SUSTAINABLE ENERGY SOLUTIONS

Cryogenic Carbon Capture Development

DOE Award No. DE-FE0028697

Project Kick-Off Meeting
NETL Pittsburgh

Larry Baxter, PI
Kyler Stitt, Project Manager

December 9, 2016

Presentation Outline

- Introduction to SES
- CCC technology background
- Project objectives
- Project team/project organization
- Technical approach/project scope
- Project schedule and associated milestones
- Decision points and success criteria
- Project budget
- Project risks/risk management

SES INNOVATION

Sustainable Energy Solutions

Founded in Early 2008

Support From

- Brigham Young University
- DONG Energy
- Clean Coal Task Force (Wyoming)
- ARPA-E
- CCEMC (Canada)

Headquarters in Orem, UT

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The SES Team

Andrew Baxter, CEO/Cofounder

- Two successful startups
- Led company for past 7-years
- MBA, Rice University

Dr. Larry Baxter, Technical Director/Cofounder

- 30+ years in energy research
- Inventor on 7 CCS patents

Ten permanent engineers

- 2 PhD, 4 Masters
- BYU, Univ. of Utah, Stanford
- Strong track record in innovation

Advisory Board

- Carl Bauer- Past director NETL, top 25 power industry
- Vernon Rice- VP and GC DuPont
- Bill Carlson- 35+ power projects

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Cryogenic Carbon Capture

Lab Validation 2008 → Bench Testing 2009-2012 → Initial Skid Testing 2012-2016 → CCC Development 2016-2019 → Pilot 2018-2020

Successfully tested two versions of process at "Skid-Scale" (~1 tonne/day CO_2) on multiple sources

Working on long-term on-site testing during CCC-Dev project

Eleven patents filed (six issued) and many more in process

About $15 million in project funding to date

CCC TECHNOLOGY BACKGROUND

Carbon Capture Not Affordable Today

CCS [carbon capture and storage] is necessary for the achievement of EU's targets for cutting greenhouse gases… The main barrier…high initial cost.

-[WSJ/London School of Economics]

WSJ LSE

"billions of tons of CO_2 can be permanently sequestered…However, today's capture technologies are not cost-effective"

-**[US Department of Energy]**

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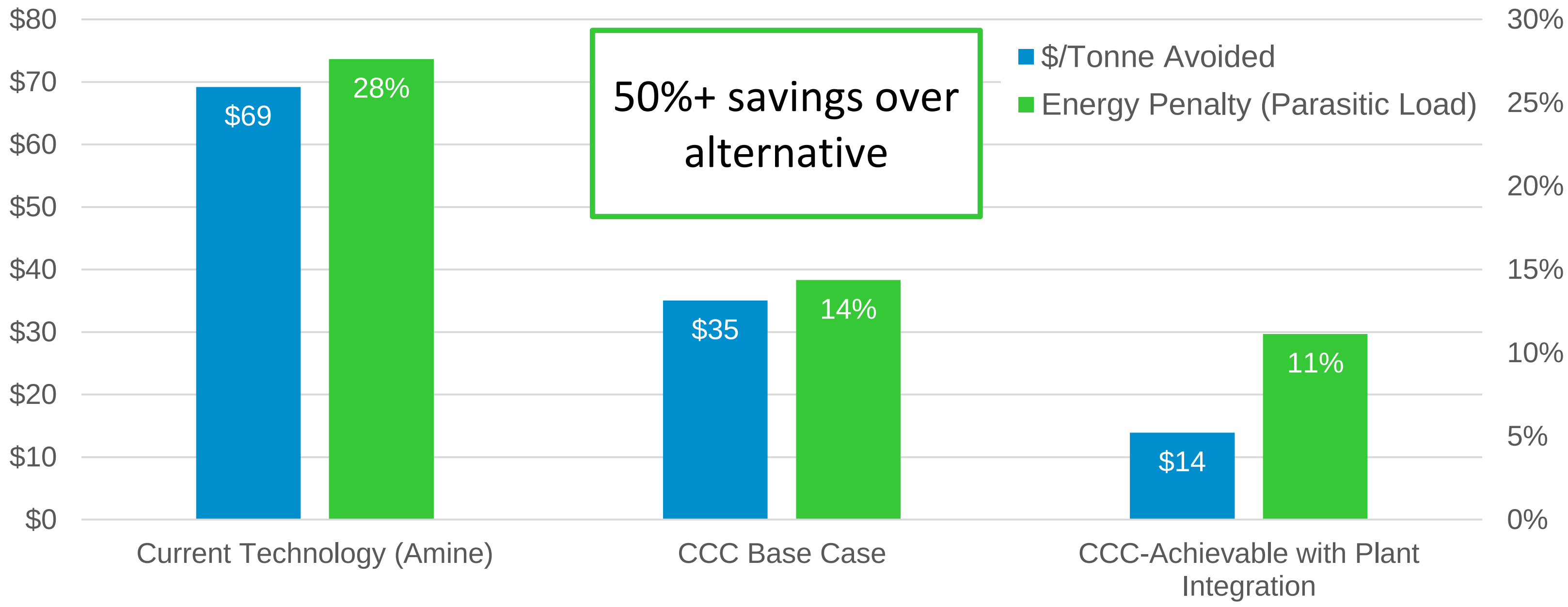
Cryogenic Carbon Capture (CCC) Cuts Costs in Half



*energy and cost savings from integration with steam cycle and offsetting cost and energy requirements for SO_X, NO_X, and Mercury controls. Additional savings and revenues could be gained from CO_2 sales and energy storage. Cost and energy numbers include compression. Amine numbers from NETL 2013

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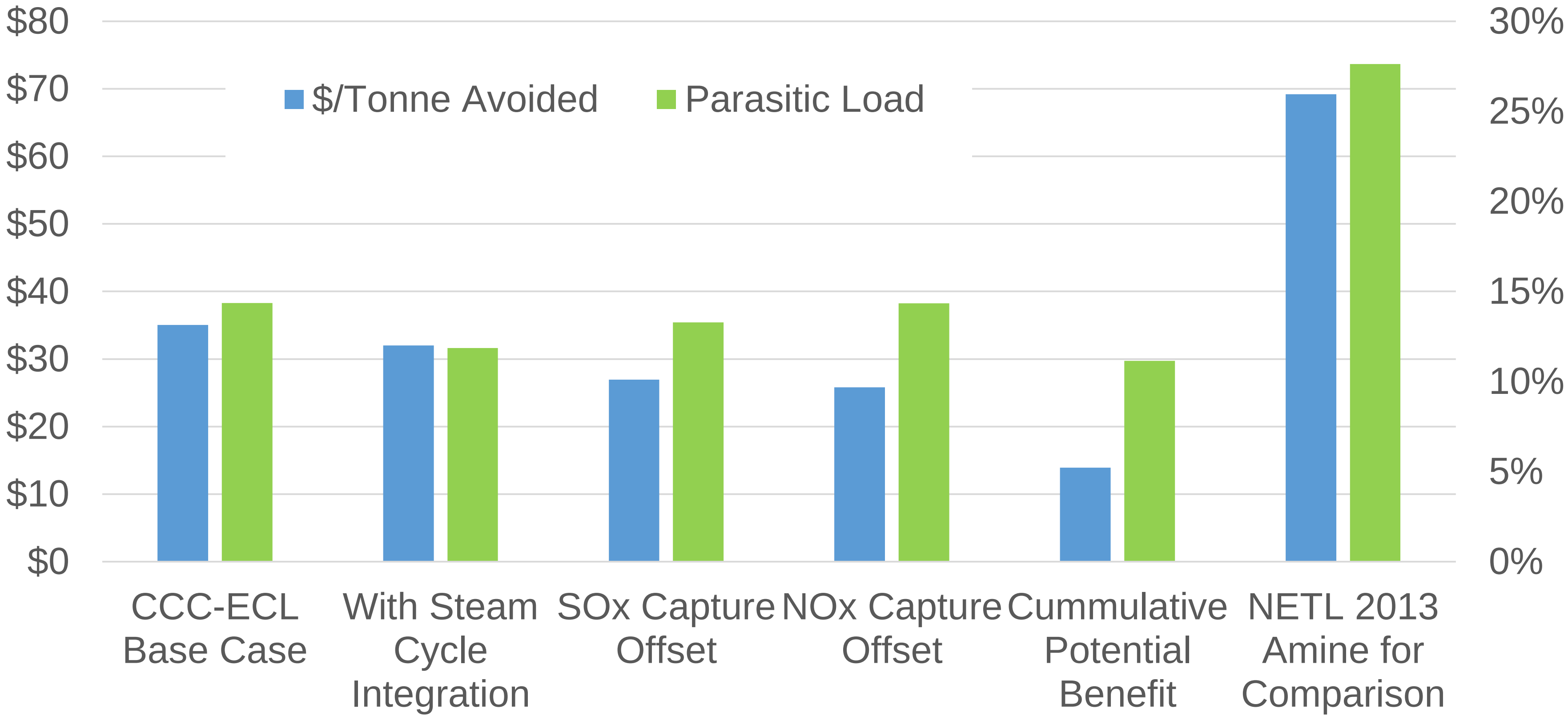
Further Cost and Energy Analysis



CCC has Additional, Unique Advantages

Widely deployable (NGCC, cement, IGCC, refineries, etc.)

