scurry County, Texas, CO2 injection has been used successfully throughout the Permian Basin of West Texas and eastern New Mexico, and is now being pursued to a limited extent in Kansas, Mississippi, Wyoming, Oklahoma, Colorado, Utah, Montana, Alaska, and Pennsylvania.

Until recently, most of the CO2 used for EOR has come from naturally-occurring reservoirs. But new technologies are being developed to produce CO2 from industrial applications such as natural gas processing, fertilizer, ethanol, and hydrogen plants in locations where naturally occurring reservoirs are not available. One demonstration at the Dakota Gasification Company's plant in Beulah, North Dakota is producing CO2 and delivering it by a 204-mile pipeline to the Weyburn oil field in Saskatchewan, Canada.

CO2 Injection and Recycling System in EOR



Enhanced Coal Bed Methane (ECBM):-

Enhanced coal bed methane recovery is a method of producing additional coalbed methane from a source rock, similar to enhanced oil recovery applied to oil fields. Carbon dioxide (CO_2) injected into a bituminous coal bed would occupy pore space and also adsorb onto the carbon in the coal at approximately twice the rate of methane (CH_4), allowing for potential enhanced gas recovery. This technique may be used in conjunction with carbon capture and storage in mitigation of global warming where the carbon dioxide that is sequestered is captured from the output of fossil fuel power plants.

4) Application of CO2 for Bio Use

i) Greenhouses
ii) Micro Algae - Bio diesel

i) Greenhouses :-

The benefits of carbon dioxide supplementation on plant growth and production within the greenhouse environment have been well understood for many years.

Carbon dioxide (CO_2) is an essential component of photosynthesis (also called carbon assimilation). Photosynthesis is a chemical process that uses light energy to convert CO_2 and water into sugars in green plants. These sugars are then used for growth within the plant, through respiration. The difference between the rate of photosynthesis and the rate of respiration is the basis for dry-matter accumulation (growth) in the plant. In greenhouse production the aim of all growers is to increase dry-matter content and economically optimize crop yield. CO_2 increases productivity through improved plant growth and vigour. Some ways in which productivity is increased by CO_2 include earlier flowering, higher fruit yields, reduced bud abortion in roses, improved stem strength and flower size. Growers should regard CO_2 as a nutrient.

ii) Micro Algae - Bio diesel :-

Due to the limited stocks of fossil fuels and the increasing emission of greenhouse gas carbon dioxide into the atmosphere from the combustion of fossil fuels, research has begun to focus on alternative biomass-derived fuels. More algal strains that have high

Growth potential, high constituent amounts of lipids and show robustness in various environmental conditions are sought.

Biodiesel from Microalgae - Methodology

Solvent extraction method

The solvent extraction method recovers almost all the oils and leaves behind only 0.5% to 0.7% residual oil in the raw material. The solvent extraction method can be applied to any low oil content materials. It can also be used for pre-pressed oil cakes obtained from high oil content materials. Because of the high percentage of recovered oil, solvent extraction has become most popular method of extraction of oils and fats. The materials use are green algae, it was obtained from the open pond system and hexane.

Experimental setup

The algae were obtained from the open pond system. It was dried by exposure to atmosphere. After drying, the algae were powdered. A 50 g sample of the dried algae was placed in the thimble of the Soxhlet apparatus. The thimble is made from thick filter paper, which is loaded in the main chamber of Soxhlet extractor. The Soxhlet extractor is placed onto a flask containing extraction solvent. The Soxhlet is than equipped with a condenser.

The solvent is heated to reflux. The solvent hexane forms vapors, which travels up a distillation arm, and floods into the chamber housing the thimble of solid. The condenser ensures that any solvent vapor that cools drips down into the chamber housing the solid material. The chamber containing the solid material slowly fills with warm solvent. Some of the desired compound will then dissolve in the warm hexane. When the Soxhlet chamber is almost full, the chamber is automatically emptied by the siphon side arm, with hexane running back to the distillation flask. This cycle was repeated for varying time. During each cycle, a portion of the oil is dissolved in hexane. After many such cycles, desired oil was concentrated in the distillation flask. After extraction hexane was removed, yielding the extracted compound. The insoluble portion of the algae remains in the thimble. The same process was repeated but this time the open pond algae were 75% moist instead of complete dry. The same process was repeated but this time, the open pond algae were 50% moist instead of complete dry.

Oil expeller method:-

The method we have tried at RGPV/ RKDF pilot study as detailed further is completely different than solvent extraction method. This is a mechanical method and we have made use of expeller to press the algae. Similar methods are screw expeller method, mechanical pressing method (by piston) and osmotic shock method. In the osmotic shock method the osmotic pressure is suddenly reduced. We have carried out our work on screw expeller. The raw materials are squeezed under high pressure in a single step. Expeller presses can recover 75% of the oil from algae. The alga was obtained from the open pond system. It was dried by exposure to atmosphere. In an expeller press, as the raw material is pressed, friction causes it to heat up; in some cases, the temperatures may exceed 120 F. The expeller we used was a screw type machine that presses oil seeds through a caged barrel like cavity. Algae entered the expeller press on one side of the press and products exit was on other side of the press.. The algae were green in long strands like fiber. Initially, the algae did not move easily into the screw. Its surface had to be wetted with water for easy movement through the caged barrel. The oil seeps through small openings that do not allow the other components to seep through. Afterwards, the pressed algae almost form cake, was removed from the machine. Pressures involved in expeller pressing create heat in the range of 140-210 F. Expeller processing cannot remove the last trace of oil from algae. A significant amount of oil was left in the cake formed. The cake formed was in large quantity. It was not subjected to solvent extraction, since the quantity of solvent required would have been much greater.

All algae are primarily made up of proteins, carbohydrates, fats and nucleic acids in varying proportion while percentages can vary with the type of algae. Some types of algae are made up of up to 40% fatty acids based on their overall mass. It is the fatty acid that can be extracted and converted in to bio fuel. CO_2 is a common industrial pollutant, thus microalgae can contribute to reducing atmospheric CO_2 by consuming CO_2 wastes from industrial sources such as power plants. In light of the fact that micro algae are the most efficient primary producers of biomass, it is very likely that they will eventually become one of the most important alternative energy sources as biodiesel.

Algae have the ability to convert carbon dioxide to biomass that can further processed downstream to produce biodiesel, fertilizer and other useful products. Photosynthetic growth of algae requires carbon dioxide, water and sunlight. It is well known fact that micro algae grow in aqueous suspensions, allows for more efficient access to H2O, CO2 and other nutrients which explain the potential for the production of more oil per unit area than other crops currently used. Moreover, production of algae can be a good source for Bio diesel production because of high oil content present in it.

[2]. Introduction - Production of Multipurpose Fuels through Carbon Capture &Sequestration

Abstract

CO_2 capture, sequestration and production of multi-purpose fuels – hydrogen, methane and biodiesel through algae route in a post combustion operation has been successfully demonstrated. The CO_2 sequestration pilot plant has been constructed at the State Technological University of MP, the 'RGPV'. This pilot project revalidated the possible use of the amine absorption system to strip the CO_2 from the flue gases but also validated the data on its efficiency for a power plant. A CO_2 capture of over 93% has been achieved using MEA solvent of 20% concentration and the required heat for stripping captured CO_2 is 3.88 MJ per kg of recovered carbon dioxide, which is provided by the low pressure steam of about 150°C and 2 bar pressure from the associated boiler of 100 kg/hr capacity. Although the stripper uses a low grade steam and some heat it contains was not used for generating power anyhow, it still causes 20% reduction of power output of boiler. Using the water gas shift reaction and a lignite / charcoal gasifier about 18% hydrogen is being produced in this pilot plant, paving the way to production of multipurpose fuels from captured CO_2. Efforts are underway to produce methane from the stable CO and hydrogen so produced, in a catalytic converter.

CO_2 from the stripper unit is also diverted to an open algae pond, where solar flux is concentrated using parabolic collectors and CO_2 is given in a regulated manner. Astimulation

study of CO_2 capture & sequestration plant on an actual coal thermal power plant has been carried out.

2.1 Chemistry of Carbon Dioxide Recycle

- The capture of CO_2 and its recycle can increase the energy efficiency and reduce the emissions.
- The CO_2 capture follows an oxy-fuel combustion system where the emissions of the power plant are 100% CO_2 while those of other Coal based power plants have 12-15% CO_2 in the flue gas stream requiring costly capture processes.
- The CO_2 is then converted into CO using a Carbon source and the waste thermal heat of the boiler/gasifier. The gain in energy is 8.5% in terms of overall energy inputs.
- This process of twin gasification is used to convert the entire Coal fuel feed stock into clean Coal gas and the Hydrogen in this feed gas is converted into Methanol. This will also obviate the need for Coal quality control.
- The remaining Coal gas mainly CO goes to the Super Critical Boiler for burning with Oxygen as fuel.
- As the feed gas is purified the quantum of CO_2 to be used for recycle and reduction would depend on the emission regulations at that point of time.

2.2 Energy Credits for different Power Cycles

A. Carbon Di-Oxide Recycling for conversion to co gives 21.88 % heat gain
B. Producing Hydrogen from Recycled CO2 the gain in the input heat would be 18.69 %
C. Producing Methanol from Recycled CO2 there is a net gain in Heat value terms of 10.65%

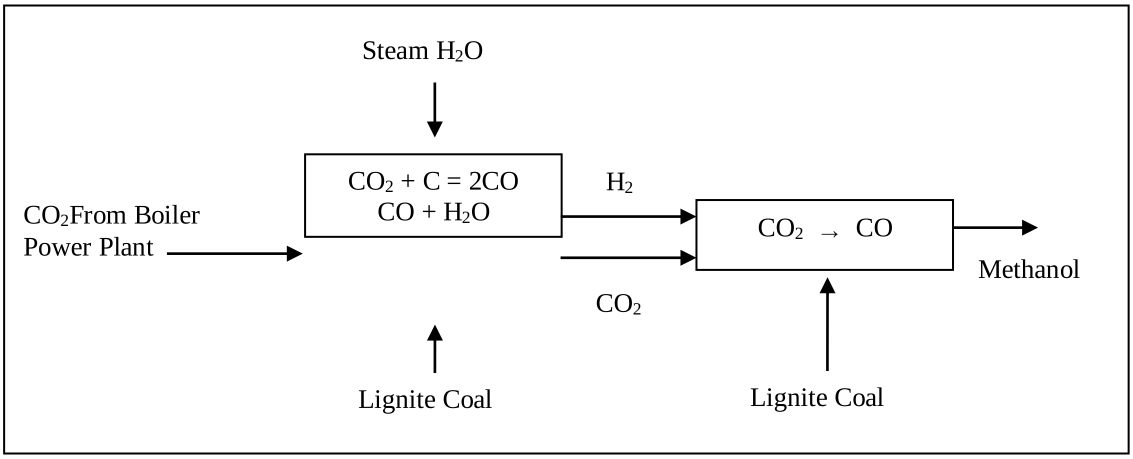
The conversion processes are explained in **APPENDIX 'I' below:**

APPENDIX 'I'

An Explanatory note on Carbon Recycling through CCS

MODE A: CARBON DIOXIDE RECYCLING FOR CONVERSTION TO CO

The process diagram is as under:



Energy in various molecules:

- Carbon Dioxide production is exothermic reaction having energy (-) 393.5 kJ/mol there is no energy in this molecule after its formation and the value of the exhaust CO_2 is in fact **zero.** The CO_2 here in heat balance is seen as a waste, which it is.
- Hydrogen has a heat value of 141.8 MJ/Kg or the heat value would be **33875 kCal/kg** or in terms of power 1 kWh = 860 kCal would be 39.40 kWh/Kg.
- Like wise the Methanol has 22.7 MJ/Kg. this would mean a heat value of **5423 KCal/kg** or in terms of power would be equivalent to 6.30 kWh/Kg.
- Carbon monoxide has a heat value of 10.112 MJ/Kg, this would mean a heat value of **2416 kCal/kg** or in terms of Power would be equivalent to 2.8 kWh/Kg.

Reaction of CO_2 to CO

In the reaction of CO_2 to CO we react 44 Kg of CO_2 having a heat value of Zero with 12 Kg of Carbon having a heat value of 7840 kCal/kg. The total heat value of **Input which would be Carbon 12 Kg x 7840 = 94080 kCal**

From this input we get 56 Kg of CO having a heat value of 2416 KCal/kgor a total of **56x2416 =1, 35, 296 KCal.**

135296 – 94080 = 41216

In percentage terms an increase of 41216/ 94080 x 100 = 43.80%.

But the reaction is endothermic requiring heat input which must be accounted for through the ratio of heat output to heat input as under:

i) The heat is required to convert the CO_2 into CO and this has been calculated as a percent of the input heat by means of the following reactions: $C + CO_2 \rightarrow 2 CO$

$\Delta H = 2 x - 110.5 - (CO_2 = 393.5 - 221) = + 172.5$ kJ, (Endothermic)

……eqn. (i)

ii) $2CO + O_2 = 2CO_2$. $\Delta H = 2x -393.5kJ = -787kJ$, (Exothermic))

ΔH Balance for the two Reactions: [787 – 172.5 = 614.5 kJ]

Or 614/787 = 78.08% heat output of the heat input. ......eqn. (ii)

Thus Endothermic Heat as percentage of input heat value is

100-78.08 = 21.92%.

Thus finally if we calculate the Heat Balance in terms of input heat value we have to deduct the heat value equal to 21.92% from the input heat value of **94080 KCal** and this would be **20622 kCal**. When we deduct this from the gain in heat value of **41216 kCal** we still have a heat balance / gain of **41216 – 20622 = 20594 kCal**.

This would translate **into**

20594/94080 x 100 = 21.88% in terms of value of inputs.

This 21.88 % is the heat gain if we produce only CO from CO_2.

MODE B: PRODUCING HYDROGEN FROM RECYCLED CO_2

From basic Chemistry, we know that:

- HEAT VALE OF HYDROGEN: 141.80 MJ /KG OR 33875 KCAL /KG.
- HEAT VALUE OF METHANOL: 22.7MJ/KG OR 5425 KCAL/KG.
- HEAT VALUE OF CARBON MONOXIDE: 10.112 MJ/KG OR 2417KCAL/KG.
- THE NORMALLY ONE KG OF HYDROGEN IS PRODUCED COMERCIALLY FROM 50 UNITS OF POWER ELECTROLYSIS AND HENCE THE HEAT VALUE OF INPUT TO PRODUCE 1 KG OF HYDROGEN WOULD BE 860X50 = 43000 KCal/KG.

B (i) without recycling of CO_2 then following would hold good.

$CO + H2O = CO_2 + H_2$ ......eqn. (iii)

Molar weights would be 28 Kg + 18 Kg = 44 Kg +2 Kg.

In terms of heat values: 28 x 2417 + 18 x 640 =

67676 KCal + 11 520 KCal = **79196 KCal** for

2 Kg Hydrogen having a heat value would be or 2 x 33875 = 67750 KCal

Or **85.55% of input heat value or a heat loss of (-) 14.55%**

B (ii) But when CO_2 is recycled there is heat gain of **21.88%**

or 21.88% of 67676 = Or a gain of **14830 KCal** in heat value terms would be there.

Then heat value of recycled 28 Kg of CO would be

67676x (100-21.88) =52846 KCal

The above reaction from recycled CO_2 in heat value terms would be:

28 Kgs Recycled CO = 52846 KCals + 18 Kgs Steam 11520 KCals = 2 Kgs H_2

As input heat or 52846 KCal + 11520 KCal = ***64 366 KCal*** *as the heat input*

And the 2 Kg of Hydrogen would be produce and its normal heat value would be 67750 KCal denoting a heat gain in molar terms of 3384 KCals for 2 Kgs H_2.

And the gain in the input heat would be 14830/79196* x 100 = 18.72 %

IN TERMS OF NORMAL INPUTS Or a net heat energy gain of 18.72% ** {Because the benefit or heat gain has to be related to the normal heat inputs and compared with it and not from inputs of the recycled heat values}*

MODE C: METHANOL PRODUCTION FROM RECYCLED CO_2

When we produce Methanol from recycled CO_2 and Hydrogen produced from recycled CO then this would result in the following heat gain:

C (i) Methanol Synthesis in KCal when Produced Normally:

Formula	$2H_2 + CO = CH_3OH$ ..... eqn. (iv)
OR Molar weight	4 Kg + 28 Kg = 32 Kg
	4 x 33875 + 28x 2417 = (203176)

Output Methanol --> 32 x 5425 = 173600 KCals

From a input heat value of = 203176 kCal input

we get ------> 173600 kCal as output

or **denoting thermal efficiency of reaction as 85 41% efficient**

C (ii) Methanol when produced from recycled CO_2.

i) 4 Kg of recycled Hydrogen would have a heat value of 2 x 64366**=1,28,732 KCal

ii) 28 Kg of recycled CO would have a heat value of 1 x 52,846 KCal

Adding i) and ii)

32 Kg of Methanol from the above recycled Hydrogen and CO = 1,81,578 KCal.

Hence one Kg of Methanol produced from recycled H_2 and CO = 5674 KCal.

When Methanol is produced from normally heat input = 6351 KCal.

When using recycled inputs there is a net gain in Heat value terms of 14.58%

5.1.1 Production of Hydrogen

In recent years hydrogen has become one of the most talked about trends in global energy. It is an energy carrier – much like electricity–that must be manufactured from primary or secondary energy sources.

Hydrogen is sometimes considered the chemical twin of electricity. Zero GHGs are produced when hydrogen is used–just like with electricity. And, like electricity, the production of hydrogen can cause emissions upstream from the end-user. Supply chains for this 21st century commodity must therefore be carefully developed.

Although use is limited now, there is significant potential for cost-effective, low-emissions hydrogen. It is expected to play a critical role in replacing hydrocarbon-based fuels in heavy and long-range transport vehicles (trucks, buses) where batteries are impractical. It will also help resolve the big challenge of decarbonizing high-temperature industrial heat, mostly produced now by natural gas and coal. It could be a storage medium for power generation, with some also used as an additive to conventional natural gas supplies.

Production of pure hydrogen reached 70 Mt and total hydrogen (including syngas) 120 Mt in 2020. Most was used in oil refineries and chemical production.

Three main routes are available for hydrogen production:

- Reforming of natural gas
- Gasification of coal or coke
- Electrolysis of water (aka water splitting).

Ninety-eight% of current hydrogen is produced from coal (via gasification) and by steam methane reforming (SMR) from natural gas. Both processes produce significant CO2 emissions if abatement is not used. Both are well suited to economical CO2 emissions abatement with CCS. A very small portion (0.3 per cent) is produced from electrolysis of water, powered by renewables. A key low-emissions route for hydrogen production is SMR coupled with CCS. Today there are four industrial-scale SMR hydrogen facilities with CCS worldwide, producing a total of around 800,000 tons of low-carbon hydrogen per year.

One of these SMR with CCS facilities is Air Products' Port Arthur, Texas hydrogen plant, a two-train SMR facility which captures CO2 from its reformer units using vacuum swing adsorption. This plant has a carbon capture capacity of almost one Mt per year, providing CO2 for EOR operations. Coal gasification with CCS is a well proven technology for mass production of hydrogen, with low emissions. Approximate hydrogen cost estimates, from reputable CCS-equipped coal gasification and SMR pathways are much lower cost than electrolysis from renewables

TABLE TOP PLANT AT RKDF UNIVERSITY FOR PRODUCTION OF HYDROGEN FROM CAPTURED CO2

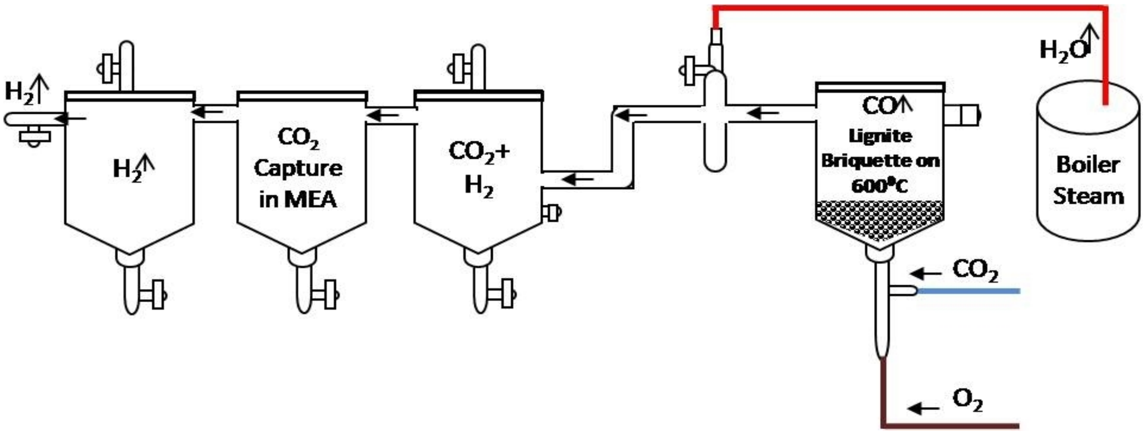
Conversion of CO_2 into CO & H_2: Conversion of CO2 into CO is being achieved through the use of FeC catalyst. FeC is prepared using aqueous solution of FeCl3 with lignite and kept for 24 hrs and then mixture is washed till chloride is free. Again the lignite is dipped into urea for 5-6hrs and washed again for removal of residual chloride. Thereafter lignite is mixed with lime for bonding to make briquettes.

Underlying reactions are:

$CO_2+C=2CO$

&$CO+H_2O=H_2+CO_2$

The Schematic diagram of the Hydrogen Production table top plant is as under



RESULT:

- Using flue gas containing CO_2 & treated lignite the carbon monoxide was analytically evaluated of the order of 20% to 25% by weight. The CO obtained having a Low Heat Value (LHV) of 2417 kCal/kg would reduce the fuel required by the boiler and also reduce the net emissions, once recycled back to the boiler using separate short flame burners.

- CO production in stable form and to produce fuel molecules like H2 using water gas shift reaction.

- H2 formation was evaluated to the extent of 1.43%-1.79% by weight equivalent to H2 by volume 17.44% to 21.83% creating the opportunity to the production of multipurpose fuels from captured CO2.

VIEWS OF THE TABLE TOP PLANT FOR HYDROGEN AT RKDF UNIVERSITY

THE PROCESS OF GASIFICATION IS SHOWN HERE USING LIGNITE WITH OXYGEN SUPPORT& CAPTURED CO2

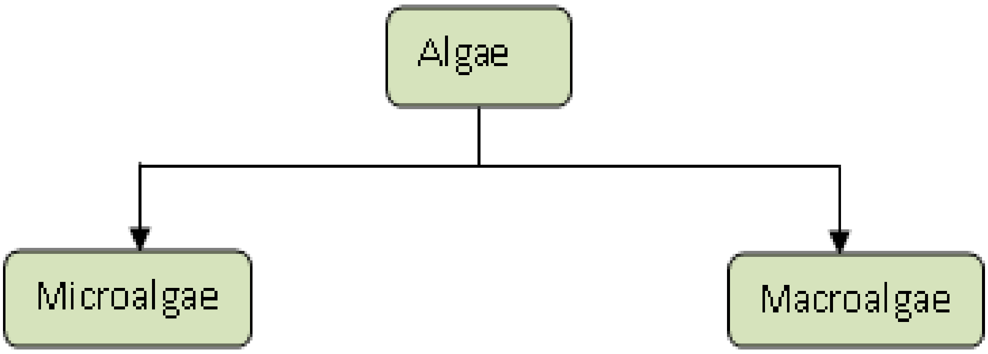
5.1.2 Production of Bio-diesel through Algae Route

Due to the limited stocks of fossil fuels and the increasing emission of greenhouse gas, carbon dioxide, in to the atmosphere from the combustion of fossil fuels, research has begun to focus on alternative biomass-derived fuels. More algal strains that have high growth potential and high constituent amounts of lipids, and show robustness in various environmental conditions are sought.

The microalgae are veritable miniature biochemical factories and appear more photosynthetically efficient than terrestrial plants and are efficient CO2 fixers. Many algae are exceedingly rich in oil, which can be converted to biofuel. The oil content of some microalgae exceeds 80% of dry weight of algae biomass. The growth of algae requires CO2 as one of the main nutrients needed. There is an opportunity to sequester CO2 by using flue gas emissions from industrial sources as the CO2 feed for algae cultivation and produce the biofuel from the algae biomass. Very few literatures are available for potential technology and applications of microalgae for carbon sequestration and biofuel production.

In general algae can be referred to as plant-like organisms that are usually photosynthetic and aquatic, but do not have true roots, stems, leaves, vascular tissue and have simple reproductive structures. They are distributed worldwide in the sea, in freshwater and in wastewater.

Classification of algae



Cultivation of Algae

There are several factors to determine the growth rate of *algae*. The following are the important factors that determine the growth rate of algae

- Light - Light is needed for the photosynthesis process
- Temperature: There is an ideal temperature range that is required for algae to grow
- Medium/Nutrients - *Composition* of the water is an important consideration (including salinity)
- pH - *Algae* typically need a pH between 7 and 9 to have an optimum growth rate
- Algae Type - Different types of algae have different growth rates
- Aeration - The algae need to have contact with air, for its CO_2 requirements
- Mixing - Mixing prevents sedimentation of algae and makes sure all cells are equally exposed to light
- Photoperiod: Light & dark cycles

A Generalized Set of Conditions for Culturing Micro-Algae

Parameters	Range	Optima
Temperature (°C)	16-27	18-24
Salinity (g.l-1)	12-40	20-24
Light intensity (lux)	1,000-10,000 (depends on volume and density)	2,500-5,000
Photoperiod (light: dark, hours)		16:8 (minimum) 24:0 (maximum)
pH	7-9	8.2-8.7

Micro algae cultivation and their uses in CO2 Capture

Amongst various CO2 sequestration technologies, the biological methods particularly the ones using microalgae, have several merits. These include, direct CO2 capture and fixation from flue gases by suitable micro algal strains and their biomass conversion into useful products. The last advantage is quite important because the separation of CO2 from flue gases takes a major portion over 70% of the total sequestration cost. In addition to these advantages, carbon fixed by microalgae is incorporated into carbohydrates and lipids, so that energy, chemicals or food can be produced from algal biomass. The advantage of microalgae over land plants as a source of transportation biofuels are as follows:

- Oil yield per area of microalgae cultures could greatly exceed the yield of the best oilseed crops.
- Microalgae grow in an aquatic medium, but need less water than terrestrial crops.
- Microalgae can be cultivated in sea water or brackish water on non-arable land and do not compete for resources with conventional agriculture.
- Microalgae biomass production may be combined with direct bio fixation of waste carbon dioxide.
- Algae cultivation does not need herbicides or pesticides
- The residual algal biomass after oil extraction may be used as feed, fertilizer or fermented to process ethanol or methane.

Materials and methods

<u>Microalgal cultures</u> –

Algae Name:- **1. *Scenedesmus obliquus,***

2. *Monoraphidium minutum*

The gratis samples of algae viz. *Scenedesmus obliquus* (Strain No.276-10) and *Monoraphidium minutum* (Strain No. 243-1) were brought into the Laboratory which were obtained from the Albert Von Haller Institute, George August University Gottingen, Germany.

For cultivation of these algae the media which are used is known as Basal media.

1. **Basal Medium** (= ES "Erddekokt + Salze")

Stock solution	**nutrient solution**	
[g/100 ml]	[ml]	
KNO_3	1	20
K_2HPO_4	0.1	20
$MgSO_4 . 7H_2O$	0.1	20

soil extract *	30
micronutrient solution **	5
de-ionized or distilled water	905

Preparation of soil extract:

The procedure is to fill a 6 liter flask one third with garden or leaf soil of medium, but not too great humus content which does not contain fertilizers or plant protective agents. Success of soil extract depends on selection of suitable soils. Those with high clay content are usually less satisfactory. Add de-ionized water until it stands 5 cm above the soil and sterilize by heating in a steamer for one hour twice in a 24 h interval. Separate the decanted extract from particles by centrifugation. Fill into small containers of stock solution each of a size appropriate to making a batch of media, autoclave for 20 min at 121°C and store in the refrigerator.

** Preparation of the micronutrient solution:

Stock solution		**applied solution**
[g/100 ml]		
$ZnSO_4 . 7H_2O$	0.1	1 ml
$MnSO_4 . 4H_2O$	0.1	2 ml
H_3BO_3	0.2	5 ml
$Co(NO_3)2 . 6H_2O$	0.02	5 ml
$Na_2 MoO_4 .2H_2O$	0.02	5 ml
$CuSO_4 . 5H_2O$	0.0005	1 ml
Disttiled water	981 ml	
$FeSO_4 . 7H_2O$		0.7 g
EDTA (Titriplex III, Merck)		0.8 g

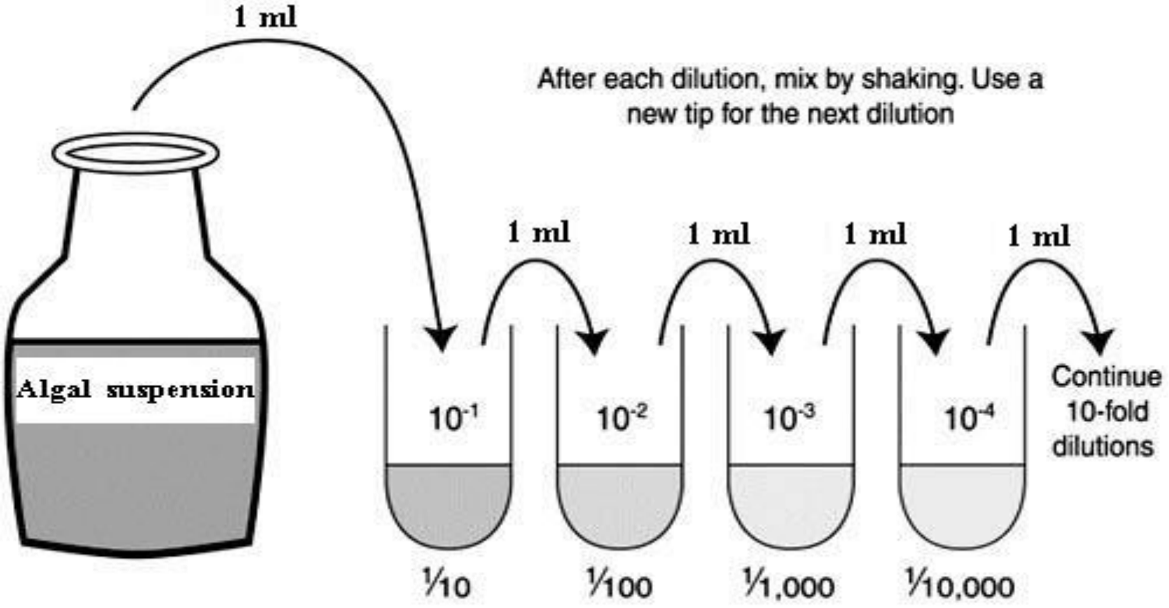
The components are Autoclaved separately in two solutions which are united after cooling. Solution I: 881 ml distilled water + stock solutions of salts without $FeSO_4$ + 0.4 g EDTA

Solution II: 100 ml distilled water + 0.7 g $FeSO_4$ + 0.4 g EDTA.

The following modifications of the Basal Medium proved suitable for many strains:

Inoculation process

The inoculation process is done in to laminar air flow chamber By serial dilution method in shahpura lake Bhopal in 250 ml,,500ml ,2lit ,4lit and then 8 lit water with aeration .After the determination of all basic parameter of water.



Aeration Mixing:

Mixing is necessary to prevent sedimentation of the algae, to ensure that all cells of the population are equally exposed to the light and nutrients, to avoid thermal stratification and to improve gas exchange between the culture medium and the air.

CELL CULTURE ROOM -BIOTECHNOLOGY DEPARTMENT RKDF

Culture in 250 ml water

Culture in 2liter water

Culture in 4 litre water

Microalgae Cultivation by using Carbon Dioxide and Aeration in Energy Park RGPV Bhopal

Microalgae Cultivation by using Carbon Dioxide and Aeration in Energy Park RGPV Bhopal

Each culture was sampled in the stationary growth phase .Culture were concentrated by centrifugation at 4000 rpm for 10 min at 20 C as shown above .

Algal Powder after Centrifugation

Biodiesel extraction from Microalgae at Bio-tech departments of RKDF / RGPV Universities

Solvent extraction method

The solvent extraction method recovers almost all the oils and leaves behind only0.5% to 0.7% residual oil in the raw material. The solvent extraction method can be applied to any low oil content materials. It can also be used for pre-pressed oil cakes obtained from high oil content materials. Because of the high percentage of recovered oil, solvent extraction has become most popular method of extraction of oils and fats. The materials use are green algae, it was obtained from the open pond system and hexane

The Experimental setup

The algae were obtained from the open pond system. It was dried by exposure to atmosphere. After drying, the algae were powdered. A 50 g sample of the dried algae was placed in the thimble of the Soxhlet apparatus. The thimble is made from thick filter paper, which is loaded in the main chamber of Soxhlet extractor. The Soxhlet extractor is placed onto a flask containing extraction solvent. The Soxhlet is equipped with a condenser.

The solvent is heated to reflux. The solvent hexane forms vapours, which travels up a distillation arm, and floods into the chamber housing the thimble of solid. The condenser ensures that any solvent vapor that cools drips down into the chamber housing the solid material. The chamber containing the solid material slowly fills with warm solvent. Some of the desired compound will then dissolve in the warm hexane. When the Soxhlet chamber is almost full, the chamber is automatically emptied by the siphon side arm, with hexane running back to the distillation flask. This cycle was repeated for varying time. During each cycle, a portion of the oil is dissolved in hexane. After many such cycles, desired oil was concentrated in the distillation flask. After extraction hexane was removed, yielding the extracted compound. The insoluble portion of the algae remains in the thimble. The same process was repeated but this time the open pond algae were 75% moist instead of complete dry. The same process was repeated but this time, the open pond algae were 50% moist instead of complete dry.

