Energy Security for the 21st Century:

Role of Nuclear Power after the Fukushima

April 2014, New York

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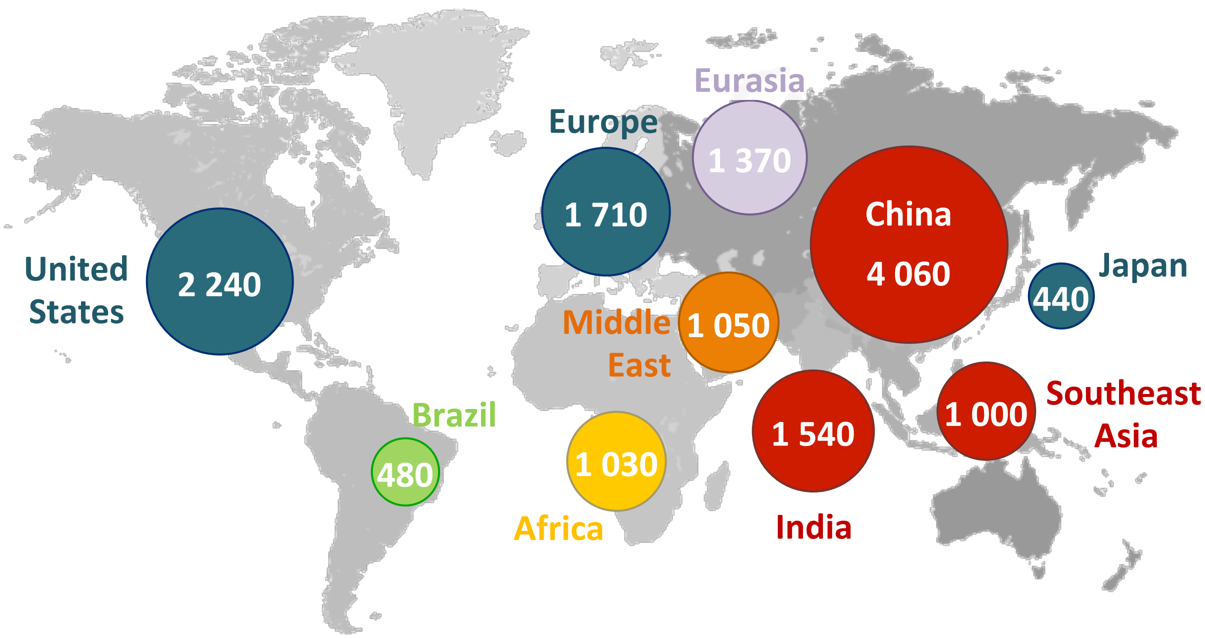
Professor of the University of Tokyo, GraSPP
Distinguished Fellow, Center on Global Energy Policy, Columbia U.
Global Associate for Energy Security and Sustainability of the IEEJ
Nobuo TANAKA

The engine of energy demand growth moves to South Asia

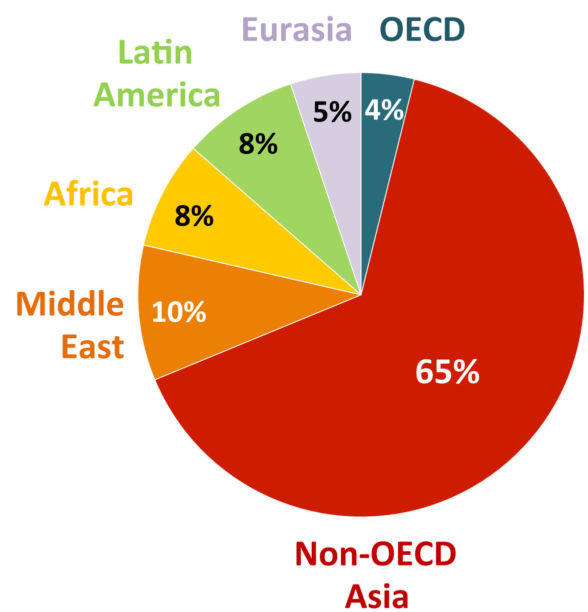
IEE JAPAN

WEO 2013

Primary energy demand, 2035 (Mtoe)

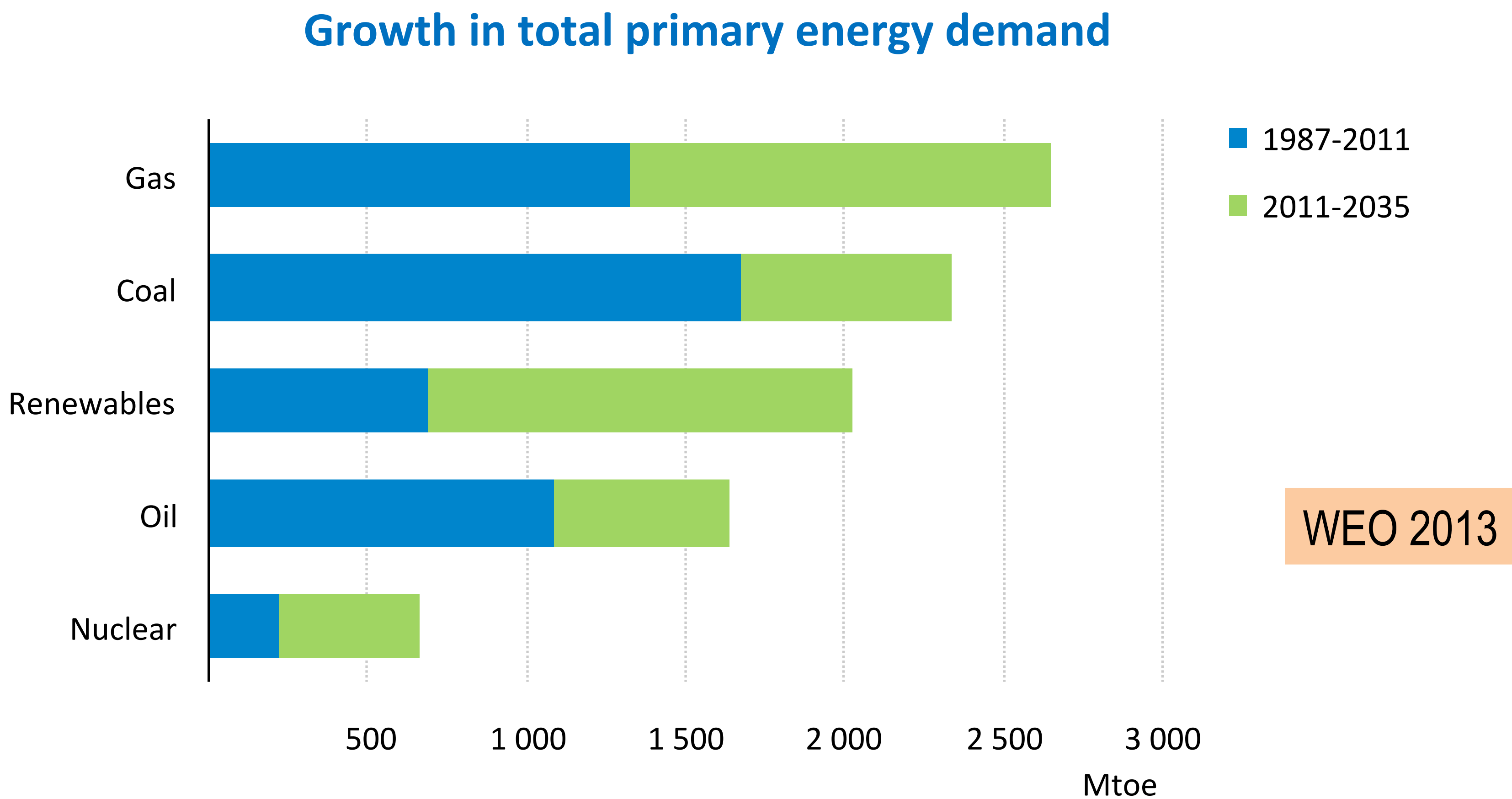


Share of global growth 2012-2035



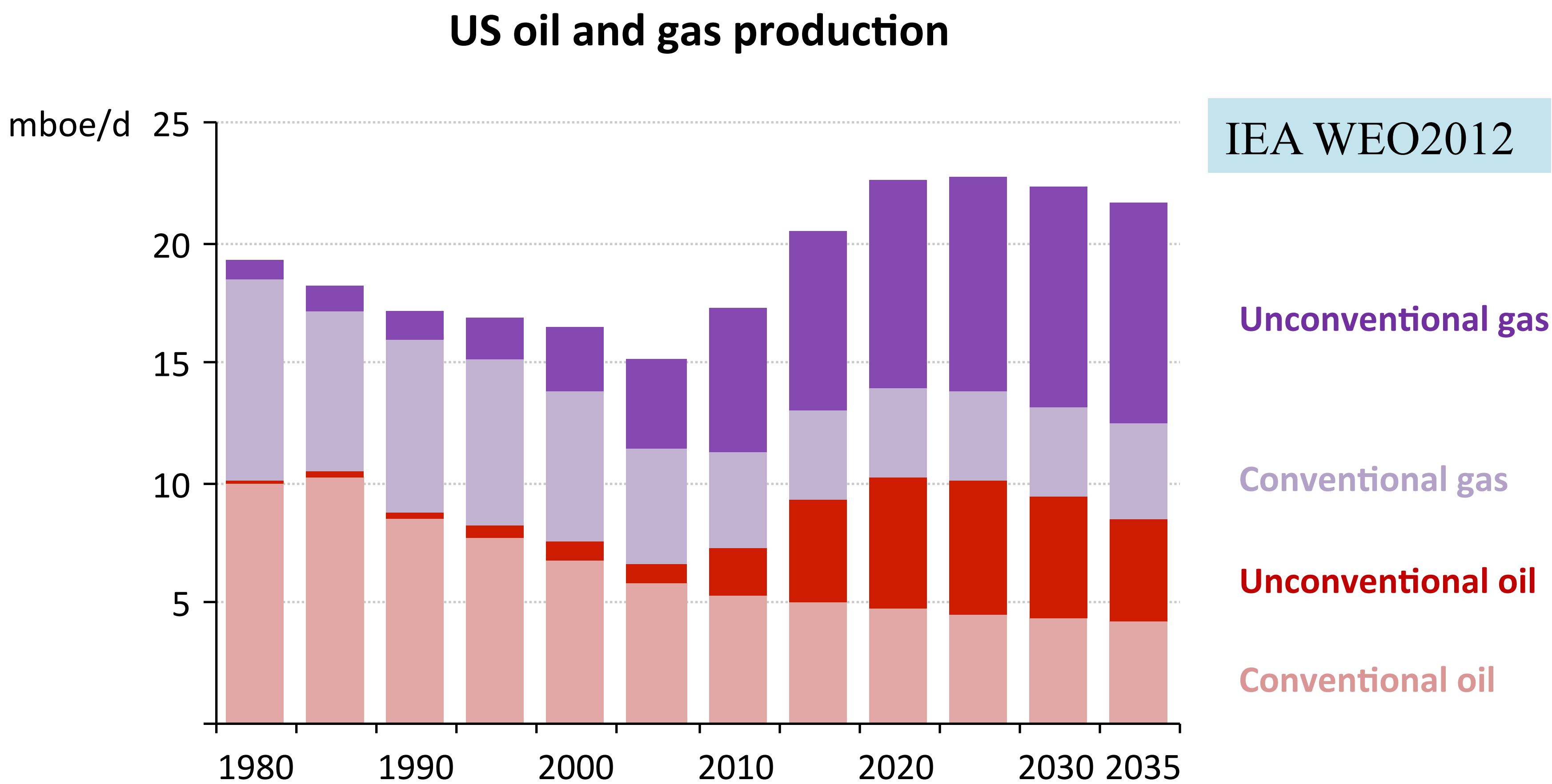
China is the main driver of increasing energy demand in the current decade, but India takes over in the 2020s as the principal source of growth

A mix that is slow to change



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

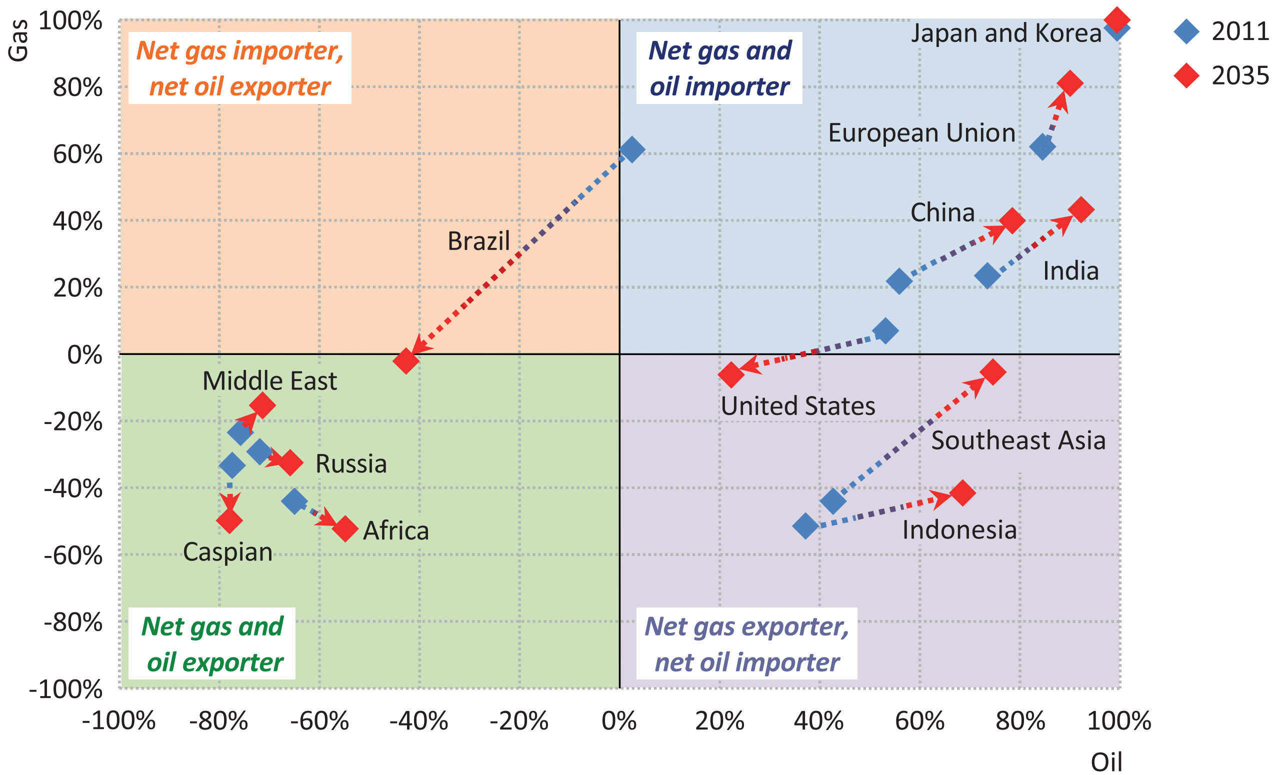
A United States oil & gas transformation



The surge in unconventional oil & gas production has implications well beyond the United States

Net oil and gas import/export shares in selected regions in the New Policies Scenario

Figure 2.12 ▷ Net oil and gas import/export shares in selected regions in the New Policies Scenario



