International Forum on Recent Developments of CCS Implementation

John Gale

General Manager

IEA Greenhouse Gas R&D Programme

Leading the Way to a Low-Carbon Future

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Athens, Greece

Presentation Scope

- Summarise what is happening in CCS development globally
- Projects – several firsts in year period
- Project drivers
- Key future developments

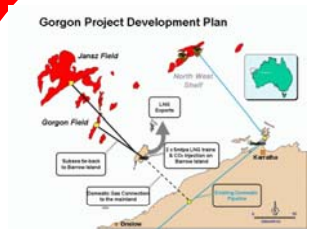
Commercial Implementation of CCS (to date)

Sleipner
1Mt/y CO_2

Weyburn
2.5 Mt/y CO_2

In-Salah
1.2 Mt/y CO_2

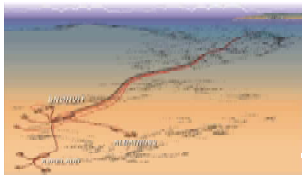
Snohvit
0.7Mt/y CO_2



Gorgon
4Mt/y CO_2

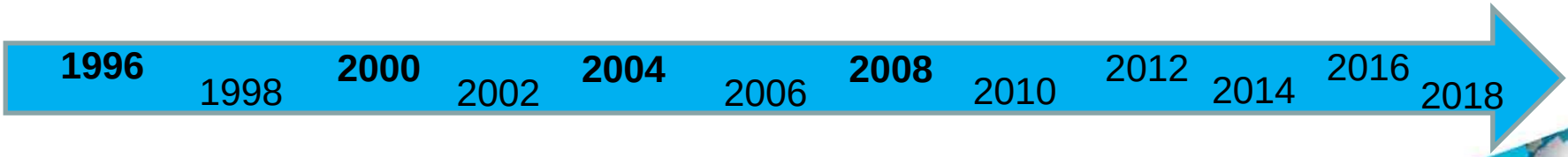
350km overland pipeline

150MWe



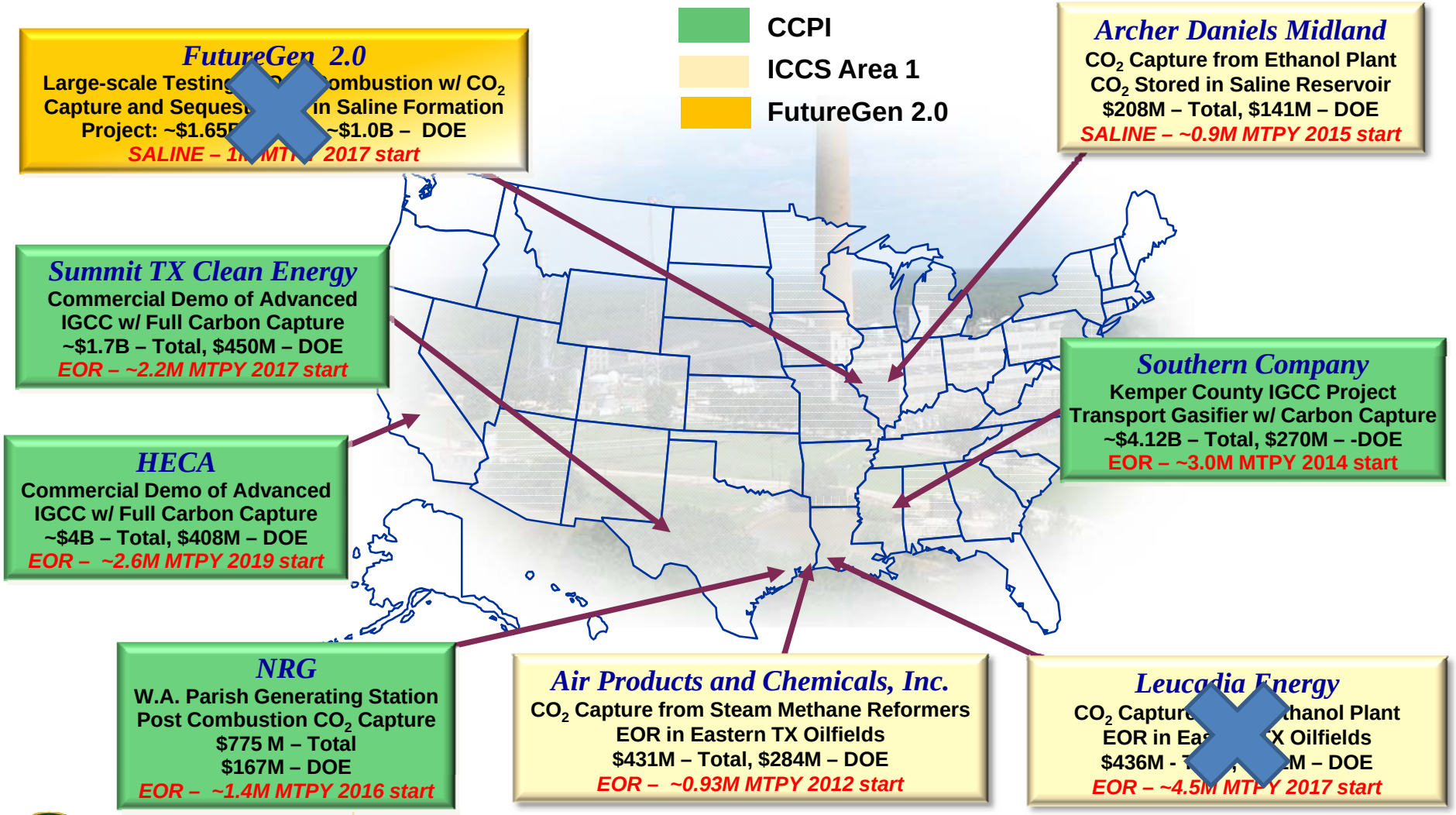
160km sub sea pipeline

- Major Scale up in Storage experience
- 600MWe power plant
- Pressure Management involved



