Outline

- Background
- Technical Approach for 10 MWe Large Pilot
- Project Details
  - Objectives
  - Project Structure
  - Project Schedule
  - Project Budget
- Risk Management
CDCL Process

- Coal enters the system.
- Volatilization occurs in the Top Section, producing Volatiles (H₂O+CO₂) and Char.
- Fe₂O₃ is produced in the Combustor.
- FeO is enhanced and enters the Bottom Section.
- The Bottom Section produces H₂O+CO₂ and Char.
- The system is designed for >96% purity,

Two-stage Counter-current Moving Bed
CDCL Commercialization Path

- OSU’s Laboratory Scale
- OSU’s Sub-Pilot 25 kW_th
- CDCL Phase I
- CDCL Phase II 250 kW_th
- HEN and Dynamic Model
- 10 MWe Pre-FEED
- 10 MWe Feasibility Study: Ph1
- Phase II&III: Large Pilot Testing 10 MW_e
- Demo 70 MW_e
- Commercial 100 - 550 MW_e

Timeline:
- 2004
- 2008
- 2011
- 2014
- 2017
- 2020
- 2023
- 2026
- 2030
- 2035
# B&W & OSU CDCL Collaboration

<table>
<thead>
<tr>
<th>Project</th>
<th>Description</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DOE</strong> Syngas CL Demo at NCCC</td>
<td>Design and demonstration of 250 kWth syngas chemical looping facility</td>
<td>2010-2017</td>
</tr>
<tr>
<td><strong>DOE</strong> Commercialization Phase I</td>
<td>Conceptual design of 550 MWe commercial plant, Techno-economic analysis (&gt;90% CO₂, &lt;35% increase in COE), Technology gap analysis</td>
<td>2012-2013</td>
</tr>
<tr>
<td><strong>DOE</strong> Phase II A</td>
<td>Laboratory cold model test, Design of 250 kWth pilot plant, Cost estimate for construction and test</td>
<td>2013-2015</td>
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<tr>
<td><strong>DOE-ODSA</strong> Phase II B</td>
<td>Construction and test of 250 kWth CDCL facility</td>
<td>2015-2017</td>
</tr>
<tr>
<td><strong>DOE-ODSA</strong> Heat Integration</td>
<td>Combustor simulation, Heat exchanger network integration and optimization, Dynamic model of integrated CDCL-steam cycle</td>
<td>2016-2018</td>
</tr>
<tr>
<td><strong>DOE-ODSA</strong> Adv. Control</td>
<td>Develop HLC-SMC process automation control architecture, Establish algorithm for high temperature ECVT sensor, Test process control and optimization concepts at 25 kWth scale</td>
<td>2015-2017</td>
</tr>
<tr>
<td><strong>DOE–ODSA 10 MWe pre-FEED</strong></td>
<td>Develop a pre-FEED of a 10MWe CDCL pilot plant</td>
<td>2017-2019</td>
</tr>
</tbody>
</table>
Development of Chemical Looping Platform Technology

DE-FE-0009761

250 kWth pilot unit

DE-NT0005289

25 kWth Sub-pilot unit

DE-FE-0023915

250 kWth SCL pilot unit

DE-FE-0026334

Control and Sensor Development

DE-FE-0029093

Combustor Development

Coal Introduction Design

System control

Interconnecting Components - Oxygen Carrier

CO₂, H₂O

Spent Air

Coal feed

Volatiles

Devolatization

Char Gasification

Enhancer gas

L-valve gas

Fe/FeO

Fe₂O₃
Particle Development

3000 Redox Cycles

Particle Strength Comparison

<table>
<thead>
<tr>
<th>Oxygen Carrier/Catalyst Particle</th>
<th>Strength (MPa)</th>
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</thead>
<tbody>
<tr>
<td>OSU OC</td>
<td>120</td>
</tr>
<tr>
<td>Other Chemical Looping Combustion</td>
<td>72</td>
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<tr>
<td>Chemical looping Steam Reforming</td>
<td>26</td>
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<tr>
<td>Commercial WGS Catalyst Pellet</td>
<td>6.8</td>
</tr>
<tr>
<td>Traditional ATR Catalyst</td>
<td>6.5</td>
</tr>
</tbody>
</table>