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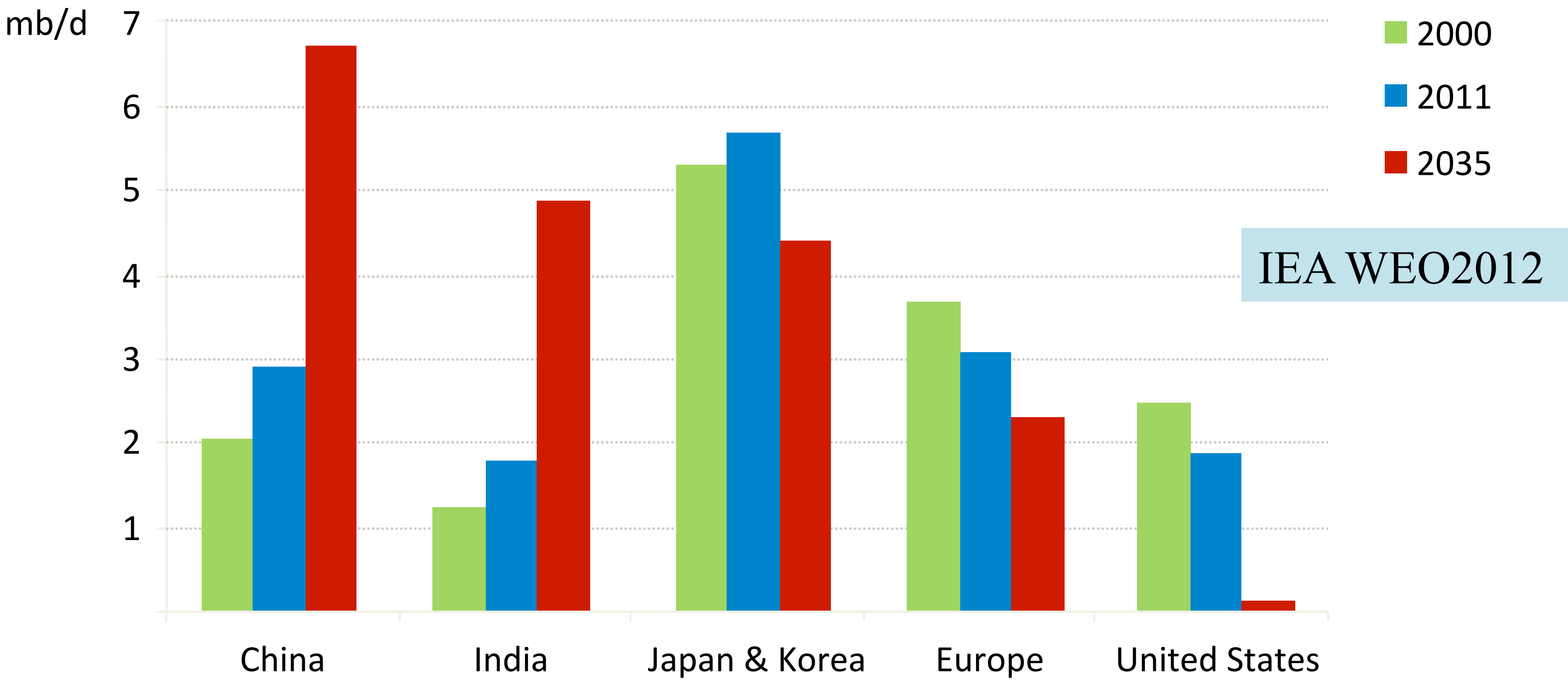
Notes: Import shares for each fuel are calculated as net imports divided by primary demand. Export shares are calculated as net exports divided by production. A negative number indicates net exports. Southeast Asia, *i.e.* the ASEAN region, includes Indonesia.

North American Energy Independence and Middle East oil to Asia: a new Energy Silk Road

Middle East oil export by destination



By 2035, almost 90% of Middle Eastern oil exports go to Asia; North America's emergence as a net exporter accelerates the eastward shift in trade

Blockage of the Strait of Hormuz may push Japan into the Economic Death Spiral.

85% of Japanese oil import
20% of Japanese LNG import
But if no nuclear reactors are running,,,,,,?

17 mbd of petroleum
(20% of global demand
& 42% of trade)

82 million tons of LNG pa
(30% of global demand)

Economic Death Spiral may hit Japan

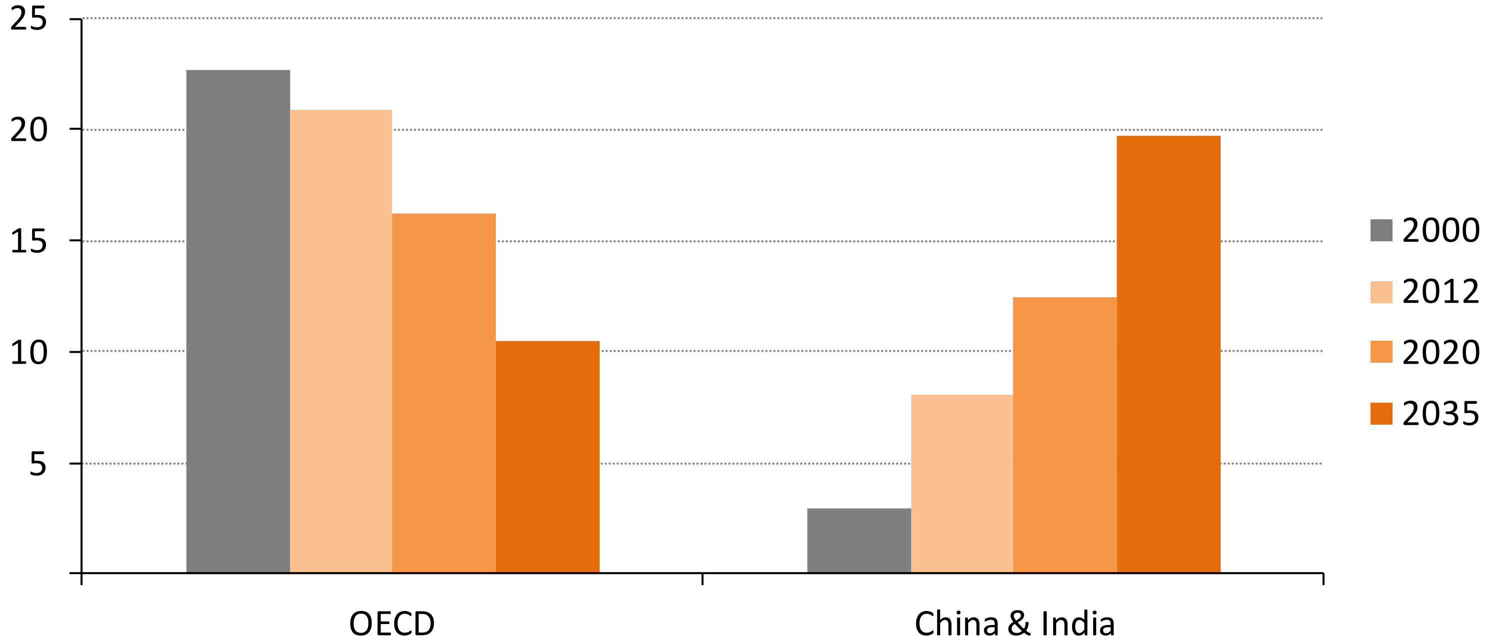
- Blockage of the Strait of Hormuz
  - Oil Price may double to $160 / barrel
  - Japan's current account surplus (9 trillion yen in 2011) may turn to deficit of 6 trillion yen.
  - Without further restarting of nuclear power plants, deficits may reach 12 trillion yen.
- Confidence on Japan's public finance may be lost.
  - Current Account surplus is the basis for confidence
  - Persisting Deficit may lead to capital flight from Japan
  - Power crisis enhances flight of manufacturing industries
- Loss of Confidence in JGB and Yen. Capital move into commodities means higher prices of oil.
- Total Economic Melt Down may happen.

China's Import Transit Routes

USDOD China Report 2013

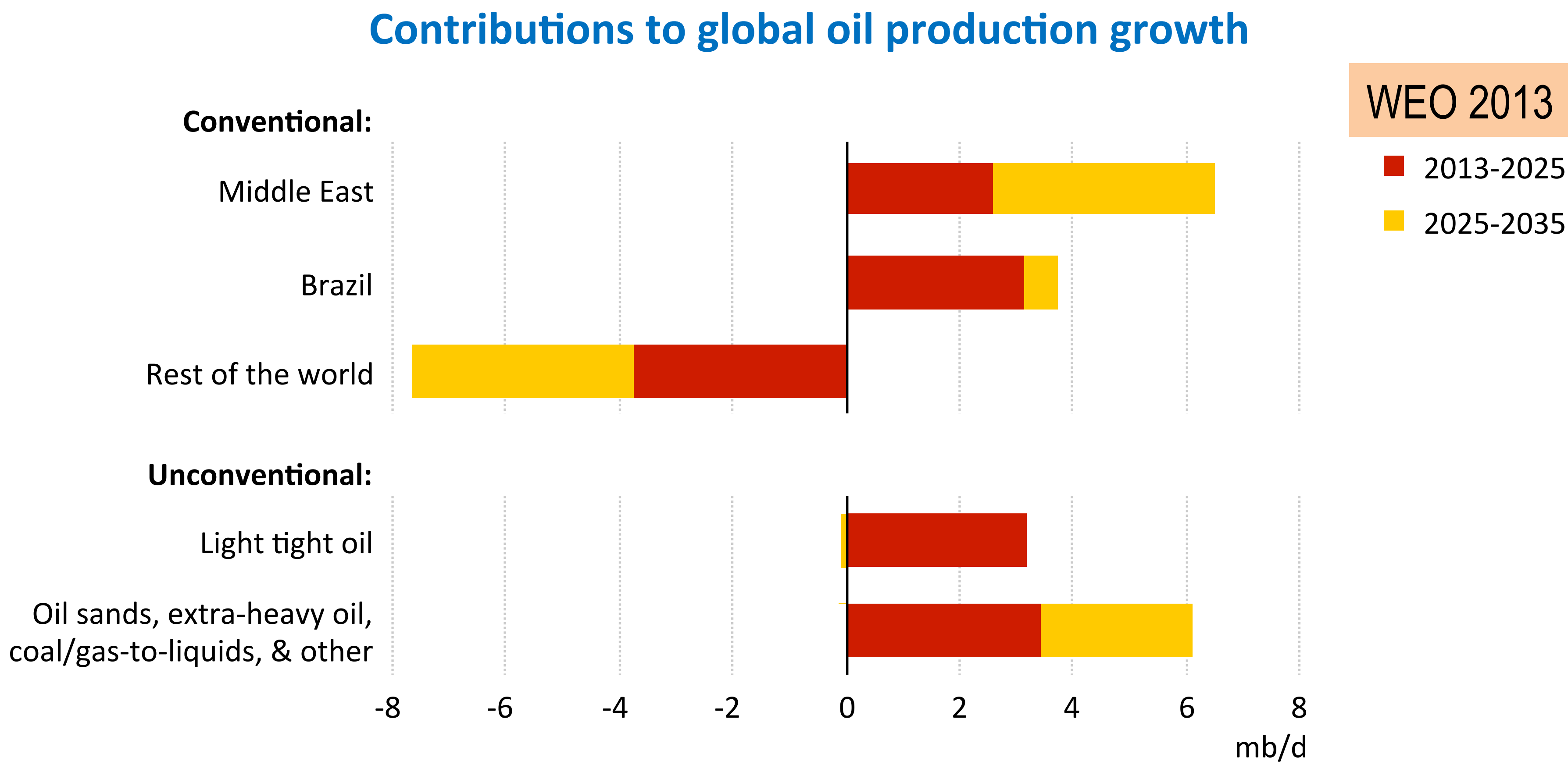
Should China and India join the IEA?

Net oil imports of selected countries in the New Policies Scenario 2013 (mb/d)



Asia becomes the unrivalled centre of the global oil trade as the region draws in a rising share of the available crude

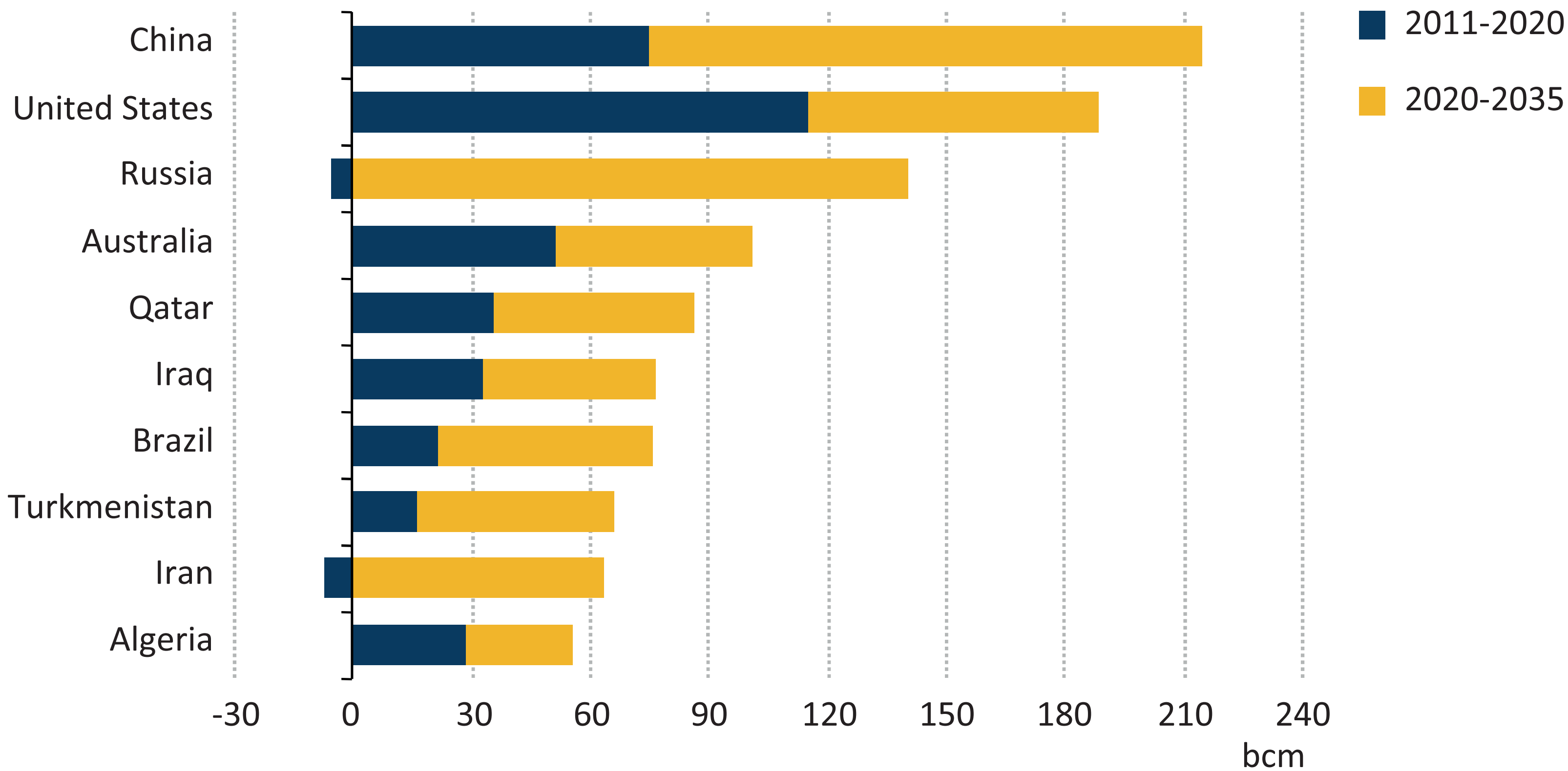
Two chapters to the oil production story



The United States (light tight oil) & Brazil (deepwater) step up until the mid-2020s, but the Middle East is critical to the longer-term oil outlook

Shale Gas revolution ?