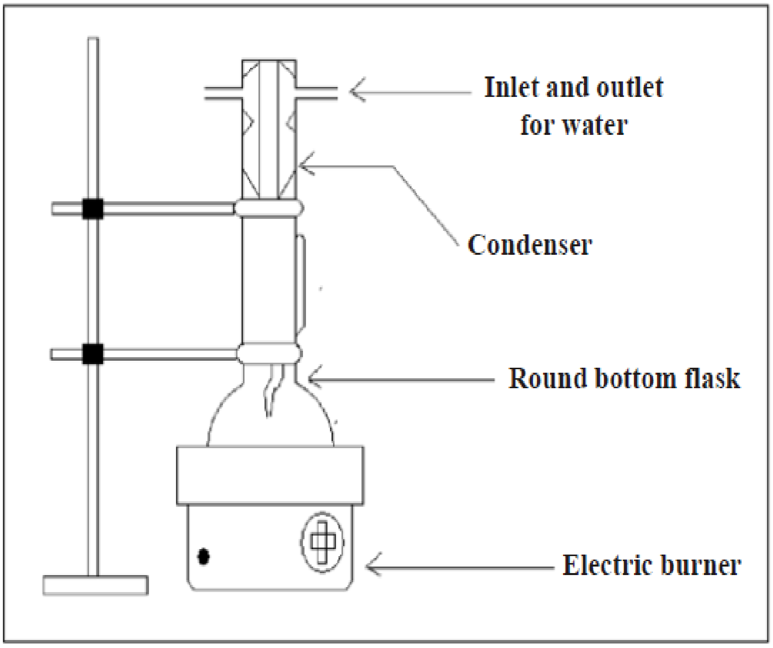


Fig.: Extraction of oil from algae by solvent extraction method (Soxhlet apparatus)

Oil expeller method

Another method we have tried is completely different than solvent extraction method. This is a mechanical method and we have made use of expeller to press the algae. Similar methods are screw expeller method, mechanical pressing method (by piston) and osmotic shock method. In the osmotic shock method the osmotic pressure is suddenly reduced. We have carried out our work on screw expeller. The raw materials are squeezed under high pressure in a single step. Expeller presses can recover 75% of the oil from algae. The alga was obtained from the same open pond system. It was dried by exposure to atmosphere. In an expeller press, as the raw material is pressed, friction causes it to heat up; in some cases, the temperatures may exceed 120°F. The expeller we used was a screw type machine that presses oil seeds through a caged barrel like cavity. Algae entered the expeller press on one side of the press and products exit was on other side of the press. The machine used friction and continuous pressure from the screw drive to compress the filamentous algae. The algae were green in long strands like fibre. Initially, the algae did not move easily into the screw. Its surface had to be wetted with water for easy movement through the caged barrel. The oil seeps through small openings that do not allow the other components to seep through. Afterwards, the pressed algae almost form cake, was removed from the machine. Pressures involved in expeller pressing create heat in the range of 140-210°F. Expeller processing cannot remove the last trace of oil from algae. A significant amount of oil was left in the cake formed. The cake formed was in large quantity. It was not subjected to solvent extraction, since the quantity of solvent required would have been much greater.

TEST RESULTS ON ALGAE

[i] Dry mass of algae *Scenedesmusobliquus*

- Before release of CO2: 5.24 gm.
- After release of the CO2: 14.22 gm.

[ii] Dry mass of algae Monoraphidium minutum

- Before release of CO2: 4.71 gm.
- After release of the CO2: 11.17 gm.

Thus the ‘Growth’ of selected micro algae found to be increased by 2.4 to 2.7 times by weight with CO2 injection.

PRODUCTION OF MULTI-PURPOSE FUELS – A NOTE

- Using flue gas containing CO_2 & treated lignite the carbon monoxide was analytically evaluated of the order of 20% to 25% by weight.
- The CO obtained having a Low Heat Value (LHV) of 2417 kCal/kg would reduce the fuel required by the boiler and also reduce the net emissions, once recycled back to the boiler using separate short flame burners.
- CO production in stable form and to produce fuel molecules like H2 using water gas shift reaction.
- H2 formation was evaluated to the extent of 1.43%-1.79% by weight equivalent to H2 by volume 17.44% to 21.83% creating the opportunity to the production of multipurpose fuels from captured CO2.

The study conducted for CO_2 capture from flue gases & release has

revalidated the Amine absorption system for the CO2 application for conversion to fuel molecules.

5.1.3 Strategies of CO_2 Storage – Introduction

5.1.3.1 VARIOUS TECHNOLOGY OPTIONS

- **CO_2 Storage in Saline Aquifers**

CO_2 storage in saline aquifers is one of the most important options due to the huge amount of storage capacity, which is estimated to be sufficient for the sequestration of 10,000 Gt of CO_2, namely the emissions from large stationary sources for more than 100 years. Compared with the other storage sites, the saline aquifers usually possess more wide distribution and greater regional coverage. Therefore, it has a better chance to be located near the CO_2 emission sources, which could reduce the cost of CO_2 transportation. The most crucial issue brought by the sequestration of CO_2 in saline aquifers is pressure build up and CO_2 plume migration in formation, which has the potential to lead to the fracturing of formation and reactivation of faults and leakage of CO_2, which should receive more attention. Birkholzer et al. conducted a numerical simulation to determine the influence of large-scale CO_2 storage with an injection rate of 1.52 million tons per year (MTPA) in an open saline aquifer. Their results indicated that there is significant pressure build up in the formation more than 100 km away from the injection zone, but the CO_2 plume migration is rather small—that is, around 2 km—and is concentrated on the top of saline aquifer due to the buoyancy effect. They also showed that the pressure perturbation may reach shallow groundwater formation when there is a caprock with relatively high permeability (higher than 10^{-18} m^2) between the saline aquifer and the shallow layers. However, the migration of reservoir fluids into groundwater formation is extremely unlikely. This demonstrates the safety of large-scale CO_2 storage in saline aquifers.

There are mainly five commercial-scale CCS projects in saline aquifers, including the Sleipner project, the Snøhvit project, the In Salah project, the Gorgon project, and the Quest project.

Regarding the Sleipner project, CO_2 was separated from the methane produced at the Sleipner field in the North Sea. Then, the CO_2 was injected into a regional saline aquifer within the Utsira Sand formation, and a total of 18 million tons were injected by 2018 since its initiation in 1996. Based on the engineering experiences from the Sleipner project, the CO_2 separated from the liquefied natural gas (LNG) project was injected to the deeper Tubåen Formation at a rate of 2000 tons per day in the Snøhvit CCS project, which is located in the Barents Sea. The project was launched in 2008 with a total amount of 1600 k-tons of CO_2 injected until August 2012, and it is expected that about 23 million tons of CO_2 will be stored there based on the projected lifetime of the Snøhvit LNG project.

The CCS project at In Salah, Algeria, is one of the world’s pioneering CCS projects. More than 3.8 million tons of CO_2 have been injected to the Carboniferous sandstone at the

Krechba field since 2004. This CCS project is unique due to the diversity of monitoring methods, including satellite monitoring and 4D seismic data, which have been used to monitor the response of formation to CO_2 injection. Meanwhile, the accessibility of these monitoring data to the public is very high so it could be a commendable case to study the CCS in saline aquifers.

The Gorgon CCS project located in the northwest of Australia, and it owns a Jurassic saline reservoir in the Dupuy Formation. In the lifetime of the Gorgon project, more than 120 million tons of CO_2 is planned to be injected at a rate of approximately 3.8 MTPA.

The Quest CCS project began in 2015 and is designed to store the CO_2 from an existing facility for upgrading heavy oil in Alberta, Canada. It is expected that approximately 27 million tons of CO_2 can be injected to the Basal Cambrian Sands formation at an injection rate of 1.08 MTPA through three to eight vertical wells.

Although the storage capacity of saline aquifers is huge, the overall progress of CO_2 storage in such aquifers throughout the world is still slow due to the lack of financial incentives. Therefore, some policies related to the taxes on carbon emission with a higher price might need to be formulated, which highlights the important role of the government on the application of CCS at a large scale.

• CO2 Storage in Depleted Oil and Gas Reservoirs

There are many advantages of CO2 storage in depleted oil and gas reservoirs. Firstly, oil and gas reservoirs have a large amount of existing equipment installed on the surface and underground, which could be reused for CO_2 storage with only minor modification. Secondly, the seal quality and integrity of the cap-rock are guaranteed and have been comprehensively characterized during the exploration and production process. Thirdly, the extent of pressure perturbations and induced stress changes is much smaller in depleted oil and gas reservoirs compared with aquifers because of the long-term extraction of oil and gas. Compared with depleted oil reservoirs, the depleted gas reservoirs are more favourable for CCS due to higher ultimate recovery and compressibility of gas, a larger storage capacity per pore volume is available. Comparing the types of reservoirs used in this form of storage, condensate gas reservoirs are more advantageous over wet and dry gas reservoirs resulting from the little remaining gas, the phase behaviour of the mixture of condensate gas and CO_2, as well as the good injectivity of it. Furthermore, the sequestrated CO_2 per pore volume in depleted condensate reservoirs is very high: approximately 13 times higher than that of the equivalent aquifer. However, attention should be paid as the phase change may occur in depleted condensate reservoirs, while not in dry and wet gas reservoirs.

A few projects dedicated to CO_2 storage have been implemented in depleted gas reservoirs. The first demonstration project in Australia named the CO2CRC Otway Project is well-known, in which the CO_2 was injected into the Waarre C Formation at a depth of about 2050 m. This project commenced in March 2008 and ended on August 2009, with a total storage capacity of 65,445 tons. It is worth mentioning that a community led “stakeholder reference group” has been set up in this project to communicate with the public and help increase their acceptance about CCS technology, which could be a demonstration for other CCS projects. Overall, the CO2CRC Otway Project demonstrates that the sequestration of CO_2 in depleted gas fields can be achieved safely, and it provides a basis for the large-scale

CO_2 sequestration in depleted oil and gas fields. According to the experience gained in this project, the suitability and storage capacity of similar depleted gas reservoirs has been evaluated. For example, the depleted P18-4 gas field on the offshore of Netherlands and the DF-1 South China Sea Gas field, owning a potential capacity of 1 Gt and 8 Mt respectively, are identified as suitable sites for the sequestration of CO_2.

Generally, due to the advantages of low risk and cost-effectiveness, CCS in depleted reservoirs can play an important role in the mitigation of global warming, before the wide application of large-scale CCS in saline aquifers.

- ## CO_2 Storage in Coal Beds

CO_2 injection into coal beds is another attractive strategy for CO_2 storage. Most of the suitable coal beds for CO_2 storage are located at a depth ranging from 300 to 900 m. The sequestration of CO_2 in coal beds possesses the major advantage that the potential coal beds are usually located nearby the existing or planned coal-fired power plants. Therefore, the transportation cost could be reduced significantly. However, CO_2 storage in coal beds is still an immature technology, and only some pilot studies have been conducted on its suitability and storage capacity. The evaluated effective storage capacity of Cretaceous–Tertiary coal beds in Alberta, Canada is 6.4 Gt, and the potential storage capacity for the coal beds in China is about 142.67 Gt, which signifies the potential contribution of coal beds on the mitigation of CO_2 emissions.

- ## CO_2 Storage in Deep Ocean

The CO_2 can also be directly injected into the deep ocean at water depth of more than 2700 m, where the liquid CO_2 can sink downward to the seafloor, because the CO_2 is denser than seawater under high pressure and low temperature]. The storage capacity is extremely large due to the enormous volume of the ocean. However, this CCS technology cannot be applied widely because it may affect the marine environment.

- ## CO2 Storage in Deep-Sea Sediments

The option of CO_2 storage in deep-sea sediments not only combines the merits of geologic storage and ocean storage, but it also avoids many shortcomings. For example, it is free from the potential harm to the ocean ecosystems as the CO_2 is injected into the sediment deep beneath the ocean rather than directly into ocean. The storage mechanisms in terrestrial sequestration such as dissolution trapping, residual trapping, and mineral trapping still play a positive role. In addition, new storage mechanisms, including gravitational trapping and hydrate trapping, also work in the sequestration. The gravitational trapping comes from the fact that the higher density drives the CO_2 into the deep sea to the so-called negative buoyancy zone (NBZ). The depth at which the density of CO_2 is identical to the salinity and temperature-dependent density of seawater is approximately 2700 m. The hydrate trapping works because of the formation of CO_2 hydrate under the condition of high pressure and low temperature shots.

Despite the enormous capacity and feasibility this technology shares, it is still in the formulation technology readiness level. In addition, CO_2 storage in deep-sea sediments is far more expensive than onshore methods. In addition, it may take a long time to increase the public acceptance of this method.

The PI of the project has inferred from his experience at GHGT-14 at Melbourne, Australia and at Alberta Canada that CO2CRC project and Cretaceous–Tertiary projects are game changers and following comparative study may be found useful.

Comparative study

Option	**Advantages**	**Disadvantages**
Saline aquifer	Huge amount of storage capacity, wide distribution, commercial technology readiness level	**No economic advantage**
Depleted Oil Gas Fields	Low transportation cost due to its potential location near the coal-fired power plants, additional coal bed methane recovery	**Demonstration readiness**
Coal Bed	Low transportation cost due to its potential location near the coal-fired power plants, additional coal bed methane recovery	**Pilot Plant readiness**
Deep Ocean	Large storage capacity	**Marine life affected**
Sea Sediments	Enormous storage capacity, free from the potential harm to the ocean ecosystems	**Costly at present**

5.1.3.2 CO2 Storage Potential of Geologic Formations in India

CO_2 storage in geologic formations is increasingly being considered as a mitigation option. The suitable geologic formations in India are basalt formations including interbedded sedimentary beds, deep saline aquifers, un-mineable coal seams and depleted oil and gas reservoirs. CO_2 storage in flood basalts and underlying or interbedded sedimentary beds is an emerging area of research. Basalt is a volcanic rock that essentially consists of aluminum silicate containing ions of sodium, calcium and iron, which can combine with CO_2 to form carbonate minerals. These have inimitable properties favorable for chemical trapping of the injected CO_2 efficiently and everlastingly isolating it from the environment.

In India, two major formations viz. Deccan and Rajmahal traps are in existence wherein basalts are strategically located. The Deccan traps are one of the largest volcanic provinces in the world. It covers an area of nearly 500,000 square km and flat-lying basalt lava flows varying in thickness more than 2000 m and contains intertrappean and infrattrappean sedimentary beds of imaginatively varying thickness about 15 m in West-Central India. The volume of Deccan basalt is estimated to be 512,000 cubic km. **Rajmahal trap consists of 450 m to 600 m thick basaltic lava flows spread over an area of nearly 18,000 square km,** interbedded with contemporaneous sedimentary formations of laterally varying thickness up to maximum of 30 m. These two basalt formations can be promising viable sites for CO_2 storage in India. However in view of very limited investigation on suitability of basalts and its underlying or interbedded sedimentary beds for CO_2 storage and basic information on injectivity, storage capacity, rate of conversion of gaseous CO_2 to solid carbonates minerals, only a rough estimate of the storage potential is available.

Deep saline aquifers are the most ubiquitous host medium for underground storage of CO_2. Regional scale assessments to evaluate overall feasibility and storage capacity based on formation thickness, depth, heterogeneity, continuity of cap and base rocks and geologic structure are desired.

Another related issue of importance is injection of CO_2 in un mineable coal deposits to store the carbon and simultaneously enhance the recovery of coal bed methane. Coal measure formations in India are spread over 63,605 square km in 62 coalfields belonging to two geological ages viz., the Gondwana formations in peninsular India of the Permian age and the Tertiary coal in the northern and north-eastern hilly regions of the Eocene-Miocene age. Besides coal, lignite deposits in younger formations are also suitable for CO_2 storage and enhanced gas recovery. **Out of 240 billion tonnes of total coal resources in India, only 90 billion tonnes have been estimated as recoverable reserves. Rest of the unmineable coal deposits could be potential CO_2 storage sink.**

Although CO_2 storage in depleted oil reservoirs has the lowest potential of all options, it is most likely to be implemented because of additional economic benefits by enhancing oil recovery. Oil and gas reserves of India are 740 MMT and 751 BCM respectively spread over 353 oil and gas fields located in the northeastern, western and southern parts of the country.

Total carbon dioxide storage potential of geologic formations in India has been estimated to be 572 billion tons (Bt) of which storage potential of Basalt formations in the Deccan and Rajmahal traps is 200 Bt, onshore and offshore deep saline aquifers (360 Bt), unmineable coal seams (5 Bt) and depleted oil and gas reservoirs (7 Bt). Considering that cumulative CO_2 emission projections for India during the 21st century are 380 Bt-CO_2, with about two-thirds contributed by large point sources, CO_2 storage in geologic formations offers considerable technical potential for high mitigation. However these are initial estimates and would be useful for building upon this research for more specific estimation.

In a summary of this part, there are several options for the underground CO_2 storage, including the saline aquifers, depleted oil and gas reservoirs, coal beds, Deep Ocean, and the deep-sea sediments.

CO_2 storage is an integral part of the CCS chain, and therefore it is important to quantify the storage potential of geological sites suchas coal fields, oil and gas fields, and deep saline water-bearing reservoir rocks. Presently, there is a lack of knowledge in this area due to a general dearth of essential data required to characterize these sites. Nonetheless, some attempts have been made at evaluating the storage potential in India, initially by Singh et al. who estimated that roughly 5 Gt CO_2 could be stored in un-mineable coal seams, 7 Gt CO_2 in depleted oil and gas reservoirs, 360 Gt CO_2 in offshore and onshore deep saline aquifers, and 200 Gt CO_2 viamineralization in basaltrocks.ThelatterreferstolaboratoryexperimentsconductedbyMcGraileetal.thatdemonstratedarelativelyrapid chemical reaction of CO_2-saturated pore water with basalts to form stable carbonate minerals. This could be quite an appealing opportunity for India as a very extensive portion of the central peninsula consists of one of theworld'slargestbasaltlavaflowsknownastheDeccantrapformation.However,thisconceptisstillintheexperimentalphaseandcanonlybeconsideredapossibilityifthebasaltisadequatelypermeabletotheCO_2andcanbedemonstratedtobesafeandsecure. A more recent study conducted for the IEA Greenhouse Gas R&D Program [IEAGHG] has revised down the estimates first made by Singh et al.

This new assessment predicts that the storage in coal seams is likely to be constrained due to the fact that these coal reserves can be easily mined and used as fuel. Therefore, they calculate the storage potential countrywide to be more of the order of 345 Mt CO2 in the major coalfields, where none have the capacity to store more than 100 Mt CO2, and only eight of the fields can store more than 10 Mt CO2. For oil and gas reservoirs, the authors calculate the total storage capacity to be between 3.7 and 4.6 Gt CO2. In addition, the PI noted during PCCC4 at Alabama, USA on the basis of discussions with CIL team at the conference PCCC4, that only a few fields, such as the Bombay High field, offshore Mumbai, are thought to have ample storage for the lifetime emissions of a medium sized coal-fired power plant. None of the fields, it would seem, are large enough to store the lifetime emissions of India's planned UMPPs (currently estimated at 28-29 Mt CO2/year for a period of 35 years, or 1 Gt CO2 roughly). However, the PIs do believe that there may be significant CO2 storage potential "in the oil and gas-bearing sedimentary basins around the margins of the peninsula, especially in the offshore basins, but also onshore in the states of Gujarat and Rajasthan. Yet, these potential storage sites are not well placed in respect to major CO2 sources occurring in the central parts of the peninsula. Some areas in the northeast, such as Assam, are thought to have possible CO2 storage, though this region is quite distant from the main emission sources, requiring thousands of kilometers worth of pipeline infrastructure, particularly if they were not to cross Bangladesh. Their study concludes that more realistic storage capacities for saline aquifers need to be quantified, most likely with the aid of oil and gas exploration information, such as seismic and well data.

5.1.3.3 SINGRAULI COAL FIELDS OF NCL FOR CO2 INJECTION FROM PROPOSED ANPARA CCS PLANT

The linked coal field of ANPARA TPS 2x500 MW whose feasibility study of the CCS plant has been done are KHRIA, KAKRI & various basket mines of NCL in Singrauli Coal fields of Northern Coal Fields (NCL)

The NCL Coal Fields in Singrauli region are of Gondwana origin and out of 240 billion tonnes of total coal resources in India, only 90 billion tonnes have been estimated as recoverable reserves. Rest of the un-mineable coal deposits could be potential CO_2 storage sink as listed below:

ABOUT SINGRAULI COAL FIELDS

The Singrauli Coalfield is located between latitudes 24012’ N and 230 47’ N. It is spread over nearly 2,200 km2 (850 sq mi) but only a small part of the coalfield, around

220 km2 (85 sq mi), has been identified as promising by the Geological Survey of India. The north-eastern part of the coalfield sits on a plateau with an altitude of 500m above mean sea level, well above the lower plains of 280m altitude.

The coal reserves in the north-eastern part of Singrauli coalfield, covering an area of around 220 km2 (85 sq. mi), is 9,121 million tonnes, out of which 2,724 million tonnes are proved reserves and the rest is inferred or indicated. Important coal seams in this part of Singrauli coalfield are: Jhingurda (130–162 m thick), Purewa (8–25 m thick) and Turra (12–22 m thick). Qualitatively, the products of these seams are generally high moisture (6-9 per cent) and high ash (17-40 per cent) coals. The volatile matter ranges from 25-30 per cent. The calorific value of the coal varies from 4,200-5,900 Kcal/kg.Almost all of India’s coal reserves are of Gondwana coal. Thickness of coal seams in Indian coalfields generally ranges from 1 m to 30 m. An exceptionally thick seam of 138 m has been discovered in Singrauli coalfield.

Most of the coal produced from Northern Coalfields Limited is dispatched to pithead power plants. Some of the power plants in the area are: Singrauli Super Thermal Power

Station, Rihand Thermal Power Station, Anpara Thermal Power Station, Obra Thermal Power Station, Vindhyachal Thermal Power Station and Renusagar Thermal Power Plant

As regards ANPARA B TPS – 2x500 MW is concerned, it may be noted that Kakri & Bina Coal mines are nearer to the plant and are almost depleted to a great extent and these could be selected for CO2 injection. The length of pipe will not exceed 5 KM.

Jhingurdah	**3.00**	**Remarks**
Amlohri Expansion OCP	**10.00**	
Bina Extension OCP	**6.00**	**CO2 Injection Site**
Kakri OCP	**3.00**	**CO2 Injection Site**
Khadia Expansion OCP	**10.00**	
Krishnashila OCP	**4.00**	**CO2 Injection Site (LATER)**
Nigahi Expansion OCP	**15.00**	
Jayant Expansion OCP	**20.00**	
Dudhichua Expansion OCP	**20.00**	
Block-B Expansion OCP	**8.00**	
BinaKakri Amalgamation OCP	**14.00**	
Semaria OCP	**2.00**	
Nigahi Expansion OCP	**25.00**	
Total	**115.00**	

List of NCL coal field & their capacities in million tons per year are given for reference

CLOSING REMARKS ON SEQUESTRATION OPTIONS FOR ANPARA 500 MW CCS PROJECT:

Storage site selection for a CCS project is initiated by basin and regional-scalesuitabilityassessments.Onlysedimentarybasinswithoil and gas reservoirs, deep sandstone and carbonate aquifers, coalbeds, and salt beds are often targeted for a CO_2 sequestration practice. Comparatively, active or depleted oil and gas reservoirs and deep aquifers have been recognized as the best CCS sites for a large-scale disposalofCO_2.

Estimated CO2 storage potential in India

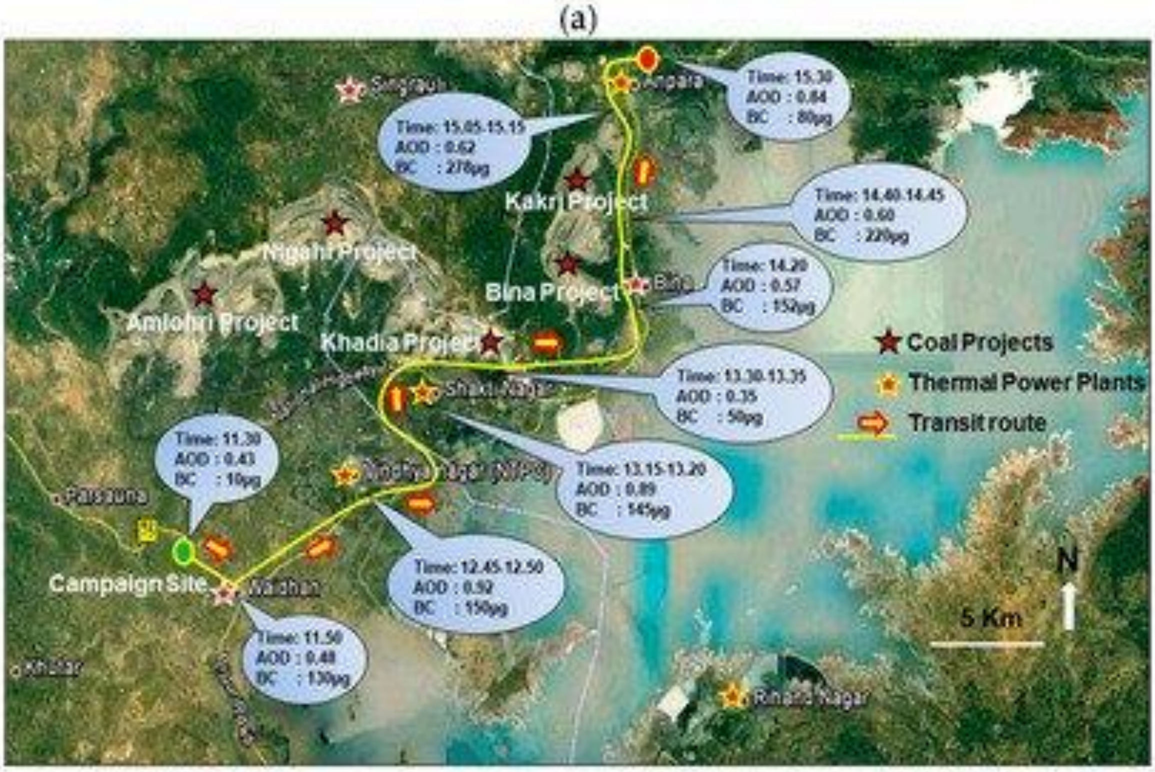
- deep saline reservoirs (on and off shore) estimates : ~ 360 GtCO2 360 GtCO2
- Depleted oil and gas wells estimates: ~ 7 GtCO2
- Un -mineable coal seams: 5 GtCO2
- Volcanic rock : 200 GtCO2
- NCL Singrauli Region : 1.16 GtCO2

Our feasibility study shows that for 5000 Unit No.4 of ANPARA B TPS -2x500 MW (EPC by Toshiba Corp, Japan) the best solution would be

- **INITIALLY USE KAKRI COAL FIELD FOR SEQUESTRATION**
- **NEXT USE BINA COAL SEAM FOR CO2 SEQUESTRATION**
- **THE PIPELINE COST WILL BE MINIMUM VIA ANPAR SHAKTINAGAR ROAD SIDE**
- **THE OLD WARF WALL OF KAKRI MINE SHALL BE USED FOR CO2 PUMPING STATION**

SINGRAULI COAL FIELDS & POWER PLANTS

(a)



(b)

CHAPTER – 5.2

DAS & SCADA

Chapter -5.2: DATA Acquisition System (DAS) – Results & SCADA Out-put Analysis (Under Erection & Commissioning)

NOTE: While writing the Project Completion Report the DAS & SCADA systems work of CCS Pilot Plant at RKDF University is under hold due severe COVID Conditions as such its 'Output Analysis' will be submitted as supplementary report.

This section deals with:

1. **DAS & SCADA – Broad Specs.**
2. **CCS Monitoring System Design**
3. **Offer of M/S DUREND CONTROLS**
4. **Minutes of meeting for placement of 'Order'**

Preamble:

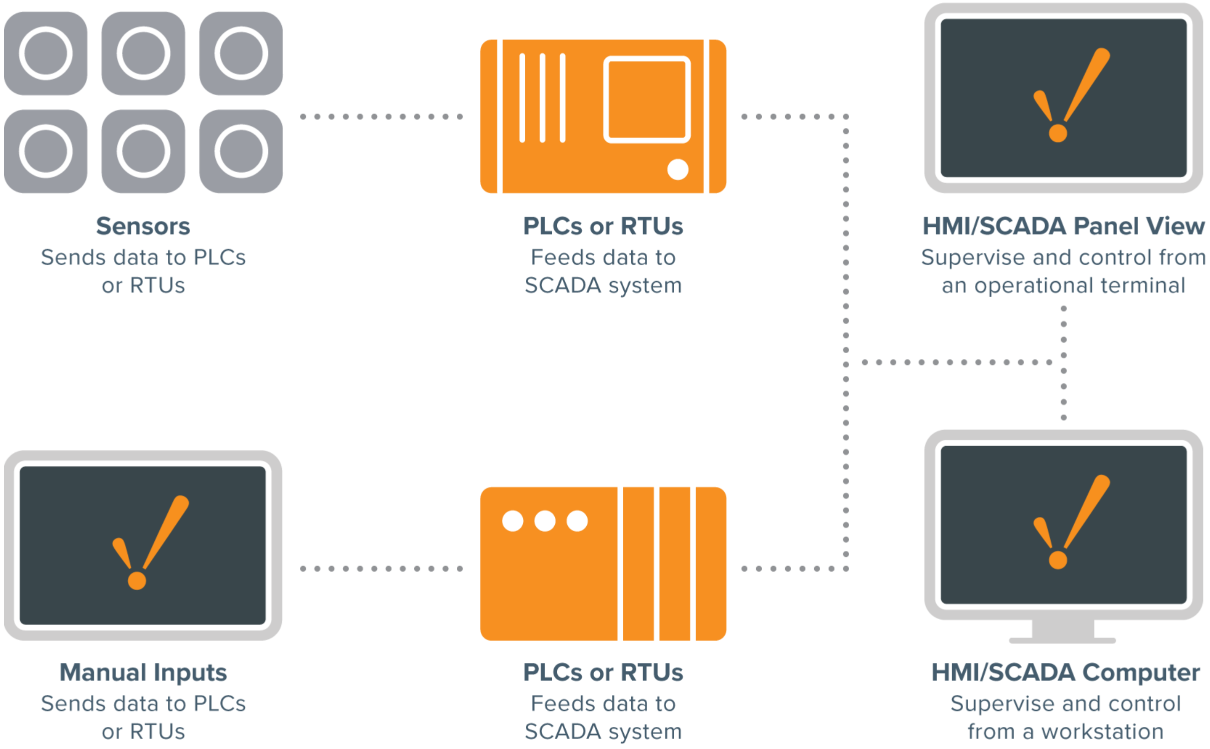
Supervisory control and data acquisition (SCADA) is a system of software and hardware elements that allows industrial organizations to:

- Control industrial processes locally or at remote locations
- Monitor, gather, and process real-time data
- Directly interact with devices such as sensors, valves, pumps, motors, and more through human-machine interface (HMI) software
- Record events into a log file

SCADA systems are crucial for industrial organizations since they help to maintain efficiency, process data for smarter decisions, and communicate system issues to help mitigate downtime.

The basic SCADA architecture begins with programmable logic controllers (PLCs) or remote terminal units (RTUs). PLCs and RTUs are microcomputers that communicate with an array of objects such as factory machines, HMIs, sensors, and end devices, and then route the information from those objects to computers with SCADA software. The SCADA software processes, distributes, and displays the data, helping operators and other employees analyse the data and make important decisions.

For example, the SCADA system quickly notifies an operator that a batch of product is showing a high incidence of errors. The operator pause the operation and views the SCADA system data via an HMI to determine the cause of the issue. The operator reviews the data and discovers that Machine 4 was malfunctioning. The SCADA system's ability to notify the operator of an issue helps him to resolve it and prevent further loss of product.



SCADA systems are used by industrial organizations and companies in the public and private sectors to control and maintain efficiency, distribute data for smarter decisions, and communicate system issues to help mitigate downtime. SCADA systems work well in many different types of enterprises because they can range from simple configurations to large, complex installations. SCADA systems are the backbone of many modern industries, including the following:

- **Energy**
- Food and beverage
- Manufacturing
- Oil and gas
- **Power**
- Recycling
- Transportation
- Water and waste water
- **Environmental Control Systems**

Virtually anywhere you look in today's world; there is some type of SCADA system running behind the scenes: maintaining the refrigeration systems at the local supermarket, ensuring production and safety at a refinery, achieving quality standards at a waste water treatment plant, or even tracking your energy use at home, to give a few examples.

Effective SCADA systems can result in significant savings of time and money. Numerous case studies have been published highlighting the benefits and savings of using a modern SCADA software solution such as Ignition.

Modern SCADA systems allow real-time data from the plant floor to be accessed from anywhere in the world. This access to real-time information allows governments, businesses, and individuals to make data-driven decisions about how to improve their processes. Without SCADA software, it would be extremely difficult if not impossible to gather sufficient data for consistently well-informed decisions.

Also, most modern SCADA designer applications have rapid application development (RAD) capabilities that allow users to design applications relatively easily, even if they don't have extensive knowledge of software development.

The introduction of modern IT standards and practices such as SQL and web-based applications into SCADA software has greatly improved the efficiency, security, productivity, and reliability of SCADA systems.

SCADA software that utilizes the power of SQL databases provides huge advantages over antiquated SCADA software. One big advantage of using SQL databases with a SCADA system is that it makes it easier to integrate into existing MES and ERP systems, allowing data to flow seamlessly through an entire organization.

Historical data from a SCADA system can also be logged in a SQL database, which allows for easier data analysis through data trending.

HISTORICALLY SCADA IN CCS:

CCS Systems have been using Supervisory Control and Data Acquisition SCADA systems for EOR and other applications of captured CO2. They utilize computer technology to continuously gather data (e.g., pressure, temperature, and delivery flow rates) from remote locations on the pipeline. SCADA systems can also provide input for real-time models of the pipeline operation. SCADA systems in CCS plants are being used to measure the flow rate, pressure, and temperature of the CO2 and provide sufficient information for the system normal operation. SCADA systems are used for remote monitoring and operation of the compressor stations and the pipeline. These systems are designed to provide operators at a central control center with sufficient data on the status of the pipeline to enable them to control the flows through the compressors and the pipeline as necessary. Metering is used for computational pipeline monitoring (CPM) leak-detection systems for single-phase lines (without gas in the liquid). Currently CO2 pipelines are not required to have CPM, mainly because it is technically difficult. Other leak-detection methods, such as pressure point analysis and aerial and visual surveys may be used to ensure safe CO2 transport.

DATA LOGGER & SCADA SYSTEM FOR CARBON CAPTURE PILOT PLANT AT RKDF UNIVERSITY (Onsite PLC/SCADA/ DAS Programming & Commissioning)

The basic purpose of installation of SCADA on the pilot plant is carry our Energy balance of the Re-boiler (Reactor Tank) which is getting steam from two sources – Solar Thermal @ 50 kg / hr. and a coal fired boiler of capacity 250 kg/ hr. flue gas and steam @ 45 kg/ hr. at 8 bar pressure. Accordingly a NIT was floated as shown further.

Efforts were made to see that following guide-lines are followed by the supplier of DAS / SCADA:

- State of the art system which is capable of measurement and monitoring capabilities.
- USB based data logging system to keep data safe.
- RS 485 output to save data on cloud. Web based monitoring shall be possible
- Flow meter capable of accurately measuring 10 kg/hr to 50 kg/hr. steam and flue gas up to 250 kg/hr.

- Mixing Control Valve to ensure constant pressure to the Carbon Sequestration unit
- SCADA connectivity – to see the trends and reports
- Pressure Control Setting of control valve possible using panel
- Providing user friendly interface

The Offer of M/S DUREND CONTROL was lowest and accordingly a meeting of review committee of both Universities (RKDF & RGPV) was held to finalize the offer, deliverables and time schedule of erection from April – June 2021. Advance of Rs. 97500 has been released through PFMS.

