NFiP Nasjonal forskerskole i petroleumsfag
Petroleum Research School of Norway

NorTex Petroleum Cluster

The Research Council of Norway

COLORADO SCHOOL OF MINES

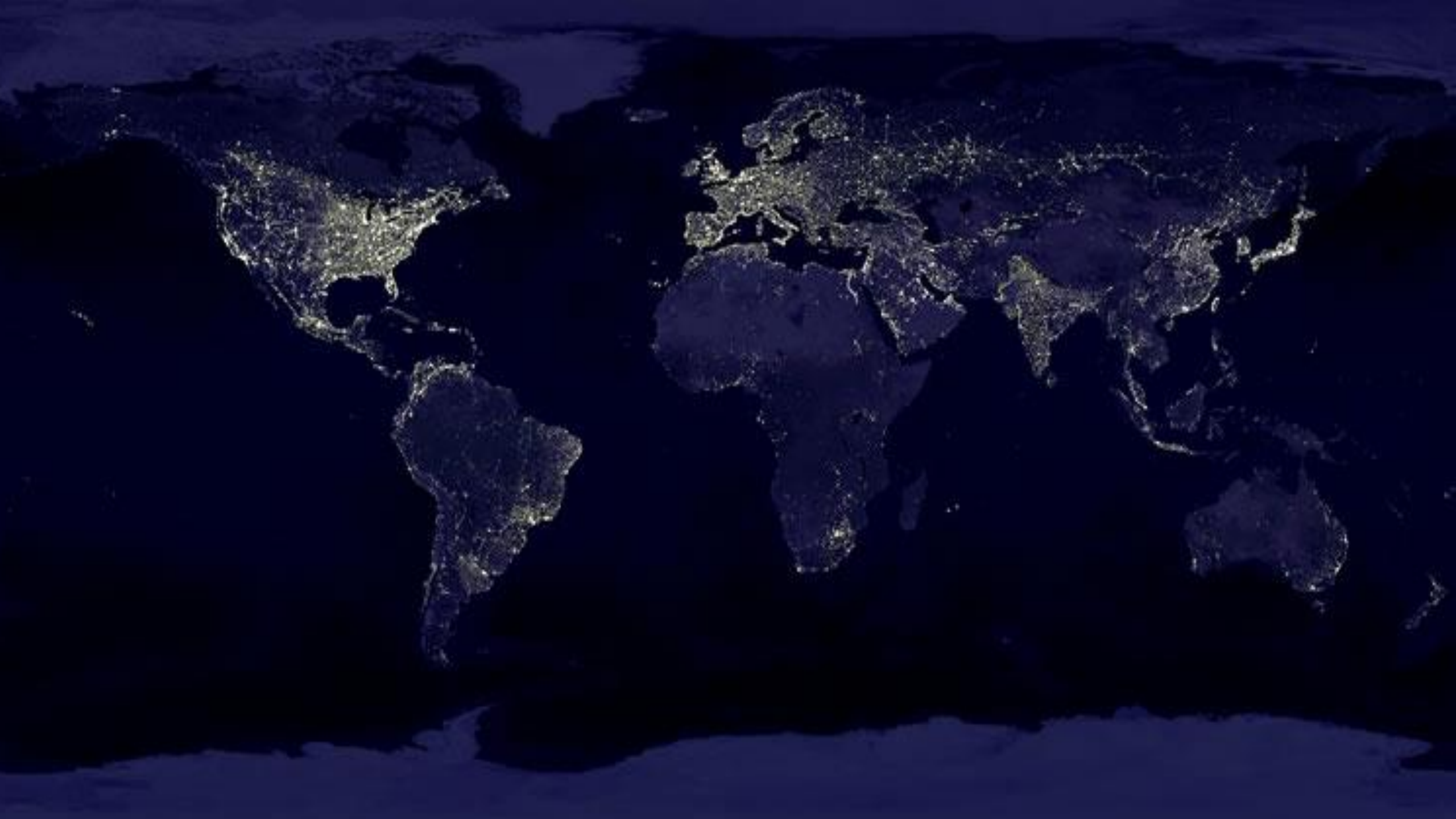
The Payne Institute for Public Policy
COLORADOSCHOOLOFMINES EARTH ENERGY ENVIRONMENT

Norwegian Consulate General
San Francisco

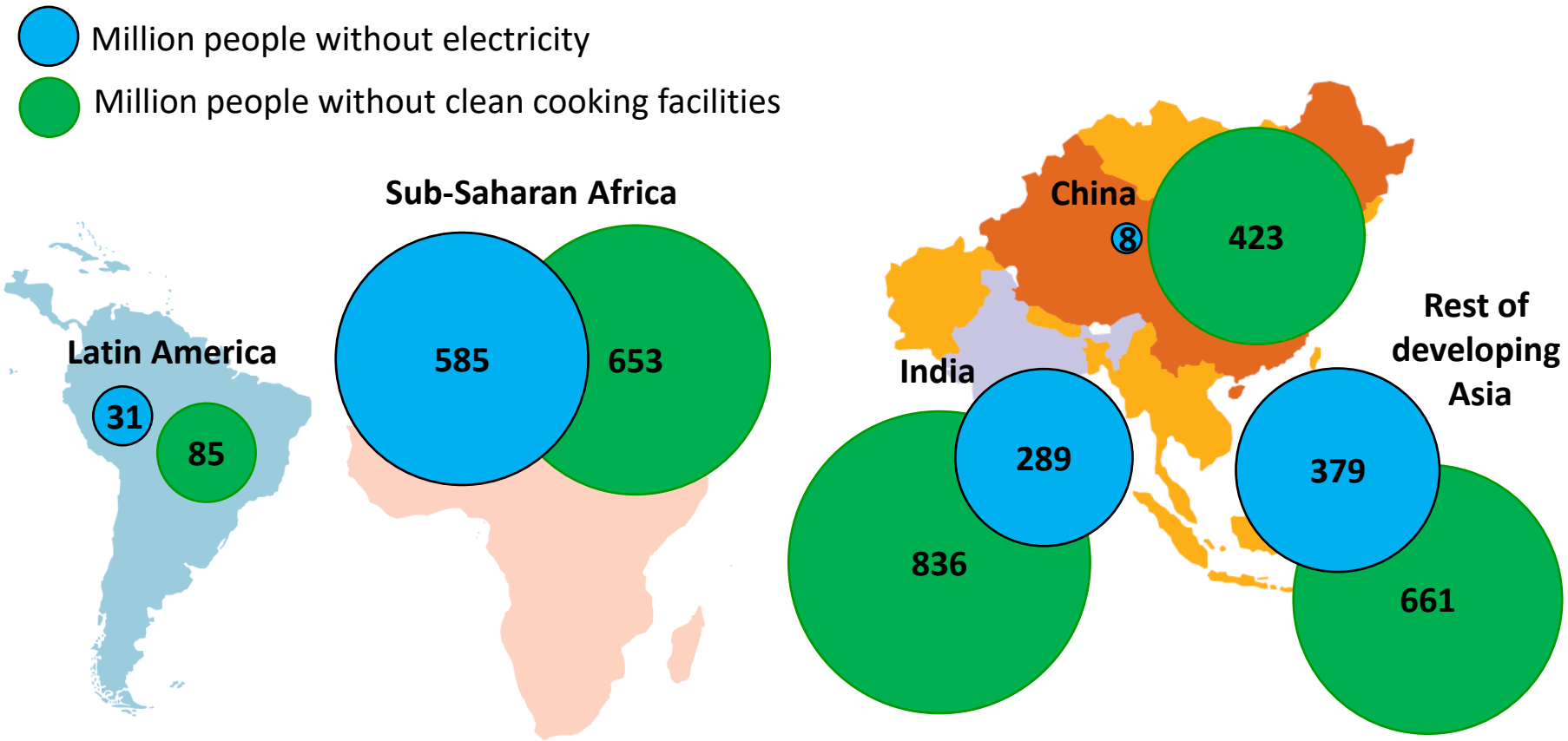
CCUS Assessment

Prof. Arne Graue
Dept. of Physics and Technology
University of Bergen, NORWAY

Whole Value Chain CCUS Conference Week, Nov. 14th-18th, 2022, Golden, CO, USA.