Figure 3.4 ▷ Change in annual natural gas production in selected countries in the New Policies Scenario



Russian Gas Pipelines

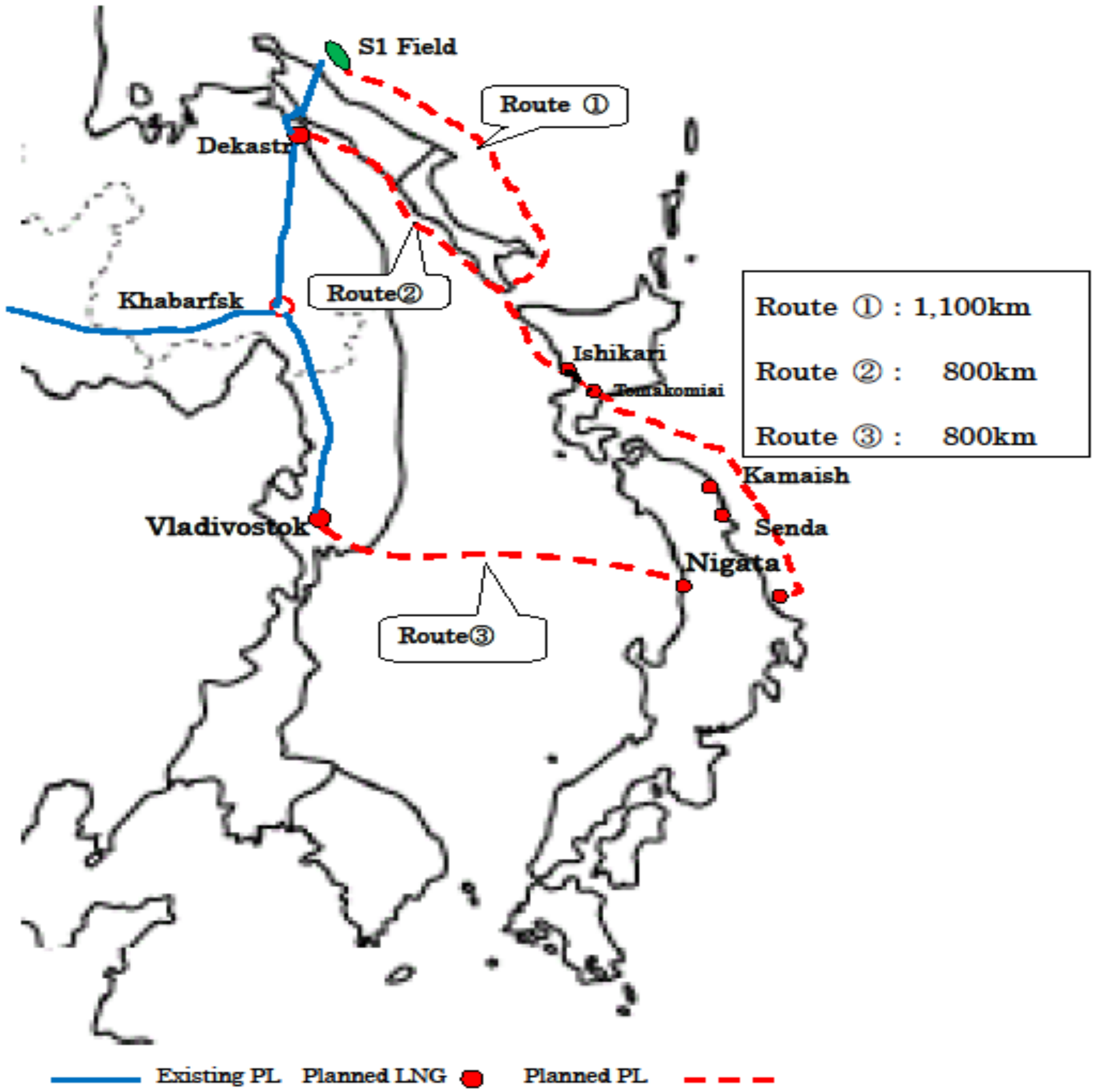
Russian Gas Infrastructure

The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

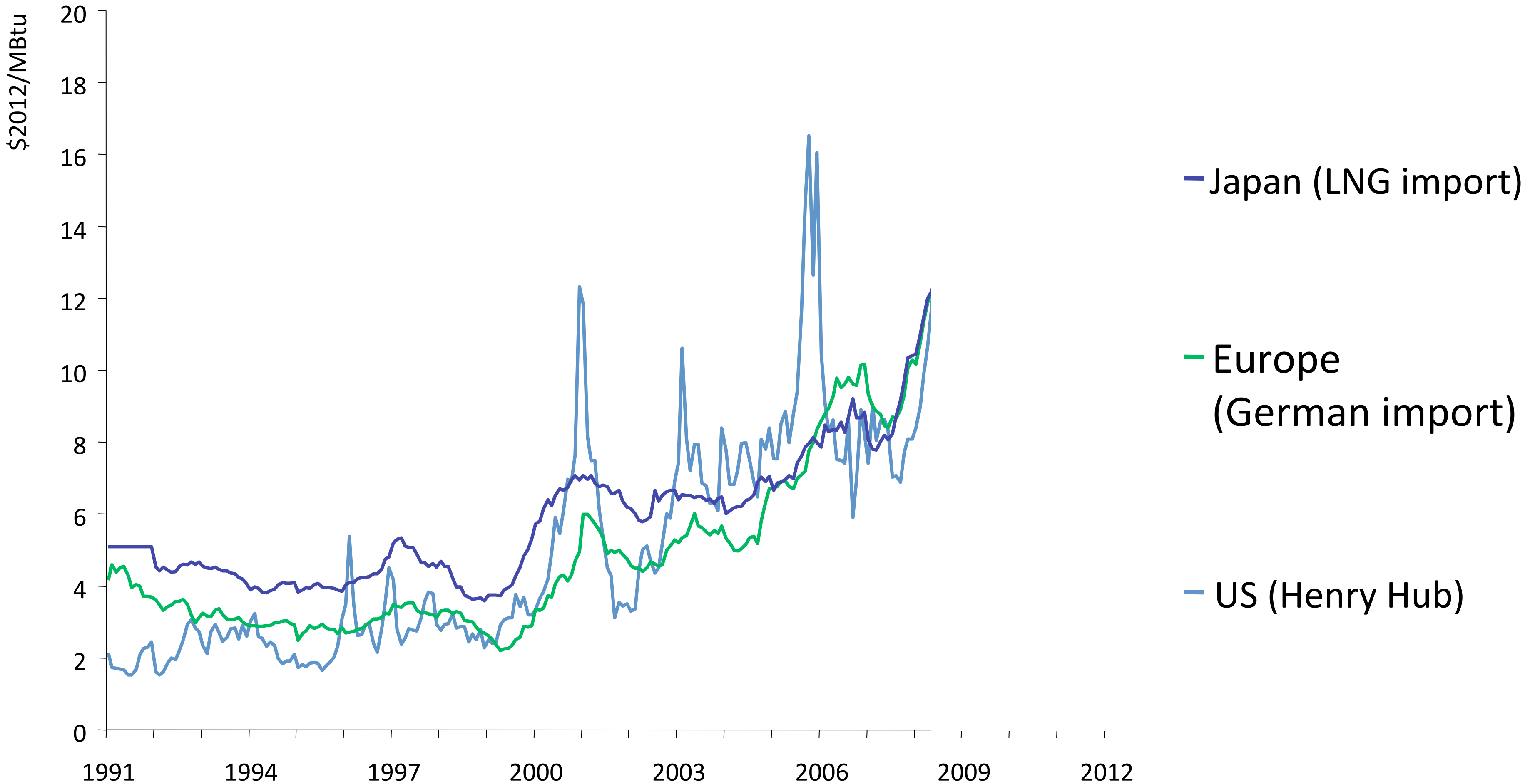
Source: IEA

Mid-Term Oil & Gas Market 2010, IEA

Natural Gas Pipeline from Russia to Japan



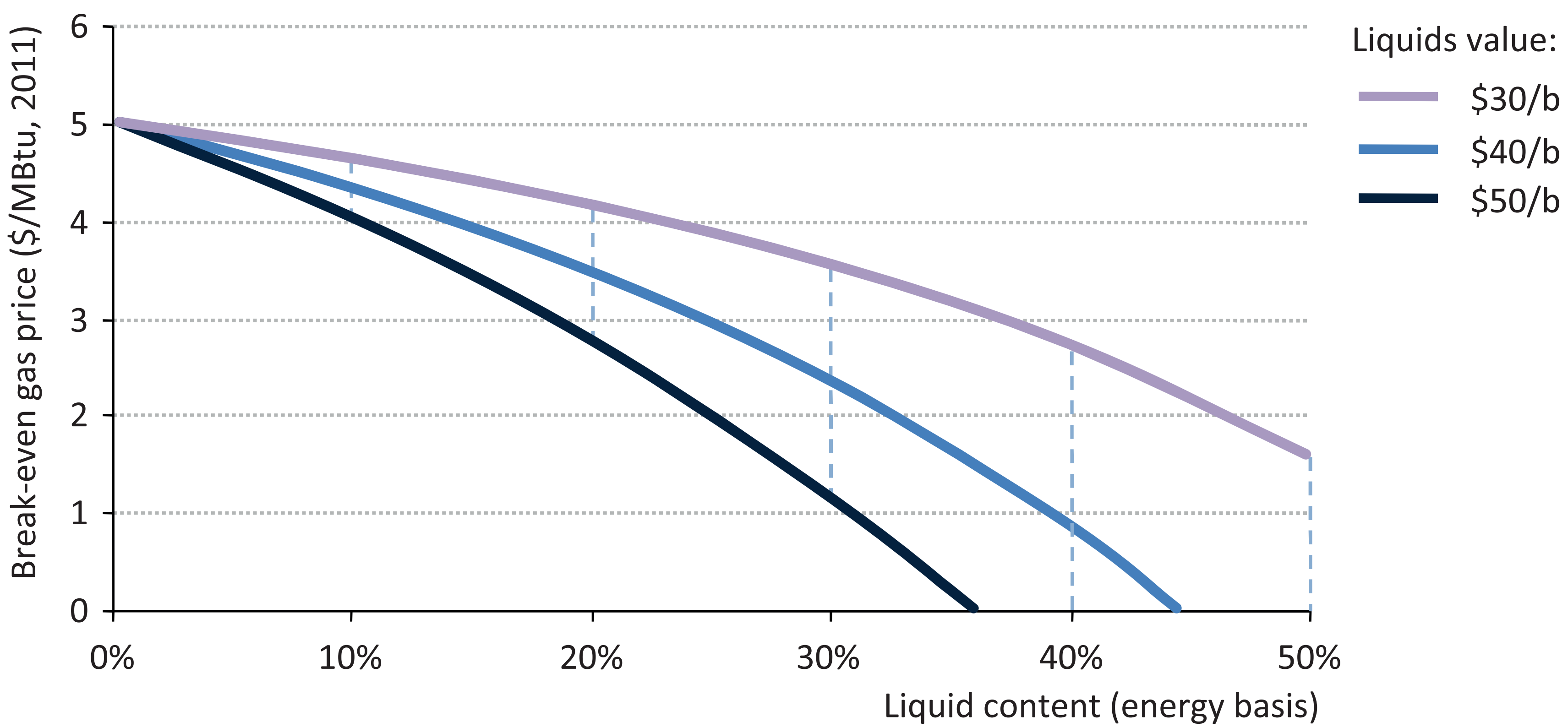
LNG pricing : a competitiveness burden on Asian economies



Developing a Natural Gas Trading Hub in Asia (2013 by IEA)

The higher the oil price goes, the lower the gas price becomes.

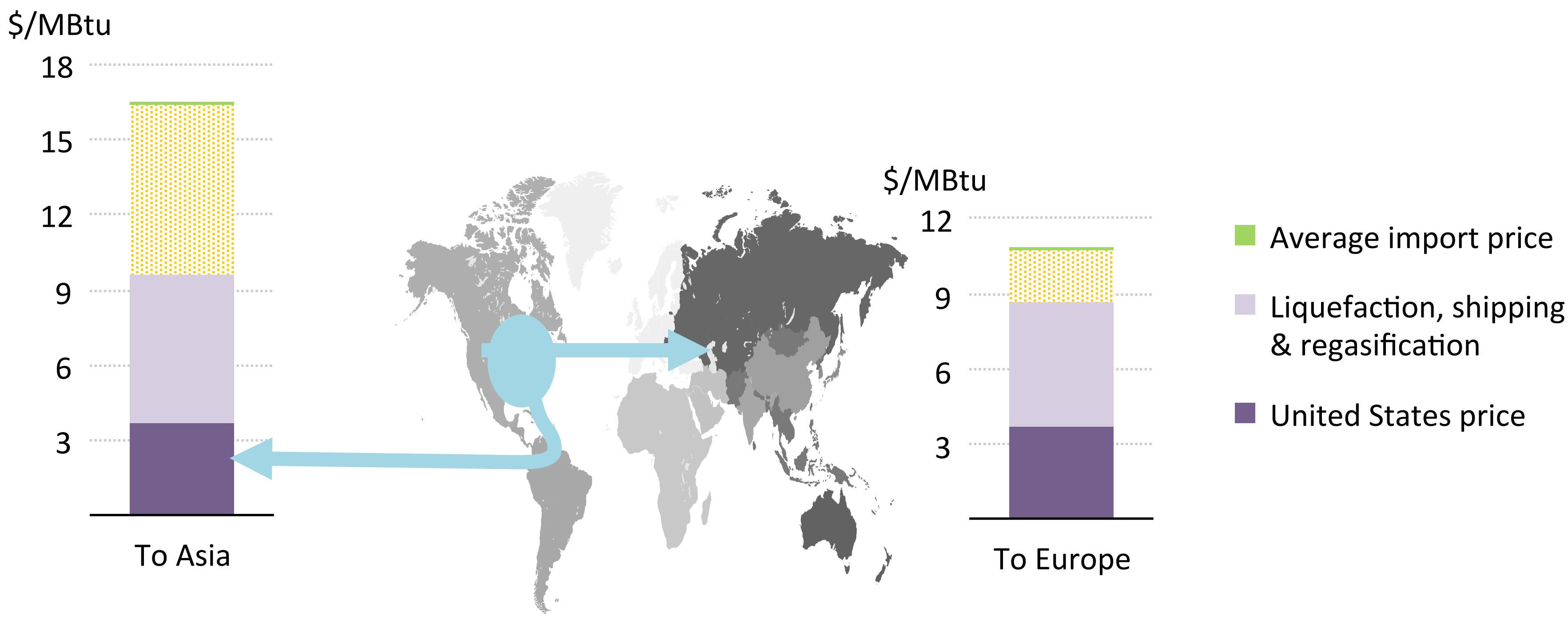
Figure 4.7 ▻ **Relationship between break-even price (gas price needed to recover well costs) and the liquid content of the gas produced**



