Development of a Novel Gas Pressurized Stripping (GPS)-Based Technology for CO_2 Capture from Post-Combustion Flue Gases

DE-FE0007567

Carbon Capture Scientific, LLC.

CONSOL Energy Inc.

Nexant Inc.

Western Kentucky University

HiGee USA Inc.

Presented by Shiaoguo (Scott) Chen

DOE Carbon Capture Technology Meeting, June 23-26, 2015, Pittsburgh, PA

CARBON CAPTURE SCIENTIFIC, LLC.

Acknowledgements and Disclaimer

Funded by U.S. Department of Energy/ National Energy Technology Laboratory under Agreement No. DE-FE0007657

NETL: Andrew Jones and Lynn Brickett

NCCC: Supporting team

About Carbon Capture Scientific, LLC

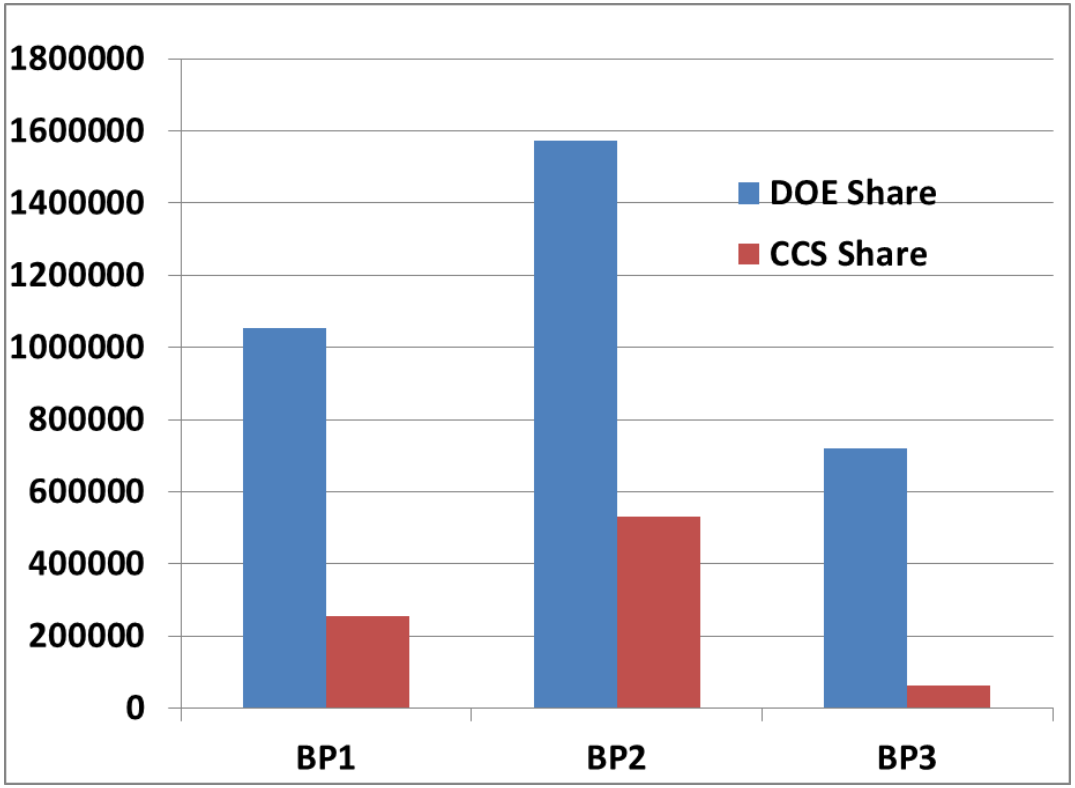
- Early stage company located in Pittsburgh, PA
- Two patents were granted for CO_2 capture technologies
- Bench-scale development funded by the Department of Energy / National Energy Technology Laboratory
- Chemical Engineers/Scientists with strong expertise in process design, simulation and optimization
- Technology development based on transition from thermodynamic analysis, to process simulation, to bench-scale prototyping
- Continuing to make key hires to build in-house expertise for current and future large-scale projects

Project Budget

	Budget, $
DOE	3,347,370
CCS	847,799*
Total	4,195,169

*including cost share from CONSOL Energy, Western Kentucky University, and HiGee USA

(Cost share is ~20%)



DOE funding and cost share based on Budget Period

Project Participants

Partner/ Organization	Lead Contact(s)	Key Role(s)
DOE-NETL	Andrew P. Jones, Project Manager	Funding & Sponsorship
Carbon Capture Scientific, LLC	Shiaoguo (Scott) Chen, PI Zijiang (John) Pan, Co-PI	Process optimization Bench-scale experiments
CONSOL Energy Inc.	Daniel P. Connell, Co-PI Richard Winschel, Technical advisor	Phase equilibrium experiments and related process design
Nexant Inc.	Gerald Choi, PI Robert Chu, Sr. Chemical Engineer	Techno-economic analysis
Western Kentucky University	Prof. Wei-Ping Pan	Consultant on corrosion testing
HiGee USA	Prof. Jiangfeng (Jeffery) Chen	Specialty equipment (RPB) provider

Project Objectives

Overall Objective

- Develop a breakthrough Gas Pressurized Stripping (GPS) process-based technology for CO_2 capture from post-combustion flue gases

Specific Objectives

- Perform bench-scale tests of individual process units to obtain necessary process design data for the pilot scale
- Conduct computer simulations to maximize the benefit of the GPS technology for existing power plants
- Carry out experimental investigation of selected solvents to minimize the economic risk of the GPS technology.
- Perform bench-scale tests of a rotating packed bed (RPB) to evaluate performance.
- Design, build, and test a GPS skid capable of processing 500 SLPM actual coal-derived flue gas in a column-based GPS system operating at the National Carbon Capture Center (NCCC).