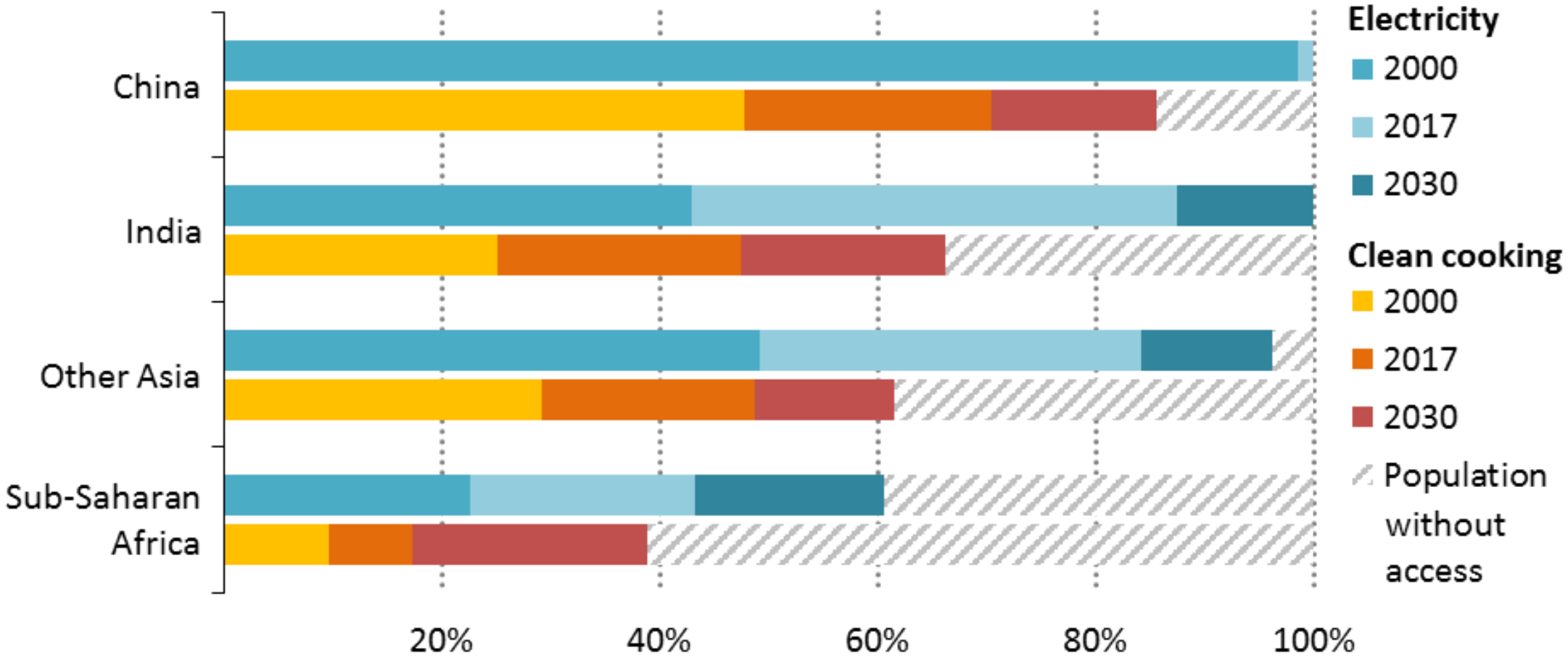


Energy Poverty is Widespread



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

Access to electricity and clean cooking in the New Policies Scenario



International Energy Agency (2018), World Energy Outlook 2018, OECD/IEA, Paris

SUSTAINABLE DEVELOPMENT GOALS

The Global Energy Challenge

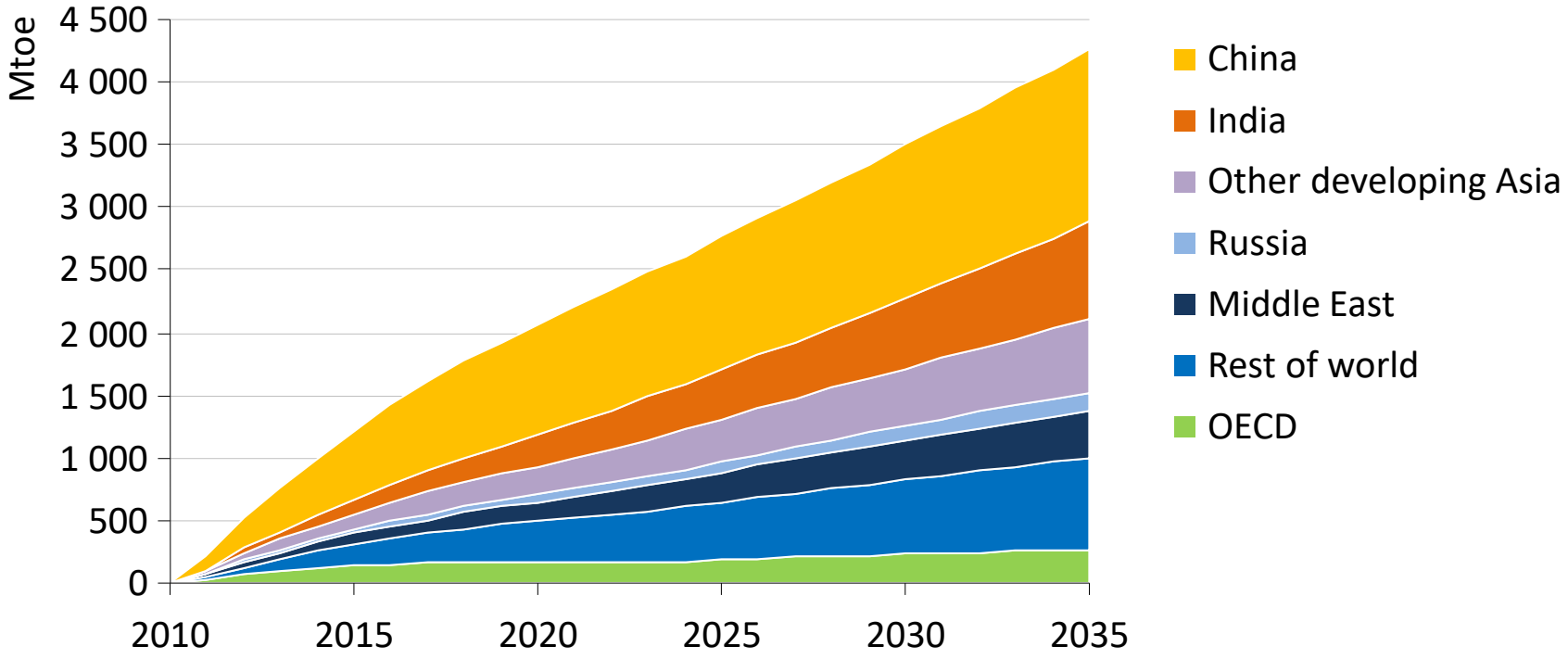
- More energy
- Cleaner energy
- Energy security – oil & gas