LNG from the United States can shake up gas markets

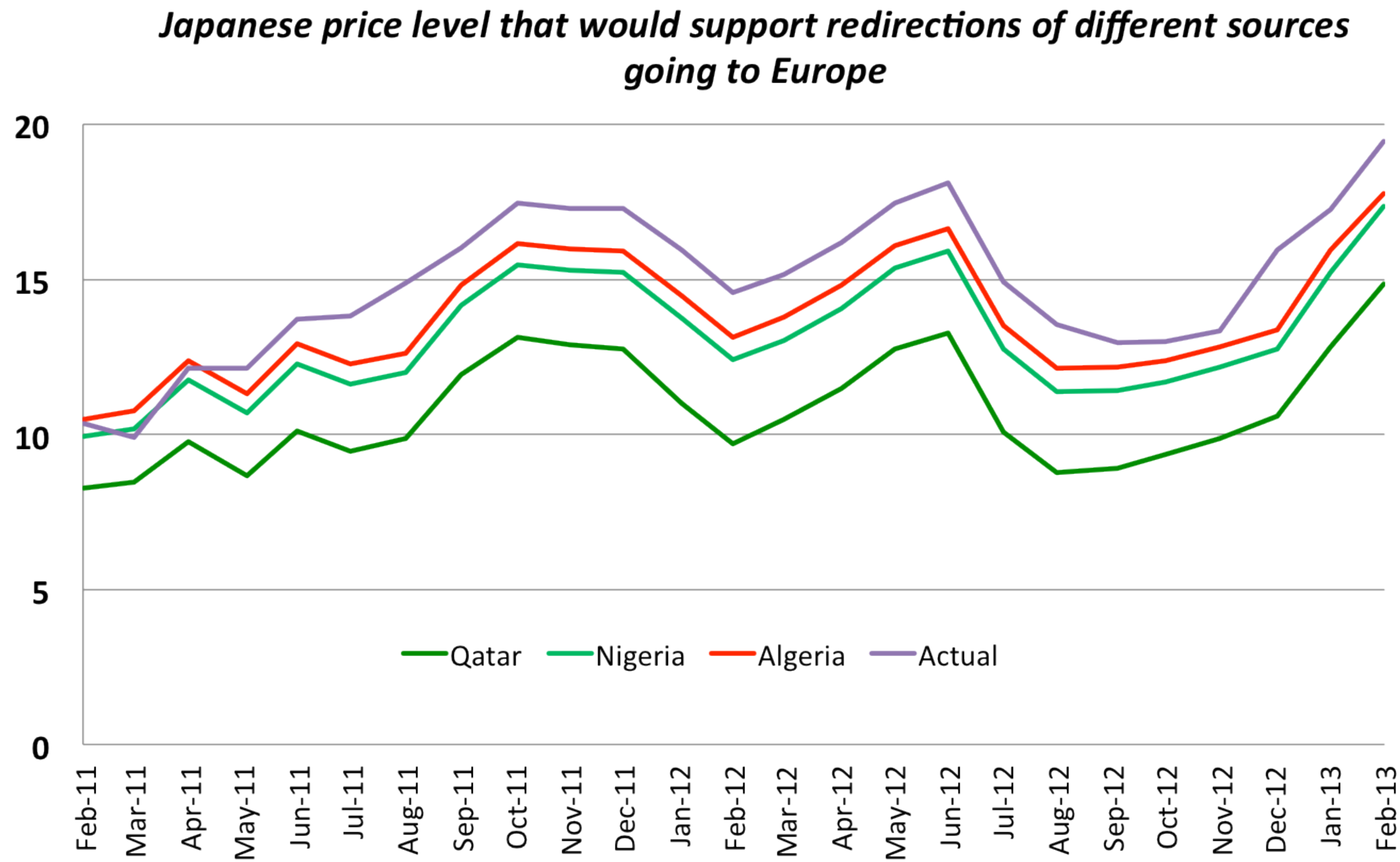
WEO 2013

Indicative economics of LNG export from the US Gulf Coast (at current prices)

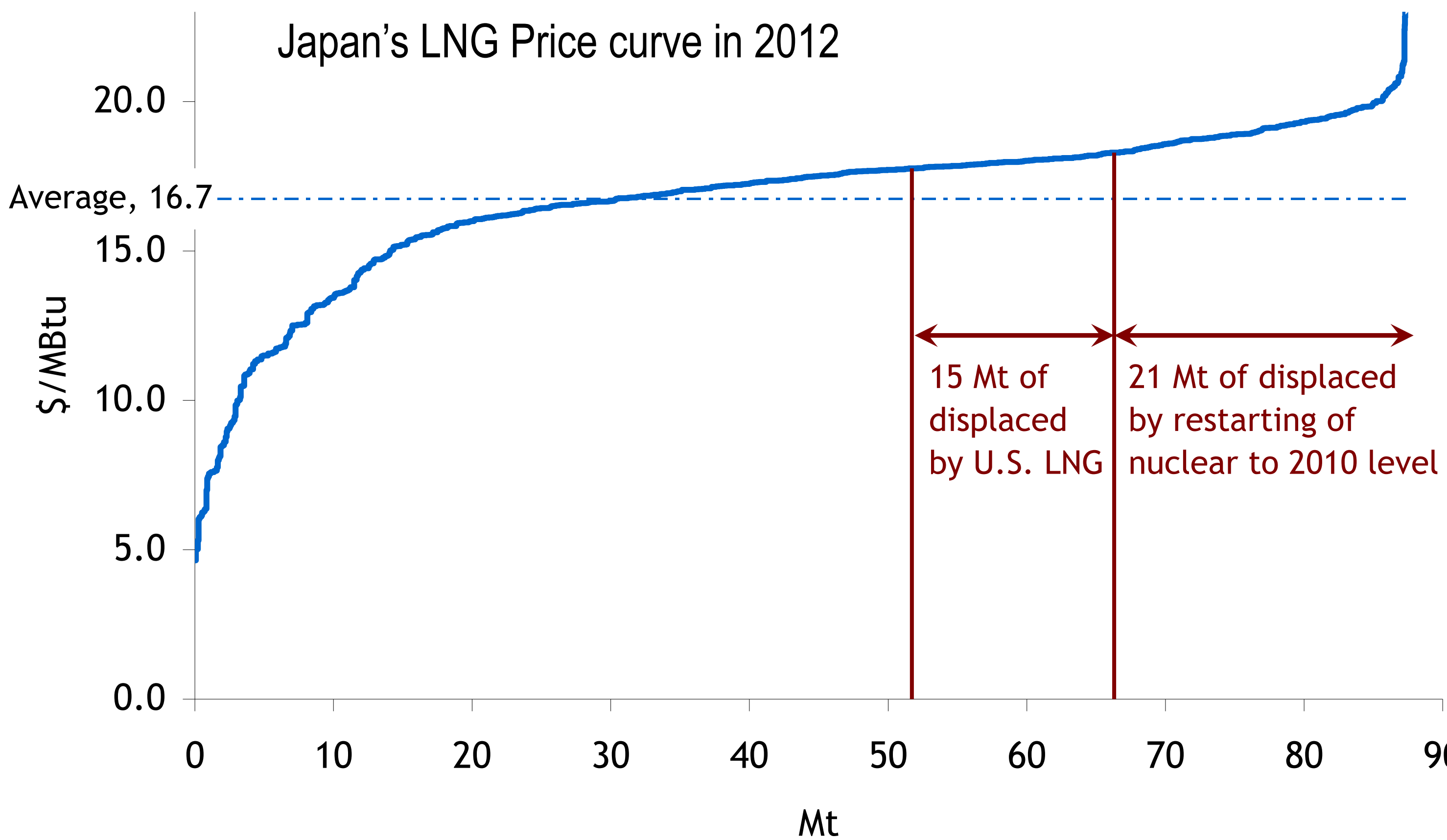


New LNG supplies accelerate movement towards a more interconnected global market, but high costs of transport between regions mean no single global gas price

Destination clauses and inefficient trade with Europe is a USD 10 billion burden on Japan



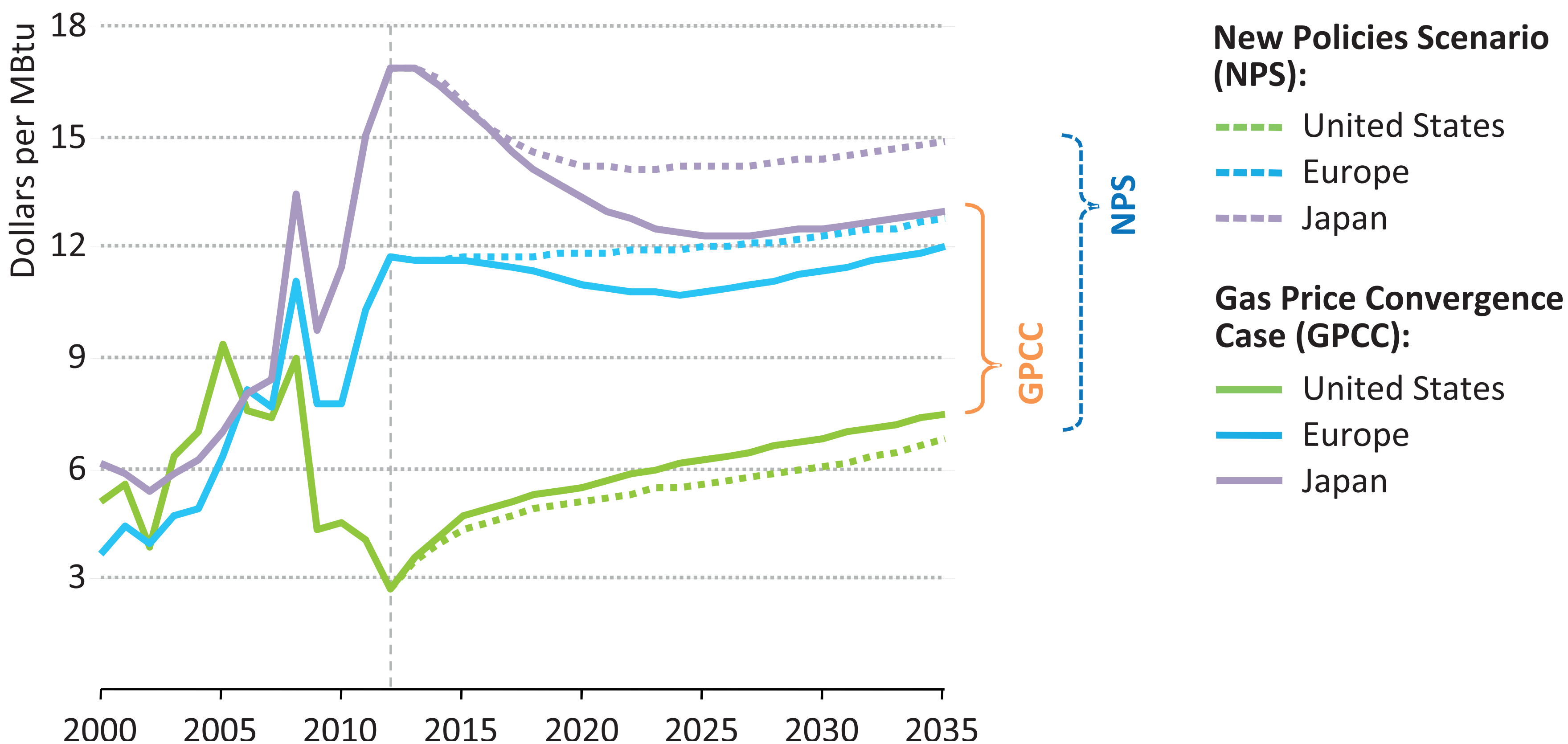
Impacts of US LNG and Nuclear restarting to the LNG prices to Japan



IEEJ input to LNG conference 2013

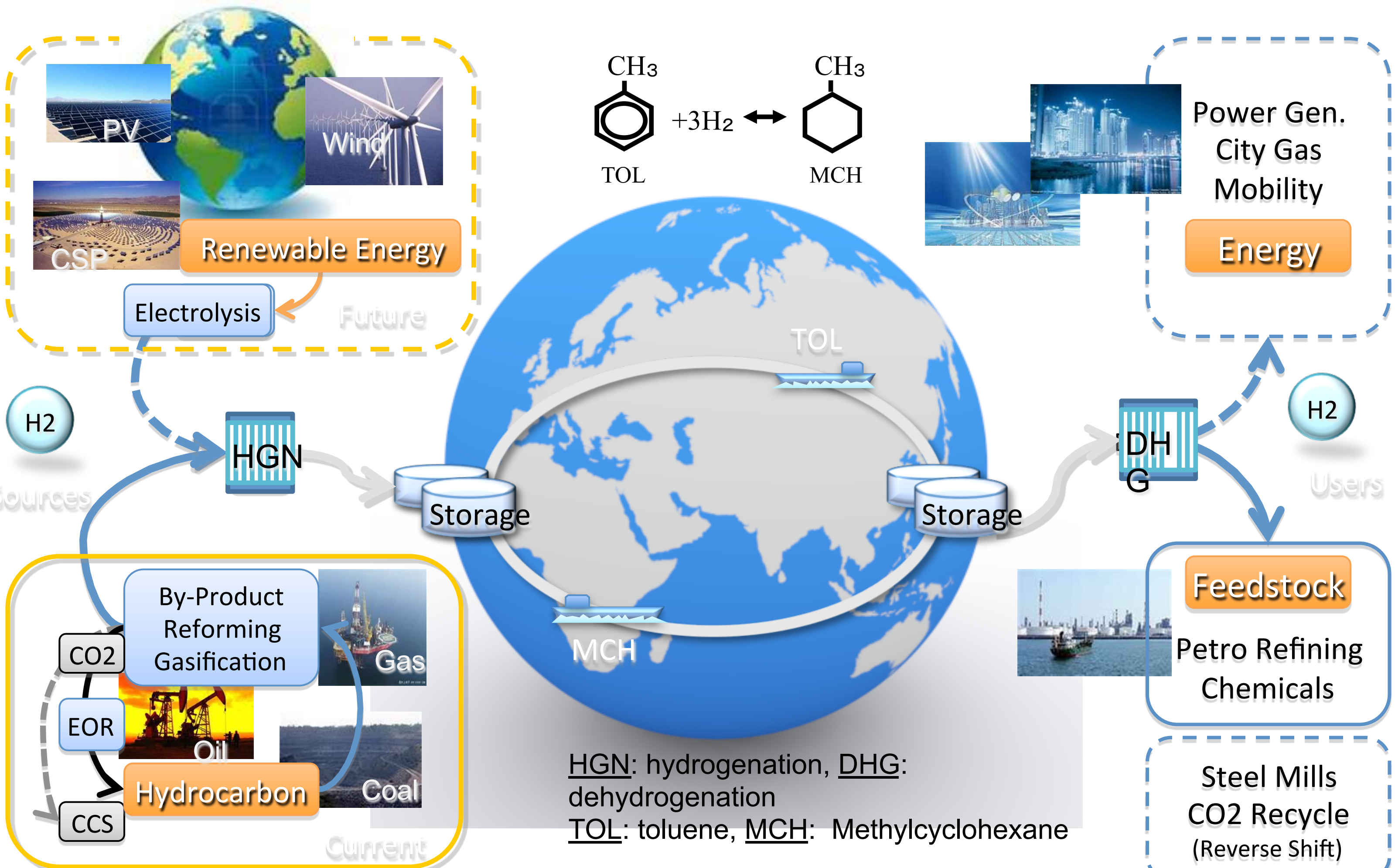
Two Price Zones may appear.

Figure 3.11 ▷ Regional gas prices in the New Policies Scenario and in the Gas Price Convergence Case



Introduction - Chiyoda's Hydrogen Supply Chain Outlook

- Chiyoda established a complete system which enables economic H2 storage and transportation.
- MCH, an H2 carrier, stays in a liquid state under ambient conditions anywhere.



HGN: hydrogenation, DHG: dehydrogenation
TOL: toluene, MCH: Methylcyclohexane

- H2 Supply of a 0.1-0.2mmtpa LNG equivalent scale (M.E. to Japan) could be feasible.

Methane Hydrate, Next unconventional ?