Installation of Optimization Software "ASPEN Plus" for reduction of Energy penalty in generation of solvent through use of Solar thermal was included in the scope

However due to Severe COVID -19 conditions only on-line work like design calculations and simulation studies on ASPEN Plus could be performed till date as detailed in section 5.3 of this chapter. The final report of on this chapter will be submitted as supplementary report as the COVID situation improves and labor intensive erection, testing & commissioning is completed.

Following sections are included further:

- **DAS & SCADA – Broad Specs.**
- **CCS Monitoring System Design**
- **Offer of M/S DUREND CONTROLS**
- **Minutes of meeting of internal review committee under Chairmanship of VC Sir, RGPV for SCADA / DAS order placement and review of testing / trial run of 30 days**

DAS & SCADA – BROAD DETAILS

RAMKRISHNA DHARMARTH FOUNDATION UNIVERSITY, AIRPORT BYPASS ROAD, GANDHI NAGAR, Near RGPV, BHOPAL- 462033
www.rkdf.ac.in

TENDER ENQUIRY- (CPRI/ RKDF/ Project / 02: Dated 8, March 2021)

Sealed Tenders are invited for Supply & Installation of Delta Make PLC with Analogue & Digital I/OS with Control Panel and SCADA Software for CCS (*carbon capture and Sequestration*) at – RKDF University – Bhopal (Madhya Pradesh)

BROAD SPECIFICATIONS:

DATA LOGGER & SCADA SYSTEM FOR CARBON CAPTURE PLANT

(Onsite PLC/SCADA/ DAS Programming & Commissioning)

Delivery: The delivery must be a period of 3-4 weeks from the date confirmation of techno commercial clear OGA & Drawing.

Price Basis: F.O.R Bhopal (MP).

Warranty: The switchgears & PLC/SACDA shall be warranted for the period of 12 month from the date of supply as per OEM Norms.

Loading & Unloading of Goods: It shall be in suppliers Scope

All Field Control & Power Cable supply, lying & Installation in agencies Scope of Work

Procurement & Installation of Flow Transmitters (Output) 4-20mA in the Scope of agency

PC, Minimum i3, 256SSD, 8GB RAM with minimum 15 Minutes UPS Backup Supplied by University

SCADA Control Room Develop by agency including a Big Size (Minimum 4 ft. x2ft.) display at site

Pressure Transmitters & RTD Supplied by you & Installation by RKDF University

Both Technical & Financial bids should be submitted through by hand/ speed post / registered post/ courier by 13 March 2021 (3:30 PM).

Note: For any clarification contact on e-mail vksethi1949@gmail.com & for details of the project refer our website rkdf.ac.in

All presentations before committee headed by Hon'ble VC RKDF University as constituted by DG (Research)

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DR V K SETHI
DG (RESEARCH)

ANNEXURE 1 – FEATURES OF PERFORMANCE MONITORING SYSTEM

- State of the art system which is capable of measurement and monitoring capabilities.
- USB based data logging system to keep data safe.
- RS 485 output in case customer wants to save data on cloud. Web based monitoring possible with additional IIOT attachment
- Flow meter capable of accurately measuring 10 kg/hr.
- Mixing Control Valve to ensure constant pressure to the Carbon Sequestration unit
- SCADA connectivity optional – to see the trends and reports
- Pressure Control Setting of control valve possible using panel
- Providing user friendly interface
- Creates a database with date and time stamp which can be used for analysis and improvements

ANNEXURE 2 – SCOPE OF SUPPLY

S No	ITEM DESCRIPTION	QUATITY
1	**STEAM FLOW METER**	2
	Accelarabar	
	Moisture Separator	
	Condensate Pots	
	DP Transmitter, Temperature Transmitter and Gauge Pressure Transmitter	
	Set of Valves and Tubings	
2	**Flue Gas Flow Measurement**	1
	Insertion type DP Flow Element	
	DT Transmitter and Temperature Transmitter	
	Set of Valves and Tubing's	
3	**Mixing Type Control Valve**	1
	3 way Mixing Valve with Electrical Actuator	
	Gauge pressure Transmitter	
4	**Control and Display Unit**	1
	Steam Flow Meter Inputs	
	Flue Gas Flow Inputs	

	Control Valve - PID Control	
	USB Data Logging	
5	**SCADA – Supervisory Control and Data Acquisition System – Optional**	**1**
	Data Logging, trends and Reports on your computer	
6	**Data Logging, Reports on Web Based Platform**	**1**

ANNEXURE 3 – Exclusions

S NO.	DESCRIPTION
1	Provide tapping for steam flow meter, gauge pressure transmitter, temp probes in flue gas, feed water, steam, oil and ambient ducting and all Fabrication activity
2	Installation of the controller in boiler house.
3	All Legal formalities at site, if any
4	Power supply for the controller.
5	Computer / laptop / desk top
6	Cabling between the Controller and PC
7	Other than Scope of supply (cable trays / cable support, fabrication, any Electronic hardware for multiple connections to PC, etc.)

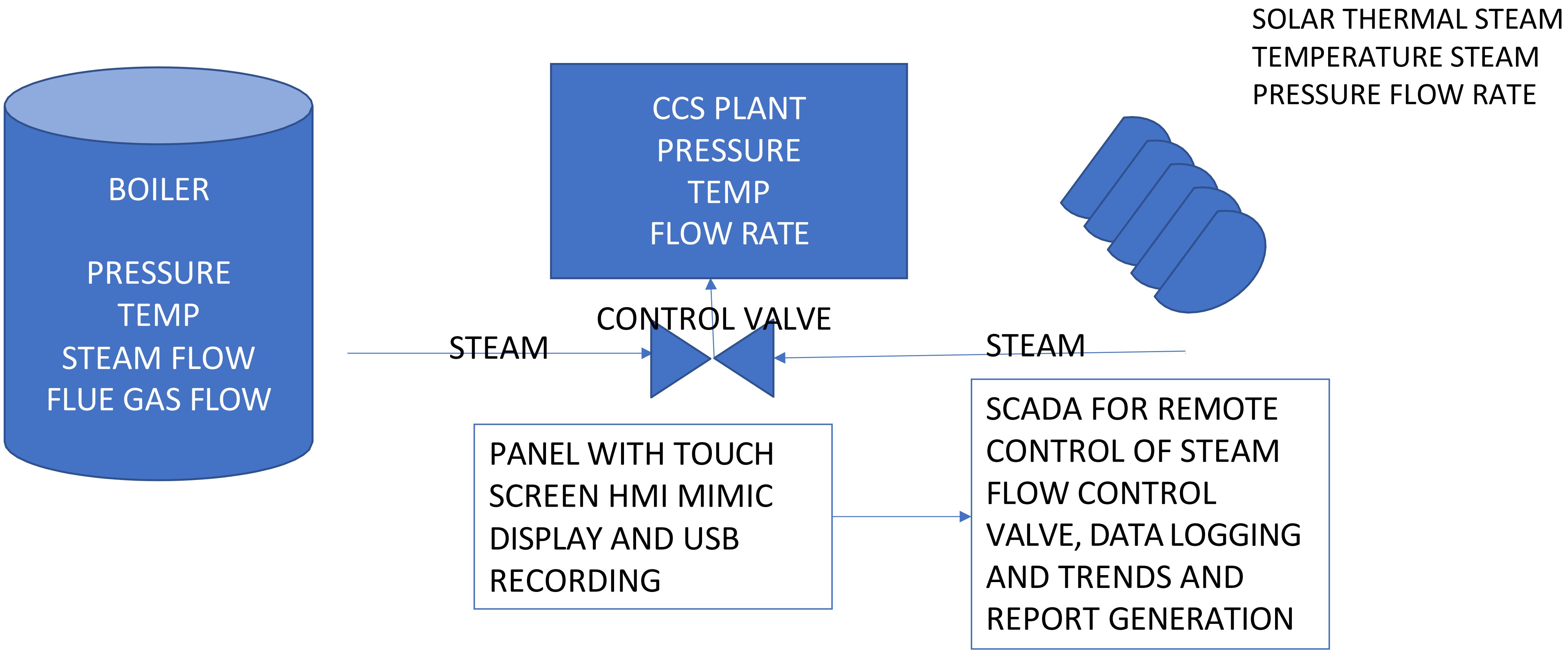
DAS & SCADA

PRODUCT STRUCTURE CARBON CAPTURE & SEQUESTRATION UNIT

CPRI (RSOP) PROJECT

AT RKDF UNIVERSITY

CONCEPT



SOLAR THERMAL STEAM
TEMPERATURE STEAM
PRESSURE FLOW RATE

BOILER

PRESSURE
TEMP
STEAM FLOW
FLUE GAS FLOW

CCS PLANT
PRESSURE
TEMP
FLOW RATE

CONTROL VALVE

STEAM

STEAM

PANEL WITH TOUCH SCREEN HMI MIMIC DISPLAY AND USB RECORDING

SCADA FOR REMOTE CONTROL OF STEAM FLOW CONTROL VALVE, DATA LOGGING AND TRENDS AND REPORT GENERATION

DATA INPUT

- BOILER
  - MAX – AVG – MIN PRESSURE
  - MAX – AVG – MIN TEMPERATURE
  - MAX – AVG – MIN STEAM FLOW RATE
  - BOILER FLUE GAS DUCT DIA/SIZE
  - BOILER FLUE GAS TEMPERATURE
  - STEAM LINE DIA/ AREA

- SOLAR THERMAL
  - MAX – AVG – MIN PRESSURE
  - MAX – AVG – MIN TEMPERATURE
  - MAX – AVG – MIN STEAM FLOW RATE
  - STEAM LINE TO REACTOR- DIA

- CCS (Reactor/ Reboiler)
  - MAX – AVG – MIN PRESSURE
  - MAX – AVG – MIN TEMPERATURE
  - MAX – AVG – MIN STEAM FLOW RATE
  - STEAM LINE SIZE

  - IS THIS AN RS 485 INPUT FROM CCS, OR WE WILL NEED TO PUT DUPLEX INSTRUMENTS OR SPLIT THE SIGNAL FROM CCS PANEL
  - CONTROL VALVE WILL BE A 3 WAY CONTROL VALVE OPERATING ON PRESSURE

DURAND Controls

Offered Project Name:- Offer for SCADA System for CCS Plant

OFFER REF. NO. : DC/20-21/RKDF/CCS SCADA/0712

Consigner Correspondence:- **Off:-** 20/B, Nema Complex, Opp. BHEL Jubilee Gate, Indrapuri, Bhopal (MP) 462022 **Factory:-** Plot No. 27, Industrial Area, Pipalkhiriya, District Raisen, Bhopal (MP) 4250901	Phone:- +91 9301818278 / +91 9302253811 E-Mail:- info@durendcontrols.in Website:- www.sme.in/durend GST No.:- 23ABLFS7952F1ZW PAN No.:- ABLFS7952F

To, **RKDF UNIVERSITY** Abbas Nagar, Karond BHOPAL (MP) **GST No.: NA**	Contact Person: Mr. V.K. Sethiji Designation: Ex. V.C. Contact No.: +91 9713902378 Email: vksethi1949@gmail.com Website: NA

Dear Sirs,

This is **M/s. Durend Controls** is an **ISO 9001:2008 & ISO 9001:2015, NSIC & MSME, CRISIL Rated & CPRI Approved** credential company, working in the field of industrial automation solution & electrical Panel manufacturing business in Madhya Pradesh. Our corporate office is in Bhopal (MP) & branch is in indore (MP). We are having a good team of members across the Madhya Pradesh to serve in the same field. We are having latest machineries & having around 17,500 Sq. fit industrial area space with well equipped office. The turnover thereafter has consistently grown with the magnanimous support from our Customer, vendors and well wishers, who has given us the necessary impetus, support and Confidence.

Presently we are exclusively involved in manufacturing, sales & services of various electrical & automation product & Projects as listed below;

- ✓ SCADA & PLC Based Automation Solution
- ✓ AC / DC / Servo Drives & Motor Based Solution
- ✓ Projects Related to Machines Retrofitting on Turnkey Basis
- ✓ Energy & Vibration Monitoring System
- ✓ Customized Reporting Software Development
- ✓ Specialized Job for Pharmaceutical / Life Science / Food & Beverages / Water Supply Scheme
- ✓ Busducts Designing / Cable Tray / Feeder Pillar / Junction Boxes / Relay Panel / Etc.
- ✓ MCC Panel / LT Panel / PCC Panel / APFC Panel etc.
- ✓ Complete Plant Electrical Contract on Turnkey Basis.

Thanks & Regards,

Manager (Electrical & Automation)
Durend Controls – Bhopal (MP)

Price Offer

Tender / Enq. No.: A per our Visit **Dated:** 07.12.2020

We are offering our best techno commercial offer for Supply of SCADA system for CCS Plant.

Sr. No.	Item Description	Qty.	Unit Price	Amount
1	SCADA software License of Min. 64 Tags.	1 Nos	Rs. **205000/-**	Rs. **205000/-**
2	Complete Panel With PLC and I/O system for 12 No. of analog Input 4 – 20 mA signal	1 Set		
3	Thermocouple sensor for Flu gas and Steam	5 Nos		
4	Pressure Sensor for Flu gas and Steam	5 Nos		
5	Programing and installation Charges	1 Job	Rs. **15000**/-	Rs. **15000/-**
Total Basic Amount				**Rs. 220000.00**
GST @ 18% Extra				**39600.00**
Final Taxable Amount:				**RS. 259600.00**

Enclosure:-

1. Terms & Conditions - **Annexure –A**
2. Exclusions - **Annexure – B**
2. Drawing - **After Complete T&C Approved Clear PO**

Annexure – A, Terms & Conditions

1.	**GST & HSN Code:** All taxes & duties payable as extra with the quoted price in the offer GST will be @ 18% extra (Our GST No. 23ABLFS7952F1ZW), Bhopal (MP), HSN Code will be 8537.
2.	**Validity:** The validity of the quoted offer will be 30 days only.
3.	**Terms of Payment:** Payment 35% advance & balance 65% against PI, after complete testing of Panels at our factory at Bhopal.
4.	**Delivery:** The delivery shall be a period of 4 - 6 Weeks from the date confirmation of techno commercial clear PO/WO and OGA & Drawing (If any) shall be submitted within 7 days of the PO/WO.
5.	**Price Basis:** F.O.R RKDF University , Abbas Nagar, BHOPAL (MP).
6.	**Warranty:** The supplied system shall be warranted for the period of 12 month from the date of supply as per OEM Norms.
7.	**Inspection & Testing:** Purchase must be liable to test & inspect the panel before dispatch from M/s. DUREND Controls, Site Add. Plot No. 27, Industrial Area, Pipalkhiriya, Dist: Raisen (MP). If Required.
9.	The quoted offer as per your requirement. If anything else is needed apart from this offer, please share with us before placing the PO/WO.

Thanks & Regards,

Annexure – B, Exclusions

1	**All Field Wiring and Cable will be in your Scope**
2	**Gas Analyzer and Flow meters will be in your Scope .**
3	**One Desktop PC of min. I3 grade will be in your Scope for SCADA System. If Supplied By us then Rs. 30,000/- Extra will be charged.**
4	**Installation and Mechanical work of all field Instruments will be in your scope.**
5	**All above listed work are exclusions Hence not covered in the quoted Price. If done by us then labour charges will be Extra.**

Thanks & Regards,

Manager (Electrical & Automation)
Durend Controls – Bhopal (MP)

Ph. : (O) 0755-2740395
Website : www.rkdf.ac.in
Email : info@rkdf.ac.in

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No. DC(R)/RKDF/CPRI/CCS/ Project/ 2020-21 Dated : 18 /03 / 2021

Dr. M Venkateswara Rao

Director, R&D Management Division

CENTRAL POWER RESEARCH INSTITUTE (CPRI)

Prof. C V Raman Road, Sadashivanagar Post Office

P.B. No. 8066, BANGALORE – 560 080

**Sub: Request for Time Extension without any additional financial requirement –
(Ref. Progress report for Jan 2021 to March 8, 2021: Q 8 - Part)**

Ref: RSOP Project "Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant – Feasibility Study"

Sir,

In reference to CPRI (RSOP) mail dated March 10, 2021 and with reference to our request for time extension vide progress report Q-8, as above, we are submitting herewith request for extension of the project till June 2021 due to following reasons:

1. **As per the minutes of review meeting date March 1, 2021 under chairmanship of VC, RGPV (The state Tech. University – Govt. of MP) Para 5, Copy enclosed as ENCL: 01, a data logger along with SCADA System is to be installed for generating more data for its viability / techno commercial analysis and on-line monitoring of the plant through internet. Accordingly an order was placed on the agency on L-1 basis of NIT issued. Copy of the NIT & Supply Order is as per ENCL: 02. Also kindly refer RSOP Proforma for the purchase of equipment (ENCL: 03)**

2. **The testing of plant in terms of reduction in Energy penalty can be well established with Solar Thermal Integration during high Solar Flux Months, viz. April – June 2021, particularly with the use of Scheffler discs for steam production in our Concentrated Solar Plant (CSP) for regeneration of solvent**

3. **Since the project is required to run in the night time also with steam from thermal Energy storage (TES) of the CSP, there are some optimization issues with TES as on date, as the supplier of TES from USA is not able to visit India in the current pandemic.**

①

4. Project Completion report is to be compiled running into several volumes: State of Art, Feasibility report of mega scale CCS plant, Way forward in CCS deployment with options for conversion of Multi-purpose Fuels etc. In fact the associated H_2 and Algal Bio-diesel plant under construction and likely to complete by June 2021.

It may be mentioned that the project execution in a live project like this has become increasingly difficult due to COVID – pandemic being a highly labor-intensive activity.

In view of above it is requested that a time extension without any financial implication may be given and we may be allowed to utilize the balance CPRI – RSOP fund beyond 31st March 2021 through PFMS

With kindest regards

Vinod K Sethi
18-3-2021

Dr. Vinod Krishna Sethi

DG (Research) RKDF Univ. & PI

Director General (Research)
RKDF University

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ENCL:01

(1/2)

Minutes of Meeting
Of
Project Monitoring Committee Meeting
On
Carbon Capture & Sequestration Project

(Funded by CPRI, GoI)

Venue: Hon'ble VC office, RGPV, Bhopal

Time: 11:30 am to 12:30 pm **Date: 01/03/2021**

Title of the Project: *Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant – Feasibility Study*

Present:

- Dr. Sunil Kumar , Hon'ble VC RGPV Bhopal (Chairperson & CO-PI)
- Dr. Sudesh Kumar Sohani , Hon'ble VC RKDF Bhopal
- Dr. V K Sethi, Principal Investigator (PI)
- Dr. Savita Vyas , Professor , SoEEM RGPV ,Co-PI
- Er. A K Bhargav , Ex GM BHEL, Bhopal (Industry expert) (on-line)
- Dr. M.L. Kori , Director Research , RKDF University
- One external member from EPCO, Bhopal, Sh. Lokendra Thakkar (On-line)
- Dr. Pankaj Jain, A.P. SoEEM (Meeting convener)

Discussions were held agenda wise as under:

1) Briefing on status of CCS project By Dr. V K Sethi, PI
   Briefing was done on status of CCS project By Dr. V K Sethi, PI. He informed that the Trial run of 30 days has started on Nov 11, 2020 and has been completed on Feb 18, 2021. He informed that the project is being reviewed by BHU Management Center and discussions with NTPC (NETRA) are under way for installation of Table-Top / Skid mounted plant at the 500 MW Unit site.
2) Presentation by Sunrise CSP Ltd. regarding their Erection & commissioning work.
   Presentation was done by Mr. Deepak Gadhiya & Mr. Pankaj Kumar Singh
3) Discussion on technical parameters achieved on testing.
   The technical parameters, as-built drawings and test results were presented by SUNRISE CSP (I) Pvt. Ltd.

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4) Discussion on Project implementation in National perspective by Dr. Savita Vyas, CO-PI
National perspective of CCS was presented by Dr. Savita Vyas

5) Discussion on Future Road map of this project vis-a vis Global climate related aspects by Dr. Sunil Kumar, CO-PI .**Hon'ble VC RGPV was of the view that we have to look forward for implementation of CCS project at world level. Also he added that we have to generate more data for its viability/techno commercial analysis and for that we have to install a data logger system at earliest.**

6) Regarding 10% (second last) payment for Sunrise CSP subsequent upon completion of Trial Run.
The committee recommended for release of 10% payment of M/S SUNRISE CSP (I) Pvt. Ltd. on completion of 30 days trial run as per terms of contract, as confirmed by PI .] 'A'

S. Kumar

Dr. Sunil Kumar , Hon'ble VC RGPV Bhopal (Chairperson & CO-PI)

S K Sohani 1.3.2021

Dr. Sudesh Kumar Sohani , Hon'ble VC RKDF Bhopal

Dr. V K Sethi, Principal Investigator (PI)

S. Vyas

Dr. Savita Vyas , Professor , SoEEM RGPV ,Co-PI

[online consent]

Er. A K Bhargav , Ex GM BHEL, Bhopal (Industry expert)

Dr. M.L. Kori , Director Research , RKDF University

Sh. Lokendra Thakkar (On-line) GM, EPCO, Bhopal

Dr. Pankaj Jain, A.P. SoEEM (Meeting convener)

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ENCL: 02

RAMKRISHNA DHARMARTH FOUNDATION UNIVERSITY, AIRPORT BYPASS ROAD, GANDHI NAGAR, Near RGPV, BHOPAL- 462033
www.rkdf.ac.in

TENDER ENQUIRY- (CPRI/ RKDF/ Project / 02: Dated 8, March 2021)

Sealed Tenders are invited for Supply & Installation of PLC with Analogue & Digital I/OS with Control Panel and SCADA Software for CCS (*carbon capture and Sequestration*) at – RKDF University – Bhopal (Madhya Pradesh)

BROAD SPECIFICATIONS:

DATA LOGGER & SCADA SYSTEM FOR CARBON CAPTURE PLANT

(Onsite PLC/SCADA/ DAS Programming & Commissioning)

Delivery: The delivery must be a period of 3-4 weeks from the date confirmation of techno commercial clear OGA & Drawing.

Price Basis: F.O.R Bhopal (MP).

Warranty: The switchgears & PLC/SACDA shall be warranted for the period of 12 month from the date of supply as per OEM Norms.

Loading & Unloading of Goods: It shall be in suppliers Scope

All Field Control & Power Cable supply, lying & Installation in agencies Scope of Work

Procurement & Installation of Flow Transmitters (Output) 4-20mA in the Scope of agency

PC, Minimum i3, 256SSD, 8GB RAM with minimum 15 Minutes UPS Backup Supplied by University

SCADA Control Room Develop by agency including a Big Size (Minimum 4 ft. x2ft.) display at site

Pressure Transmitters & RTD Supplied by you & Installation by RKDF University

Both Technical & Financial bids should be submitted through by hand/ speed post / registered post/ courier by 13 March 2021 (3:30 PM).

Note: For any clarification contact on e-mail vksethi1949@gmail.com & for details of the project refer our website rkdf.ac.in

All presentations before committee headed by Hon'ble VC RKDF University as constituted by DG (Research)

COPY TO: INDIA MART INTERMESH LIMITED, NEW DELHI ON THEIR WEBSITE

DR V K SETHI

DG (RESEARCH)

5/9

Ph. : (O) 0755-2740395
Website : www.rkdf.ac.in
Email : info@rkdf.ac.in

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No. DG(R)/RKDF/ SCADA/CCS/CPRI/2020-21 Dated : 15/03/2021

Consignee Correspondence:- **RKDF University** Airport Rd, Abbas Nagar, Gandhi Nagar, Bhopal, Madhya Pradesh 462033 GST No.: BPLA03038A	Contact Person: Dr. V K Sethi Principal Investigator Contact No.: 9713902378 Email ID: vksethi1949@gmail.com Website: www.rkdf.ac.in

Consigner Correspondence:- **M/s. Durend Controls** **Off:-** 20/B, Nema Complex, Opp. BHEL Jubilee Gate, Indrapuri, Bhopal (MP) 462022 **Factory:-** Plot No. 27, Industrial Area, Pipalkhiriya, District Raisen, Bhopal (MP) 4250901	Contact Person: Mr. Digvijay Singh Phone:- +91 9302253811 / +91 9301818278 E-Mail:- info@durendcontrols.in Website:- www.sme.in/durend GST No.:- 23ABLFS7952F1ZW PAN No.:- ABLFS7952F

Work Order

Quotation No.: (CPRI/ RKDF/ Project / 02: Dated 8, March 2021) Dated: 15.03.2021

We are placing the Work Order against your above mentioned Quotation Dated 08.03.2021 with final techno commercial negotiation for Supply & Installation of Delta Make PLC with Analogue & Digital I/Os with Panel and SCADA System for CCS(**carbon capture and Sequestration**) at – RKDF University – Bhopal (Madhya Pradesh)

Sr. No.	**Item Description**	**Qty.**	**Amount**
1	Supply & Installation of Delta Make PLC with Analogue & Digital I/Os with Control Panel and SCADA Software for CCF (**carbon capture and Sequestration**) at – RKDF University – Bhopal (Madhya Pradesh) BOM as per **Annexure – B**	1 Nos.	1,95,000
2	Onside PLC/SCADA Programming & Commissioning	1 Nos.	
3	Thermocouple sensor for Flu gas and Steam	5 Nos.	
4	Pressure Sensor for Flu gas and Steam	5 Nos.	
5	Programing and installation Charges	1 Job	
GST		**18%**	35,100
Total Amount			Rs. 2,30,100
Total Amount in Words: Two lac thirty thousand one hundred only/-			

Director General (Research)
RKDF University

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Terms & Conditions	
1.	**GST & HSN Code:** All taxes & duties payable as extra with the quoted price and GST will be @ 18% extra; HSN Code must be clearly mentioned during submission of the Invoice.
2.	**Terms of Payment:** Payment 50% Advance with work order, Payment of 20 % on supply of equipment at RKDF Campus, Payment of 20% will be after installation & commissioning of complete system. Remaining 10% will be release after 15 days successful run.
3.	**Delivery:** The delivery must be a period of 2-3 weeks from the date confirmation of techno commercial clear OGA & Drawing.
4.	**Price Basis:** F.O.R Bhopal (MP).
5.	**Warranty:** The switchgears & PLC/SACDA shall be warranted for the period of 18 month from the date of supply as per OEM Norms.
6.	**Inspection & Testing:** We will liable to test & inspect the panel before dispatch from M/s. DUREND Controls, Site Add. Plot No. 27, Industrial Area, Pipalkhiriya, Dist: Raisen (MP). If Required.
7.	**Loading & Unloading of Goods:** It shall be in vendor Scope.
8.	**All Field Control & Power Cable supply, lying & Installation in our Scope of Work.**
9.	**Procurement & Installation of Flow Transmitters (Output) 4-20mA in our Scope.**
10.	**PC, Minimum i3, 256SSD, 8GB RAM with minimum 15 Minutes UPS Backup Supplied by us.**
11.	**SCADA Control Room Develop by RKDF, Vendor has to arrange a Big screen display Size (Minimum 4 ft. x2ft.)**
12.	**Pressure Transmitters & RTD Supplied by you**

15-3-21

Director General (Research)
RKDF University

ENCL:03

Form No: CPRI/PM/R&D/RSoP/F-2Rev: 00Dated: 08/12/2017

RESEARCH SCHEME on POWER (RSOP)

PROFORMA FOR THE PURCHASE OF THE EQUIPMENT

Details of equipment required for the project PLC with Analog & Digital I/os with Control Panel & SCADA/DAS assigned to RKDF Unit & RGPV Bhopal Research Station under Research Scheme on Power for the year 2020-21

1.	**Details of the equipment**	SCADA/DAS SYSTEM
2.	**Date of commencement (actual)**	: 15/3/2021
3.	**Whether similar equipment are already available with the Organization / Institute. If so how many**	: NO
4.	**The detailed Justifications / reasons for the purchase of the Equipment now proposed**	: As per Enclosure
5.	**How exactly the equipment now proposed is to be used in project under study**	: For on-line Real time Monitoring
6.	**Whether it is indigenous equipment or to be imported** *Indigenous critical gas sensors are imported* → No	:
7.	**Cost of the Equipment (F.O.R destination price)**	2,30,100=00
8.	**Approximate period of delivery** *2-3 weeks*	: 2-3 weeks
9.	**Present status in ordering the equipment**	: ordered
10.	**Amount of advance payment to b made if any and at what stage** 50% with PO	**:50%**
11.	**Approximate time required for ordering the equipment**	: ordered
12.	**If the studies could be carried out with the equipment already available and the equipment now indented can expedite the studies, a short note on savings of manpower / money may be furnished.**	: N.A
13.	**Year for which the equipment purchased / to be purchased**	: 2021
14.	**Remarks**	: Refer: M.O.M. Dated 1-3-2021 & Associated note for Time extension

15-3-2021

Principal Project Investigator

Note: **The above details are to be furnished for all the equipments whose cost is more than Rs 50,000/- per piece for total cost of various equipments** ***(even if comes to equal or more than any one of them is costing less than Rs.50,000/-)***

प्रोफे. (डॉ.) सुदेश कुमार सोहनी
Prof. (Dr.) Sudesh Kumar Sohani
B.Tech., M.E. (CEG-Chennai), PhD (IIT Delhi)
Vice Chancellor

Phone : (O) 0755-2742516
Website : www.rkdf.ac.in
Email : vc@rkdf.ac.in
sudesh_sohani@hotmail.com

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No. 214/VC/RKDF/2021

Dated : 26 / 2 /2021

Circular

A meeting is convened to review the progress of the CPRI Funded Project entitled **"Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant - Feasibility Study"**, as per the following schedule:

Time – 11:30am to 12:30 pm
Date - Monday, 1st March 2021
Venue – Hon'ble VC Office, RGPV, Bhopal

Project Monitoring Committee members as given below are requested to attend:

- Dr. Sunil Kumar , Hon'ble VC RGPV Bhopal (Chairperson & CO-PI)
- Dr. Sudesh Kumar Sohani , Hon'ble VC RKDF Bhopal
- Dr. V K Sethi, Principal Investigator (PI)
- Dr. Savita Vyas , Associate Professor , SoEEM RGPV ,Co-PI
- Er. A K Bhargav , Ex GM BHEL, Bhopal (Industry expert)
- Dr. M.L. Kori , Director Research , RKDF University
- Shri Lokendra Thakkar, G.M., EPCO, Bhopal
- Dr. Pankaj Jain, A.P. SoEEM (Meeting convener)

Specific points of agenda are as follows:

- ❖ Briefing on status of CCS project By Dr. V K Sethi, PI
- ❖ Presentation by Sunrise CSP Ltd. regarding their Erection & commissioning work.
- ❖ Discussion on technical parameters achieved on testing.
- ❖ Discussion on Results & findings of project.
- ❖ Discussion on Project implementation in National perspective by Dr. Savita Vyas, CO-PI
- ❖ Discussion on Future Road map of this project vis-a vis Global climate related aspects by Dr. Sunil Kumar, CO-PI
- ❖ Regarding 10% (second last) payment for Sunrise CSP subsequent upon completion of Trial Run.
- ❖ Any other point with the permission of Chair.

S K Sohani
26.2.2021

Dr. Sudesh Kumar Sohani
Vice Chancellor

CC: Copy to all concerned with the request to attend the meeting.

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Airport Bypass Road, Gandhi Nagar Campus, Bhopal 462033, M.P., India
E-mail : vc@rkdf.ac.in; sudesh_sohani@hotmail.com; web.: www.rkdf.ac.in

CHAPTER – 5.3

ENERGY PENALTY - OPTIMIZATION

Chapter - 5.3: Energy Penalty optimization in regeneration of Solvent through Steam from Solar Thermal Plant

Preamble – Absorbent vs. Adsorbent

Energy penalty: CCS requires additional energy input and India's power requirement is yet to be fulfilled. Thus, energy penalty plays as barrier in India for deployment of Post-combustion Carbon Capture Technology. The thermal energy required for regeneration of CO_2-rich adsorbents or absorbents is usually regarded as the most important criterion to evaluate different materials and processes for application in commercial-scale CO_2 capture systems. It is expected that the regeneration heat can be greatly reduced by replacing the mature aqueous Monoethanolamine (MEA) technology with amine-based solid adsorbents capturing systems, due to the much lower heat capacity of solid adsorbents comparing to aqueous MEA and the avoidance of evaporating a large amount of water in the regenerator. Comparing to the MEA technology, the regeneration heat for solid adsorbent based systems has not received adequate attention especially on the impacts of process related parameters. Further, the methodologies used in previous investigations to calculate the regeneration heat may have deficiencies in defining the working capacities, adopting proper heat recovery strategies and/or evaluating the effect of moisture co-adsorption. Based on the parametric analysis, the calculated regeneration heat for the PEI/silica adsorbent based system is found to be around 2.46 GJ/tCO_2, which is much lower than the value of 3.9 GJ/tCO_2 for a typical aqueous MEA system and is also lower than 3.3 GJ/tCO_2 for an advanced MEA system. Sensitivity analysis of all the parameters has also been conducted and the results have shown that working capacity, moisture adsorption and heat recovery ratios are the most influential factors. With more proficiency and development in the energy efficient process designs, the advantages of a solid adsorbent based capturing system over typical MEA systems will be justified.

1. Introduction- Literature Survey on Energy Penalty

Carbon Capture and Storage (CCS) from large point sources such as coal-fired power plants has been considered as one main technology to address rising CO_2 emissions as a result of continual fossil fuel utilization. Post-combustion capture (PCC) using MEA solvent is a front runner for future commercial deployment of CCS in fossil fuel power plants, partly due to the fact that it can be retrofitted to the existing power plants. However, implementing CCS in fossil fuel power plants will result in an increase in the cost of electricity by up to 60% according to the current state-of-art technology as the energy requirement for the whole CCS chain is high. For capture, the energy consumption is the sum of the thermal energy needed to regenerate the solvents/sorbents and the electrical energy required to operate pumps, blowers and fans. Further, energy is also required to compress the CO_2 to the final pressure required for transport and storage. Among these energy requirements for capture, the regeneration heat greatly impacts on the operational costs and the overall energy efficiency of the CCS-integrated power plant. In principle, the regeneration heat for a post-combustion CO_2 capture process with an aqueous solvent or a solid adsorbent includes the sensible heat required to elevate the solvent or sorbent to the desorption temperature, the latent heat required to overcome the endothermic reaction responsible for removing CO_2 from the solvent or sorbent and the latent heat for water vaporization.