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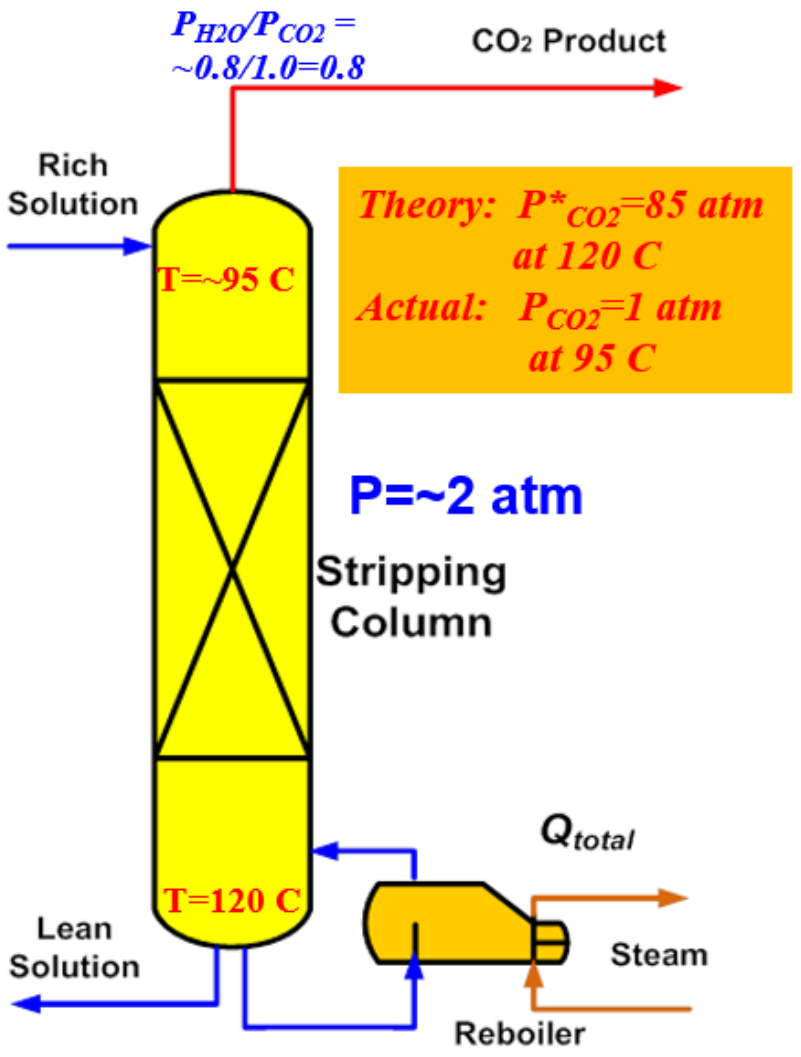
Issues with Conventional Strippers

- ***Water vapor is used as stripping gas,*** **thus operating pressure is limited by the vapor pressure of the lean solution at the reboiler temperature**
- ***Water vapor is also used as a heat carrier*** **which leads to a temperature gradient along the column**
- ***Low operating pressure*** **results in a high ratio of P_{H2O}/P_{CO2} at the top of the stripper**



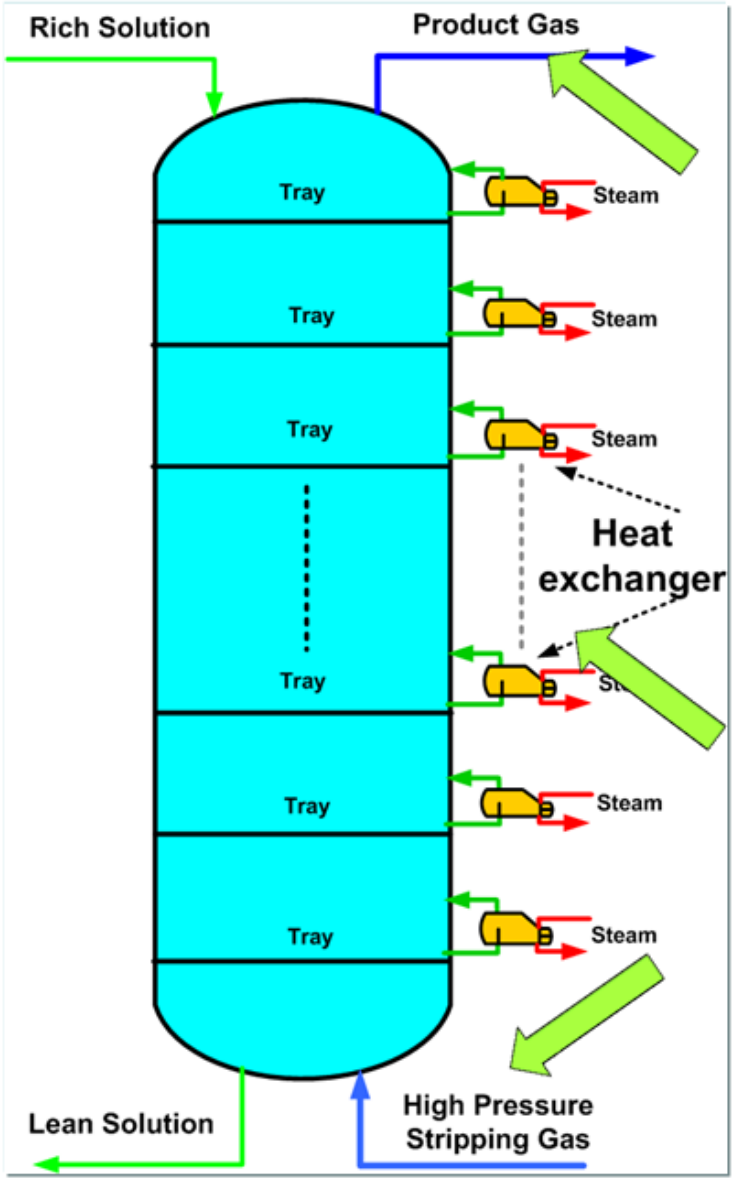
Consequences:

–Low thermal efficiency

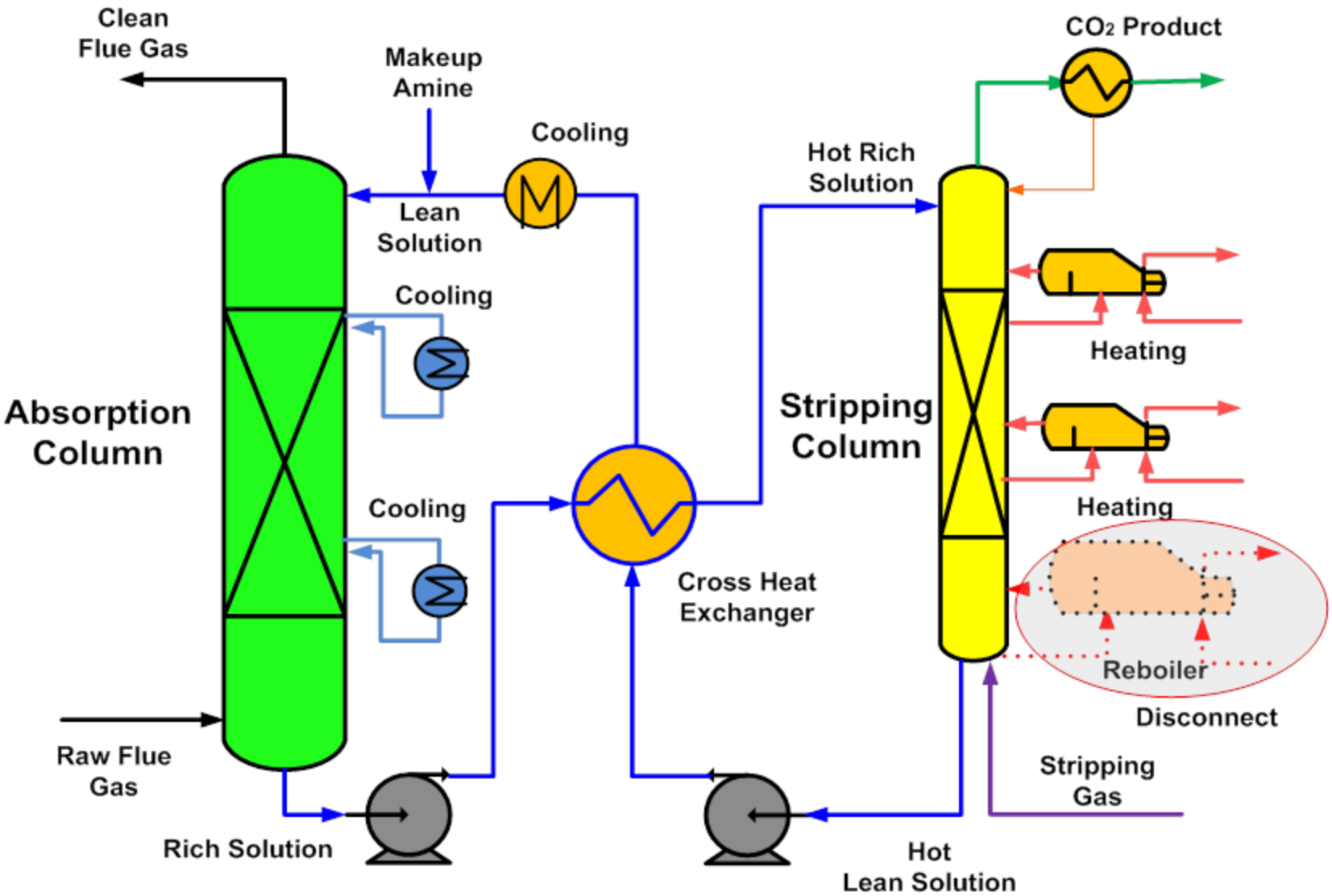
–High compression work

Novel Gas Pressurized Stripping (GPS) Column

- **Adding a high pressure stripping gas stream into the column**
  - ✓ Eliminating water as stripping gas
  - ✓ Enables high operating pressure
- **Adding side heaters to provide heat**
  - ✓ Eliminates the necessity of using water vapor as heat carrier
  - ✓ Reduces temperature gradient in the stripper
- **Product gas is a mixture of stripping gas and CO_2 along with water vapor**
  - ✓ Increased CO_2 partial pressure
  - ✓ Requires a separation unit