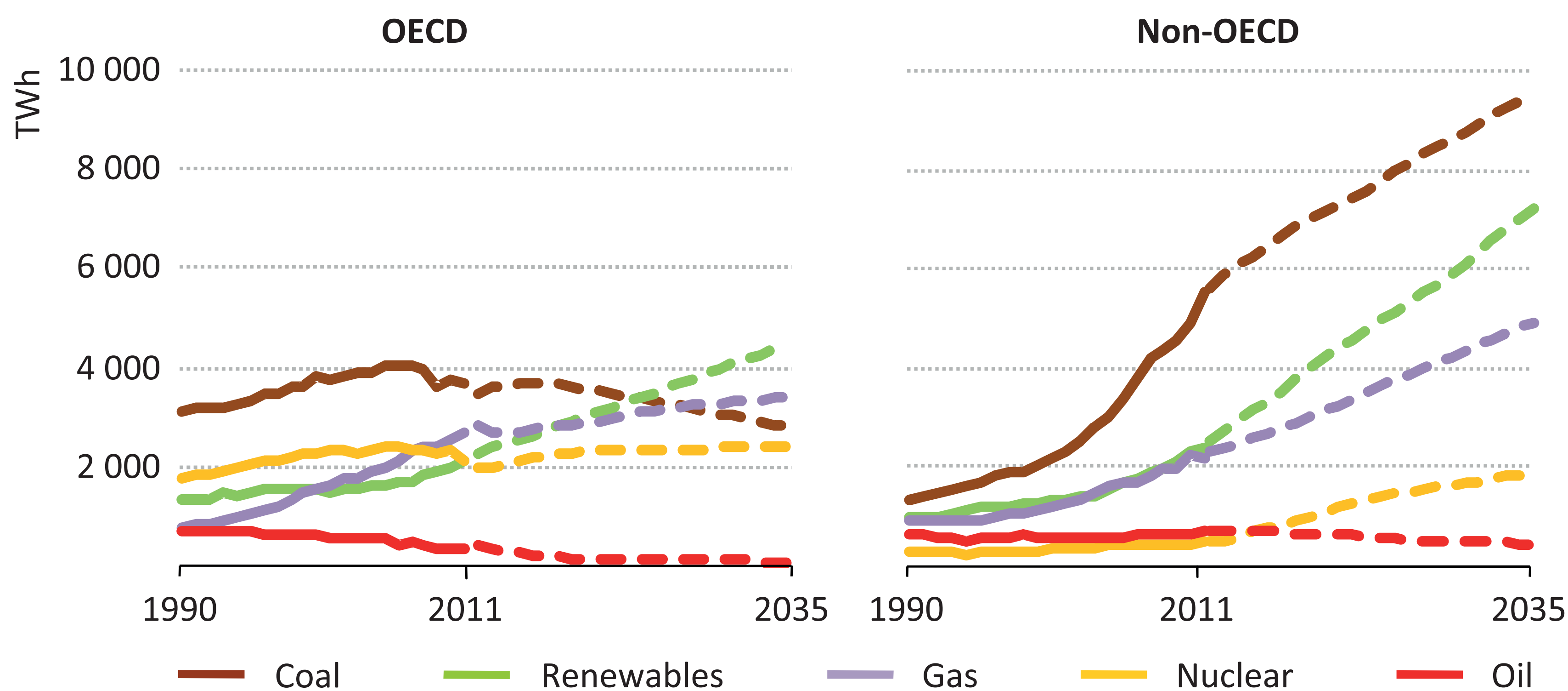
An Energy Coup for Japan: 'Flammable Ice'

Photo by JOGMEC

Resource estimates vary by several orders of magnitudes, with many falling between 1000 and 5000 tcm, or between 300 and 1500 years of production at current rates. The USGS estimates that gas hydrates worldwide are more than 10 to 100 times as plentiful as US shale gas reserves. The Japanese government aims to achieve commercial production in ten to fifeen years, *i.e.* by the mid- to late-2020s. (IEA WEO2013) (IEA)

World Electricity Generation grows by 70% led by renewables in OECD and by coal in non-OECD countries.

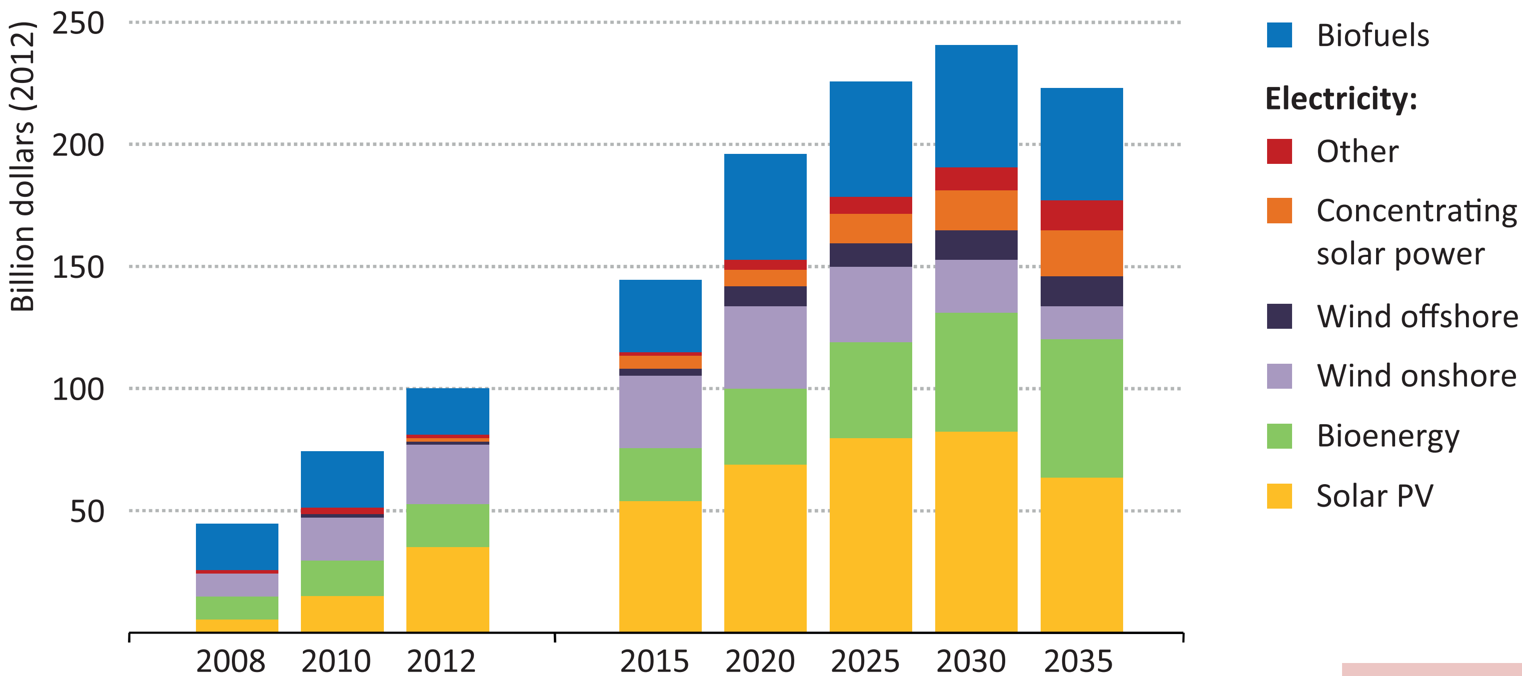
Figure 5.3 ▷ Electricity generation by source in the New Policies Scenario



IEA WEO2013

Renewables needs $4.7 trillion of subsidies by 2035.

Figure 6.15 ▷ Global renewable energy subsidies by source in the New Policies Scenario



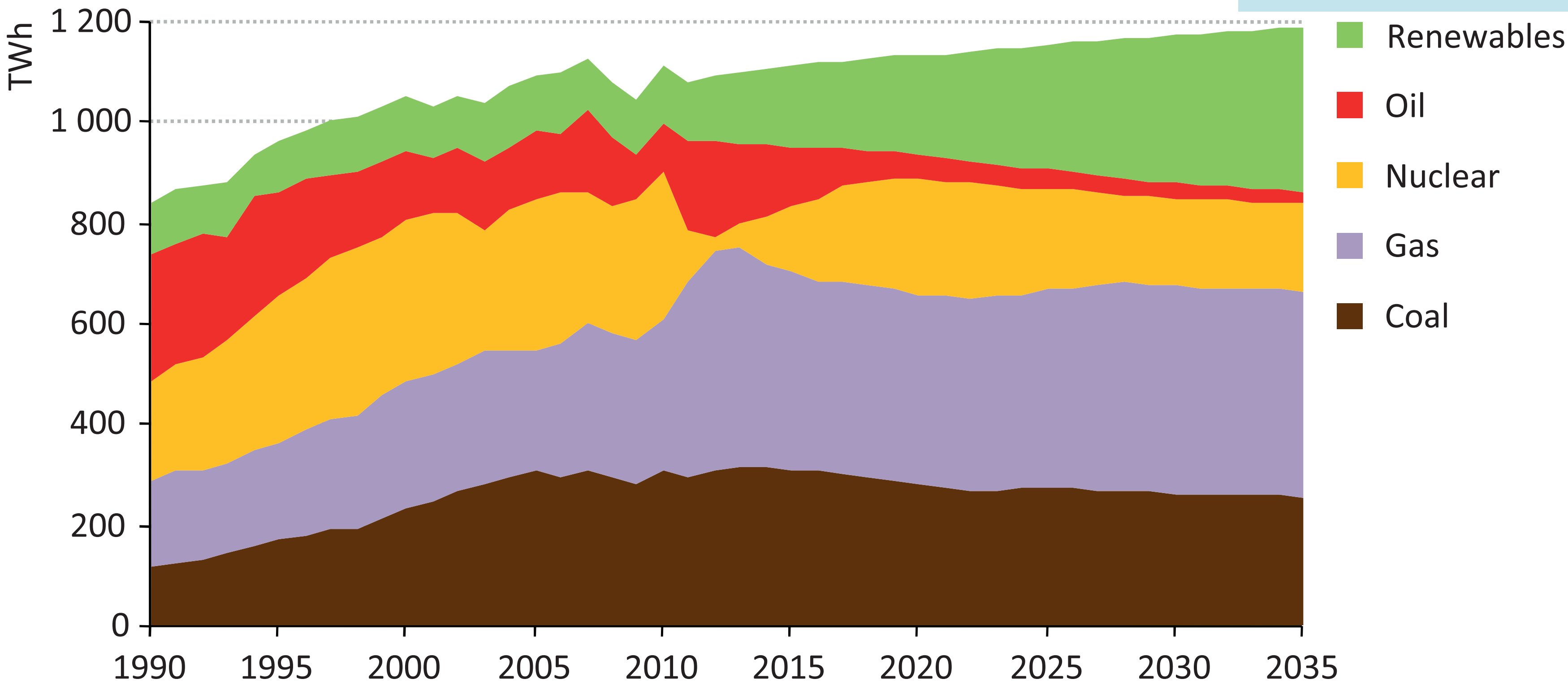
Notes: Other includes geothermal, marine and small hydro.

WEO 2013

Japan's Power Sector: Renewables, gas and energy efficiency leading the charge

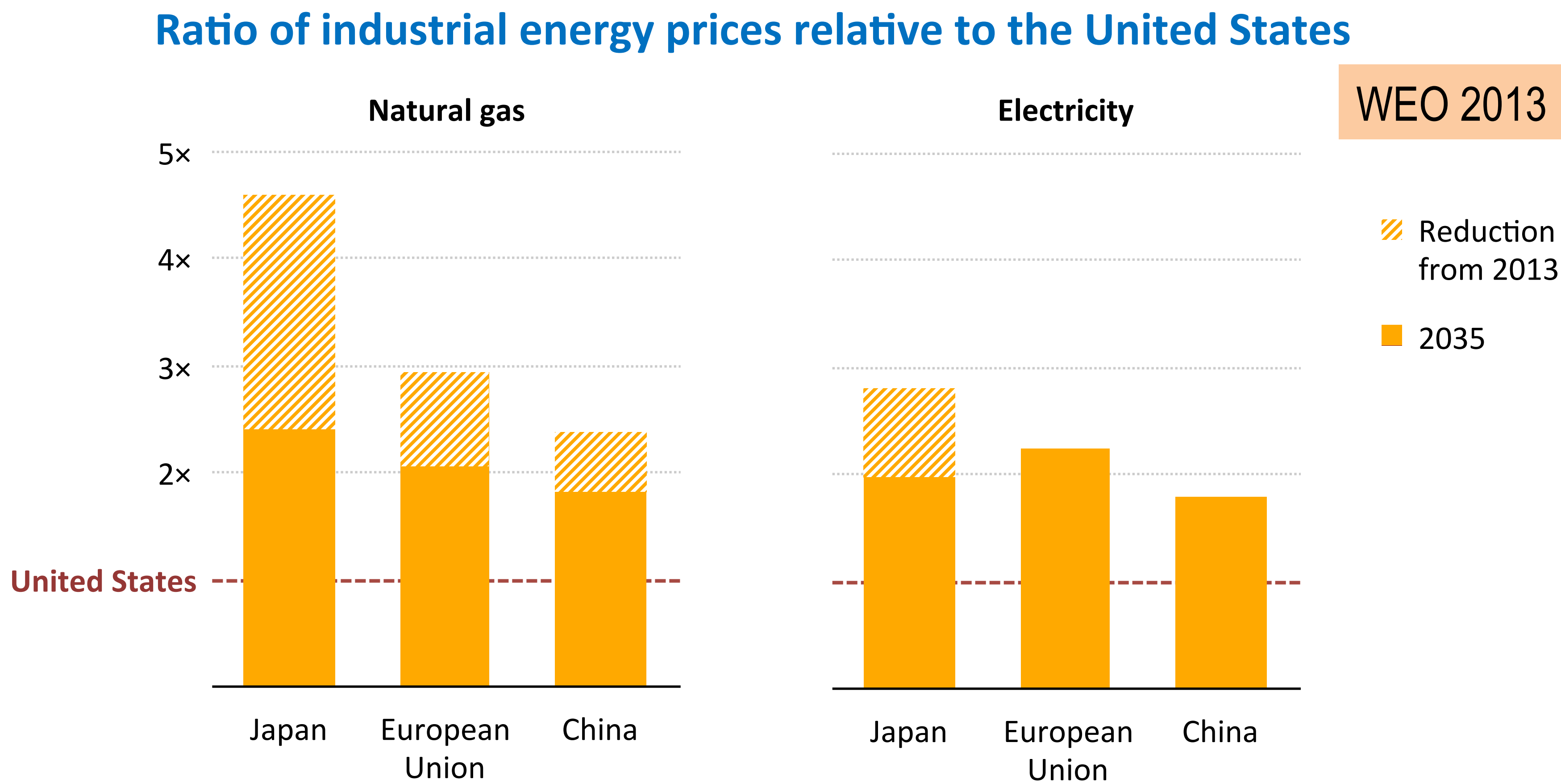
Figure 6.13 ▷ Japan electricity generation by source in the New Policies Scenario

IEA WEO2012



A decline in nuclear is compensated by a 3-fold increase in electricity from renewables, a continued high reliance on LNG imports & improvements in efficiency