Monoethanolamine (MEA) scrubbing technology has been successfully demonstrated in gas- and coal-fired plants with mega power outputs and is treated as a benchmark technology for CO_2 capture from large-scale power plants. A regeneration heat of 4.2 GJ/tCO_2 was proposed by Chapel et al. for their optimized MEA-based CCS process called Econamine FG™ technology. Alie et al concluded that the lowest energy requirement of 4 GJ/tCO_2 could be achieved at lean solvent loading between 0.25 and 0.30 mol CO_2/mol MEA using a flow sheet decomposition method. Singh et al modelled the MEA process for a 400 MWe coal fired power plant and estimated the specific thermal energy requirement to be 3.8 GJ/tCO_2. In average, a value of 3.9 GJ/tCO_2 can be regarded as the energy requirement for a benchmark MEA based capture system.

The high energy requirement makes CCS process costly. Technology developers and researchers have concentrated their effort on developing new and/or optimizing existing technologies to minimize the regeneration heat. For example, Li et al investigated the electrical efficiency of the supplementary fired combined cycles integrated with the MEA-based capture system and concluded that the modifications can reduce the efficiency penalty caused by CO_2 capture to only 2.6% of Lower Heating Value (LHV). The Fluor Econamine FG Plus™ technology requires a much lower energy requirement of 3.24 GJ/tCO_2 which is achieved by optimizing process configurations such as split flow, absorber intercooling and improved solvent formulation. Similarly; Abu-Zahra et al also proposed a 30% MEA absorption system with the thermal energy requirement of 3.3 GJ/tCO_2 achievable through optimizing the lean solvent loading, the amine solvent concentration as well as the stripper operating pressure. Therefore, a representative value of 3.3 GJ/tCO_2 has been adopted now as the energy requirement for an advanced MEA based system with optimized process configurations. Although it has been reported that some other amine aqueous solutions based systems may lead to an even lower energy requirement, such as 2.5–2.6 GJ/tCO_2 , the 30% MEA absorption system is the most well-known and mature technology and therefore is used as a reference for comparison.

By replacing the amine carrier from aqueous water to solid substrates, it is believed that the regeneration heat can be greatly reduced due to the much lower heat capacity of solid sorbents comparing to aqueous MEA and the avoidance of evaporating significant amounts of water in the regenerator. However, unlike MEA technology, which has been extensively investigated for process optimization to minimize the regeneration heat, a comprehensive knowledge on the regeneration heat of solid adsorbent system is lacking, especially concerning the impact of key parameters. Gray et al proposed a simplified energy equation to calculate the regeneration heat for a solid adsorbent based system:

$$Qr = \Delta Ha + M\ Cp,s\ \Delta T$$

Where Q_r *(kJ/mol) is the regeneration heat,*
ΔH_a *(kJ/mol) is the heat of adsorption,*
M (kg) is the solid mass,
$C_{p,s}$ *(kJ/kg K) is the solid specific heat capacity*
And ΔT *(K) is the change in temperature.*

Using a similar equation, Sjostrom and Krutka estimated the regeneration heat for different types of amine based adsorbents and found the values varying in a large range of 1.9–6.1 GJ/tCO_2 depending on the amine types, regeneration conditions and working capacities. Based on above, Heesink et al estimated a regeneration heat of 1.7 GJ/tCO_2 for their amine based solid adsorbents. Li et al. calculated the regeneration heat for PEI/silica adsorbents with different molecular weights of PEI and found the values to be around a lower value of 1.7–1.8 GJ/tCO_2.

The heat of adsorption of an amine-based solid adsorbent depends upon the amine type, molecular weight and adsorption conditions.

The studies estimating the energy penalty of CCS in the Indian Power Plants are as under:

- Suresh et al - Retrofitting Oxyfuel Combustion Supercritical and ultra-supercritical double reheat system : 29.79%-31.67%
- Karmakar and Kolar – Monoethanolamine (MEA) capture Subcritical :31-40%
- Karmakar et al Subcritical, supercritical and ultra- supercritical boilers :29-43% Singh
- and A B Rao – Amine, Ammonia, Membrane, Oxyfuel; use of auxiliary gas boiler Subcritical and supercritical boilers :39-53 %

Monoethanolamine (MEA) was evaluated as the base case system in her thesis by Anusha Kothandaraman. Simulations showed the energy penalty for CO2 capture from flue gas from coal-fired power plants to be 0.01572 kWh/gmol CO2. The energy penalty from CO2 regeneration accounted for 60% of the energy penalty while the compression work accounted for 30%. The process flexibility in the MEA system was limited by degradation reactions. It was found that different flow sheet configurations for energy recuperation in the MEA system did not improve energy efficiency significantly. Chilled ammonia was explored as an alternative to MEA for use in new coal-fired power plants as well as for retrofitting existing power plants. The overall energy penalty for CO2 capture in chilled ammonia was found to be higher than in the MEA system, though energy requirements for CO2 regeneration were found to be lower. The energy penalty for 85% capture of CO2 in the chilled ammonia system was estimated to be 0.021 kWh/gmol CO2. As compared to the MEA system, the breakdown of the energy requirements was different with refrigeration in the absorber accounting for 44% of the energy penalty. This illustrates the need to perform a system wide comparison of different solvents in order to evaluate the performance of various solvent systems. Heat is required in the reboiler to heat up the solvent to the required temperature; to provide the heat of desorption and to produce steam in order to establish the required driving force for CO2 stripping from the solvent. This leads to the main energy penalty on the power plant. In addition, energy is required to compress the CO2 to the conditions needed for storage and to operate the pumps and blowers in the plant.

The simulations show that the energy penalty for CO2 capture from flue gas from coal-fired power plants is 0.01572 kWh/gmol CO2 and from NGCC plants is 0.02388 kWh/gmol CO2. This leads to a de-rating of 17% for the NGCC plant and 24% for the coal-fired power plant; not an acceptable situation.

2. Analysis of methods to reduce Energy Penalty

The regeneration of amine solution is the most energy intensive process responsible for huge energy penalty on the coal fired power plant. One such solution to reduce the energy penalty of CCS based coal fired plant is the use of auxiliary sources of energy for amine regeneration. Howard J. Herzog et al. analysed the CCS energy needs in retrofitted coal power plants using auxiliary natural gas boilers. In a similar context, in the GHGT -14 paper of the PI & CO-PIs & INTEC open source chapter by PI, we investigated the feasibility of using renewable energy technologies (particularly solar thermal) as auxiliary energy sources for amine regeneration in CCS thereby mitigating CO2 while keeping the net power generation of the CCS plant unaffected. The modelling studies have also been carried out using ASPEN Plus software and we could reach a level of 2.18 MJ/kg CO2 level in RKDF CCS Pilot Plant.

Integration of CO2 capture and storage (CCS) into coal-fired power stations is seen as a way of significantly reducing the carbon emissions from stationary sources. A large proportion of the estimated cost of CCS is because of the additional energy expended to capture the CO2 and compress it for transport and storage, reducing the energy efficiency of the power plant. This Pilot Plant study uses heat integration using solar thermal to reduce the overall energy penalty and, therefore, the cost of implementing CCS for power plants where the additional heat and power for the CCS plant will be provided by the existing power plant. A set of 10 Solar Thermal Scheffler Units of 5 kg/hr. steam each (Total 50kg/hr. capacity) are used for regeneration of solvent as the basis for the study using ASPEN Plus software which shows that the energy penalty can be reduced by up to 50% by including effective heat integration to a level of 2.18 MJ / kg CO2 or 2.18 GJ / ton of CO2. It is also noted that energy penalty can be further reduced by pre-drying the coal in the boiler.

3. Effect of Coal quality:

We have also found that Indonesian coal being imported these days by Coal India Ltd. has least amount of incombustible material, which incurs least amount of auxiliary energy penalty for our ‘Reference’ plant (ANPARA B TPS – 2x500 MW; Unit no. 4 of 500 MW by TOSHIBA as EPC) and Amine-CC plant resulting in highest net capacity generation. Though the plant in study using imported coal has highest net electricity generation, its high coal price results in higher LCOE and the cost of CO2 avoided than Indian coal.

In case of oxyfuel-CC, Indonesian coal has lower net electricity generation compared to Indian coal due to high sulphur content in coal resulting in increased energy consumption by LSD system. The Raniganj coal of CIL has highest C/O ratio among the five coals we studied and thus requires more amount of air for complete combustion, thereby increasing the volume of flue gas generated for Amine-CC and Oxyfuel-CC. This results in high energy consumption by emission control technologies and much larger energy penalty after CC. The high flue gas volume results in high CO2 avoidance cost in case of Amine-CC. However, in case of oxyfuel-CC, its low cost of coal (Rs./GJ) and low Sulphur content plays a much prominent role and reduces its CO2 avoidance

4. Design Aspect of Reactor & Absorption Tower of Pilot Plant

Optimisation of absorber liquid-to-gas ratio (L/G) is a prime parameter. Tests were conducted to optimise the absorber L/G ratio at 90% CO2 removal for MEA solvent. The tests were carried out by operating the absorber at a fixed flue gas throughput (250 kg /h) and changing the solvent flow rate. The stripper unit pressure was held constant at 2 bar (abs.) and the CO2 recovery was tuned to approximately 90% by adjusting the steam input to the reboiler. Because the CO2 removal degree has been held constant, changing the L/G ratio also implies changing the solvent lean loading. With MEA, the lowest specific steam demand (Approx. 4 GJ/ton CO2 = 4 MJ/ kg CO2) was obtained at L/G ratio of approximately 2.5kg/kg. However, the specific steam demand is nearly constant for L/G ratios between 2.0 and 3.0kg/kg indicating that the optimum is quite broad for MEA. At the higher L/G ratio (3.8), the specific steam demand clearly increases. At L/G ratios below 2.0kg/kg, it was not possible to maintain the 90% CO2 removal.

In the case with MEA, oxidative degradation and carbonate polymerization are very significant causes of MEA consumption. The complex degradation mechanisms of MEA have been investigated in several publications. However, the relative importance of the different degradation mechanisms is still not completely clear. Among the more simple degradation products of MEA are ammonia, aldehydes and carboxylic acids. The degradation of MEA is also reported to be catalysed by the presence of certain metallic elements, e.g. V, Fe and Cu. These species may enter the solvent due to the presence of fly ash, corrosion products, and corrosion inhibitors.

5. Abstract:

Of the different technologies for CO2 capture, capture of CO2 by chemical absorption is the technology that is closest to commercialization. While a number of different solvents for use in chemical absorption of CO2 have been proposed, a systematic comparison of performance of different solvents has not been performed and claims on the performance of different solvents vary widely. In this chapter a comprehensive flow sheet models have been built for each of the solvent systems, using ASPEN Plus as the modelling tool. The overall energy consumption in the CO2 capture system was calculated and an evaluation of the required equipment size for critical equipment in the system was performed with steam drawn from Boiler and from Solar Thermal. The degradation characteristics and environmental impact of the solvents were also investigated.

Monoethanolamine (MEA) was evaluated as the base case system in this chapter. Simulations showed the energy penalty for CO2 capture from flue gas from coal-fired power plants to be taken as 3.9 MJ/kg CO2 with steam from boiler and 2.18 MJ/kg CO2 with Solar steam alone for Solvent regeneration. The energy penalty from CO2 regeneration accounted for 60% of the energy penalty while the compression work accounted for 30%. As far as we are concerned our pilot plant is for production of multi-purpose fuels and not for any compression process. The process flexibility in the MEA system was limited by degradation reactions. We have used solvent recovery condenser as discussed in details at chapter 4.

6. CONCLUDING REMARKS:

This study introduces a simple method to predict the minimum energy requirement for a post-combustion CO_2 capture process. The key assumption for this approach is that the minimum water vapor losses can be calculated by assuming the CO_2 is saturated with water at the top of the regenerator, but that no additional stripping steam is required. The minimum energy consumption values calculated with this method are about 10 to 20% lower than those found in practice.

The minimum heat requirements are shown to be most dependent of:

- Heat of absorption solvent
- Regeneration pressure
- Solvent temperature
- Vapour pressure of CO_2 over the loaded solvent at absorber bottom

Based on the learning from this work, the following suggestions may be made for solvent and process development in the post-combustion CO_2 capture field.

Optimal heat of absorption

In a wide range of operating conditions, solvents with a heat of absorption in the 55 – 65 KJ/mol CO_2 range show the lowest values for energy consumption. Only when the process is operated at very low temperatures, with a solvent below 35 ºC, solvents with a heat of absorption below 40 KJ/mol become attractive. However, at these temperatures solvents may run into viscosity, solubility and kinetic limitations. Further, in many locations chilling will be additionally required.

Cyclic loading

When a heat exchanger with an approach of 5 ºC is used, only small benefits are gained from a very high cyclic loading. A solvent with a cyclic loading of 15 wt. % will lose 0.13 MJ/kg CO_2 to sensible heat, a solvent with a cyclic loading of 5% will lose 0.38 MJ/kg. However, below 5 wt. % the energy consumption goes up quite quickly. Also, pumping duty and equipment sizing must be taken into account in this assessment.

A cost sensitivity analysis was done for different steam cycles (Subcritical, Supercritical, and Ultra Supercritical), for different coal types (and for plants with and without CO2 capture across a range of net plant sizes (250MW to 750MW). The results are presented below:

'The costs for plants with CO2 Capture generally decrease with increasing plant size until a new train is required in the CO2 capture system, at which point the cost rises slightly".

The results showed that the solvent characteristics of high CO2 cyclic capacity and low absorption heat had a critical effect on reducing the thermal energy requirement for CO2 capture. In the case of CO2 capture from 12% CO2 containing flue gas, the lowest thermal energy requirement was shown as approximately 2.18 GJ/t-CO2 with steam from Solar Thermal Scheffler units (10 Nos.) and the efficiency penalty of power generation was reduced to 7.2% pt.

The results mean that amine-based solvents are still attractive in post-combustion CO2 capture. This comprehensive analysis for a CO2 capture and compression integrated with a thermal power plant was for process evaluation and will be extended to apply to other amine- based CO2 capture technologies and other CO2 emission sources.

CHAPTER – 6

CONCLUSIONS

CHAPTER – 6.1

MAIN CONCLUSIONS

CHAPTER -6

CHAPTER-6.1: MAIN CONCLUSIONS

CPRI- RSOP Project Title:

"Post Combustion Carbon Capture & Sequestration (CCS) Plant on a Coal Fired Power Plant - Feasibility Study"

The Prime Objectives of the R&D Project are:

I. To provide a potential ground under aegis of MOP for developing and demonstrating feasibility of Sustainable Clean Coal Thermal Power Plants equipped with Carbon Capture & Sequestration Technology.

II. Exploring options for reducing energy penalty through solar thermal & other options

  a. Process optimization leading to improve design of MEA Solvent reactors, System optimization studies.
  b. Design & Engineering - Data Acquisition System & Instrumentation
  c. Pilot study of CO_2 sequestration to a simulated coal seam in the used coal mines
  d. Pilot study of CO_2 Sequestration to Algae pond for production of Bio-diesel

These Objectives have been fulfilled through:

1) **Installation of Solar Integrates Carbon Capture Pilot Plant of Capacity 45 kg/hr. of CO2 (250 kg/hr. Flue Gas from the associated Coal Fired Boiler installed for the purpose).**

2) **Feasibility Study of Installation of Retrofit Post Combustion Carbon Capture Plant on 500 MW ANPARA B TPS – 2x500 MW in Singrauli region of MP**

   The feasibility study has examined various options like:

   - **Captured CO_2 to depleted Coal mines**
   - **Captured CO_2 for EOR**
   - **Other NOVEL Options of Sequestration**

3) **Pilot Study of Production of Multi-purpose Fuels**
   - **Production of Hydrogen**
   - **Bio-diesel through Algae Route**

1.0. The Solar Integrated CCS pilot Plant of Capacity 45 kg/hr. CO2 capture as per following broad specs:

The plant for Carbon Capture & Sequestration is indeed a Carbon Capture & Utilization Plant (CCU) which is in Sir J C Bose Interdisciplinary Research Park at RKDF University, Gandhi Nagar Campus Bhopal in the area of 15 x 25 meter. The Plant has been tested by supplying steam for regeneration of MEA Solvent both from Boiler and 8 Nos. Solar Thermal Scheffler Units as shown below:


RKDF
STEAM & FLUE GAS GENERATOR
(COAL FIRED BOILER FOR CCS PLANT)


STEAM & FLUE GAS GENERATOR
(COAL FIRED BOILER FOR CCS PLANT)
SOLAR INTEGRATED CCS PLANT WITH BOILER

The plant is installed on a concrete foundation in which MEA Tanks, Gasifier, Water-gas-shift (WGS) reactor, pumps and piping etc. are installed in single-tier structural frame-work. The flue gas is being tapped-off @ 6 tons per day or 250 kg/hr. (i.e. CO_2@ 18% about 45 kg per hour) running in a 8 hr. shift and regeneration in 2 shifts with solar steam having 4-8 hr. additional thermal storage capacity. Adjacent Solar Thermal Plant with thermal storage has been installed on ground. The size reduction of the land area requirement is due to the following reasons:

- Use of high density (in excess of 300 kWh/m^3) Halide salt in the Solar Thermal Unit for production of steam for MEA solvent regeneration & WGS reaction
- Optimized design of reactors and the gasifier through CFD modeling
- Steam requirement will be met by 8 parabolic discs of 5 kg/hr. capacity along with up to 16 hr. thermal storage of Halide salts supplied by RPI USA. Additionally 2 Scheffler units have been provided for meeting steam requirement in case of lower solar flux in cloudy days.

Other Specifications of the pilot plant are:

Additional water requirement is 70 kg per hour for:

- Steam generation: 40 kg per hour
- Water-gas-shift reaction: 18 kg per hour
- Fluidized bed gasification process: 10 kg per hour
- Chamber cooling : 2kg per hour

Additional Power Requirement of the system is as under

Auxiliary Power requirement of 100 kW has been worked out as under for the entire CCS integrated with ‘Solar thermal’ system

- Pumps, Boiler etc.: 40 kW
- Solar Tracker motor for 2 axis tracking: 30 kW
- Gasifier fluidized blower: 20 kW
- DAS Monitoring: 10 kW

2. ANALYSIS OF TRIAL RUN RESULTS

The project has met its all goal and intense testing is performed. The CCS plant has achieved following:-

- CO2 Capture efficiency of 87-90% achieved
- CO2 release from Reactor is of the order of 18-23%
- The Energy Penalty in re-generation of Solvent has come down to a level of 2.18 MJ/ Ton of CO2 from standard value achieved elsewhere of 4.2 MJ/ Ton of CO2 as discussed in this Chapter (section 5.3)
  This has been possible through use of SOLAR THERMAL ENERGY FOR PRODUCTION OF STEAM.
- The average temperature of reactor when it starts release of CO_2 is 115℃ with 2.3% of CO_2 & increase to 18.5% at 159℃.
- The maximum steam inlet temperature in Boiler & Scheffler is 169℃ & 174℃ respectively. The average temperature of steam at inlet is 111.77℃.
- The maximum achieved temperature is 174℃ at 11 kg/cm^2 pressure and overall average temperature of Solar thermal dish is 152.70℃ & average pressure of 4.51 kg/cm^2.
- The average suction vacuum is - 2.60 kg/cm^2& discharge pressure is 2.62 kg/cm^2, after the treatment of flue gas.
- The maximum temperature & pressure achieved in reactor is 159℃ & 8 kg/cm^2. The average temperature & pressure throughout the trial run is 62.73℃ & 1.60 kg/cm^2.
- The overall average at time of trial run the CO_2 entering the system & exit of system is 13.14% 4.89% of CO_2 - which is twice as per preset goal of capturing 30% of CO_2.
- The average CO_2 released from the reactor vessel is 18.13%.
- The water tank of 4000 Liter is used to condense the MEA solution & recollected in intermediate tank.

2.1.PILOT STUDY RESULTS ON ALGAE TO BIO-DIESEL & HYDROGEN PRODUCTION

TEST RESULTS ON ALGAE

[i]Dry mass of algae *Scenedesmus obliquus*

- Before release of CO2: 5.24 gm.
- After release of the CO2: 14.22 gm.

[ii] **Dry mass of algae Monoraphidium minutum**

- Before release of CO2: 4.71 gm.
- After release of the CO2: 11.17 gm.

Thus the 'Growth' of selected micro algae found to be increased by 2.4 to 2.7 times by weight with CO2 injection.

2.2. PRODUCTION OF MULTI-PURPOSE FUELS – A NOTE

- Using flue gas containing CO_2 & treated lignite the carbon monoxide was analytically evaluated of the order of 20% to 25% by weight.
- The CO obtained having a Low Heat Value (LHV) of 2417 kCal/kg would reduce the fuel required by the boiler and also reduce the net emissions, once recycled back to the boiler using separate short flame burners.
- CO production in stable form and to produce fuel molecules like H2 using water gas shift reaction.

- H2 formation was evaluated to the extent of 1.43%-1.79% by weight equivalent to H2 by volume 17.44% to 21.83% creating the opportunity to the production of multipurpose fuels from captured CO2.

The study conducted for CO_2 capture from flue gases & release has revalidated the Amine absorption system for the CO2 application for conversion to fuel molecules through pilot studies for algal Bio-diesel & Hydrogen production.

3 SCALING-UP : FEASIBILITY STUDY

3.1 THE SCALED-UP CCS PLANT ON A 500 MW UNIT:

In this project the scaling-up has been envisaged to 30% CO_2 Capture & Sequestration to produce multi-purpose fuels on a 500 MW Unit at selected thermal plant in Singrauli region. Since a 500 MW unit emits about 8000 tons of CO_2 per day (about 330 tons per hour), the scaled-up carbon capture and sequestration plant will be of capacity 100 tons per hour. No compression and storage of CO_2 is presently envisaged.

The sequestration options covered in the project are related to CCU:

- Production of Algal Bio-mass @55 tons per hour using selected species of Algae viz. Scenedesmus obliquus, Monoraphidium minutum and ClorolaVelgaris in the specially designed bio-reactor for culture preparation and algal pond. These varieties have been tested to have growth in the Ash decantation water also. Bio-diesel shall be produced using trans-stratification process.

- Production of CO from CO_2 using gasifier and thereby producing Hydrogen using water-gas shift (WGS) reactors. Performance of WGS catalysts under wide range of CO-to-Steam ratios will be investigated for an optimum level.

The strategy of scaling-up of the pilot plant of the proposal is briefly given below:

- Optimization of scale of carbon capture (range 30% to 100%)
- Algae plant stage of implementation for species to grow.
- Feasibility study of power plant modification required for production of multi-purpose fuels like H_2 , CH_4 etc.
- Analysis to utilization of CCS Plant produced H2 in fuel cell for lighting application
- CO recycling option to boiler – burner design
- Energy penalty reduction through various option of solar thermal- technologies
- Sequestration to coal seams of depleted mines

Incorporation Solar thermal plant of capacity 70 tons per hour for steam production both for MEA solvent regeneration and WGS reaction with a make-up water consumption of 4.5%, i.e. 3 tons/hr. This novel concept of using Renewable Energy will reduce energy penalty from a level of 15-17% to about 4-5% {ref. Energy Procedia 114 (2017) 1288 – 1296}

- Corresponding to above the estimated quantities of in-puts required are:
    - Land Area between Stack-area Slab (now being used for De-sulfurization) & Fuel Oil corridor in front of the stack: … 70 mx125 m, with reactors at 2 levels (Refer figures 1 & 2 A & B).
    - Additional Water requirement … 4-5 tons per hour as make-up & gasification
    - Additional Power requirement … 4 MW, that increases auxiliary power consumption by 0.8 %

3.2. SEQUESTRATION TO THE DEPLETED COAL - MINE:

The feasibility study of sequestration for 500 MW ANPARA B TPS infers that:
Estimated CO2 storage potential in India is-

- deep saline reservoirs (on and off shore) estimates : ~ 360 GtCO2 360 GtCO2
- Depleted oil and gas wells estimates: ~ 7 GtCO2
- Un -mineable coal seams: 5 GtCO2
- Volcanic rock : 200 GtCO2
- NCL Singrauli Region : 1.16 GtCO2

Our feasibility study shows that for 500 MW Unit No.4 of ANPARA B TPS -2x500 MW (EPC by Toshiba Corp, Japan) the best solution would be

- **INITIALLY USE KAKRI COAL FIELD FOR SEQUESTRATION**
- **NEXT USE BINA COAL SEAM FOR CO2 SEQUESTRATION**
- **THE PIPELINE COST WILL BE MINIMUM VIA ANPAR SHAKTINAGAR ROAD SIDE**
- **THE OLD WARF WALL OF KAKRI MINE SHALL BE USED FOR CO2 PUMPING STATION**

The following are presently considered as items which are being demonstrated /verified at the CO_2 Capture Demo Plant, as discussed in various sections of this TECHNICAL REPORT using SCADA / DAS under execution.

i. Performance Issues

- CO_2 Capture mass flow
- CO_2 Capture rate
- Energy required to capture CO_2
- Overall effect on performance of the power plantequipped with CO_2 capture facility

ii. Operability Issues

- Effects of flue gas property (including Coal properties)
- Effects of CO_2 capture rate setting
- Effects of heat inputs to CO_2 capture
- Start-up, shut-down, transient operations
- Part load, part capture operability

iii. Environmental Issues

- Emissions for CO_2 capture facility
- Solvent Degradation and its effects

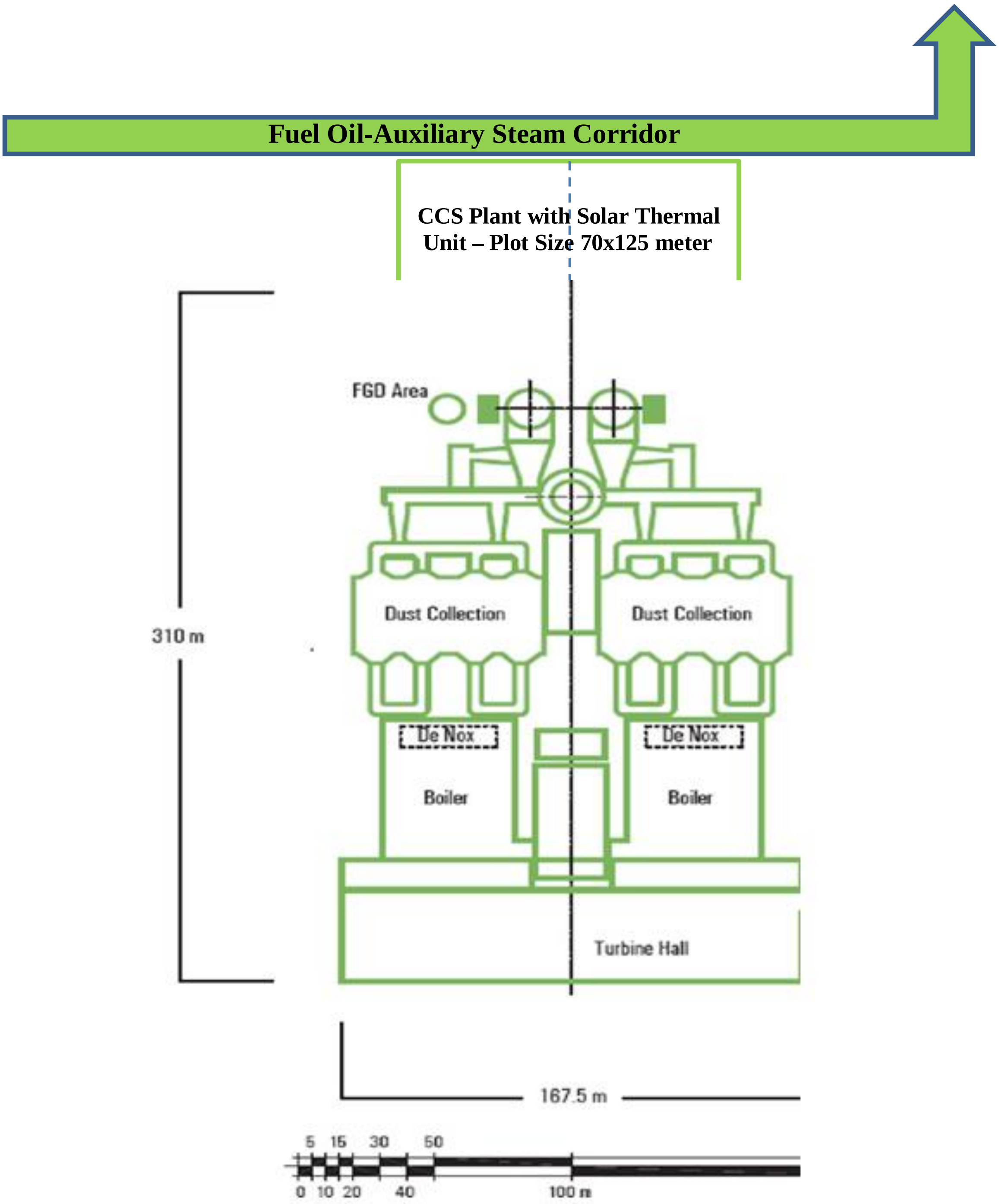
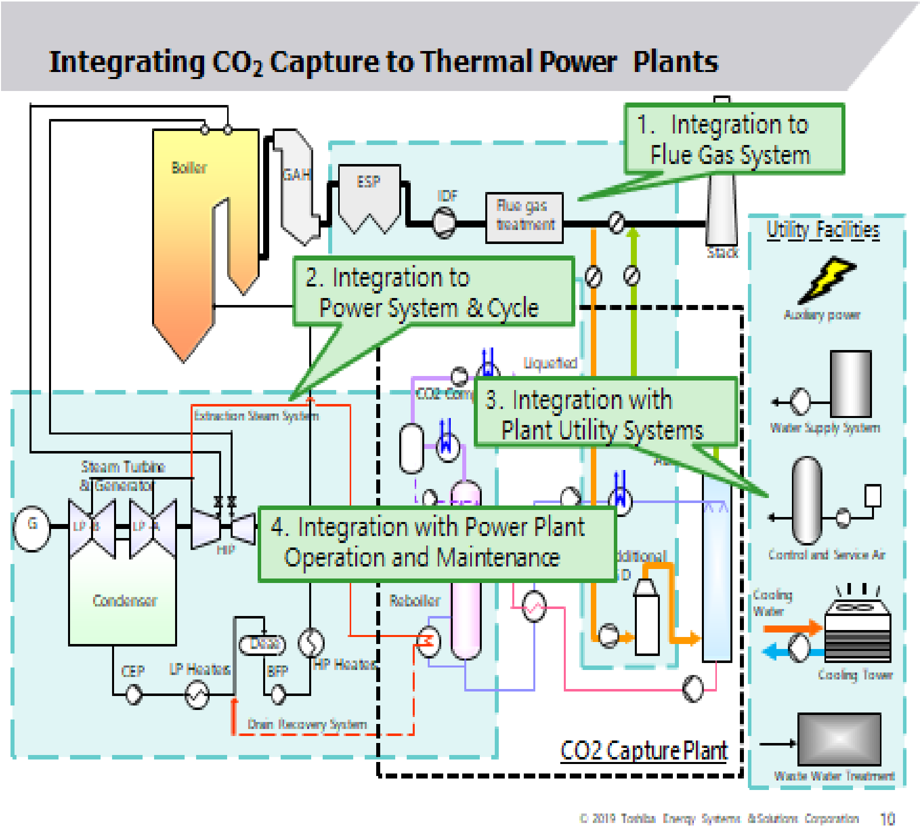


Fig: 1 -Layout of Scaled-up CCS Plant of 30% capacity integrated with Solar Thermal Unit

AREA FOR SOLAR THERMAL SCHEFFLER UNITS
10 NOs of STEAM GENERATING CAPACITY OF 7 TON PER HOUR EACH, FOR SOLVENT REGENERATION

+ INPUT WATER PUMPING CAPACITY OF 5 TONS/ HOUR



Integrating CO_2 Capture to Thermal Power Plants

1. Integration to Flue Gas System

2. Integration to Power System & Cycle

3. Integration with Plant Utility Systems

4. Integration with Power Plant Operation and Maintenance

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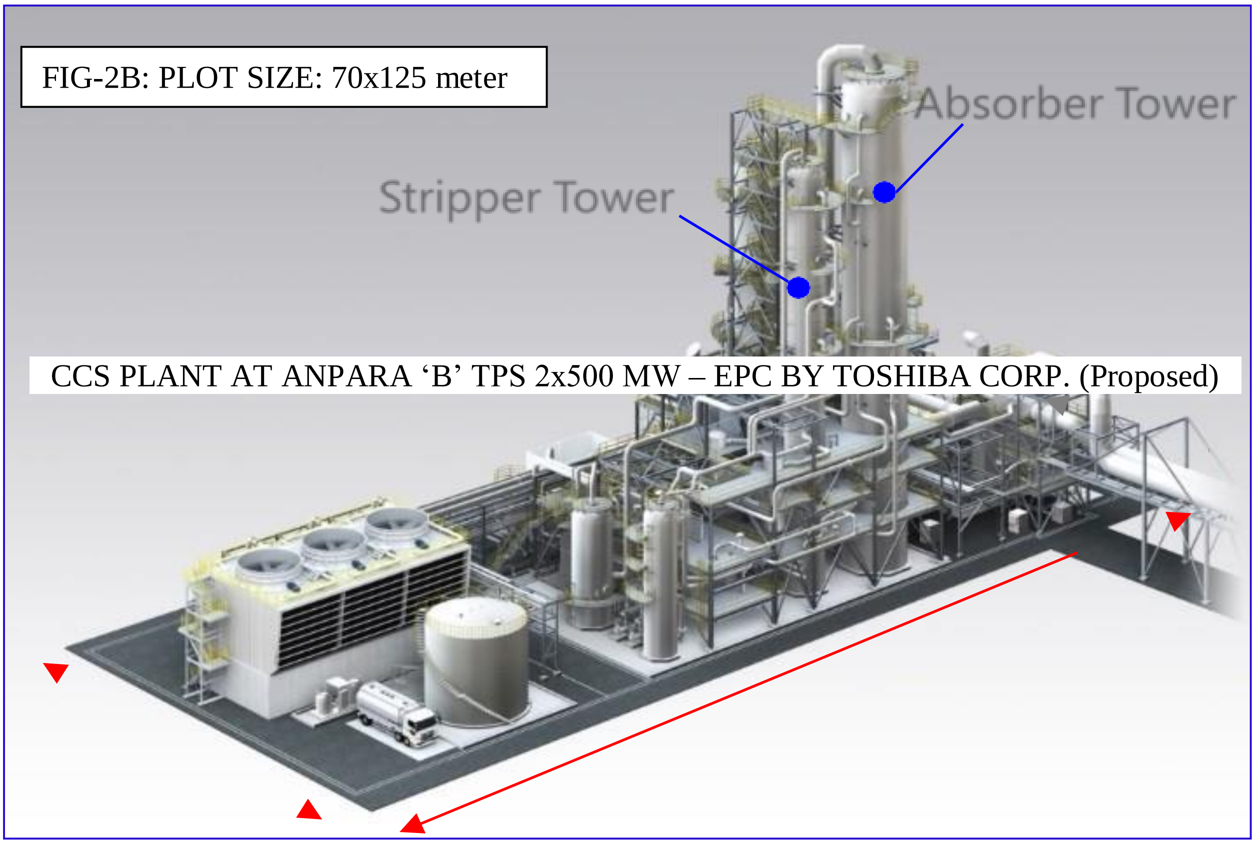
FIG-2B: PLOT SIZE: 70x125 meter



CCS PLANT AT ANPARA 'B' TPS 2x500 MW – EPC BY TOSHIBA CORP. (Proposed)

FIGURES - 2 A & B : THE DESIGN of CCS PLANT AT ANPARA 500 MW UNIT

CHAPTER – 6.2

FUTURE PERSPECTIVE – SUSTAINABLE DEVELOPMENT & ISSUES

CHAPTER-6.2: FUTURE PERSPECTIVE – SUSTAINABLE DEVELOPMENT & ISSUES

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  c. Pilot study of CO_2 sequestration to a simulated coal seam in the used coal mines
  d. Pilot study of CO_2 Sequestration to Algae pond for production of Bio-diesel

These Objectives have been fulfilled through:

1) **Installation of Solar Integrates Carbon Capture Pilot Plant of Capacity 45 kg/hr. of CO2 together with associated Solar Thermal Plant through EPC Contractor M/S SUNRISE CSP (I) Pvt. Ltd. Baroda. A Coal Fired Boiler has been installed for the purpose as no Power utility could allow us to install the plant at their Power station.**

2) **Feasibility Study of Installation of Retrofit Post Combustion Carbon Capture Plant on 500 MW ANPARA B TPS – 2x500 MW in Singrauli region of MP with the support of TOSHIBA CORPORATION as EPC Contractor of the Project.**

1.0 FURURE PESRPECTIVE

1.1. CCS for Sustainable Development

India as a fast growing economy is pursuing strategic knowledge mission for focused research in the area of climate change. Our R&D in Carbon Capture & Sequestration (CCS) will be initially focused on post combustion carbon capture on coal fired power plants. India is 3rd largest emitter of world after China and US with a share of 6.9% in global emission of CO_2, however, India's per capita GHG emission is only 1.6 MT per annum (MTPA) which is well below the world average 7.5 MTPA. National Mission on Strategic Knowledge for Climate Change aims to develop a better understanding of Climate Science impacts and challenges. The planning commission has announced the Government's interest in adding a ninth mission i.e. 'Clean Coal Technologies mission' that would include Carbon Capture & Sequestration. As regards Carbon Capture & Sequestration (CCS) on coal fired power plants in India is concerned, an innovative concept of integrating solar thermal for steam production will pave way for reducing energy penalty in regeneration of solvents from a level of over 15% to around 05%. This technical report in its chapter 5.3, deals with an innovative approach of CCS in which the major issues of energy penalty reduction have been taken care of through use of Solar Steam Generation, through concentrated solar plant (CSP) with thermal energy storage (TES).