Major CCS Demonstration Projects

Project Locations & Cost Share



U.S. DEPARTMENT OF ENERGY | Fossil Energy

Air Products and Chemicals, Inc. ICCS Area 1

Steam Methane Reforming with CO_2 Capture

- Port Arthur, TX (Hydrogen plant at Valero Refinery)
- 90%+ CO_2 capture (Vacuum Swing Adsorption) from 2 steam-methane reformers (SMRs) yielding ~925,000 tonnes CO_2/year
- ~30 MWe cogeneration unit to supply makeup steam to SMRs and operate VSA and compression equipment
- CO_2 to Denbury "Green" pipeline for EOR in Texas at West Hastings oil field
- Total Project: $431 MM; DOE Share: $284 MM (66%)

Key Dates

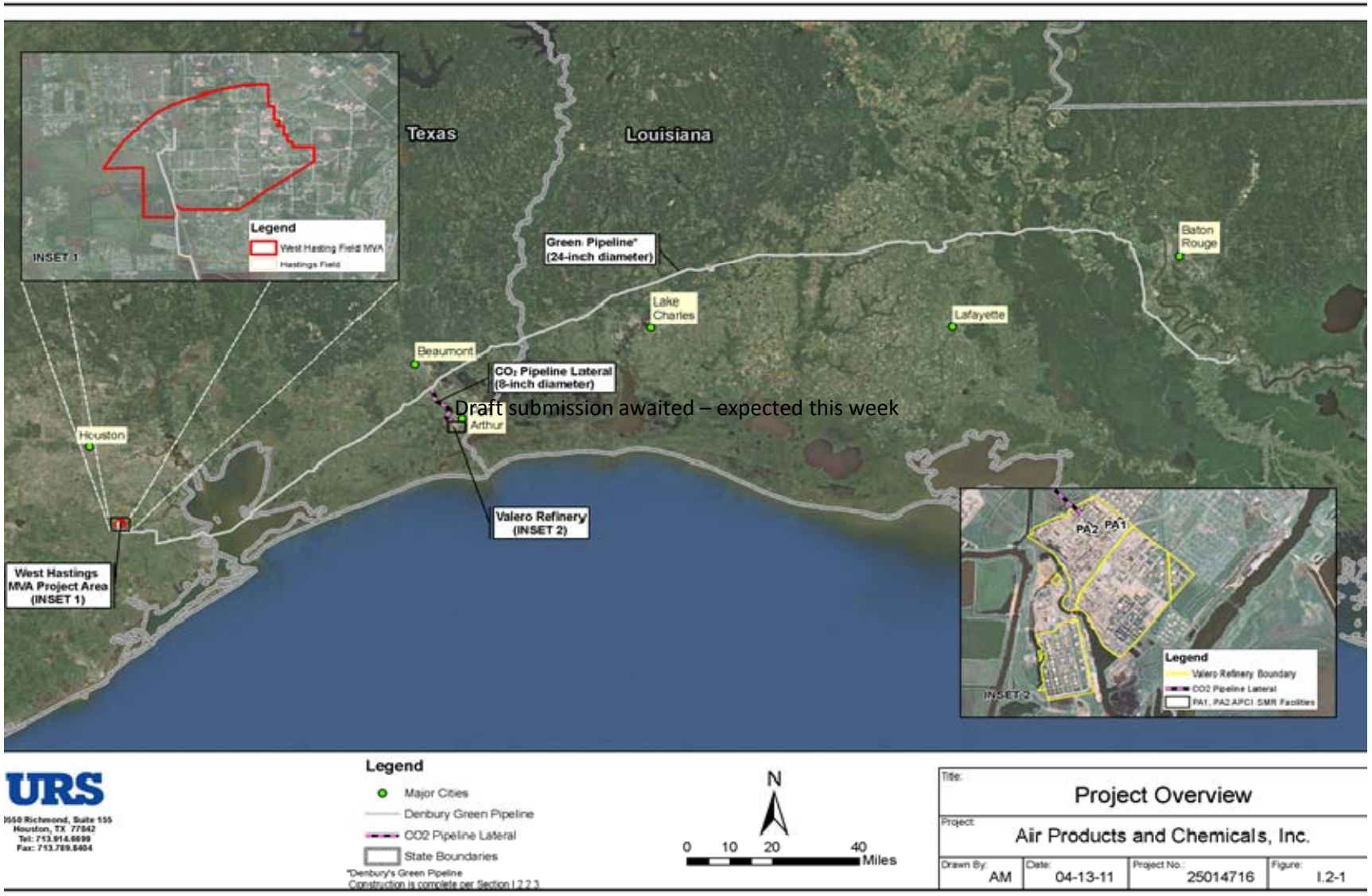
- Phase 2 Awarded: Jun 15, 2010
- FEED completed: Nov 2010
- Permit By Rule (PBR) and Standard Air Permits issued: May 2011
- NEPA FONSI: Jul 2011
- Construction started: Aug 2011
- Operation started: Dec 2012

