



**US - NORWAY
COLLABORATION ON CCS/CCUS**



***“CO₂ Foam EOR and CO₂ Injection in Hydrates –
CCUS Enablers for Efficient, Cost Saving and More Sustainable Oil & Gas
Production: Offshore International Whole Value Chain CCUS Collaboration”***

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“CO₂ for EOR as CCUS”, Rice Univ., Houston, TX, Oct. 4-6th, 2017



Success Criteria for Global CO₂ Storage

- Industry participation
 - Sustainable Economy; Improved technologies & cut cost
 - CO₂ EOR
 - Verification at Field Scale & at Relevant Location
 - Cost Effective On-Shore Analogues
 - Offshore pilots
 - Whole Value Chain Pilots
 - Whole Value Chain Field Wide CCUS

International Whole Value Chain CCUS Collaboration Offshore

CCUS-WVC: Carbon Capture, Transport, Utilization and Storage

Two Business Cases Enables CO2 Sequestration:

- Integrated EOR (IEOR) with CO2 Foam EOR
- Exploitation of Hydrate Energy using CO2

The Way Forward:

- Promising lab results
- Onshore field tests
- Offshore field tests



Large Scale Collaboration: Governments, Academia & Industry

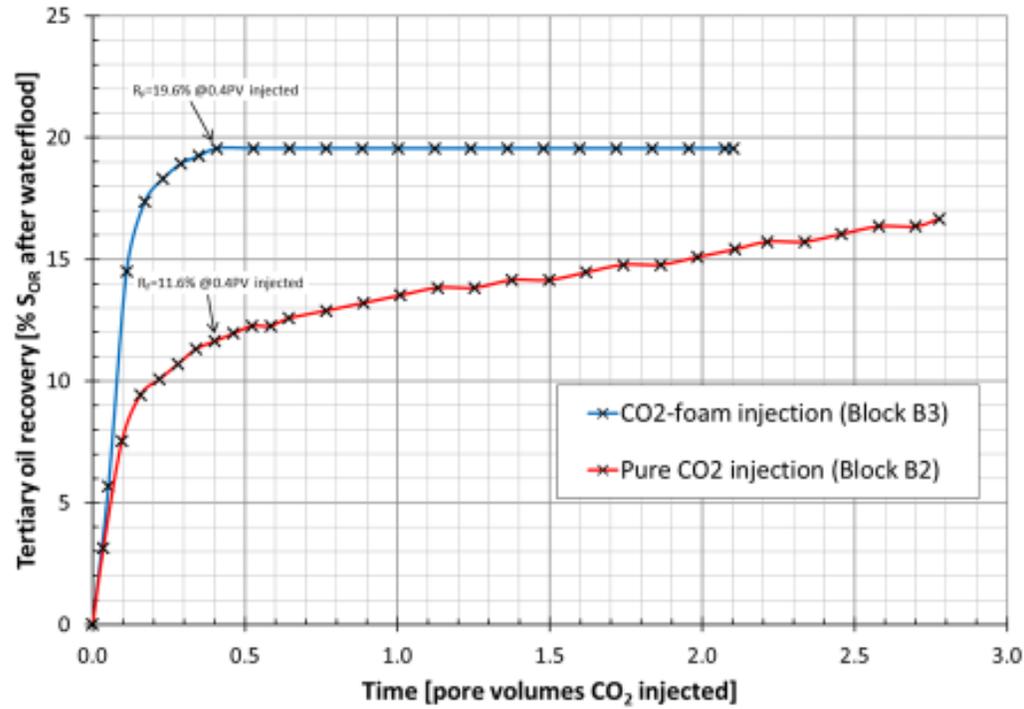
11 UNIVERSITIES :

- Rice University
- University of Texas at Austin
- U. of Houston
- Stanford U.
- Imperial College, London
- TREFLE, Bordeaux, France
- New Mexico Tech
- TU Delft, The Netherlands
- NTNU, Trondheim, Norway
- University of Stavanger, Norway
- University of Bergen, Norway