Despite the fact that we in India have taken a giant leap forward in increasing the installed capacity from a mere 1713 MW in 1950 to over 3,79.13 MW as on March 2021, the renewable energy sources however contribute 24.5% with total capacity of over 91,154 MW. This contribution has a major social and economic impact on rural and remote area population and towards our commitment towards abatement of Climate Change. The growth of clean energy technologies for mega Power generation, such as the Solar Mega Power under Mission mode, Solar Thermal and PV, Clean Coal Technologies, CCTs, i.e. Supercritical power plants, Integrated Gasification Combined Cycle (IGCC) and fluidized bed combustion (FBC) are key to the success Green Power Mission for India. Carbon Capture & Sequestration (CCS) is considered as the frontier Green Energy technology.

The CCS option towards sustainability may lead to an opportunity for course- correction in line of thinking of our Planners, Engineers & Scientists working in the arena of Green Power technology & development. The time appears to be ripe for implementation of CCS on an actual Thermal Power Plant.

The actions to be adopted for pursuing strategic mission for combating climate change caused by coal fired power generation are as under:

- **India has declared to reduce its GHG intensity by 33-35% by 2030 and is planning to install 175 GW renewable power by 2022 which will be 40% of total power generating capacity at that time (today's level is 3,79,13 MW).**
- **Also India is contemplating to sequester 2.5-3.0 billion tons of CO_2 emission through additional forest and tree cover.**

Low Carbon Technology Vision for India together with strategies, challenges & opportunities in Green Power for energy security environmental sustainability are put forward in this paper covering Carbon Capture & Sequestration as a key factor. While there is growing trend of carbon dioxide emissions by energy sector since coal continue to play role in primary energy consumption, the urgency of CCS deployment in countries where coal is the main stay is very important.

1.2. The Balance and futuristic task in the R&D Project:

i. SCADA / DAS Commissioning:

The commissioning of SCADA / DAS system is under hold due to COVID related lock-down while its designs and spade-work has been completed; online. As regards Energy Penalty optimization and CFD modeling and all results have been calculated and compiled using *ASPEN plus* software. The optimization figures like energy penalty of 2.18 MJ / ton of CO2 are to be validated by actual out-put of SCADA unit.

ii. While pilot study of Algae selection and production of Bio-diesel has been done as detailed in Chapter 5.1, the Algae Pond Civil works are under hold and actual tests on variety of Algae will be carried out as the Pandemic related situation improves.

iii. Hydrogen has been produced using a table-top plant as discussed in chapter 5.1 using captured CO2 from the re-boiler (Reactor Tank) and Water gas shift reaction. For a full scale trial run we may have wait for situation to improve, as discussed above.

A 'Supplementary Technical Report' will be submitted after submission of PCR to CPRI as the COVID Pandemic situation improves and all the above (i) to (iii) tasks are completed.

2.0 ISSUES YET TO BE RESOLVED:

2.1. Project Authorities perspective on installation of Carbon Capture & Sequestration Plant on their Power Projects:

NOTE: This is based on discussions with Project Authorities of KORADI THERMAL POWER STATION Unit of Size 660 MW at NAGPUR, GRASHIM INDUSTRIES CAPTIVE THERMAL POWER Plant of size 40 MW at NAGDA & ANPARA 'B' TPS – 2x500 MW – Unit No. 4 on which feasibility study was performed in association with EPC contractor TOSHIBA Corp. Japan with the administrative consent of erstwhile UPSEB, LUCKNOW (Now - UPRVUNL).

- While the project authorities were positive about installation of proposed pilot unit both at Koradi & Grasim Industries Nagda, they expressed the desire to examine results of trail run at University site in terms of Carbon capture efficiency and reduced energy penalty in regeneration of solvents. The same will be submitted with the approval of CPRI at a later date.
- Power Plant authorities also desired to have a formal letter from CPRI (MOP) for installation of the innovative pilot project of Carbon Capture with Solar Thermal Integration.
- A tri-partite MOU was also required as suggested by project authorities, although they appreciated this initiative which is towards abatement of climate change
- No response has however been received from NALCO Industries, yet, on our request letter to them as they are forerunners in Algae to Bio-diesel Project at their captive power plant at ANGUL.

THE DOUBTS OF POWER PLANT AUTHORITIES WERE CLARIFIED AS UNDER:

1. The initial installation will require shutdown of one ID Fan (on the side of our CCS Plant) for few hours to tap off a 2-inch pipe stub with a shut-off valve for which we will get ample opportunities in a power plant in planned / break-down maintenance

2. The number of days we will need to install CCS plant will depend on site and accessibility and support we get from the Plant owners and has to be discussed and decided mutually, normally it requires 40 -60 days to fully commission the CCS plant

3. The CCS plant operation will not have any effect on their plant operation as we require flue gas drawn by blower from the outlet of ID Fan going to Chimney. The flue gas drawl is very small to affect the ID Fan operation in any way

THUS IN CONCLUSION OF REPLIES TO ABOVEIT WAS DECIDED THAT THE PLANT WILL BE INSTALLED AT SITE ONLY AFTER TESTING AT THE UNIVERSITY SITE – HENCE A COAL –FIRED BOILER HAS BEEN PROVIDED ON THE PILOT PLANT

2.2 Other **Issues / Technologies to be explored further**

- Feasibility study of power plant modification required for production of multi-purpose fuels like H2, CH4 etc.
- Analysis to utilization of H2 produced from Captured CO2 & Steam in fuel cell for lighting application
- CO recycling option to boiler – burner design of short flame burners
- Solvent selection and improved solvents over and above MEA
- Striping shower energy / heat input reduction though co-generation and MEA recovery

2.3 Un-resolved Issues – A representative list:

The following may be regarded a representative list of un-resolved issues which can be taken care-of when the CCS plant is installed at the selected 500 MW Unit in Singrauli region.

1) Methane recovery from the depleted mine with CO2 injection
2) Algae selection that can grow in the Ash Pond / decantation well of Ash handling plant
3) Water requirement optimization in the scaled-up plant
4) Auxiliary power optimization on the actual mega Units
5) Benefits with application of CCS on Ultra Mega Power Projects of Supercritical Steam parameters.
6) Policies of Ministry of Power & MOEF towards CSS commitment: Genesis in this direction
7) Public acceptance of CCS
8) Funds for CCS from UNFCCC & World Bank etc.

CHAPTER – 7

TECHNOLOGY KNOW-HOW REPORT

Chapter -7: TECHNOLOGY KNOW-HOW REPORT

Chapter -7.1: Scaling up of CO_2 Capture Plant on a 500 MW Coal fired Thermal Unit - Water, Power, Land requirement and project authority's perspective

Chapter - 7.2: Heat / Energy Balances, HBD/ PI DIAGRAMS for a 500 MW Unit

CHAPTER – 7.1

SCALING UP OF CO2 CAPTURE PLANT ON A 500 MW COAL FIRED THERMAL UNIT

CHAPTER - 7.1

Scaling up of CO_2 Capture Plant on a 500 MW Coal fired Thermal Unit - Water, Power, Land requirement and project authority's perspective

1.0 Preamble:

Names and Addresses of identified User Agencies

Anpara B TPS- 2x 500 MW (Owner: UPRVUNL, LUCKNOW)

The thermal plants in India have a thermal efficiency of 35% and an emission ratio of 0.90kg/kWh of CO2 emissions as published by CEA. The reduction of 20% intensity would translate to a decrease of 0.20kg/kWh of CO2 emissions to 0.70kg/kWh CO2 emissions by 2022. This decrease is possible by a combination of abatement and recycling measures. However, the CO2 reduction by an Amine system of 10% CO2 capture would mean an Energy penalty of the order of 30%. This can be reduced to level of 10-15% and can be demonstrated only after establishment of full scale CO2 Capture and Sequestration plant on an actual coal fired Unit and carrying out System Optimization studies & Integration with Solar Thermal. Efforts have been made with UPRVUNL in collaboration with TOSHIBA Corp. the EPC contractor & supplier of the Anpara B TPS for establishment of CCS plant on one of the pit head unit no. 4 of 500 MW at ANPARA in SINGRAULI Region of UP and MP border.

The deliverables in brief are described below:

- Establishment of the first Pilot plant of CO_2 capture and sequestration on actual Thermal Power Plant of capacity 500 MW for future development of Technology as to provide formidable support to the Govt. of India in the 'Climate Change Mission'.

- The CO2 so captured needs to be either compressed to be used in Enhanced Oil Recovery or recycled. The better option would be that the same be recycled. The system addition to the existing thermal plants would be a two stage gasifier to use up this CO2. This would help recycle the Carbon of the CO2 and the treated/ converted CO would be re-fed into the Boiler by means of a Gas Burner
- This would work in two ways. This would reduce the fuel required by the boiler and also reduce the net emissions to below 0.70 kg/kWh.

2.0 Collaborative Framework for CCS Demo in India

To find a potential ground for collaboration between India and Japan and its respective organizations, to the goal of developing and demonstrating Sustainable clean coal thermal power plants equipped with carbon capture Technology, to the benefit of both countries and relevant parties involved

The following figure provides an insight into the Project Collaborative Framework and Methodology:

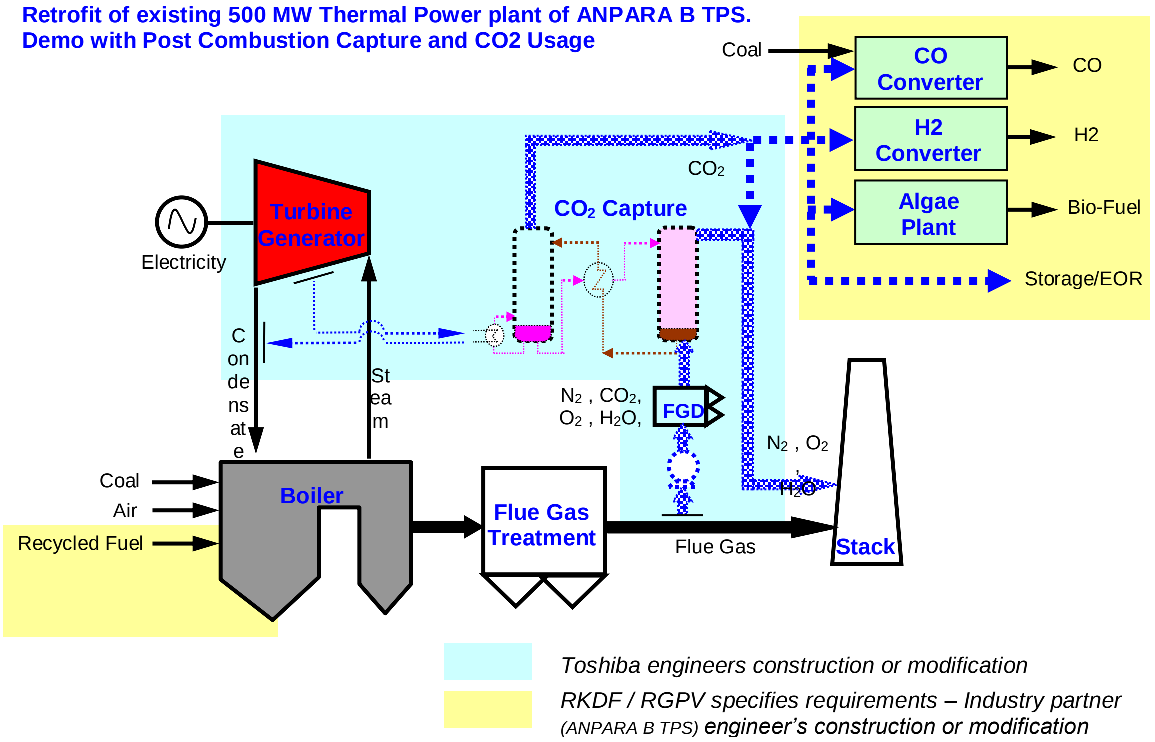
Fig. 01 Schematic of Demo Project

Fig. 02 Demo Project Implementation Scheme

Fig. 03 Demo Project Implementation Scheme

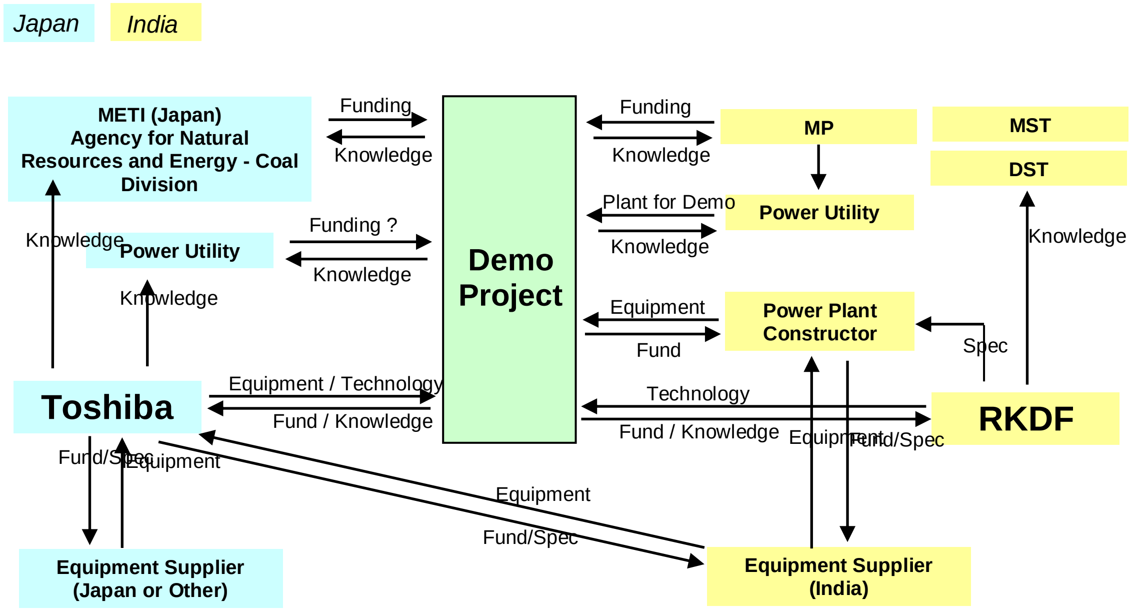
The justification of the project is evident from the deliverable in terms of an establishment of the first Pilot plant of CO_2 capture and sequestration on actual Thermal Power Plant of capacity 500 MW for future development of Technology as to provide formidable support to the Govt. of India in the 'Climate Change Mission'.

Fig. 01 Schematic of Demo Project



Collaboration: Toshiba Corporation (Japan)

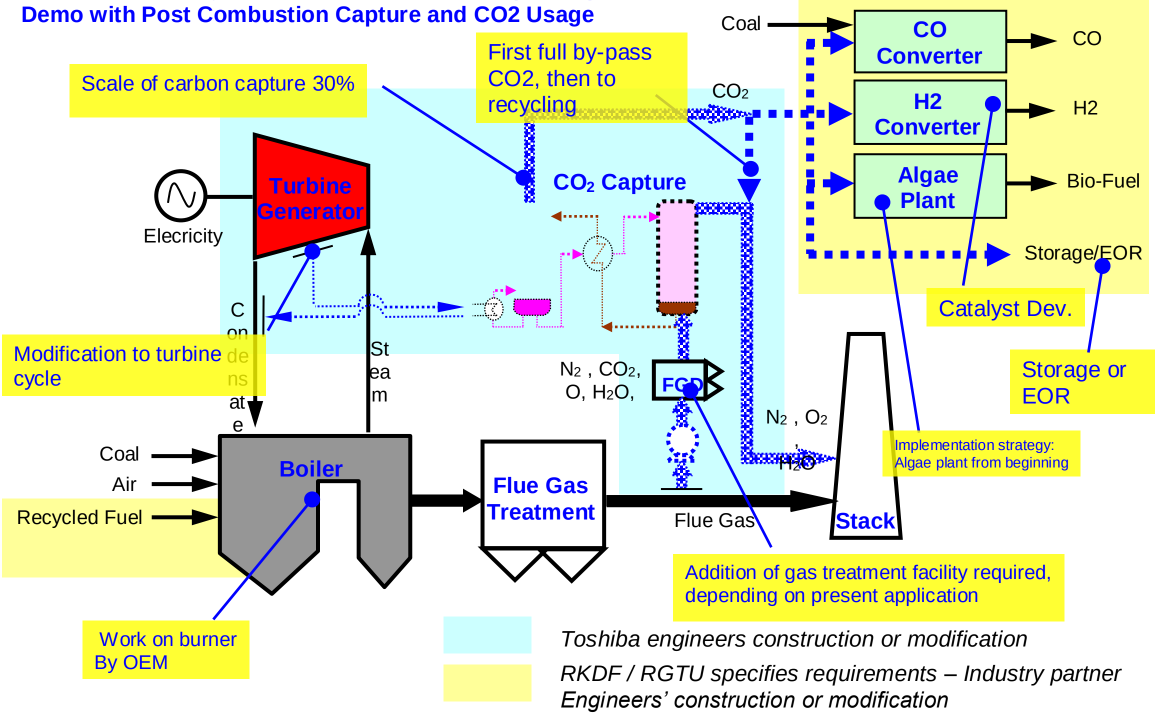
Fig. 02 Demo Project Implementation Scheme



METI: Ministry of Economy Trade and Industry MP: Ministry of Power
NTPC: National Thermal Power Company MST: Ministry of Science and Technology DST: Department of Science and Technology

Fig. 03 Demo Project –Strategy Plan

Retrofit of existing 500 MW coal fired thermal power plant in India.
Demo with Post Combustion Capture and CO2 Usage



3.0 Scaling up CO2 capture plant on a 500 MW unit

In this project the scaling-up has been envisaged to 30% CO_2 Capture & Sequestration to produce multi-purpose fuels on a 500 MW Unit at selected thermal plant in Singrauli region. Since a 500 MW unit emits about 8000 tons of CO_2 per day (about 330 tons per hour), the scaled-up carbon capture and sequestration plant will be of capacity 100 tons per hour. No compression and storage of CO_2 is presently envisaged.

The sequestration options covered in the project are related to CCU:

- **Production of Algal Bio-mass @55 tons per hour using selected species of Algae viz. Scenedesmusobliquus, Monoraphidiumminutum and ClorolaVelgaris in the specially designed bio-reactor for culture preparation and algal pond. These varieties have been tested to have growth in the Ash decantation water also. Bio-diesel shall be produced using trans-stratification process.**

- **Production of CO from CO_2 using gasifier and thereby producing Hydrogen using water-gas shift (WGS) reactors. Performance of WGS catalysts under wide range of CO-to-Steam ratios will be investigated for an optimum level.**

Incorporation Solar thermal plant of capacity 70 tons per hour for steam production both for MEA solvent regeneration and WGS reaction with a make-up water consumption of 4.5%, i.e. 3 tons/hr.

This novel concept of using Renewable Energy will reduce energy penalty from a level of 15-17% to about 4-5% {ref. Energy Procedia 114 (2017) 1288 – 1296}

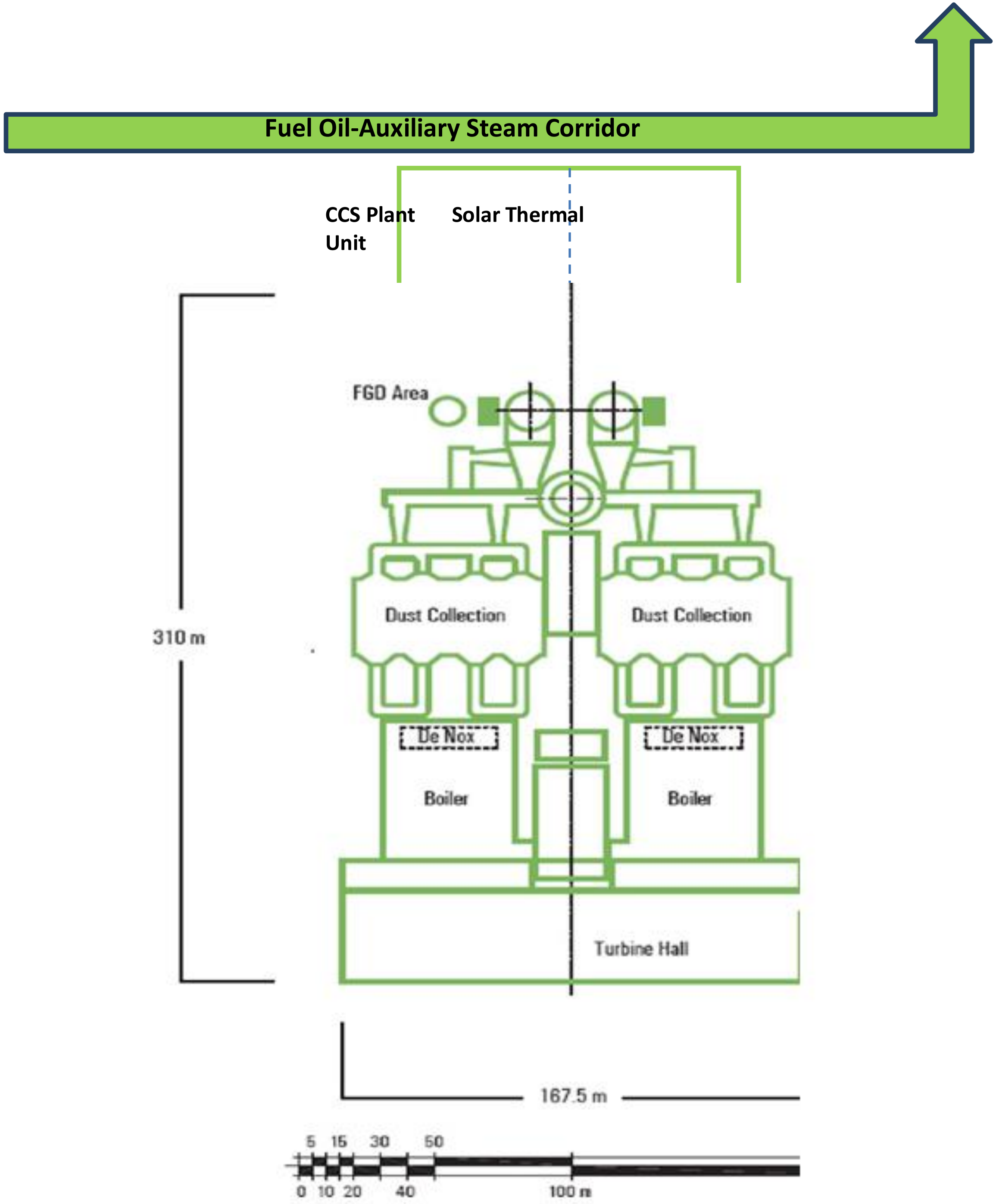
- **Corresponding to above the estimated quantities of in-puts required are:**
  - **Land Area between Stack-area Slab (now being used for De-sulfurization) & Fuel Oil corridor in front of the stack: … 70 mx125 m, with reactors at 2 levels (Refer figure 2).**
  - **Additional Water requirement … 4-5 tons per hour as make-up & gasification**
  - **Additional Power requirement … 4 MW, that increases auxiliary power consumption by 0.8 %**

Location of CO2 Capture & Sequestration Plant at Anpara B TPS of Utpadan Nigam

Area for CO2 Plant 13.5 meter x 40 meter

CO2 to be tapped off from this duct

Fig: 02Layout of Scaled-up CCS Plant of 30% capacity integrated with Solar Thermal Unit



CHAPTER – 7.2

HBD OF 500 MW ANPARA UNIT NO 4

Chapter – 7.2 : SPECIFICATIONS & HEAT / ENERGY BALANCES, HBD/ PI DIAGRAMS FOR 500 MW UNIT-ANPARA B TPS

1.0 General Description of Anpara B TPS – 2x500 MW

1.1 PREAMBLE

Anpara Thermal Power Station is presently comprising of 3x210 MW units in Stage I and 2x500MW units in Stage II. It is located on the eastern bank of Rihand Reservoir about 24 km From Rihand Dam along the Nation highway no 51 near the village Anpara within 3 km from the Renusagar Power Plant of Hindalco. Singrauli Coal fields are about 10 km from the project site and stretch up to 30 km. The linked mines for the project are Kakri and Kharia, for which a MGR coal transportation system has been commissioned and caters to the present stages of the project. The ash disposal from both the stages is done in the main ash dyke having a Rock fill dam about 11 km from the plant. Both coal transportation MGR system and Ash pond has been designed to cater to all the stages of the project.

This section deals with the "General Description of existing Anpara Project" together with common facilities and Station Philosophy.

1.2 Existing stages of the Project – Stage I (3x210MW) & Stage II (2x500MW)- THE MAIN PLANT

Three 210 MW units with TG of KWU design and CE design boilers, both supplied by M/s BHEL with CEA as Consulting Engineers are commissioned during March, 86, February 87 and March 1988 respectively, as Anpara –'A' TPS. Two 500 MW units with **Toshiba** Turbines and **MHI** Boilers complete with all auxiliary and ancillary systems have been commissioned in 1993 and 1994 as Anpara – 'B' TPS. A layout plan for Anpara 'A' and Anpara 'B' along with proposed Anpara 'B' Extension (2x500 MW) is shown at drawing no **ANP – B – EXT – 01.**

Data sheet of the 500MW Steam Turbine (Toshiba Corporation) and auxiliaries is as per **Annexure 1.1.** The broad specifications of the Boiler designed and supplied by Mitsubishi Heavy Industries (MHI) are as per **Annexure 1.2.** The Steam Turbine is Tandem compound condensing reheat turbine with common high pressure and intermediate pressure (HIP) casing, capable of two shift operation, coupled to AC generator of 500 MW. The regenerative feed heating system consists of following main organs in addition to the Gland steam coolers and Air ejectors:

- **HP Heaters** - Double flow surface type Indirect contact Heaters with U- type Seam less steel tubes (SA-213 : TP 304) (2 sets)
- **DEAERATOR** - Direct contact spray & tray type with horizontal Storage tank of capacity 10 minutes of boiler MCR feed flow at 2/3rd level
- **L.P. HEATER** - Surface type double flow with U-shaped seamless

Steel (SA-213: TP 304) Indirect contact heater. (3 Nos.)

◆ **BOILER FEED PUMP**

MAIN BOILER FEED PUMPS - 2x 60% flow capacity each driven by It's own auxiliary steam turbine.

(Steam supply from tertiary SH line during start-up and from IP exhaust in normal running)

START & STANDBY FEED PUMP - 2x 30% variable speed feed pump Controlled by hydraulic coupling.

Broad specifications of the associated boiler are:

The Boiler is an 'Assisted Circulation, Radiant Reheat' boiler with dry bottom furnace having steam generating capacity 1720 tonnes/hr at 178 kg/cm2 pressure and 543°C at superheater outlet.

Furnace heat release - 110,000 kcal/hr/m^3
Reheat steam - pressure drop: 2.9 kg/cm^2
- temperature : 541°C
Flue gas velocity : 10 to13 m /sec.

Boiler auxiliaries

i) **Air heater**: - Rotary, bisector, regenerative Ljungstrom type (60% capacity each) 2 nos. for primary and 2 nos. for secondary air).

ii) Electrostatic precipitators (EP or ESP)

- Limit of dust emission : 100 mg/Nm^3 with coal having

Ash - 49.3%
Moisture - 5%
C.V. - 3188 Kcal/kg
F.G. Outlet temperature - 160C
Fly ash - 80% of total ash

- Collecting area : 279.2m^3 per m^3/sec of flue gas
- Ash resistively : 4x10 ohm cm at 150C
- Gas velocity : 0.75 m/sec in EP
- Treatment time : 42 sec
- Hopper capacity of ash collection – 12hrs
- Efficiency with six fields in service 99.8%

iii) Pulverizer

Pressurized slow speed (ball) mills – 8 nos. of capacity 78 t/hr with worst coal.

iv) FANS

ID	-	Variable speed up to 600 rpm Radial type (2x60%)
FD	-	constant speed, horizontal and radial flow centrifugal type with variable pitch blades with max speed of 750 rpm (2x50%)
PA	-	Centrifugal radial flow type (2x50%)

The Station Auxiliaries and Station Philosophy is discussed below:

1.3 WATER SYSTEMS

1.3.1 Station Circulating Water (CW) System

The plant has been designed on pond cooling system by drawing water from the Rihand reservoir close to the plant. An approach channel with a water carrying capacity of 141 M^3/Sec has been provided and has been designed for meeting the total requirement of Anpara-A, B, & B- Extension Projects, keeping in view the fluctuation in reservoir water level. Intake structure for total station has been constructed under Anpara –A TPS. Two similar CW pumps houses one for Anpara-A and B TPS and other for Anpara –B extension TPS have been planed. The pump house for Anpara –A & B TPS has been constructed and the space has been left for CW Pump House of Anpara- ‘B’ extension stage. The estimated cooling water consumption per 500 MW machine is 22.5 m^3 / sec (81,000 t/h). The raw water required for cooling in the condensers is carried through RCC ducts for both the existing stages from pump house to respective units. A triple duct section with each duct section having cross section area of 4mx4m has been provided. One of the sections is meant to feed 3x210 MW units and other two sections for one 500 MW unit each. From these RCC ducts cooling water to the condensers of each unit is conveyed through mild steel pipes.

The discharge from the condensers to each unit is taken through pipes finally terminating to RCC discharge ducts with a seal pit in between. Within the station area, the discharged water is carried in these RCC ducts which have been constructed for Anpara-B TPS along with of Anpara-A TPS. These ducts are finally converting into a discharge channel, sized for ultimate capacity outside station fence. In the layout space provision has been kept to lay future intake and discharge ducts for 500 MW units of Anpara- ‘B’ extension TPS.

For the purposes of catering the power supply at 6.6 kV to the CW pumps of the “A” a 132/6.6 kV substation has already been constructed close to the pump house with a capacity to cater for Anpara-B TPS requirements for water system.

1.3.2 Auxiliary Water System

An auxiliary water storage pond has been constructed for the Station-A, which meet the auxiliary water requirements for Anpara-B TPS and ‘B’ Extension also. Emergency raw water supply to diesel engine driven fire service pumps is also from this pond. This fire station meets the requirements of CW area only. The water supply to the auxiliary pond is tapped off from RCC pressure duct for condensers originating at the CW pump house through 1600-mm diameter MS pipes. Arrangement for additional supply is made to cater to the requirements of Anpara-B extension TPS.

1.3.3 Water Clarification Plant:

To meet the requirement of clarified water for heat exchangers and auxiliary mechanism, a water clarification plant to meet the requirement of Anpara-A station has been provided between the grid axis 12A+50 and 14A and 41B and 44B.

For Anpara-B station a separate water clarification and filtration plant has been provided between grid axis 40B and 43B.

1.3.4 Water Treatment Plant:

A water treatment plant with 4x75 t/h streams of de-mineralizers to meet the feed water make up requirement for the Anpara –A station has been provided and a common water treatment plant for both Anpara ‘B’ & ‘B’ Extension i.e. 4x500 MW has been provided.

1.3.5 Potable Water:

To meet the station and colony potable water requirement of Anpara TPS the raw water from the auxiliary water pump house is pumped to raw water treatment plant of Anpara Project for making it potable. The plant is located between grid axis 12A+50 and 14A and 47B and 48B. The potable water from this area is pumped to various places for station use. These facilities are to be extended for Station –B extension.

1.4 Coal Transportation & Handling

1.4.1 Coal Transportation System:

Merry-go-round rail of Coal Transportation has been provided for this power station. The entire demand of Anpara-A, B and B-Ext. plants is envisaged to be met from Khadia Coal Mines, but initially the coal for Anpara –A & B TPS coal is obtained from Kakri/Bina Coal mines. The entire MGR system has been completed. The wagons and locomotives and MGR are owned by UPRVUN.