- Stability over 3000 redox cycles at 1000 °C; equivalent to 8 months of commercial operation
- High attrition resistance compared with commercial FCC particles in jet-cup experiment
25 kW$_{th}$ Sub-Pilot Demonstration

- > 800 hours of operational experience
- > 200 hours continuous successful operation
- Smooth solids circulation
- Complete ash separation in reducer.
- Achieve nearly pure CO$_2$ from reducer outlet
- 17 test campaigns completed
200-hour Continuous Sub-Pilot Test

Sample Data: PRB Process Performance
- Continuous steady carbon conversion from reducer throughout all solid fuel loading (5-25kWth)
- <0.25% CO and CH₄ in reducer outlet = full fuel conversion to CO₂/H₂O
- <0.1% CO and CO₂ in combustor = negligible carbon carry over, nearly 100% carbon capture
Outline

- Background
- Technical Approach for 10 MWe Large Pilot
- Project Details
  - Objectives
  - Project Structure
  - Project Schedule
  - Project Budget
- Risk Management
CDCL Technology Development

**Laboratory 2.5 kWth**
- Particle recyclability and reactivity
- Individual reactions in the reducer and combustor

**25 kWth**
- Integrated operation reducer and combustor for more than 200 hours
- Coal conversions
- \( \text{CO}_2 \) Purity

**250 kWth**
- Adiabatic reducer operation for more than 250 hours
- Process efficiency
- Evaluate emissions
- Large scale particle manufacturing
- Particle attrition

**4 x 2.5 MWe**
- Long Term operation
- Coal distribution
- Modular integration and operation - Start up, turn down, shutdown cycles
- Steam generation
- Economics

**1 x 70 MWe**
- Commercial Operation of a single module
- Fabrication
Scale Up Plan

Laboratory
2.5 kWth

Critical Dimension Scale up Factor: x1
Reducer reactor
Critical Dimension: 1.5"

25 kWth

Critical Dimension Scale up Factor: x4
Reducer reactor
Coal distribution
Distance: 6"

250 kWth

Critical Dimension Scale up Factor: x6
Reducer reactor
Coal distribution
Distance: 3’

4 x 2.5 MWe

Critical Dimension Scale up Factor: x2.3
Reducer reactor
Coal distribution
Distance: 7’

1 x 70 MWe

Critical Dimension Scale up Factor: x2.8
Reducer reactor
Coal distribution
Distance: 20’
10 MWe Modular Pilot Design

- 4 Modules of 2.5 MWe
- 1st module will be built and operated to validate the design.
- Following modules will be constructed
- Integration of the modules operation and controls
CDCL Steam Generation Scheme

Reducer

Comb

FeO/Fe

CO₂+H₂O

Coal

CO₂/Steam

Fe₂O₃

SSH

PRI

ECON

AH

Air

Precipitator

ID Fan

Stack

N₂+O₂

Feed Water

Attemp

Vertical Separator

Pump if needed

Down comer

To Membrane Walls

To Steam Turbine

CO₂/Steam
Advantage of Modular Design and Sparing Philosophy

- **Startup**
  - Sequential module startup with sharing resources

- **High Reliability**
  - Independent steam generation
  - Easier for scheduling maintenance
  - 4-33% modules provide full load capacity with module-out of service

- **Flexible Operation**
  - Fast response
  - Turn down/up
  - Particle exchange among modules
## Technology Gap and Mitigation Plan

