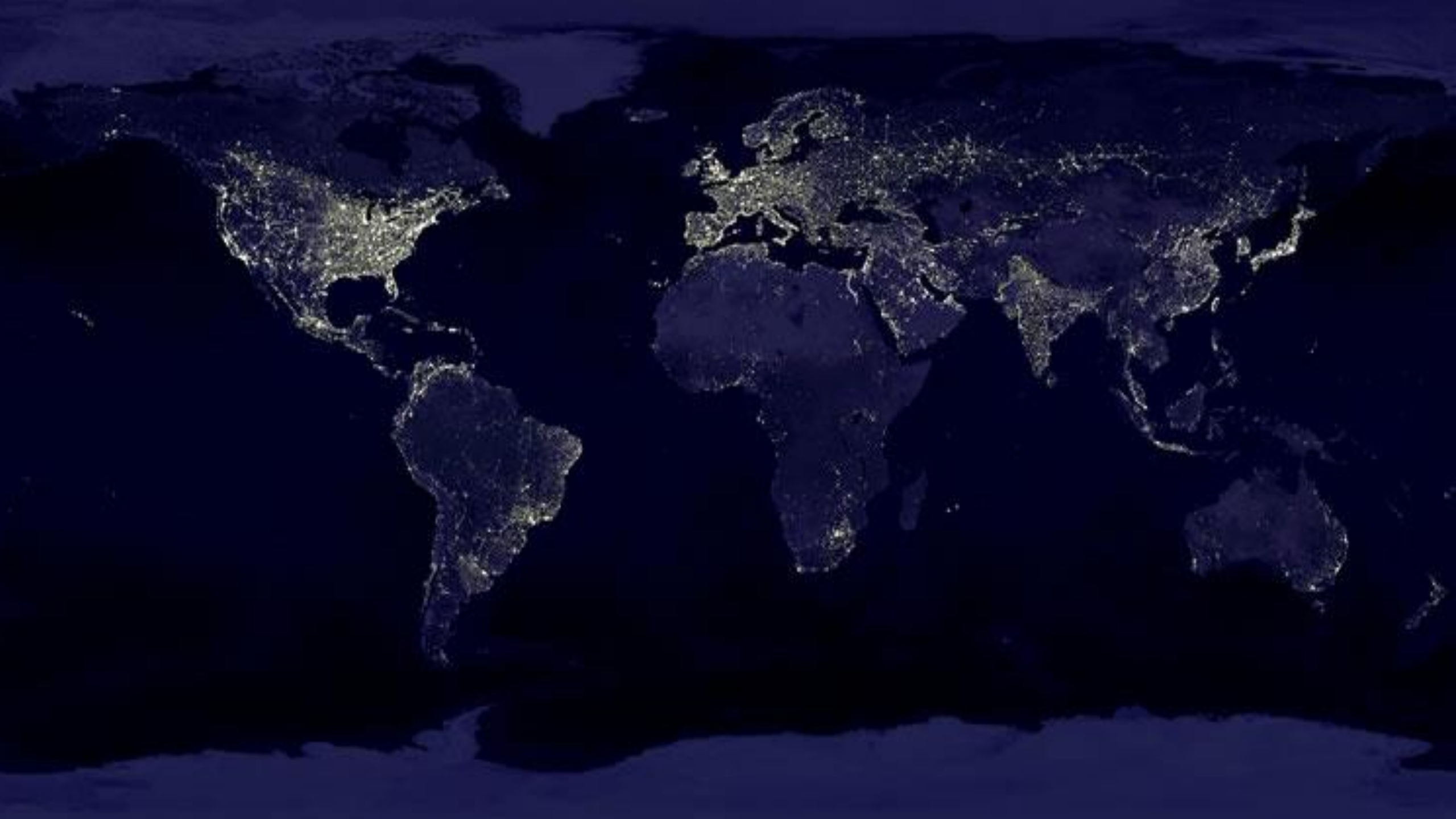
CCUS Enables Petroleum as Energy Security for More Sustainable Energy in the Future

