Development of Post Combustion Capture Technology

Authors:

Carbon Capture and Storage Technology Seminar
February 2, 2011
Agenda

- Introduction to Doosan Power Systems
- Development of Post-Combustion Capture (PCC)
  - Relationship with UoR and HTC Purenergy
- Projects Supporting PCC Development and Commercialisation
  - Boundary Dam Pilot
  - Emissions Reduction Test Facility (ERTF)
  - CCPilot100+
  - Basin Electric FEED
- Managing the Risk
- Conclusions
Part of the Doosan Group

Doosan Group

Doosan Heavy Industries & Construction

Casting and Forging  Nuclear  Doosan Power Systems  Power Plant  Construction  Desalination

<table>
<thead>
<tr>
<th>Turnover</th>
<th>Employees</th>
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<tbody>
<tr>
<td>Doosan Group</td>
<td>$15 Billion</td>
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<tr>
<td>Doosan Heavy Industries &amp; Construction</td>
<td>$5 Billion*</td>
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<tr>
<td>Doosan Power Systems</td>
<td>$1.3 Billion</td>
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</tbody>
</table>

*Figures exclusive of DPS data and correct to the end of the financial year for 2009.
A Proud Heritage

Doosan Power Systems

- Babcock and Wilcox established
- Babcock Power Ltd
- Babcock Energy Ltd
- Mitsui Babcock Energy Ltd
- Doosan Babcock Energy Ltd
- Škoda Power public limited company
- Privatisation establishment of daughter companies within Škoda a.s.
- Count Wallenstein founds the original engineering workshop
- Emile Škoda buys the workshop
“To be a global leader in delivering advanced clean energy technologies, products and services.”
### Doosan Carbon Capture Technologies

#### Oxyfuel

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>160KWs at Doosan ERTF*</td>
</tr>
<tr>
<td>2008</td>
<td>ERTF Oxyfuel Conversion</td>
</tr>
<tr>
<td>2009</td>
<td>40MWt OxyCoal™ Burner at Doosan CCTF</td>
</tr>
<tr>
<td>2012/14</td>
<td>Full Power Plant Demo Expected 100-250MW</td>
</tr>
<tr>
<td>2020</td>
<td>Forecast to be fully commercialized by 2020</td>
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#### Post Combustion Capture (PCC)

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1987</td>
<td>UoR development of PCC</td>
</tr>
<tr>
<td>2000</td>
<td>Boundary Dam 5M PCC donated to University for research</td>
</tr>
<tr>
<td>2003</td>
<td>UoR’s ITC completed</td>
</tr>
<tr>
<td>2008</td>
<td>Doosan invest into HTC taking 15% &amp; exclusive rights to PCC technology</td>
</tr>
<tr>
<td>2009/10</td>
<td>ERTF converted to PCC Test Facility</td>
</tr>
<tr>
<td>2013/16</td>
<td>Antelope Valley FEED &amp; Ferrybridge Demo</td>
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<tr>
<td>2020</td>
<td>Large Scale Power Plant with CCS</td>
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<td></td>
<td>Commercial CCS Market</td>
</tr>
</tbody>
</table>

*Over 20 years of experience in carbon capture*
Post Combustion Capture Technology
Post Combustion Capture Technology – Solvent Scrubbing

Process Diagram
University of Regina (UoR) has specialised in Carbon Capture since 1987 – Initially driven by Enhanced Oil Recovery in the Province.

HTC’s Technology Centre is commercially aligned with Doosan, University of Regina’s International Test Centre (ITC) for CO₂ Capture, and International Risk Assessment Centre.

CO₂ Enhanced Oil Recovery technical expertise and close proximity to the Weyburn EOR field.

Laboratories for Solvent development, material and process

One stop for solvent development, process enhancement and plant integration
Advanced Solvent designer (RS family) solvent providing:
- Low cost, commercially available ingredients
- High efficiency system
- Low degradation rates

Scale-up validated against actual operating data from several plants as large as 800 TPD (with +/- 3% accuracy)

Most importantly, scale-up is only achievable through a complete and thorough understanding of:
- All physical and chemical properties (kinetics, diffusivity, etc.)
- Operating conditions
- Proper application of numeric modeling tools

Patents in place for high efficiency configured to advanced solvent
Patents in place for steam side plant integration

Advanced solvent, advanced process and optimised integration provide maximum Customer value
Facilities and Projects

Facilities & Technology create winning edge

**ITC 1t/day & Boundary Dam, 4t/day**
- University of Regina have been developing Carbon Capture technology for over 20 years / Boundary Dam in Operation since 2000 / ITC opened in 2003