<table>
<thead>
<tr>
<th>Design/Technology Issues</th>
<th>Past Mitigation</th>
<th>Ongoing Mitigation</th>
<th>Plan Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Particles</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Manufacturing Cost</td>
<td>Under OSU’s Scope</td>
<td>Particle Manufacturer (JM)</td>
<td>Multiple Manufacturers</td>
</tr>
<tr>
<td>Attrition</td>
<td>250 kWth / NCCC</td>
<td>Attrition Tests / 250 kWth</td>
<td>10 MWe Large Pilot</td>
</tr>
<tr>
<td>High Temperature Resistance</td>
<td>TGA</td>
<td>TGA / 250 kWth</td>
<td>10 MWe Large Pilot</td>
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<tr>
<td><strong>Reducer</strong></td>
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</tr>
<tr>
<td>Coal Injection &amp; Distribution</td>
<td>25 kWth Sub-Pilot</td>
<td>Coal RXN Model / 250 kWth</td>
<td>10 MWe Large Pilot</td>
</tr>
<tr>
<td>Char Residence Time</td>
<td>25 kWth Sub-Pilot</td>
<td>Coal RXN Model / 250 kWth</td>
<td>10 MWe Large Pilot</td>
</tr>
<tr>
<td>Ash Separation / Enhancer Gas</td>
<td>CFM / 25 kWth Sub-Pilot</td>
<td>CFM / 250 kWth</td>
<td>10 MWe Large Pilot</td>
</tr>
<tr>
<td>Char Carryover</td>
<td>CFM / 25 kWth Sub-Pilot</td>
<td>CFM / 250 kWth</td>
<td>10 MWe Large Pilot</td>
</tr>
<tr>
<td>Pressure Drop</td>
<td>Phase I /25 kWth Sub-Pilot</td>
<td>250 kWth</td>
<td>10 MWe Large Pilot</td>
</tr>
<tr>
<td>CO₂ Purity</td>
<td>25 kWth Sub-Pilot</td>
<td>250 kWth</td>
<td>10 MWe Large Pilot</td>
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<tr>
<td>Sulfur, NOx, Hg Emissions</td>
<td>25 kWth Sub-Pilot</td>
<td>250 kWth</td>
<td>10 MWe Large Pilot</td>
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<tr>
<td>Alkaline Management</td>
<td>2” BFB Studies</td>
<td>2” BFB Studies</td>
<td>10 MWe Large Pilot</td>
</tr>
<tr>
<td><strong>Combustor</strong></td>
<td></td>
<td></td>
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<tr>
<td>Heat Exchanger surface</td>
<td>B&amp;W’s CFB Technology</td>
<td>B&amp;W’s CFB Technology</td>
<td>10 MWe Large Pilot</td>
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<tr>
<td>Auto-thermal Operation</td>
<td>Phase I (Calculation)</td>
<td>250 kWth</td>
<td>10 MWe Large Pilot</td>
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<tr>
<td><strong>Process</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Operation</td>
<td>25 kWth Sub-Pilot / NCCC</td>
<td>250 kWth</td>
<td>10 MWe (modular)</td>
</tr>
<tr>
<td>Start up/Shut down</td>
<td>25 kWth Sub-Pilot / NCCC</td>
<td>250 kWth</td>
<td>10 MWe (modular)</td>
</tr>
<tr>
<td>Safety</td>
<td>25 kWth Sub-Pilot / NCCC</td>
<td>250 kWth</td>
<td>10 MWe (modular)</td>
</tr>
</tbody>
</table>
250 kW\textsubscript{th} Pilot Plant - Design

Pilot Design:
- Reducer Design
- Material and Energy Balances
- Support Structure Design
- Detail Construction Drawings

Specifications
- Materials: Refractory lined Carbon Steel
- Max Operating Temperature: 2012 °F
- Reducer: Counter-current moving bed
- Combustor: Bubbling bed
- Overall Height: 32 ft
- Footprint = 10’ x 10’
- Thermal Rating: 250 kW\textsubscript{th}
- Coal Feed Rate: 70 lb/hr
- Coal Size: Pulverized coal
- Particle Transport: Pneumatic
- Oxygen Carrier: Iron based
- Size: 1.5 mm
250 kW$_{th}$ Pilot Plant
# 250 kW<sub>th</sub> Test Campaign Summary

