

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

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Workshop on Hydrogen Production with CCS
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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



Air Products builds and operates hydrogen plants of all sizes, from $<1 \text{ kNm}^3/\text{h}$ to $>170 \text{ kNm}^3/\text{h}$, tied to pipelines or as standalone "on-site" facilities

Catlettsburg, Kentucky
 $>35 \text{ kNm}^3/\text{h}$



Norco, Louisiana
 $>170 \text{ kNm}^3/\text{h}$



Tarragona, Spain
 $66 \text{ kNm}^3/\text{h}$



Rotterdam, Netherlands
 $>130 \text{ kNm}^3/\text{h H}_2$



PHG Range 100 – 830 Nm³



Cressier, Switzerland
 $8 \text{ kNm}^3/\text{h}$



Mantova, Italy
 $17 \text{ kNm}^3/\text{h}$

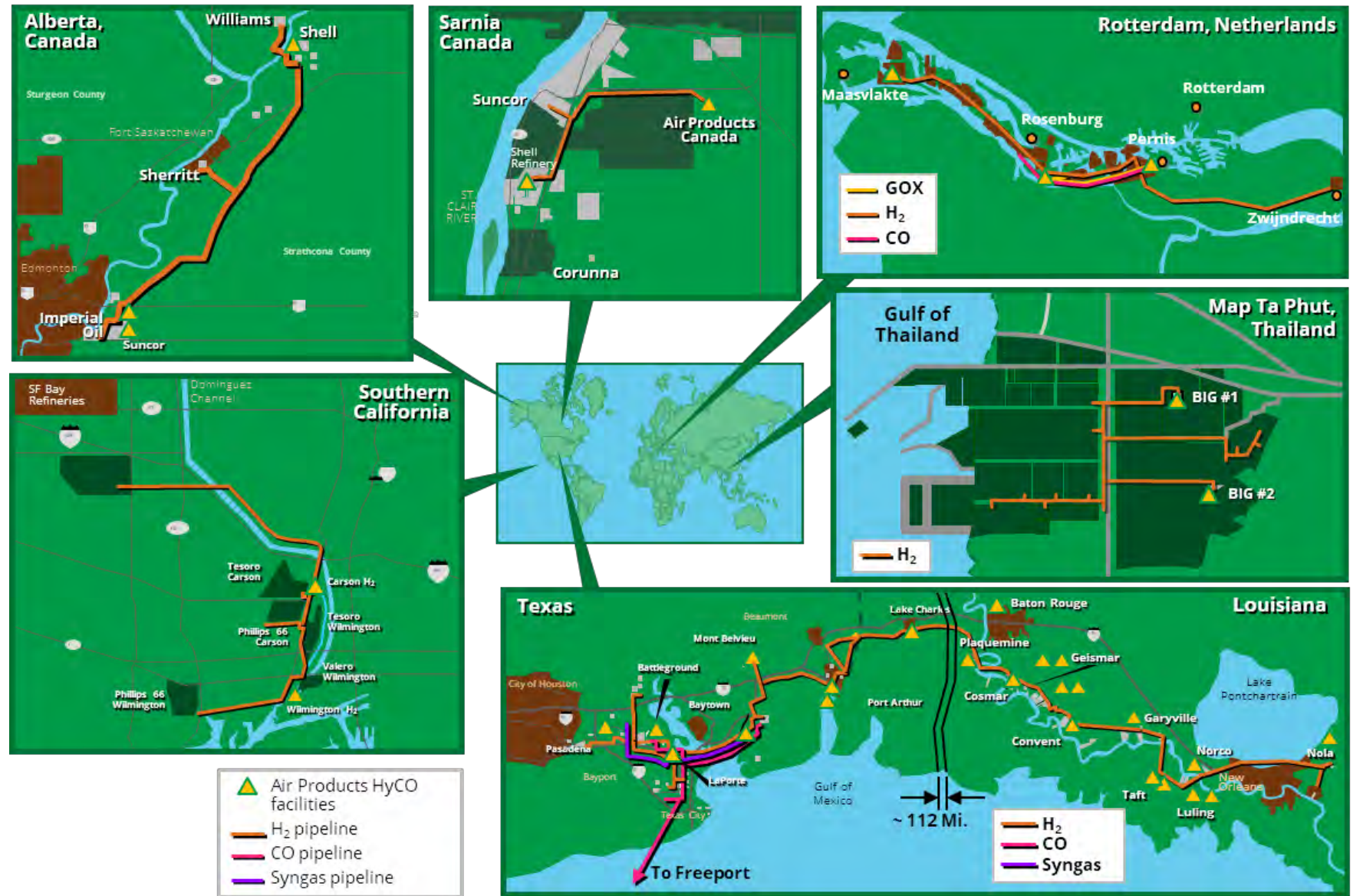


Chengdu, China
 $100 \text{ kNm}^3/\text{h H}_2$



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Leading Global Hydrogen Pipeline Positions