GPS Based Post-Combustion CO_2 Capture Technology



Optimized GPS Process

Advantages of GPS-Based Processes

- **Uses commercial off-the-shelf technology**
  - Proven unit operations
  - TRL should be as high as other conventional absorption/stripping processes
  - Suitable for large scale applications such as power plants
- **High Thermal Efficiency**
  - High stripping pressure thus reduced mechanical CO_2 compression work
  - Low stripping heat
- **Flexible**
  - Applicable to different solvents with different heat of reactions
  - Applicable to all absorption/stripping processes
  - Applicable to new or existing power plants
  - Applicable to existing amine based process with slight modifications

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Project Schedule: Oct.1, 2011 –June 30, 2015

Tasks	Task Duration			Task Focus	Performer				
	1-12 BP1	13-33 BP2	34-45 BP3		CCS	HiGee	CONSOL	Nexant	WKU
Task 1. Project planning & management				N/A	X				
Task 2. GPS column study and its optimization				Process	X				
Task 3. Optimization of GPS process for existing plant				Process	X				
Task 4. Simulations of Alternative Separations method for GPS stripping gas				Process	X				
Task 5. Phase equilibrium data measurement				Solvent	X		X		
Task 6. First absorption column testing				Process	X		X		
Task 7. GPS column design/fabrication/testing				Process	X		X		
Task 8. Second absorption column testing				Process	X		X		
Task 9. Stability of solvent at high loading & T				Solvent	X				X
Task 10. Corrosion test at high loading & T				Solvent	X				X
Task 11. RPB unit evaluation at CCS Lab				Equipment	X	X			
Task 12. Survey of EH&S of GPS process				Solvent	X				
Task 13. Preliminary techno-economic analysis				Economics				X	
Task 14. Revision of techno-economic analysis				Economics				X	
Task 15. Updated techno-economic analysis				Economics				X	
Task 16. Design/fabrication of a bench scale GPS unit with Conventional Columns				Process	X				
Task 17. Bench-Scale Testing of the Skid Mounted Column Based GPS System				Equipment	X				

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BP1 Tasks: All Completed on Schedule

Task #	Description	Simulation / Experiment	Comments
2	GPS column study and its optimization	Simulation	**Completed**
5	Phase equilibrium data measurement	Experiment	**Completed**
6	First absorption column testing	Experiment	**Completed**
9	Stability of solvent at high loading and high T	Experiment	**Completed**
13	Preliminary techno-economic analysis	Simulation	**Completed**

Milestones Achieved for BP1

Task	Title/Description	Planned Completion Date	Actual Completion Date	Verification Method
2	GPS column study and optimization to achieve thermal efficiency of 60% or greater	9/30/2012	7/9/2012	Design review with NETL / Presentation of data
9	Solvent loss due to degradation of solvent is less than 3 kg/ton CO_2	9/30/2012	7/9/2012	Design review with NETL / Presentation of data

BP2 Tasks

Task #	Description	Simulation / Experiment	Focus	Status
1	Project Management	---	Project Management	
3	Optimization of GPS process for existing plant	Simulation	Identify optimal operating conditions for GPS process	**Completed**
4	Simulation of alternative separation for GPS stripping gas	Simulation	Identify separation process to follow GPS process	**Completed**
7	GPS column design/ fabrication and testing	Experiment	Experimentally validate GPS concept	**Completed**
8	Second absorption column testing	Experiment	To recover stripping gas	**Completed**
10	Corrosion test at high loading and high temperature	Experiment	Obtain corrosion data	**Completed**
11*	RPB unit evaluation at CCS Laboratories	Experiment	Assess RPB potential to replace conventional column	**Completed**
14	Revision of techno-economic analysis	Simulation	Identify cost reduction potential	**Completed**
16*	GPS system design/ fabrication and installation	Experiment	Establish a skid mounted GPS system	**Completed**

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**** Revised or new task for BP2***

Milestones Achieved for BP2

Task #	Description	Planned Completion Date	Actual Completion Date
1	Host site agreement executed	**6/30/2013**	**6/30/2013**
3	Overall energy performance column and solvent less than or equal to 0.22 kwh/kg CO_2	**9/30/2013**	**12/30/2012**
4	Overall energy performance of system less than or equal to 0.20 kwh/kgCO_2	**9/30/2014**	**2/25/2013**
7	GPS column efficiency experimental measured at 50% or greater	**9/30/2013**	**2/25/2013**
16	Complete design of bench-scale GPS test unit for conventional columns	**4/30/2013**	**5/20/2013**
16	Completion of the fabrication and shakedown of the skid-mounted GPS system using water and air	**3/31/2014**	**5/23/2014**
16	Complete installation of 500 SLPM column-based GPS bench unit at NCCC	**5/31/2014**	**8/10/2014**