<table>
<thead>
<tr>
<th>Test Campaigns</th>
<th>Main Achievements</th>
<th>Lessons Learned</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Refractory bake out</td>
<td>Heated up to 1600 °F for more than 24 hrs</td>
<td>o Quench system&lt;br/o&gt; o Need extra NG injection</td>
</tr>
<tr>
<td>#2 Unit shake down, start up</td>
<td>- Reached 1800 °F&lt;br&gt;- Achieved expected solid circulation&lt;br&gt;- Characterization of&lt;br&gt;temperature/pressure&lt;br&gt;distributions, gas&lt;br&gt;sampling and analysis</td>
<td>o Coal injection pressure unbalance&lt;br/o&gt; o Blower capacity low at startup</td>
</tr>
<tr>
<td>#3 Coal injection test</td>
<td>- Reached 1950 °F&lt;br&gt;- Injected coal successfully&lt;br&gt;- High volatile conversion&lt;br&gt;- Attrition rate &lt; 0.18%/hr</td>
<td>o Air infiltration&lt;br/o&gt; o Agglomeration due to over heating</td>
</tr>
</tbody>
</table>
## Lessons Learned and Solutions

<table>
<thead>
<tr>
<th>Lessons Learned</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High flame temp may cause particle agglomeration</td>
<td>Operate burner under a leaner condition to maintain a lower flame temperature</td>
</tr>
<tr>
<td>Air should be preheated to a higher temperature to reduce burner demand</td>
<td>Modify the flange and piping to be stainless steel to allow higher inlet temp of air</td>
</tr>
</tbody>
</table>
| Air infiltration exists under vacuum condition       | • Seal the reducer better before next test  
|                                                      | • Operate under positive pressure        |
250 kW_{th} Pilot – Test Results

Attrition rate < 0.18%/hr
250 \(KW_{th}\) Pilot – Test Results

- high coal volatile conversion
- Carbon slip into the combustor not observed
Goal of Ongoing Work

- Temperature of Bottom Moving Bed reducer above 1650 °F
- Limit the amount of agglomerates and maintain long-term (>300 hours) stable solid circulation
- Demonstrate reduction-oxidation cycling of particles
- Continuous operation with coal injection for minimum 24 hours
- Coal conversion > 90%
- Attrition rate under reaction condition < 0.1%/hr
- Achieve adiabatic reducer operation
Outline

- Background

- Technical Approach for 10 MWe Large Pilot

- Project Details
  - Objectives
  - Project Structure
  - Project Schedule
  - Project Budget

- Risk Management
Phase I Objectives

• Form the team
• Secure funding and commitments
• Host site agreement
• Environmental information volume
• Cost and schedule estimates for Phase II
Phase II/III Objectives

**NETL 10 MWe PHASE II**

- 2.5 MWe module design
- CDCL integration with existing plant
- Balance of Plant (BOP) equipment specifications
- Process control specifications
- Proposal and cost estimates for Phase III

Year: 2019-2020

**NETL 10 MWe PHASE III-A**

- Construction and operation of first module
- Commissioning first module and BOP

Year: 2020-2022

**NETL 10 MWe PHASE III-B**

- Construction of remaining modules
- Commissioning and testing of full plant

Year: 2022-2025

Objective: Demonstrate 10 MWe CDCL pilot plant
Project Participants

- Federal Agencies
  - DOE/NETL

- State Agency
  - Ohio Development Services Agency

- Project Participants
  - Babcock & Wilcox (B&W)
  - Ohio State University (OSU)
  - Clear Skies Consulting
  - Dover Light & Power (DPL)
    - Trinity Consultants
    - Worley Parsons
  - Electric Power Research Institute (EPRI)

- Industrial Review Committee
  - American Electric Power
  - Duke Energy
  - FirstEnergy
  - CONSOL Energy
  - Johnson Matthey (JM)
# Division of Responsibility

<table>
<thead>
<tr>
<th>Team</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Babcock &amp; Wilcox</td>
<td>Project management; technology lead; CDCL engineering design</td>
</tr>
<tr>
<td>Ohio State University</td>
<td>Technology support</td>
</tr>
<tr>
<td>Clear Skies Consulting</td>
<td>Provide industrial representation and guidance</td>
</tr>
<tr>
<td>Dover Light &amp; Power</td>
<td>Provide host site and the related information</td>
</tr>
<tr>
<td>Johnson Matthey*</td>
<td>Large-scale oxygen carrier manufacture</td>
</tr>
<tr>
<td>EPRI</td>
<td>Techno-economic analysis</td>
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<tr>
<td>Worley Parson</td>
<td>Provide engineering services for the BOP to integrate CDCL equipment</td>
</tr>
<tr>
<td>Trinity Consulting</td>
<td>Environmental impact assessment, EIV and NEPA</td>
</tr>
</tbody>
</table>