Status

- PA-1 initiated operation: Mar 3, 2013
- PA-2 initiated operation: Dec 16, 2012
- Full capacity achieved: Apr 2013
- CO_2 compressor trip; damage to internals; May 29, 2013; CO_2 compressor restart: July 1, 2013
- Has operated at >100% of design when necessary
- 1MM tonnes CO_2 delivered on 4/24/14
- 1,111,076 tonnes CO_2 delivered as of 6/9/14


Existing SMR
Co-Gen Unit
CO_2 Compressor & TEG Unit
CO_2 Surge Tanks
Blowers
VSA Vessels
Air Products and Chemicals, Inc. - Port Arthur 2

CO_2 Transportation to Sequestration Site
(from Final Environmental Assessment)



Draft submission awaited – expected this week

Global Status of CO2-EOR

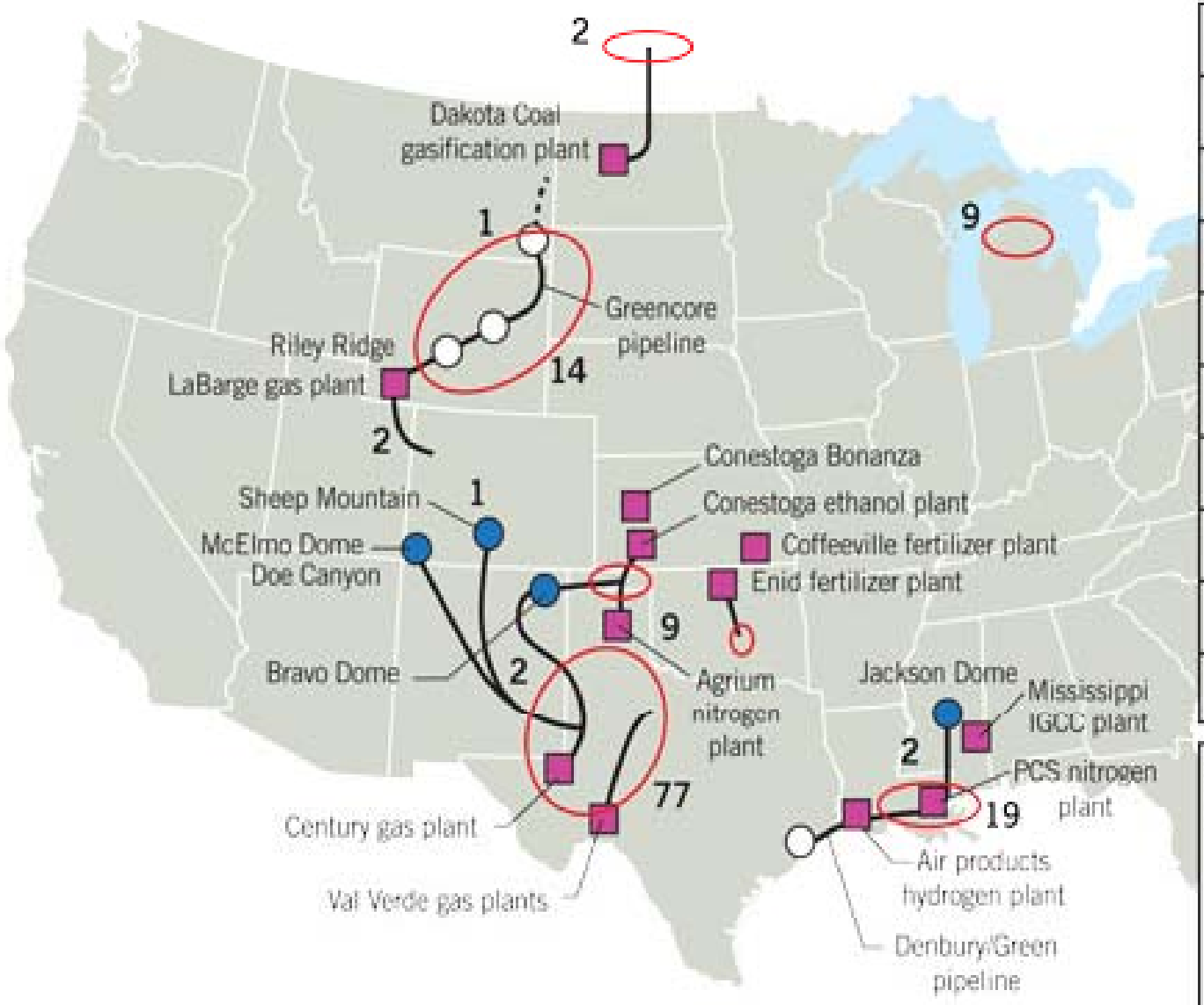
- Principally North America (USA + Canada)
  - USA
    - 136 projects injecting 3.5Mt CO_2
    - Many projects Operating since mid 1980's
    - 3600km pipeline network – mostly non anthropogenic CO_2
    - Regulatory process developed – EPA Class II Wells
    - Drivers
      - » Tax incentives for increased oil production
      - » Readily accessible "cheap" CO_2
      - » Large numbers of small fields with high ROIP levels
      - » High exploration capacity