6 OIL COMPANIES:

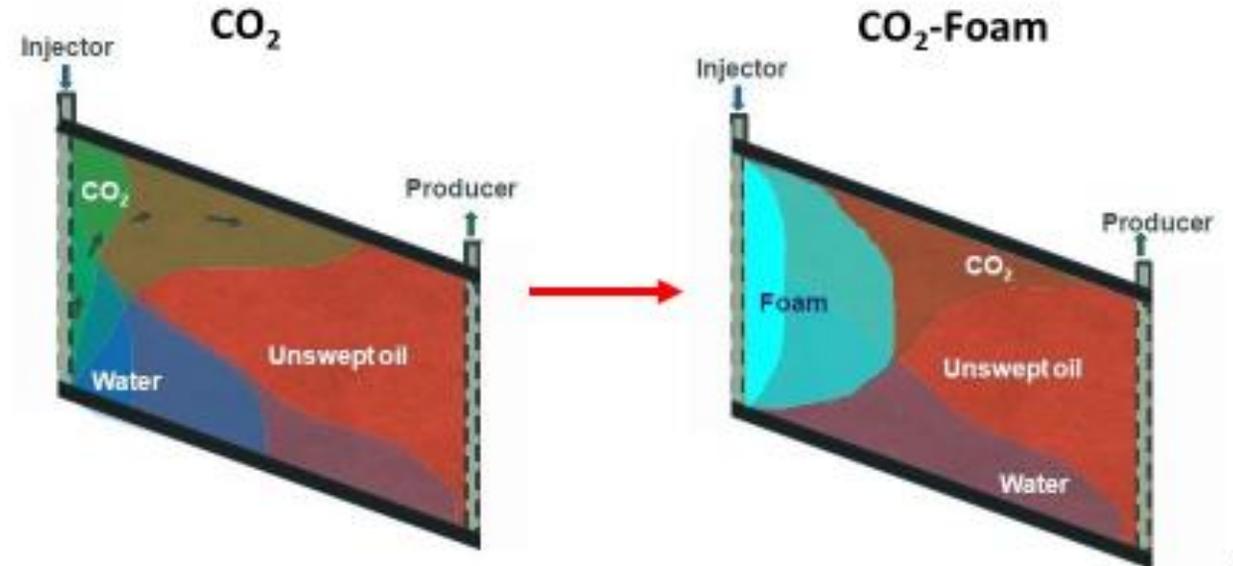
- Statoil
- Shell (Advisor Ft. Stockton)
- Total (Advisor East Seminole)
- Tabula Rasa
- StableRock Energy (Operator FS)
- Schlumberger





CO₂-foam

- Mitigates gravity override
- Improves sweep efficiency



analogous for free

- Success requires CO₂ monitoring
- USDOE funding for SWP may be available; propose joint efforts!



Business Model for Bilateral Collaboration on Monitoring CO₂ Foam EOR in On-Shore Texas Field Pilots

- CO₂ Foam EOR for Mobility Control increases oil production, reduces operational cost and store more CO₂ than conventional CO₂ EOR
- Two CO₂ Foam EOR Field Pilots as US Norway Collaboration in West Texas
- Funding is obtained from Climit/RNC and 7 oil companies as the projects are important as reservoir analogues for NCS
- Success requires CO₂ monitoring
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Lab to Field: CO₂ Foam EOR Field Pilots

OBJECTIVE

Cost-effective “Roadmap for Success” for CO₂ EOR implementation on Norwegian Continental Shelf through onshore field trials in Texas

WHY TEXAS?