“Colours” of hydrogen in the energy transition

- Most hydrogen is from fossil fuels
 - if all the associated CO₂ 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 CO₂ 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

CO₂ removal from SMR – 3 options

Table 1: Levelised Cost of H₂ (LCOH), CO₂ Avoidance Cost and Overall CO₂ Capture Rate (IEAGHG, Techno-Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS. Technical Report 2017-02, 2017)

Capture Case	LCOH Euro Cent/Nm ³	CO ₂ Avoidance Cost Euro/t	Overall CO ₂ Capture Rate
No capture	11.4	-	-
Option 1	13.5	47.1	56%
Option 2	14.2	66.3	54%
Option 3	16.5	69.8	90%

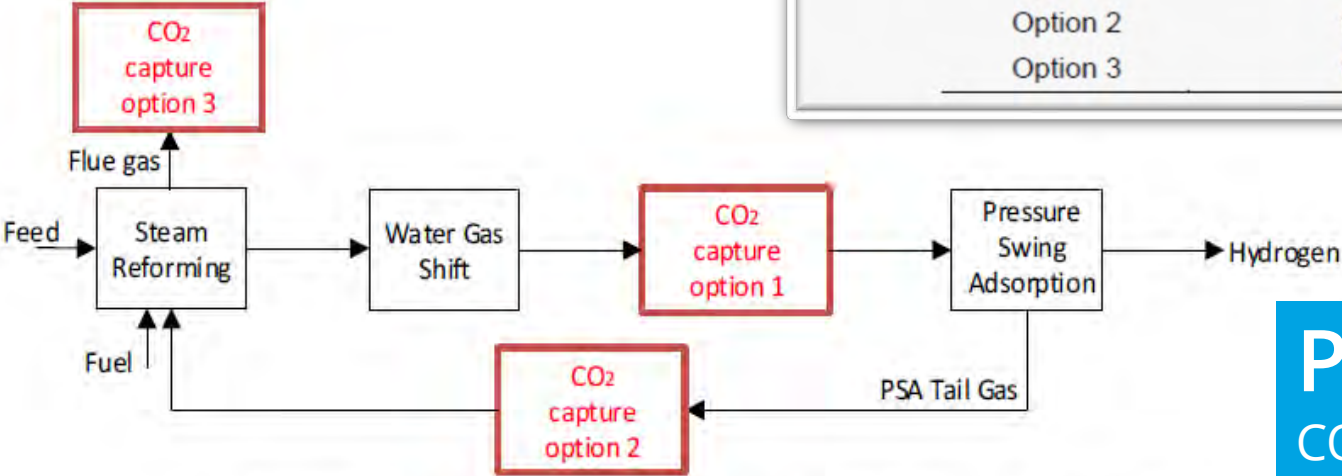
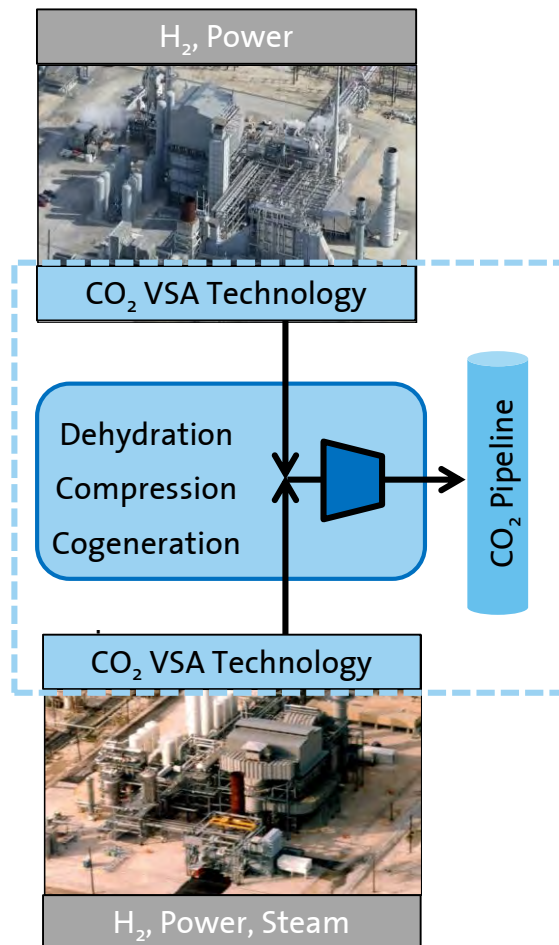


