SHELL CANSOLV
DEPLOYING CCS WORLDWIDE

PCCC2
Bergen, September 2013

Shell Cansolv

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Resources: Our use of the term “resources” in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

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AGENDA

- Shell Cansolv and Shell Projects
- The Journey to Boundary Dam Project
- Next Steps on CO2 Capture at Shell Cansolv
1.0 CANSOlv AND SHEll ProjEcts

Developing CCS projects globally
ROYAL DUTCH SHELL & CANSOLV

UPSTREAM
- Exploration and production of hydrocarbon
- 50% oil / 50% gas
- 3.4 million BOE per day
- 80% of RDS net earnings & CAPEX

DOWNSTREAM
- Production, supply distribution (retail) of petroleum products & chemicals
- Trading
- Maintain Shell Brand

PROJECTS & TECHNOLOGY
- Delivering major projects eg. > 500 mln CAPEX
- Providing differentiating technologies to Upstream and DS business & key Shell partners

Shell Cansolv

RDS 2012 Financial Results
- CFFO – $46 Billions (B)
- Net earnings – $25 B
- Dividends Redust. $11 B
- Net CAPEX $30 B

Fun facts
- Total oil production 85 mmb/d
- Canada #6 at 3.6 mmb/d
- Canada second largest oil reserves in the world

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NATURAL GAS: A DESTINATION FUEL
Shell developing CCS projects globally

Shell involvement in CCS Projects;
- Industrial scale projects in operation
- Industrial scale projects in construction
- Industrial scale projects planned
- Demonstration projects, joint industry partnerships

Demonstration projects, joint industry partnerships
Industrial scale projects in construction
Industrial scale projects in operation
Industrial scale projects planned
Demonstration projects, joint industry partnerships

Weyburn
Midale
TCM
Boundary Dam
Aberthaw
Quest
Peterhead
Gorgon
Otway

Shell Technology
Operator: Saskpower
SSE PETERHEAD - CCGT CO$_2$ CAPTURE AND SEQUESTRATION

- Completed Pre-FEED study for Scottish & Southern Energy
- Project co-funded by DECC (UK)
- Retrofit of a ~300MW CCGT to include CCS
- Sequestration of CO$_2$: Goldeneye (off-shore North Sea)
Location: South Africa
Scale: 170 tpd CO₂ capture
— 90% removal
Natural Gas Boilers
— Not CCGT’s
Construction complete: June 2013
Successful start-up: August 2013
CO₂ generated for on-site use
Strategy: Project makes client self-sufficient on steam and CO₂
COMPARISON BETWEEN CO2 AND SO2 CAPTURE PLANTS

Total Absorber Cross Sectional Area [m²]

0.0 100.0 200.0 300.0 400.0 500.0 600.0 700.0

Xstrata CEZ
Lanxess
ConocoPhillips
DCU Coker
DCU FCCU
Chalco Boiler
IOCL
GDLY
RWE
Lanxess
SaskPower
SSE
Peterhead

2001
2002
2002
2006
2006
2009
2012
2013
2012
2013
2013
TBD

SO₂
CO₂
2.0
THE JOURNEY TO THE BOUNDARY DAM PROJECT

Project Scope and Lessons learned
- 1,000,000+ tpy CO$_2$ captured
- CO$_2$ sold to Cenevous for EOR
- SO$_2$ (~60 tpd) converted to acid & sold
- Overall investment: CAD 1.24BB
- Construction @ 85%+
- Start-up will be early 2014
Absorber - Breakdown

- Prescrubber section (higher corrosion resistance zone) quenches gas and removes some dust, chlorides and fluorides
- \( \text{SO}_2 \) Absorber removes \( \text{SO}_2 \)
- \( \text{CO}_2 \) Absorber removes \( \text{CO}_2 \)
- Water wash (cooled) is last line of defense - keeps amine from exiting the system
SASKPOWER BD3: CO$_2$ REGENERATOR

- One of the largest strippers worldwide
- 5 large Compabloc reboilers
- Equipped with MVR heat recovery
- Constructed offsite

8 meters
LESSON LEARNED #1: ABSORBER GEOMETRY

Detailed engineering reviews done to confirm compatibility and effectiveness, including:

- CFD analysis
- Value Engineering
- Aspen + design modeling
- Estimate TIC Cost comparison

**Outcome: Design Validation**

- CFD analysis confirmed expected performance and mechanical design
- Rectangular/Square geometry equivalent in process and superior in costs
LESSON LEARNED #2: ABSORBER MOC

Detailed engineering reviews done to confirm compatibility and effectiveness, including:

- Review of past corrosion coupon analysis
- Vendor qualification
- 3rd party specialist confirmations
- Estimate TIC Cost comparison

OUTCOME: MOC SELECTED

- Analysis and studies confirmed compatibility of alternate (to steel) MOC
- Concrete structure (with acid resistant lining) equivalent in process and superior in costs
Shell Cansolv supporting clients/partners in their Permits to Operate
Complete mapping of emission points and stream characterization
Generation of consistent HSE package
based on laboratory testing for:

- Toxicology
- Environmental fate
- Biodegradability
- Compatibility with PPE (gloves and cartridges)

**Challenges:** Lack of available data applicable for such a project

**Outcomes:** Data generated indicate that CANSOLV amine-based CO₂ Capture system is eco-friendly and can be operated with low HSE risk

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**Ecotox Example:** Chronic toxicity results reported as the LC50 (trout, daphnia) or EC50 (growth, yield for algae).

<table>
<thead>
<tr>
<th>Chemical</th>
<th>7-day Larval Growth &amp; Survival Pimephales promelas</th>
<th>3-brood Reproduction &amp; Survival Ceriodaphnia dubia</th>
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<tbody>
<tr>
<td></td>
<td>Survival (LC50, mg/ L)</td>
<td>Growth (IC25, mg/ L)</td>
</tr>
<tr>
<td>Amine 1</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Amine 2</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Nitrosamine 1</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
</tr>
</tbody>
</table>

95% Confidence interval and NOEC reported in brackets where applicable.
SASKPOWER BD3 150MW $SO_2/CO_2$ CAPTURE

**Unique** Cost savings features employed

- Material on construction: Ceramic/carbon tile lined concrete absorbers & lean amine tank
- Rectangular tower to save on plot space and optimize packing design/installation
- Integrate Heat Recovery between $SO_2$ and $CO_2$ systems for ultimate energy performance

**Unique** plant permitting experience (operation & environmental)

**Unique** proven constructability: Only commercial scale project worldwide
3.0

NEXT STEPS IN CO₂ CAPTURE AT SHELL CANSOLV

What else we’re doing...
TESTING STRATEGY FOR CO₂ CAPTURE TECHNOLOGY

Scale (ton CO₂/day)

- Lab bench
- AVU
- Lab Pilot
- Pilot External
- Demo
- 170
- 50
- 3,300

Discover
Develop
Demonstrate
Deploy

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PILOTING NEW DC-201 FOR CO$_2$ AT NCCC, ALABAMA, USA

Pilot unit: 10ton CO$_2$/day (0.5MWe slipstream)
Operated by the National Carbon Capture Center

Absorber
overall dimensions 35 m tall by 0.64 m OD diameter
3 packing sections of 6.1 m each
2 intercooling stages

Capacity: X2 over MEA

MEA 30 to 35wt%

STEAM
-35% over MEA

13% CO$_2$ in inlet gas
Carbonate Slurry - 3rd Generation Post Combustion Technology

- Pilot plant Shell Technology Center Amsterdam, Capacity of pilot plant max 25 kg/d CO₂
- **Demonstrated continuous operation** for precipitating carbonate process
- **Energy efficiency confirmed** for regeneration in the lower end of the 2.2 -4 MJ/kg through pilot plant operation and detailed process modeling
- **Additional energy efficiency improvements identified**

**Chemistry**

1. \( \text{CO}_2 \text{(aq)} + \text{H}_2\text{O} + \text{CO}_3^{2-} \rightarrow 2 \text{HCO}_3^- \)
2. \( \text{K}^+ + \text{HCO}_3^- \rightarrow \text{KHCO}_3 \)

An accelerator is used to enhance mass transfer of CO₂ to liquid phase