World Scale Hydrogen Production – Opportunities for large-scale CO₂ capture

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Global Hydrogen Capabilities and Experience

- Worldwide leadership position in outsourced Hydrogen production and recovery
  - Hydrogen supplier since 1975
  - Supply >3.7 million Nm³/h of hydrogen
- Strong focus on the refining and chemical industries
- Own and operate over 80 hydrogen plants around the world
- Established reputation for high reliability operation
  - Over 1400 operating years for Hydrogen plants
- Complete technology portfolio in Hydrogen, CO, Syngas equipment
  - Proprietary Separation Systems (membrane, PSA, cold boxes)
  - Global Alliance with TechnipFMC for reforming technology

Kochi (India): First ever twin steam methane reformers designed and built by Air Products with a combined capacity of 16.4 tons per hour of hydrogen production.
Air Products builds and operates hydrogen plants of all sizes, from <1 kNm$^3$/h to >170 kNm$^3$/h, tied to pipelines or as standalone “on-site” facilities.

- **Catlettsburg, Kentucky**
  - >35 kNm$^3$/h

- **Norco, Louisiana**
  - >170 kNm$^3$/h

- **Tarragona, Spain**
  - 66 kNm$^3$/h

- **Mantova, Italy**
  - 17 kNm$^3$/h

- **Rotterdam, Netherlands**
  - >130 kNm$^3$/h H$_2$

- **Chengdu, China**
  - 100 kNm$^3$/h H$_2$

- **Cressier, Switzerland**
  - 8 kNm$^3$/h

- **PHG Range**
  - 100 – 830 Nm$^3$
“Colours” of hydrogen in the energy transition

- Most hydrogen is from fossil fuels
  - if all the associated CO$_2$ is emitted to atmosphere, that hydrogen is “grey”
- Fully renewable “green” hydrogen can be produced by (a) electrolysis from renewable electricity or (b) reforming of biogas
  - “green” cannot yet replace “grey” hydrogen
- “Blue” hydrogen – is hydrogen from fossil fuels but with CO$_2$ capture – this is widely seen as essential step in the energy transition
  - “Blue” hydrogen creates the infrastructure to enable the expansion of “green” hydrogen
  - “Blue” hydrogen can achieve negative emissions when fed with biogas
Decarbonised Hydrogen

$\text{CO}_2$ removal from SMR – 3 options

Port Arthur $\text{CO}_2$ Project

$\text{CO}_2$ capture from syngas by $\text{CO}_2$ VSA

Option 1

Table 1: Levelised Cost of $\text{H}_2$ (LCOH), $\text{CO}_2$ Avoidance Cost and Overall $\text{CO}_2$ Capture Rate (IEAGHG, Techno-Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS. Technical Report 2017-02, 2017)

<table>
<thead>
<tr>
<th>Capture Case</th>
<th>LCOH Euro Cent/Nm$^3$</th>
<th>$\text{CO}_2$ Avoidance Cost Euro/t</th>
<th>Overall $\text{CO}_2$ Capture Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>No capture</td>
<td>11.4</td>
<td>47.1</td>
<td>56%</td>
</tr>
<tr>
<td>Option 1</td>
<td>13.5</td>
<td>66.3</td>
<td>54%</td>
</tr>
<tr>
<td>Option 2</td>
<td>14.2</td>
<td>69.8</td>
<td>90%</td>
</tr>
<tr>
<td>Option 3</td>
<td>16.5</td>
<td></td>
<td></td>
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</tbody>
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Air Products’ Port Arthur CO2 Project

New technology to recover anthropogenic CO2 for EOR

- Retrofit of two Steam-Methane Reformers (SMR) located in the middle of a refinery
- Capture and purification of CO2 from hydrogen plants (see previous slide “Option 1”) for EOR
- Technology developed by Air Products
- 90%+ capture of CO2 from syngas
- ~2600 t/d (50 MMSCFD) of CO2 to Denbury’s Green Pipeline for West Hastings oilfield
- 30 MWe cogeneration unit to generate power and make-up steam
- Full capacity achieved April 2013

Capturing 1 million tonnes/year of CO2 since 2013
CO₂ Capture – Port Arthur Project Answers

- **Where will the CO₂ go?**
  - Port Arthur is 13 miles (21 km) from Denbury’s existing “Green” 300+ Mile (~500 km) CO₂ Pipeline used for CO₂ EOR

- **Who will pay for the CO₂ capital and operating costs?**
  - US Government grant from the recovery act
  - Tax credits 45Q for CO₂ stored by EOR
  - Denbury pays for CO₂ to use in EOR applications

Scale is important: **1 million tonnes/year of CO₂**
Air Products has the Core Competencies required to be a supplier of Syngas

Acquired Shell and GE gasification technologies to enhance our core competency in gasification
Benefits of Gasification

A versatile and mature technology

- **Gasification technology has been in use since the 1800s**
  - Widely used to produce transportation fuel due to petroleum shortage in WWII

- **Adaptable to various hydrocarbon feedstocks**
  - Coal, petcoke, oil residue, natural gas, and others
  - Utilizes natural resources available

- **Diverse applications / end products**
  - Syngas for power generation and chemicals
  - H₂ for refineries
  - CO for chemicals

- **Sustainability**
  - No smog-causing particulates
  - Concentrated, capture-ready CO₂ stream
  - Sulfur removal allows the use of high sulfur coal

- **Low incremental operating cost**
  - Economical in low oil price environment
Executing our gasification strategy

Energy, environmental, emerging markets

- GE Gasification Technology Announcement (November 2018)
- Shell Gasification Technology acquisition (May 2018)
- Juitai 100% APD $0.65B 2022
- Yankuang JV $0.65B 2022
- Jazan Gasifier/Power JV $3.5B 2022
- Jazan ASUs JV $8B 2019
- Lu’An JV $1.5B 2018

Large ASUs for China coal gasification

Project capital represents 100%, not APD share
Project dates represent expected onstream
CO₂ Capture from Gasification

- Gasification for syngas typically has a CO₂ removal step
  - Minimising additional capital for capture costs
  - Still requires dehydration, CO₂ compression, pipelines
- Gasification with CO₂ capture allows you to use high carbon content feed stocks to produce high value products with zero carbon emissions
- Air Products has developed a Road Map of technology applications for CO₂ capture on coal and heavy resid feedstocks
Summary

- Large scale hydrogen production from steam methane reforming is widely practised
- Piping hydrogen is well understood: 100’s miles of hydrogen pipelines around the world, connecting dozens of hydrogen plants with many customers
- Syngas production by gasification or reforming produces CO$_2$ in quantities amenable for use in enhanced oil recovery (EOR)
- Air Products has demonstrated CO$_2$ capture from SMRs
  - However, ATRs may be better suited to high levels of CO$_2$ capture from natural gas
- Gasification (of bottom of the barrel, pet coke, coal) could play a part in Blue hydrogen

- There are many demonstrated technology options for CCS but the problem remains:

Where will the CO$_2$ go? Who will pay? And pay attention to scale!
Thank You
tell me more