Easily retrofitted to existing plants

95%+ Capture

Option of grid-scale energy storage*

Multi-pollutant capture (SO_X, NO_X, Hg)

*see appendix slide for details

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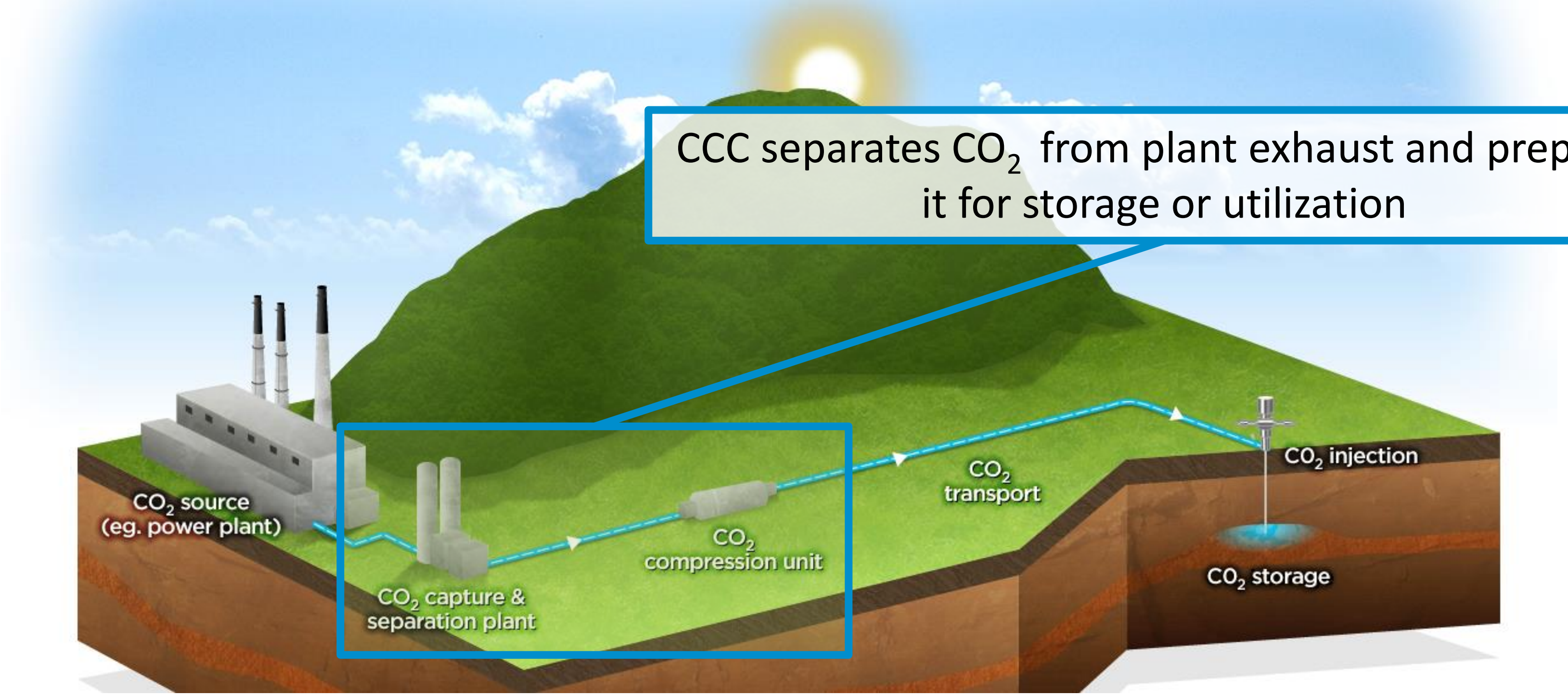
CCC Separates and Pressurizes CO_2

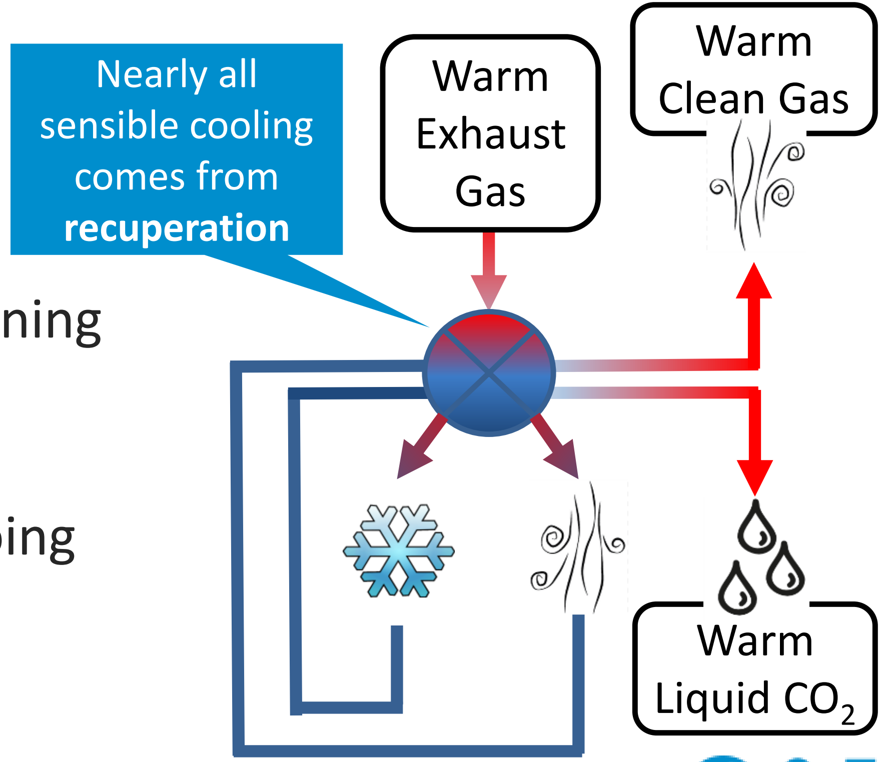
CCC separates CO_2 from plant exhaust and prepares it for storage or utilization



CCC is a Conceptually Simple Process

Patented process and equipment:

1. Cool the exhaust gas until CO_2 freezes
2. Separate solid CO_2 from remaining gases
3. **Recuperate energy** by cooling incoming warm gas with outgoing cold gas
4. Two variations (CFG, ECL)



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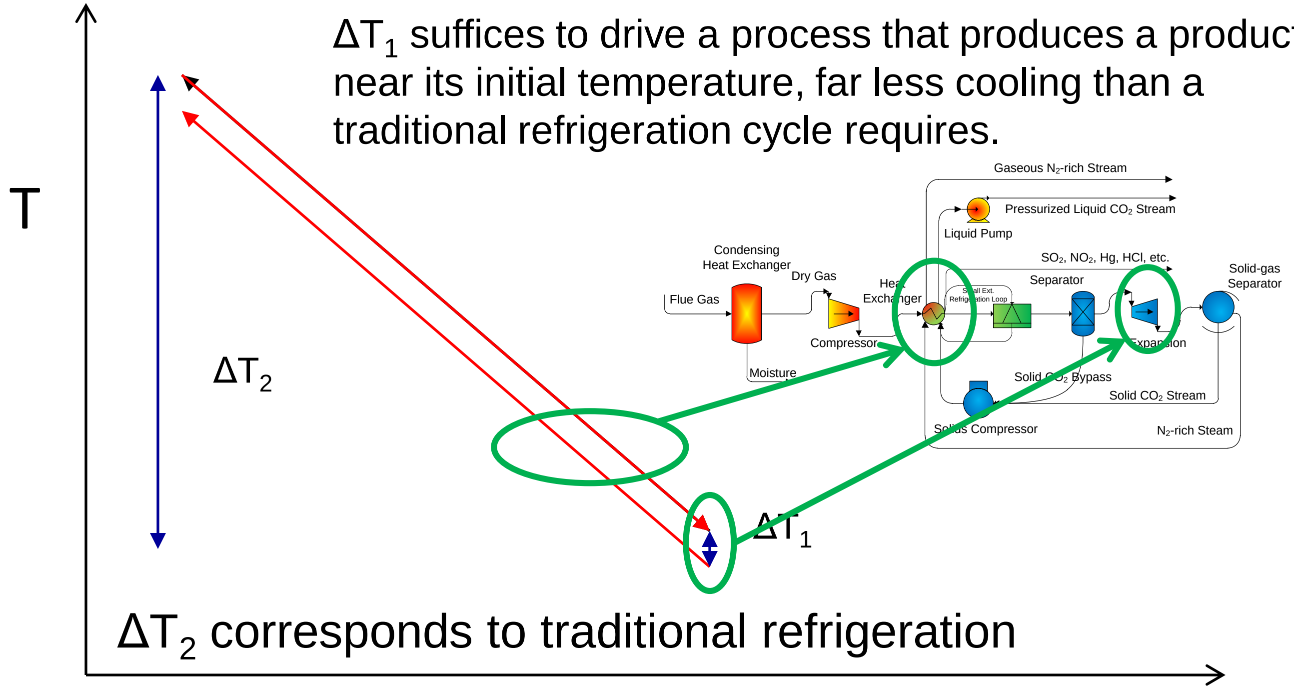
Basic Principles