Prof. Arne Graue

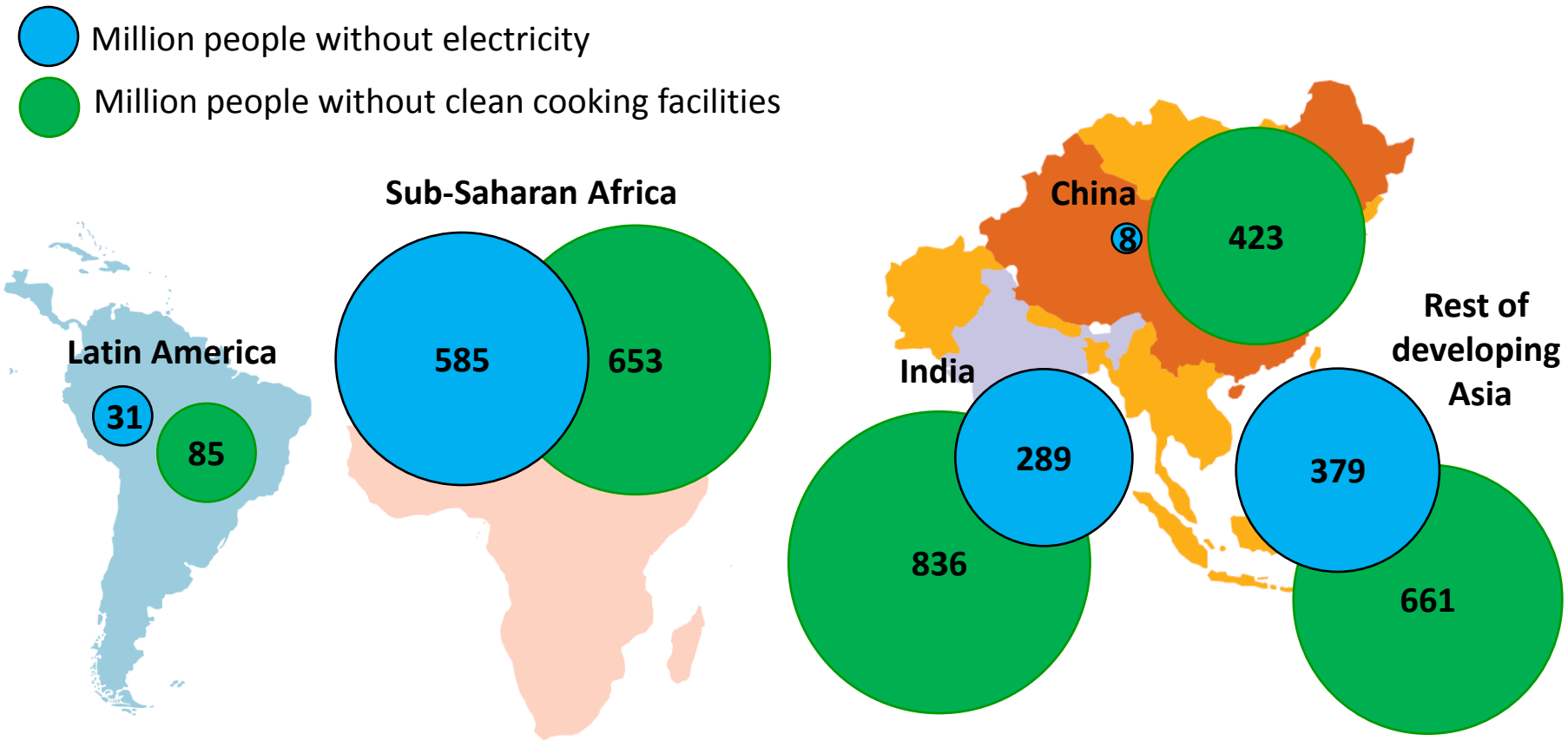
Dept. of Physics and Technology

University of Bergen, NORWAY

Whole Value Chain CCUS Student Week, Oct. 15th - 19th, 2018, Golden, CO, USA.



Energy Poverty is Widespread



1.3 billion people in the world live without electricity
& 2.7 billion live without clean cooking facilities

The Global Energy Challenge

- More energy
- Cleaner energy
- Energy security – oil & gas

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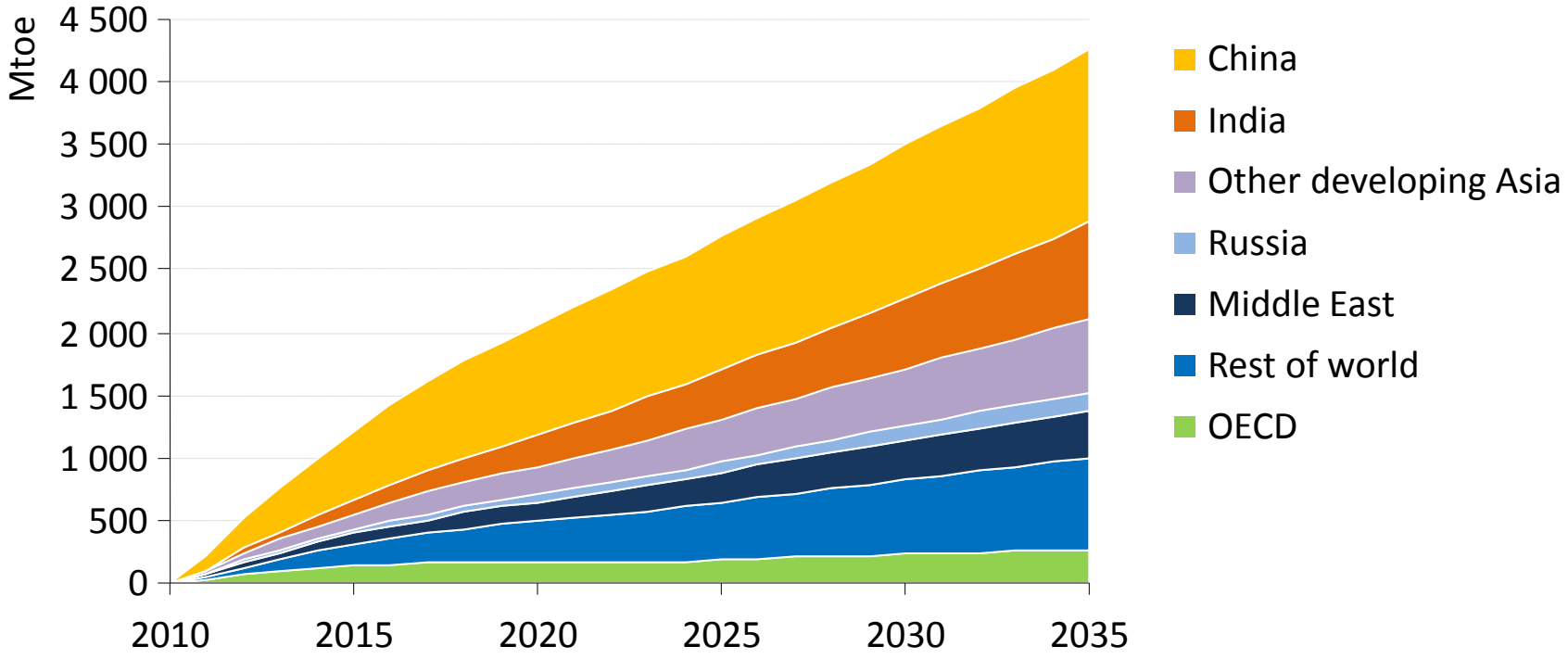
The Global Need for Energy Continues to Rise