The Global Energy Challenge

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

The Global Need for Energy Continues to Rise

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



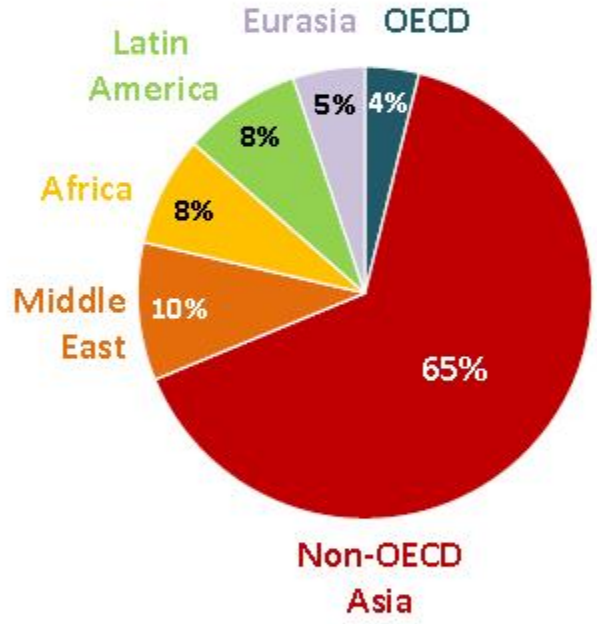
Source: International Energy Agency

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

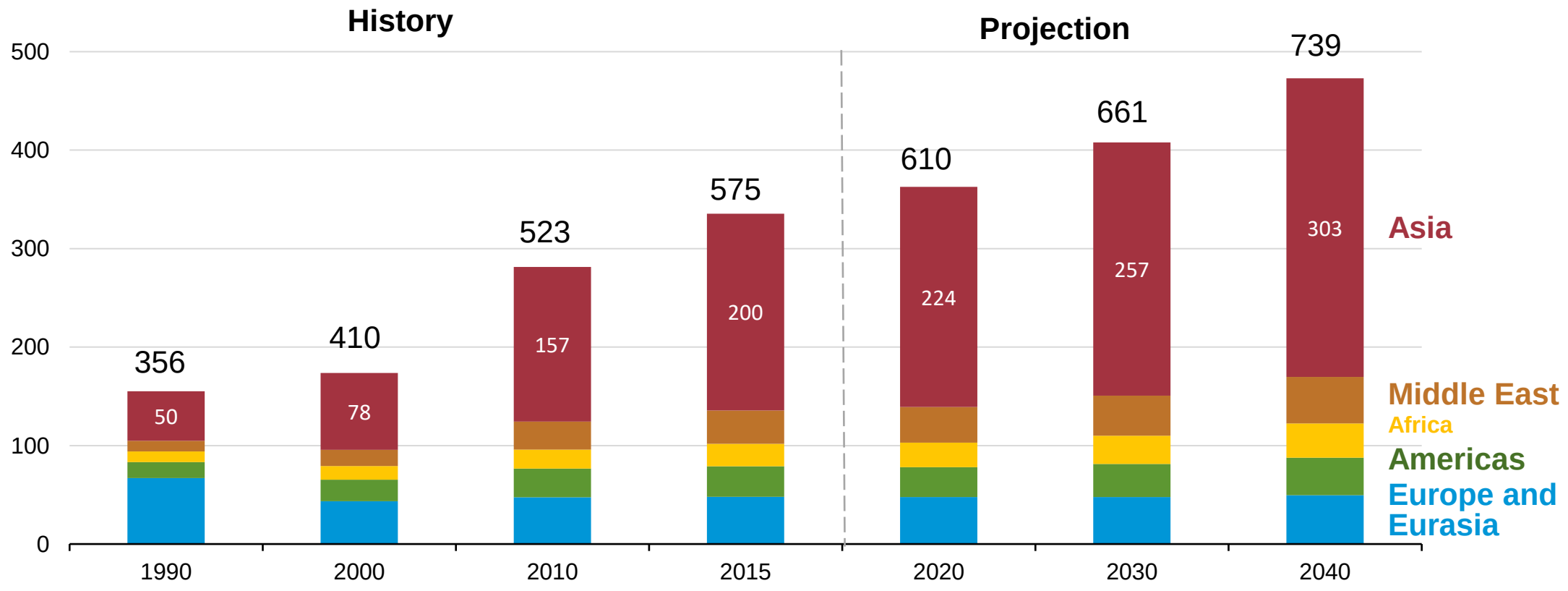


China is the main driver of increasing energy demand in the current decade, but India takes over in the 2020s as the principal source of growth