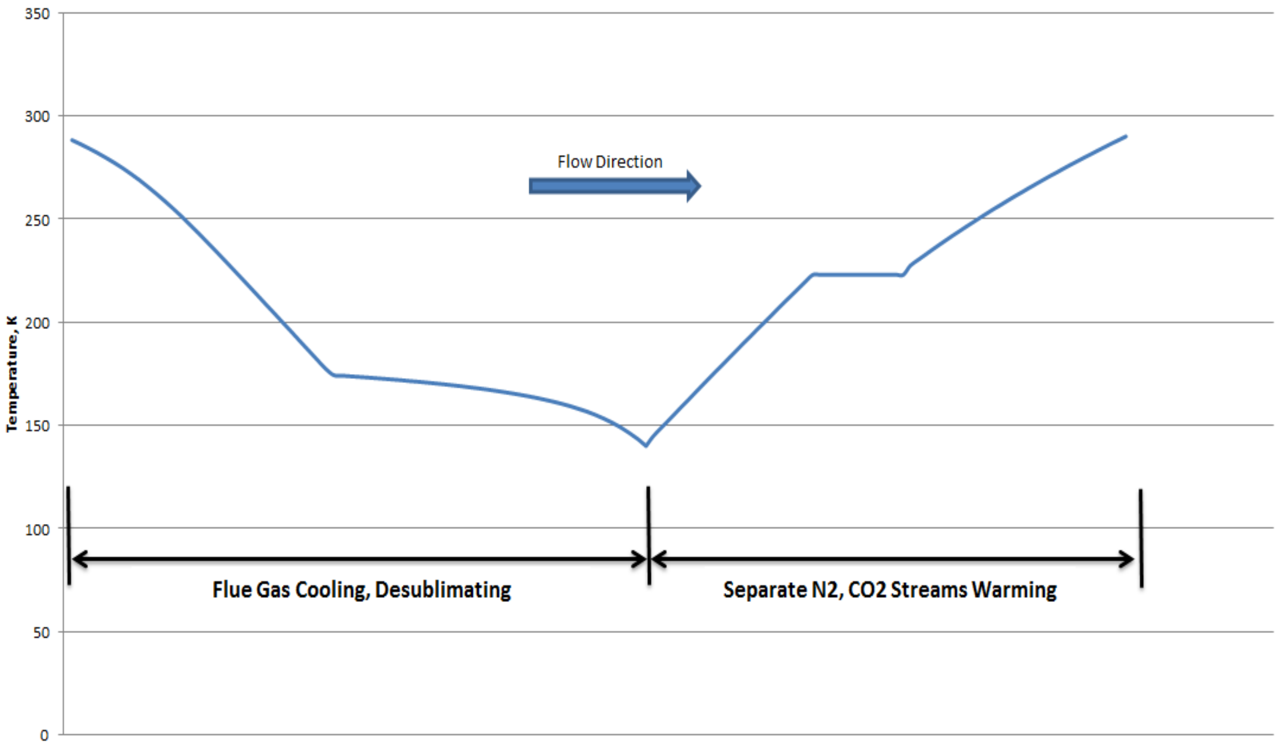
ΔT_1 suffices to drive a process that produces a product near its initial temperature, far less cooling than a traditional refrigeration cycle requires.



ΔT_2 corresponds to traditional refrigeration

Distance or Q

Actual Gas Temperature Profiles



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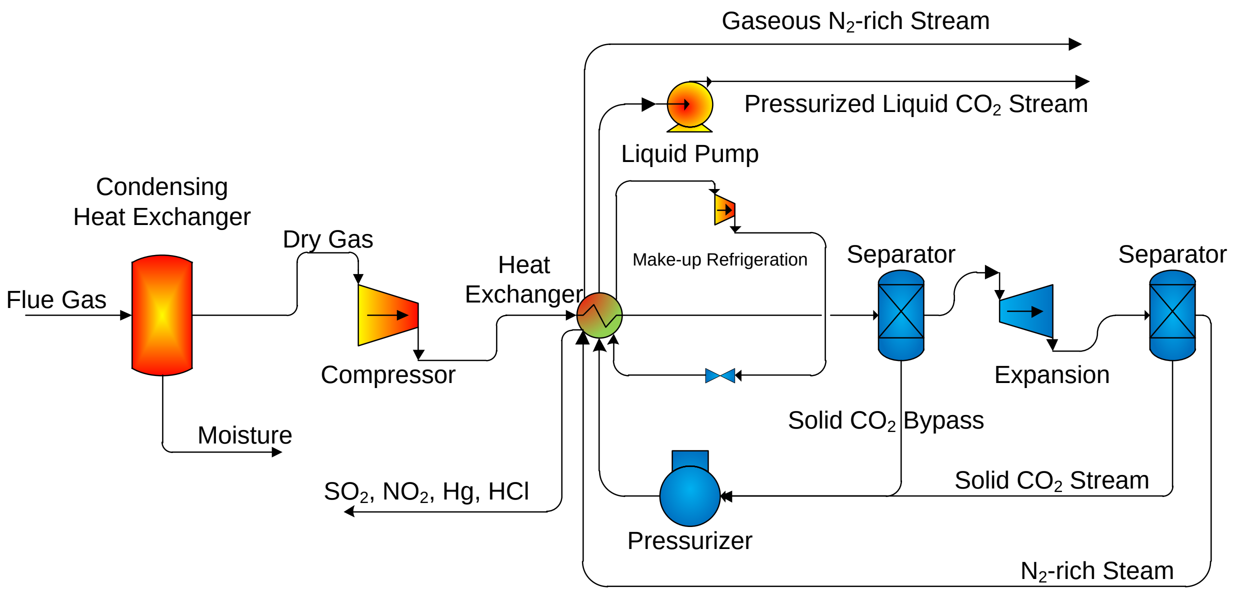
Compressed Flue Gas (CFG) Process

- Compresses and expands flue gas
- Max flue gas pressure is 5-7 bar
- Uses sour gas compressor and solids-forming expander
- Some energy and operational advantages