Growth in primary energy demand in the IEA's New Policies Scenario



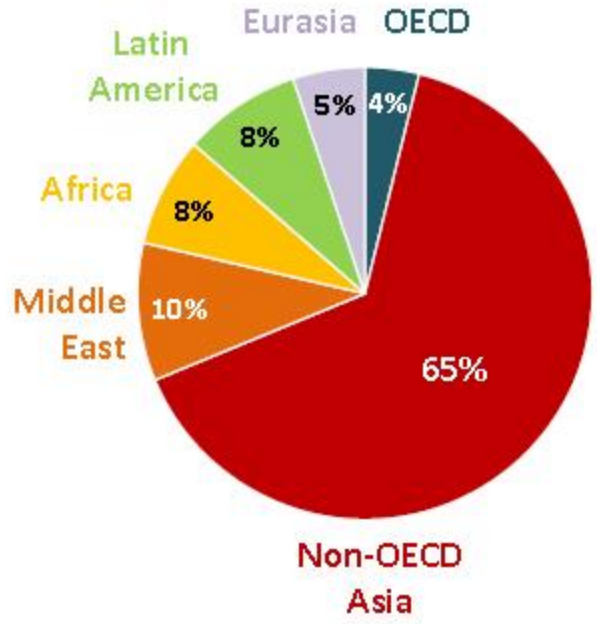
Source: International Energy Agency

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

The Global Energy Challenge

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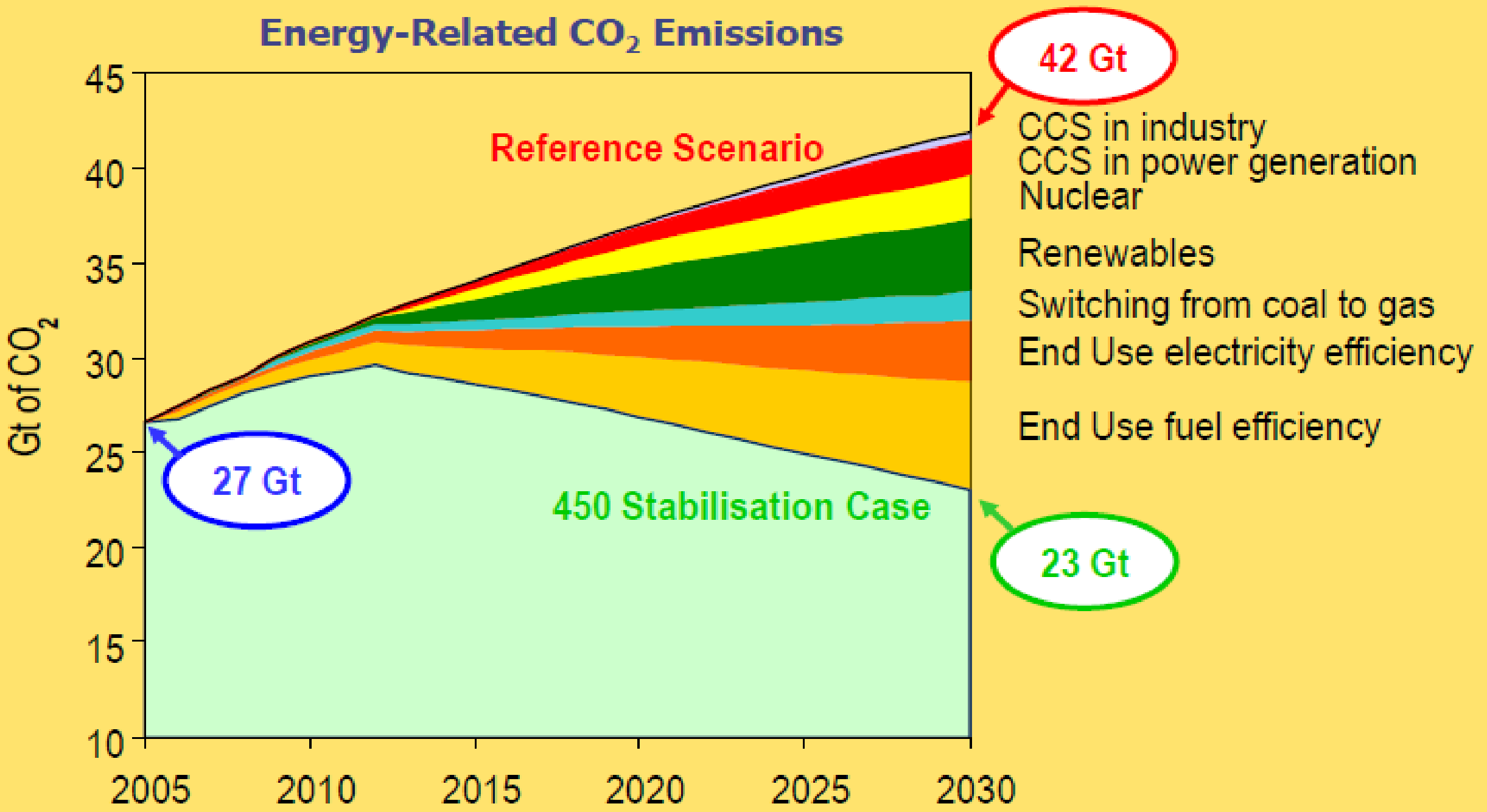
- Cleaner energy
- Energy security – oil & gas