Tasks for BP3

Task	Title/Description	Focus	Duration
1	Project Planning & Management	Project management	7/1/14~6/30/15
12	Survey of EH&S of GPS process	EH&S survey	10/1/14~6/30/15
15.0	Updated techno-economic analysis		5/1/15~6/30/15
15.1	Equipment sizing using updated data	Economics	5/1/15~6/30/15
15.2	Techno-economic analysis	Economics	5/1/15~6/30/15
17.0	Bench-Scale Testing of the Skid Mounted Column Based GPS System	Experiments to evaluate the GPS process	7/1/14~6/30/15
17.1	Bench unit commissioning	Process	Completed by 2/27/15
17.2	Bench unit parametric testing	Process	Completed by 3/27/15
17.3	Bench Unit long-term testing	Process and solvent	3/28/15~5/31/15
17.4	Equipment tear down and return to CCS facilities	Process	6/1/15~6/30/15

Milestones for BP3

Task	Title/Description	Planned Completion Date	Verification Method
12	Completion of Preliminary EH&S Assessment	6/30/2015	Topical Report
15	Completion of techno-economic analysis of the GPS system using updated data	6/30/2015	Topical Report
17	Complete commissioning of the skid-mounted GPS system at NCCC	Completed 2/27/2015	Review with NETL / NCCC
17	Completion of the parametric tests of GPS system at NCCC	Completed 3/27/2015	Review with NETL /NCCC
17	Completion of the continuous running of the GPS skid for >2000 hours	5/30/2015	Review with NETL / NCCC
17	Completion of equipment tear down and return to CCS facilities	6/30/2015	Review with NETL /NCCC

Success Criteria for BP3

Task	Description	Planned Completion Date	Actual Completion Date	Verification Method
15	Increase in capital equipment costs of less than or equal to 10% over existing process	3/31/2015	6/9/2015	Topical Report and Review with NETL
17	At operating temperature around 120°C, the GPS column operating pressure >4 bar and CO_2 purity >95%	3/31/2015	6/9/2015	Review with NETL / NCCC
17	Overall electricity equivalent energy requirement of the GPS process less than 0.23kWh/kgCO_2	3/31/2015	6/9/2015	Review with NETL / NCCC
17	CO_2 capture cost of <$45/tonne for NETL Baseline Case 12	3/31/2015	6/9/2015	Review with NETL / NCCC
17	Cumulative running time of the GPS skid for >2000 hours	6/30/2015		Review with NETL / NCCC

Task 16: GPS Skid Design/ Fabrication and Testing

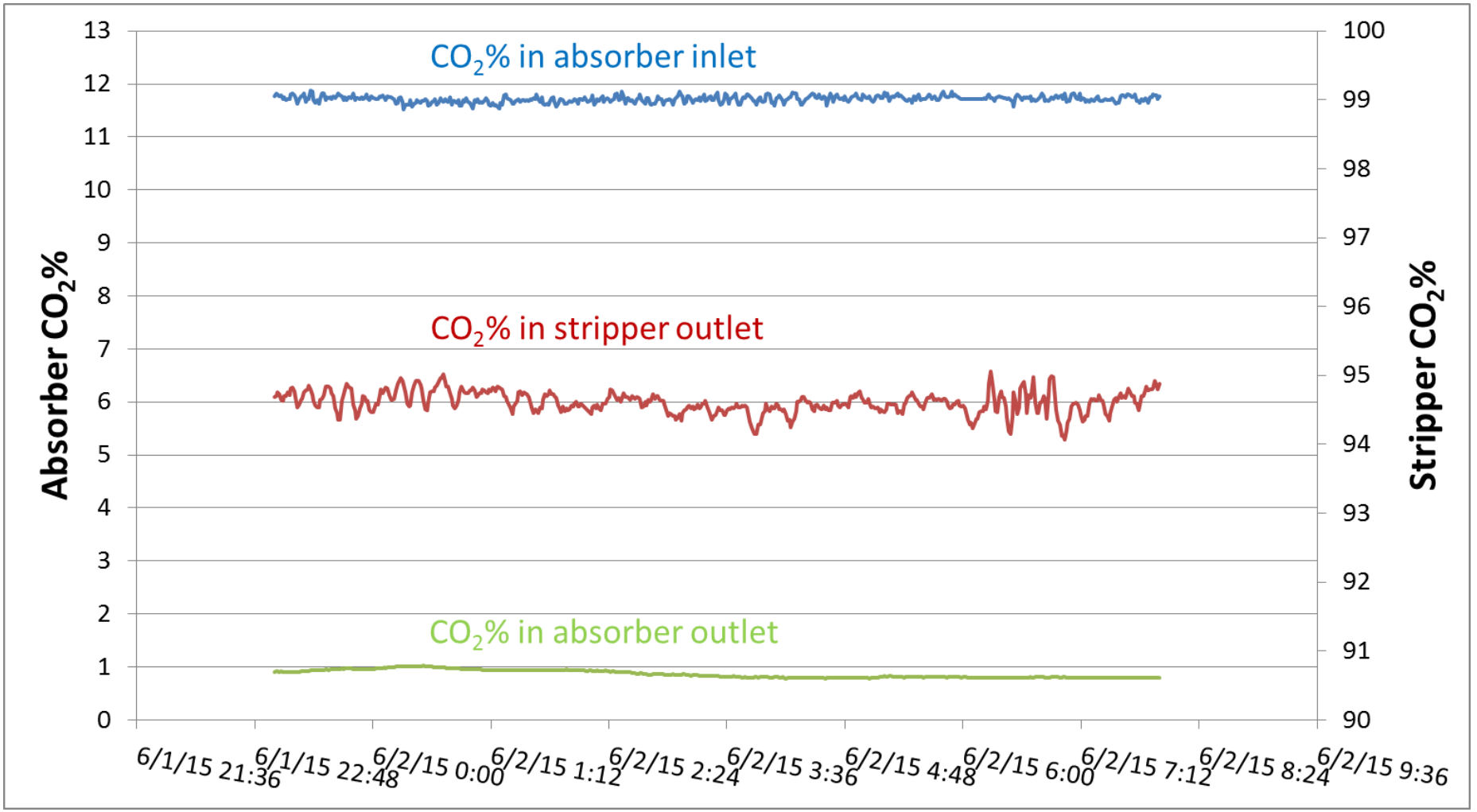
Two Columns:

- **Absorber: ID=8”, H=32’**
- **Stripper: ID=6”, H=30’**

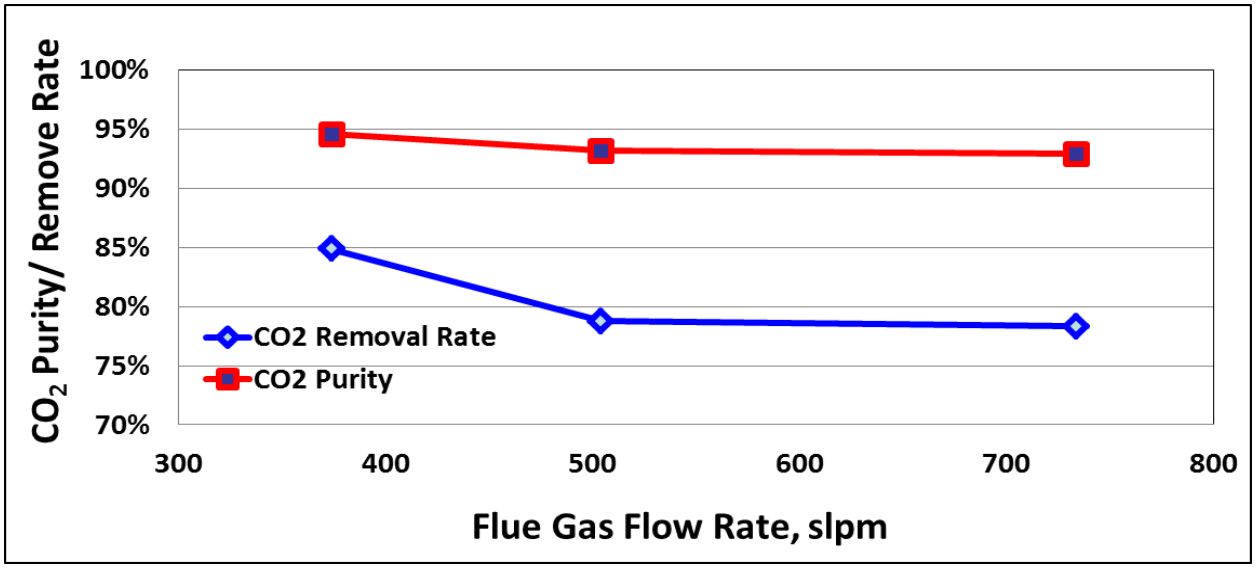
Other Major Units:

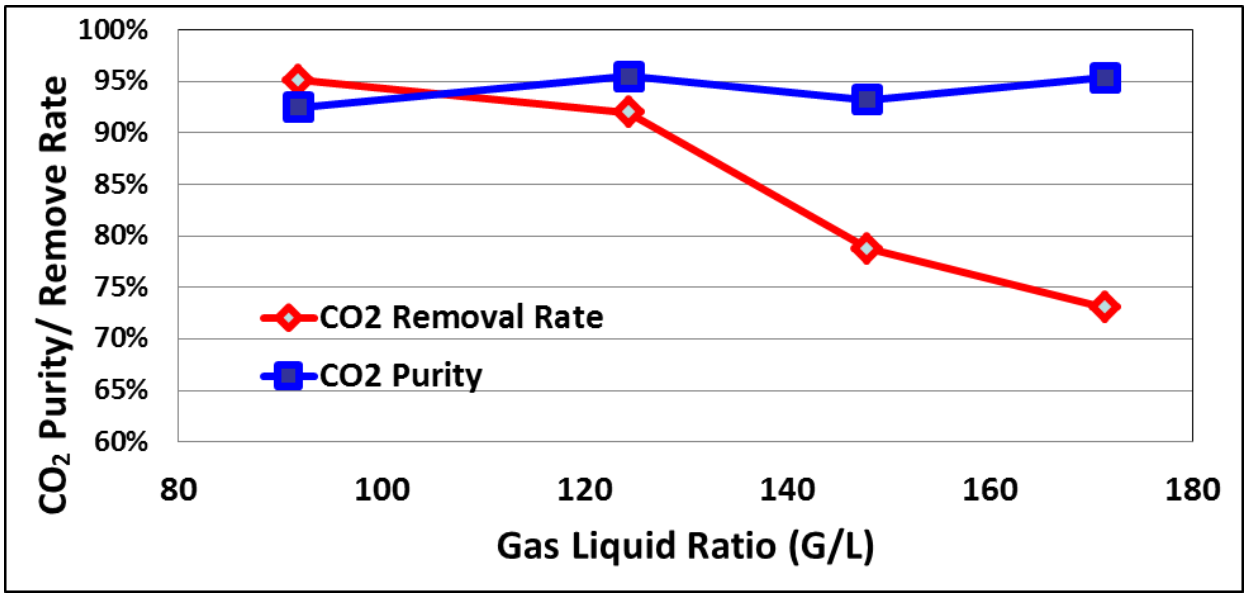
- **Cross heat exchanger**
- **Two inter-stage cooling**
- **Two inter-stage heating**

