Carbon Engineering

Dilute Source CO_2 Capture: Management of Atmospheric Coal-Produced Legacy Emissions

FE0026861

Carbon Engineering

Management Team

Adrian Corless
CEO

David Keith
Exec Chair / Founder

David St. Angelo
CTO

Susan Koch
CFO

Jean-François Béland
VP Corporate Strategy

Investors / Partners

- Bill Gates
- Murray Edwards

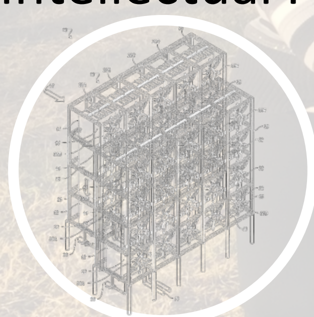
Canada

SPX   Royal HaskoningDHV   STT   Technip

Team

- 26 employees
- Target ~30 by end-2017

Intellectual Property



8 patent families:

- P-Ca process
- Air Contactor
- Low-CI fuel manufacture

Headquarters

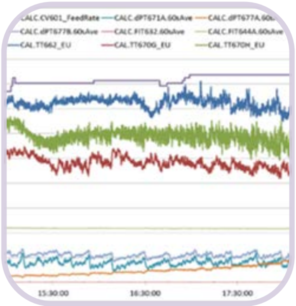
SQUAMISH

Recognition

$25 M
Virgin Earth
Challenge
Finalist

Project Overview

Overall Project Objectives



Cultivate a dilute source CO_2 DAC technology that can be applied to re-capture legacy coal-based emissions directly from the atmosphere

Develop a better understanding of DAC performance through lab and pilot study, and codifying these results in TEA format

Project Overview

Funding, Participants and Performance Dates

Total Project Budget: $1.875 M USD

Federal Cost Share: 80% ($1.5 M USD)

Non-Federal Cost Share: 20% ($375 k USD)

Project Participants: Carbon Engineering

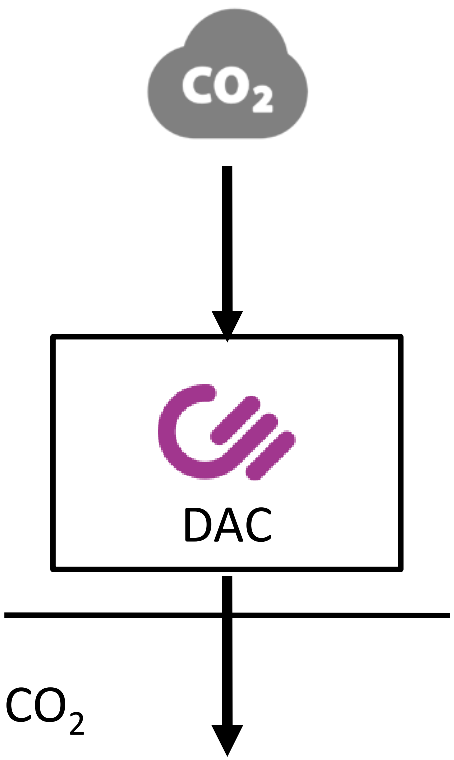
Project Performance Periods:

BP1: 2016-09-19 – 2017-09-18
BP2: 2017-09-19 – 2018-09-18

DAC: Direct Air Capture of CO_2

Carbon Engineering

Inputs: Air, water, energy.