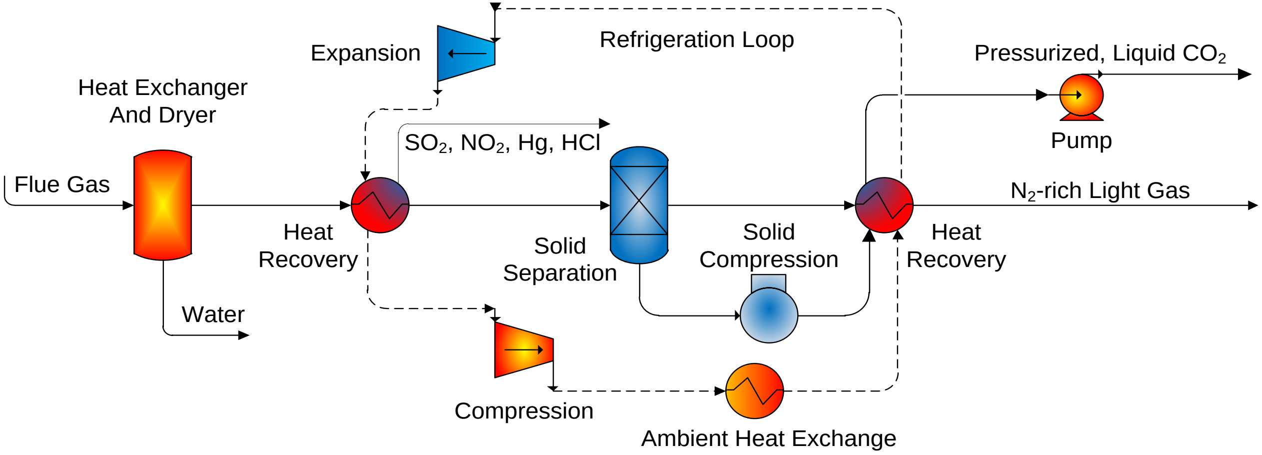


External Cooling Loop (ECL) Process

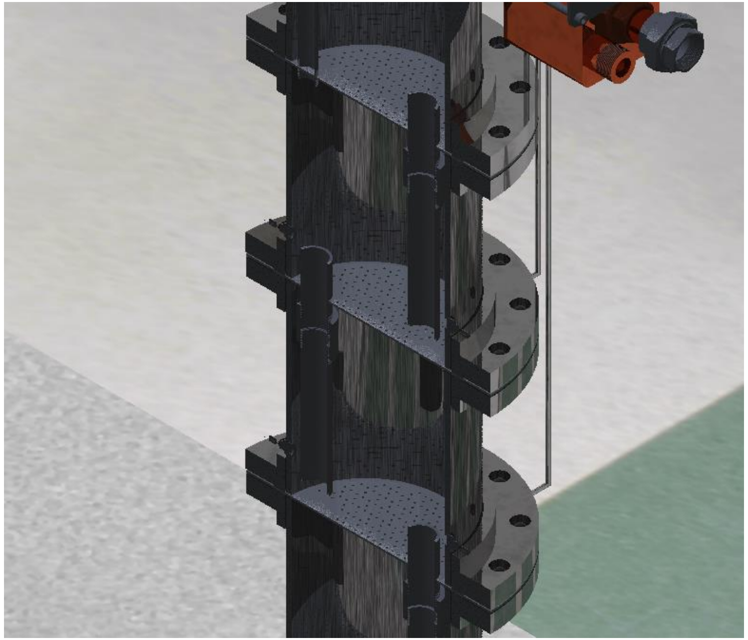
Flue gas remains at atmospheric pressure

Lower capex than CFG: no sour-gas compressor or solids-forming expander required

Capable of energy storage for load leveling and renewables integration on the grid



Patented Heat Exchanger Captures Solid CO_2



Videos

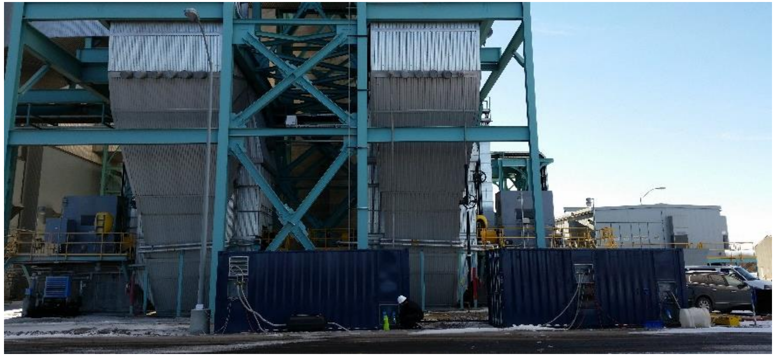
- Solids separation: https://youtu.be/9ZzIlBA3y9I
- Solids melting: https://youtu.be/MFX0jUjIPLw

Two-Minute Descriptive Video

https://www.youtube.com/watch?v=6kZ6EyI_iBc

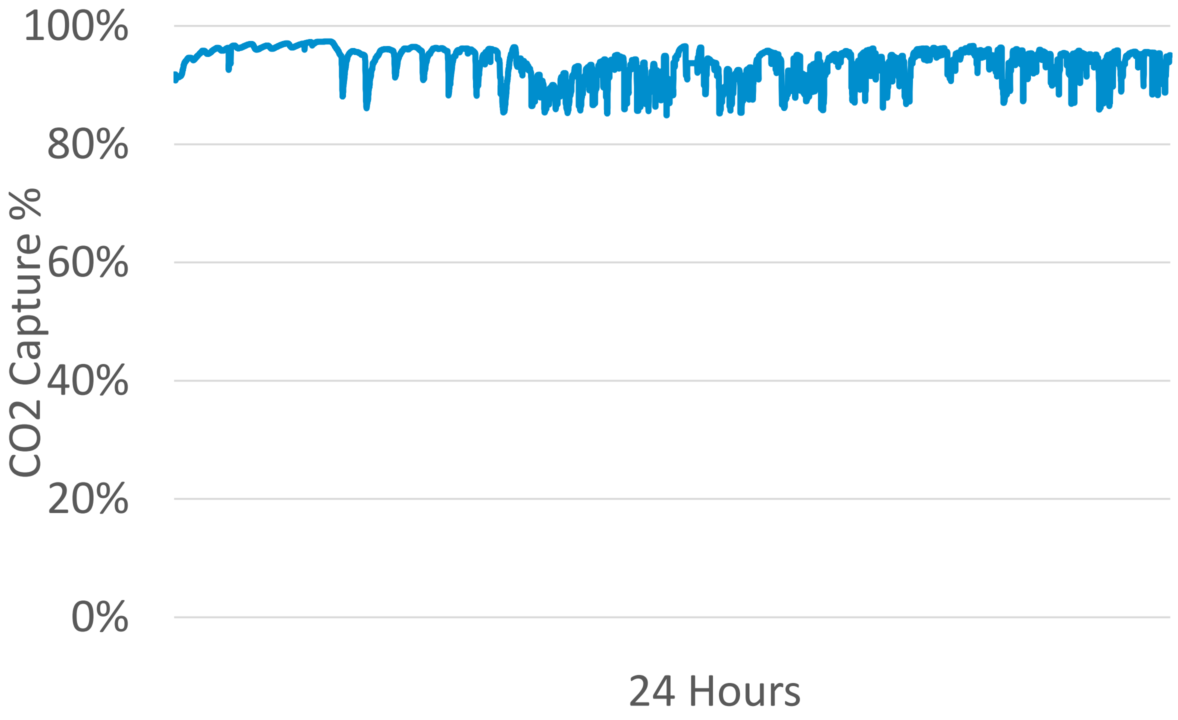
Short video was produced by Brigham Young University where initial research was done on the process. Sustainable Energy Solutions currently owns all intellectual property related to the CCC process.