1.4.2 Coal Handling System:

Coal Handling Plant for Anpara- B TPS has been constructed having capacity to cater for emergency requirements of Anpara-B TPS units. An interconnection from Anpara-B to B extension is to be constructed as discussed further at section 2.0. **The specifications Anpara B Coal Handling Plant are as under:**

- Capacity…2100 t /h (Normal) and 2520 t / h (max.)
- Functions…Direct feeding, Stacking and Reclaiming
- Track hopper… 2400 t/h
- Peddle feeder…1260 t /h (4 nos.)
- Primary crusher…1200 t/h, Rotary breaker (4 nos.)
- Secondary Crusher…1260 t / h, Ring granulator type
- Stacker reclaimer …2520 t /h, travelling speed 30 m/min to 3 m/min

1.5 Fuel Oil Handling System:

The fuel oil unloading and storage facilities for full station are located between the grid axis 10A+40 to 12A and 22B to 24B+50. The facility consists of unloading 70 wagons at a time, 35 wagons on each track. One pump house and three numbers storage tanks each of 4000 m^3 capacity provided for Anpara-A station are adequate for Anpara –B station also. Space provision exists for additional three storage tanks of similar capacity. Day tanks with pressurizing and heating units for each boiler have to be provided close to 500 MW units' area.

1.6 Ash Handling System:

Broad specifications of the Ash handling system of 2x500 MW Anpara 'B' units are:

- Ash water ratio…1: 10 (Lower ratio proposed for future units)
- Flushing water… 2060 m^3 / h
- Ash slurry pump… 4x50%, 1132 m^3 / h, 105 mWcl
- Ash disposal … 0.65 million tonnes per annum per unit

1.7 Mill Reject System:

Mill reject removed by conveyor system has been provided for Anpara-A stations. The conveyor from the mill bunker bay is taken out in a conveyor gallery for discharging the rejects over ground in a mill reject collecting are between the grid axis 9A+10 and 9A+60 and 25B and 26B. In view of the fact that slow speed ball mills have been called for in the Anpara-B TPS, no reject system is envisaged.

1.8 Outdoor Switchyards:

A separate 400/132 kV outdoor switchyard has been provided for the Station-A. The 400 kV switchyard consists of twelve bays including one spare. The basic principle of this outdoor yard is that two main buses and a by-pass are provided to facilitate breaker maintenance without shutdown of any lines or generators. The outdoor switchyard for the station-B is in continuation of the Station-A switchyard on the eastern side. The 400/132KV switchyard of Station –A and the 400/132 switchyard associated with the Station-B are interconnected by means of breakers, isolators etc for exchange of power in case of emergency.

1.9 Auxiliary Steam Supply:

Auxiliary steam supply header provided for station-B is fed from the following sources:

i. From an auxiliary boiler of rated capacity of 60t/h at 18 Ata and 230 degree C when none of the main steam generators is in operation.
ii. From one or more of the operating main steam generator of Anpara – A, through a pressure reducing and desuper-heating station provided for each unit.

1.10 Diesel Generating Sets:

The existing station has three numbers 400kW-diesel generating sets one for each 210 MW unit for purposes of emergency power supplies to vital low voltage auxiliaries. The B Station is provided with 3-nos. diesel generating sets.

1.11 Workshop Facilities :

A well equipped Central workshop comprising of equipment and machinery has been provided with Anpara – A & B TPS. Additional workshop facilities for facilitating erection, operation and maintenance of the Anpara –B- extension TPS shall be required to be developed.

1.12 Fire Fighting System:

Fire detection and protection system based on up to date technology is provided for Anpara-A & B TPS. Reliable fire detection, location and alarm system covers all area. Hydrant system, covering all areas, mulsifire system covering outdoor electrical equipments, sprinkler system covering cable galleries, fuel oil, coal handling plant, boiler operating floor etc. Halon system for Main and DAS control room, conventional portable extinguishers, foam generators etc for all the places are provided.

1.13 Air Conditioning System:

Air conditioning plants for the air conditioning of service house unit control board rooms, switchyard control rooms, building at EP control room have been provided for Anpara –A & B TPS. The air conditioning plant for service house and UCBs has been located in the basement floor of service house. The air conditioning plants for the extension stage of Anpara –B are to be provided separately as per requirements, on the ground floor as no basement is envisaged for Anpara –B TPS and B-extension stage.

1.14 Hydrogen Generation Plant:

A hydrogen generation plant of capacity 2x15 m^3/hr to meet the requirement of hydrogen for the station has been provided in station-A designs. The plant has been located between the grid axis 10A+50 & 11A and 25B + 50 & 26B. The same hydrogen generation plant is expected to serve Anpara 'B' extension also.

SPECIFICATIONS OF MAJOR EQUIPMENT FOR THE ANPARA-B POWER PLANT PROJECT

-2x500 MW

2.0 SPECIFICATIONS OF MAJOR EQUIPMENTS OF ANPARA 'B' EXTENSION PROJECT-2 x 500 MW

2.1 Plant Configuration:

A Heat Balance Diagram (HBD) of Anpara B Thermal Power Project comprising of two units of 500 MW - (2x500MW) is as per attached figure I.

2.2 Main Plant Equipment

2.2.1 Steam Generators and Accessories

The Steam Generator

Both the two boilers are Radiant Reheat single reheat with tangentially fired furnace and having controlled steam parameters from 60% - 100 % load. The steam generator will be designed as a single drum, controlled circulation water tube, direct fired, balanced draft furnace with single reheat suitable for semi-outdoor installation with the following Guaranteed Technical particulars:

Maximum continuous rating	1720 t/hr
Super heater outlet pressure at MCR	177.6 kg/cm^2 (abs)
Super heater outlet temperature from 60-100% MCR	543 ^{0} C
Reheater outlet temperature from 60-100% MCR	541 ^{0} C
Reheater pressure drop	2.9 Kg/Cm^2
Boiler Efficiency at MCR for design coal as per Annex. 2.1	84.54%
Total auxiliary power consumption	27887 kW
Flue gas out let temperature	145 ^{0} C
Feed water inlet temp	250 ^{0} C

The steam generator has been designed for pulverized coal corner firing with steam atomized heavy fuel oil for burner supports. Compressed air atomized light diesel oil may also be used for igniters and initial warm up when starting from cold. The steam generator has a corner fired, water cooled furnace, radiant and convection super heaters and reheaters, attemperators, economizers, regenerative air heaters, steam -coil heaters and 60% capacity HP/LP bypass system.

PA Fan, FD Fans

The boiler has 2 x 50% capacity Primary air (PA) fans and 2 x 50% capacity Forced draft (FD) fans for supplying the required primary/secondary air for the boiler. These fans will have Aerofoil design blades with both side air entry to the impeller

ID. Fans

The boiler is equipped with 2 x 55% capacity double Inlet types radial flow ID Fans with variable speed drive.

Boiler Circulation Pumps

There are 3 x *50%* controlled circulation glandless motor pump sets connected from the down comers from the steam drum.. Each pump will be driven by squirrel cage wet stator type motor. The suction/discharge pressures is of the order of 196/210 kg/cm^2 with a total head of 30 M.

Soot Blowing System

An auto control operated Intelligent Soot blower System is provided. The steam generator is provided with 32 Nos. long retractable soot blowers and 88 Nos. wall blowers. The entire soot blower operations are carried out from the DCS as detailed further.

Burner Management & Automatic Plant Control Systems

The steam generator is equipped with complete burner management system including mill automation and secondary air control with all required accessories as detailed at the **DCS System (Control and Instrumentation)** write up as per Annex. 2.2.

Electrostatic Precipitators

The dust collection system consists of a four pass electrostatic precipitator (ESP). The electrostatic precipitator ash collection hoppers will have a capacity sufficient for twelve (12) hours operations at maximum collection rate in any section of the electrostatic precipitator. The ESP's will be provided complete with motorized rapping mechanisms, rectifier transformers, hoppers and their heaters and all associated auxiliaries. The hopper outlet shall be provided with a diversion gate **for Dry Fly Ash collection System.** The ESP will be capable to limit dust emission to 100 mg/Nm^3 with one ESP Field series out of service at MCR firing with worst coal having ash content 49.3%, Moisture 5*%,* Calorific value 3188 Kcal/kg at 60 RH and 40^{0}C.

Mills & Milling System

It has eight (8) Tube mill pulverizers (ball mills) for pulverized fuel firing. Each mill has a gravimetric raw coal feeder. The pulverised fuel from each mill is taken through pulverized fuel piping to all corners of the furnace. The burners are arranged for tilting/tangential firing. Six pulverisers would meet the normal rating of the 500MW with designed coal while one will be for maintenance and one as stand by.

2.2.2 Steam Turbine and Auxiliaries

The Steam turbine is a tandem compound, double exhaust; twin cylinders condensing type with single reheat. It has combined HP & IP module **(HIP)**. The unit has following guaranteed technical parameters:

PARAMETER	RATED VALUE	UNIT
Terminal Output at 169 kg/cm^2 / 538 ^{0} C / 538 ^{0} C	500,000	kW
Design back pressure	76.6	mm Hg abs.
Rated steam flow	1508	T/h
VWO (Valve wide Open) flow rate	1635	T/h
Final feed water temperature	250	^{0} C
Operating frequency range	47.5 to 51.5	Hz
Vibration level	50 peak to peak (on Shaft) and 25 peak to peak (on bearing pedestal)	Microns
HP turbine exhaust pressure	41.8	Kg/cm^2
IP turbine inlet pressure	37.6	Kg/cm^2

The two cylinder turbine (HIP + LP) has H.P +I.P. casing (opposed flow) having 7 H.P. and 6 I.P. stages in single casing. The L.P. casing (double flow) has 2x5 stages with the last stage blade length of the order of 1067 mm. The no load steam flow through turbine shall be approx. 77 t/h at 60 kg/cm^2. The turning gear speed shall be 3 to 6 rpm and maximum allowable temperature at exhaust hood shall be 107^{0}C.

Part of the steam exhausted from the medium pressure cylinders is being used in boiler feed pump-turbines having an output of approximately 2 x 9MW for 2 x 50% capacity turbo driven BFPs. The main turbine and the boiler feed turbine combined, uses three (3) low pressure heat exchanger type feed water heaters, one direct contact deaerator and two (2) trains of H.P. indirect heat exchanger type feed water heaters. The drains from the L.P. heaters is cascaded to the condensate before L.P. Heater (2) and from the H.P. heaters to the deaerator. Each heat exchanger type heater will use integral de-super-heating and drain cooling sections as required.

2.2.2.1 Turbine Auxiliary Systems

i. H.P. & L.P. By-pass system

ii. Boiler feed pumps

iii. Condensate pumps

iv. L.P. & H.P. heaters and Deaerator

v. Closed cycle D.M. Aux. cooling water system

vi. Steam condensers

vi. Steam Condenser

A single shell, one-pass, surface type condenser at exhaust of each turbine is located on the ground floor. The condenser has a required effective cooling surface area, designed for cooling -water temperature of 33^{0}C.The condenser is directly welded to the lower half of the LP turbine casing and is supported by spring foundation located underneath the condenser bottom plate. The condenser has two separate identical tube bundles on circulating water system so as to provide one-half tube bundle operation, and condenser tubes of welded stainless steel type 304 are provided transversely to the turbine shaft.

The condenser will effect deaeration to maintain the oxygen content of condensate below 0.02 cc/liter at condenser outlet.

2.3 ELECTRICAL AND C&I SYSTEM:

2.3.1 Generator:

The salient technical particulars of the generator are as given below:

Apparent power	: 589000 KVA
Power Factor	: 0.85 (Lag)
Active Power	: 500000 kW
Rated voltage/voltage range	: 21 KV + 5%
Speed/Frequency	: 3000 rpm/ 50 Hz
Stator current	: 16200 Amps.
Type of cooling stator winding	: Direct H_2O
Laminated core	: Radial H_2

Rotor : Direct H_2
Minimum guaranteed short circuit ratio : 0.48 + 10%
Minimum initial short circuit current (Peak value) : 250 kA + 30%
Steady state short circuit current : 24.6 kA + 15%
Permissible continuous negative sequence : 8% of rated current

2.3.2 Excitation System:

Each generator is provided with thyristorised static excitation system which makes it possible to provide full ceiling voltage, either positive or negative, almost instantaneously under conditions of system disturbances. The system includes transformer, AVR cubicle, thyristor, convertor cubicle and field circuit breaker. Current transformer for control, regulation, protection and metering of the generator would be either provided in the generator stator terminal bushing both on the lines as well as neutral sides, or would be housed in the isolated phase bus duct (IPB).

2.3.3 Hydrogen Cooling and Stator Coolers

Hydrogen gas at rated pressure of 4.2 kg/cm^{2}G is used for cooling the 500MW generator. Four (4) hydrogen gas coolers are provided for each generator to cool down the hydrogen gas by cooling water fed from closed cycle aux. D.M. water system. In the stator cooling water system, two (2) stator cooling water coolers are provided for each generator.

2.3.4 Switching & Switchyard

The power generated at 21 KV is stepped up to 400 kV through generator transformers of suitable capacity and then further stepped up to 800kV for connection to the U.P. Grid.

Suitable H.T. and L.T. dry type transformers are provided for power supply to auxiliaries at 6.6 KV, 415 V and 220 volts are provided for supplying D.C. Power for instrumentation and control equipments. A set of station batteries areprovided for supply of D.C. Power to emergency lube oil pump and seal oil pumps etc. in case of grid failure. The station D.C. distribution bus will meet DC Power requirement for station auxiliaries.

2.3.5 Control & Instrumentation System

Microprocessor based Distributed Digital control and Monitoring Information System (DCS) is provided for safe operation, monitoring and control of the main power plant and its auxiliaries from the control room. Local panels is also provided at the boiler, turbo generator, boiler feed pumps and other areas where local attendance will be necessary. Separate control and instrumentation panels have been provided for the plant auxiliary system like, the cooling water system, coal handling system, ash handling system, circulating water pumps & compressors etc.

The major control systems are as follows:

- Three element automatic feed water control with pressure compensated and anticipatory arrangement.

- Boiler feed control by variable speed boiler feed pump drive control to maintain constant differential pressure across feed water regulating valves.

- Automatic combustion control to maintain turbine throttle steam pressure at preset values and to maintain correct present fuel-air ratio for continuous efficient operation. Anticipatory devices will be provided.

- Steam generator furnace draft control at all loads of the steam generator to maintain a negative draft.
- Mill cool-air mixture temperature control at preset values suitable for drying the coal.
- Main steam temperature controlled by spray attemperation. Reheat temperature will be first controlled by burner tilt and then if necessary by spray attemperation, Turbo-supervisory devices also provided.
- Burner management and supervisory system will ensure efficient combustion conditions in the furnace at all times and minimize risks of explosions.

Miscellaneous turbine controls will include condenser hot well level controls, hot well make up control, deaerator level control, gland seal steam pressure control and other safety interlocks necessary for the efficient and safe operation of the turbo generators.

2.3.6 Protective Relay System

This covers protective relaying scheme for all elements pertaining to:

i. Generator, Rotor and Generator transformer unit.

ii. Unit auxiliary transformer

iii. Station auxiliary transformer

iv. 400/800 KV buses, by-pass and bus-coupler breakers

v. 800 KV lines and line reactors

vi. 6.6 KV/433 V transformers

vii. 6.6 KV motors

viii. 415 V motors

ix. 6.6 KV bus bars

x. 6.6 KV station supply feeders

xi. 415 V bus

2.3.7 Storage Battery

220 V DC storage battery of suitable capacity (10 hours discharge rate) is envisaged for each unit. Another separate battery of suitable capacity (10 hours discharge rate) is envisaged to meet the D.C. power requirement of switch- yard equipments. The capacities of these batteries shall be chosen on the basis of one hour duration of total AC power supply failure in the station. Provision for Trickle charging and quick charging sets (static rectifier type, 415 V, 3 phase) shall also be made for the storage batteries along with necessary DC switch boards for emergency lighting, and giving supply to unit and station auxiliaries etc.

2.3.8 Emergency Diesel Generating Sets

The DG sets (415 volts, 3 phase, 50 C/S) along with all accessories and boards are envisaged to meet the following loads under emergency conditions:

a. Standby bearing lubricating oil pump.

b. Hydrogen seal oil pump.

c. Turning gear/Turbine jacking oil pump. & Emergency lighting etc.

2.3.9 Communicating System

Suitable communication system is provided in the power house area so that communication between key operating personnel in the power station plant could be established through a page and party system. Telephone system will also be provided.

2.3.10 Structure for Laying Cables

The power and control cables required from various equipments to their associated switchgear and control centers havebeen laid in cable channels, cable galleries, cable shafts in the power house area.

2.3.11 Miscellaneous Electrical equipment/systems

Various other electrical equipments/system like the generator bus duct, power control cables and switch gears, auxiliary power system, switch yard and carrier communication equipments, equipment of grounding system, lighting system & emergency diesel set etc. would be provided as per normal practice for plants and as per relevant IS. The salient features of these systems shall be in line with the existing Anpara B TPS.

2.4 Plant Auxiliaries

The following auxiliary systems are envisaged for which details are found in next volume:

i. Ash and slurry disposal plant together with Ash pond

ii. MGR and Coal handling Plant (augmentation)

iii. Water treatment plant (augmentation)

iv. Fire Fighting facilities (extension)

vi. Circulating Water System

The next section deals with the Ecology and Environment impact of the Anpara 'B' project and its future extension.

3.0 ECOLOGY OF ENVIRONMENT OF IMPACT OF ANPARA 'B' EXTENSION PROJECT

3.1 ECOLOGICAL ASPECTS:

3x210 MW 'A' Thermal and 2x 500 MW 'B' Thermal Power Plants are running at high plant load factor. Anpara 'B' extension Power Station with 2x500 MW are proposed. Nearby at a distance of 6 km Renusagar Thermal Power Station of 360MW is also running. In a radius of 25 Km there are three NTPC Thermal Power Stations viz. Shakti Nagar, Vindhyachal and Rihand which are in operation. Kanoria Chemicals and Hindalco Aluminum Factory are also existing at a distance of more than 30 to 35 km radius.

The detailed rating/capacity of the nearby industries are given below:

i)	Singrauli Super Thermal Power Station (NTPC)	–2000 MW
ii)	Vindyachal Super Thermal Power Station (NTPC)	- 2260 MW
iii)	Rihand Super Thermal Power Station (NTPC)	- 1000 MW
iv)	Renusagar Power Co.	- 360 MW
v)	Anpara Thermal Power Plant (UPRVUNL)	- 1630 MW
vi)	Hindalco Industries, Renukoot	- Production of Aluminium
vii)	Kanoria Chemicals, Renukoot	- Production of Industrial Chemicals
viii)	Hitech Carbon, Renukoot (Carbon Products)	- 20000 T/Yr.
ix)	Coal Mines of NCL (Kakri, Bina, Marrack, Jayant, Dudhichua, Nigai, Amlori, Moher, Jingrudha & Gorbi)	- 32.2 Million T/Yr.

The nearby area is mostly forest and some agricultural lands.

According to District Statistical books, the details of the occupation of the people are given below: -

	OCCUPATION	PERCENTAGE
i)	Farmer & Agricultural labour	30
ii)	Employed Person (Govt./Public Sector/Pvt. Sector)	21
iii)	Self Employed	14
iv)	Craftsman	1
v)	Other jobs	6

vi) Unemployed 28

As far as Ecological Impacts are concerned the following is the summery of the same

- At the time of construction of 'A' & 'B' TPS all persons affected by the project and the local population were fully informed about the ultimate capacity of 3150 MW of Anpara. Out of this only 1650 MW have so far been constructed. The remaining 1000 MW is now proposed through Anpara 'B' Extension.
- Since land for construction of Anpara 'B' Extension is already available with the project no question of Land acquisition arises.
- Adequate compensation in consultation with district authorities were given in place of land and plots against residences when the land was originally acquired for construction of Anpara A&B.
- Maximum possible employment to the land oustees has been provided, roads and hand pumps have been provided for them in the resettlement colony.
- Almost all the resettlement works have been finalized and for 'B' Extension plant the land is available without the need for any further acquisition.
- There is no adverse reaction so far from national and international non-governmental organizations (NGO's).

Thus there appears to be no adverse Impact on the 'Ecology' with the setting up of the Anpara 'B' Extension plant

3.2 ENVIRONMENTAL ASPECTS

As per U.P Pollution Board the environmental norms are being followed as per various standards and norms issued by Ministry of Environment & Forest (MOEF) The Ministry of Environment and Forest, GOI regulates environmental aspects including ash utilization aspects as per notification issued in the Gazette of India The Project has taken several initiatives for **Ash utilization.**
These include:

- ➢ Characterization of Pond Ash / Dry ash / Bottom Ash of Anpara TPS and utilization in Road construction … through Central Road Research Institute (CRRI)
- ➢ Ash utilization for Agriculture purposes…through Central Fuel Research Institute (CFRI)
- ➢ Ash for Mine filling…through Central Mining Research Institute (CMRI)

These studies are under finalization for implementation by the Project and by the time Anpara 'B' Extension project comes on bar these would have implemented.

Further, as regards air quality and effluent disposal norms are concerned these are being met as summarized below:

- Environmental precautions are taken care by constructing high chimney as per G.O.I guidelines (For Anpara 'A' TPS, the height of the chimney is 220 m and for Anpara 'B' TPS the height of the chimney is 275 m). The atmospheric pollution in the acceptable level of SPM of 150 mg/Nm^3 is being achieved through Electro static precipitator's efficiency over 98.5%.

- The ash slurry is discharged in an ash dam from where clean water is discharged into the Rihand Reservoir through decantation and two-stage settlement at far off from population. Coal dust is checked by sprinkling water over coal in Coal Handling yard and by plantation at all possible available areas of the project.

Further the project specific Environment Control measures are:

PERFORMANCE GUARANTEE TEST

- M/s Mitsui & Co. LTD in constitution with C.E.A and M/s B.H.E.L have performed the Performance Guarantee Test for Anpara 'B' and 'A' respectively and achieved the permissible standards as per norms prescribed by MOEF and U.P State Pollution Control Board.

WASTE WATER

- Waste cooling water is being discharged through open discharge channel 8-m wide, 4 m deep x 3 Km long passing through various natural hydraulic jumps into the Rihand reservoir. For Anpara 'B' extension the cooling towers will be used if required after conducting the environmental studies.

- Discharge water is meeting the reservoir at a difference of max. 3^0C above the reservoir water temperature.

- Since the reservoir is considerably large (area 468 Km^2 at full) there is no impact on the ecology of the water.

SAFETY AND SECURITY MEASURES

All safety measures against leakage of steam; oil and hydrogen are installed. Restricted entries of outsiders in the Power plant area, proper permit to Work procedures for shut down for execution of work etc. are being observed. Waste chemicals are neutralized before discharging in open channel. A testing laboratory has been set up for regular checking and monitoring of effluents.

4 DATA SHEET

STEAM GENERATOR & AUXILIARIES INCLUDING HP PIPING AND VALVES:

Note: Composition of material shall be furnished along with the specification of material wherever given:

1. Main Steam Generator

A. Steam Generator

i) Manufacturer	MITSUBISHI HEAVY INDUSTRIES & BHEL	
ii) Design Code	IBR/ASME/ASTM/JIS/ANSI	
iii) Type of steam generator	MITSUBISHI-CE radiant reheat controlled circulation boiler (Semi-outdoor type)	
iv) Type of firing	MITSUIBISHI-CE tilting tangential corner firing tangential corner firing	
v) Type of superheater (drainable/non-drainable)	Dry SH: Drainable other; Non-drainable	
vi) Total auxiliary power consumption with performance coat at Boiler MCR (kW)	29697	
Break up (at BMCR) of the above for:	No. KW	KW
- ID Fans	2x 2365	4730
- FD Fans	2x1915	3830
- PA Fans	2x2140	4280
-Scanner air fan	1x15	15
-Pulverisers	6x2100	12600
-Boiler circulation pumps	2x225	450
-EP's	2650	2650
-EP hopper heater	1344x0.5	672
-Any other item not-covered above		470
ix) Minimum boiler load without oil support.	30% BMCR for performance coal, 40% BMCR for worst coal etc	
x) Minimum boiler load at which the boiler furnace shall be stable in case of sudden load throw off from 100% unit load.	50% BMCR	
B. Furnace		
i) Type	Water cooled membrane wall hopper bottom	
ii) Combustion chamber volume (m3)	14280	
iii) Furnace dimensions (m3) width x depth x height	17.843 m x 15.367 m x 59.282 m	
iv) Design Pressure for:		
a) Furnace	+660 mmWC	
b) Connected air and gas ducting	+660 mmWC	
c) EP Casing	+660 mmWC	
v) Water walls		
Total heating surface (m2)	6240	
Water wall tube		
-OD & thickness max.	50.8x 5.6	
-Design metal temp (C)	395	

-Design pressure (kg/cm2.g):	205
-Total weight (Tonnes)	525
-material	SA210C
vi) Water wall header	
Material	SA106C
OD & thickness (mm)	1,062x 99
Design Pressure	210
Total Weight(tones)	90
C. Boiler Drum	
i) Specification of material	SA299
ii) Thickness of shell (mm)	190
iii) Elevation of drum (M)	FL +70m
iv) Drum length & diameter (MxM)	24 x 1.780
v) Design pressure (kg/cm2.g)	205
vi) Design metal temp. (C)	367
viii) Purity of saturated steam leaving the drum (ppm)	<0.02
Total dissolved solids silica content	
ix) Drum weight (tones)	
-without internals	216
-with internals	224
x) Water capacity at MCR conditions (in seconds) between normal and lowest water level permitted	22
D. Super heater	
i) Total heating area (m2)	
Radiant	4660
Convective	9440
ii)Number and type of thermo-couples fitted to Superheater tubes in pent house	C-A Type
E. Superheater Attemperator	
i) Type	Spray water injection type
ii) No. of stages of attemperation	2
iii) Specification of material	SA 106 C, SA 335-P12
iv) Range of boiler load in which rated steam temperature can be maintained:	
(a) For superheated steam temp.	60~100% B-MCR
(b) for reheated steam temp.	60~100% B-MCR
v) Maximum spray water flow rate (Tonnes/hr)	
a) superheater spray	280
b) Reheater spray (emergency)	90
F. Reheaters	
i) Total heating area (m2)	7010
ii) No. of stage	3
G- Reheater Primary Temperature control	
in case of tilting burners	
i) Max. angle of tilt upwards ( )	30
ii) Max. angle of tilt downwards (0)	30
iii) Type of tilt downwards (0)	Motor Drive
I. Economiser	
i) Type :	Bare tube in-line arrange went, horizontal type

ii) Specification of tube material	SA210A1
iii) Tube outside diameter and thickness	51.0 x 5.0
iv) Max. gas aide metal temp. of tubes (0C)	427
J. Boiler Mountings & Fittings	
i) Drum safety valves manufacturer	TA VALVE Co. Ltd or Equivalent
Type and rating number and set pressures	Full lift/ 1500-II… 205 & 211 kg/cm2g
Specification of material	SA216WCB SA216 WCB
ii) Super heater safety valves	
Manufacturer	TOA Valve Co. Ltd or equivalent
Type and rating	Full lift/2500-II
Number and set pressures	3/188.5 kg/cm2g
Specification of material	SA217WC9
iii) Reheater safety valves	
Manufacturer	TOA VALVE CO. LTD or equivalent
Type and rating	Full lift/600 , 1500
Number and set pressures	2/48 kg/cm2g 1/49 kg/cm2
Specification of material	1/51 kg/cm2 11/52.5 kg/cm2
iv) Electrometric safety valve on superheater outlet	
Manufacturer	TOA VALVE CO. LTD or equivalent
Type of actuator	Electrically actuated
Number and set pressures	3/184 kg/cm2g
Capacity of Valve (kg/sec)	27.55 kg/sec per each
v) Drum level gauges	
Manufacturer	Bunks or equivalent
Type	Bi-coler
Number	Two
Location	Each side
Size	1 1/2B
2. STEAM GENERATOR AUXILIARIES	
A. Boiler water Circulation pumps	
Type of pumps	Centrifugal
No. provided	3
capacity	2,940 m3/h
Head	30m
Nos. required for Boiler MCR	2
B. Regenerative Air heater	
Manufacturer	MHI or equivalent
Type	Ljungstrom
No. of air heaters per boiler	2
Max. operating temp. (^{0}C)	410 ^{0}C
Max. expected air leakage (%) (to flue gas side)	23.6%(Primary) and 6.6% (Secondary)
Elements	
Total effective heating surface in contact with the flue gases m^2	
Secondary air	-- 38,190 m^2
Primary Air	12,420 m^2
Total effective heating surface in contact with the inlet air (m2)	
Secondary air	-- 38,190 m^2
Primary air	12420 m^2 --

Gas flow area	19.6 m^2	42.1 m^2
Air flow area	19.6 m^2	42.1 m^2
Size of electric motor (KW)	7.5 KW	18.5 KW
Speed of retention of the motor and gear ratio	1,500 rpm	1,500 rpm
	1/109	1/155
Size of air water (HP)	7 HP	8.4 HP
Speed of rotation of air water and gear ratio	400 rpm	275 rpm
Material:-	1/7.1	¼.89
Elements hot end	SPCC	
Elements cold end	CRLS (Corrosion resistant Ion alloy steel)	
Shaft	850 C	
Seals hot end	Carbon tool steel (SKS)	
seals cold end	CALS	
casings	SS	
C. Steam coil air Heaters	**1 ry**	**2 ry**
i) Air inlet Temp. (0C)	16	10
ii) Air outlet temp (0C)	90	90
iii) Air flow rate Nm3/sec	21	140
iv) Max. steam flow rate required (kg/hr)	5,000	25,000
D. DRAFT PLANT	**FD Fans**	**ID Fans**
i) Manufacturer	MHI, MAKAJIMA, MFG. CO. or equivalent	
ii) Type	Centrifugal	Centrifugal
iii) Number of fans per boiler	2	2
iv) Volume flow rate NM3/sec	454.8	554.0
v) Total pressure (mm W.C)	305	175
vi) Total air infilteration assumed (%)	Approx. 2%	
vii) Total air heater leakage assumed	196 Tonnes/hr	
viii) Margins included in		
a) Flow rate (%)	25.0	20.0
b) Total pressure (%)	50.0	44.0
ix) Fan efficiency at rated capacity (%)	73.9	76.8
x) Starting torque (kg.m)	400	200
xi) Size of motor (KW)	2220	3470
xii) Method of flow	Inlet vane	Inlet vane plus Hydraulic coupling
xiii) Range of control	0~90 degree	0~90 degree
xiv) Rated speed (rpm)	735	600
xv) Type of coupling	Gear	Gear
xvi)Materials of construction of various components (shaft, impellers, coupling hub etc)	Standard as per IS	
E. SOOT BLOWERS		
i) Manufacturer	LASB	WB
Blowers	BHEL	BHEL
Control Equipment	Copes-vulcan or equivalent	
ii) Type	T30 MARKILE RW5E	
iii) Condition of steam used for blowing		
Pressure (Kg/cm^2 g)	30	30
Temperature (C)	340	340
iv) Source of steam	Tertiary SH inlet	
v) Total operating time per group	176 min	66 min
vi) Number, voltage and capacity of power, supply feeder to soot blower MCC	AC 415 V,	2 KVA one feeder
vii) Number of soot blowers per a boiler		
Super heater	18	