USA CO2-EOR Experiences

- Commercial technology proven to recover cost effectively additional oil
- Robust regulatory process tested for over 20 years
  - Potential problems with new EPA Class VI wells for CO_2 Storage
  - Limited monitoring under Class II well program
- Safety record industry good
  - US DOT records on pipeline safety
    - Good track record over 20+ years
  - No associated issues – like CBM or unconventional oil and gas
- Not originally as well researched as storage
  - IEAGHG Weyburn-Midale CO2-EOR monitoring and stage project (2000-2012)

CO_2-EOR OPERATIONS, CO_2 SOURCES: 2014

FIG. 1



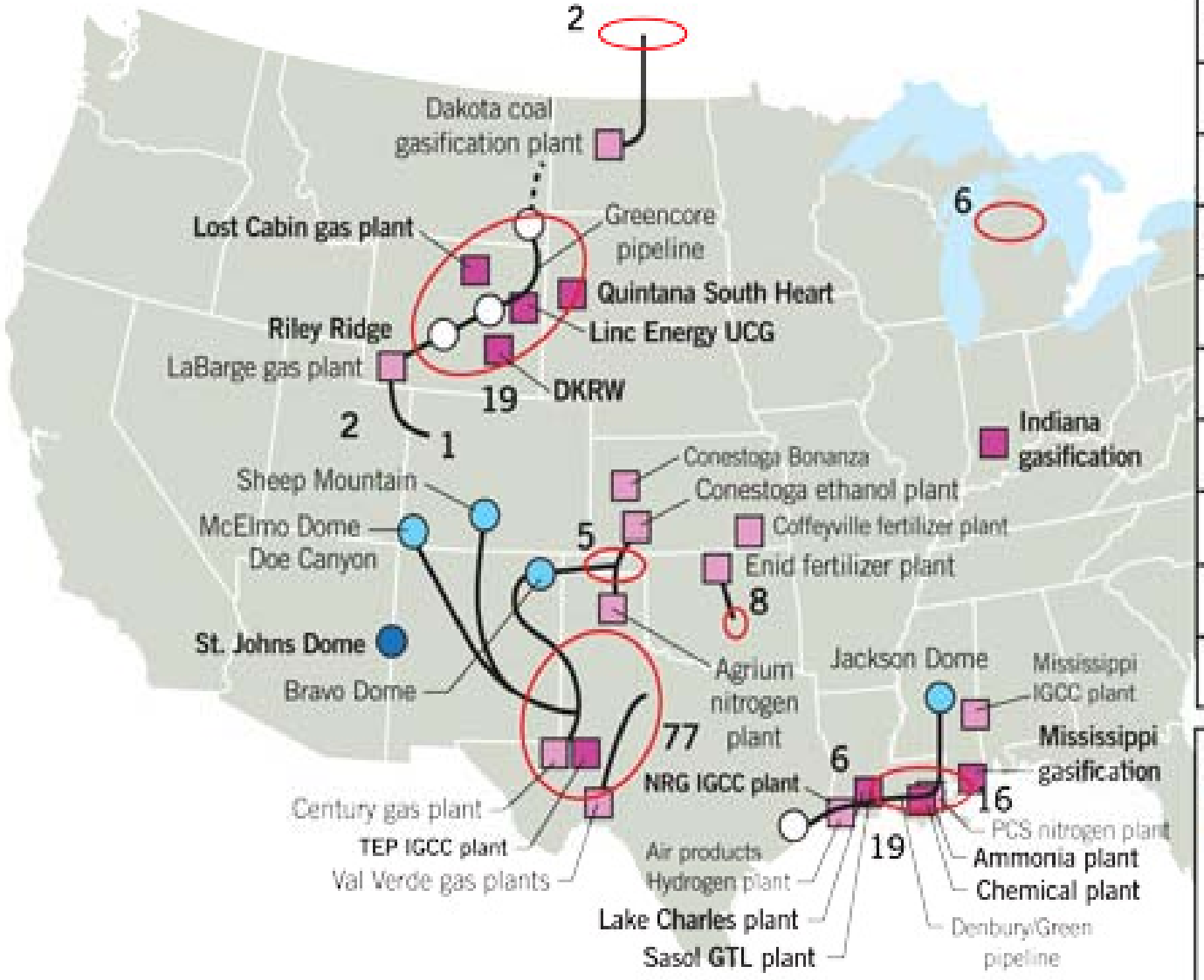
Oil production, 2014	
CO_2 –EOR projects	136
Oil production, 1,000 b/d	300
CO_2 supplies, 2014	
Number of sources	17
• Natural	5
• Industrial	12
CO_2 supply, MMcfd	3.5
• Natural	2.8
• Industrial	0.7