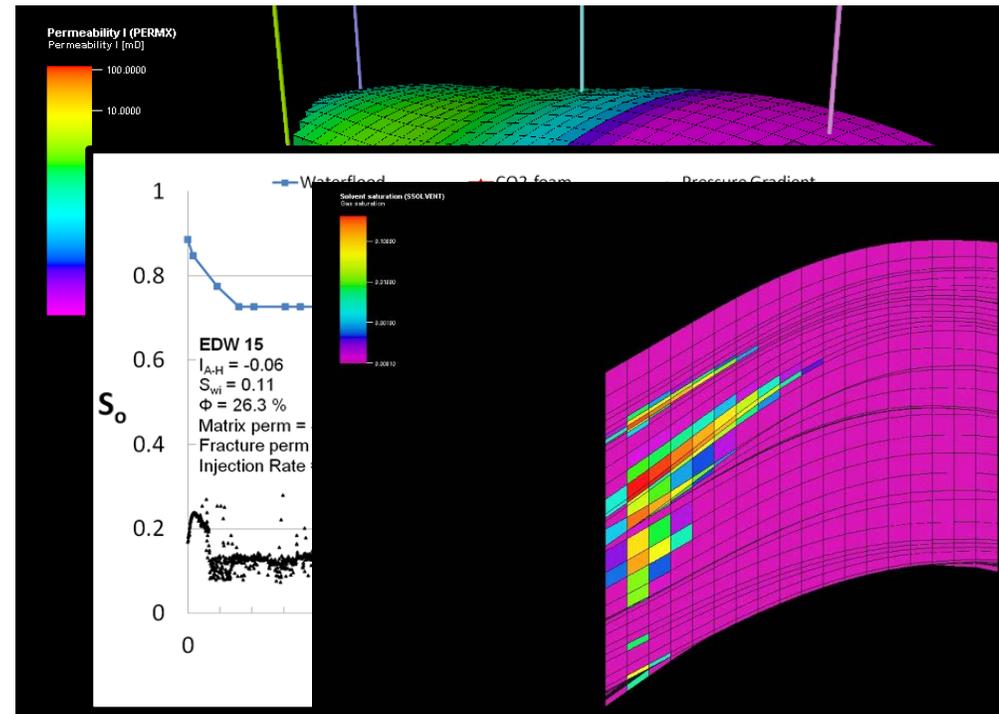
- CO₂ is commercially available; w/infrastructure
- Up-scaling; major challenge in oil recovery
- Fraction of costs of off-shore field tests
- Fast results: short inter-well distances
- 30 years experience in Texas on CO₂ EOR

COLLABORATORS

U. of Bergen	Total	Stanford U.
U. of Bordeaux	Rice U.	National IOR centre
U. of Houston	TU Delft	Schlumberger
Statoil	UT Austin	Shell

FUNDING 15MNOK

Norwegian Research Council, CLIMIT program
Oil Industry (Shell, Total, Schlumberger, Statoil)
+ local independent operators



Laboratory Results

More Oil produced:

CO₂ Foam EOR produces 10-30% additional oil after waterflooding

Faster Production:

Operational times reduced up to 90%.

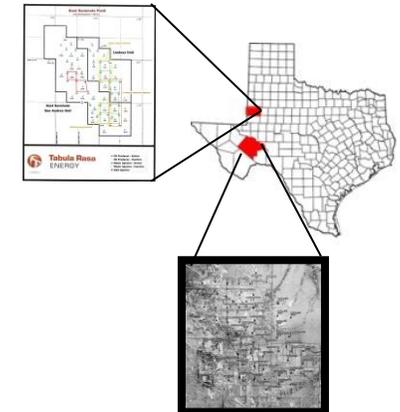
Laboratory Team

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Anders Frøland (MSc)
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Simulation Team

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Anna Bang (MSc)
Max Castro (MSc)
Stine Kristiansen (MSc)

East Seminole Well Location Map



Ft. Stockton Well Location Map

Simulation Results

Efficient Oil Production:

CO₂ Foam EOR increase sweep efficiency

More CO₂ stored:

Displace water to increase CO₂ storage volume

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- Success will be enhanced by CO₂ monitoring; cost effective on-shore
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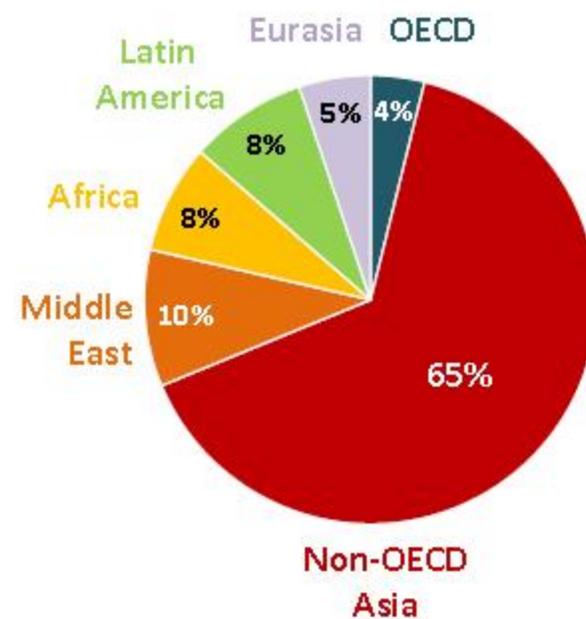
The engine of energy demand growth moves to South Asia