Pictures of Skid-Scale Testing



Cement Plant

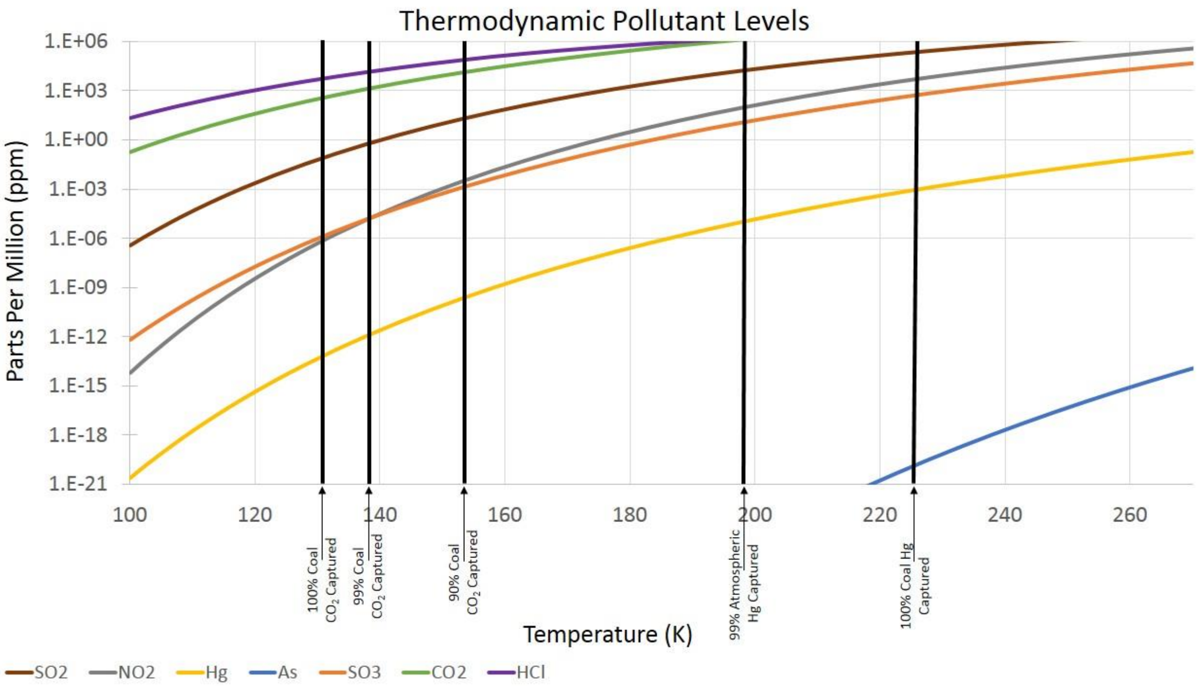
CO_2 Field-Test data



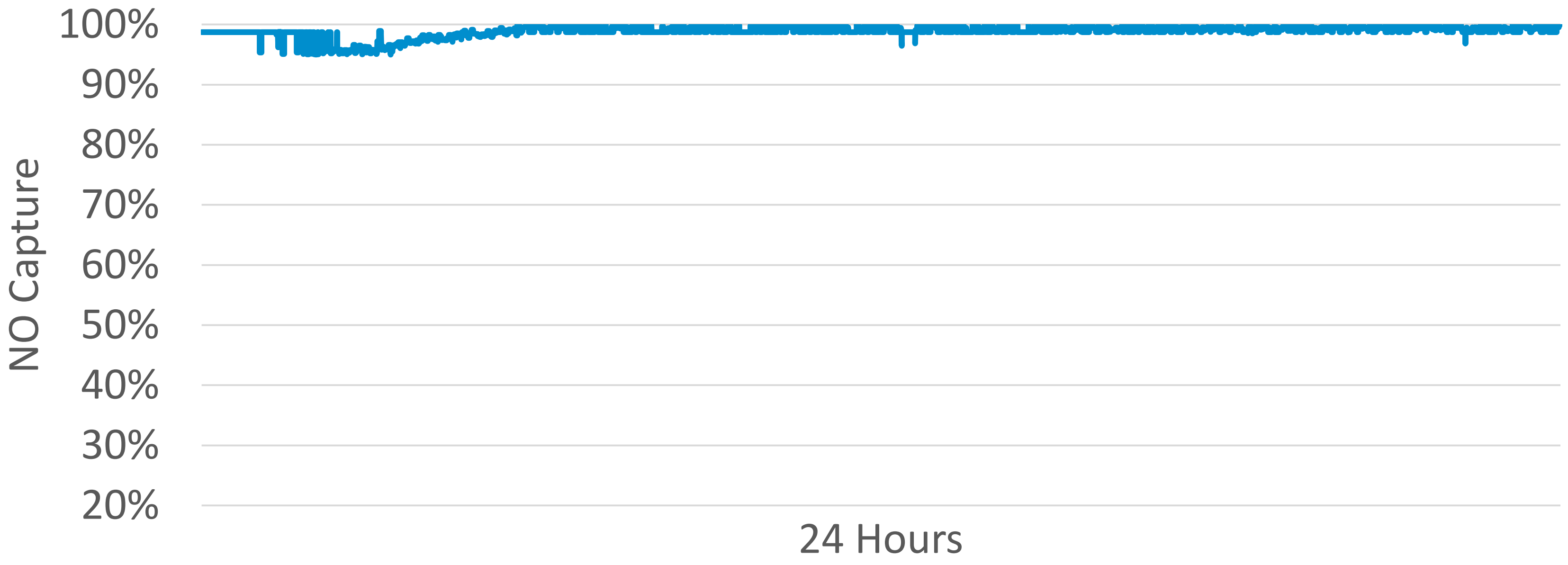
Over 95% average capture at commercial coal plant

Noise due to instrumentation

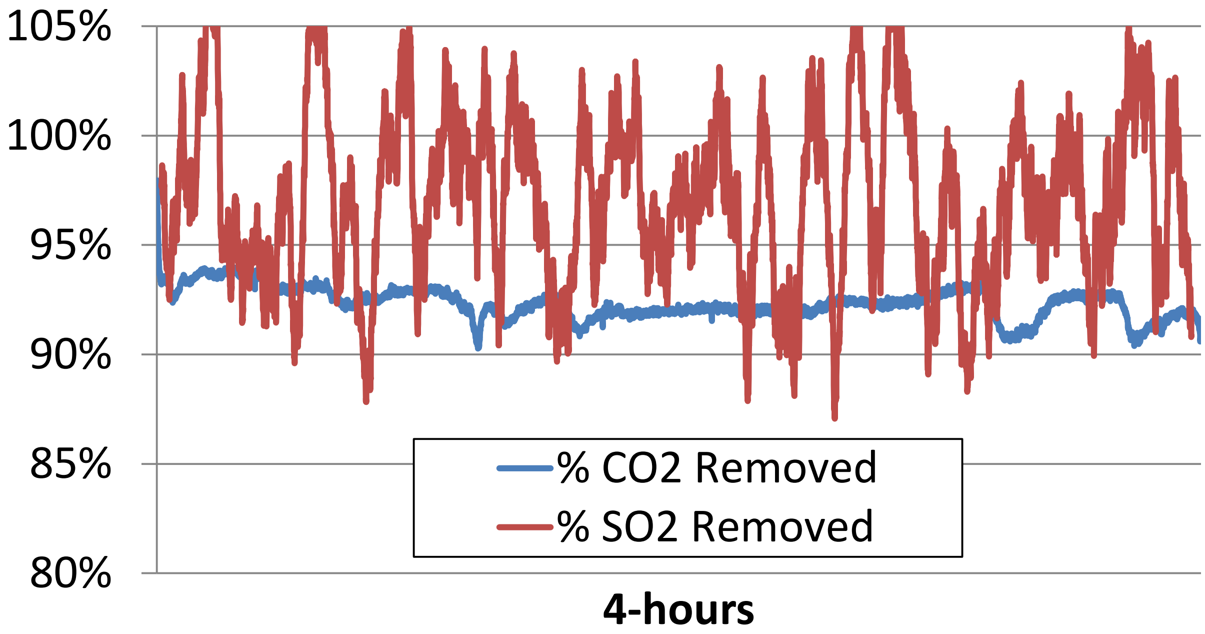
Pollutant Removal



NO_X Field Test Data



SO_X Capture Data



Over 99% average capture

SO_2 noise due to instrumentation sensitivity at low levels

Mercury

Emissions from CCC are less than 1 PPT

This represents less mercury than was in the air when it entered the power plant

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A Platform of CO_2 Treating Technologies

Post-Combustion Carbon Capture

NG Pipeline Treating

NG Liquids Treating

Liquefied NG Treating

Cryogenic Carbon Capture (CCC), can remove CO_2 from almost any stationary gas source.

Project Objectives

- Increase the reliability, efficiency, and scalability of the Cryogenic Carbon Capture™ (CCC) process and prepare it for a pilot demonstration.
- Objective of Budget Period 1
  - Improve key areas of the process through iterative design and experiment, culminating with a recommendation for improvements to be integrated in the large existing skid-scale system developed under non-federal funding called the CCC external cooling loop (CCC-ECL™) system.
- Objective of Budget Period 2
  - Integrate the recommended improvements into the CCC-ECL™ system and confirm their contributions through experimental process testing. Modeling and estimation improvements will improve the techno-economic analyses.

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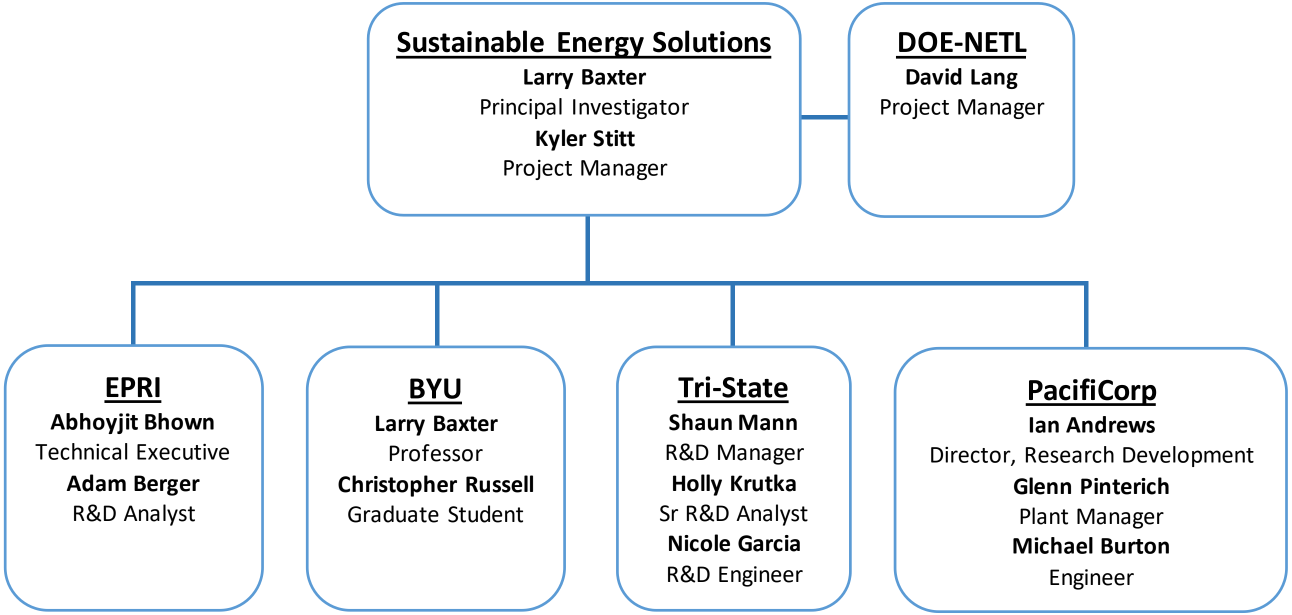
CCC Development Project Organizational Chart