136 Number of CO_2-EOR projects
Natural CO_2 source
Industrial CO_2 source
CO_2 pipeline
CO_2 proposed pipeline

Source: Advanced Resources International Inc. based on OGJ EOR/Heavy Oil Survey 2014 and other sources

PROJECTED CO_2, EOR OPERATIONS, AND CO_2 SOURCES: 2020

FIG. 4



Oil production, 2020	
CO_2 –EOR projects	147
Oil production, 1,000 b/d	638
CO_2 supplies, 2020	
Number of sources	30
• Natural	6
• Industrial	24
CO_2 supply, MMcfd	6.5
• Natural	3.4
• Industrial	3.1

147 Number of CO_2-EOR projects

Natural CO_2 source

Industrial CO_2 source

CO_2 pipeline

CO_2 proposed pipeline

Source: Advanced Resources International Inc. based on OGJ EOR/Heavy Oil Survey 2014 and other sources

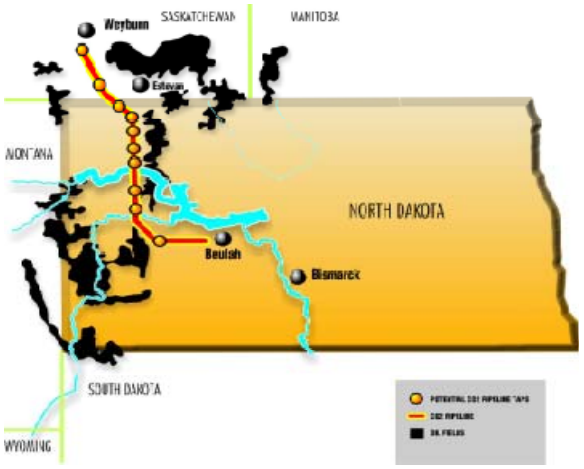
Boundary Dam – the first commercial scale CCS demonstration Project

What are the drivers?

- Regulatory
  - Emissions cap – 0.42t/MWh
- Market
  - Electricity demand to grow
  - Monopoly supplier
  - Long term supply contract
- Energy Costs
  - Coal – predictable future price
  - Gas price volatility
- Limited RE options
  - Wind?
- Government support for CAPEX
- CO_2 Market
  - CO_2 demand for EOR/price
  - Demand expected to grow
  - Experience
    - Pilot testing
    - Weyburn CO_2 monitoring project
    - Pipeline/pipeline & EOR operators
  - No public concerns

Experience

- Permitted and constructed without issue
- No operational issues reported – continuous supply to Cenovus



350km overland pipeline

- First fully monitored CO2-EOR project
- Established best practise for monitoring
- Demonstrated fate of CO2 using seismic monitoring
- Demonstrated importance of baseline monitoring
  - Supposed leak from site was disproved based on baseline monitoring

Future plans

- Boundary Dam 4 and 5 retrofits to follow
- Need to reduce CCS costs to negate need for Government subsidy
  - Boundary Dam 3 identified 30% reduction in CAPEX and 20% in OPEX
- Oil price???