WORLD
ENERGY
OUTLOOK
2013

Primary energy demand, 2035 (Mtoe)

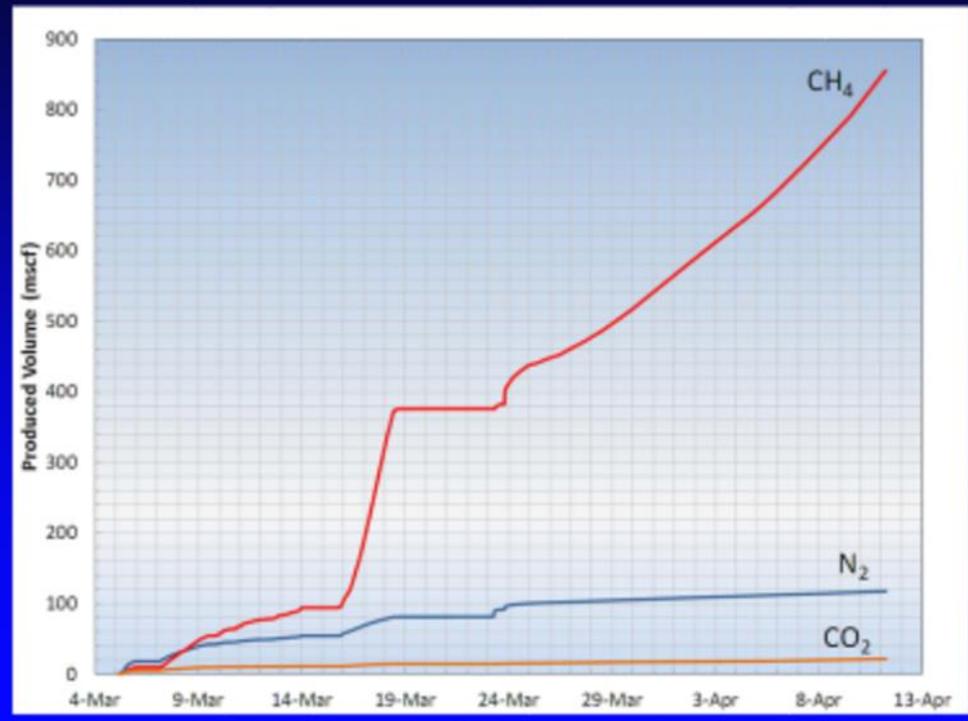


Share of global growth
2012-2035



*China is the main driver of increasing energy demand in the current decade,
but India takes over in the 2020s as the principal source of growth*