Energy-Related CO_2 Emissions
Gt of CO_2
45
40
35
30
25
20
15
10
2005
2010
2015
2020
2025
2030
Reference Scenario
450 Stabilisation Case
42 Gt
27 Gt
23 Gt
CCS in industry
CCS in power generation
Nuclear
Renewables
Switching from coal to gas
End Use electricity efficiency
End Use fuel efficiency

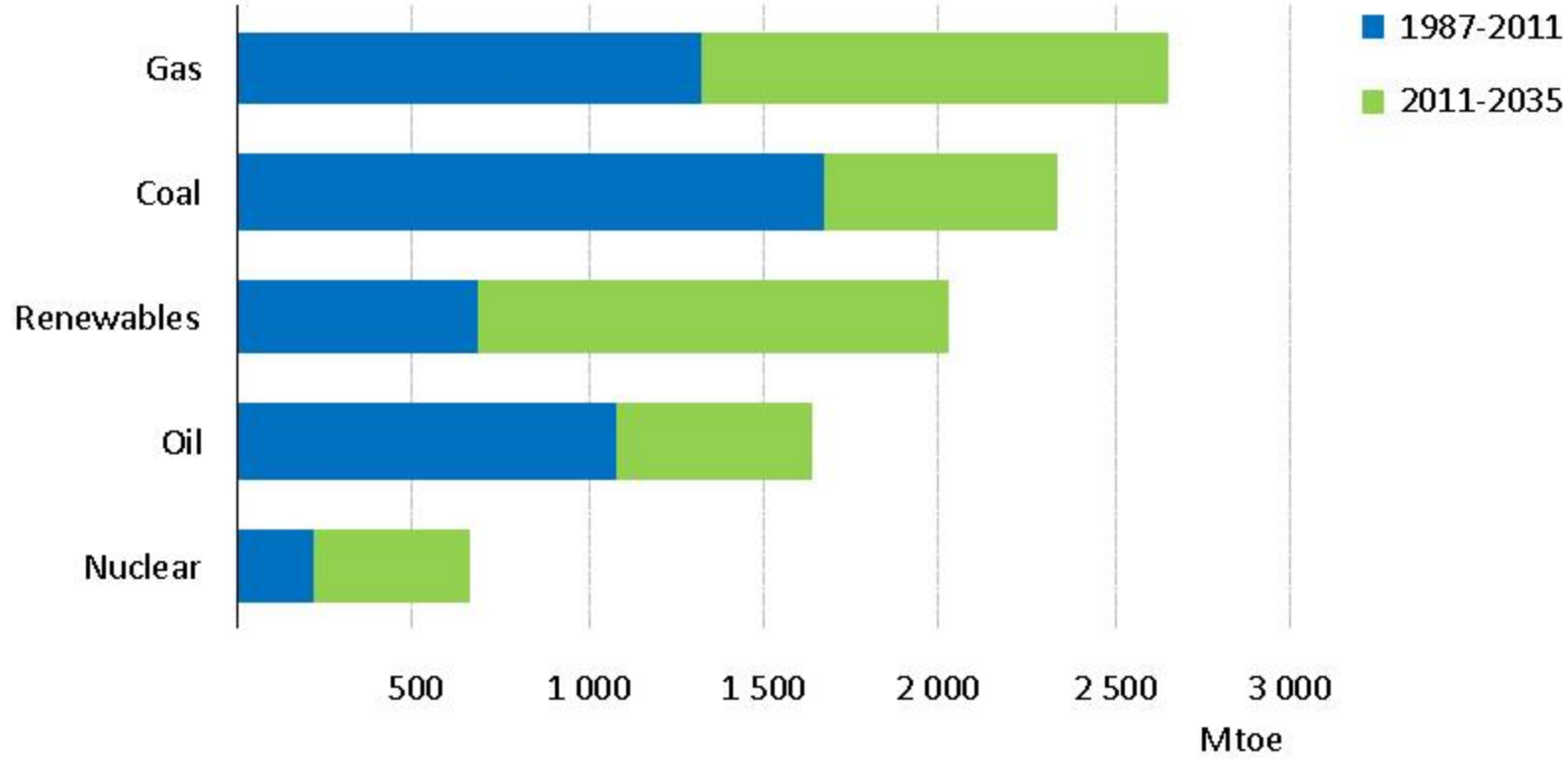
The Global Energy Challenge

- More energy
- Cleaner energy
- Energy security – oil & gas

A mix that is slow to change

WORLD ENERGY OUTLOOK 2013

Growth in total primary energy demand

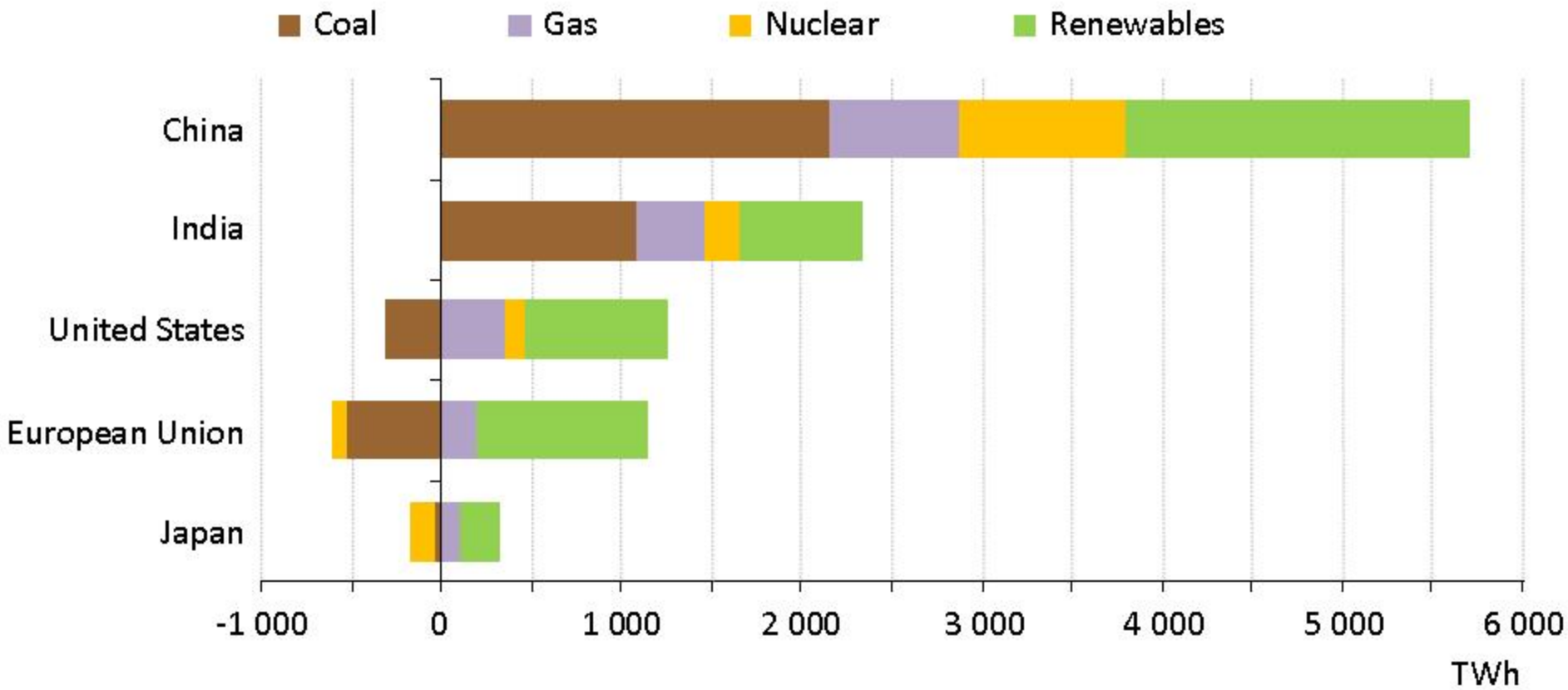


Today's share of fossil fuels in the global mix, at 82%, is the same as it was 25 years ago; the strong rise of renewables only reduces this to around 75% in 2035

A power shift to emerging economies

WORLD ENERGY OUTLOOK 2012

Change in power generation, 2010-2035



The need for electricity in emerging economies drives a 70% increase in worldwide demand, with renewables accounting for half of new global capacity

CCUS Business Opportunities

Key Factors:

- **Energy Strategies & Commercial Revenues**
- **Disruptive New Technologies & Upscaling**
- **Climate Impacts**