CO2-EOR outside North America

- North Sea
  - Studies by Norway and UK, Shell and BP have shown CO_2-EOR be uneconomic in North Sea
    - Large field size, low sweep efficiency
    - High recovery rates using other EOR techniques
    - Large CO_2 volumes to be transported offshore, high infrastructure costs
    - Platform modification costs considered to be high
  - Prospects for near offshore CO2-EOR in Danish Oil Fields explored by Maersk – status unknown
  - UK Cost Reduction Task Force identified CO2-EOR as potential cost saving element for future CCS deployment
    - Tax incentives for brown field CO2-EOR opportunities
    - Opportunities were more limited than in USA
    - Synergies between CCS and CO2-EOR

CO2-EOR outside North America

- China
  - Desire to reduce oil imports
    - Large importer – small producer
    - CO2-EOR attractive proposition to expand internal production
  - 12 CO2-EOR pilots currently underway
  - Likely expansion of CO2-EOR in Northern China
    - » Linked to high concentration CO_2 production from CTL, Fertiliser and Methanol production
  - China lacks technical capacity to develop CO2-EOR
    - Drilling rigs, oil industry expertise etc.,
  - US-China Co-operation agreement to share technical knowledge from CCS demonstrations
    - Trade - turbine experience and CO2-Eor experience

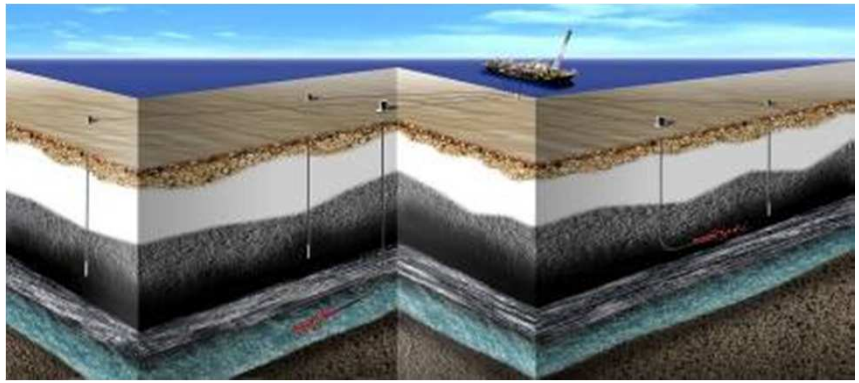
Lulea Project, Brazil
Handling of CO2 in the Pre-Salt Hydrocarbon Fluids

Motivation:

- High (8 to 20%) CO_2 content in the gas phase in some wells;
- Although it doesn't have target obligations to reduce its emissions, Brazil is committed with climate change control;
- Accordingly, Petrobras and partners in the pre-salt blocks do not consider to vent the CO_2 associated to the produced gas.

Questions raised:

- What is the best way to capture the CO2 in an offshore ultra-deep water environment (2,100 m WD), 300 km from shore?
- What is the best option for sequestrating the captured CO2?



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Natural Gas Processing

CO_2 Content in the fluids address challenges:

- **Size & Footprint**
- **Weight**
- **Efficiency**

FPSO Cidade Angra dos Reis

Membranes:

- **Better for medium or high CO_2 content.**
- **Smaller footprint**
- **Simple to operate and easy to maintain**
- **Process a wide range of CO_2 in the inlet stream.**