Gas Production from the Field Test

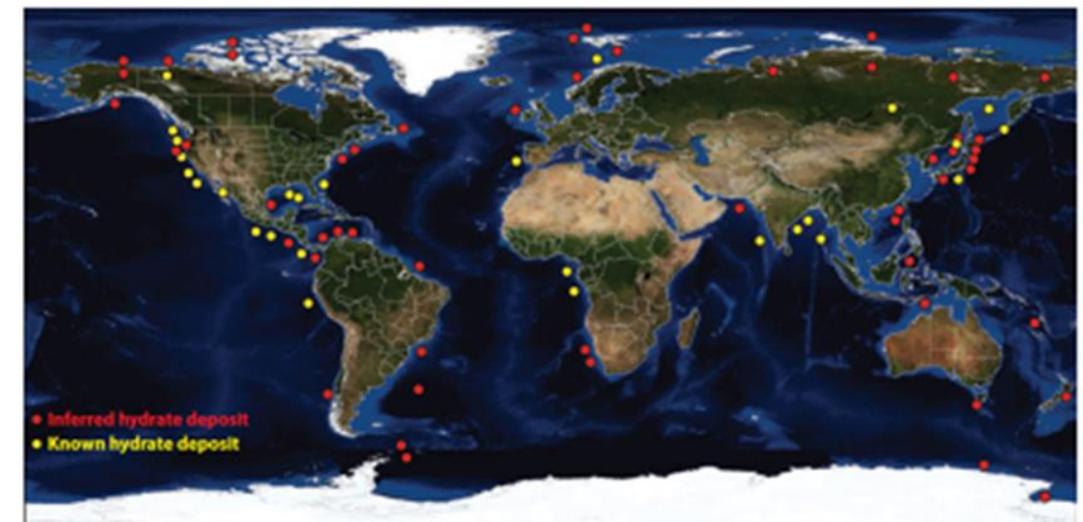


Ignik Sikumi #1 Flowback/Drawdown: Gas composition

Renewed interest

– Significant amount of energy

- Permafrost regions
- Marine environments (high water column)



Hester and Brewer, 2009

- Funding from other stake holders than oil and gas industry
- Whole Value Chain Cost obtained on Capture, Transport and Storage
- Integrating State of the Art Technologies; drilling cost at 50%
- Boundary conditions explored

Two offshore regions of interest:

1. South East Asia and India

2. Gulf of Mexico

Positive response from India:

- USGS/USDOE hydrate exploration; methane production in 2018
- Directorate General of Hydrocarbons interested in both technologies
- Venture Capital from private investors obtained for 3 years operation
- Funding from other stake holders than oil and gas industry
- Whole Value Chain Cost obtained on Capture, Transport and Storage
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INDIA:

CAPTURE

- 4 companies interested
- one company has 4 units installed in India

TRANSPORT

- Worldwide only 4 ships capable
- Pipeline combination cost evaluated

STORAGE

Two birds with one stone:

- CO2 foam EOR
- CO2 injection i hydrates for methane production



Business Opportunities in Asia



Hydrates – an unique energy source

- No similar size of energy reserves present in Asia provides strategies for countries with energy poverty and lack of energy resources
- Favorable gas prices in a potent Asian market (7 – 9 times higher than in North America)

Oil production – need to cut costs

- Lower oil prices demand higher extraction rates from oil fields to increase efficiency
- EOR can make important contribution to future world oil supply as access to new exploration acreage is difficult and expensive

Accelerated public energy demand

- Rapid economic growth in Asia
- Urgency for developing sustainable energy solutions
- IEA predicts that 65% of the growth of the world energy demand will occur in non-OECD Asia

High CO₂ availability

- Numerous Asian oil fields are currently producing as much as 70% CO₂
- Large production of CO₂ in industrial clusters
- CCUS can be one of the most important measures in Asia to cut pollution and meet COP21 targets

Integrated
CO₂-EOR

CO₂-CH₄
Exchange

Applying CO₂ as a commodity in CO₂ injection, either for:

- CO₂ foam EOR
- Methane production from hydrates

Will significantly contribute to the supply of energy in Southeast Asia and enable CO₂ sequestration

Easy accessible CO₂ sources in Asia



Non-exhaustive list of reservoirs and industrial clusters with high CO₂ concentration

Malaysia

- K5 Gas Field (70% CO₂)
- Tangga Barat Gas Field (48% CO₂)
- Muda Gas Field (47% CO₂)
- Cakerawala Gas Field (37% CO₂)