- **License to Operate & Public Perception**
- **Government, Industry & Academia Interactions**

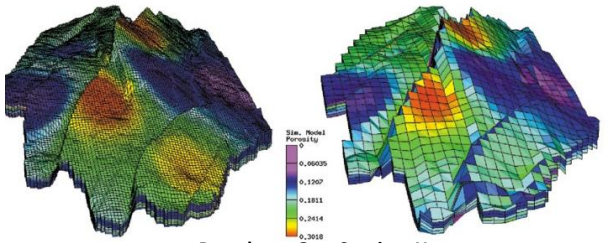

Norway's Sovereign Wealth Fund Hits $1 Trillion
Largest sovereign wealth funds by assets under management in 2017*
Fund
Country
Origin
Assets
Government Pension Fund - Global
Norway
Oil
$1t
Abu Dhabi Investment Authority
UAE
Oil
$828b
China Investment Corporation
China
Non-Commodity
$814b
Kuwait Investment Authority
Kuwait
Oil
$524b
SAMA Foreign Holdings
Saudi Arabia
Oil
$514b
Hong Kong Monetary Authority Investment Portfolio
Hong Kong
Non-Commodity
$457b
SAFE Investment Company
China
Non-Commodity
$441b
Government of Singapore Investment Corporation
Singapore
Non-Commodity
$359b
Qatar Investment Authority
Qatar
Oil & Gas
$320b
National Social Security Fund
China
Non-Commodity
$295b
@StatistaCharts
* As of September 19, 2017
Source: The Sovereign Wealth Fund Institute
Forbes
statista

Success Criteria for Global CO_2 Storage

- Industry participation
  - Sustainable Economy; Disruptive Technologies at Low Cost
    - CO_2 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