Asia is projected to have the largest increase in energy use of non-OECD regions

IEO2018 Reference case
non-OECD energy consumption by region

quadrillion Btu



Source: EIA, International Energy Outlook 2018

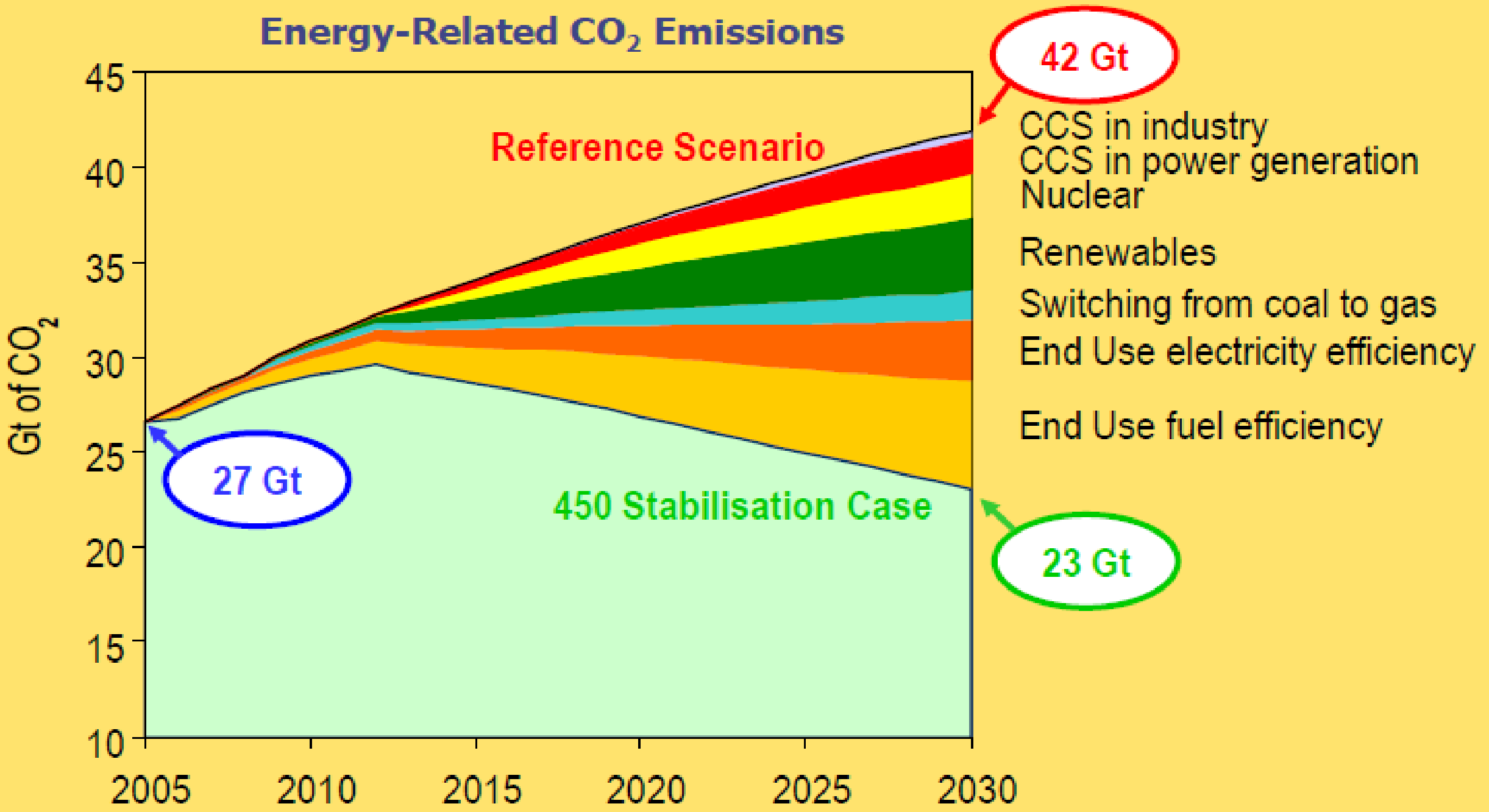
The Global Energy Challenge

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

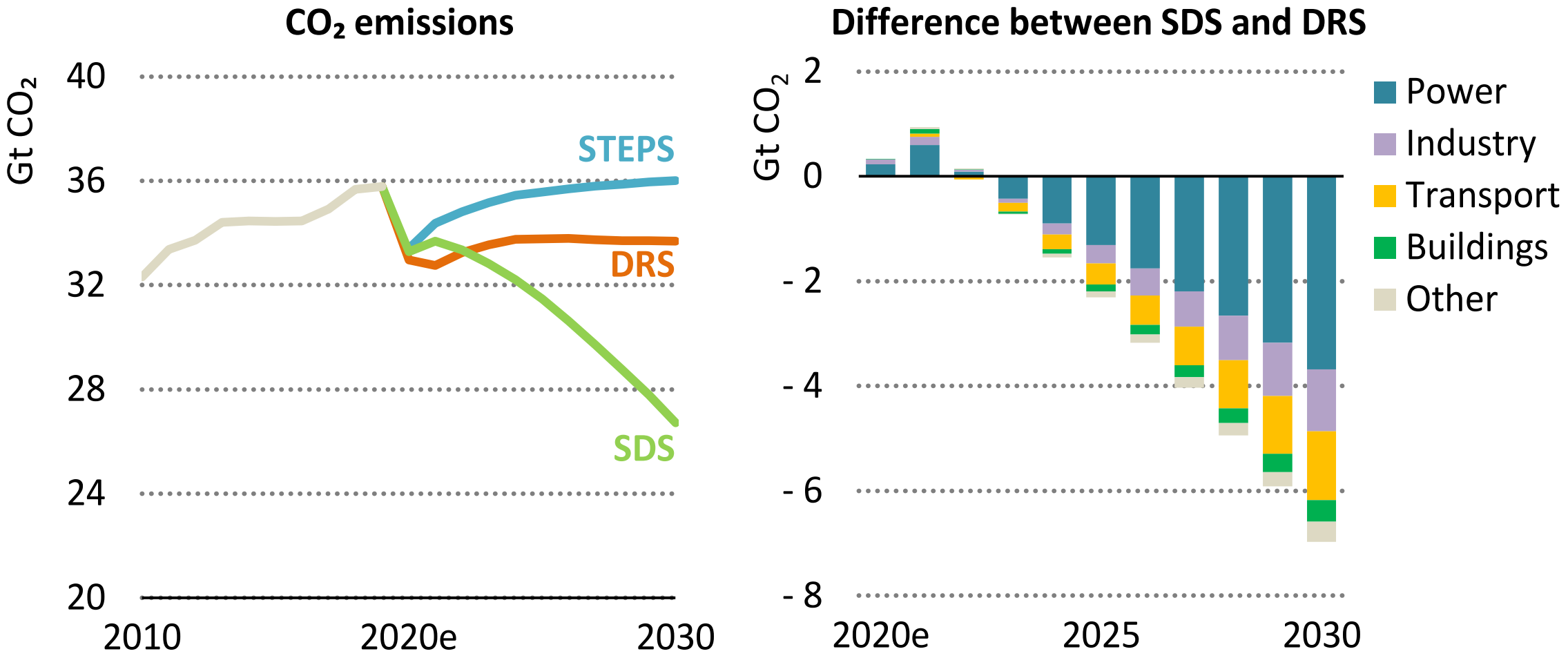
Large methane emissions from oil and gas operations detected by satellite in 2019 and 2020

International Energy Agency (2020), World Energy Outlook 2020, IEA, Paris

SCA2008-41

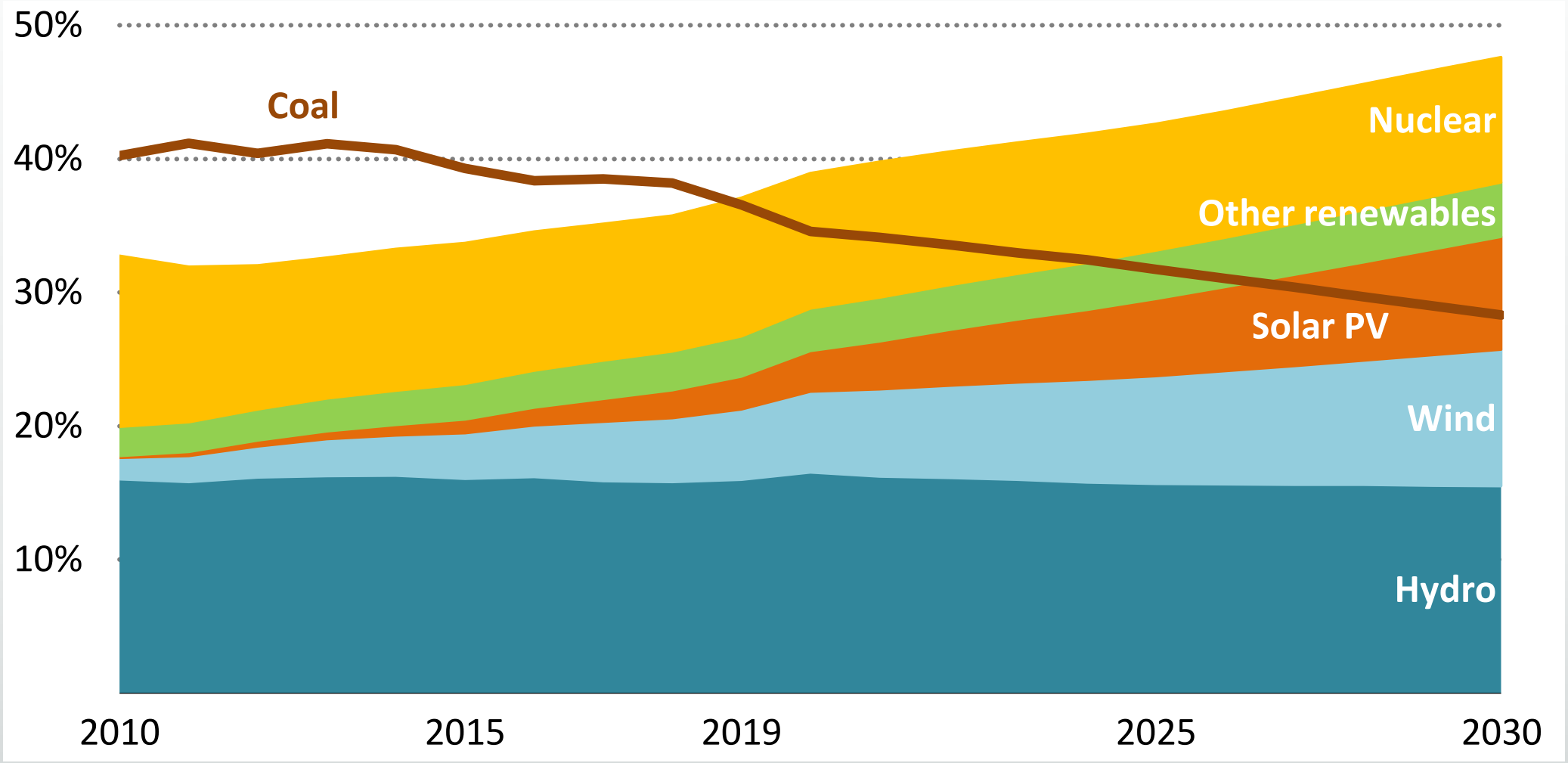

Energy-Related CO_2 Emissions
Gt of CO_2
45
40
35
30
25
20
15
10
2005
2010
2015
2020
2025
2030
Reference Scenario
450 Stabilisation Case
42 Gt
27 Gt
23 Gt
CCS in industry
CCS in power generation
Nuclear
Renewables
Switching from coal to gas
End Use electricity efficiency
End Use fuel efficiency

