Improving Coal Power Economics: Retrofitting Flameless Pressurized Oxy-Combustion with Integral CO2 Capture

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NCC Spring Annual Meeting, Washington DC, April 12, 2019
Agenda

• FPO technology
  – Philosophy and performance vs. traditional combustion
  – Added value
  – Development path

• Large Pilot Planning
  – Update on DOE Project DE-FE0031580
  – Cycle diagram
  – Plan for commercial-scale cycle

• LCOE for FPO with Integral CC
  – Comparison with SCPC technology, with and without PCC
  – FPO firing PRB coal, New-Build and Retrofit

• FPO Retrofitting
• Projected Output of New-Build and Retrofit Plants
• Outlook for Commercialization
FPO versus traditional combustion processes

**Philosophy and purpose**

- Recover energy from low ranking coal and other brown fuels
- Enable CO₂ capture on an economically viable basis
- Minimize emissions of NOx, particulates and heavy metals

**Proven technology outperforms traditional combustion**

- Flameless combustion using industrial oxygen in an atmosphere of CO₂ and water vapor
- Complete oxidation: low TOC & zero soot at combustor exit
- Zero thermal NOx: organic nitrogen converted to N₂
- Flue gas volume reduced by ~ 85% minimizes scrubbing cost
- No fly-ash: all Incombustibles end in zero carbon slag
Added Value of Itea FPO

• Accepts up to 65% water content: fuels fired as slurry in water

• Enables use of low-ranking coals up to 40% ash, including alkaline ash

• Enables CO$_2$ capture (CC) on an economically viable basis

• Addresses peaking by fast response: from 5% to 100% capacity in <1/2 hr

• Retrofittable to supercritical and subcritical pulverized coal plants

• Potential for Small Modular Power Plants 80 to 350-MWe
FPO - Development Path

**Planned development**

- Large Pilot for coal power with CO$_2$ Capture – Planning Project started leading to

- 240 to 500-MWth Modular Unit for commercial coal power plant with Integral CO$_2$ Capture (CC) – Retrofit or New-Build

**Timeline:**
- 2017-2020: Large Pilot Plant Planning
- 2021-2022: Pilot Plant Construction
- 2023-2025: Test Program & Engineering 240-500 MWth unit
- 2024-2027: Commercial Plant Construction
Large Pilot Planning - Update

DOE funded planning projects

• DE - FE0027771 - Completed early 2019
• DE-FE0031580 (Phase 1) - Started July 2018

• Development of a Large Pilot as a scale up of 5-MWth pilot plant operating at Itea’s Gioia del Colle R&D Centre, Italy since 2006

• Pre-FEED

• Cycle modeled in Aspen Plus

• Cycle design and optimization complete

• Near complete combustion shown with zero fly ash and high purity of CO2

• Pilot will fire high- and low-rank coals over 2 year test program

Next step

• Phase 2 FEED
FPO Commercial Application – Cycle Diagram

Legend:
- **Components**
  - Input/Output
  - FPO
  - Steam Power
  - Heat and Water Recovery
- **Streams**
  - Input/Output
  - Flue Gas
  - Water/Steam
  - Recovered Water
  - Auxiliary Steam

ASU Oxygen

Coal prep. and slurry

FPO Combusstor

Hot Gas Quencher

OTSG

Blower

ASU commercial GOX efficiency

Coal water-slurry logistics

Improved boiler (OTSG)

Pressurized flue gas to Turbo-expansion

CO₂ recovery with simplified CPU
• Combustor scaled from Large Pilot to 240 to 500-MWth

• 500-MWe with ASU and CO2 Separation is possible with 3 X 500-MWth combustors

• Modular approach limits costs of combustor and steam generator

• Turbo-expander acts as control from pressurized loop to heat recovery and cleanup

• Potential CHP format could provide improved economics in favorable locations
# Comparison of LCOE for SCPC, PCC and FPO 550-MWe

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>PRB SCPC no CC Baseline (S12A) updated to $2018</th>
<th>PRB SCPC with PCC Baseline (S12B) updated to $2018</th>
<th>Projected nth-of-a-kind PRB FPO / Integral CC based on ITEA Projection</th>
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<tbody>
<tr>
<td>Power-in (LHV)</td>
<td>MWth</td>
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<tr>
<td>Gross Power</td>
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<tr>
<td>Efficiency % LHV</td>
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<td>40.4%</td>
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<td>Total Plant Cost $M</td>
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- PRB Coal LHV 19.7 MJ/kg (8,486 Btu/lb), S 0.2%, 4.5% ash, 27% moisture
- Projected nth-of-a-kind based on 350-MWe ENEL detailed engineering study, scaled up to 550-MWe for Italy location. Used NETL methods for technology comparative studies
- For USA location capital cost, applied exchange rate of $1.12/€1.00 throughout. For USA operating cost, applied exchange rate of $1.12/€1.00 to Italian costs.
## FPO Performance Firing PRB Coal, New-Build & Retrofit

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Power-in (LHV): $1,369 for New Build, $1,963 for Retrofit
Gross Power: $583 for New Build, $673 for Retrofit
Parasitic Power: $33 for New Build, $123 for Retrofit
Net Power: $550 for both New Build and Retrofit
Efficiency: 40.4% for New Build, 28.0% for Retrofit
Total Plant Cost: $1,293 for New Build, $2,281 for Retrofit
LCOE: $92.3 for New Build, $178.1 for Retrofit
LCOE compared to S12A Baseline: 193% for New Build, 119% for Retrofit
LCOE compared to S12B Baseline: 61.5% for New Build, 46.9% for Retrofit
FPO Retrofitting

- **ASU**
- **FPO Firing Module**
- **CPU CO2 Compression & Liquefaction**

**Existing 550 MWe SCPC Coal Power Plant**

- **Coal Park**
- **Power Island**
- **Plant Utilities**
- **Radiant & Convective Heat Recovery**

**FPO Retrofitting**

- FPO Firing Module replaces Boiler of existing power plant
- FPO Firing Module, ASU & CPU would be constructed next to Power Island of existing plant
- Existing boiler would be shut down and FPO Firing Module connected to Power Island
## Retrofit FPO Plant with Integral CO2 Capture Firing PRB Coal (ITEA Prospect)

<table>
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<th>CAPEX</th>
<th>Efficiency</th>
<th>Capacity</th>
<th>CO2</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>($M)</td>
<td>(% LHV)</td>
<td>(MWe net)</td>
<td>(t/hr) [1]</td>
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<tr>
<td>Retrofit to Subcritical</td>
<td>$760</td>
<td>31.5%</td>
<td>567</td>
<td>600</td>
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<tr>
<td>Retrofit to SCPC</td>
<td>$736</td>
<td>36.7%</td>
<td>550</td>
<td>500</td>
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[1] Assumes capture of 90% of CO2 produced
Outlook for Commercialisation

FPO provides a pathway towards affordable, efficient, and clean coal power with integral CO2 capture

With growth of renewables, U.S. market will need more load-following plants

• High availability based on standby at 5% capacity rate and coal storage on site
• FPO fast response to fluctuating demand
• FPO can operate as base load, daily cycling or renewable cycling response

CO2

• FPO captures over 90% of CO2 as clean stream ready for compression and liquefaction

Opportunities for FPO Technology

• Retrofitting FPO to coal plants in favourable locations provides solution for potentially stranded assets, reducing CO2 emissions by 90% and increasing revenue by producing CO2 and load-following.
• High efficiency and CO2 capture firing low-ranking coals as-mined, without drying
• Potential for Small Modular Power Plants 80 to 350-MWe