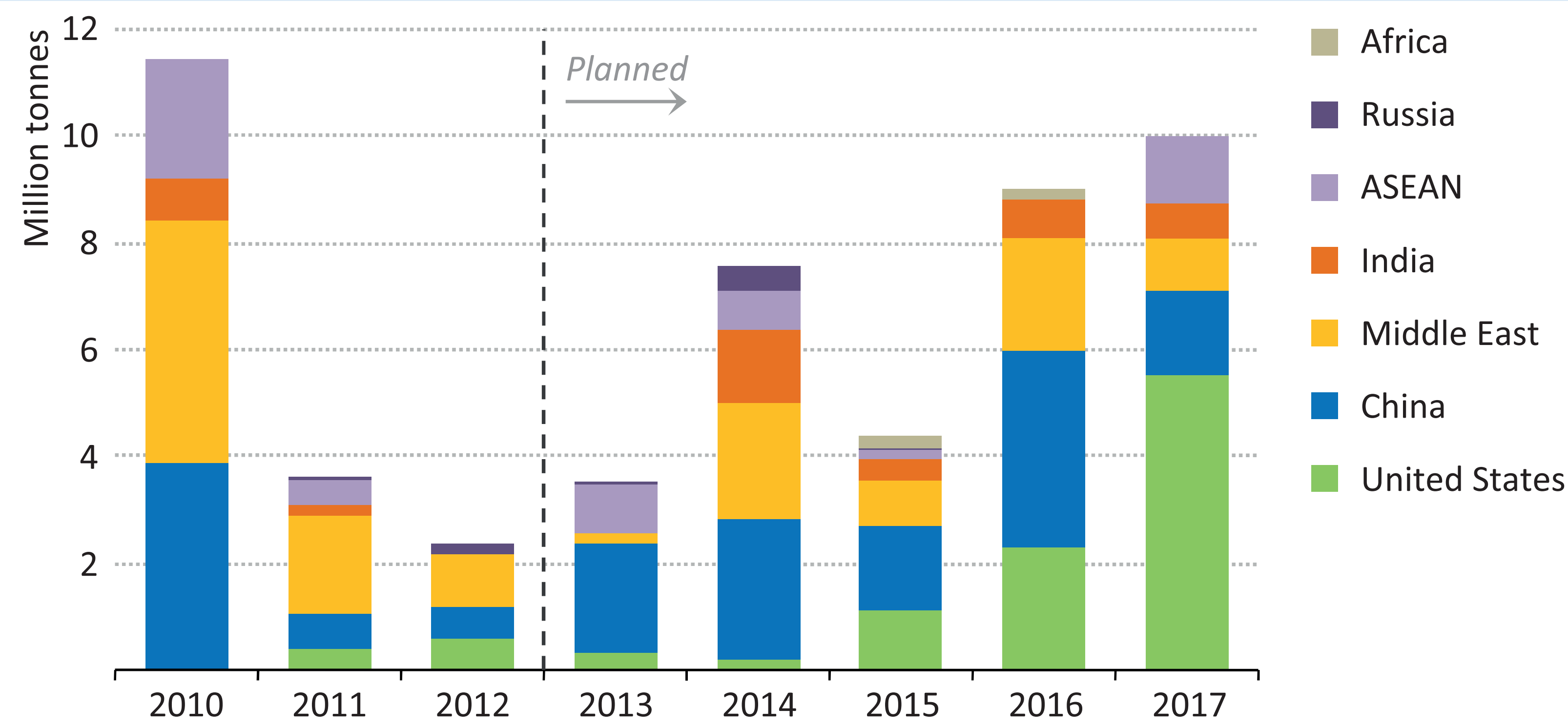
Who has the energy to compete?



Regional differences in natural gas prices narrow from today's very high levels but remain large through to 2035; electricity price differentials also persist

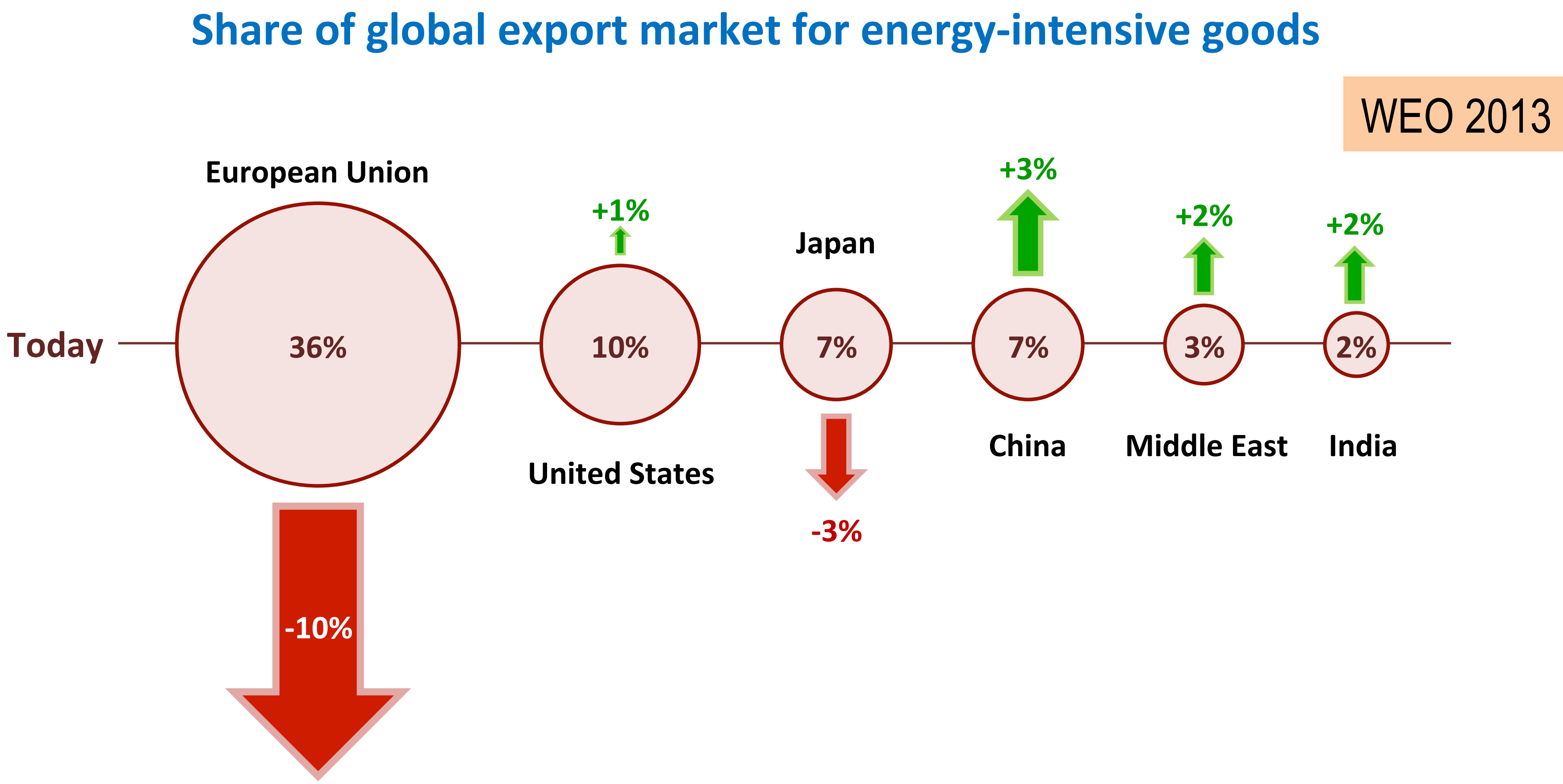
The Remarkable Renaissance of US petrochemicals

Figure 8.15 ▻ **Historical and planned ethylene capacity additions by region**



Sources: ICIS (2013); IHS (2013); METI (2013); Platts (2013); US EIA (2013); and IEA analysis.

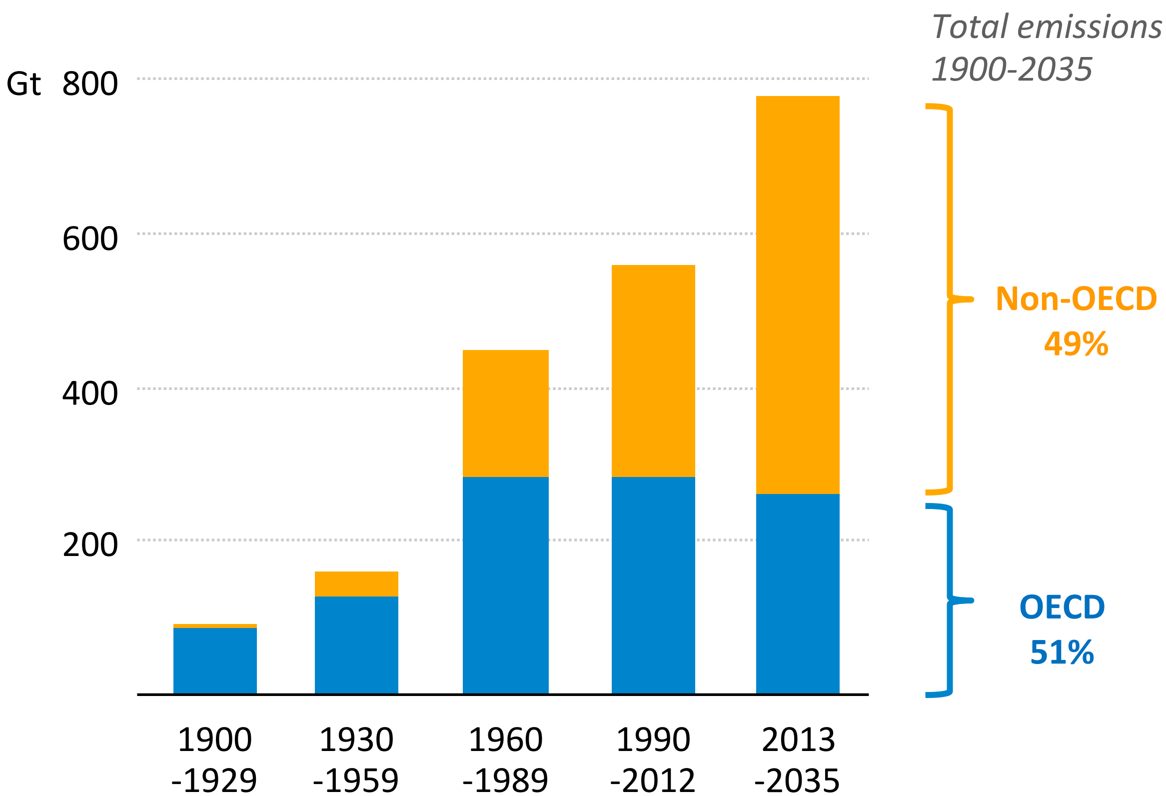
An energy boost to the economy?



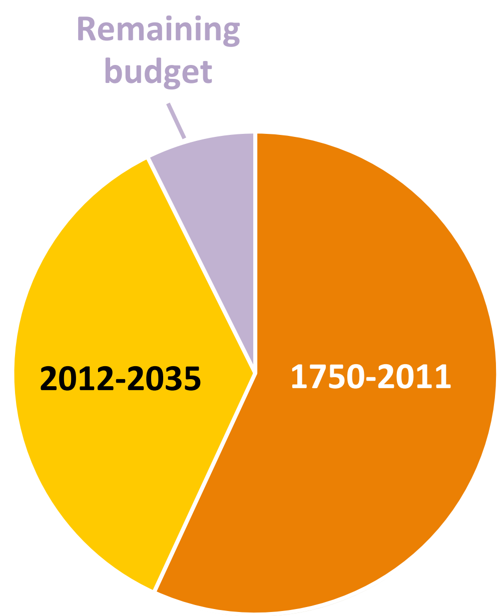
The US, together with key emerging economies, increases its export market share for energy-intensive goods, while the EU and Japan see a sharp decline

Emissions off track in the run-up to the 2015 climate summit in France

Cumulative energy-related CO_2 emissions



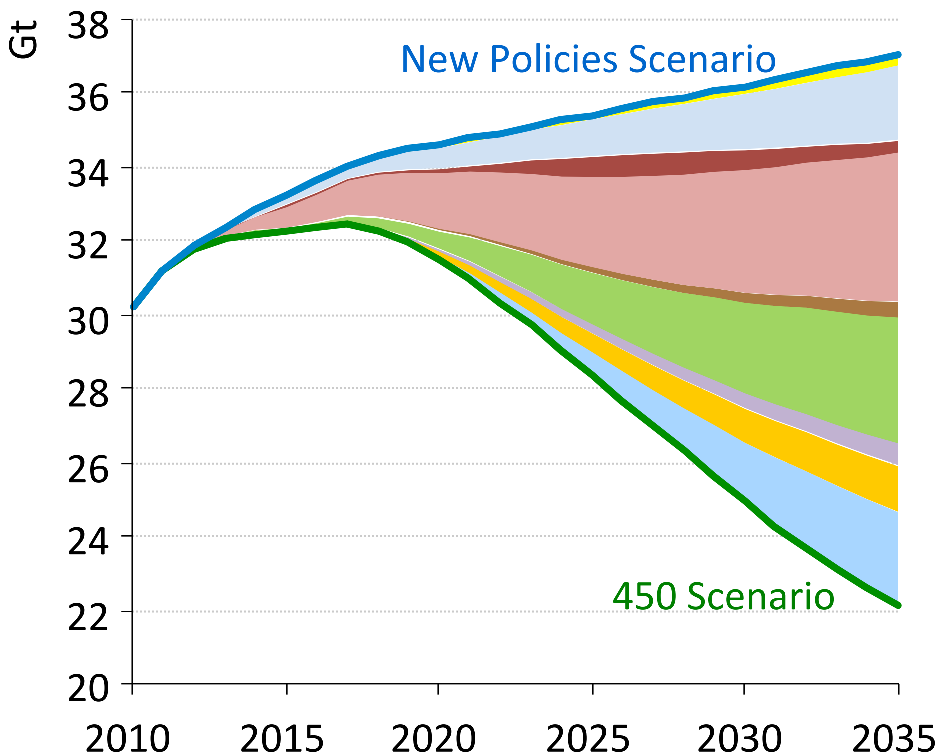
'Carbon budget' for 2 °C



WEO 2013

Non-OECD countries account for a rising share of emissions, although 2035 per capita levels are only half of OECD;the 2 °C 'carbon budget' is being spent much too quickly

450ppm Scenario: reducing CO2 by half by 2050 and containing temperature increase to 2 degrees C.

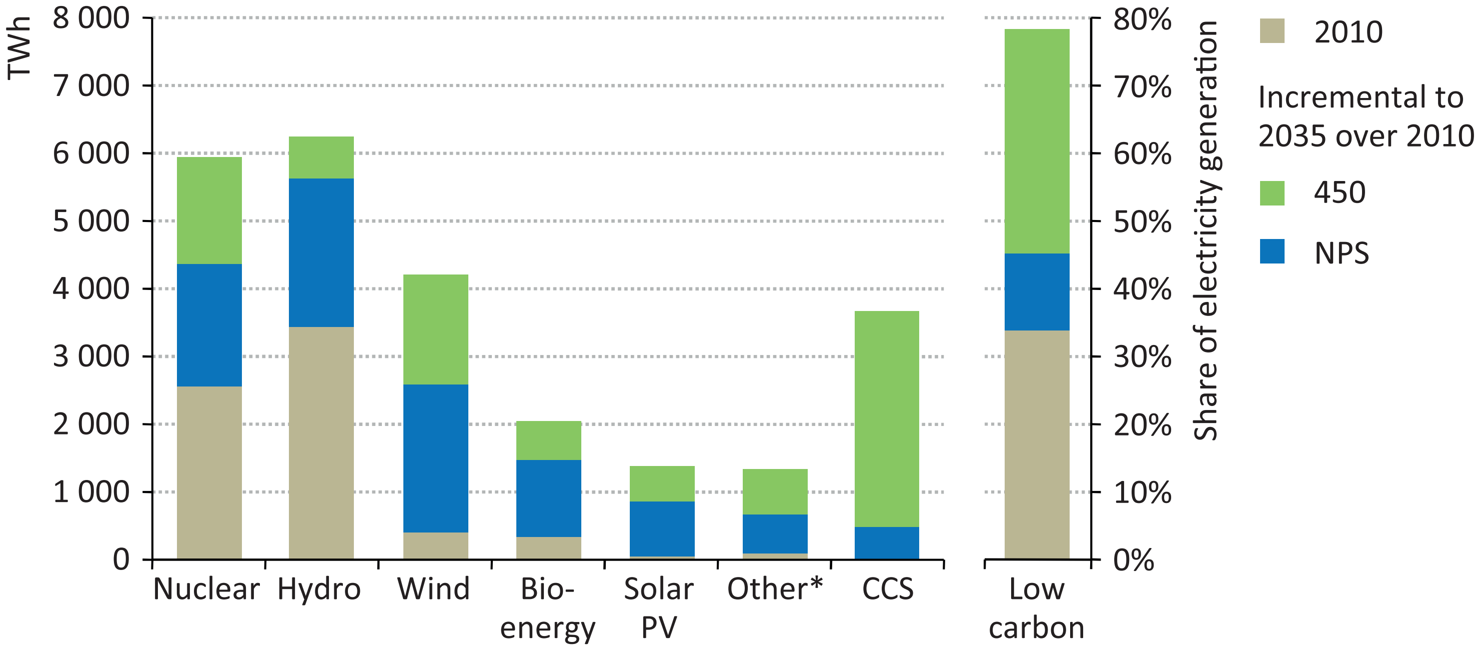


CO_2 abatement	2020	2035
Activity	2%	2%
End-use efficiency	18%	13%
Power plant efficiency	3%	2%
Electricity savings	50%	27%
Fuel and technology switching in end-uses	2%	3%
Renewables	15%	23%
Biofuels	2%	4%
Nuclear	5%	8%
CCS	4%	17%
Total (Gt CO_2)	**3.1**	**15.0**

WEO 2012

Energy efficiency reduces CO_2 emissions by 2.2 Gt in 2020 & 6.4 Gt in 2035, but efficiency's share in CO_2 abatement falls by 2035 as renewables & CCS are used more

Figure 8.6 ▷ **Electricity generation from low-carbon technologies and share by scenario, 2010 and 2035**



* Other includes geothermal, concentrating solar power and marine.