Output: CO_2

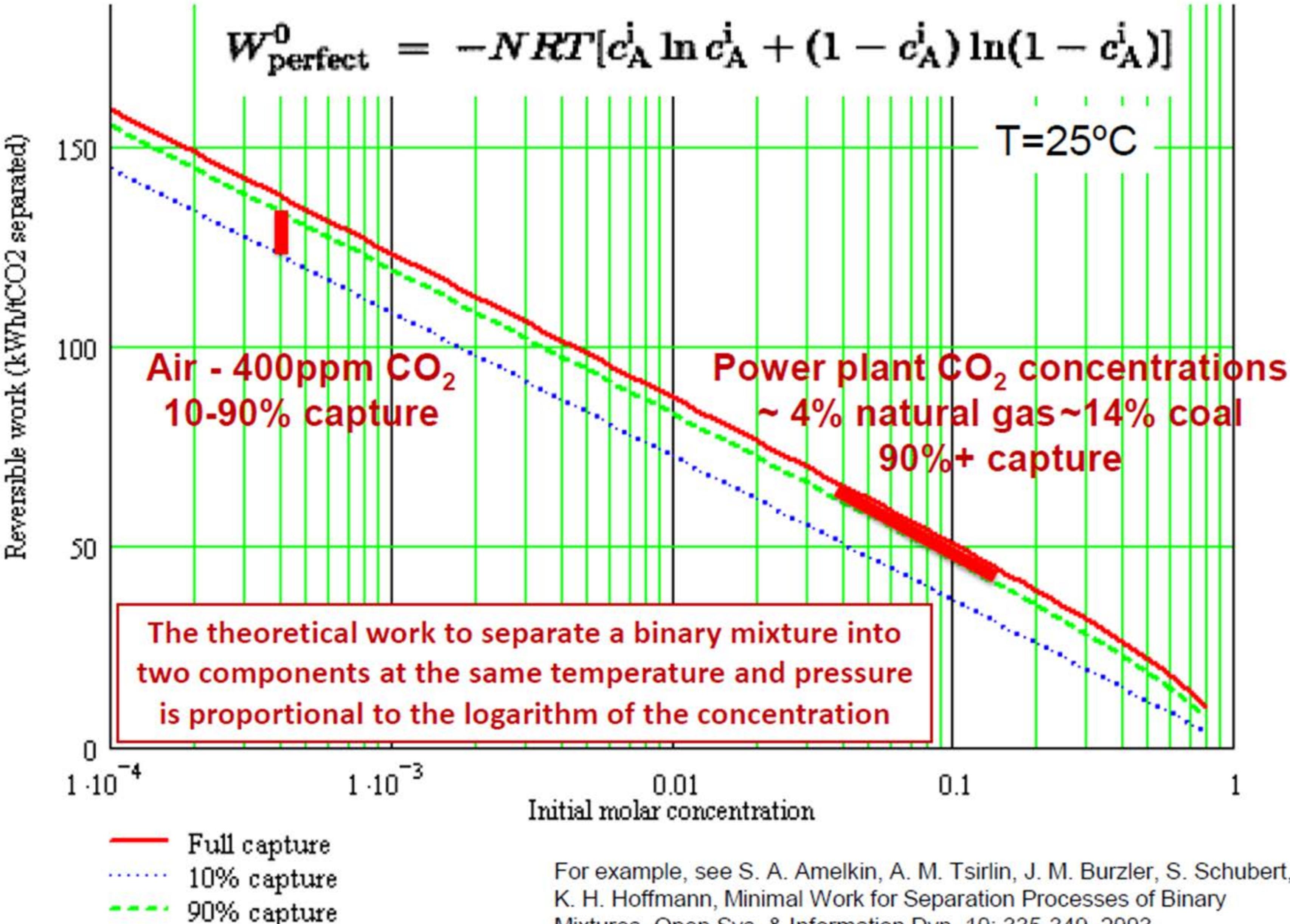
storage, industrial use, or fuel production

Strategic and Transformative Technology:

- Negative Emission Technology
- Can locate anywhere
- Manages emissions from any source
- Highly scale-able

Compared to CCS:

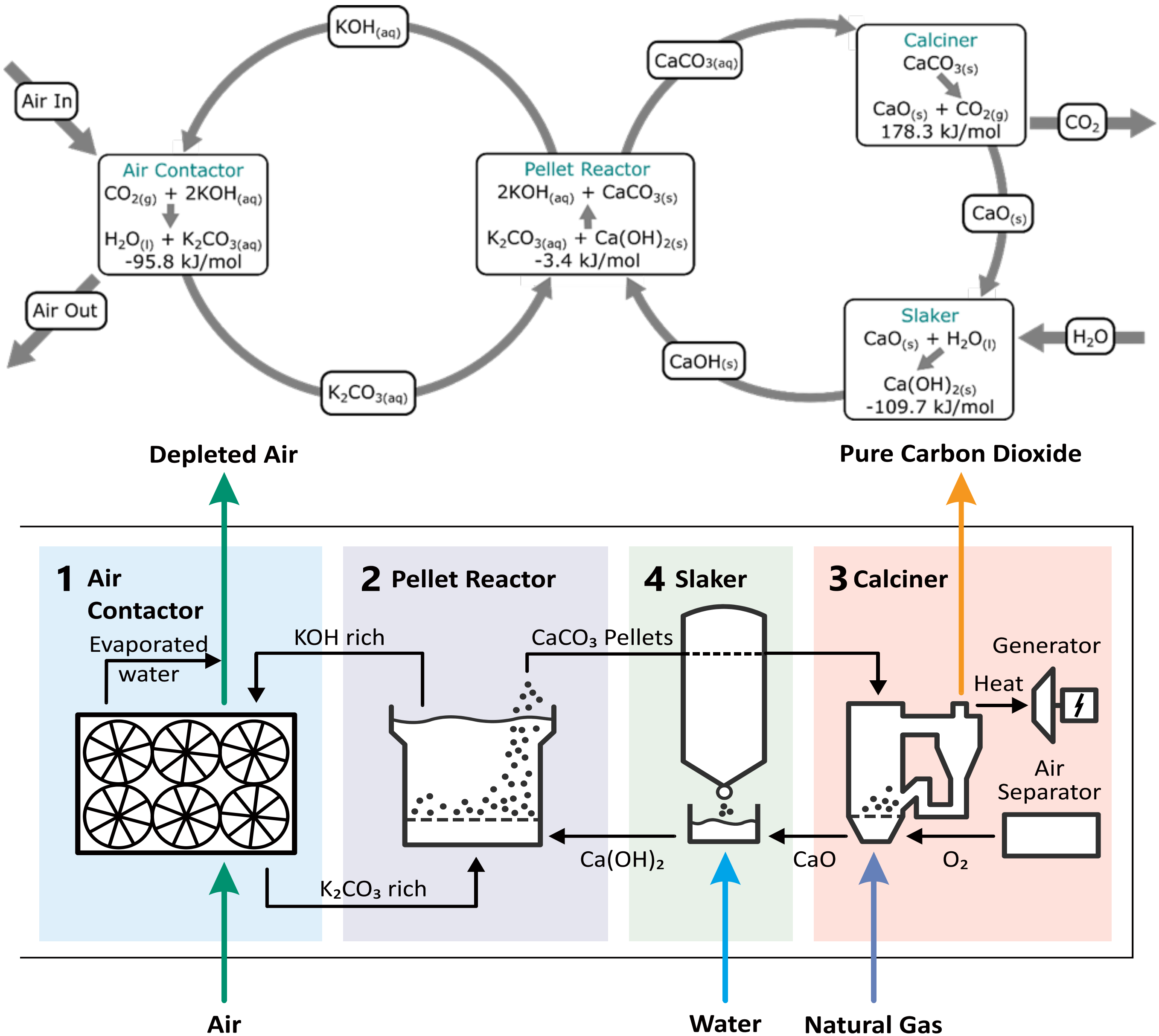
- Higher thermodynamic barrier
- Larger air volume to be processed



For example, see S. A. Amelkin, A. M. Tsirlin, J. M. Burzler, S. Schubert, K. H. Hoffmann, Minimal Work for Separation Processes of Binary Mixtures, Open Sys. & Information Dyn. 10: 335-349, 2003.