* Join in Phase II/III
Phase I Team Organization

NETL/DOE:
- Project Manager

OSU
- CO-Principal Investigator
  - Prof. L-S. Fan
  - Dr. A. Tong

B&W
- Principal Investigator
  - Dr. L. Vargas

B&W
- Contract Manager
  - Dr. J. Bao

Industrial Review Committee
- Dr. R. Statnick

B&W
- Task I
  - Project Management & Planning
  - Dr. L. Vargas
  - Dr. J. Bao

B&W, OSU, EPRI, DLP, Trinity
- Task 2
  - Commitments and EIV
  - J. Bao/A. Tong/A. Maxson/D. Fillippi

B&W, OSU
- Task 3
  - Cost and schedule estimate
  - L. Vargas/J. Bao/T. Flynn/A. Tong

B&W, OSU
- Task 4
  - Phase II Proposal
  - L. Vargas/J. Bao/T. Flynn/A. Tong
# Tasks and Schedule

## 10 MWe CDCL Large Pilot Facility

### Project Tasks

<table>
<thead>
<tr>
<th>Description</th>
<th>Phase I</th>
<th>Budget Period 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.0 Project Management, and Reporting (Phases I, II, III)</strong></td>
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<tr>
<td>1.1 General Project Management</td>
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<tr>
<td>1.2 Project Review Meetings</td>
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<tr>
<td>1.3 Quarterly Progress Reports</td>
<td></td>
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<tr>
<td>1.4 Project Final Report and Close-out Documents</td>
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<tr>
<td><strong>PHASE I</strong></td>
<td></td>
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<tr>
<td><strong>2.0 Project Commitment and Complete Environmental Information Volume (EIV)</strong></td>
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<tr>
<td>2.1 Host Site Agreement and Team Commitments</td>
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<tr>
<td>2.2 Draft Environmental Assessment</td>
<td></td>
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<tr>
<td>2.3 Develop Environmental Information Volume</td>
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<tr>
<td>2.4 Draft State of Ohio EPA Permit-To-Install (PTI)</td>
<td></td>
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<tr>
<td>2.5 Draft Mitigation Action Plans (MAP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3.0 Cost and Schedule Estimates for Phase I</strong></td>
<td></td>
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<tr>
<td>3.1 Develop Phase II Project Work Breakdown Structure (WBS)</td>
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<tr>
<td>3.2 Prepare a Cost Breakdown and Estimate for Phase II Workscope</td>
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</table>

**Milestone: Final Report**

**Milestone: Environmental Information Volume (EIV)**

**Milestone: Cost Breakdown Structure for Phase II**

**Milestone: Cost Estimate for Phases II and III**

**Milestone: Topical Report**
### PHASE II

#### 5.0 Release of Functional Specifications
- 5.1 Heat and Material Balance
- 5.2 Mechanical Design and Drawings
- 5.3 Electrical Designs and Drawings
- 5.4 General Arrangement Drawings
- 5.5 Hazard Design and Operation (HAZOP)
- 5.6 NEPA Study
- 5.7 Phase III Test Plan
- 5.8 Operating Procedures

#### 6.0 Balance of Plant Equipment Specifications
- 6.1 Balance of Plant Specifications and Modifications
- 6.2 Environmental Control Equipment
- 6.3 CO2 Compression Equipment
- 6.4 Waste Treatment and Disposal

#### 7.0 CDCL Integration with Existing Steam Turbine Equipment Specifications
- 7.1 Steam Turbine Components
- 7.2 CDCL Specific Piping and Instrumentation Drawings

#### 8.0 Process Controls Specifications & Drawings
- 8.1 Plant PLC specifications
- 8.2 Upgrade Existing Controls to Accommodate CDCL unit
- 8.3 Focal Point Optimization
- 8.4 ProTRAX Dynamic Model & Simulator
- 8.5 P&IDs and Drawings

#### 9.0 General Arrangement Drawings (Process and Equipment)
- 9.1 CDCL Equipment Arrangement Drawings
- 9.2 Balance of Plant General Arrangement Drawings