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Roles and Lead Personnel

Organization	Relationship	Roles (Task #'s)	Lead Personnel
Sustainable Energy Solutions	Prime Recipient	Manage and participate in all tasks. Primary responsibility for project management (1), unit ops evaluation and selection (2, 3, 4, 5, 6, 7, 8), techno-economic analysis (9, 13), skid modifications and preparations (10), and operation and testing (11), and quantifying improvements in the skid system (12)	Kyler Stitt - Project Manager Larry Baxter – PI
Electric Power Research Institute (EPRI)	Contractor	Will be primarily responsible for independent evaluation of the technology, specifically process modeling and techno-economic analysis (9, 13)	Abhoyjit Bhown – Technical Executive
Brigham Young University	Contractor	Support for techno-economic analysis (9, 13), and thermochemistry modeling and testing for dissolved carbon dioxide and multipollutant capture (3, 8)	Larry Baxter – Professor
Tri-State	Contractor	Primarily responsible for the EH&S Risk Assessment (14) and support for the techno-economic analysis (9, 13)	Holly Krutka – Senior Research and Development Analyst
Pacificorp	Host Site	Primarily responsible for preparation of the host site (10)	Ian Andrews – Dir. Resource Development

BUDGET PERIOD 1 APPROACH AND SCOPE

Task 2. Flue Gas Drying - Technical Approach

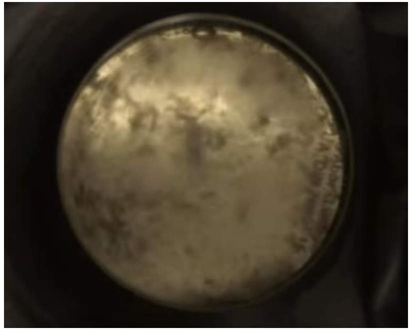
- Adsorption
- Phase Change Drying
- Alternative Techniques

Task 3. Dissolved Carbon Dioxide – Technical Approach

- Mitigate potential HX fouling
  - Pressure and temperature variation
- Alternative heat exchangers
  - Fluidized particle self-cleaning HX
  - Shell-and-tube, also exploring cleaning technologies
  - Fluidized Bed without contact liquid
  - Modifications to existing heat exchangers

Task 4. Solid-Liquid Separations – Technical Approach

- Alternative solid-liquid separations units
  - Enhanced Screw Press
  - Rotating cylinder compression
  - Pre-filtering including hydrocyclones and vibration filters which increase overall efficiency



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Task 5. Heat Exchanger Testing – Technical Approach

- Heat Exchanger Comparison
  - Bubbler – Existing HX in both single and multi-stage forms
  - Spray Tower – Tested at smaller scale, we will be doing a design overhaul and development of system that can work at any scale
  - Fluid Bed
- Figures of Merit
  - Footprint
  - Pressure Drop
  - Complications to the balance of the process

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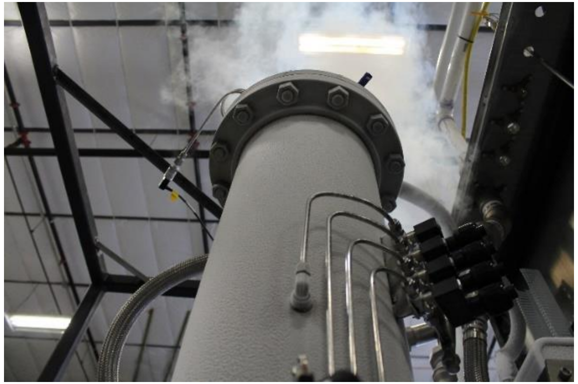
Task 6. Instrumentation and Controls

- Improving on the following areas
  - Solids loading in the slurry
  - CO_2 content in the melter
  - Pressure drop across the solids separator into the melter.
- Figures of merit
  - Amount of operator attention/intervention required
  - Ability to follow flow transients and upsets

Task 7. Light Gas Dispersal – Technical Approach

- Theoretical and experimental work to determine safe methods for dispersal
- Modeling matching heat source streams



Task 8. Multi-Pollutant Capture – Technical Approach

- Improve predictive capability for SO_2, NO, NO_2, Mercury, PM_{10}, and HCl
- Aspen and in-house models with validation using Cryogenic Unit Bench (CUB) and in-house analyzers

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Task 9. Techno-Economic Analysis – Approach

- Will work closely with NETL and other project team members (EPRI, Tri-State, BYU)
- Based upon computer modeling following best practices, as implemented in the various NETL reports on carbon capture and as supplemented by utility and industrial experts experienced in such analyses
- Discussion of differences depending on the loan and ownership structure of the utility
- Energy penalties - calculated using in-house modeling software
- Cost analyses
  - Include an analysis that uses NETL installation factors, costs of capital, fees, etc. for direct comparison to other published NETL results
  - Some of our project team members use more specific and significantly different factors
  - Effective cost of capital differ markedly among institutions and affect the projected economics
  - Will include analyses pertinent to some of our project team members in this activity

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BUDGET PERIOD 2 APPROACH AND SCOPE

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Task 10. Skid Modification – Technical Approach

- Will incorporate the technologies selected in Budget Period 1 into the skid and shakedown the resulting systems in preparation for long-term, in-house and field testing
- Shakedown testing will include unit and full-skid testing of the modified CCC-ECL™ skid
- These tests will include a variety of inlet gas conditions to test the updated controls, valves, unit operations, and process monitoring devices
- Tests will last from a few minutes to over 10 hours to ensure that all modifications to the system are correct and robust.

Task 11. Skid Operation – Technical Approach

Subtask 11.1 Test Plan

Subtask 11.2 Host Site Agreement

- coordinating with PacifiCorp or other host site

Subtask 11.3 Operation

- Operating the improved CCC system for 500 continuous hours at 1 tonne/day conditions
- In-house testing and field testing of the unit will occur, with in-house using mixed $N_2/O_2/CO_2$ gases

Task 12. Quantify System Figures of Merit

- BP1 develops individual unit ops figures of merit
- This task quantifies improvement in system figures of merit
- Provides summary information on these improvements
- Will include projected improvements compared to realized improvements in:
  - Efficiency
  - Robustness
  - Scalability

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Task 13. TEA – Technical Approach

- Objective is to quantify theoretical improvements based on:
  - Improvement to units ops in BP1
  - Results of in-house and field testing in BP2
- Continuation of previous period, and will use similar analysis methods

Task 14. EH&S Risk Assessment – Technical Approach

- Work with Tri-State to develop formal safety assessment
- Elements of EH&S Assessment
  1) All potential ancillary or incidental air and water emissions, and solid wastes identified
  2) Description of various toxicological effects of the substances in above
  3) Properties related to volatility, flammability, explosivity, etc
  4) Compliance and regulatory implications
  5) Engineering analysis of potentially hazardous materials
  6) Precautions for safe handling and conditions for safe storage

CCC Dev Gantt Chart

	Start Date	End Date	Cost	Budget Period 1 10/1/2016-9/30/2017 Q1	Q2	Q3	Q4	Budget Period 2 10/1/2017-3/31/2019 Q5	Q6	Q7	Q8	Q9	Q10
Task 1. Project Management and Planning	10/1/2016	3/31/2019	$190,164.65										
Subtask 1.1 Project management	10/1/2016	3/31/2019											
Milestone 1.1 Submit management plan	10/31/2016	10/31/2016											
Milestone 1.2 Complete project kick-off meeting	12/9/2016	12/9/2016											
Subtask 1.2 Briefings and reports	10/1/2016	3/31/2019											
Subtask 1.3 Host site coordination	10/1/2016	3/31/2019											
Task 2. Drying	10/1/2016	9/30/2017	$35,929.59										
Milestone 2.1 Select drying approach	3/31/2017	3/31/2017											
Task 3. Dissolved Carbon Dioxide	10/1/2016	9/30/2017	$546,176.67										
Milestone 3.1 Select solubility approach(es)	3/31/2017	3/31/2017											
Milestone 3.2 Solubility Equipment Ordered and Received	6/30/2017	6/30/2017											
Task 4. Solid Liquid Separations	10/1/2016	9/30/2017	$577,502.33										
Milestone 4.1 Select solid–liquid separation approach(es)	12/31/2016	12/31/2016											
Task 5. Heat Exchanger Testing	10/1/2016	9/30/2017	$456,530.78										
Milestone 5.1 Select experimental heat exchanger approach(es)	3/31/2017	3/31/2017											
Milestone 5.2 Receive experimental heat exchanger equipment	6/30/2017	6/30/2017											
Task 6. Instrumentation and Controls	10/1/2016	9/30/2017	$596,206.44										
Task 7. Light Gas Dispersal	4/1/2017	9/30/2017	$22,664.07										
Milestone 7.1 Select light-gas dispersal approach	6/30/2017	6/30/2017											
Task 8. Multipollutant Capture	10/1/2016	9/30/2017	$108,801.65										
Milestone 8.1 Complete validation of simulator with comprehensive pollutant description	9/30/2017	9/30/2017											
Task 9. Phase 1 Techno-Economic Analysis	10/1/2016	9/30/2017	$122,507.04										
Milestone 9.1 Demonstrate simulator with new unit ops	3/31/2017	3/31/2017											
Milestone 9.2 Complete techno-economic analysis including skid simulation with new processes validated at UO level	9/30/2017	9/30/2017											
Task 10. Skid Modification and Shakedown	10/1/2017	9/30/2018	$1,158,993.10										
Milestone 10.1 Finalize plans to modify skid	12/31/2017	12/31/2017											
Milestone 10.2 Complete skid modifications	8/31/2018	8/31/2018											
Milestone 10.3 Complete skid shakedown testing	9/30/2018	9/30/2018											
Task 11. Skid Operation	4/1/2018	3/31/2019	$739,010.26										
Subtask 11.1 Test Plan	4/1/2018	9/30/2018											
Milestone 11.1 Finalize test plan	9/30/2018	9/30/2018											
Subtask 11.2 Host site agreement	4/1/2018	9/30/2018											
Milestone 11.2 Finalize host site agreement	9/30/2018	9/30/2018											
Subtask 11.3 Operation	10/1/2018	3/31/2019											
Milestone 11.3 Complete skid testing	3/31/2019	3/31/2019											
Task 12. Quantify System Figures of Merit	10/1/2017	3/31/2019	$76,877.87										
Milestone 11.1 Finalize figures of merit definition	12/31/2017	12/31/2017											
Milestone 11.2 Demonstrate figures of merit	3/31/2019	3/31/2019											
Task 13. Phase 2 Techno-Economic Analysis	10/1/2017	3/31/2019	$160,714.31										
Milestone 13.1 Complete techno-economic analysis	3/31/2019	3/31/2019											
Task 14. Environmental Health and Safety	12/31/2017	3/31/2019	$92,269.17										
Milestone 14.1 Complete EH&S risk assessment	3/31/2019	3/31/2019											