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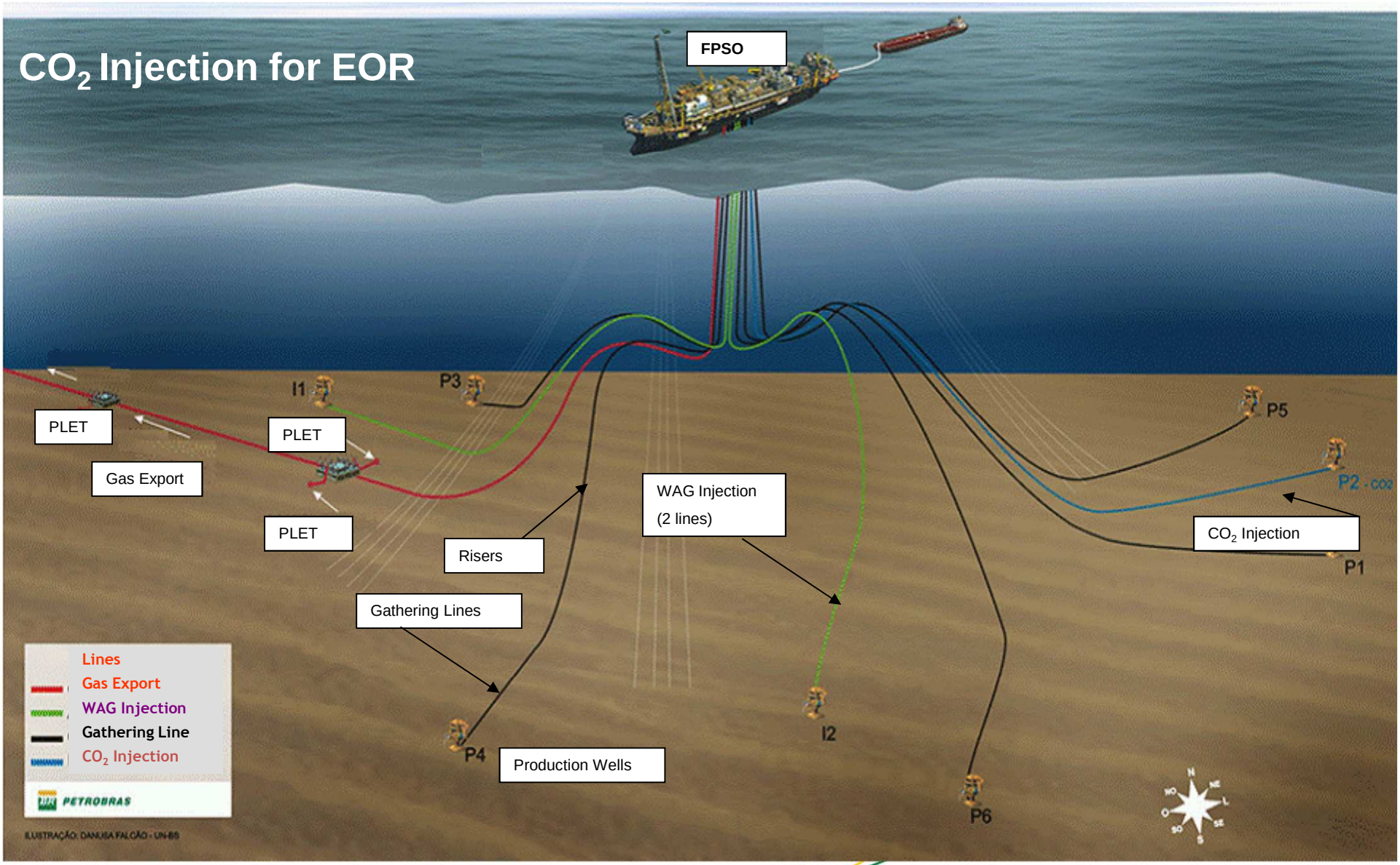
WAG-CO2 EOR



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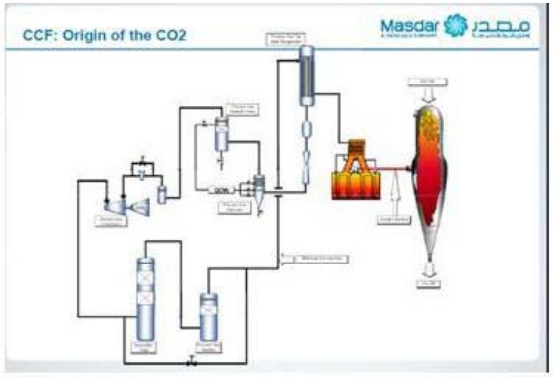
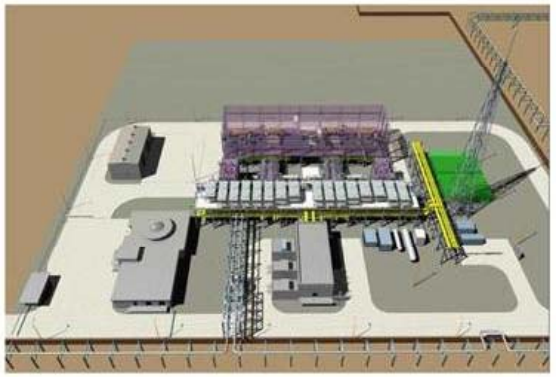
ESI CCS Project Technical Overview