#### 10.0 Building and Utilities Design and Cost Estimate
- 10.1 General Construction - project manager, construction supervision
- 10.2 Site Construction - building excavation, utilities, pavements, site upgrades
- 10.3 Concrete - building and equipment foundations concrete
- 10.4 Masonry, Metals, Wood & Plastic, Building Envelope, Doors & Windows, Finishes
- 10.5 Special Construction, Fire Protection, Restrooms, Lighting, General Utilities

#### 11.0 Prepare Phase III Proposal & Firm Cost Estimate
- 11.1 Prepare Firm Cost Estimate and Schedule
- 11.2 Prepare Phase III Proposal

#### 12.0 Purchase Requisitions for Mechanical Components
- 12.1 CDCL-Specific Components - fabricated and purchased
- 12.2 CDCL Piping and Instrumentation Drawings

#### 13.0 Purchase Requisitions for Instrumentation and Controls
- 13.1 PLC Components and Upgrade to Existing controls Requisitions
- 13.2 Balance of Plant Instrumentation and Controls Requisitions
- 13.3 CDCL Integration with Existing Steam Turbine Equipment Requisitions

#### 14.0 Order long-lead items (optional)
- Order Steel and Materials of Construction
## 10 MWe CDCL Large Pilot Facility

### Phase III-A

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>15.0</td>
<td>Construction and Operation - First Module</td>
</tr>
<tr>
<td>15.1</td>
<td>Equipment Procurement</td>
</tr>
<tr>
<td>15.2</td>
<td>Procurement of Electrical and Instrumentation Equipment</td>
</tr>
<tr>
<td>15.3</td>
<td>Fabricated Components</td>
</tr>
<tr>
<td>15.4</td>
<td>Supplies and Consumables</td>
</tr>
<tr>
<td>15.5</td>
<td>Oxygen Carrier Manufacturing</td>
</tr>
<tr>
<td>15.6</td>
<td>Building Erection</td>
</tr>
<tr>
<td>15.7</td>
<td>Equipment Installation</td>
</tr>
<tr>
<td>15.8</td>
<td>Fabricated Components Installation</td>
</tr>
<tr>
<td>15.9</td>
<td>Instrumentation and Controls Installation</td>
</tr>
<tr>
<td>16.0</td>
<td>Commissioning of First Module and BOP Equipment</td>
</tr>
<tr>
<td>16.1</td>
<td>Individual Equipment Commissioning</td>
</tr>
<tr>
<td>16.2</td>
<td>Cold-Flow Tests Commissioning</td>
</tr>
<tr>
<td>16.3</td>
<td>Hot-flow Test Commissioning and Refractory Dry out</td>
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<tr>
<td>16.4</td>
<td>Upgrades to First Module Design Specifications</td>
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</tbody>
</table>

### Project Timeline

<table>
<thead>
<tr>
<th>Quarter</th>
<th>2020</th>
<th>2021</th>
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<tbody>
<tr>
<td>Q2</td>
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<tr>
<td>Q3</td>
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<td>Q4</td>
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<tr>
<td>Q1</td>
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</table>

**Legend:**
- **Red**: Project Completion
- **Blue**: Project Initiation
<table>
<thead>
<tr>
<th>Project Tasks</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHASE III-B</strong></td>
<td>Construction of remaining modules</td>
</tr>
<tr>
<td>17.0</td>
<td>Upgrades to remaining module design</td>
</tr>
<tr>
<td>17.1</td>
<td>Equipment and Instrumentation</td>
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<tr>
<td>17.2</td>
<td>Fabricated Components</td>
</tr>
<tr>
<td>17.3</td>
<td>Supplies and Oxygen Carrier Manufacturing</td>
</tr>
<tr>
<td>17.4</td>
<td>Construction</td>
</tr>
<tr>
<td>17.5</td>
<td>Equipment Installation</td>
</tr>
<tr>
<td>17.6</td>
<td>Fabricated Components Installation</td>
</tr>
<tr>
<td>17.7</td>
<td>Instrumentation and Controls Installation</td>
</tr>
<tr>
<td>18.0</td>
<td>Commissioning and testing of full plant</td>
</tr>
<tr>
<td>18.1</td>
<td>Commissioning of second, third and fourth module</td>
</tr>
<tr>
<td>18.2</td>
<td>Commissioning of full plant</td>
</tr>
<tr>
<td>18.3</td>
<td>Operation and Testing of Complete System</td>
</tr>
<tr>
<td>19.0</td>
<td>Final Report Preparation</td>
</tr>
<tr>
<td>19.1</td>
<td>Update on Thecno-Economic Assessment of the CDCL technology</td>
</tr>
<tr>
<td>19.2</td>
<td>Final Report and Close Out Documents</td>
</tr>
</tbody>
</table>
Host Site: Dover Light & Power