BP1 Milestones

Budget Period	ID	Task Number	Description	Planned Completion Date	Verification Method
1		1	Submit Project Management Plan	10/31/2016	Project Management Plan submitted to NETL/DOE
1		1	Complete project kick-off meeting	12/9/2016	In person kick-off meeting for project; project kick-off meeting slides submitted to NETL/DOE
1		2	Select drying approach	3/31/2017	First conceptual plan submitted in Quarterly Report to NETL/DOE
1		3	Select solubility approach(es)	3/31/2017	Finalized conceptual plan submitted in Quarterly Report to NETL/DOE
1		3	Solubility equipment ordered & received	6/30/2017	Receipt of solubility equipment documented in Quarterly Report to NETL/DOE
1		4	Select solid–liquid separation approach(es)	12/31/2016	Finalized conceptual plan submitted in Quarterly Report to NETL/DOE
1		5	Select heat exchanger approach(es)	3/31/2017	Finalized conceptual plan submitted in Quarterly Report to NETL/DOE
1		5	Receive experimental heat exchanger equipment	6/30/2017	Receipt of heat exchanger equipment documented in Quarterly Report to NETL/DOE
1		7	Select light-gas dispersal approach	6/30/2017	Finalized conceptual plan submitted in Quarterly Report to NETL/DOE
1		8	Complete validation of simulator with comprehensive pollutant description	9/30/2017	Simulation results submitted in Quarterly Report to NETL/DOE
1		9	Demonstrate simulator with new unit ops	3/31/2017	Simulation results submitted in Quarterly Report to NETL/DOE
1		9	Complete techno-economic analysis including skid simulation with new processes validated at UO level	9/30/2017	Techno-Economic Analysis Report submitted to NETL/DOE

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BP2 Milestones

2		10	Finalize plans to modify skid	12/31/2017	Designs of new unit ops submitted in Quarterly Report to NETL/DOE
2		10	Complete skid modifications	8/31/2018	Details of skid modification submitted in Quarterly Report to NETL/DOE
2		10	Complete skid shakedown	9/30/2018	Test results and any resulting skid modifications submitted in Quarterly Report to NETL/DOE
2		11	Finalize test plan	9/30/2018	Details of test plan submitted in Quarterly Report to NETL/DOE
2		11	Finalize host site agreement	9/30/2018	Details of host site agreement submitted in Quarterly Report to NETL/DOE
2		11	Complete skid testing	3/31/2019	Field testing results submitted in Quarterly Report to NETL/DOE
2		12	Figures of merit definition finalized	12/31/2017	Definition of figures of merit submitted in Quarterly Report to NETL/DOE
2		12	Demonstrate figures of merit	3/31/2019	Figures of merit submitted in Quarterly Report to NETL/DOE
2		13	Complete techno-economic analysis	3/31/2019	Techno-Economic Analysis Report submitted to NETL/DOE
2		14	Complete EH&S risk assessment	3/31/2019	EH&S Risk Assessment Report submitted to NETL/DOE

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Budget Period 1 Success Criteria

Drying	Verified solution which will reduce the dewpoint temperature of the flue gas to a maximum of -70 C with a total parasitic load increase of less than .247 GJ/tonne CO_2, while still maintaining over 90% CO_2 capture
Dissolved CO_2	Parasitic load from solution to dissolved CO_2 less than .1 GJ/tonne CO_2 captured
Solid-Liquid Separations	Demonstration of experimental solid-liquid separations system with the system achieving 70 wt% of solid CO_2 in the effluent stream at ½ tonne/day CO_2 captured for a minimum 50-hour test run Solution should not increase the overall parasitic load more than .1 GJ/tonne CO_2
Heat Exchanger	Final heat exchanger design that will be incorporated demonstrated at a minimum ½ tonne/day at above 90% CO_2 capture for 50-hour test run
Light Gas Dispersal	Dispersal technique that is approved by a certified Safety Engineer

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Budget Period 2 Success Criteria

Demonstration Unit	Demonstration Unit - 500 Hour continuous run at 1 tonne/day CO2 flowrate at 90% CO2 capture
Techno-Economic Analysis	Finalized techno-economic analysis for full scale system that has been thoroughly reviewed by sub-contractors reflecting a parasitic load of less than 1.1 GJ/tonne CO2 captured

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BP1 Success Criteria - Drying

- Verified solution which will reduce the dewpoint temperature of the flue gas to a maximum of -70 C with a total parasitic load increase of less than .247 GJ/tonne CO_2, while still maintaining over 90% CO_2 capture

BP1 Success Criteria – Dissolved CO_2

- Experimentally demonstrate solution that reduces the parasitic load to less than .1 GJ/tonne CO_2

BP1 Success Criteria – Solid-Liquid

- Demonstration of experimental solid-liquid separations system with the system achieving 70 wt% of solid CO_2 in the effluent stream at ½ tonne/day CO_2 captured for a minimum 50-hour test run
- Solution should not increase the overall parasitic load more than .1 GJ/tonne CO_2

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BP1 Success Criteria - HX

- Final heat exchanger design demonstrated at a minimum ½ tonne/day at above 90% CO2 capture for 50-hour test run

BP1 Success Criteria – Light Gas Dispersal

- Dispersal technique that is approved by a certified Safety Engineer

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BP2 Success Criteria - Demonstration

- Demonstration Unit - 500 hour continuous run at 1 tonne/day CO_2 flowrate
- Demonstration at over 90% capture

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BP2 Success Criteria - TEA

- Finalized techno-economic analysis for full scale system that has been thoroughly reviewed by sub-contractors reflecting a parasitic load of less than 1.1 GJ/tonne CO_2 captured at full scale and at 90% Capture
- Cost of less than $40/tonne CO_2

BUDGET

Project Funding Profile

	Budget Period 1		Budget Period 2		Total Project	
	10/1/2016-9/30/2017		10/1/2017-3/31/2019			
	Government Share	Cost Share	Government Share	Cost Share	Government Share	Cost Share
SES	$1,422,662	$996,100	$2,169,883	$0	$3,592,545	$996,100
BYU	$15,000	$0	$25,000	$0	$40,000	$0
Tri-State Generation and Transmission	$0	$28,000	$0	$42,000	$0	$70,000
Electric Power Research Institute (EPRI)	$50,919	$34,497	$59,785	$40,503	$110,704	$75,000
Total	**$1,488,581**	**$1,058,597**	**$2,254,668**	**$82,503**	**$3,743,249**	**$1,141,100**
Cost Share		42%		4%		23%

Quarterly Project Costing Profile

	Total for Budget Period 1	10/1/2016-12/31/2016	1/1/2017-3/31/2017	4/1/2017-6/30/2017	7/1/2017-9/30/2017
Federal	$1,488,581	$366,479	$366,479	$377,811	$377,811
Non-Federal	$1,058,597	$1,011,724	$15,624	$15,624	$15,624
Total	$2,547,178	$1,378,204	$382,104	$393,436	$393,436