Thailand

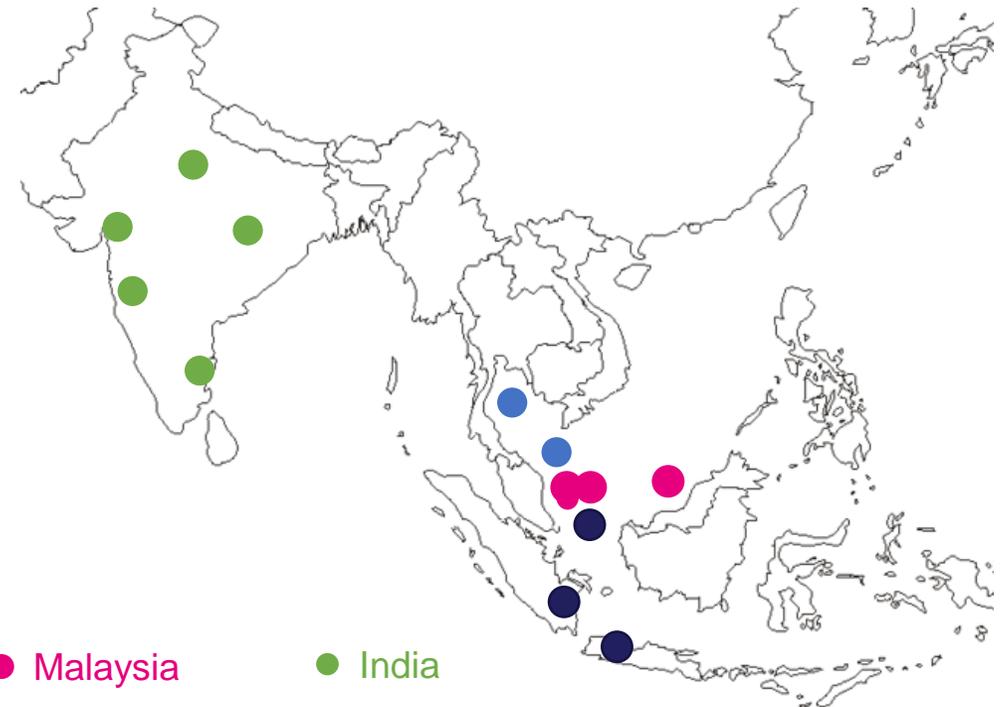
- Malay Basin, Group I (shared with Malaysia)
- Jasmine Field

Indonesia

- Natuna Gas Field (up to 75% CO₂)
- West Java Field (up to 75% CO₂)
- South Sumatra Basin

India

- Mumbai-Pune Belt
- Chennai Region
- Dehli Region
- Chotanagpur Plateau Region
- Ahmedabad-Vadodara Region



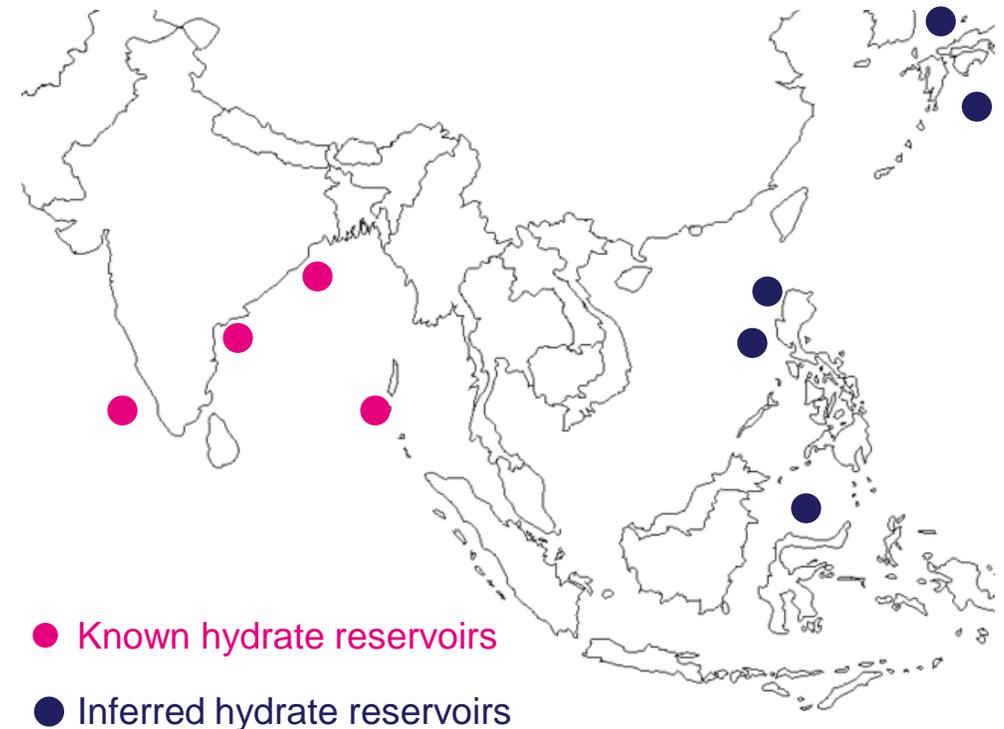
Map show non-exhaustive list of reservoirs and industrial clusters with high CO₂ concentration

Large commercial opportunities for LNG production from hydrate basins in Asia



Major hydrate basins identified in Asia show high potential to meet current and future energy needs