Reheater	6
Economiser	8
Air Heater	4
Total	36 + Wall blower 88
F- Pressure Reducting & Desuperheating station	
i) Pressure reducing & Desuperheating station	1) Fisher, UK or Japan 2) Masolian India or France 3) Introl, India or UK. 4)Instrumentation Limited Palghat or equiv. Cage guided single stage or multi stage diaphragm actuated valve
No. of Valves	On e one
Flow capacity of each valve (tones/hr)	Max. 125 25
Upstream steam pressure (kg/cm2 g)	Approx. 182 46
Upstream steam temperature	450 350
Down stream steam temperature	340 320
ii) Desuperheaters	
Manufacturer	To be decided during detail Engineering
G. Fuel preparation & Firing System	
a) Raw coal feeders	
i) Manufacturer	YAMATO SCALE CO. LTD STOCK of Co. or equivalent
ii) Type	Volumetric type
iii) Max. capacity (tones/hr)	50 t/h
iv) Method of output control	Variable speed
(v) Type of drive	Variable speed type
vi) Material of construction	Mild steel stainless steel
vii) Feeder inlet and outlet chuts/size (mm)	600 (inlet) 900 (outlet)
Pulverizers	
i) Manufacturer	IHI, MHI or equivalent
ii) Type	Ball will
iii) Number per boiler	8
iv) Overall dimension	Approx. 15, 200 mm, 6, 000
v) Speed of pulveriser (rpm)	16.3
vi) Design capacity (tones/hr)	
b) with worst coal	78 t/h
vii) Crushed coal size at inlet to mill (mm)	20
viii) Sleve size analysis of Pulverised coal	Above 70% through 200 U.S mesh sleeve
ix) Specification of material for grinding parts	
Grinding rings/armour/plates/ armour belts and nuts/liners/feet wearing parts.	Linera_______Ni-hard
Balls/Rollers/coupling belts & brushes/dust guard and seals/ gears and pinions.	Wedge bar------------Ni-hard
x) Estimated life of above grinding parts in hours with performance coal and worst coal	Liners ---------------------4~8 years Wedge bar------------------2~8 years Ball---------------------------0.05~0.2 kg/ton of coal
xi) Number of pulverisers required at MCR of boiler	
a) with worst coal	6
b) with performance coal	5
D. Fans	**Primary air fans seal air fans scanner air fans**
i) Manufacturer	NAKAJIMA MFG. Co. Ltd, MHI or equivalent
ii) Type	Centrifugal
iii) No. of fans per boiler	2 1 1

iv) Shaft speed (rpm)	1,500	1,500	3,000
v) Design capacity (Nm3 per sec)	136.5	1.0	1.83
vi) Source of air supply	FDF outlet	FDF outlet	FDF outlet
vii) Method of input and control	Inlet vane	No control	No control
viii) Fan efficiency (at design point)	79%	50%	50%
e. Pulverized Fuel piping			
i) Material of Pipes	Straights Bends	Mild Steel Mild Steel	
ii) Material of linings	Straights Bends	None Mild Steel	
iii) Max. velocity of fuel mixture (m/sec)	29 m/s		
f. Coal Burners			
i) Manufacturer	MITSUIBISHI HEAVY INDUSTRIES		
ii) Type	Pulverised coal direct firing		
iii) No. per pulveriser	4		
iv) Elevation of burners	FL+ 34 m (top) /FL + 24 m (bottom)		
v) Specification of material for burner body	SCH 11		
g. Fuel Oil Pumps			
i) Manufacturer	KOSAKA LAVO or equivalent		
ii) Type	Screw		
iii)Capacity of each pump(m3/hr)	49		
iv) Total discharge pressure (kg/ cm2)	40		
v) Pump speed (rpm)	1,450		
vi) Max. absolute viscosity in centi-poise of the oil, the pump can handle	Approx. 200 C		
vii) Whether electrical/steam traced?	Steam		
h. Fuel oil heaters			
i) Manufacturer	SEO KCATSU Co. or equiv		
ii) Type	U-Tube type		
iii) Number			
iv) Flow capacity of each heater (kg/hr) and heating surface (m^2)	40,000 kg/h 90 m^2		
v) Design temperature of fuel oil at			
-Inlet	60 C		
-Outlet	120 C		
vi) Heating steam			
-Flow (kg/hr)	2,500		
-Pressure (kg/cm^2g)	15		
I) Oil Burners			
i) Manufacturer	MITSUIBISHI HEAVY INDUSTRIES		
ii) Type	Steam atomizing M-Jet		
iii) No. of burners per boiler	16		
iv) Max. turn down rattle	1:4		
v) capacity of each burner (tones/hr)	2.6 tonnes/hr		
vi) Specification of material for:			
Burner Body	SCPH2		
Burner Tip	SKH-51		
vii) Atomising Steam pressure	10.5 kg/cm2g		
xi) Fuel Oil ignitors			
i) Manufacturer	TOHO MFG. Or equivalent		
ii) Type and model number	H.E.A		
iii) Retractable or stationary	Retractable		
iv) Heat input per ignitor	16 joule		

v) No. per boiler and location	16 each oil burner
H) Piping & Valves	
Standard to which piping has been designed copy of the standard	IBR/ASME/ASTW/JIS/IS
ELECTROSTATIC PRECIPITATOR	
Data Sheets	
A. GENERAL	
i) Manufacturer	BHEL
ii) Manufacturer’s model no.	4 FAA-7x 45-2x114135
iii) No. of electrical fields in series in the direction of flow	Seven (7)
iv) Treatment time	42
v) Specific collecting area M^2/M3/sec	279.2
vi) Max. gas velocity (m/sec)	0.75
vii) No. of Bus sections per field	8
B. Predicted preference at design conditions	
i) Dust concentration at EP inlet, mgm/Nm3	80720 (wet)
ii) Dust concentration at EP outlet, mgm/Nm3	100 (wet)
iii) Overall precipitation efficiency %(with six fields in service)	99.876
iv) Precipitation efficiency % (with five fields in service)	99.72
v) Pressure drop across	28
vi) Gas Temp. drop access EP, C	5
vii) Total power consumption, kW	
a) EP	2330 (Corona power)
b) EP Hopper heaters	672
C) Collecting Electrodes	
i) Material	IS 513 Gr. DD or equivalent
ii) Size & type of electrodes	G Type
Width (mm)	750
Height (mm)	13500
Thickness (mm)	1.5
iii) No. of electrodes per precipitator	1848/4-462
iv) No. of electrodes per precipitator	3234
v) Total active collecting area	258552
vi) Type of suspension	From hocks
vii) Spacing between electrodes (mm)	300
D. Discharge electrodes	
i) Material	Austentic stainless steel to UHB 904 L or equiv
ii) No. of electrodes	16416/4=4104 or total per ESP …28728
iii) Electrodes size mm	2.7 mm dia
iv) Length of the electrodes (M)	71080/4= 17770 124390
v) Type of suspension	Hook
vi) Spacing along the direction of flow (mm)	225
E. Ropping mechanism for collecting Electrodes	

i) Type	Tumbling hammers
ii) No. of rapping sets per EP	7
iii) Adjustable range of rapping frequency provided	1-20 rmp/hr
iv) Rapper controller	
a) Type	Synchronous programmers
b) Method of frequency control	Cars mounted on synchronous programmer
c) Method of intensity control	Not previous
v) Power consumption KW	11
vi) Type of mounting	Horizontal, feet mounting
vii) Normal time to complete one rapping cycle (sec)	3600
viii) Rapping energy of each rapping set (Kg. m)	2.55
F. Rapping mechanism -discharge electrodes	
(i) Type	Tumbling hammer
(ii) No. of rapping sets per EP	14
(iii) Adjustable range of rapping frequency provided	10 rpm/hr
iv) Rapper controller type	Synchronous programmers
(b) Method of frequency control	Cars mounted on synchronous programmer
(c) Method of intensity control	Not provided
v) Power Consumption KW	21
vi)Type of mounting	Vertical, flange mounted
vii) Normal time to complete one rapping cycle (sec)	3600
viii) Rapping energy of each rapping set	1.56
G. Heigh tension support insulators	
i) Type	Conical
ii) Material	Percelian
iii) Leakage distance (mm)	Min 500
iv) Min. flash over (KV)	105
v) Method of preventing fouling of insulation by flue gas	Insulators are kept in heated compartments
H. Transformer rectifier unit	
i) Manufacturer	BHEL
ii) KVA Rating	94.2
iii) No. per EP	14
iv) Primary voltage volts	415
v)Peak DC volt & current (KV&MA)	70/1200
vi) Method of cooling	Oil cooled
vii) Class of insulation	A
viii) Temperature rise above ambient temp 0C	50
ix) Half or full wave rectification	Full wave
x) Insulating fluid	Volume- 750 litres specificaton-according IS-335
I) Transformer rectifier	
Control cubicles	
i) No. per EP	14
ii) Method of voltage control	Automatic
iii) Adjustable range of spark rate controller	1-50 sparks/min
J) Gas distribution Device	
i) Type	Perforated Screen at EP inlet

ii) Material	Mild steel
iii) Method of cleaning provided	Tumbling hammer
K. Dust Hoppers	
i) Type	Pyramidal
ii) Material	Mild steel
iii) Total no. of hoppers per EP	28
iv) Anticipated ash collection in hoppers at each zone at design conditions:	
First zone, kg/hr	141780
Second zone kg/hr	16680
Third zone, kg/hr	5840
Fourth zone, kg/hr	1330
Fifth Zone, kg/hr	700
Sixth zone, kg/hr	260
Seventh zone, kg/hr	67
v) Hopper storage capacity, m3	9270
vi) Hopper valley angle	60
vii) Capacity of hopper heaters provided per hopper KW	6
L. Precipitator Casing	
i) Type and construction	Internal bracing
ii) Material	Mild Steel
iii) Design pressure, kg/cm^2	660 mm WC
iv) Design temperature, 0C	300
v) Cross section area for gas flow of each EP, M^2	307.8
vi) Plate thickness; mm	6

STEAM TURBINE AND AUXILIARIES

STEAM TURBINE (Main)

A. Technical Data

i) Manufacturer	Toshiba Corporation
ii) Type	TCDF- 42^0 (2 casing)
iii) speed	3,000
iv) output (kW)	500,000
- Rated output (kW)	500,000
- Maximum continuous rating (kW)	500,000
-Most economical continuous rating (kW)	500,000
-Peaking capacity with time duration, if any	530,930 KW under continuous operation at VWO and at CWT-33 ^{0} C and 3% Make Up
v) Throttle flow (in tones/hr)	1507.425
vi) Steam pressure before and Emergency stop valves in kg/cm^2 g	169
vii) Steam temperature before main (emergency) stop valves (in ^{0}C)	538
viii) HP exhaust pressure (in kg/cm^2 abs)	41.8
ix) HP exhaust temperature (^{0}C)	337.2
x) Pressure before IP interceptor valves (in Kg/Cm2 absolute)	37.6
xi) Temperature before IP interceptor valves (^{0}C)	538
xii) Number of HP exhaust connections	1
xiii) Size and number of cross ever pipes from IP to LP cylinder (s)	60” x1
xiv) Total weight of the turbine (tones)	580
xv) Minimum height of hook of bridge crane required from the level of machine house (m)	9.5
xvi) Name and weight of the heaviest part of the turbine for erection and maintenance (tones)	For erection LP lower casing 110 tonnes . For maintenance LP Rotor; 52 tonnes
xvii) Number of impulse, impulse reaction and reaction stages in	
a) HP	7
b) IP	5
c) LP	5
xviii) Length of the longest blade (in mm)	1,066.8
xix) Total exhaust area (LP Turbine) including the exhaust area for penultimate stage (if provided) (m2)	9.53x 2/flow (Penultimate stage not applicable)

xx) Design pressure and temperature of:				
Valve chest (MSV)	186 kg/Cm2g			
H.P Cylinder casing	177 kg/cm2g, 541 ^{0}C at inlet			
I.P Cylinder casing	52 kg/cm2 at inlet			
L.P casing	10kg/cm2 350 ^{0} C at inlet			
xxi) Bearings - details of each bearing separately				
Size	12”x7”	16”x9”	17” x 15”	20” x 15”
Type	DTP	DTP	KL	KL
Lining Material	Limiting material			
(DTP):	(DTP: Double Tilting Pad Type, EL : Elliptical Type)			
xxii) Type of Couplings	Rigid Couplings			
xxiii) Control (Governor)				
Valves	Four (4)			
Number of	9”x 4”			
Size	Single seated			
Type	Venturi Type			
Max. pressure drop (Kg/Cm^{2})	5.0			
Material				
a) Body	Cr-Mo Steel			
b) Trim	Cr-Mo Steel Forging			
c) Stem	Forging			
B. Operating Conditions				
Exhaust back pressure (Kg/Cm^{2} abs) at:				
a) Rated cooling water temperature (33 ^{0} C)	At MCR Output … 0.104			
b) Maximum cooling water temperature (38^{0}C)	At MCR Output …As per heat balance (later)			
c) Minimum cooling water temperature (12^{0}C)	At MCR output …As per heat balance (later)			
ii) Maximum output with one half of the condenser out of service (KW) at 33^{0}C & 38 ^{0}C cooling water inlet temperature	375,000 KW(33^{0}C) 280,000 KW (38^{0}C)			
v) Combined critical speeds of turbine generator unit (R.P.M)	HIP	2,050	4,900	
	LP	1,560	3400	
	GEN	950	2,530	
vii) Maximum steam flow passing ability at rated inlet steam parameters and corresponding capability (kW) at rated cooling water inlet temperature (33^{0}C) at max. cooling water inlet temperature (38^{0}C) and at minimum cooling water inlet temperature (12^{0}C)	33^{0}C	38^{0}C		
a) Maximum steam flow passing ability (tones/hr)	1634.469	1634. 469		
b) Corresponding power generating capability (kW)	530,930 530,830 (at Valve wide open and 3% make up)	520,910		
viii) a) Minimum steam temp. & pressure at which machine may be rolled from cold condition	60Kg/cm2g 350^{0}C			
b) set point of exhaust hood spray (c)	65^{0}C			
ix) Minimum stable lead in MW for continuous operation	20% (i.e. 100MW)			

x) Recommended duration restriction of time for stable house load operation 2 hrs

SINGRAULI COAL FOR ANPARA 'B' TPS - QUALITY BASED ON 60% RH AND 40^0C

	For initial 2 years	**For initial 20 yrs**	**After 20 yrs of the plant life**
A. Range			
Moisture (%)	5.9-7.2	5.4 -7.5	5.0-6.9
Ash (%)	24.3 - 35.9	27.5 - 38.2	31.1- 49.3
Volatile matter %	-	23.4	-
Calorific value Kcal/kg)	4318-5221	4174-4874	3188-4624
Total moisture %	11 to 22%	11 to 22%	11 to 22%
B. Average Quality			
Moisture (%)	6.6	6.3	6.1
Ash (%)	31.0	33.8	37.1
Calorific value Kcal/kg	4677	33.8	37.1
Total moisture in as received coal is expected to vary from 11 to 22%			
Ultimate Analysis of Coal	**Turra seam**	**Purewa bottom seam**	**Purewa top seam**
Ultimate Analysis: Dry Mineral matter free basis			
C%	79.5-81.2	78.4-80.3	78.0-79.3
H%	4.5-5.0	4.3-5.3	4.7-5.0
N%	1.5-1.7	1.4-1.7	1.6-1.8
S%	0.4	0.5	0.5
O_2%	12.7-13.4	14.8	13.4
2. Ash fusion temp. softening Temp. (^{0}C)	1170-1220	1200-1220	1180-1220
Hemispherical Temp ^{0} C	1400	1400	1400
Hard Grove Index	51-64	48-71	55-106
Caking property of coal CSN	<3	<3	
True specific gravity of coal	1.12-1.44	1.12-1.44	
ASH			
$S10_2$	54.58%		
AL_2O_3	25.21%		
Fe_2O_3	13.35%		
TiO_2	1.40%		
SO_3	0.89%		
P_2O_3	0.32%		
MnO	0.23%		
CaO	1.88%		
MgO	2.03%		
Alkalies (by difference)	0.11%		
Total	**100**		

INTEGRATED UNIT OPERATION & EFFICIENCY

The units are designed to run at base load in safe and efficient manner through a Microprocessor based Distributed Digital Control and Monitoring Information System (DCS) as detailed at Annex. 2.2. Control of both units shall be through a common control room.

The units are expected to display lowest possible Turbine heat rate of the order of 1950 kCal/ kWh and Unit Heat Rate of the order of 2300 kcal/kWh

Heat balance diagrams in various operating conditions at various CW inlet temperature conditions shall be provided at the time of detailed engineering. The overall Power Cycle envisaged in the Heat balance and Optimization study shall be as per diagram no ANP-B – FIG 01

HEAT / ENERGY BALANCES, HBD/ PI DIAGRAMS FOR 500 MW UNIT- ANPARA B TPS FOLLOW

CHAPTER – 8

PROGRESS REPORTS, SOE & UC SUBMITTED TO CPRI

Updated Report for the *Quarter JAN - MAR* **year** *2021*

(Up to Date of submission of PCR)

PROJECT DETAILS

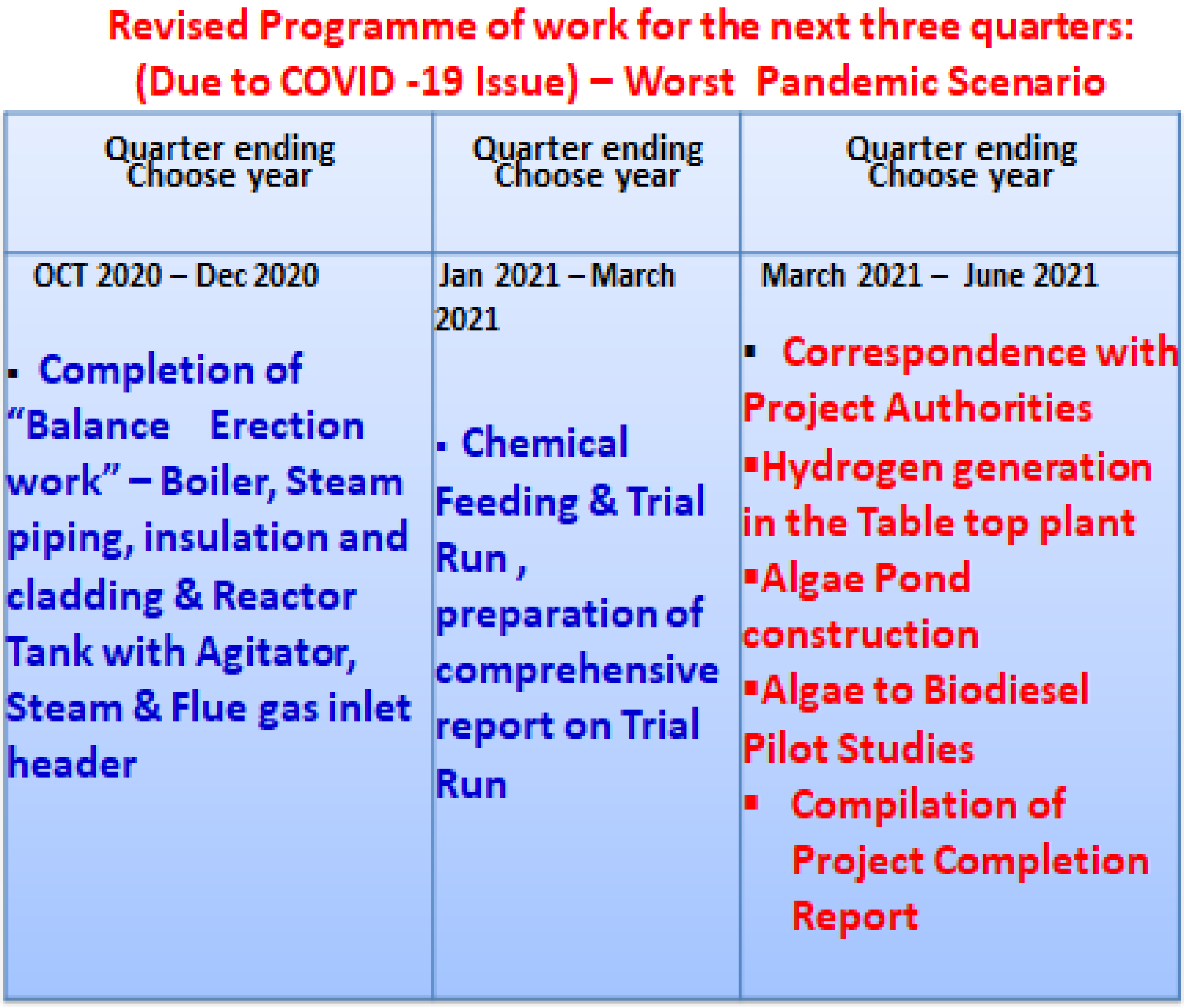
SL No	Particulars	Details / Information
1	**Project Title:**	
	Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant – Feasibility Study	
2	**a) Name of PI and Dept. where the project is implemented**	**Dr. V K Sethi, Director General Research RKDF University, Gandhi Nagar Bhopal and RGPV (The State Technological University of Madhya Pradesh), Bhopal**
	b) Details of PhD candidates / RA / SRF / JRF / Consultants / Temporary Staff involved in the project	**Post-Doctoral candidate Dr. Ravi S Pippal** Boiler Operator: Virendra K Mishra & Chemical Plant Operator: GaurvaVerma Staff: Mr. Manjur Ali, Technician, Anil, Helper
3	**Name of the Research Station/ Institute/Organization& Place**	Integrated Interdisciplinary Research Center, R&D Group, RKDF University
5	**CPRI Codes:**	
	a) R&D Management Code no	Click here to enter text.
	b) Accounts Code no	
	c) FAS (H.O) Project ID	
6	**Schedule of the project:**	
	a) Month & Year of project sanction	6 February 2019
	b) Date of commencement of the Project	1 April 2019
	c) Scheduled date of completion	31 March 2021
	d) Project extension date (If any)	NA
	e) Duration (Years)	Two years
7	**Project outlay (*Rs Lakhs*)**	**Rs. 38.50 Lacs (CPRI Grant 35 Lacs + 3.50 Lacs for Management & University Equity Rs. 15.00 Lacs)**
8	**Aim / Objectives of the Project (*State the scope of investigation / research*):**	
	• To provide a potential ground under aegis of MOP for developing and demonstrating feasibility of Sustainable Clean Coal Thermal Power Plants equipped with Carbon Capture & Sequestration Technology. • Exploring options for reducing energy penalty through solar thermal and other options: o Process optimization leading to improved design of MEA Solvent reactors, System optimization studies. o Design & Engineering - Data Acquisition System & Instrumentation o Pilot study of CO_2 sequestration to a simulated coal seam in the used coal mines &Pilot study of CO_2 Sequestration to Algae pond for production of Bio-diesel	

PROGRESS ACHIEVED

SL No	Particulars	Details / Information
1	**Cumulative progress of work planned (*as per the proposal*) & work achieved up to the previous quarter (in percentage):**	
	Quarter1& 2: Design & Engineering completed, Tendering process initiated as per final drawings and Plant operation Procedure finalized - *Progress report submitted (Q1 : March 2019 & Q2 : April to June 2019)* **Quarter 3:** Pilot Plant Erection site preparation activities at University Site for plant testing using coal fired boiler- – *Progress report submitted (Q3: July to Sept. 2019)* **Quarter4:** Plant Erection Work 90% Completed – *Progress report submitted (Q4: October to Dec 2019)* **Quarter 5:***(Q5: Jan to March 2020)*Revised Project schedule based on COVID-19 conditions & Resolution of Issues related to selection of Site Power Plants for CCS Plant Installation. Order placed for Supply of Boiler for Flue gas production and Steam generation to be incorporated with the CCS Plant at site ***(NOTE: No Activities from <u>April to June 2020</u> due to lock-down – This 'Period' is considered Null & Void)*** **Quarter 6:** *(Q6: July to September 2020)* Balance erection works of the CCS Plant and incorporation of Flue gas / Steam generator (A Coal Fired Boiler) completed by September 2020 end. **Details are as per progress report of Q-6, July to September 2020.** **Quarter 7:** *(Q7: October to December 2020)* Balance erection works related to modification required for integration with Coal fired Boiler with CCS Plant completed in October 2020. Incorporation of Flue gas / Steam generator (The Coal Fired Boiler) together with installation of Combustion Gas Analyzers, Instrumentation and Trial Run Data Acquisition system completed by October 2020 end. The up to date UC & Expenditure detail (Formats nos. 4& 6 RSOP) for the quarter October to December 2020 submitted. **Quarter 8:** ***(Q8: Jan 2021 March 31, 2021 & Beyond)*** **TRIAL RUN of 30 Days completed in Feb 2021 end. Several Modifications were done as detailed in the Project Report at <u>Chapter 4</u> of this PCR. It is noted that the CO2 Capture efficiency of MEA Solvent has been calculated to lie in between 78.34 % to 80.50% and release rate of CO2 from the Reactor is of the order of 19-20%. The operating Instructions of the plant and safety aspects of handling chemicals etc. are also given at <u>Chapter 4</u>.** Due to Lock down in April & May 2021, no project activities except following are being performed:[1[Construction of Algae Pond [2] Provision of SCADA & DAS [3] PCR Compilation	

<table>
<tr><td rowspan="2">2</td><td>Progress of the work carried out during the quarter (Physical Progress):</td></tr>
<tr><td>All balance modification works related to integration with coal fired boiler of the CCS Plant completed. Boiler erection and testing also completed as per procedure given at Chapter 4.1. Thirty day’s trial Run as per contract of the CCS plant, stated on 11 Nov 2020 and completed in Feb 2021.</td></tr>
<tr><td rowspan="2">3</td><td>Progress of the work carried out during the quarter (Technical Progress):</td></tr>
<tr><td>Modification works of Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant Project at RKDF University along with the associated Coal Fired Boiler has been completed on 31 October 2020 and the plant has undergone almost 2 months trial run.
NOTE: The Final trial operations in Jan to March 2021 using associated coal fired boiler was also witnessed by a review committee as per MOM dated March 01, 2021 including PI, CO-PIs and members from BHEL & Government of MP so as to enable them to discuss outcome of trial run results and decide for feasibility of CCS plant on a large TPS. Accordingly letters have been issued to NTPC (NETRA) & UP / MP Power Generation Cos.</td></tr>
<tr><td rowspan="2">4</td><td>Cumulative achievement up to the present quarter in percentage (attach bar chart of activity planned as per original proposal and actual achievement as an Annexure):</td></tr>
<tr><td>As per attached Bar Chart (Revised due to PANDEMIC)</td></tr>
<tr><td rowspan="2">5</td><td>Slippage and reasons for slippage in progress of project:</td></tr>
<tr><td>No Activities from April to June 2020 due to lock-down – This ‘Period’ may be considered as Null & Void</td></tr>
<tr><td rowspan="2">6</td><td>Proposed remedial action to overcome slippage in subsequent quarters:</td></tr>
<tr><td>Testing & Commissioning shall be accelerated in high solar flux period and installation of SCADA System along with Data Acquisition System from March to May 2021</td></tr>
<tr><td>7</td><td>Revised Program of work for the next three quarters:
(<i>If different from the Original proposal</i>) : As per page 2 of ENCL : 06
<table>
<tr><th>Quarter ending
<i>Choose year</i></th><th>Quarter ending
<i>Choose year</i></th><th>Quarter ending
<i>Choose year</i></th></tr>
<tr><td>December 2020</td><td>March 2021</td><td>June 2021 - Online Monitoring and discussion with Project authorities for installation at selected Power Plant</td></tr>
</table></td></tr>
<tr><td rowspan="2">8</td><td>Details of Papers Published (<i>Specify title</i>) /Seminars and Workshop conducted/attended (<i>Please enclose copy of publications</i>) (prior intimation :</td></tr>
<tr><td>Only on-line events conducted due to COVID issue like On-line lectures to M Tech (Thermal) & On-line address in the Climate change conferences (University & State level). List of Paper Publication and Patent is as per forthcoming Chapter 9</td></tr>
</table>

** Kindly furnish details of papers proposed before submission and forward soft as well as hard copies of paper to CPRI



Revised Programme of work for the next three quarters: (Due to COVID -19 Issue) – Worst Pandemic Scenario

Quarter ending Choose year	Quarter ending Choose year	Quarter ending Choose year
OCT 2020 – Dec 2020	Jan 2021 – March 2021	March 2021 – June 2021
▪ Completion of "Balance Erection work" – Boiler, Steam piping, insulation and cladding & Reactor Tank with Agitator, Steam & Flue gas inlet header	▪ Chemical Feeding & Trial Run , preparation of comprehensive report on Trial Run	▪ Correspondence with Project Authorities ▪Hydrogen generation in the Table top plant ▪Algae Pond construction ▪Algae to Biodiesel Pilot Studies ▪ Compilation of Project Completion Report

Letter/ Office Order No	Actual Transaction	Amount	Scheme Code - Scheme Name
dg9r0/project/ccs/cpri/2020-21/pfms	3/31/2021 0:00	12000	CENTRAL POWER RESEARCH INSTITUTE
dg9r0/project/cpri/ccs/2020-21/helper	3/31/2021 0:00	1500	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/project/ccs/2020-21/account	3/31/2021 0:00	10000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/project/cpri/ccs/2020-21/technician1	3/31/2021 0:00	3000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/project/rkdf/ccs/SCADA/2021	3/22/2021 0:00	97500	CENTRAL POWER RESEARCH INSTITUTE
dg(R)/cpri/project/contigency/2021	3/22/2021 0:00	30000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/project/cpri/uc-soe 2021	3/8/2021 0:00	10000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/project/manpower helper	3/8/2021 0:00	3000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/project/manpower(technician)/2021	3/6/2021 0:00	6000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/Project/Sunrise CSP/Trail Run /2020-21	3/1/2021 0:00	310000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/Project/Installation Accessories	2/16/2021 0:00	12000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS PROJECT/FLUE GAS GENERATOR/2020-21	2/10/2021 0:00	50000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/project/ccs/cpri/2020-21/03	12/7/2020 0:00	23900	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/contigency/2020-21	11/26/2020 0:00	39170	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/Project/CCS/CPRI/2020-21	12/7/2020 0:00	34392	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CCS/CPRI/Boiler/Coal	11/3/2020 0:00	50000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/ccs/project/pfms/sept 2020	9/22/2020 0:00	6000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/ccs/project/audit-account/2020	9/22/2020 0:00	10000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/bpiler/ccs/project/2020	9/22/2020 0:00	48990	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/PROJECT/CCS/CPRI/2020/SUNRISE	9/19/2020 0:00	280000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/2020-21/contingent expenditure/Aug	9/3/2020 0:00	60000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Boiler/Civil works/PFMS/2020-21	8/17/2020 0:00	10000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/ccs/2020-21/II Inst./BOILER AUX	8/14/2020 0:00	200600	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Manpower/ Plumber	11/30/2020 0:00	9000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Manpower/PFMS/2020-21	8/10/2020 0:00	12000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Manpower/JRF/2020-21	8/10/2020 0:00	25300	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Manpower/PLUMBER/TECHNICIAN/2020-21	8/10/2020 0:00	12000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/2020-21/II INST/AUG 22020	8/17/2020 0:00	420000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/CHEMICALS/CONSUMABLES /2020-21	8/17/2020 0:00	100000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/RKDF/CPRI/CCS project 2019-20	3/10/2020 0:00	2709	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/project/cpri/2019/salary/nov	12/5/2019 0:00	5000	CENTRAL POWER RESEARCH INSTITUTE

DG(R)/RKDF/CPRI/CIVIL WORK 2/NOV 2019	11/13/2019 0:00	10000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/RKDF/Project/CCS/OCT/-JRF	11/1/2019 0:00	20000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/RKDF/Project/ccs/oct/02-tech	11/1/2019 0:00	5000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/RKDF/CCS-Project/tour/04	10/23/2019 0:00	6000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/ CPRI/ Project-CCS/tour/ Oct/ 1	10/22/2019 0:00	14816	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/Project-CCS/ Tour/ Oct/2	10/22/2019 0:00	12510	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/Project-CCS/ Tour/Oct/3	10/22/2019 0:00	2800	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/RKDF/PROJECT/CPRI/CIVIL-SHAHZAD/2019-20	10/4/2019 0:00	30000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/RKDF/PROJECT/CPRI	10/3/2019 0:00	4800	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/RKDF/PROJECT/CPRI/2019-20	10/3/2019 0:00	9500	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/PROJECT/2019-20/salary	9/2/2019 0:00	17500	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/Project/2019-20/SalaryPT	9/2/2019 0:00	3000	CENTRAL POWER RESEARCH INSTITUTE
DGR/RKDF/Grasim/Tour/2019-20	8/29/2019 0:00	5985	CENTRAL POWER RESEARCH INSTITUTE
DG/RKDF/CPRI/AUG/2019-20/STIPEND	8/2/2019 0:00	20000	CENTRAL POWER RESEARCH INSTITUTE
DG/RKDF/CPRI/2019-20/TOUR	8/2/2019 0:00	4380	CENTRAL POWER RESEARCH INSTITUTE
493/vc/rkdf/2019-20	7/1/2019 0:00	20000	CENTRAL POWER RESEARCH INSTITUTE
VC/CPRI/CCS/2009-20/02	6/12/2019 0:00	6000	CENTRAL POWER RESEARCH INSTITUTE
481/VC/RKDF/CPRI/CCS/2019-20	6/8/2019 0:00	1200000	CENTRAL POWER RESEARCH INSTITUTE
		3286352	

Form No: CPRI/PM/R&D/RSOP/F-6 **Rev: 00** **Dated: 08/12/2017**

RESEARCH SCHEME ON POWER (RSOP)

UTILIZATION CERTIFICATE (UC)

Report for the *Quarter JAN - MAR* **year** *2021 (Up to March 31, 2021)*

SL No	Particulars	Details / Information
1	**Project Title :**	
	Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant – Feasibility Study	
2	**Name of the Research Station / Institute / Organization & Place**	RKDF University, Airport Bypass Road , Near RGPV, Gandhi Nagar, Bhopal 462033& RGPV (The State Technological University of Madhya Pradesh)
3	**Principal Project Coordinator**	Dr. V K Sethi , Ex. VC & DG (research) RKDF University
4	**CPRI Codes:**	
	a) R&D Management Code no	
	b) Accounts Code no	
	c) FAS (H.O) Project ID	
5	**Project Outlay (*Rs Lakhs*)**	Rs. 38.50 Lacs (CPRI Grant 35 Lacs + 3.50 Lacs for Management & University Equity Rs. 15.00 Lacs)
6	**Schedule of the project:**	
	a) Month & Year of project sanction	6 February 2019
	b) Date of commencement of the Project	5 March 2019
	c) Scheduled date of completion	31 March 2021
	d) Project extension date (If any)	30 June 2021
	e) Duration (Years)	Two years

7 **Year wise allocation of grant (*Rs Lakhs*):**

First Year	Second Year	Third Year
14.00	21.00	-

8 **FINANCIAL PROGRESS:**

a) Grants received from CPRI (Rs Lakhs):

Installment	Date	For the Financial year			Total
		2019-20	*2020-21*	***	
I	*17-12-2018*	*14.00*			
II	*04-08-2020*		*21.00*		
III	-	-	-		
IV	-	-	-		

b) ***Utilization of Grants:***

SL No	Nature of Expenditure	For the Financial year(*Rs.*)			Cumulative (Rs Lakhs) Round off
		2019-20	*2020-21 (up to 8th march 2021)*	*Total Rs.*	
1	*Establishment Expenditure (Fellowship / Salary of temporary staff)*	*1,10,800*	*1,83,800*	*2,94,600*	*2.946 Lacs*
2	*Travel expenditure*	*46,491*	-	*46,491*	*0.465 Lacs*
3	*Capital Equipment / Accessories+ Consumable (MEA- Solvent)*	*12,00,000*	*15,15,382*	*27,15,382*	*27.153 Lacs*
4	*Testing / Consultancy*	-	-		

	5	*Miscellaneous(Test bed foundation + Minor Civil Works+ Audit and A/C)*	*42,709*	*1,87,170*	*2,29,879*	*2.30Lacs*
	6	*TOTAL*	*14,00,000*	*18,86,352*	*32,86,352*	*32.864 Lacs*
	***** Appropriate Financial years may be mentioned**					

9. Certificate from Organization / Institution:-

(a) Certified that out of **Rs. 21.00 Lacs** of grant-in-aid sanctioned during the year **2020-21** and Rs. **NIL** on account of unspent balance of the previous year, a sum of **Rs. 18.864 Lacs** have been utilized and that balance of Rs. **2.136 Lacs** remaining unutilized till 31 March 2021 has been carried forward for the remaining period of this quarter (year: 2021-22) up to June 30 2021. /**Balance 2.136 Lacs as on 31 March 2021**

(b) Certified that I have satisfied myself that the conditions on which the grants-in-aid was sanctioned have been duly fulfilled/are being fulfilled and that I have exercised necessary checks to see that the money was actually utilized for the purpose for which it was sanctioned.

(c) Quarterly Progress Report (QPR) for the corresponding quarter is enclosed.

Kindly strike off what is not applicable under point 9 (a).

Director General (Research)
RKDF University

Sethi 5.4.2021.