	Total for Budget Period 2	10/1/2017-12/31/2017	1/1/2018-3/31/2018	4/1/2018-6/30/2018	7/1/2018-9/30/2018	10/1/2018-12/31/2018	1/1/2019-3/31/2019
Federal	$2,254,666	$340,814	$350,868	$535,620	$535,620	$245,872	$245,872
Non-Federal	$82,503	$6,751	$15,151	$15,151	$15,151	$15,151	$15,151
Total	$2,337,169	$347,564	$366,018	$550,771	$550,771	$261,023	$261,023

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Budget Period/Fiscal Year Project Costing

Budget Period	Fiscal Year (year in which the cost will be incurred, not appropriated)	Performing Organization	Planned Costs	
			Federal Share	Non-Federal Share
1	FY2017	SES	$1,422,662.00	$996,100.00
2	FY2018	SES	$1,446,588.67	$0.00
2	FY2019	SES	$723,294.33	$0.00
1	FY2017	BYU	$15,000.00	$0.00
2	FY2018	BYU	$16,666.67	$0.00
2	FY2019	BYU	$8,333.33	$0.00
1	FY2017	Tri-State Generation and Transmission	$0.00	$28,000.00
2	FY2018	Tri-State Generation and Transmission	$0.00	$28,000.00
2	FY2019	Tri-State Generation and Transmission	$0.00	$14,000.00
1	FY2017	EPRI	$50,919.00	$34,497.00
2	FY2018	EPRI	$39,856.67	$27,002.00
2	FY2019	EPRI	$19,928.33	$13,501.00

RISK ANALYSIS

Technical Risks

Risk Description	Probability (Low, Moderate, High)	Impact (Low, Moderate, High)	Risk Management Mitigation and Response Strategies
Operating desublimating HX: Fouling, plugging	Low	High	Camera inside HX to observe conditions, ability to vary inlet temperatures and flowrates to flush solids buildup
Operating desublimating HX: Liquid level upsets	Low	Moderate	Constant level monitoring with alarms, programmed controls to counteract upset, liquid containment to stop overflow
Major equipment failure	Low	High	Purchase high-quality equipment, follow maintenance schedules, regular review of equipment performance
Sensing & control failures	Moderate	Moderate	Redundant sensors when possible, built-in control warnings of problems
CO_2 solubility solutions difficult to implement at this scale	Moderate	Moderate	Mitigation plans such as self-cleaning heat exchangers or a fluidized bed heat exchanger which at this scale that may be less efficient than at larger (e.g., pilot- or full-scale) scale, but will demonstrate the overall effect of the solubility solutions on system
Dryer: insufficient water removal	Moderate	High	Designing a HX similar to the desublimating HX for water removal, increasing the inlet gas pressure, adding an additional bank of mol-sieve dryers
Dryer: cost too high for system implementation	Moderate	High	Implementing HX similar to desublimating HX for water removal
Dryer: footprint too large, thus limiting field test sites	Low	Moderate	Negotiate for field test sites with ample ground for a larger-than-expected process footprint
Dryer: pressure drop too high	Low	Moderate	Over-sizing blower to ensure sufficient pressure
Solid–liquid separation unreliable	Moderate	Moderate	Explore alternative separation system(s) that are not yet commercially mature under these conditions

Additional Risks

Resource Risks			
Reliance on 3rd-party vendors, specifically the difficulty of working with vendors for first-of-its-kind equipment	Moderate	Moderate	Get quotes from multiple vendors for equipment, allowing for fast turnaround if a vendor can no longer provide the equipment, and have back-ups for particularly sensitive pieces of equipment such as pumps in case of failure
Coordination with solid–liquid separations scaling companies	Moderate	Moderate	Looking for additional partners, creating in-house capabilities
Management Risks			
Loss of key personnel	Low	High	SES works hard—and succeeds—at providing an attractive work environment to help retain personnel. SES requires a thorough information transfer from departing personnel to ensure our ability to continue work on affected projects
IP risks	Low	Moderate	Recently completed agreements with NewVistas Capital have substantially addressed these issues and will allow for a broadening of the patent portfolio

Appendix Slides

More than Carbon Capture

CCC provides for clean, affordable electricity from fossil fuels and can capture CO_2, SO_X, Mercury, and particulates in one process

CCC also allows for better use of renewables through grid-scale **energy storage**

In addition to CCC SES has other solutions under development.

- Cryogenic natural gas processing (gas sweetening, NGL, LNG)
- Dynamically responding heat exchangers

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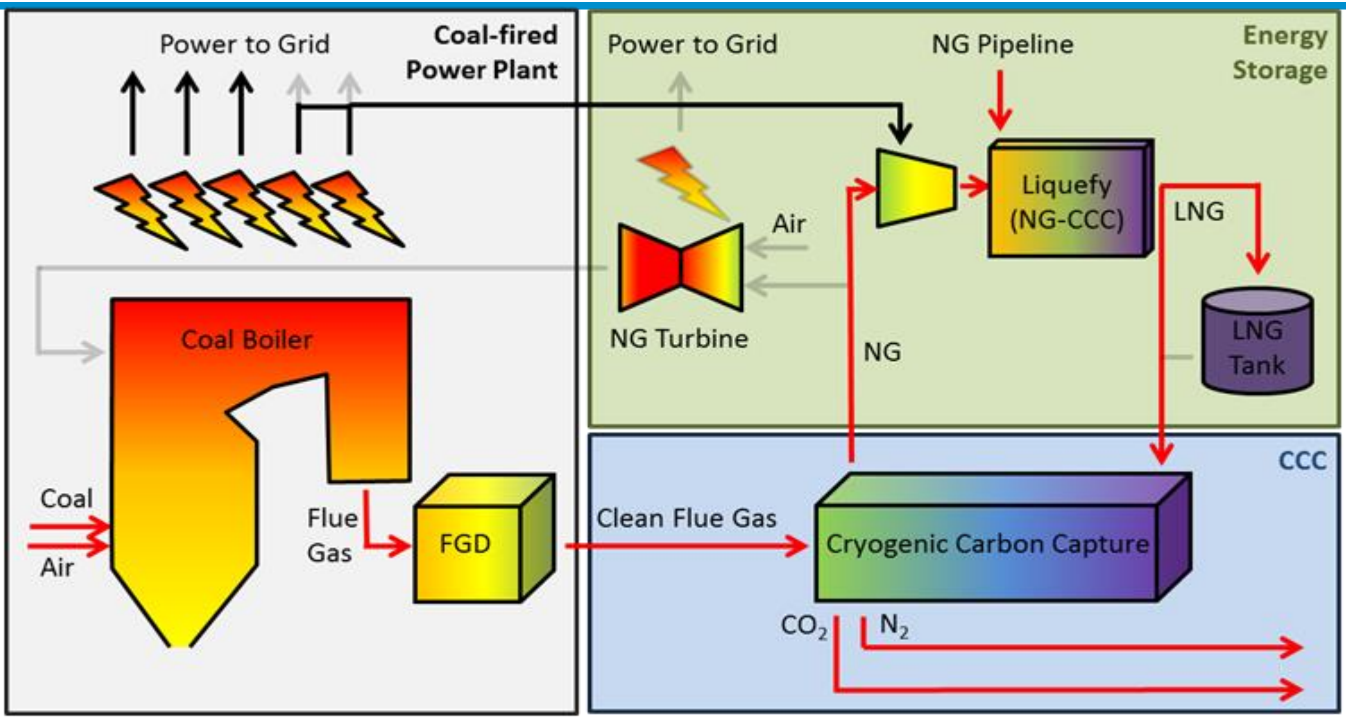
Energy Storing



Energy Storage Could Nearly pay For Carbon Capture

- An 800 MW_e Coal plant with CCC stabilized +/- 400 MW_e supply swings from renewables
- 2.1-2.7 ¢/kWh in value compared with 2.5 ¢/kWh cost of CCC
- Using 12-months of real data from Southern California

Model Results

- An 800 MW_e power plant with CCC stabilized +/- 400 MW_e grid surges associated with periodic demand cycles and intermittent renewable availability with no need for spinning reserves or other supplementary power.
- Power demand cycles, wind availability, and general costs taken from actual grid data (southern California).
- 250 MW_e surge in wind power that occurs in the evening, as power demand generally is in rapid decrease, was effectively absorbed by CCC and delivered the next day during peak power.
- Similar load following with coal being constant is possible, but requires larger storage tank and NG replacement rate.

Economic Bottom Line

- Energy Storage Increases Net Revenue (Profit)
  - 22-30% increase in profit with storage
  - Translates to an additional 2.1-2.7 ¢/kWh additional revenue
- CCC process costs comparable (2.3-3.1 ¢/kWh)
- Additional benefits not included in these costs
  - No need for backup power for wind and no price suppression from wind
  - Major equipment operates at essentially steady load, increasing useful lifetime and decreasing unplanned shutdowns and scheduled and unscheduled maintenance.
  - Integrates diverse power sources effectively
  - Greatly increases the value of intermittent power sources
  - Enable permits
  - Decreases need for spinning reserve and peaking power (both very costly)

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