Length Scales

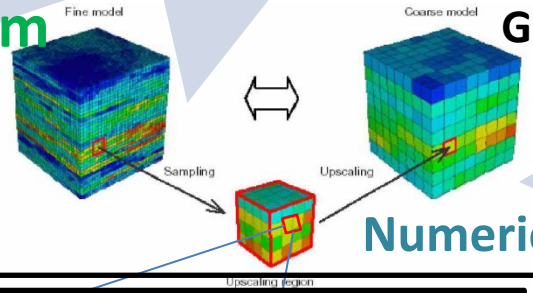
10^3-10^4m



Petroleum Geo-Services Homepage
www.pgs.com

10^1-10^2m

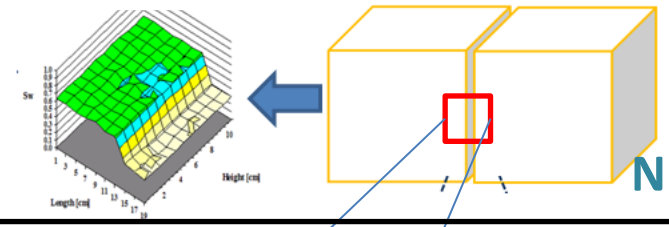
GRIDBLOCK SCALE



Numerical Simulations

10^{-1}-10^0m

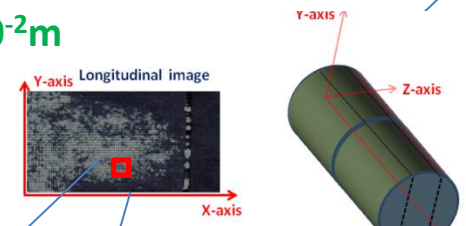
BLOCKSCALE



Nuclear Tracer

10^{-3}-10^{-2}m

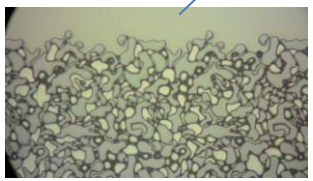
CORESCALE



MRI and CT

10^{-5}-10^{-3}m

MICROSCALE



Microscopy

Imaging techniques

Next Generation CO_2 Flooding

- Main challenges in CO_2 EOR:
  - Early CO_2 breakthrough and poor sweep efficiency
  - Up-scaling laboratory EOR to field performance

- US White Paper:
  - Mobility control in CO_2 EOR, USDOE/Advanced Resource International Inc.
  - Target: 137 Billion bbl

- US import of foreign oil may be reduced by 30%

- “Next generation CO_2 EOR technology" based on mobility control

- 68 billion barrels of oil: 1,35 billion bbl of oil every year for 50 years

- Similar results in the North Sea; pilot in the Snorre Field

- Economic at oil price of US$ 85 and CO_2 price of US$ 40/ton

- Need more CO2

- Carbon Capture Utilization and Storage (CCUS) a win-win situation

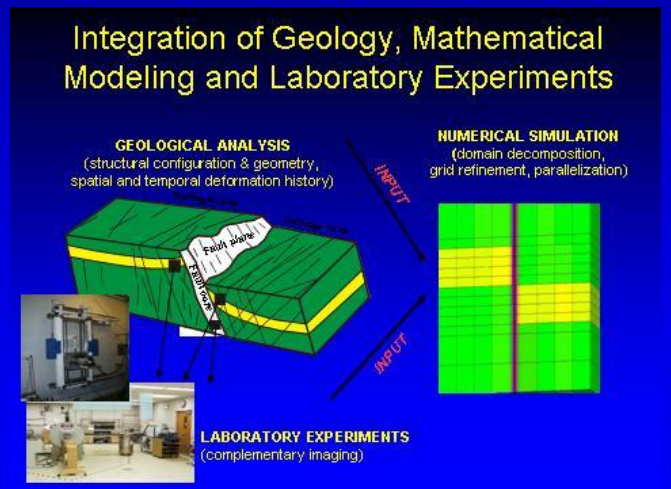
CO_2 EOR Enables CCUS: Integrated EOR (IEOR) for CO_2 Sequestration

CO_2 Foam EOR Mobility Control in Field Pilots in Texas

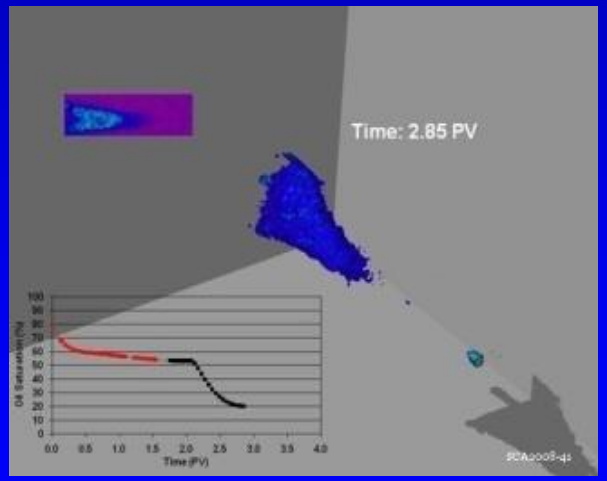
Collaboration: 11 Universities in France, The Netherlands, UK, USA and Norway