Capture Performance of GPS Bench Unit at NCCC



Task 17: Bench Scale Test Results





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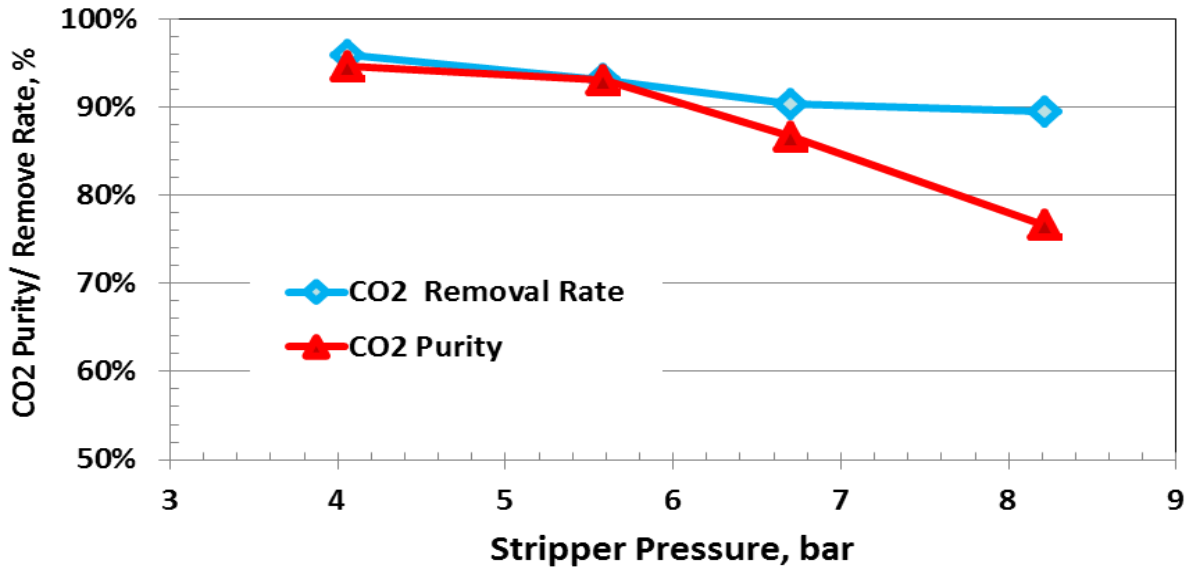