Signature of Principal Investigator

(*With designation*)
Date: 5-4-2021

Head of Accounts/Auditors

C.F.A.O.
R.K.D.F. University, Bhopal

(*With seal*)

5.4.2021

Signature of HOD / Head of the Institution / Organization
(*With Official Designation and Seal*)
Date:

Vice Chancellor
RKDF University
Airport Bypass Road,Gandhi Nagar
BHOPAL (M.P.) 462033

EXPENDITURE REPORT OF RSOP PROJECT

(To accompany QPR)

Expenditure Report of Research Project for the Quarter Ending March 2021

(Jan to March 31, 2021) FY: 2020-21 **(Attach separate sheet for each project)**

SL No	Particulars	Details / Information
1	**Project Title:** Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant – Feasibility Study	
2	Name of the Research Station / Institute / Organization & Place	**RKDF University, Airport Bypass Road , Near RGPV, Gandhi Nagar, Bhopal 462033 & RGPV (The State Technological University of Madhya Pradesh)**
4	Project outlay (*Rs Lakhs*)	**Rs. 35.00 Lacs (GRANT to RKDF) + Rs. 3.5 Lacs (To CPRI for Monitoring**
5	**Schedule of project:**	
	a) Month & Year of project sanction	**Feb 2019**
	b) Date of commencement of the Project	**March 5, 2019**
	c) Scheduled date of completion	**March 31, 2021, (Revised to March 2021 due to COVID ISSUE)**
	d) Project extension date (If any)	**30 June 2021**
	e) Duration (Years)	**1.5 years (Revised to 2.5 years due to COVID – 19)**
6	**Name of the Officers and Staff associated with the project (*Indicate change of personnel if applicable*)** PDF Fellow: Dr. Ravi S Pippal, Staff: Mr. Manjur Ali, Technician, Mr. Anil (Helper), Mr. Tej Singh, Boiler Operator & Mr. Gaurva Verma, Chemical Plant Operator	

7

Expenditure incurred till March 8, 2021: Rs. 14,00,000 + Rs. 17,32,352 = Rs.31,32,352

(a) Expenditure Plan for 8th March 2021 to 31st March 2021: GRANT RECEIVED Rs. 35,00,000

Recurring Expenditure (Rs)	*Non-recurring Expenditure (Rs)*	*Total (Rs)*
50,000	**1,00,000**	**1,50,000**

(b) Expenditure during the Quarter Jan 1,2021 to Mar 8, 2021: Refer ENCL (UC Attached)

Recurring Expenditure (Rs)	*Non-recurring Expenditure (Rs)*	*Total (Rs)*
(8-31 MARCH) **16,500**	(8-31 MARCH) **1,37,500**	**1,54,000**

(c) Cumulative Expenditure up to March 31,2021

TOTAL EXPENDITURE : 31,32,352+1,54,000 = 32,86,352

TOTAL GRANT RECEIVED: 35,00,000 *(Balance= Rs. 2,13,648)*

8 **Details of other Organizations (*if any*) associated with this project**

RGPV, The State Technological University of Madhya Pradesh (Govt. of MP) as co-investigators (CO-PIs)

5/4/2021

Name and Signature of the Principal Investigator (*With Designation*)

Director General (Research)
RKDF University

Form No: CPRI/PM/R&D/RSOP/F-6 **Rev: 00** **Dated: 08/12/2017**

RESEARCH SCHEME ON POWER (RSOP)

UTILIZATION CERTIFICATE (UC)

Report for the *Quarter JAN - MAR* **year** *2021 (Up to March 8, 2021)*

SL No	Particulars	Details / Information
1	**Project Title :**	
	Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant - Feasibility Study	
2	**Name of the Research Station / Institute / Organization & Place**	RKDF University, Airport Bypass Road , Near RGPV, Gandhi Nagar, Bhopal 462033& RGPV (The State Technological University of Madhya Pradesh)
3	**Principal Project Coordinator**	Dr. V K Sethi , Ex. VC & DG (research) RKDF University
4	**CPRI Codes:**	
	a) R&D Management Code no	
	b) Accounts Code no	
	c) FAS (H.O) Project ID	
5	**Project Outlay (*Rs Lakhs*)**	Rs. 38.50 Lacs (CPRI Grant 35 Lacs + 3.50 Lacs for Management & University Equity Rs. 15.00 Lacs)
6	**Schedule of the project:**	
	a) Month & Year of project sanction	6 February 2019
	b) Date of commencement of the Project	5 March 2019
	c) Scheduled date of completion	31 March 2021
	d) Project extension date (If any)	NA
	e) Duration (Years)	Two years
7	**Year wise allocation of grant (*Rs Lakhs*):**	

First Year	Second Year	Third Year
14.00	21.00	-

8 FINANCIAL PROGRESS:

a) Grants received from CPRI (Rs Lakhs):

Installment	Date	For the Financial year			Total
		2019-20	*2020-21*	***	
I	*17-12-2018*	*14.00*			
II	*04-08-2020*		*21.00*		
III	-	-	-		
IV	-	-	-		

b) ***Utilization of Grants:***

SL No	Nature of Expenditure	For the Financial year(*Rs.*)			Cumulative (Rs Lakhs) Round off
		2019-20	*2020-21 (up to 8th march 2021)*	*Total Rs.*	
1	*Establishment Expenditure (Fellowship / Salary of temporary staff)*	*1,10,800*	*1,67,300*	*2,78,100*	*2.781 Lacs*
2	*Travel expenditure*	*46,491*	-	*46,491*	*0.465 Lacs*
3	*Capital Equipment / Accessories+ Consumable (MEA- Solvent)*	*12,00,000*	*14,17,882*	*26,17,882*	*26.179 Lacs*
4	*Testing / Consultancy*	-	-		

	5	*Miscellaneous(Test bed foundation + Minor Civil Works+ Audit and A/C)*	*42,709*	*1,47,170*	*1,89,879*	*1.899Lacs*
	6	*TOTAL*	*14,00,000*	*17,32,352*	*31,32,352*	*31.324 Lacs*
	***** Appropriate Financial years may be mentioned**					

9. Certificate from Organization / Institution:-

(a) Certified that out of **Rs. 21.00 Lacs** of grant-in-aid sanctioned during the year **2020-21** and Rs. **NIL** on account of unspent balance of the previous year, a sum of **Rs. 17.32352 Lacs** have been utilized and that balance of Rs. **3.67648 Lacs** remaining unutilized till 8th march 2021 has been carried forward for the remaining period of this quarter (year: 2020-21). **/Balance 3.67648 Lacs as on 8 March 2021**

(b) Certified that I have satisfied myself that the conditions on which the grants-in-aid was sanctioned have been duly fulfilled/are being fulfilled and that I have exercised necessary checks to see that the money was actually utilized for the purpose for which it was sanctioned.

(c) Quarterly Progress Report (QPR) for the corresponding quarter is enclosed.

Kindly strike off what is not applicable under point 9 (a).

8. 3. 2021

Signature of Principal Investigator

Director General (Research)
RKDF University

DG(Research)

(With designation)

Date: 8- 3 - 2021

8.3.2021

Head of Accounts/Auditors

C.F.A.O.
R.K.D.F. University, Bhopal

(With seal)

8 · 3 · 2021

Signature of HOD / Head of the Institution / Organization

(With Official Designation and Seal)

Date:

Vice Chancellor
RKDF University
Airport Bypass Road,Gandhi Nagar
BHOPAL (M.P.) 462033

Letter/ Office Order No	Actual Transaction Date	Payment Advice No	Amount	Scheme Code - Scheme Name
dg(r)/project/cpri/uc-soe 2021	3/8/2021 0:00	C032107985267	10000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/project/manpower helper	3/8/2021 0:00	C032107992488	3000	CENTRAL POWER RESEARCH INSTITUTE
DG(r)/cpri/project/manpower/2021	3/8/2021 0:00	C032107998405	6000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/Project/Sunrise CSP/Trail Run /2020-21	3/1/2021 0:00	C022129871312	310000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/Project/Installation Accessories	2/16/2021 0:00	C022122483975	12000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS PROJECT/FLUE GAS GENERATOR/2020-21	2/10/2021 0:00	C022114631460	50000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/project/ccs/cpri/2020-21/03	12/7/2020 0:00	C122008457406	23900	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/contigency/2020-21	11/26/2020 0:00	C112036857605	39170	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/Project/CCS/CPRI/2020-21	12/7/2020 0:00	C122008444088	34392	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CCS/CPRI/Boiler/Coal	11/3/2020 0:00	C112042336237	50000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/ccs/project/pfms/sept 2020	9/22/2020 0:00	C092037603374	6000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/ccs/project/audit-account/2020	9/22/2020 0:00	C092037603877	10000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/bpiler/ccs/project/2020	9/22/2020 0:00	C092037609104	48990	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/PROJECT/CCS/CPRI/2020/SUNRISE	9/19/2020 0:00	C092022147277	280000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/2020-21/contingent expenditure/Aug	9/3/2020 0:00	C082034921774	60000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Boiler/Civil works/PFMS/2020-21	8/17/2020 0:00	C082010178935	10000	CENTRAL POWER RESEARCH INSTITUTE
dg(r)/cpri/ccs/2020-21/II Inst./BOILER AUX	8/14/2020 0:00	C082001624694	200600	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Manpower/ Plumber	11/30/2020 0:00	C112042334054	9000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Manpower/PFMS/2020-21	8/10/2020 0:00	C082001361517	12000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Manpower/JRF/2020-21	8/10/2020 0:00	C082001362227	25300	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/Manpower/PLUMBER/TECHNICIAN/2020-21	8/10/2020 0:00	C082001364122	12000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/2020-21/II INST/AUG 22020	8/17/2020 0:00	C082001365045	420000	CENTRAL POWER RESEARCH INSTITUTE
DG(R)/CPRI/CCS/CHEMICALS/CONSUMABLES/2020-21	8/17/2020 0:00	C082001365652	100000	CENTRAL POWER RESEARCH INSTITUTE
			1732352	

Director General (Research)
RKDF University

EXPENDITURE REPORT OF RSOP PROJECT

(To accompany QPR)

Expenditure Report of Research Project for the Quarter Ending December 2020

(Jan to March 8, 2021) FY: 2020-21 **(Attach separate sheet for each project)**

NOTE: REPORT FOR THE QUARTER APRIL – JUNE 2020 IS NIL DUE TO LOCK DOWN & NO ACTIVITIES ON PROJECT

<table>
<tr><th>SL No</th><th>Particulars</th><th>Details / Information</th></tr>
<tr><td>1</td><td colspan="2">Project Title:
Post Combustion Carbon Capture & sequestration (CCS) Plant on a Coal Fired Thermal Power Plant – Feasibility Study</td></tr>
<tr><td>2</td><td>Name of the Research Station / Institute / Organization & Place</td><td>RKDF University, Airport Bypass Road , Near RGPV, Gandhi Nagar, Bhopal 462033 & RGPV (The State Technological University of Madhya Pradesh)</td></tr>
<tr><td>4</td><td>Project outlay (<i>Rs Lakhs</i>)</td><td>Rs. 35.00 Lacs (GRANT to RKDF) + Rs. 3.5 Lacs (To CPRI for Monitoring</td></tr>
<tr><td rowspan="6">5</td><td colspan="2">Schedule of project:</td></tr>
<tr><td><i>a) Month & Year of project sanction</i></td><td>Feb 2019</td></tr>
<tr><td><i>b) Date of commencement of the Project</i></td><td>March 5, 2019</td></tr>
<tr><td><i>c) Scheduled date of completion</i></td><td>March 31, 2021, (Revised to March 2021 due to COVID ISSUE)</td></tr>
<tr><td><i>d) Project extension date (If any)</i></td><td>September 2020 to March 2021 (6 months)</td></tr>
<tr><td><i>e) Duration (Years)</i></td><td>1.5 years (Revised to 2 years due to COVID – 19)</td></tr>
<tr><td rowspan="2">6</td><td colspan="2">Name of the Officers and Staff associated with the project (<i>Indicate change of personnel if applicable</i>)</td></tr>
<tr><td colspan="2">PDF Fellow: Dr. Ravi S Pippal, Staff: Mr. Manjur Ali, Technician, Mr. Anil (Helper), Mr. Tej Singh, Boiler Operator & Mr. Gaurva Verma, Chemical Plant Operator</td></tr>
<tr><td rowspan="2">7</td><td colspan="2">Expenditure incurred till Dec 2020: Rs. 14,00,000 + Rs. 13,41,352 = Rs. 27,41,352</td></tr>
<tr><td colspan="2">(a) Expenditure Plan for 8th March 2021 to 31st March 2021: GRANT RECEIVED Rs. 35,00,000
<table>
<tr><th><i>Recurring Expenditure (Rs)</i></th><th><i>Non-recurring Expenditure (Rs)</i></th><th><i>Total (Rs)</i></th></tr>
<tr><td>50,000</td><td>3,10,000</td><td>3,60,000</td></tr>
</table>
(b) Expenditure during the Quarter Jan 1,2021 to Mar 8, 2021: Refer ENCL (UC Attached)
<table>
<tr><th><i>Recurring Expenditure (Rs)</i></th><th><i>Non-recurring Expenditure (Rs)</i></th><th><i>Total (Rs)</i></th></tr>
<tr><td>31,000</td><td>3,60,000</td><td>3,91,000</td></tr>
</table>
(c) Cumulative Expenditure up to March 8,2021
TOTAL EXPENDITURE : 27,41,352+ 3,91,000 = 31,32,352
TOTAL GRANT RECEIVED: 35,00,000 <i>(Balance= Rs. 3,67,648)</i></td></tr>
<tr><td rowspan="2">8</td><td colspan="2">Details of other Organizations (<i>if any</i>) associated with this project</td></tr>
<tr><td colspan="2">RGPV, The State Technological University of Madhya Pradesh (Govt. of MP) as co-investigators (CO-PIs)</td></tr>
<tr><td></td><td colspan="2"></td></tr>
</table>

8/3/2021

Name and Signature of the Principal Investigator (*With Designation*)

Director General (Research)
RKDF University

CHAPTER – 9

PUBLICATIONS & PATENTS

CHAPTER -9: LIST OF PAPERS PRESENTED & PUBLISHED DURING PROJECT PERIOD & PERTAINING TO SOLAR THERMAL & CARBON CAPTURE & SEQUESTRATION BY THE PI

			If paper is presented			If the paper is published					
Sl. NO.	Paper title	Authors	Name of the Conference where presented	Venue of the Conference where presented	Date of the Conference where presented	If published, the name of the Journal	Issue no. of the Journal	Volume No. of the Journal	Page no. in the Journal	Month & Year of the Journal	Whether the paper is National Paper or International Paper
1.	**CHAPTER TITLE: An Innovative Approach in Post Combustion Carbon Capture and Sequestration towards Reduction of Energy Penalty in Regeneration of Solvent**	**Dr. V K Sethi & Dr. Partha S Dutta**	-	-	-	**OPEN SOURCE BOOK INTEC OPEN BOOK TITLE: Carbon Capture, Utilization and Sequestration**	**http:/dx.doi.org/10.5772/ intechopen.73109** **Print ISBN 978-1-78923-764-1** **Online ISBN 978-1-78923-765-8**			**April 2019**	**OPEN- SOURCE INTERNATIONAL BOOK CHAPTER (SOLAR THERMAL APPLICATION)**

2.	**Strategies & Challenges in Implementation of Next-Gen Solar Thermal Plants in India Coupled with 24x7 Thermal Storage**	**Dr. V K Sethi**	-	-	-	**IAPE'19, Oxford UK**	**http:/dx.doi.org / 10.17501** **ISBN : 987-1-912532-05-6**	**April 2019**	**Proc. Of International Conference "IAPE'19" OXFORD UK**
3	**Study On Future of Solar Thermal Storage System Using Concentrated Solar Power**	**Anil Kumar , V K Sethi , Suresh Ku Soni Sachin Tiwari**					**International Journal of Innovative Engineering Research (E-ISSN: 2349-882X) Vol 1, Issue 6,**	**June 2020**	
4	**Solar Thermal Plants coupled with a Thermal Storage- a Review of Thermal Storage options.**	**Anil Kumar & Vinod Krishna Sethi**	**International Conference on Energy, Environment and Economics, ICEEE Edinburgh UK**	**Edinburgh UK**	***14-16 August 2018,***			**Aug 2019**	**Proc. Of ICEEE, Edinburgh, UK**

5.	An Innovative Approach for Carbon Capture & Sequestration on a Thermal Power Plant through Conversion to Multi-Purpose Fuels – A Feasibility Study in Indian Context	Vinod Krishna Sethi, Savita Vyas	13th International Conference on Greenhouse Gas Control Technologies, GHGT-13	Lausanne Swtzerland	14-18 Nov 2016					2018	Science Direct Energy Procedia 2017
6.	A Pilot Study of Post Combustion Carbon Capture & Sequestration Pilot Plant aimed at Feasibility Analysis of Installation of a Carbon Capture, Utilization and Sequestration (CCUS) Plant on a Large Thermal Unit in India.,	Dr. Vinod Krishna Sethi, Partha S Dutta & Savita Vyas	14th International Conference on Greenhouse Gas Control Technologies, GHGT- 14	Melbourne, Australia-	21st - 25th October, Published by ELSEVIER , April 2019					2019	Science Direct Energy Procedia 2018 Proc. Of GHGT-14
7	Energy Storage Technologies- An Overview	Anil Kumar, V K Sethi, Suresh Kumar Soni, Sachin Tiwari				International Journal of Science, Engineering and Technology Research	(IJSETR) Volume 9, Issue 5, May 2020, ISSN: 2278 - 7798			May 2020	

1	**PATENT APPLICAION** **(submitted in May 2020)** **As per Form 2 (39 of 1970) The Patent Rule 2003**	**1. Dr. V K Sethi (DG- Research / PI)** **2. Dr. Sadhna Kapoor (Chancellor RKDF University)** **3. Director / Scientist(D) (SOLAR R&D MNRE), New Delhi**	**A REACTOR FOR REDUCING ENERGY PENALTY IN A SOLAR THERMAL INTEGRATED CARBON CAPTURE PLANT WITH 24x7 ENERGY STORAGE**

LIST OF PAPERS PRESENTED & PUBLISHED DURING PROJECT PERIOD & PERTAINING TO R&D PROJECT SPONSORED BY CPRI TO RKDF UNIVERSITY

			If paper is presented			**If the paper is published**					
Sl. NO.	Paper title	Authors	Name of the Conference where presented	Venue of the Conference where presented	Date of the Conference where presented	If published, the name of the Journal	Issue no. of the Journal	Volume No. of the Journal	Page no. in the Journal	Month & Year of the Journal	Whether the paper is National Paper or International Paper
1.	**CHAPTER TITLE: An Innovative Approach in Post Combustion Carbon Capture and Sequestration towards Reduction of Energy Penalty in Regeneration of Solvent**	**Dr. V K Sethi & Dr. Partha S Dutta**	-	-	-	**OPEN SOURCE BOOK INTEC OPEN BOOK TITLE: Carbon Capture, Utilization and Sequestration**	**http:/dx.doi.org/10.5772/ intechopen.73109 Print ISBN 978-1-78923-764-1 Online ISBN 978-1-78923-765-8**			**April 2019**	**OPEN- SOURCE INTERNATIONAL BOOK CHAPTER**

2.	**Strategies & Challenges in Implementation of Next-Gen Solar Thermal Plants in India Coupled with 24x7 Thermal Storage**	**Dr. V K Sethi**	-	-	-	**IAPE'19, Oxford UK**	**http:/dx.doi.org / 10.17501** **ISBN : 987-1-912532-05-6**	**April 2019**	**Proc. Of International Conference "IAPE'19" OXFORD UK**
3	**Energy Storage Technologies- An Overview**	**Anil Kumar, V K Sethi, Sachin Tiwari, Prashant Mishra**	**2nd International Conference on "Contemporary Technological Solutions Towards Fulfilment of Social Needs"**	**RKDF University Bhopal** **(Sponsored by: MPUVNL & ECPO, Bhopal**	**28-29 Sept. 2019**				
4	**Study On Future of Solar Thermal Storage System Using Concentrated Solar Power**	**Anil Kumar , V K Sethi Suresh Ku Soni Sachin Tiwar**					**International Journal of Innovative Engineering Research (E-ISSN: 2349-882X) Vol 1, Issue 6,**	**June 2020**	
5	**Solar Thermal Plants coupled with a Thermal Storage- a Review**	**Anil Kumar & Vinod Krishna Sethi**	**International Conference on Energy, Environment and Economics, Edinburgh UK**	Edinburgh UK	***14-16 August 2018,***				

	of Thermal Storage options.										
6	**A Pilot Study of Post Combustion Carbon Capture & Sequestration Pilot Plant aimed at Feasibility Analysis of Installation of a Carbon Capture, Utilization and Sequestration (CCUS) Plant on a Large Thermal Unit in India.,**	**Dr. Vinod Krishna Sethi, Partha S Dutta & Savita Vyas**	**14th International Conference on Greenhouse Gas Control Technologies, GHGT- 14**	**Melbourne, Australia-**	**21st - 25th October, Published by ELSEVIER , April 2019**						

THE PUBLISHED PAPERS ARE ATTACHED BELOW AT ENCL: 03

CHAPTER – 10

PFMS SUMMARY & EQUITY

Chapter 10.1- PFMS SUMMARY (CAPITAL EXPENDITURE)

S. No.	RTGS (Details of Payment)	Amount in Rs.	Date	Cheque No	Remarks
1.	RTGS – UBI - PFMS	**12,00,000**	**11-6-2019**	**33021039**	**Advance payment as per contract PFMS –SUNRISE CSP (I) Pvt. Ltd. Baroda**
2.	UTR No. PUNB234510764039	**2,00,000**	**13-12-2019**	**3320880**	**Equity of RKDF for 2 Nos. Solar Discs – SUNRISE CSP (I) Baroda – Through PFMS Entry**
3.	UTR No. PUNB235911013861	**2,80,000**	**31-12-2019**	**3320881**	**Equity of RKDF for 2 Nos. Solar Discs – SUNRISE CSP (I) Baroda– Through PFMS Entry**
4.	RTGS – UBI - PFMS	**1,00,000**	**17-08-2020**	**33048795**	**PFMS–SUNRISE CSP (I) Pvt. Ltd. Baroda**
5.	RTGS – UBI - PFMS	**4,20,000**	**18-08-2020**	**33048796**	**PFMS–SUNRISE CSP (I) Pvt. Ltd. Baroda**
6.	RTGS – UBI - PFMS	**2,80,000**	**17-09-2020**	**33048803**	**PFMS–SUNRISE CSP (I) Pvt. Ltd. Baroda**
7.	RTGS – UBI - PFMS	**3,10,000**	**02-03-2021**	**33048825**	**PFMS–SUNRISE CSP (I) Pvt. Ltd. Baroda**
	TOTAL	**27,90,000**			**PFMS SUMMARY SHEET ATTACHED**

S. No.	RTGS (Details of Payment)	Amount in Rs.	Date	Cheque No	Remarks
1.	UTR No. PUNB234510764039	**2,00,000**	**12-12-2019**	**3320880**	**Equity for 2 Nos. Solar Discs – SUNRISE CSP (I) Baroda (Included in List A)**
2.	UTR No. PUNB235911013861	**2,80,000**	**26-12-2019**	**3320881**	**Equity for 2 Nos. Solar Discs – SUNRISE CSP (I) Baroda (Included in list – A)**
3.	Cheque No. 3320870 & 3320877	**40,000**	**7-10-2019 / 25-11-2019**	**3320870 & 3320877**	**Sehzad Khan for CCS Plant Foundation**
4.	CCS Project Contingency	**11,990**	**4-12-2020**	**876246**	**Contingent Expenditure in Trial Run & Commissioning from RKDF University Account**
5.	CCS Project Contingency	**15,000**	**5-12-2020**	**876247**	**Contingent Expenditure in Trial Run & Commissioning from RKDF University Account**
6.	CCS Project Contingency	**6,350**	**10-12-2020**	**8876265**	**Contingent Expenditure in Trial Run & Commissioning from RKDF University Account**
7.	CCS Project Contingency	**6545**	**18-12-2020**	**876330**	**DO**

8.	CCS Project Contingency	**28,346**	**19-1-2021**	**876573**	Salary to Project Staff – Boiler Operator & CCS Plant Operator Plus payment for piping, fittings, Tanks & Welding work
9.	CCS Project Contingency	**24,796**	**2-2-2020**	**876410**	**DO**
10.	CCS Project Contingency	**10,000**	**2-2-2020**	**876406**	**DO**
11.	CCS Project Contingency	**31,400**	**18-2-2021**	**844426**	**DO**
12.	CCS Project Contingency	**15,000**	**26-3-2021**	**919661**	Hotel Charges
	TOTAL (3 to 12)	**1,89, 427**			

13. List C: Salary of Mr. Pankaj Kumar Singh: 6000 + 20,000 + 20,000 + 9500 + 6000 = 61,500

+ Audit & Account Charges: @ Rs. 10,000 for QPR 1 to QPR 8 (31 -3-2021) = Rs. 80,000

TOTAL EQITY PAID : = Rs. 13.109 Lacs {Rs. 3,30,927 for testing & commissioning as per- Sl. No. 3-13, above + 2 SOLAR SCHEFFLER UNITS (Rs. 4.80 Lacs- Sl. No 1&2 above,) + BOILER COAL FIRED 250 kg/ hr. flue gas (Rs. 5, 00 Lacs – By STEAM THERM Boilers; Bhopal)}

APPENDIX – I: CCS PLANTS WORLD-WIDE

APPENDIX – II: HBD DIAGRAM: 500 MW UNIT AT ANPARA

ENCL- 01: FULL TEXT OF REFERENCE PAPERS – FOLDER

ENCL- 02: COPIES OF PROGRESS REPORTS - FOLDER

ENCL- 03: PUBLICATIONS & PATENT APPLICATION - FOLDER

COMMERCIAL FACILITIES IN OPERATION

FACILITY TITLE	STATUS	COUNTRY	OPERATION DATE	INDUSTRY	CAPTURE CAPACITY (Mtpa) (MAX)	CAPTURE TYPE	STORAGE TYPE
Terrell Natural Gas Processing Plant (formerly Val Verde Natural Gas Plants)	Operational	United States	1972	Natural gas processing	0.40	Industrial Separation	Enhanced Oil Recovery
Enid Fertilizer	Operational	United States	1982	Fertiliser production	0.20	Industrial Separation	Enhanced Oil Recovery
Shute Creek Gas Processing Plant	Operational	United States	1986	Natural gas processing	7.00	Industrial Separation	Enhanced Oil Recovery
Sleipner CO2 Storage	Operational	Norway	1996	Natural gas processing	1.00	Industrial Separation	Dedicated Geological Storage
Great Plains Synfuels Plant and Weyburn-Midale	Operational	United States	2000	Synthetic natural gas	3.00	Industrial Separation	Enhanced Oil Recovery
Core Energy CO2-EOR	Operational	United States	2003	Natural gas processing	0.35	Industrial Separation	Enhanced Oil Recovery
Sinopec Zhongyuan Carbon Capture Utilisation and Storage	Operational	China	2006	Chemical production	0.12	Industrial Separation	Enhanced Oil Recovery
Snøhvit CO2 Storage	Operational	Norway	2008	Natural gas processing	0.70	Industrial Separation	Dedicated Geological Storage
Arkalon CO2 Compression Facility	Operational	United States	2009	Ethanol production	0.29	Industrial Separation	Enhanced Oil Recovery
Century Plant	Operational	United States	2010	Natural gas processing	5.00	Industrial Separation	Enhanced Oil Recovery & Gelogical Storage
Bonanza BioEnergy CCUS EOR	Operational	United States	2012	Ethanol production	0.10	Industrial Separation	Enhanced Oil Recovery
PCS Nitrogen	Operational	United States	2013	Fertiliser production	0.30	Industrial Separation	Enhanced Oil Recovery
Petrobras Santos Basin Pre-Salt Oil Field CCS	Operational	Brazil	2013	Natural gas processing	4.60	Industrial Separation	Enhanced Oil Recovery
Lost Cabin Gas Plant	Operation suspended	United States	2013	Natural gas processing	0.90	Industrial Separation	Enhanced Oil Recovery
Coffeyville Gasification Plant	Operational	United States	2013	Fertiliser production	1.00	Industrial Separation	Enhanced Oil Recovery
Air Products Steam Methane Reformer	Operational	United States	2013	Hydrogen production	1.00	Industrial Separation	Enhanced Oil Recovery
Boundary Dam Carbon Capture and Storage	Operational	Canada	2014	Power generation	1.00	Post-combustion capture	Enhanced Oil Recovery
Uthmaniyah CO2-EOR Demonstration	Operational	Saudi Arabia	2015	Natural gas processing	0.80	Industrial Separation	Enhanced Oil Recovery
Quest	Operational	Canada	2015	Hydrogen Production Oil sands upgrading	1.20	Industrial Separation	Dedicated Geological Storage
Karamay Dunhua Oil Technology CCUS EOR	Operational	China	2015	Chemical production methanol	0.10	Industrial Separation	Enhanced Oil Recovery
Abu Dhabi CCS (Phase 1 being Emirates Steel Industries)	Operational	United Arab Emirates	2016	Iron and steel production	0.80	Industrial Separation	Enhanced Oil Recovery
Petra Nova Carbon Capture	Operation suspended	United States	2017	Power generation	1.40	Post-combustion capture	Enhanced Oil Recovery
Illinois Industrial Carbon Capture and Storage	Operational	United States	2017	Ethanol production – ethanol plant	1.00	Industrial Separation	Dedicated Geological Storage
CNPC Jilin Oil Field CO2 EOR	Operational	China	2018	Natural gas processing	0.60	Industrial Separation	Enhanced Oil Recovery
Gorgon Carbon Dioxide Injection	Operational	Australia	2019	Natural gas processing	4.00	Industrial Separation	Dedicated Geological Storage
Qatar LNG CCS	Operational	Qatar	2019	Natural gas processing	2.10	Industrial Separation	Dedicated Geological Storage
Alberta Carbon Trunk Line (ACTL) with Nutrien CO2 Stream	Operational	Canada	2020	Fertiliser production	0.30	Industrial Separation	Enhanced Oil Recovery
Alberta Carbon Trunk Line (ACTL) with North West Redwater Partnership's Sturgeon Refinery CO2 Stream	Operational	Canada	2020	Oil refining	1.40	Industrial Separation	Enhanced Oil Recovery

COMMERCIAL CCS FACILITIES IN CONSTRUCTION, ADVANCED AND EARLY DEVELOPMENT

FACILITY TITLE	STATUS	COUNTRY	OPERATION DATE	INDUSTRY	CAPTURE CAPACITY (Mtpa) (MAX)	CAPTURE TYPE	STORAGE TYPE
Yanchang Integrated Carbon Capture and Storage Demonstration	In Construction	China	Delayed to 2020s	Chemical production	0.41	Industrial Separation	Enhanced Oil Recovery
Sinopec Shengli Power Plant CCS	Early Development	China	2020s	Power generation	1.00	Post-combustion capture	Enhanced Oil Recovery
Acorn Scalable CCS Development	Early Development	United Kingdom	2020s	Oil Refining	4.00	Industrial Separation	Dedicated Geological Storage
Korea-CCS 1 & 2	Early Development	South Korea	2020s	Power generation coal-fired	1.00	Under evaluation	Dedicated Geological Storage
Sinopec Qilu Petrochemical CCS	In Construction	China	2020-2021	Chemical production	0.40	Industrial Separation	Enhanced Oil Recovery
Project Interseqt - Hereford Ethanol Plant	Early Development	United States	2021	Ethanol Production	0.30	Industrial Separation	Dedicated Geological Storage
Project Interseqt - Plainview Ethanol Plant	Early Development	United States	2021	Ethanol Production	0.33	Industrial Separation	Dedicated Geological Storage
Wabash CO2 Sequestration	Advanced Development	United States	2022	Fertiliser production	1.75	Industrial Separation	Dedicated Geological Storage
San Juan Generating Station Carbon Capture	Advanced Development	United States	2023	Power Generation	6.00	Post-combustion capture	Enhanced Oil Recovery
Santos Cooper Basin CCS Project	Advanced Development	Australia	2023	Natural Gas Processing	1.70	Industrial Separation	Dedicated Geological Storage
Fortum Oslo Varme - Langskip	Advanced Development	Norway	2023-2024	Waste-to-Energy	0.40	Post Combustion Capture	Dedicated Geological Storage
Brevik Norcem - Langskip	Advanced Development	Norway	2023-2024	Cement Production	0.40	Industrial Separation	Dedicated Geological Storage
Hydrogen 2 Magnum (H2M)	Early Development	The Netherlands	2024	Power Generation	2.00	Industrial Separation	Dedicated Geological Storage
Project Pouakai Hydrogen Production with CCS	Early Development	New Zealand	2024	Hydrogen Production and Power Generation	1.00	Industrial Separation	In evaluation
Caledonia Clean Energy	Early Development	United Kingdom	2024	Power generation with potential for co-production of Hydrogen for heat and transport applications	3.00	Post-combustion capture	Dedicated Geological Storage
Cal Capture	Advanced Development	United States	2024	Power Generation	1.40	Post-combustion capture	Enhanced Oil Recovery
Velocys' Bayou Fuels Negative Emission Project	Early Development	United States	2024	Chemical Production	0.50	Industrial Separation	Dedicated Geological Storage
OXY and Carbon Engineering Direct Air Capture and EOR Facility	Early Development	United States	Mid 2020s	Air	1.00	Industrial Separation	Enhanced Oil Recovery
LafargeHolcim Cement Carbon capture	Early Development	United States	Mid 2020s	Cement Production	0.72	Industrial Separation	In Evaluation
HyNet North West	Early Development	United Kingdom	Mid 2020s	Hydrogen Production	1.50	Industrial Separation	Dedicated Geological Storage
Gerald Gentleman Station Carbon Capture	Advanced Development	United States	Mid 2020s	Power Generation	3.80	Post-combustion capture	In Evaluation
Mustang Station of Golden Spread Electric Cooperative Carbon Capture	Advanced Development	United States	Mid 2020s	Power Generation	1.50	Post-combustion capture	In Evaluation
Prairie State Generating Station Carbon Capture	Advanced Development	United States	Mid 2020s	Power Generation	6.00	Post-combustion capture	Dedicated Geological Storage
Plant Daniel Carbon Capture	Advanced Development	United States	Mid 2020s	Power Generation	1.80	Post-combustion capture	Dedicated Geological Storage
Lake Charles Methanol	Advanced Development	United States	2025	Chemical production	4.00	Industrial Separation	Dedicated Geological Storage
Dry Fork Integrated Commercial Carbon Capture and Storage (CCS)	Early Development	United States	2025	Power Generation	3.00	Post-combustion capture	Dedicated Geological Storage
Net Zero Teesside - CCGT Facility	Early Development	United Kingdom	2025	Power Generation	6.00	Post-combustion capture	Dedicated Geological Storage
Abu Dhabi CCS Phase 2: Natural gas processing plant	Advanced Development	United Arab Emirates	2025	Natural Gas Processing	2.30	Industrial Separation	Enhanced Oil Recovery
Red Trail Energy BECCS Project	Early Development	United States	2025	Ethanol Production	0.18	Industrial Separation	Dedicated Geological Storage
The Illinois Clean Fuels Project	Early Development	United States	2025	Chemical Production	2.70	Industrial Separation	Dedicated Geological Storage
Clean Energy Systems Carbon Negative Energy Plant - Central Valley	Early Development	United States	2025	Power Generation	0.32	Oxy-combustion Capture	In Evaluation
Project Tundra	Advanced Development	United States	2025-2026	Power Generation	3.60	Post-combustion capture	Dedicated Geological Storage
Northern Gas Network H21 North of England	Early Development	United Kingdom	2026	Hydrogen Production	1.50	Industrial Separation	Dedicated Geological Storage
Hydrogen to Humber Saltend	Early Development	United Kingdom	2026-2027	Hydrogen Production	1.40	Industrial Separation	Dedicated Geological Storage
Drax BECCS Project	Early Development	United Kingdom	2027	Power Generation	4.00	Industrial Separation	Dedicated Geological Storage
Ervia Cork CCS	Early Development	Ireland	2028	Power generation and Oil Refinery	2.50	Industrial Separation	Dedicated Geological Storage
The ZEROS Project	In Construction	United States	Late 2020s	Power Generation (Waste to Energy)	1.50	Oxy-fuel combustion capture	Enhanced Oil Recovery