Coordinator: Arne Graue, Dept. of Physics, University of Bergen, NORWAY

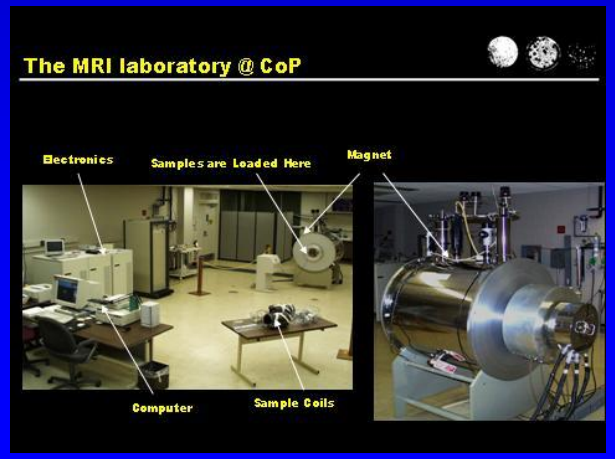
Funding: CLIMIT Program at the Research Council of Norway and 7 oil companies



Lab to pilot field test



MRI of CO_2 injection



Complementary NTI & MRI facilities

Lab to Field: CO_2 Foam EOR Field Pilots

OBJECTIVE

Cost-effective "Roadmap for Success" for CO_2 EOR implementation on Norwegian Continental Shelf through **onshore field trials in Texas**

WHY TEXAS?

- CO_2 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 CO_2 EOR

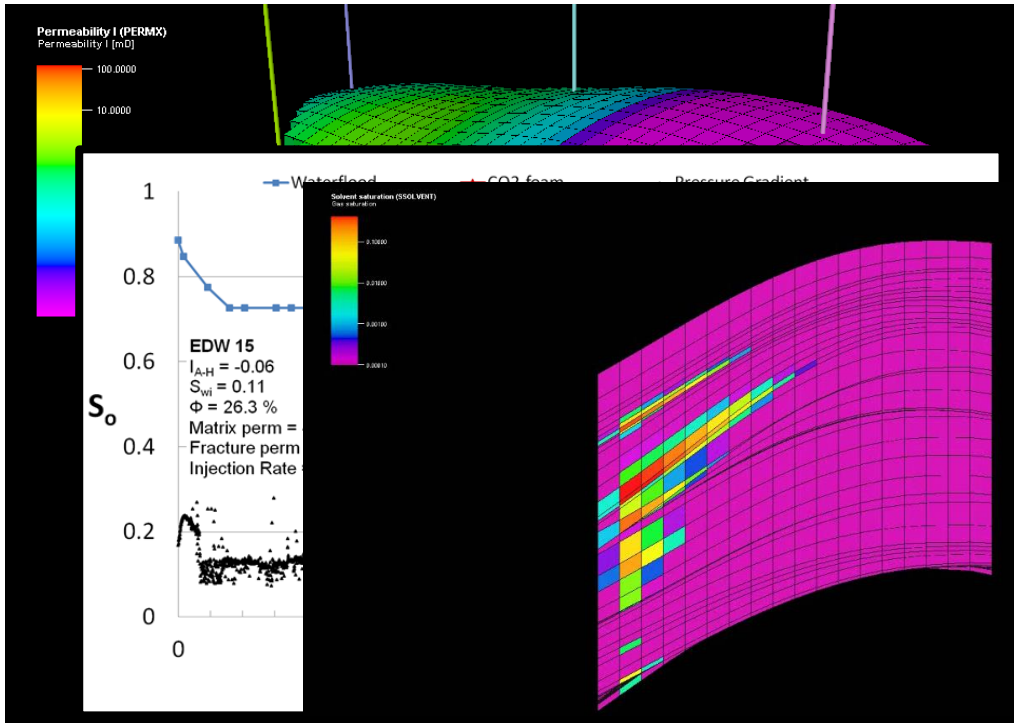
COLLABORATORS

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

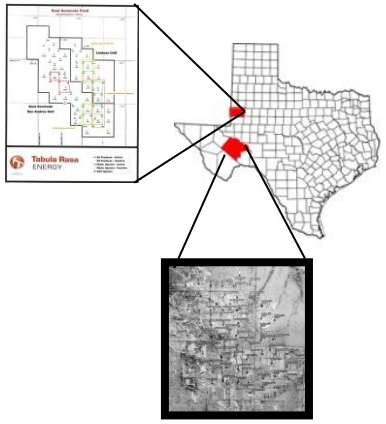
FUNDING 15MNOK

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

1981 1987 2014



East Seminole Well Location Map



Ft. Stockton Well Location Map

Simulation Results

EFFICIENT Oil Production:
CO_2 Foam EOR increase sweep efficiency

MORE CO_2 stored:
Displace water to increase CO_2 storage volume

Laboratory Results

MORE Oil produced:
CO_2 Foam EOR produces 10-30% additional oil after waterflooding

FASTER Production
Operational times reduced up to 90%.

Laboratory Team

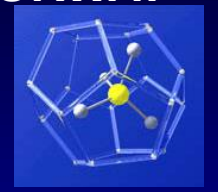
Sunniva Fredriksen (PhD)
Arthur Uno Rognmo (PhD)
Michael Jian (PhD)
Connie Wergeland (MSc)
Anders Frøland (MSc)
Andreas G. Polden (MSc)

Simulation Team

Zachary Alcorn (PhD)
Mohan Sharma (PhD)
Lars Petter Grønvigh (MSc)
Anna Bang (MSc)
Max Castro (MSc)
Stine Kristiansen (MSc)

CO_2 Storage in Hydrate Reservoirs with Associated Spontaneous Natural Gas Production

