The Future of Advanced Carbon Capture Research and Development: An Air Products Perspective

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Hydrogen as an enabler

- Decarbonisation of hydrocarbons with CCS provides an energy source with zero or very reduced CO_2 emissions
- Produced hydrogen allows for decarbonised energy distribution and energy storage
  - Transportation
  - Heating and power
  - Energy intensive industry
- Integrated with green energy projects, it can provide carbon neutral energy storage and back-up
- Viable projects will only happen if you can answer two fundamental questions:

Where will the CO_2 go?
Who will pay?

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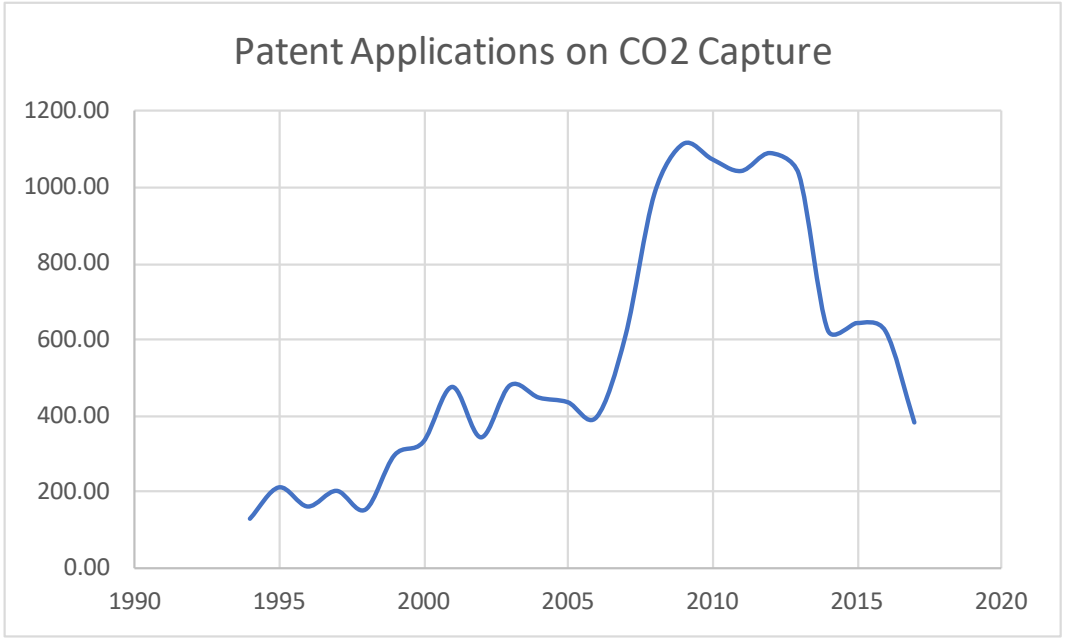
The Rise and fall …and rise? …of CO_2 capture

- Power companies drove interest in CO_2 capture from large coal power station 2005-2012
- 2008 recession eventually led to demise of most projects – the US being the exception due to existing enhanced oil recovery (EOR) demand for CO_2
- Renewed interest in US, EU, Canada, China
  - Multiple projects with a single storage solution
  - Energy clusters with hydrogen integration for distribution and storage



US leadership in CCS Projects

- More operating projects than ROW combined
- 100s of miles of existing super critical CO_2 pipelines for EOR
- Long term EOR experience
- Federal 45Q – Tax credit provided for projects that capture and store CO_2.
  - Updated in 2018
    - $35/MT for use in enhanced oil recovery (EOR)
    - $50/MT for sequestration