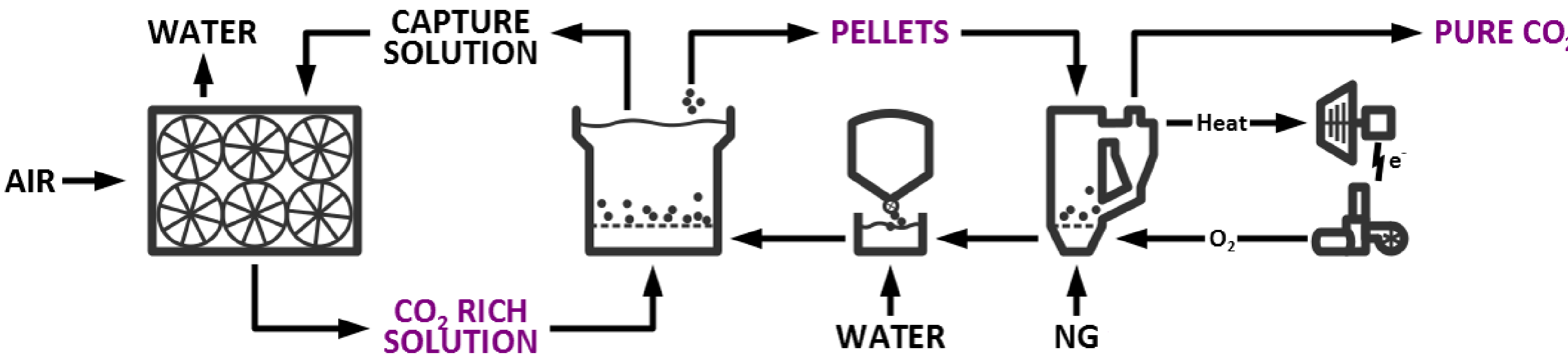
CE's DAC Technology

Carbon Engineering



CE's DAC Technology - Partnerships

Carbon Engineering



SPX

Leading global cooling tower supplier.

Key technical similarities with CE air contactor.

Supplying CE air contactor.

Joint engineering and development.

Royal HaskoningDHV

Pelletization technology holders for wastewater.

3 years collaboration on CE's pellet reactor unit.

Supplying CE pellet reactor.

Continued joint development.

Technip

Global EPC, plus ore roasters and kilns.

Joint development of CE's CFB kiln.

Technical oversight for CE pilot calciner.

Calciner technology provider.

Hardware Development History

2005: Spray Tower

2008: Packed Tower

2010: Lab air contactor

2013: Pellet Reactor Tests

2011-2012: Air Contactor Prototype

2013: Calciner Tests

2014-2015: Full end-to-end pilot plant

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Project Structure

Project Management

Materially advance state of the art of dilute source CO_2 capture:

Tasks 2 and 3

Pilot Operation, Sensitivity Analysis, and Component Optimization

Testing, Performance Analysis, and Technology Optimization

Move technology towards commercialization:

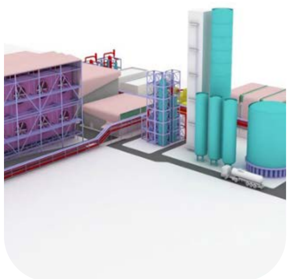
Tasks 4 and 5

Engineering Input for Scale-up and Technology Cost Projections

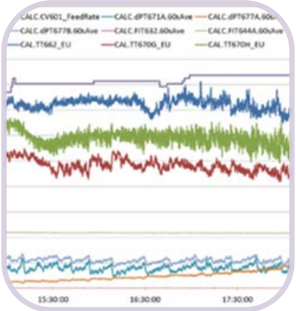
Technology Cost Projections and Technical Assessment of Applicability to Coal Stream

Project Objectives – Tasks 2 & 3

Overall Operation and Lab Objectives



Cultivate a dilute source CO_2 DAC technology that can be applied to re-capture legacy coal-based emissions directly from the atmosphere

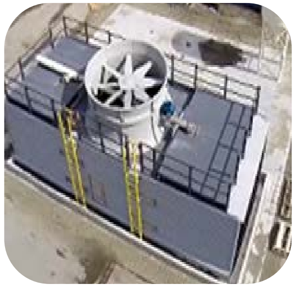


Develop a better understanding of DAC performance

Capitalize on CE's DAC Pilot Research Platform, research program and technical expertise to achieve the above objectives – DOE Project Tasks 2 & 3

Technical Activities: Budget Period 1 (Task 2)

2: DAC Applied Research and Development



Pilot Operations:

2.1: Sensitivity Analysis and Testing

2.3: System and Component Stress Testing

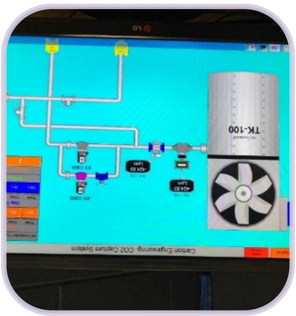
DAC Development and Enhancement:

2.2: Technology Research and Development

2.4: Sub-system Optimization

What programs leveraging CE's DAC Pilot Research Platform are available to deliver the above learnings?