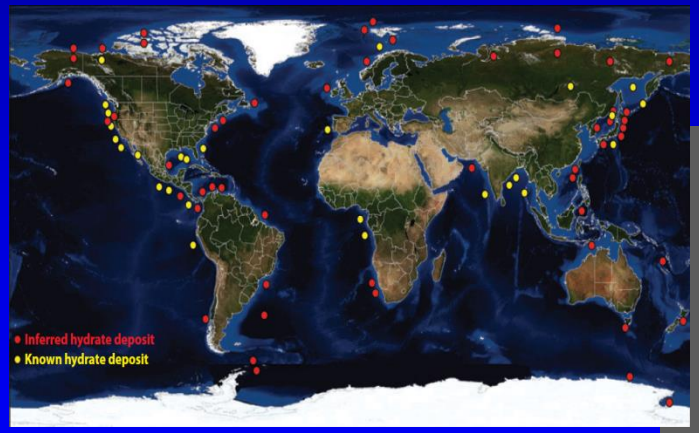
Arne Graue and Bjørn Kvamme, Dept. of Physics, University of Bergen, NORWAY
Funding: ConocoPhillips, Statoil and The Research Council of Norway



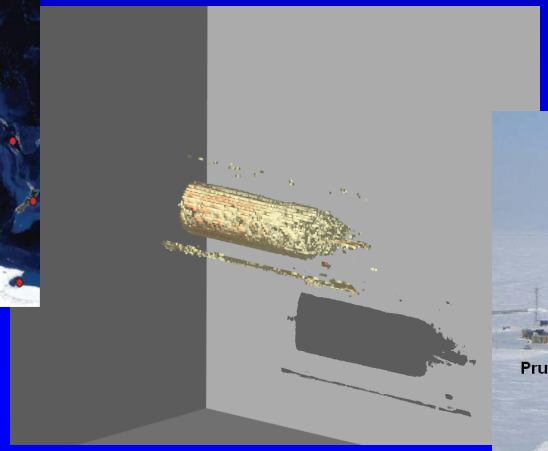
Objectives:

Experimentally and theorethically determine spontaneous methane production when hydrate is exposed to CO2; with the purpose of CO2 sequestration.

Methane hydrate reservoirs



***In-Situ* imaging (MRI) of hydrate formation**

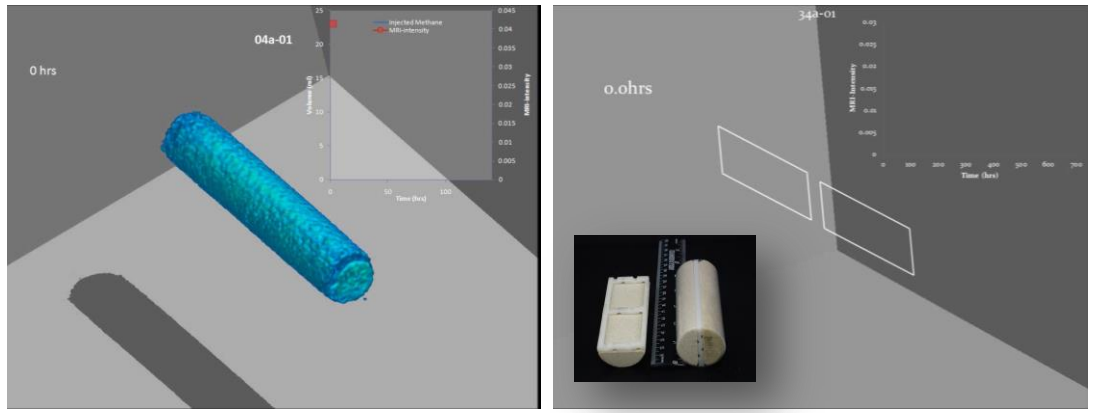


Methane production by CO_2 injection in field test in Alaska 2012

Energy for the Future
Gas Production WITH CO_2 Storage in Hydrates

Energy bound in hydrates **is more than combined energy** in conventional oil, gas and coal reserves

UiB Laboratory Verification of Technology



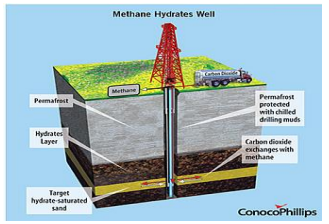
< 10 year

US $30 mill

Field Verification of UiB Technology

"*While this is just the beginning, this research could potentially yield significant new supplies of natural gas.*"

U.S. Energy Secretary Steven Chu, May 2nd 2012



DOE, ConocoPhillips and JOGMEC at the Iġnik Sikumi test site, Alaska

What are Methane Hydrates?

Methane hydrates are ice-like structures with natural gas trapped inside, and are found both onshore and offshore along nearly every continental shelf in the world.

Excerpt from U.S. Energy Secretary Steven Chu's statement

. . .to conduct a test of natural gas extraction from methane hydrate **using a unique production technology, developed through laboratory collaboration between the University of Bergen, Norway**… [D]emonstrated that this mixture could **promote the production of natural gas**. Ongoing analyses of the extensive datasets acquired at the field site will be needed to determine the **efficiency of simultaneous CO_2 storage in the reservoirs**.

Summary

Use of CO_2 as a commodity:

Business Case for CO_2 Storage:

- **CO_2 EOR**
- **Integrated EOR (IEOR) with Foam: *Carbon Negative Oil Production***
- **Exploitation of Hydrate Energy: *Carbon Neutral Gas Production***

Way Forward

New technologies ready for industrial scale implementation:

- **Onshore in Permian Basin, USA (80% CO_2EOR, EOR target 137Bbbl)**
- **Offshore Opportunities: NCS, Middle East, Asia, Africa and Brazil**
- **International Whole Value Chain CCUS Collaboration Offshore**

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