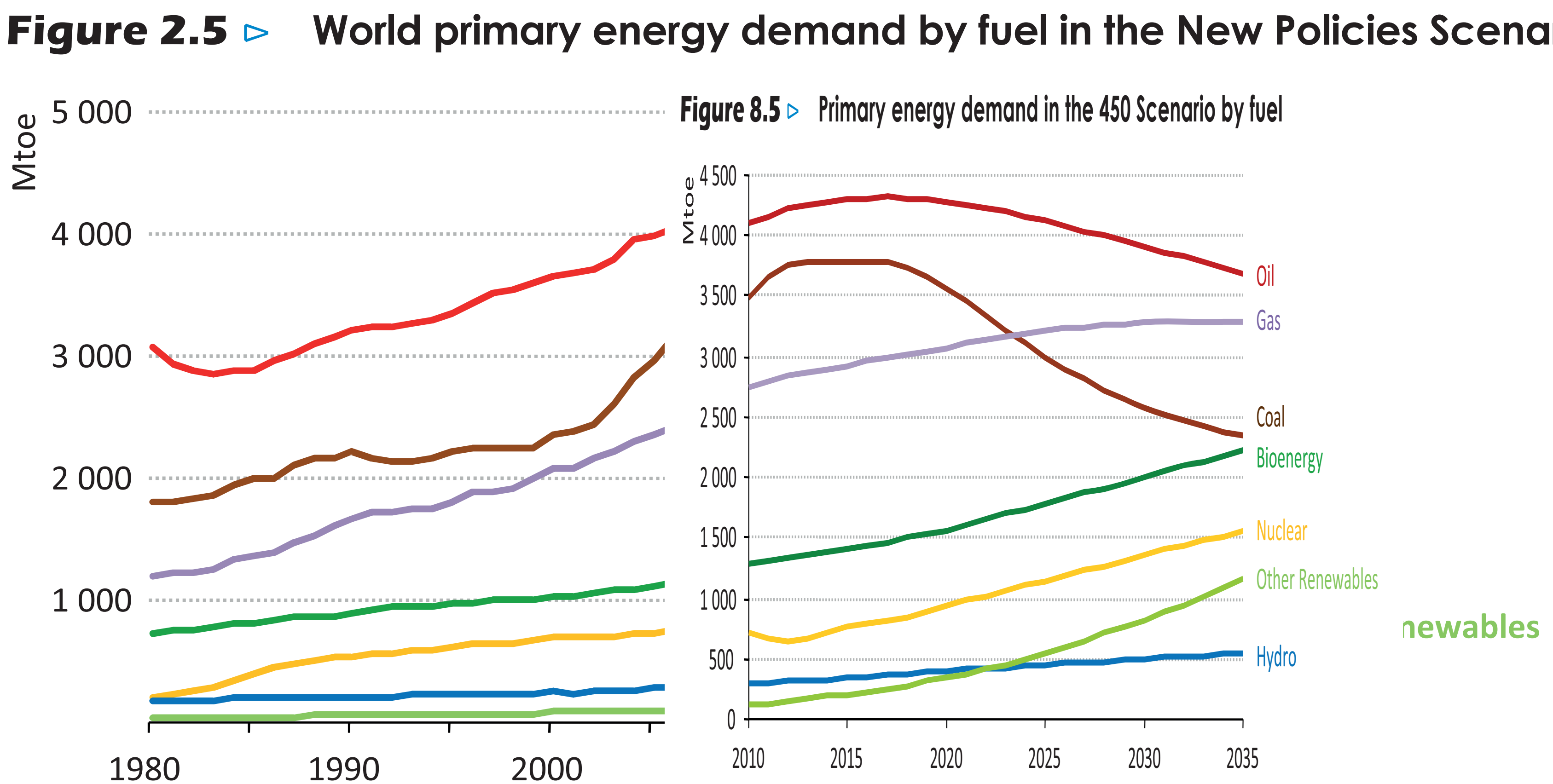
Note: 450 = 450 Scenario; NPS = New Policies Scenario.

IEA WEO2012

Can we build 16 GW of nuclear power plants a year?
\+ Can we build 60 GW of wind power plants a year? (2010 = 198 GW)
\+ Can we build 50 GW of Solar PV capacities a year? (2010 = 38GW)
And CO2 price will be more than $120 per ton.

Impact of 450 ppm Scenario on Oil Market

WEO 2013

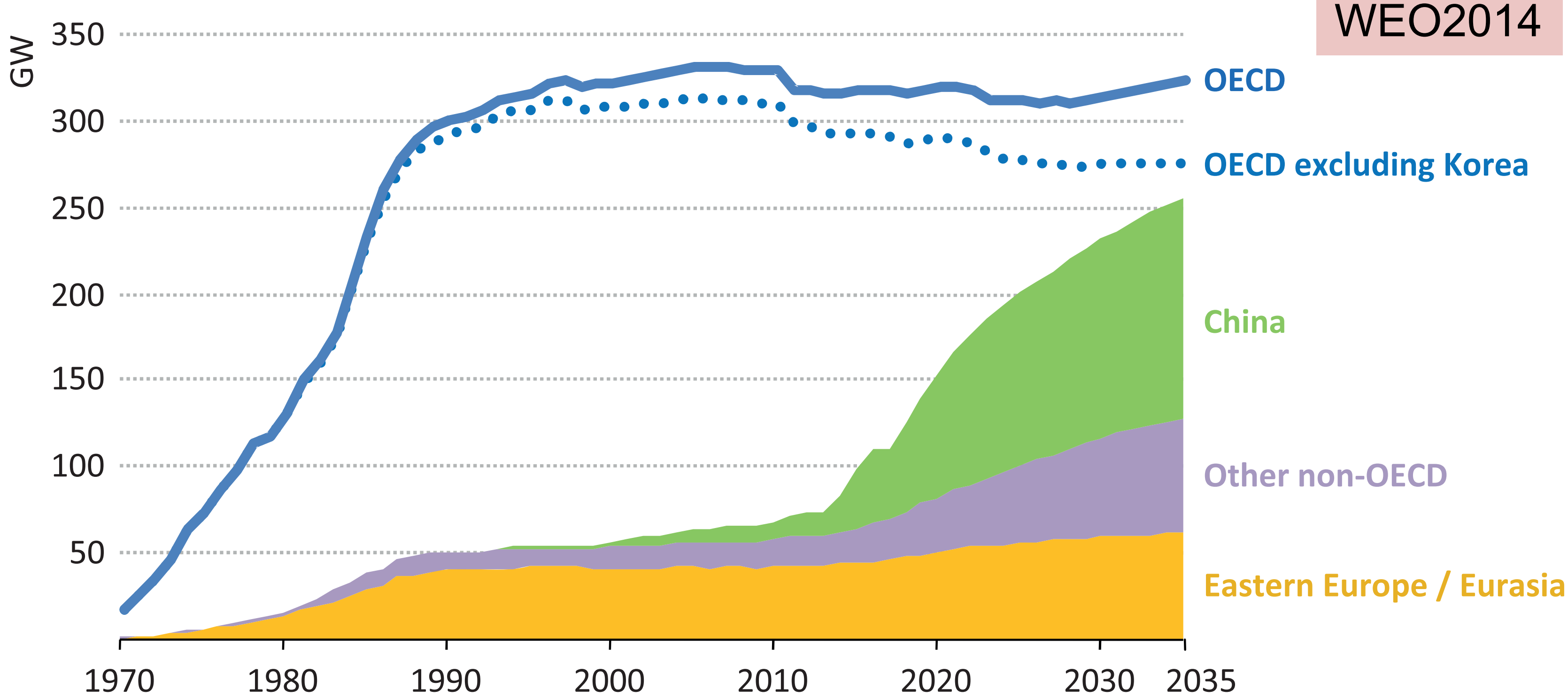


The Stone Age didn't end because we ran out of stones.

Nuclear's future

Figure 5.12 ▷ Nuclear power installed capacity by region in the New Policies Scenario

WEO2014



Share the Lessons of the Fukushima

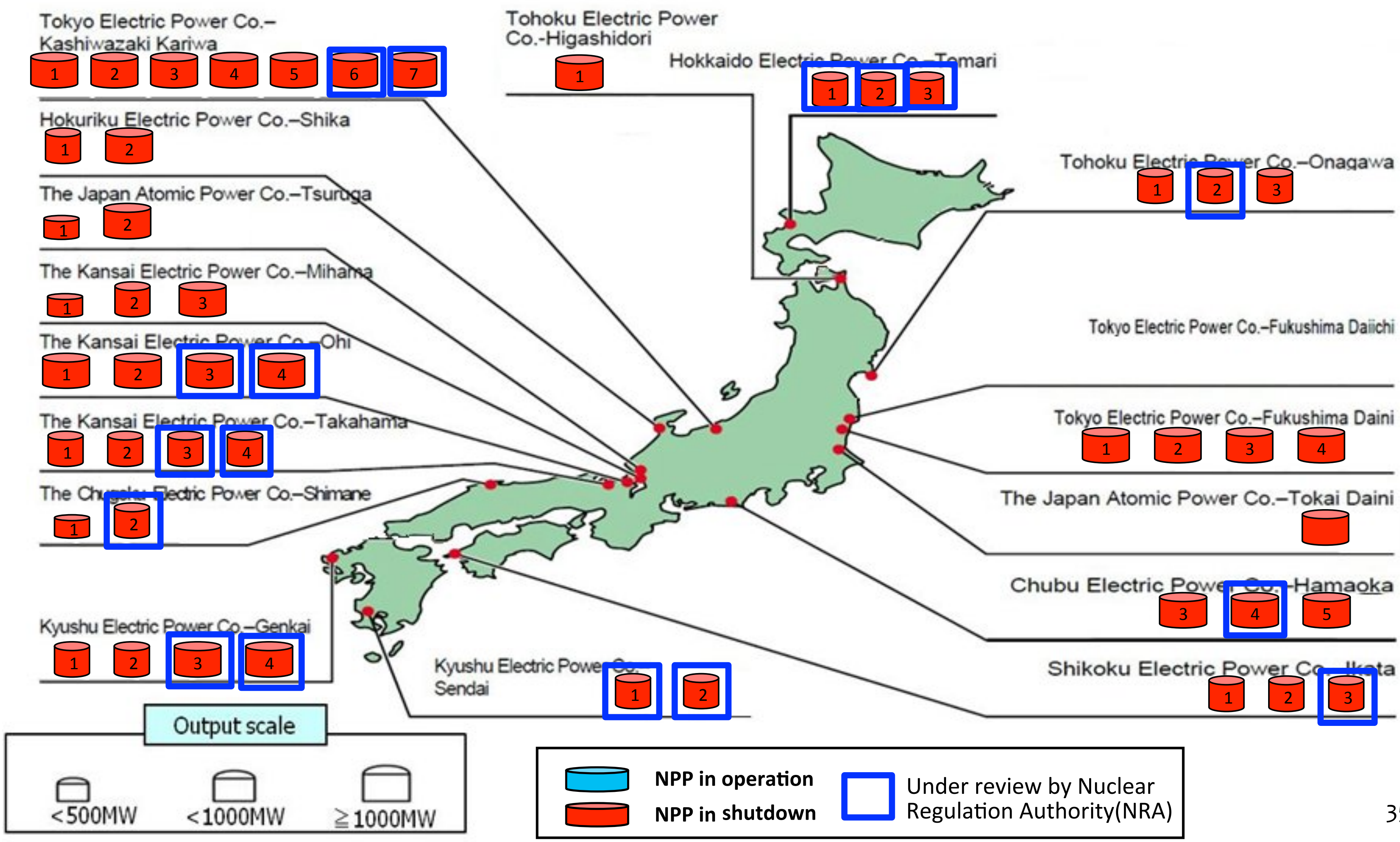
- Lessons to be Shared
  - Think about the unthinkable; Tsunami and Station Black Out. Large scale Blackout. Change total mind set for “Safety”.
  - Prepare for the severe accidents by defense in depth, common cause failure & compound disasters. NRC’s B-5-b clause was not accepted despite its suggestion.
  - Clarify why it happened only to Fukushima Daiichi and NOT to other sites like Fukushima Daini, Onagawa, Tokai-daini.
- Safety Principles
  - Fukushima accident was caused by human error and should have been avoided. (Parliament Investigation Commission report)
  - International Cooperation : A nuclear accident anywhere is an accident everywhere.
  - Independent Regulatory authority ; Transparency and Trust, “Back Fitting” of regulation
- Secured supply of Electricity
  - Power station location
  - Strengthened interconnection of grid lines
- Once disaster has happened, Recovery from disaster is at least as important as preparing for it.
  - FEMA like organization and training of the nuclear emergency staff including the self defense force ; integration of safety and security.

– New Technology. New type of Reactors such as Integral Fast Reactor.

Nuclear Power Plants in Japan

〇There are 48 nuclear power plant units in Japan. All of them (in red) is in temporary shutdown as of February 17 2014.

〇**17 units (in blue squares)** are under review for restart by the Nuclear Regulation Authority in accordance with its new safety standard.



New Basic Energy Plan : A proposal to the government - by an advisory committee of METI (Dec. 17, 2013)

Evaluation of each energy source

Feasible energy mix will be promptly proposed, considering the situation of restart of NPPs and introduction of renewable energy, etc.

(1) Nuclear Power

- Nuclear power is an important base load power source to be utilized from the viewpoint of stable supply, cost reduction, and global warming on the major premise of safety assurance.

- The dependency on nuclear power generation will be lowered as much as possible by energy saving and introducing renewable energy as well as improving the efficiency of thermal power generation, etc.

  Under this policy, the necessary scale of nuclear power will be identified and maintained taking Japan's energy situations into account such viewpoint as energy security, cost reduction, global warming and maintaining nuclear technologies and human resources.

- Put the highest priority to safety and on the premise that the government makes the best efforts to sweep away concerns among public, and the nuclear power plants whose safety has been confirmed by the Nuclear Regulation Authority are proceeded to restart.