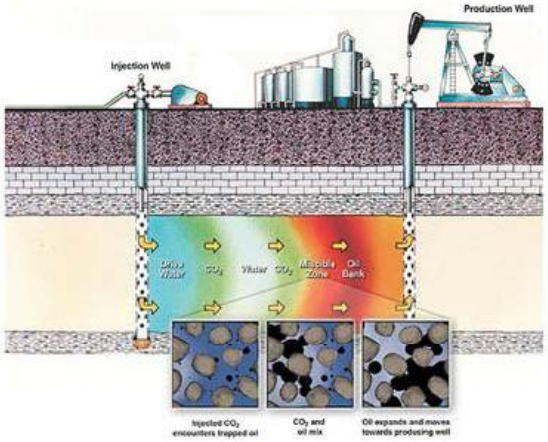


CO2 Source (ESI) and Capture



CO2 Compression & Dehydration

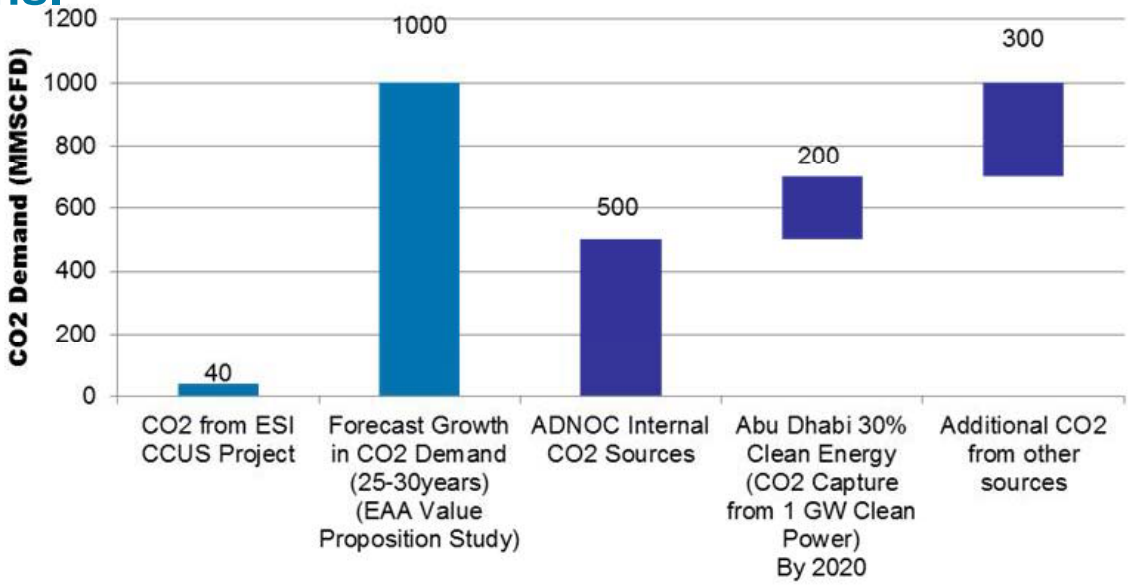
CO2 Transportation



CO2 Injection in Rumaitha & Bab fields

Abu Dhabi CCS: Future Potential

- **CO_2 as an EOR agent has been endorsed:**
  - Success of the ESI CCS Project and Rumaitha / Bab Injection are key to future development.
- **Changing landscape in Abu Dhabi with potential CO_2 targets for field testing and development:**
  - CO_2 capture linked to ADNOC field demand and performance;
- **Whilst preliminary, the EAA CCS Value Proposition study forecast a growing CO_2 demand in the next 25-30 years, based on ADNOC estimations.**



Europe – the sick man of CCS

- CCS Directive launched and tested
  - ROAD issued storage Permit
- ETS launched
  - Low price of carbon
- EEPR – 6 projects funded all bar one ended
- ROAD project in Netherlands stalled
- Norway stops Mongstad full scale project
- UK left looking at CCS projects
  - White Rose project funded under NER300

UK – Deregulated Energy Market

- £1bn Government supported demonstration programme
  - £500k FEED studies
    - Peterhead – gas plus CCS
    - White Rose, coal plus oxy-firing
    - FID expected early 2015
- Changed market principles to allow for future low carbon technology investment
  - Contracts for Difference, Cfd's
  - Strike price set to generate long term stable revenues for investors
  - Secure fixed electricity prices for consumers

Contracts for difference

- Used to develop investment for:
  - Hinkley Point C nuclear power plant
  - 8 Renewables projects
    - 5 off shore wind
    - 2 conversions of existing coal fired power plant to 100% biomass firing
    - 1 biomass CHP plant
  - First renewable call over subscribed – next call autumn 2014
  - Two CCS demonstrations projects in 2015

Summary

- CCS implementation proceeding at a steady pace in parts of world.
  - All first of kind plants cannot mass fabricate like solar panels !!!
- CO2-EOR supporting early demonstration of CCS
  - Helping to financially de-risk projects
  - Effect of oil price crash unknown ??
- Need a stronger price signal on carbon
- UK leading on market reform to support CCS implementation.
- All eyes on COP in Paris in December
- Is CCS in a race with renewables in parts of the world?

Thank you, any Questions?

Contact me at: john.gale@ieaghg.org

	**Website:**	www.ieaghg.org
	**LinkedIn:**	www.linkedin.com/groups/IEAGHG-4841998
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