Air Contactor Performance Testing



Achieve low solvent loss, high mass transfer and increase energy efficiencies

Fan, liquid pumping power tests

Solvent loss measurement at different conditions

Water use monitoring

Packing design (R&D)

Nozzle and Basin Design (R&D)

Technical Activities: Budget Period 1 (Task 2)

Pellet Reactor Performance Testing

Achieve high retention, and loading rates with low pumping and capital requirements

Fluid velocity testing

Lime injection optimization

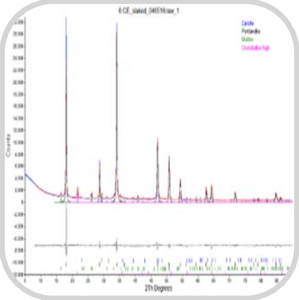
Pellet composition/purity analyses

Process solution condition testing

Technical Activities: Budget Period 1 (Task 2)

Slaker Performance Testing

Achieve highly reactive, slaked lime slurry from calcined CaO



Grit, impurity content

Temperature

Particle size

Slurry pumpability

Technical Activities: Budget Period 1 (Task 2)

Calciner Performance Testing

Achieve calcination of feedstock pellets over extended run times long enough to collect data and prove system operability

Temperature envelope

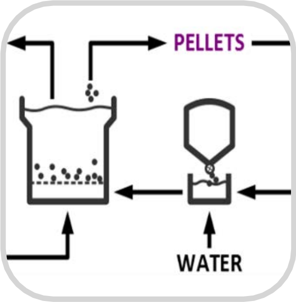
Alkali and impurity solids content over time

Lime mud toleration

Alternative fuels

Technical Activities: Budget Period 1 (Task 2)

Overall System Testing



Achieve high operating hours, collect operations and maintenance data

Long term data logging – operations and maintenance

Stress Testing

NPE and misplaced PE buildup monitoring

Solution/process conditions

Technical Activities: Budget Period 2 (Task 3)

3: DAC Applied Research and Development

Pilot Operations and Testing:

3.2: Long term effects

DAC Development and Enhancement:

3.1: Application and Implications

3.3: Alternative Technologies Investigation

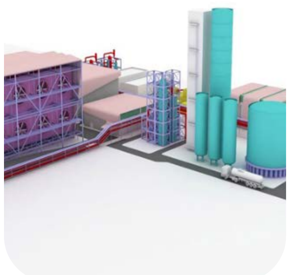
Technology Optimization:

3.4: Data Analysis and Ongoing Development

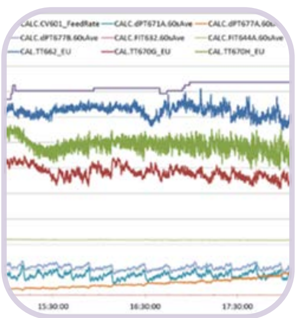
3.5: Synthesis of Results and Recommendations

Project Objectives – Tasks 4 & 5

Overall Engineering and Costing Objectives



Advance technological readiness of direct air capture system by developing better understanding of system costs through TEA

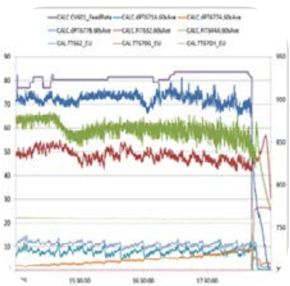


Develop commercial-scale specifications for major equipment through engagement with vendors

Leverage results from CE's DAC research platform pilot in Tasks 2 & 3 to deepen understanding of costs at commercial scales

Technical Activities: Budget Period 1 (Task 4)

4: Engineering Input for Scale-up and Cost Projections



Engineering Inputs to Scale:

4.1: Define performance characteristics for commercial scale up activities

Technology Analysis Plan:

4.2: TAP based on existing engineering and data

Commercial Readiness of DAC:

4.3: Major Equipment Specification and Vendor Engagement

Technical Activities: Budget Period 2 (Task 5)

5: Engineering Input for Scale-up and Cost Projections

Engineering Inputs to Scale:

5.2: Design Basis for Commercial Scale-up

Techno-Economic Assessment:

5.3: DAC Applicability to Coal – Technology Assessment

Commercial Readiness of DAC:

5.1: Core engineering: 1st order commercial plant design

5.4: Gap and Deficiency Identification, Path Forward

Technical Activities

Project Risks and Mitigation

<u>Technical Risks</u>

System Component Underperformance

<u>Mitigation</u>

On-going relationships with industrial equipment vendors

<u>Project Execution Risks</u>

Research Pilot is damaged or land becomes unavailable

<u>Mitigation</u>

Detailed SOP and HSE Policy
Good relationship with lessor

<u>Resource Risks</u>

Failure to acquire sufficient resources for the project

<u>Mitigation</u>

CE well funded and staffed
Will hire as necessary

Project Schedule: BP1 (2016 Sep 19 – 2017 Sep 18)