Energy sector and industrial process CO_2 emissions in the scenarios, 2010-2030



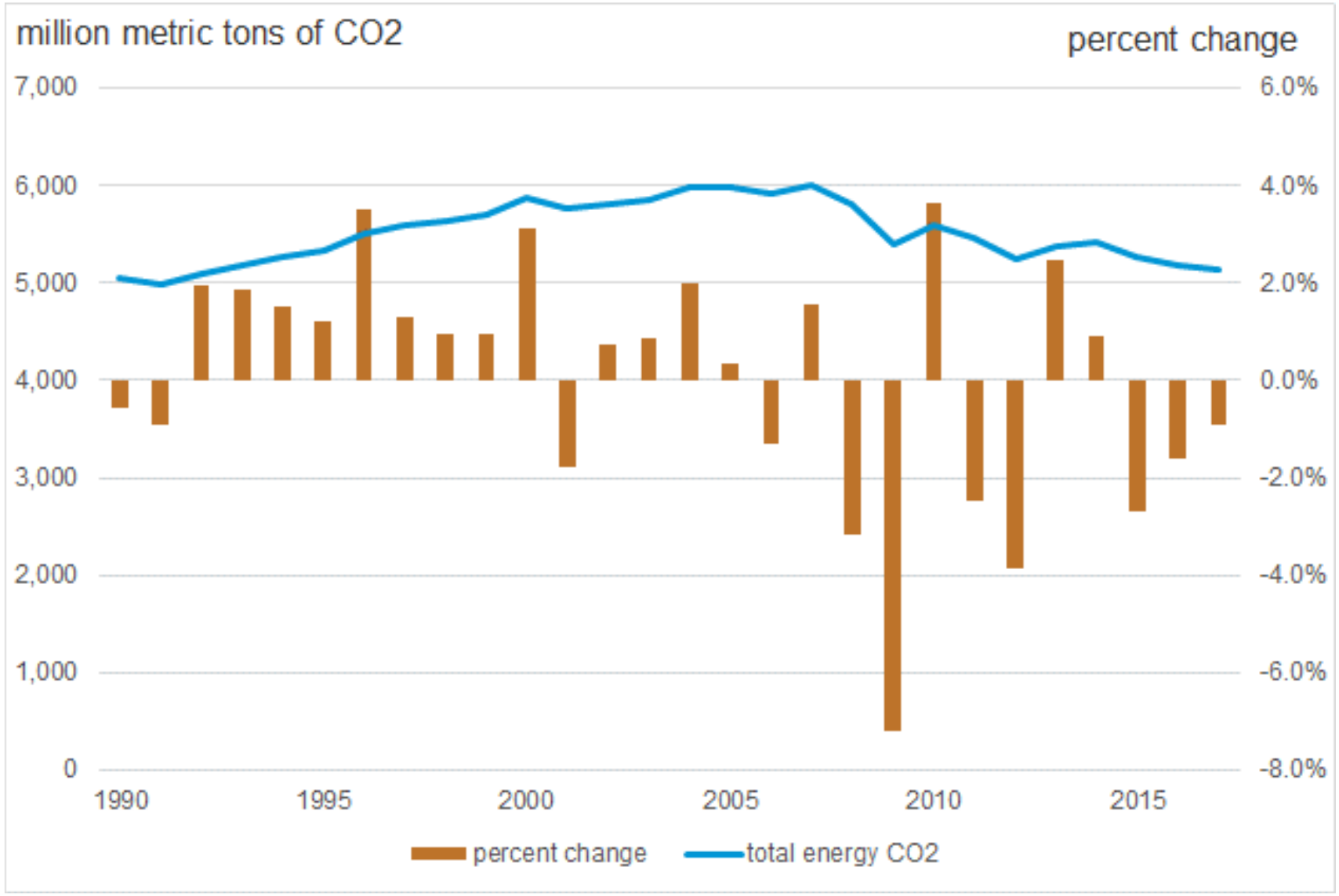
International Energy Agency (2020), World Energy Outlook 2020, IEA, Paris

Renewables, nuclear and coal shares of global electricity supply in the Stated Policies Scenario, 2010-2030