Project	Location	Onstream	Sector
Century Plant	Texas, United States	Operating since 2010	Industry, Natural Gas Processing
Terrell Natural Gas Processing Plant (formerly Val Verde)	Texas, United States	Operating since 1972	Industry, Natural Gas Processing
Petra Nova Carbon Capture	Texas, United States	Operating since 2017	Power, Coal Power Generation
Air Products Steam Methane Reformer	Texas, United States	Operating since 2013	Industry, Hydrogen Production
Enid Fertilizer	Oklahoma, United States	Operating since 1982	Industry, Chemicals (ammonia)
Coffeyville Gasification Plant	Kansas, United States	Operating since 2013	Industry, Chemicals (ammonia)
Illinois Industrial Carbon Capture and Storage	Illinois, United States	Operating since 2017	Industry, Refining (biofuels)
Shute Creek Gas Processing Plant	Wyoming, United States	Operating since 1986	Industry, Natural Gas Processing
Lost Cabin Gas Plant	Wyoming, United States	Operating since 2013	Industry, Natural Gas Processing
Great Plains Synfuel Plant and Weyburn-Midale	North Dakota, United States & Saskatchewan, Canada	Operating since 2000	Industry, Refining (SNG)

CCS North America (ref International Energy Agency)

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Project Overview: State-of-the-Art Carbon Capture from Two Port Arthur, TX SMRs

- American Recovery and Reinvestment Act Funding
- ~1 million tons of CO2 to be recovered and purified annually starting late 2012
- Valero providing land, rights-of-way, utilities
- Air Products supplying compressed and purified CO_2 to Denbury for injection into TX oilfields for enhanced oil recovery

U.S. DEPARTMENT OF ENERGY

VALERO

Denbury

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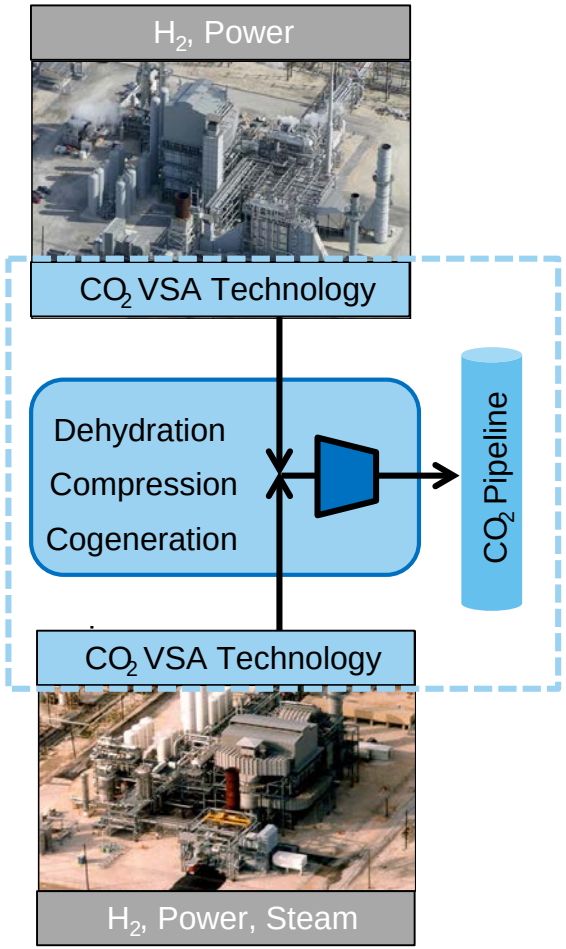
Air Products' Port Arthur CO2 Project

Technology to recover anthropogenic CO_2 for EOR



- Retrofit of two Steam -Methane Reformers (SMR) located in the middle of a refinery
- Capture and purification of CO_2 from hydrogen plants for EOR
- Technology developed by Air Products
  - Vacuum Swing Adsorbers
- 90%+ capture of CO_2 from syngas
- ~2600 t/d (50 MMSCFD) of CO_2 to Denbury's Green Pipeline for West Hastings oilfield EOR
- 30 MWe cogeneration unit to generate power and make-up steam
- Full capacity achieved April 2013