Project Schedule	Q1	Q2	Q3	Q4
Task 1.0 - Project Management	■	■	■	■
1.1 - Management	■	■	■	■
1.2 - Reports	■	■	■	■
1a - Annual Report				◊
Task 2.0 - DAC R&D, Ops, Testing, Optimization				
2.1 - Sensitivity Analysis & Testing	■	■		
2.2 - DAC Technology R&D		■	■	
2.3 - Stress Testing			■	■
2.4 - Sub-System Optimization			■	■
2a - Synthesis Data Log Complete			◊	
2b - R&D Results ready for Pilot Plant Input			◊	
Task 4.0 - Engineering for Scale-Up				
4.1 - Key Engineering Inputs	■	■		
4.2 - Preliminary TAP	■	■		
4.3 - Vendor Engagement			■	■
4a - Updated PFDs and Vendor RFQs				◊

Project Schedule: BP2 (2017 Sep 19 – 2018 Sep 18)

Carbon Engineering

	Budget Period 2			
	2017/10/07 - 2018/09/18			
Project Schedule	**Q1**	**Q2**	**Q3**	**Q4**
Task 1.0 - Project Management	■	■	■	■
1.1 - Management	■	■	■	■
1.2 - Reports	■	■	■	■
1b - Final Report				◊
Task 3.0 - Applied R&D, Testing, Analysis, Optimization				
3.1 - Enhancement Applications and Implications	■	■		
3.2 - Long Term Effects	■	■		
3.3 - Solids Research	■			
3.4 - Data Analysis and Ongoing Development		■	■	
3.5 - Data Preparation for Final Report				■
3a - Identify Feasible Alternatives Path Forward	◊			
3b - Complete Long Term Effects Research			◊	
Task 5.0 - Cost Projections and Applicability to Coal Stream				
5.1 - Technology Cost Projections	■	■		
5.2 - Commercial Scale-Up Design Basis		■	■	
5.3 - DAC Applicability to Coal - Technology Assessment		■	■	
5.4 - Gap and Deficiency Identification			■	■
5a - Major Equipment Specs and Cost Model		◊		
5b - Engineering Assessment, Full Plant Cost Model				◊

BP1 Milestones

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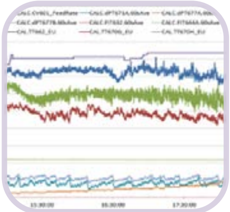
Budget Period	ID	Task Number	Description	Planned Completion Date	Verification Method
1	1a	1.0	DMP Completed	2016/12/19	DMP Submitted to DOE
1	1b	1.0	Year 1 Annual Report and Updated Project Management Plan	2017/09/30	Project Management Plan File and Report
1	2a	2.0	Synthesis Data Showing >3000 hours Pilot Operation	2017/07/01	Synthesis Data Log
1	2b	2.0	Research results from lab and technology integration ready for input to prototype development	2017/07/01	Research Summary Files
1	4a	4.0	Updated Process Flow Diagram and Vendor Request for Quote	2017/09/30	Process Flow Diagram

BP2 Milestones

Carbon Engineering

Budget Period	ID	Task Number	Description	Planned Completion Date	Verification Method
2	1c	1.0	Project Final Report	2018/09/18	Final Report
2	3a	3.0	Identification of Feasible Alternative Technologies and Path Forward	2017/12/31	Path Forward File
2	3b	3.0	Pilot Operations - Completion of Long-term Effects Research	2018/06/30	Long-term Effects Research File
2	5b	5.0	Engineering Assessment, Full Plant Cost Model	2018/09/18	Cost Model File

Progress and Current Status – Tasks 2, 4



Materially advance state of the art of dilute source CO_2 capture

Task 2

Task Objectives

- Cultivate a dilute source CO_2 DAC technology that can be applied to re-capture legacy coal-based emissions directly from the atmosphere
- Develop a better understanding of DAC performance

Current Status

- > 3000 hours DAC pilot operations during project reporting period (>7500 hours total)
- Baseline testing completed
- Achieved Air Contactor Mass Transfer success criteria
- Achieved calciner success criteria
- Achieved various PR success criteria

Move Technology Towards Commercialization

Task 4

Task Objectives

- Advance technological readiness of direct air capture system by developing better understanding of system costs through TEA
- Develop commercial-scale specifications for major equipment through engagement with vendors