- Expeditions in the Krishna-Godavari and Mahanadi Basins off the coast of India show positive findings
- Preliminary work underway for gas hydrate production testing program
- Gas hydrate reserves of India estimated at nearly 1,500 times its natural gas reserves



Source: Hester and Brewer, 2009



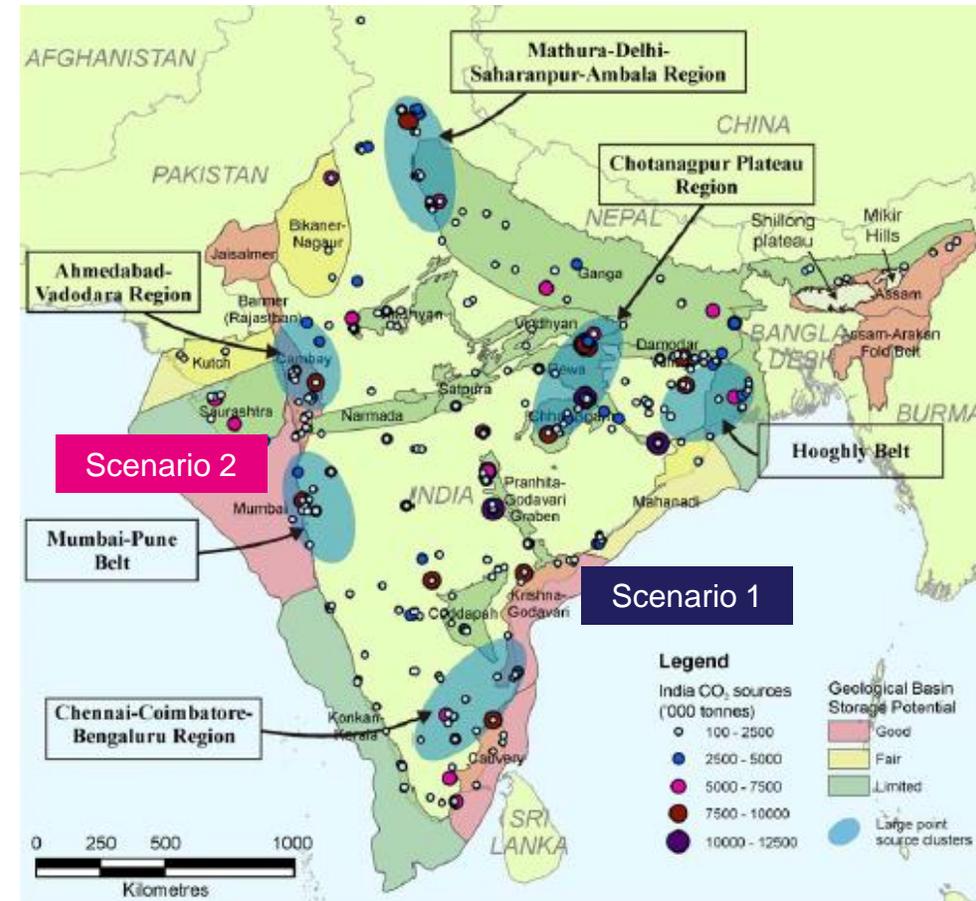
Cost of CO₂ capture and transportation in India¹

Scenario 1: CCUS on the east coast of India

- CO₂-sources:
 - Chennai-Coimbatore-Bengalure Region
- Potential storage site:
 - Ravva field (Krishna-Goodavari basin)

Scenario 2: EOR on the west coast of India

- CO₂-sources:
 - Mumbai-Pune-belt
- Potential storage site:
 - Mumbai High field (Mumbai basin)



¹ Available at: <https://www.globalccsinstitute.com/publications/regional-assessment-potential-co2-storage-indian-subcontinent>

PROPOSE:

1. Joint efforts Academia, Industry and Government
2. Adhere to the Paris agreement
3. Governmental support to initiate actions at appropriate level
4. Utilize US and Norway expertise on CO2 and offshore technologies
5. Utilize available coordination efforts when Venture Capital is available
6. Recruit next generation energy engineers
7. Combine efficient energy production with environmental action
8. Goal: More sustainable oil and gas production; may even be carbon negative



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