Capturing 1 million tonnes/year of CO_2 since 2013

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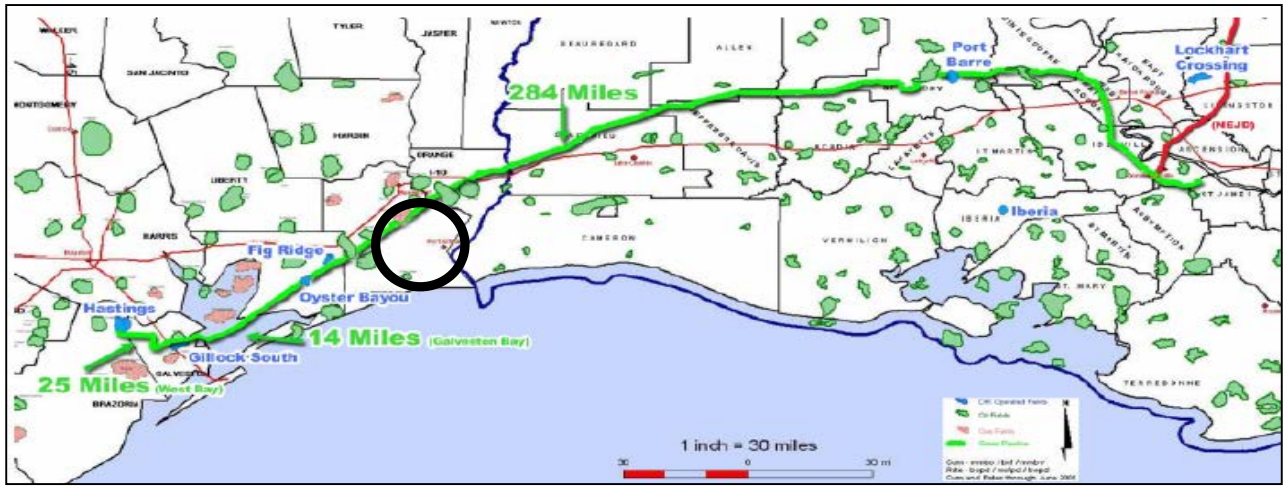
CO_2 Capture – Port Arthur Project Answers

- **Where will the CO_2 go?**
  - Port Arthur is 13 miles (21 km) from Denbury's existing "Green" 300+ Mile (~500 km) CO_2 Pipeline used for CO_2 EOR
- **Who will pay for the CO_2 capital and operating costs?**
  - US Government grant from the American Recovery & Reinvestment Act
  - Tax credits 45Q for CO_2 stored by EOR
  - Denbury pays for CO_2 to use in EOR applications



Map shows Denbury's Green CO_2 Pipeline.
Data source is Denbury, December 2011, CO_2 Flooding Conference

Air Products' CCS focus

- Looking for viable CCS opportunities
- Further retrofits of existing hydrogen SMRs
- CO_2 Capture from Gasification
  - In preparation Air Products has purchased key Gasification technology of the leading suppliers
  - Gasification with CO_2 capture allows you to use high carbon content feed stocks to produce high value products with minimal carbon emissions
  - Air Products has developed a "Road Map" of technology applications for CO_2 capture on coal and refinery heavy residue feedstocks
- Development of in-house technology e.g. CO_2 VSA
- Decarbonization of natural gas
- Partnerships for storage options

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Summary

- Fossil fuels will be part of the global energy supply for a many years to come
  - CCS means we can continue whilst meeting CO_2 emission targets
- CCS allows the use of lower cost carbon rich "heavy" feedstocks with low atmospheric CO_2 emissions
- All the necessary technology to capture, purify and store CO_2 exists and is proven in long term operation
  - Technology available to commence projects immediately
  - R&D will improve efficiency and reduce cost
- A competitive alternative to other Green Energy projects
- Seed projects can be an enabler for further R&D, pilot plants, smaller scale investments

Where will the CO_2 go?
Who will pay?

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Thank You

tell me more

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