Project $\text{CO}_2\text{NCEPT}$

2016 NETL $\text{CO}_2$ Capture Technology Project Review Meeting

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Agenda

NRG
- CCS Challenges
- Project CO₂NCEPT
- Configuration

Inventys
- Technology
- Results
- Next Steps

- Q&A
NRG is the nation’s leading integrated competitive power company

- Approximately 50K MWs of global, diverse energy
- Nearly 3,000,000 recurring retail customers
- One of the largest renewable generation companies in the U.S.
- $3 billion+ invested on environmental improvements
- Largest independent power producer in U.S.
- Fortune 200 - and - S&P 500 Index
# CCS Challenges

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<tr>
<th></th>
<th>Description</th>
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<tbody>
<tr>
<td>1. Cost</td>
<td>Commercially available technologies are capital intensive</td>
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<tr>
<td>2. Competition</td>
<td>More options and technologies are needed</td>
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<td>3. Scale</td>
<td>Technologies need to be proven at a sufficient scale</td>
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<td>4. Development</td>
<td>Approaches and incentives need to be reevaluated</td>
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<td>5. Reputation</td>
<td>Confidence in this space has eroded</td>
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NRG is in pursuit of finding the next post-combustion technology that makes a giant leap forward and Inventys could be the breakthrough this industry needs.

**Changing the CCS Conversation**
Project CO$_2$NCEPT

CO$_2$NCEPT - Confirmation Of Novel Cost-effective Emerging Post-combustion Technology.

- A 25 MWe (500tpd @ 90% capture) demonstration of the Inventys’ VeloxoTherm™ post combustion carbon capture technology at an NRG coal plant with the goal to prove that the cost of capture, both from an upfront capital requirement as well as from an operating standpoint, is lower using this technology when compared to existing baseline technologies.

- Sponsored by Funding Opportunity Announcement DE-FOA-0001190 "Small and Large Scale Pilots for Reducing the Cost of CO$_2$ Capture and Compression."

- The team successfully completed Phase 1 to validate the proposed concept, select the location, determine the approach, design a layout, and develop an indicative estimate and schedule to execute the project during Phase 2 if awarded.

A new novel CO$_2$NCEPT in pursuit of a game changer
Phase 1 results proved to the execution team that Phase 2 could be accomplished within the merits of the FOA.

Inventys Rotary Adsorption Machine (RAM)

Economically and mechanically viable to develop at a pilot scale
INVENTYS INTRODUCTION

Company

- Energy technology company focused on post-combustion CO₂ capture
- Company created in 2007 to apply the founder’s expertise in developing and deploying commercial gas separation technology using structured adsorbents

Technology

- VeloxoTherm™ intensified Temperature Swing Adsorption (TSA) using structured adsorbents and novel embodiment that can enable step-change reduction in post-combustion CO₂ capture costs
- Patents granted in US on all major aspects of technology

Team & Facilities

- Strong financial partners and project participants, as well as critical Board leadership
- Private company, 21,000-sq-ft manufacturing facility and a state-of-the-art adsorption characterization laboratory, multiple process testing & demonstration platforms
Structured Adsorbent
Solid sorbents = Low regeneration energy
Structured Adsorbents = Intensification (small equipment)

Rotary Embodiment
Continuous process created by rotating beds
Based on existing rotary air preheaters used in power plants

STRUCTURED ADSORBENTS CAN UNLOCK THE POTENTIAL OF SOLID SORBENTS FOR CO2 CAPTURE
STRUCTURED ADSORBENTS

The hydrodynamics, specific surface area, and transport properties of structured adsorbents enable critical advantages:

- low pressure drop;
- Immobilized adsorbent with no fluidization or attrition;
- High geometrical (surface) areas per reactor volume;
- High heat and mass transport due to short diffusion paths within the structured materials;
- High heat retention due to the anisotropic heat transfer properties;
- Engineered thermal properties of laminates; and,
- Laminate design allows degrees of freedom to tailor void fraction, packing densities, and hydrodynamics.

CONTAMINANT RESILIENCE

- Rapid cycle TSA process with structured adsorbents has shown ability to withstand elevated levels of SOx and other coal flue gas contaminants
- Field testing of small RAM on coal flue gas slipstream has provided important learnings, including ability to regenerate bed capacity
  - Stable operation @ ~10 – 40 ppmv SOx, beds saw extended durations of ~250ppmv during shutdowns

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<tr>
<th>Contaminant</th>
<th>Testing Completed</th>
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| SOx         | • Coal flue gas slipstream - ~40 – 300 ppmv (671 hrs)  
              • Accelerated exposure testing, including sulphuric acid |
| NOx         | • Natural gas boiler flue gas @ 72 ppmv - >2,000 hrs |
| PM          | • Testing on in-house coal w/o PM control  
              • Coal flue gas slipstream testing post-baghouse (671 hrs) |
Design Methodology
First Principles to Viable Process
During Phase 1, Inventys worked with an OEM for the rotary machine module and developed strategies for mitigating the risk of scaling up to a Large Pilot Scale Rotary Adsorption Machine:

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<th>Example of Scale-up Risk</th>
<th>Mitigation</th>
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<tr>
<td>Flow Distribution</td>
<td>CFD analysis &amp; experience of rotary heat exchanger OEM</td>
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<td>Size of Adsorbent Beds</td>
<td>Modular approach to adsorbent beds – repeating units ~1m characteristic dimension</td>
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<td>Scale-up of proprietary gas seal design</td>
<td>Modular seal segment design, allowing in-house testing of actual seal dimensions and conditions – segmented seals reduce differential wear</td>
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<td>Rotor Imbalances &amp; Process Asymmetry</td>
<td>Multiple cycles per revolution &amp; process loads balancing machine weight</td>
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PHASE 1 FINDINGS & RESULTS

- **Significant Achievements**
  - Conceptual design work completed for 15m diameter Large Scale Pilot Rotary Adsorption Machine, including scale-up risk mitigation strategy on a component & system level
  - Robust project baseline in terms of budget, scope & execution schedule completed with EPC firm to de-risk further development of Large Scale Pilot
  - Preliminary E,H&S Risk Assessment and detailed technology gap analysis completed

- Achieving overall process performance targets was based on increasing structured adsorbent bed density & using a vacuum-assisted regeneration strategy for the coal flue gas TSA cycle
- During Phase 1, performance testing of higher density adsorbent beds with vacuum regeneration showed higher than expected energy consumption
- Determined that adsorbent selection & optimization work required to de-risk ultimate economic targets for capture costs
PATH FORWARD

- VeloxoTherm™ structured adsorbent technology platform & rapid cycle TSA process architecture has demonstrated ability to unlock performance potential of solid sorbents vs other process schemes
- Promising path towards step-change reduction in capture costs relative to SOA approaches by combining VeloxoTherm™ technology platform with recent advances in raw adsorbents for CO$_2$ capture

Inventys capture system operating on coal flue gas slipstream at NRG Parish
Q&A

Thank you!

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