Figure 1: Steam methane reforming - CO₂ capture options

Port Arthur CO₂ Project
 CO₂ capture from syngas by CO₂ VSA
 Option 1

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

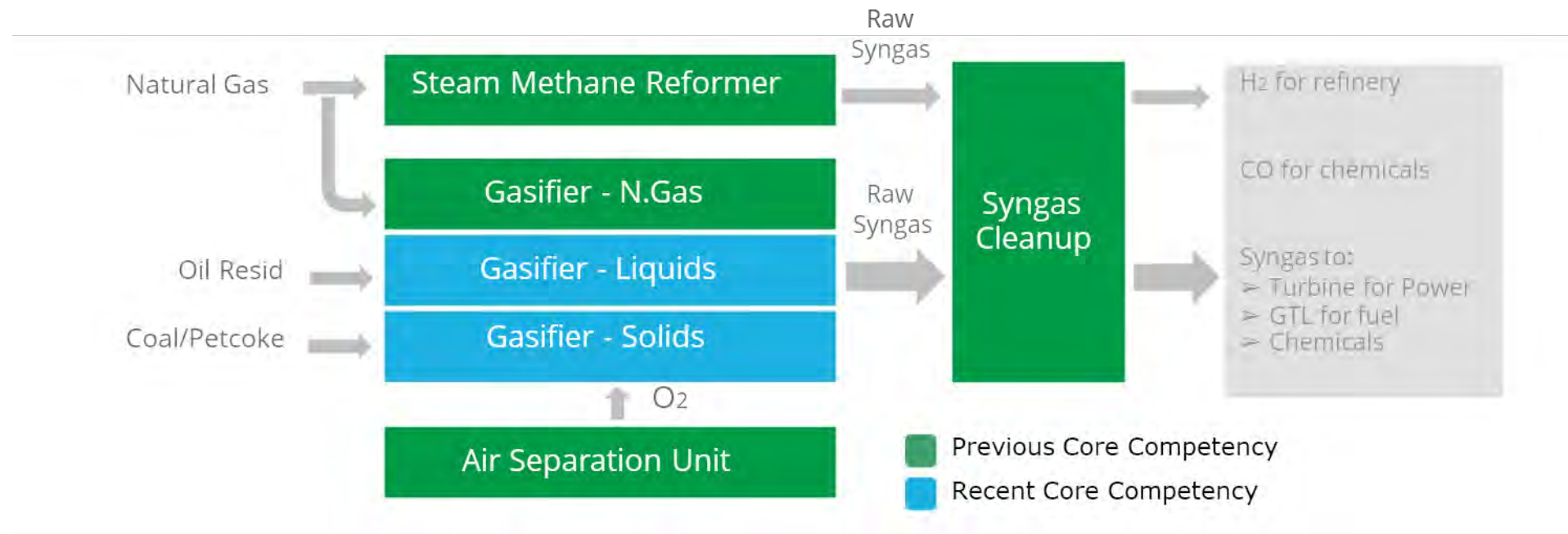
- **Where will the CO₂ go?**
 - Port Arthur is 13 miles (21 km) from Denbury's existing "Green" 300+ Mile (~500 km) CO₂ Pipeline used for CO₂ EOR
- **Who will pay for the CO₂ capital and operating costs?**
 - US Government grant from the recovery act
 - Tax credits 45Q for CO₂ stored by EOR
 - Denbury pays for CO₂ to use in EOR applications



Map shows Denbury's Green CO₂ Pipeline.
Data source is Denbury, December 2011, CO₂ Flooding Conference

Scale is important: **1 million tonnes/year of CO₂**

Air Products has the Core Competencies required to be a supplier of Syngas

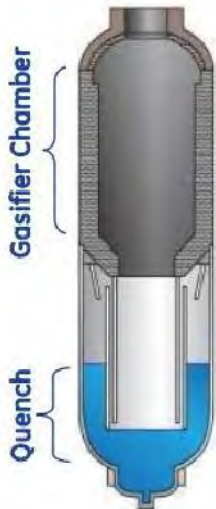


Acquired Shell and GE **gasification technologies** to enhance our **core competency** in gasification