International Energy Agency (2020), World Energy Outlook 2020, IEA, Paris

US energy-related CO2 emissions in 2017 were 849 MMmt (14%) below 2005 levels



U.S. Energy Information Administration, 2017

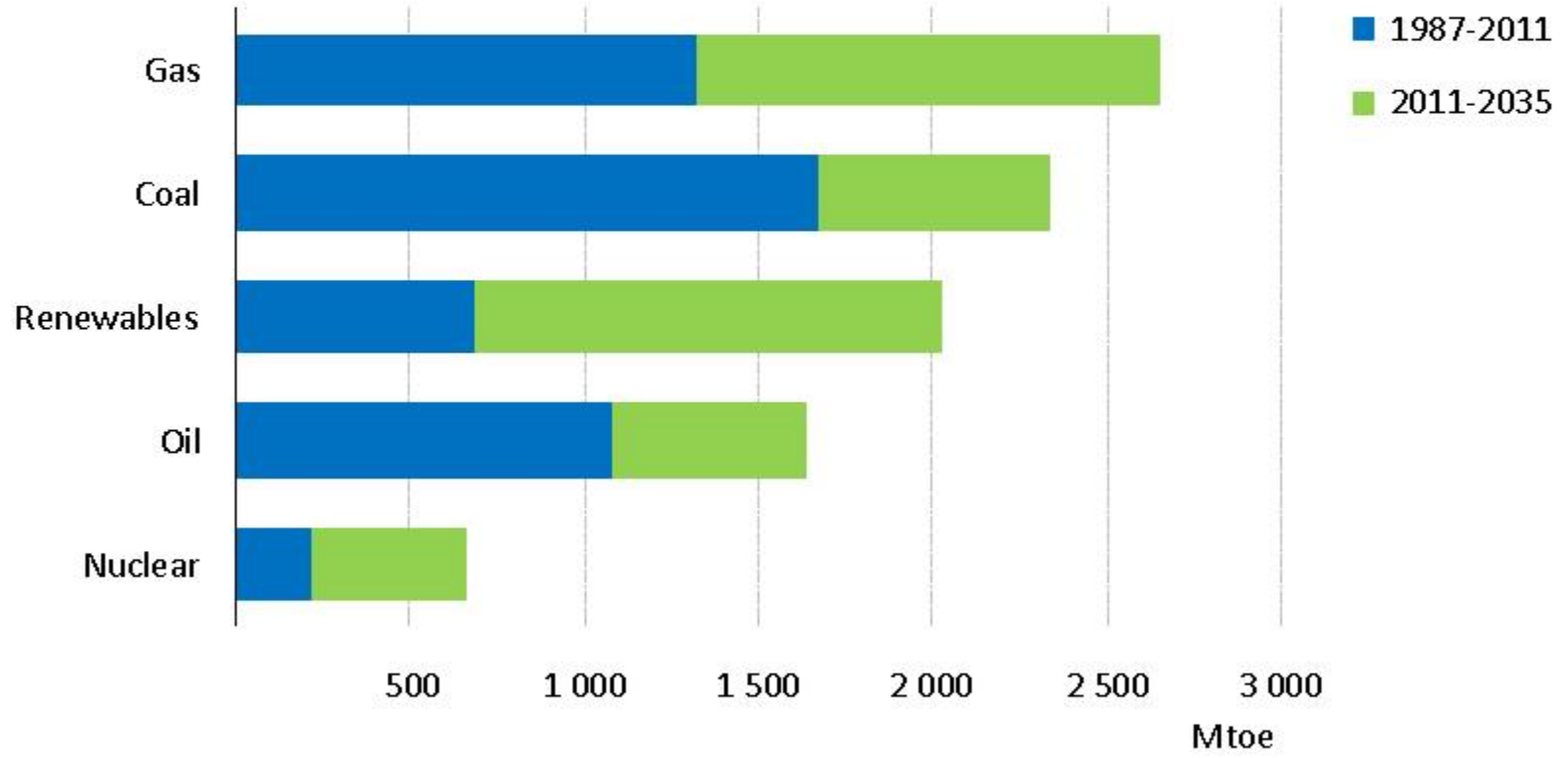
The Global Energy Challenge

- 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

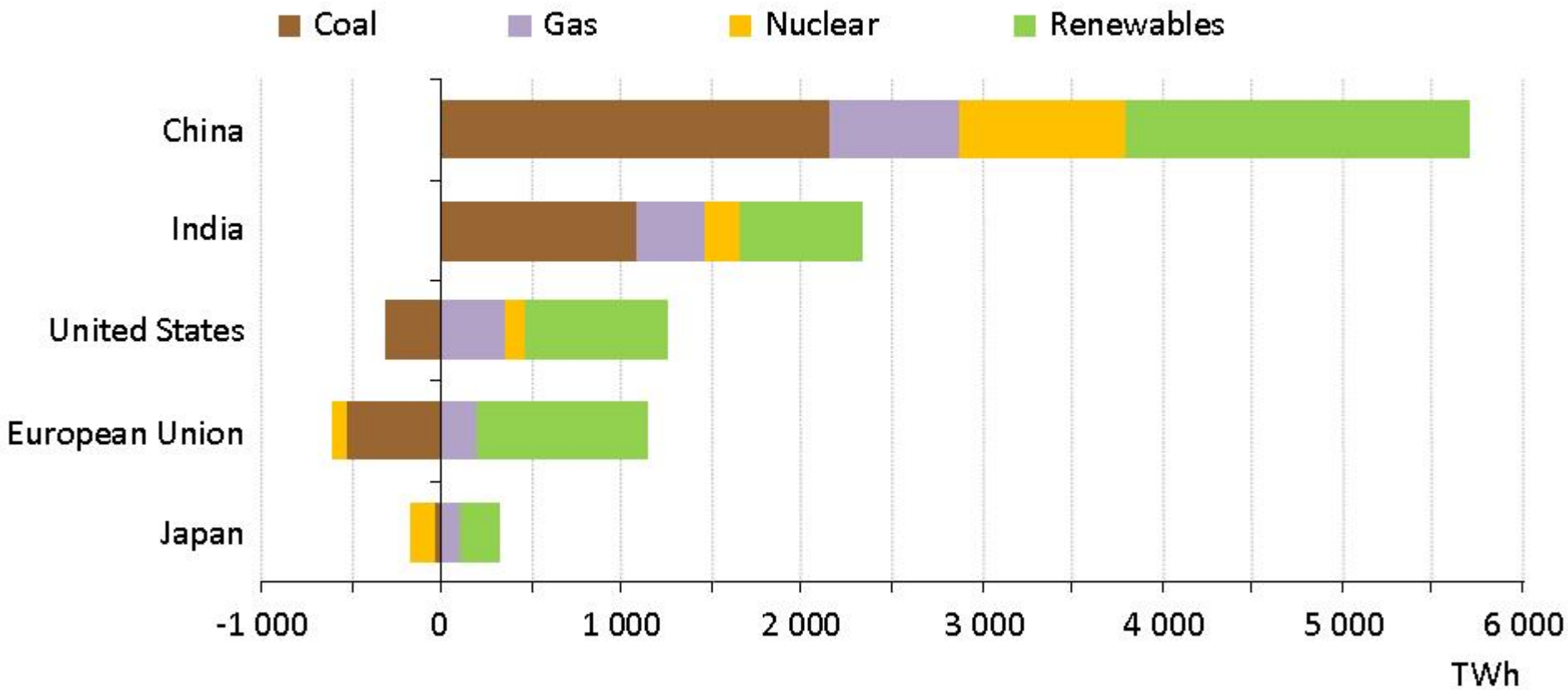


Today's share of fossil fuels in the global mix, at 82%, is the same as it was 25 years ago; the strong rise of renewables only reduces this to around 75% in 2035