**Ferrybridge, 100t/day**
- Largest PCC demonstration plant in the UK
- Access to test any solvent

**ERTF, 1t/day**
- Doosan PCC Solvent Scrubbing pilot facility currently in initial testing
- High degree of flexibility and accuracy to test wide range of Solvents & Coals

**Basin Electric, 3,000 t/day**
- Project selected for US DOE CCPI III funding
- CO₂ from the adjacent Dakota Gasification Company (~3.0 MTPY) is sold for Enhanced Oil Recovery
- FEED completed October 2010, but project deferred by client until further notice

Performance demonstrated on wide range of fuels and different plant configurations
Boundary Dam Demonstration Plant

Technology Demonstration Plant

- Operating since 1987
- Donated to UoR in 2000
- Upgraded 2008 (for TKO)
- Capture capabilities are 4 TPD
- Operating on lignite fuel
- Technology demonstration facility for client-specific parameters

BDPS CO₂ Capture Plant Performance

< 1.1kg steam/ 1 kg CO₂ captured which equates to less than 2.4 GJ/Ton CO₂ Total Capture System equates to ~110 MWe on an 800MWe

Minimised impact to existing plant performance – Industry leading plant efficiency
Demonstration Projects – Emissions Reduction Test Facility

Emissions Reduction Test Facility (ERTF) Upgrade for PCC Solvent Scrubbing
– A 160kWt combustion test facility at our R&D Centre in Renfrew, United Kingdom

- Capable of firing a very wide range of coals or natural gas.

- Originally constructed to test primary NOx reduction measures, subsequently adapted and upgraded to test secondary NOx reduction measures.

- Upgraded for oxyfuel operation as part of the OxyCoal-UK: Phase 1 project – a collaborative project sponsored by the UK government with industrial and academic participation.
Demonstration Projects – Emissions Reduction Test Facility

ERTF Solvent Scrubbing Process – Testing & Operation

Test Program and data analysis will provide:

- Understanding of the Solvent Scrubbing Process (chemistry & kinetics)
- Process Validation
- Process Optimisation

Validation of Modelling Software

- Process Modelled
- Validate modelling capabilities and application to full-scale plant design

<table>
<thead>
<tr>
<th>GAS ANALYSIS</th>
<th>LIQUID ANALYSIS</th>
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<tbody>
<tr>
<td>FGD EXIT</td>
<td>ABSORBER COLUMN</td>
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<tr>
<td></td>
<td>WATERWASH LOOP</td>
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<tr>
<td></td>
<td>LEAN AMINE LOADING</td>
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<td></td>
<td>RICH AMINE LOADING</td>
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<td></td>
<td>AMINE CONCENTRATION</td>
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<tr>
<td>WATERWASH EXIT</td>
<td>TEMPERATURES - COLUMN PROFILES &amp; STREAMS</td>
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<tr>
<td></td>
<td>PRESSURES - COLUMN PROFILES AND SYSTEM PRESSURE DROPS</td>
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<tr>
<td>CO₂ PRODUCT</td>
<td>ADDITIONAL DATA</td>
</tr>
<tr>
<td></td>
<td>• WATER BALANCE i.e. WATER WASH</td>
</tr>
<tr>
<td></td>
<td>• MAKE-UP/PURGE REQUIREMENTS</td>
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<td></td>
<td>• AUXILIARY POWER CONSUMPTION</td>
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</table>

- SO₂
- H₂O
- O₂
- CO₂
- NOx

- H₂O
- O₂
- CO₂
- NOx

![Absorber Column Profile Diagram](image-url)
ERTF Solvent Scrubbing Process – Testing & Operation

- ERTF test program and data analysis currently in progress
- Operating on conventional MEA and RS-2 advanced solvent
- Preliminary test results demonstrate 90% capture efficiency achieved on both solvents
Demonstration Projects – Emissions Reduction Test Facility

ERTF Solvent Scrubbing Process - Equipment

Absorber column
- 10” NB (DN250)
- 4-off packed bed sections (with multiple solvent feed inlet points)

Stripper column
- 8” NB (DN200)
- 4-off packed bed sections

Water Wash Column
- 8” NB (DN200)
- 1-off packed bed section

Heat exchangers
- Gasketed (plate and frame)

Pumps
- Duties met by triplex diaphragm pumps for high head – low flow duties
- Variable speed drives for efficiency and ease of control
Post Combustion Capture Demonstration Plant using Doosan Power System’s technology

- 100 t/day slip stream on SSE’s Ferrybridge Power Station
  - Largest PCC Demonstration in the UK

- Funding by the project partners, Scottish & Southern Energy, Vattenfall, Doosan Power Systems, TSB, DECC and The Northern Way