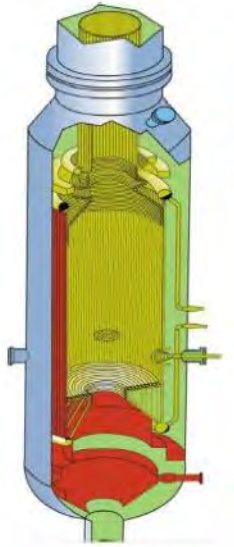
Benefits of Gasification

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

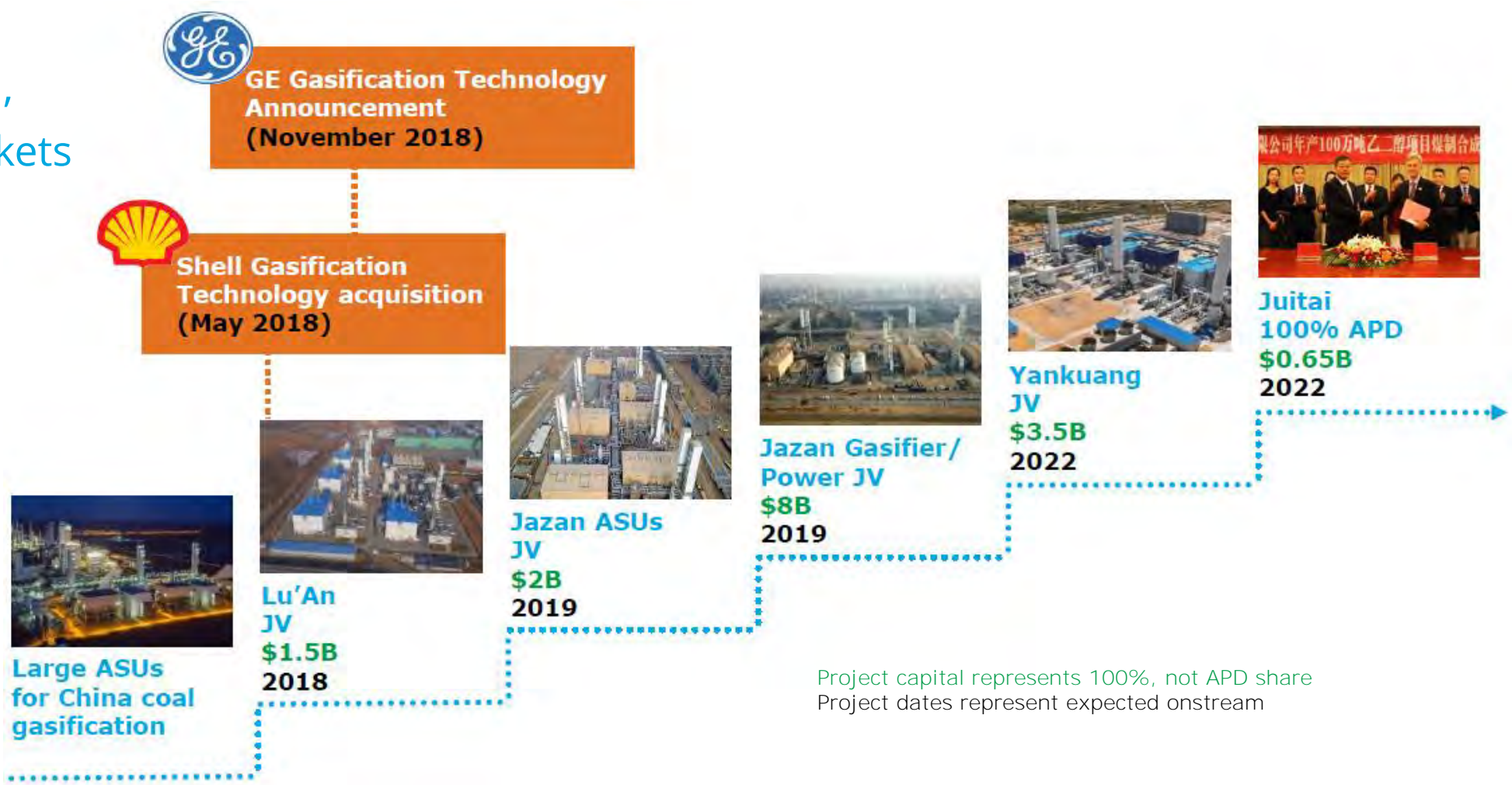


- **Diverse applications / end products**
 - Syngas for power generation and chemicals
 - H₂ for refineries
 - CO for chemicals
- **Sustainability**
 - No smog-causing particulates
 - Concentrated, capture-ready CO₂ stream
 - Sulfur removal allows the use of high sulfur coal
- **Low incremental operating cost**
 - Economical in low oil price environment



Executing our gasification strategy

Energy,
environmental,
emerging markets



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 CO₂ in quantities amenable for use in enhanced oil recovery (EOR)
 - Air Products has demonstrated CO₂ capture from SMRs
 - However, ATRs may be better suited to high levels of CO₂ capture from natural gas
 - Gasification (of bottom of the barrel, petcoke, coal) could play a part in Blue hydrogen
- There are many demonstrated technology options for CCS but the problem remains:

**Where will the CO₂ go?
Who will pay?
And pay attention to scale!**

Thank You
tell me more