A power shift to emerging economies

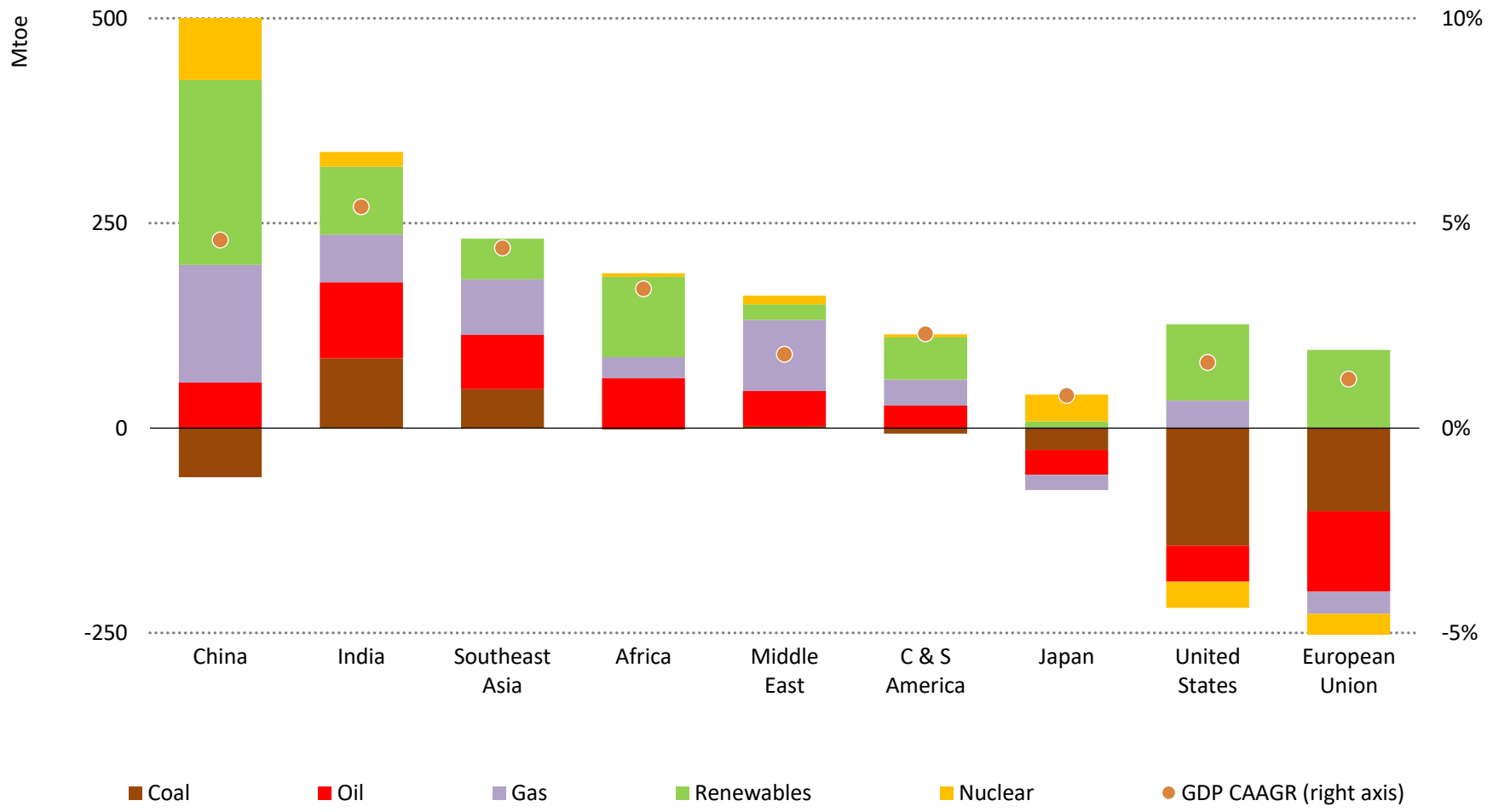
WORLD ENERGY OUTLOOK 2012

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

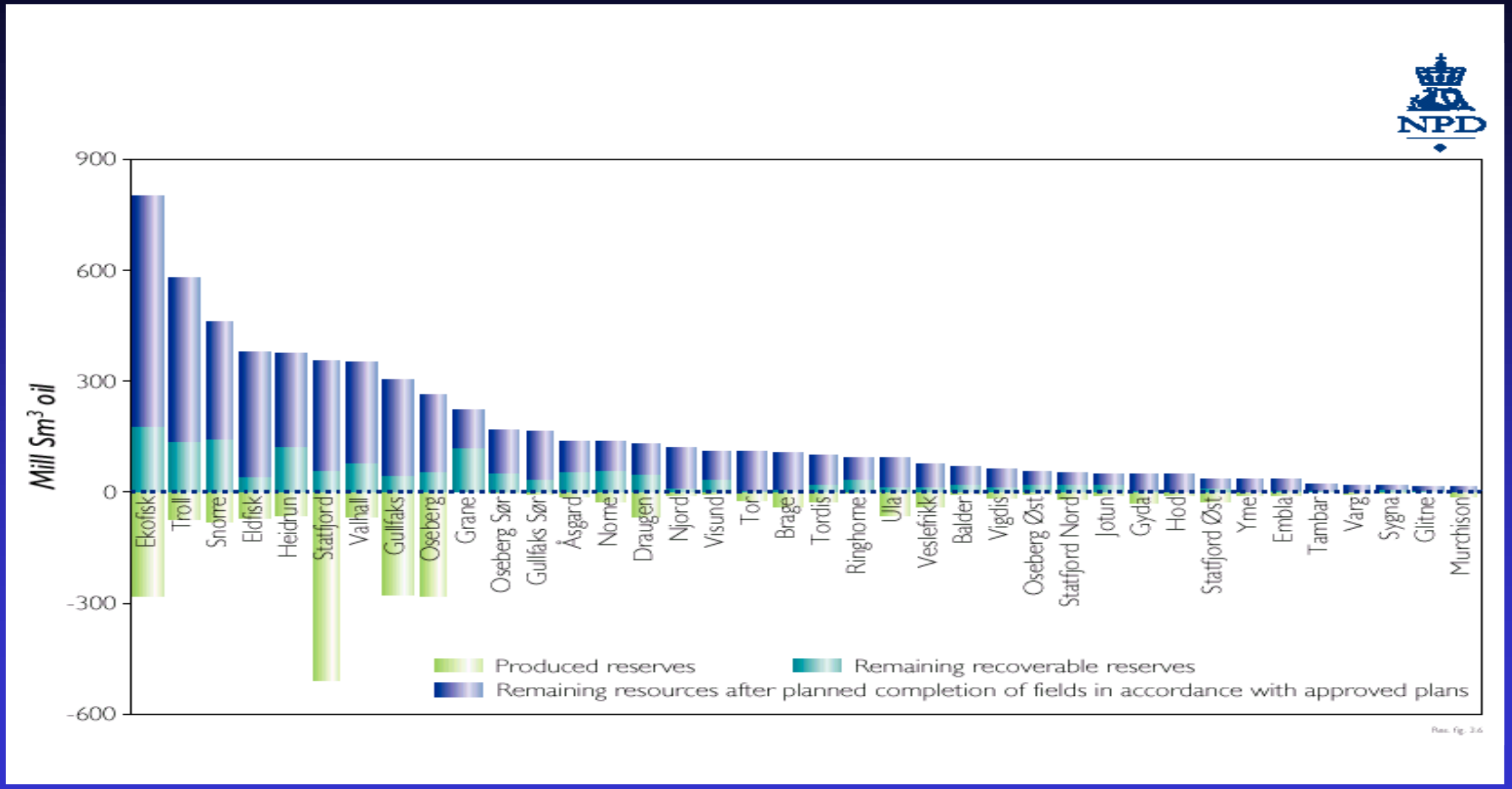
Changes in primary energy demand by fuel and region in the Stated Policies Scenario, 2019-2030



International Energy Agency (2020), World Energy Outlook 2020, IEA, Paris

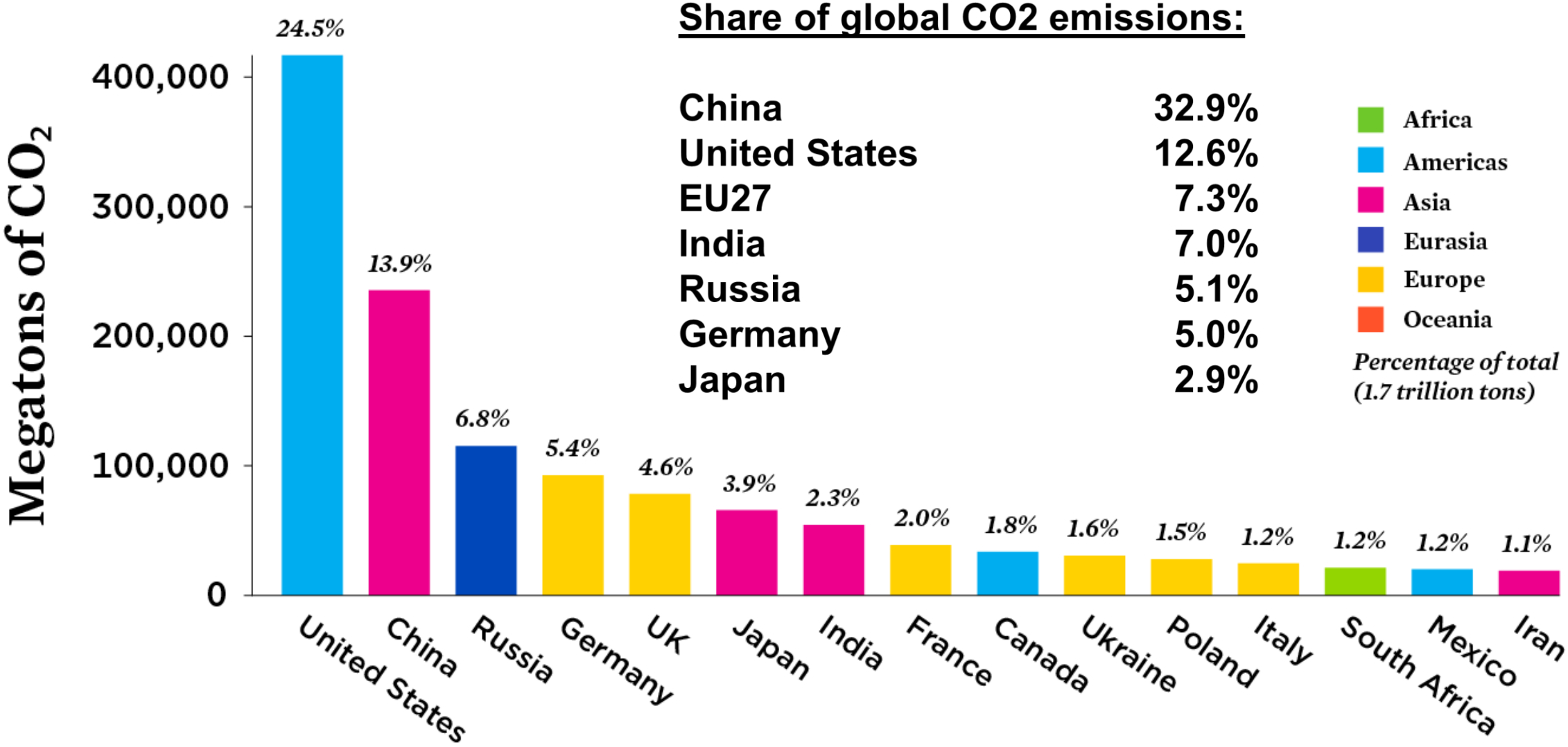

Norway's Sovereign Wealth Fund Hits $1 Trillion
Largest sovereign wealth funds by assets under management in 2017*
Fund
Country
Origin
Assets
Government Pension Fund - Global
Norway
Oil
$1t
Abu Dhabi Investment Authority
UAE
Oil
$828b
China Investment Corporation
China
Non-Commodity
$814b
Kuwait Investment 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

Petroleum Resources on the Norwegian Continental Shelf



Top CO_2 Emitting Countries, 1750-2020

(from fossil fuels and cement)