- Fast – track, for operation during 2011

- Two year test program

- Lessons learned will be incorporated into future designs.
Ferrybridge – Process Layout and Key Parameters

<table>
<thead>
<tr>
<th>PCC Design</th>
<th>100 metric tpd</th>
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<tbody>
<tr>
<td>Design CO2 removal efficiency</td>
<td>90%</td>
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<tr>
<td>CO2 Absorber Dimensions (i.dia x height; m)</td>
<td>2.3 x 39</td>
</tr>
<tr>
<td>Stripper Column Dimensions (i.dia x height; m)</td>
<td>1.1 x 30.5</td>
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</table>
Case Study – Basin Electric FEED

- Sized to capture 1.0 MM tons per year of CO₂ from Basin Electric’s Antelope Valley Power Plant
  - 3,000 tons per day
  - Treating a ~ 120 MW slipstream
  - Turnkey EPC Scope including: PCC plant, FGD polishing and CO₂ compression and dehydration

- Key FEED Deliverables:
  - Engineering studies to investigate the integration of the PCC Plant within the existing AVS and DGC infrastructure
  - Proposed EPC Scope of Work, based upon the final design of the PCC Plant
  - ± 15% EPC CAPEX and OPEX Estimate
  - Level 2 EPC Project Schedule

- Project currently deferred by client
Basin Electric – Process Layout and Key Parameters

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
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<tbody>
<tr>
<td>PCC Design Gas Flow (lb/hr)</td>
<td>1,544,000 lb/hr</td>
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<tr>
<td>Design CO$_2$ removal efficiency</td>
<td>90%</td>
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<tr>
<td>PCCC Plant Footprint</td>
<td>55,000 sq. ft.</td>
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</table>
Basin Electric – Proposed Layout within Antelope Valley Station

- Existing Maintenance Building
- PCC Building
- Existing Lime Storage
Basin Electric – Proposed Layout of Cooling Water and CO\textsubscript{2} Pipeline
Managing the Risk

<table>
<thead>
<tr>
<th>Engineering</th>
<th>Procurement and Construction Management</th>
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<tr>
<td><strong>Process Technology</strong></td>
<td>Safety/Quality</td>
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<td>Design Integrity</td>
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<td>Quantities/weights</td>
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<td>Constructability</td>
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<td>Maintainability</td>
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<td>Safety</td>
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<td>Key Issues</td>
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<td>Process Reliability</td>
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<td>Risk Mitigation</td>
<td>Process Performance</td>
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<td>Process Reliability</td>
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<td>Experience of key suppliers/partners at commercial scale</td>
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<td>RAM Studies</td>
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<td>HAZIDs/HAZOPs</td>
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<td>CFD Modeling</td>
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<td>Proper design margins</td>
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<td>Experience at commercial scale</td>
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<td>Application of safety factors and/or design margins</td>
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<td>Proven engineering processes</td>
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<td>Proven QA/QC processes</td>
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<td>Doosan Experience at commercial scale</td>
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<td>Proven processes and controls for project execution, procurement and construction management</td>
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<td>Modularization</td>
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<td>Safety procedures for site erection</td>
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<td>In house Construction</td>
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Mitigate Risk to our clients through proven experience and performance guarantees
Conclusion

- Extensive testing and validation activities conducted by UoR and HTC at the Boundary Dam Pilot and the ITC have provided an initial validation of the process technology.

- Testing being carried out by Doosan Power Systems (DPS) on the ERTF is significant because it validates the design methodology and provides a facility from which to evaluate future enhancements.

- Testing at the ERTF and CCPilot100+ will be used to further validate the scalability of the process technology and design under real world operating conditions and provide knowledge that will be incorporated in future projects.

- The FEED for Basin Electric and other projects have provided DPS the opportunity to integrate the technology to a commercial-scale plant.
Doosan Power Systems is committed to delivering unique and advanced carbon capture solutions.

- Greig Chisholma
  Senior Engineer - Plant Development Group
  E gchisholm@doosanbabcock.com

- Rebecca Gardinerb
  Senior Engineer - Plant Development Group
  E rgardiner@doosanbabcock.com

- Mark Bryanta
  Director Carbon Capture
  E mbryant@doosanbabcock.com

- Matthew Hunta
  Business Development Manager
  E mhunt@doosanbabcock.com

- Sean Blackb
  Business Development Director
  E sean.black@doosanpowersystems.com

a. Doosan Power Systems
   Porterfield Road
   RENFREW
   PA4 8DJ
   United Kingdom
   T +44 (0)141 886 4141

b. Doosan Power Systems
   5 Paragon Drive
   MONTVALE
   NJ 07645
   USA
   T +1 201 746 8603
THANK YOU