Existing
- 20 MWe Stoker coal fired boiler

Planning
- 10 MWe natural gas package boiler
- 10 MWe CDCL unit
- Increase power capacity
- Preserve a balance between coal and natural gas
- Potential CO$_2$ market from local industries
## Project Budget

<table>
<thead>
<tr>
<th>Recipients</th>
<th>Federal</th>
<th>Cost-share</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PHASE I (4/1/2018 – 7/31/2019)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B&amp;W</td>
<td>$377,859</td>
<td>$50,000</td>
<td>$427,859</td>
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<tr>
<td>OSU</td>
<td>$240,000</td>
<td>$72,500</td>
<td>$312,500</td>
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<tr>
<td>EPRI</td>
<td>$79,732</td>
<td>$19,932</td>
<td>$99,664</td>
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<td>DL&amp;P</td>
<td>$0</td>
<td>$35,000</td>
<td>$35,000</td>
</tr>
<tr>
<td>Clear Skies</td>
<td>$43,603</td>
<td>$10,901</td>
<td>$54,504</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>$741,194</strong></td>
<td><strong>$188,333</strong></td>
<td><strong>$929,527</strong></td>
</tr>
<tr>
<td>Percent</td>
<td>79.74%</td>
<td>20.26%</td>
<td>100%</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>PHASE II (2019-2020) - Estimated</strong></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Total</td>
<td>$3,000,000</td>
<td>$750,000</td>
<td>$3,750,000</td>
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</table>

<table>
<thead>
<tr>
<th><strong>PHASE III (2020-2025) - Estimated</strong></th>
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</thead>
<tbody>
<tr>
<td>Total</td>
<td>$40,000,000</td>
<td>$10,000,000</td>
<td>$50,000,000</td>
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</tbody>
</table>
Outline

- Background

- Technical Approach for 10 MWe Large Pilot

- Project Details
  - Objectives
  - Project Structure
  - Project Schedule
  - Project Budget

- Risk Management
## Risk Management

<table>
<thead>
<tr>
<th>Description of Risk</th>
<th>Probability</th>
<th>Impact</th>
<th>Risk Mitigation Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay in design activities</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Sequence the design activities to ensure that the cost estimates for Phases II can be developed</td>
</tr>
</tbody>
</table>
| Unavailable resources                                    | Moderate    | Moderate | • Accommodate B&W’s personnel to satisfy the project needs as well as B&W commercial needs  
• Give this project high priority  
• Look for contractors outside B&W |
| Poor Project Execution                                   | Low         | Moderate | • B&W has extensive experience executing similar or larger DOE projects  
• Develop project breakdown structure and task activities  
• Track performance against deliverables and milestones | |
| Delay in contract release                                | Low         | Moderate | B&W has many contracts with DOE-NETL and has compiled terms and conditions so contract negotiation should be quick.                                            |
| Cost overruns                                             | Low         | Moderate | • Track costs associated with major tasks separately  
• B&W will notify DOE on any possible budget variance and how to remedy the situation |
| Safety                                                   | Low         | High    | No operation of experimental or commercial facilities is required as part of the Phase I scope                                                        |
| Unable to acquire the design data specific to 10 MWe plant| Moderate    | High    | • Continue with the design of the plant until we gather the required information  
• Perform additional 250 kWth pilot tests to gather such information with non-federal funds  
• Install one module first and test it |
This presentation is based upon work supported by the Department of Energy under Award Number DE-FE0031582 and the Ohio Development Services Agency under Award Number OER-CDO-D-17-03.