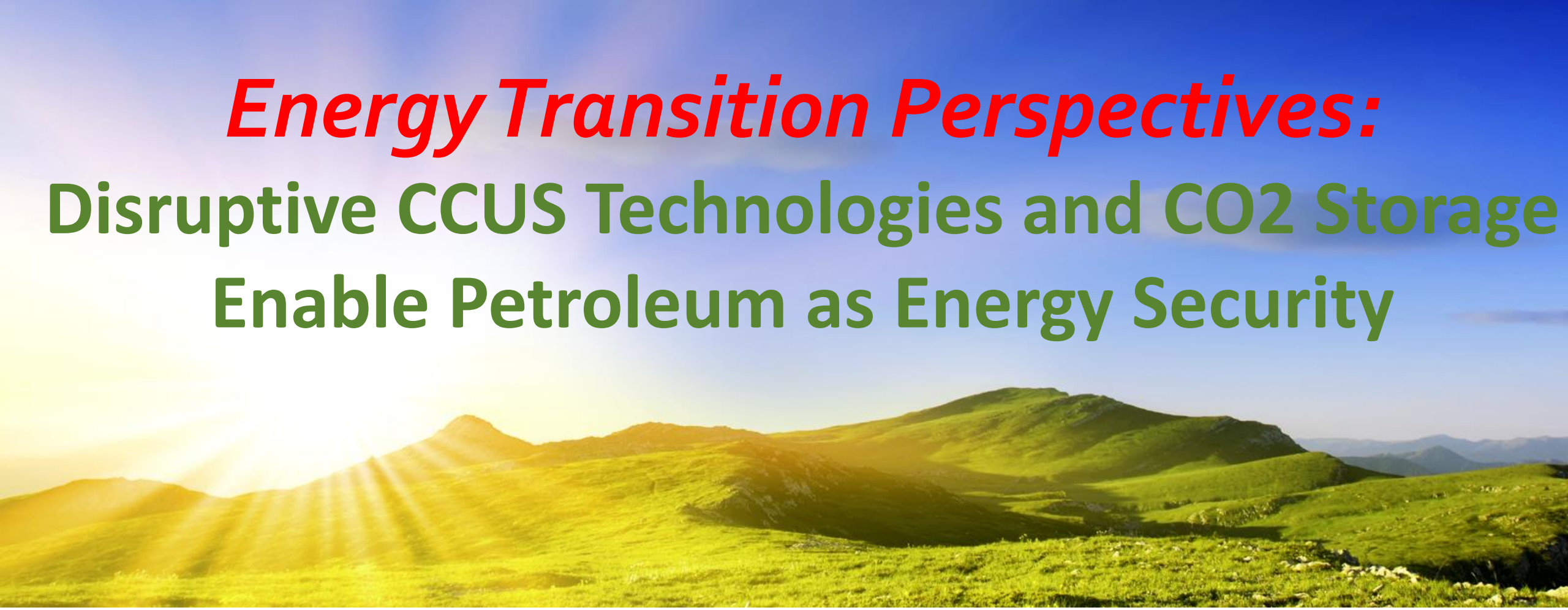
CCUS Business Opportunities

Key Factors:

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

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



Energy Transition Perspectives:

Disruptive CCUS Technologies and CO2 Storage Enable Petroleum as Energy Security

Prof. Arne Graue

Department of Physics and Technology, University of Bergen, Norway

CCUS Seminar, Nov. 1st, 2022, Los Alamos National Lab, Los Alamos, NM, USA

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

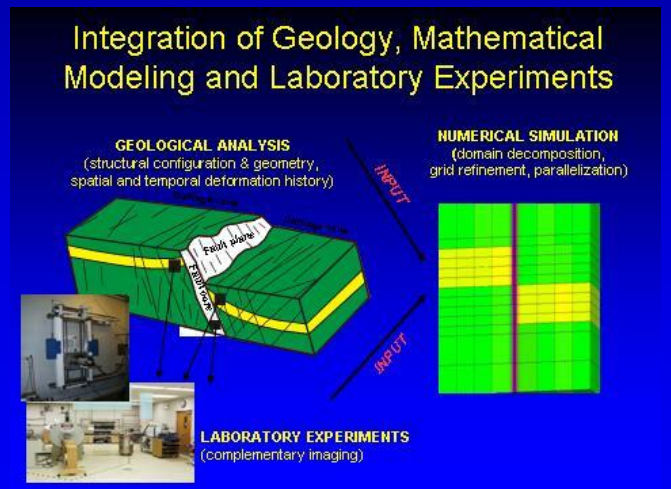
CO_2 EOR Enables CCUS: Integrated EOR (IEOR) for CO_2 Sequestration

CO_2 Foam EOR Mobility Control in Field Pilots in Texas

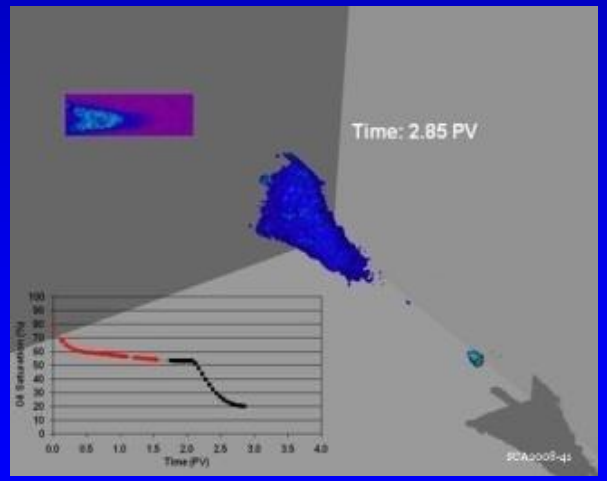
Collaboration: 11 Universities in France, The Netherlands, UK, USA and Norway

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

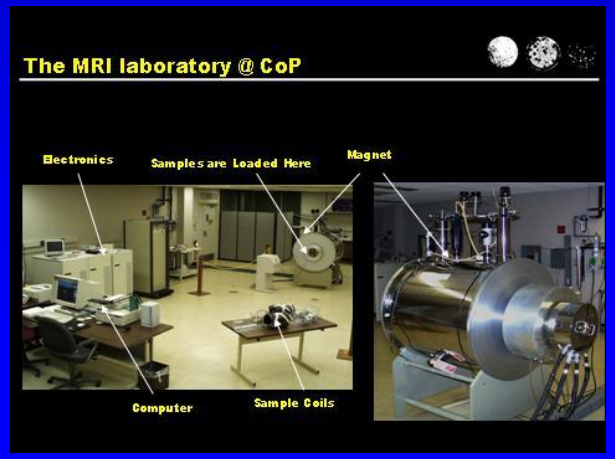
Funding: CLIMIT Program at the Research Council of Norway and 7 oil companies



Lab to pilot field test



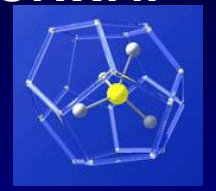
MRI of CO_2 injection



Complementary NTI & MRI facilities

CO_2 Storage in Hydrate Reservoirs with Associated Spontaneous Natural Gas Production

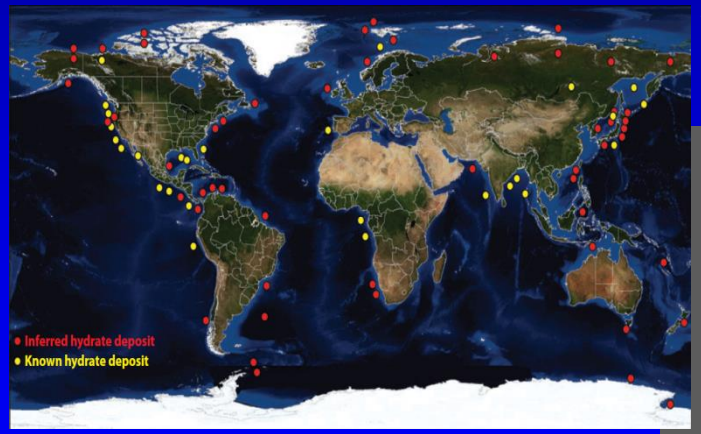
Arne Graue and Bjørn Kvamme, Dept. of Physics, University of Bergen, NORWAY
Funding: ConocoPhillips, Statoil and The Research Council of Norway



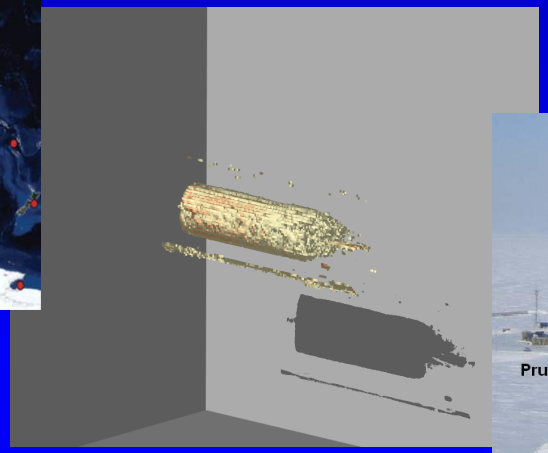
Objectives:

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

Summary

Use of CO_2 as a commodity:

Business Case for CO_2 Storage:

- **CO_2 EOR**
- **Integrated EOR (IEOR) w/Foam: *Reduced Carbon Footprint in 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**