Current Status

- Completed initial review of Technology Analysis Plan (TAP) document with DOE
- Developing detailed PFD for Techno-economic analysis

Future Work, Commercialization

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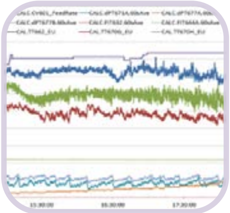


Complete Award Objectives

Further understanding of CO_2 Utilization and Market Opportunities

Current Budget Period

- Complete Tasks 2, 4, Milestones and Success Criteria
- Compile findings in final report

Near Term Planned Studies

- Pilot downstream technology for CO2 utilization

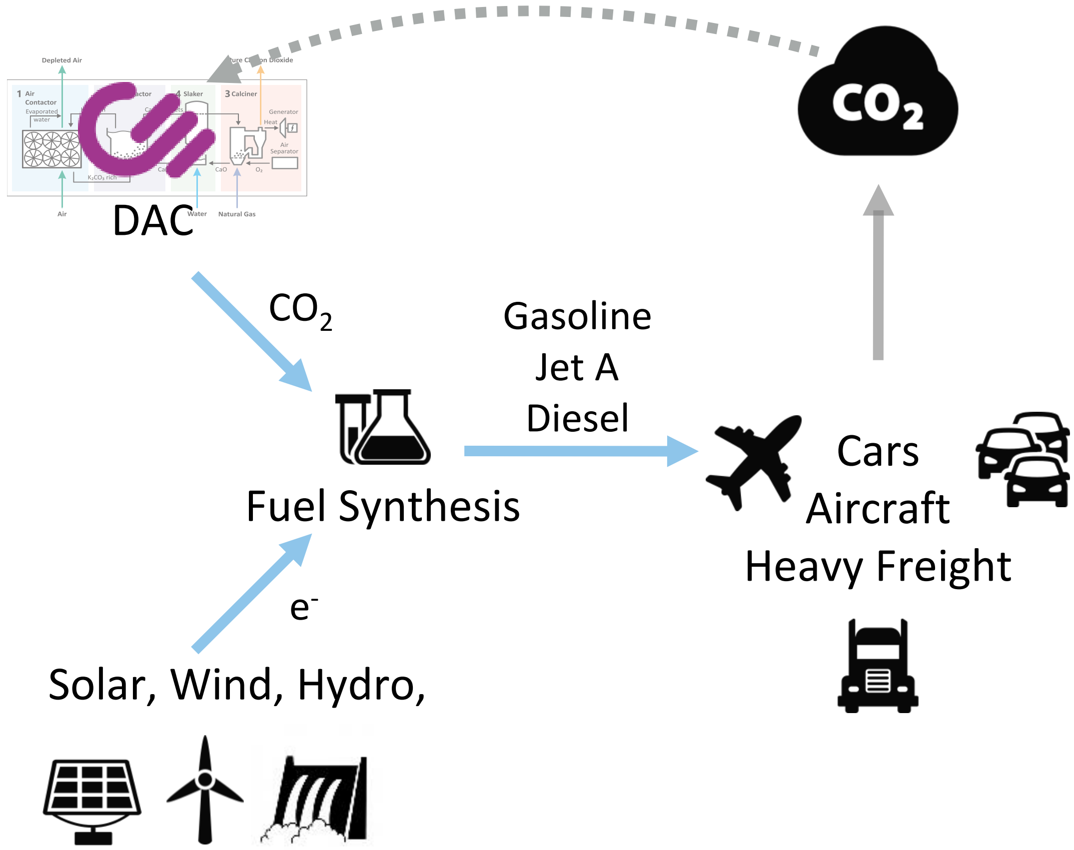
Upcoming Budget Period

- Execute Tasks 3, 5
- Long term testing and implementation of BP1 lab findings
- Complete TEA and costing study

Long Term

- Commercial validation of DAC and Fuel Synthesis processes
- Commercial deployment

“Air to Fuels” Technology



Air + H_2O + Renewables

Globally scalable supply of liquid fuels

Drop-in compatible

Enables progressive de-carbonization of transport by gradual fuel switching.

First Commercial A2F Plant

Acknowledgements

Acknowledgment: This material is based upon work supported by the Department of Energy under Award Number DE-FE0026861.

Thanks: Bruce Lani, Chuck Tomasiak

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