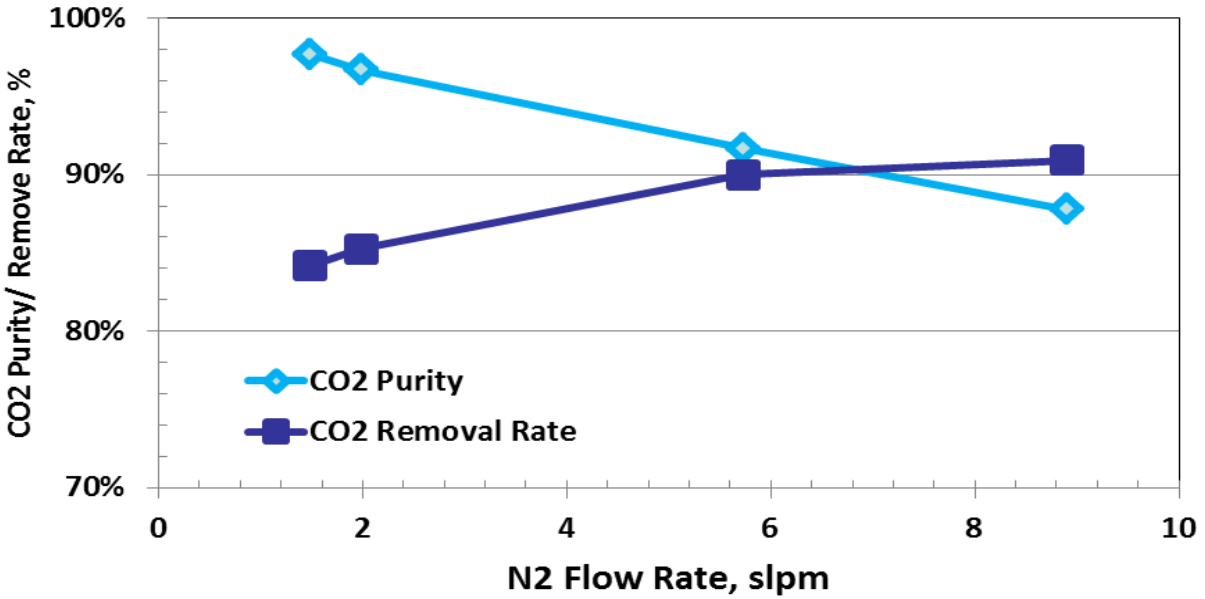

Task 17: Bench Scale Test Results

Reaction heat and Stripping Heat of the GPS Bench-Scale Unit

Run	CO_2 amount (kg/hr)	Total Steam Usage (lb/hr)	Steam Use Due to Sensible Heat and Heat loss (lb/hr)	Net Steam Usage (lb/hr)	(ΔH_R) + $Q_{stripping}$ (kJ/ kg CO_2)
1.	4.9	15.16	7.36	7.8	1562
2.	7.07	25.52	14.53	10.99	1600
3.	3.7	32.80	26.90	5.90	1597

Task 17. Energy Performance of the Optimized GPS Process

Process	Baseline MEA	GPS Process
Operating Pressure (atm)	1.8	~6
Reaction Heat (kJ/kgCO_2)	1870	1355
Sensible Heat (kJ/kgCO_2)	990	295**
Stripping Heat (kJ/kgCO_2)	690	231
Total Heat (kJ/kgCO_2)	3550	1881
Electricity Equivalent (kWh/kgCO_2)	0.29	0.12
Other load (kWh/kgCO_2)	0.04	0.04
Compression Work (kWh/kgCO_2)	0.09	0.07
Electricity Equivalent (kWh/kgCO_2)	0.42	0.23
Energy Penalty to SPC Plant (%)	30	18

***LMTD=5.12 ^{o}C*

Task 15. Revision of Techno-economic Analysis

Type of CO_2 Capture Technology	Case 11	Case 12 MEA	Nexant Inc. MEA	GPS Process
Power Production, MW				
Gross Power	580	663	704	762
Net Power	550	546	575	647
Capital Cost, $MM				
Power Plant	866.4	1109.9	1114.9	1125.5
PCC Plant	0.0	410.8	390.6	430.8
CO_2 Compression and Drying	0.0	46.4	122.4	60.5
Start Up Costs (2% TPC before Contingency)	15.5	26.4	27.4	27.2
Total Capital Cost, $MM	881.9	1,593.5	1,655.4	1,644.0
Operating Cost excl Fuel, $MM/yr				
Fixed Operating Cost	13.8	20.5	21.0	22.6
Variable Operating Cost				
Non PCC related Opt Cost	20.0	33.6	35.5	34.6
NaOH		0.9	0.9	0.9
H_2SO_4		0.3	0.3	0.3
Amine M/U		1.0	1.1	2.0
Active Carbon		0.6	0.5	0.5
Corrosion Inhibitor/Solvent MU		0.0	0.0	0.0
Total Operating Cost excl Fuel, $MM/yr	33.8	56.9	59.3	61.1
Fuel Cost, $MM/yr	64.5	92.0	92.0	92.0
LCOE (excl CO_2 TS&M), mills/kWh	63.9	112.0	109.6	97.4
% of Case 11 LCOE - Compare to 2007	100%	175%	171%	152%

Task 15. Revised Techno-economic Analysis

	Baseline Case	Nexant Inc. MEA	GPS Process
Total Output at Generator Terminals, kW	663,445	704,032	761,909
Auxiliary Load Summary, kW:			
Coal Handling and Conveying	490	490	490
Limestone Handling & Reagent Preparation	1,270	1,270	1,270
Pulverizers	3,990	3,990	3,990
Ash Handling	760	760	760
Primary Air Fans	1,870	1,870	1,870
Forced Draft Fans	2,380	2,380	2,380
Induced Draft Fans	10,120	10,120	10,120
SCR	70	70	70
Baghouse	100	100	100
FGD Pumps and Agitators	4,250	4,250	4,250
Misc Balance of Plant	2,000	2,000	2,000
Steam Turbine Auxiliaries	400	400	400
Condensate Pumps	630	630	630
Cooling Water Circulation Pumps **	12,260	15,817	15,356
Cooling Tower Fans	6,340	4,547	4,424
Transformer Losses	2,300	2,441	2,641
Amine CO_2 Capture Plant Auxiliaries	21,320	18,986	22,420
CO_2 Compression	46,900	59,187	42,223
Total Auxiliaries, kW	117,450	129,308	115,394
Net Power Export, kW	545,995	574,724	646,514
Net Plant Efficiency, % HHV	27.2	28.7	32.2
Net Plant Heat Rate, Btu/kW	12,536	11,910	10,587

Achievement and Future Work

Project Achievements

- Completed all major individual process unit tests at lab
- Design, fabrication and installation of a bench scale continuous skid-mounted GPS system and tested at NCCC
- Computer simulation tasks identified favorable GPS process configuration, leading to capital cost **<5% increase over the Baseline MEA case**
- Overall electricity equivalent energy requirement of the GPS process ***<0.23kWh/kgCO_2***
- CO_2 capture cost of ***<$37.7/tonne (without TS&M)***

Future Work

- More steady state tests to achieve 2000 accumulated operating hours
- Pilot-scale test of GPS technology
- Further process integrations to reduce cost

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