(2) Petroleum : important energy source continued to be utilized

(3) Natural Gas : important energy source expanding the role in the future

(4) Coal : base load power source excellent in stability and economic efficiency

(5) Renewable Energy : promising domestic energy source free from GHG emissions

Generations of Nuclear Energy

Generation I

Early Prototypes

- Shippingport
- Dresden
- Magnox

Generation II

Commercial Power

- PWRs
- BWRs
- CANDU

Generation III

Advanced LWRs

- CANDU 6
- System 80+
- AP600

Generation III+

Evolutionary Designs

- ABWR
- ACR1000
- AP1000
- APWR
- EPR
- ESBWR

Generation IV

Revolutionary Designs

- Safe
- Sustainable
- Economical
- Proliferation Resistant and Physically Secure

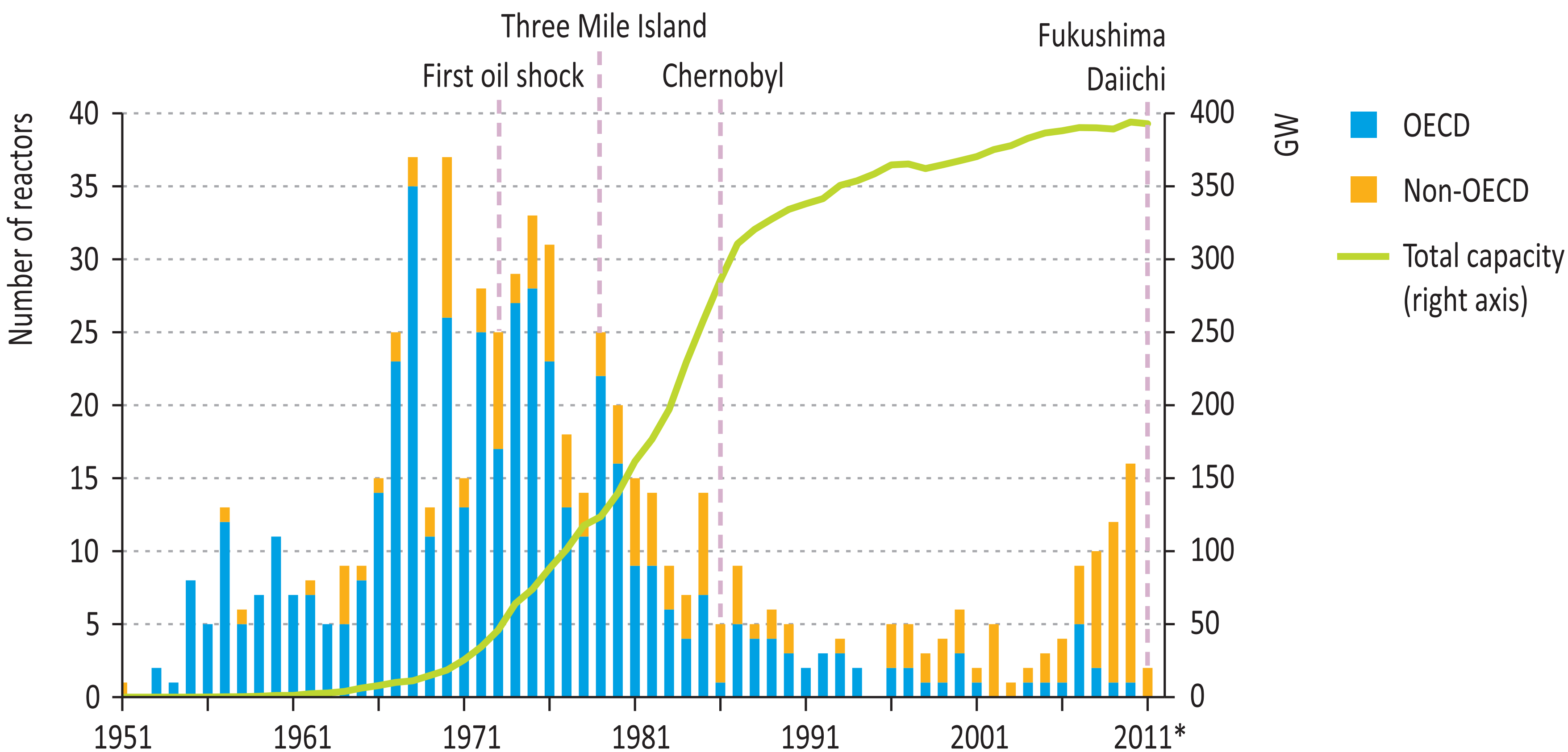
1950 1960 1970 1980 1990 2000 2010 2020 2030

Gen I | Gen II | Gen III | Gen III+ | Gen IV

http://www.gen-4.org/Technology/evolution.htm

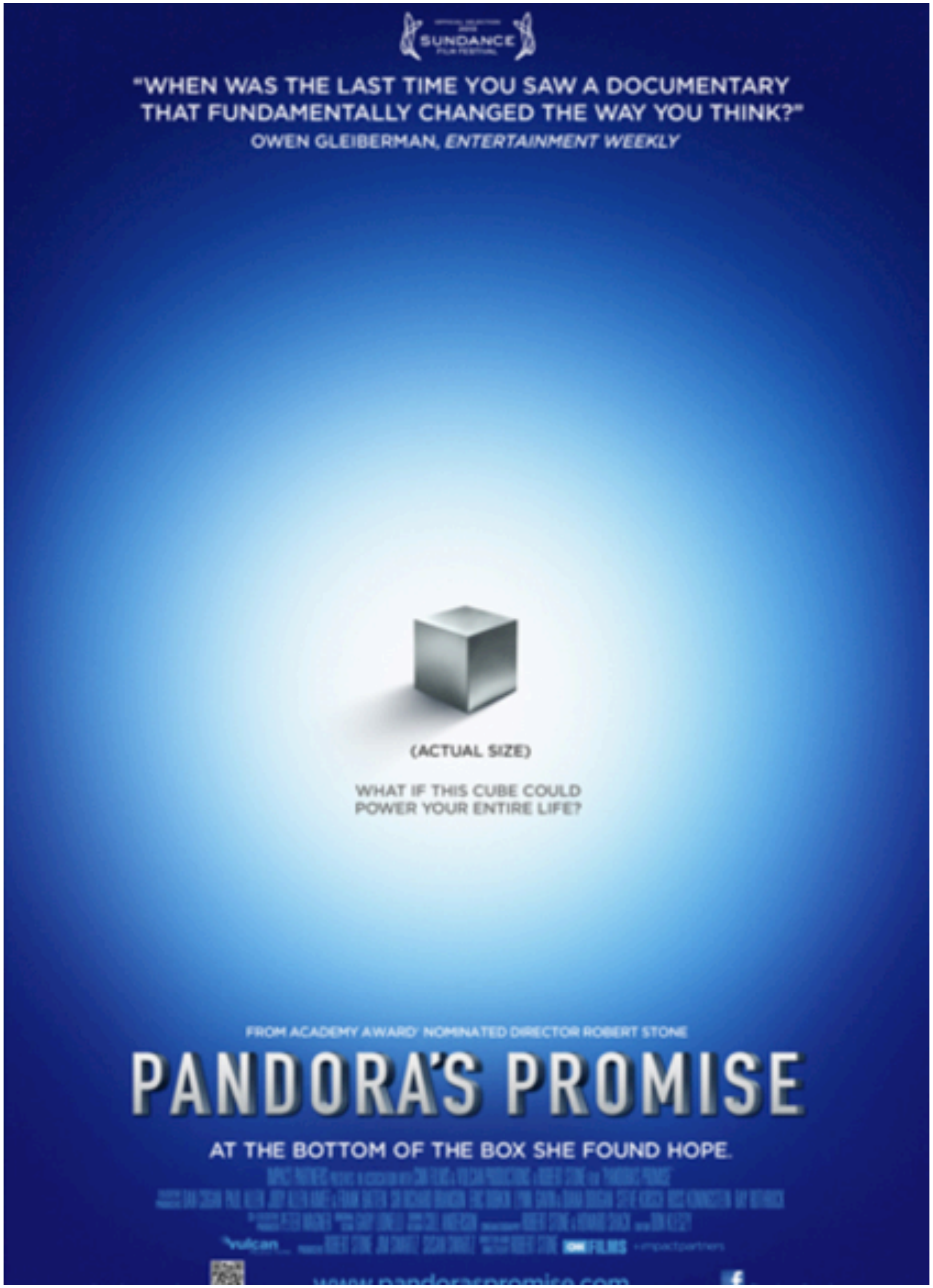
History of Nuclear Reactors

Figure 12.1 ● Nuclear reactor construction starts, 1951-2011



*Data as of 31 Aug 2011.

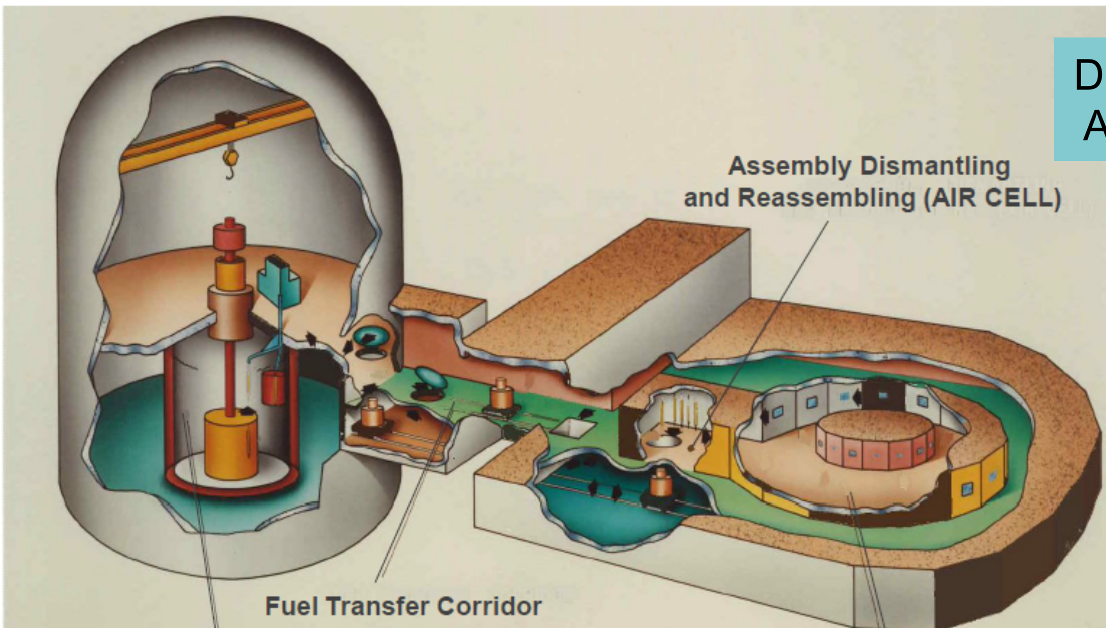
IEA WEO 2011


SUNDANCE
"WHEN WAS THE LAST TIME YOU SAW A DOCUMENTARY THAT FUNDAMENTALLY CHANGED THE WAY YOU THINK?"
OWEN GLEIBERMAN, ENTERTAINMENT WEEKLY
(ACTUAL SIZE)
WHAT IF THIS CUBE COULD POWER YOUR ENTIRE LIFE?
FROM ACADEMY AWARD NOMINATED DIRECTOR ROBERT STONE
PANDORA'S PROMISE
AT THE BOTTOM OF THE BOX SHE FOUND HOPE.

Time for Safer, Proliferation resistant and Easier Waste Management Paradigm: Integral Fast Reactor and Pyroprocessing

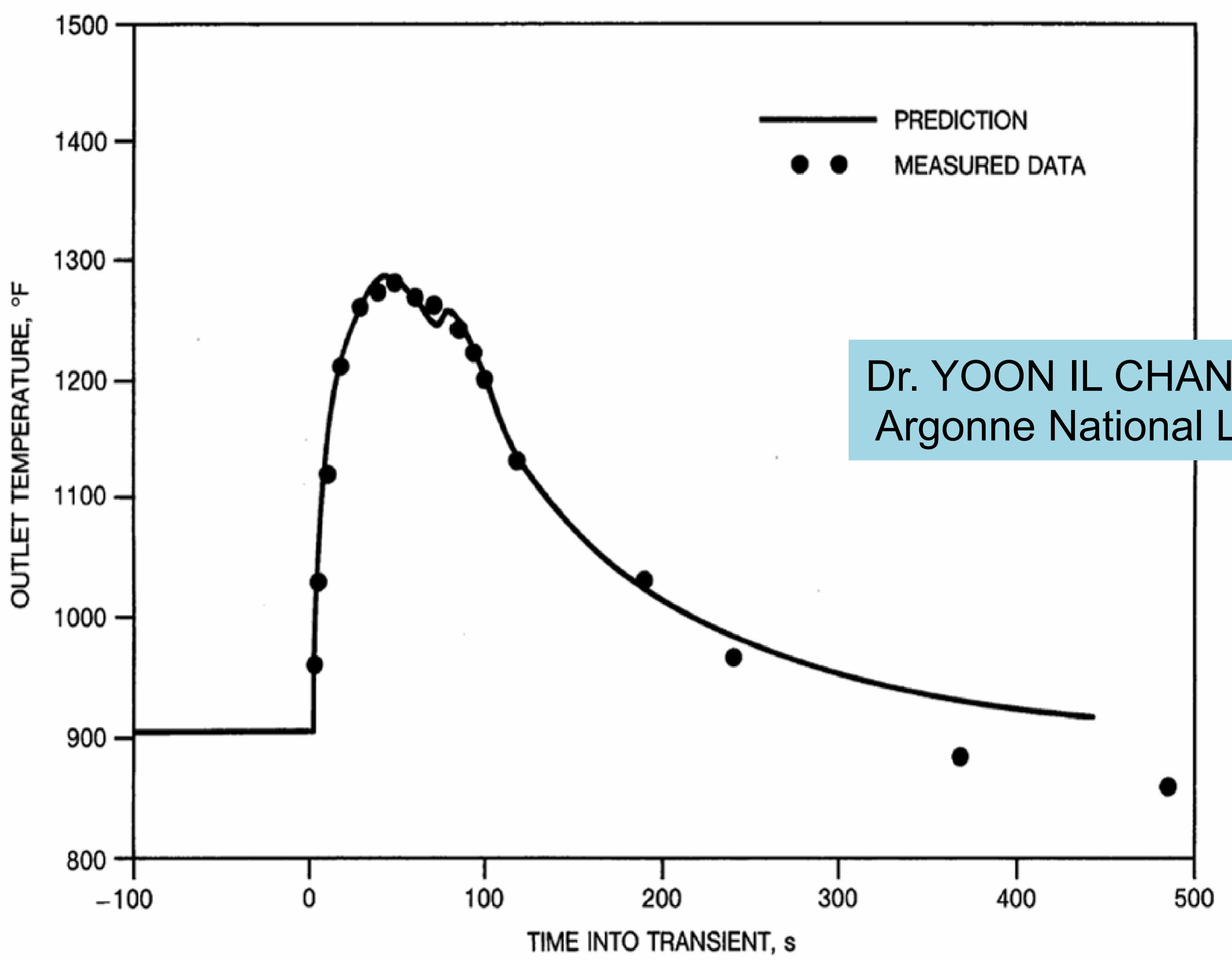
Pyroprocessing was used to demonstrate the EBR-II fuel cycle closure during 1964-69

Dr. YOON IL CHANG
Argonne National Laboratory



IFR has features as Inexhaustible Energy Supply ,Inherent Passive Safety ,Long-term Waste Management Solution , Proliferation-Resistance , Economic Fuel Cycle Closure.
High level waste reduces radioactivity in 300 years while LWR spent fuel takes 100,000 years.

Loss-of-Flow without Scram Test in EBR-II



Dr. YOON IL CHANG
Argonne National Laboratory

Technical Rationale for the IFR

✓ Revolutionary improvements as a next generation nuclear concept:

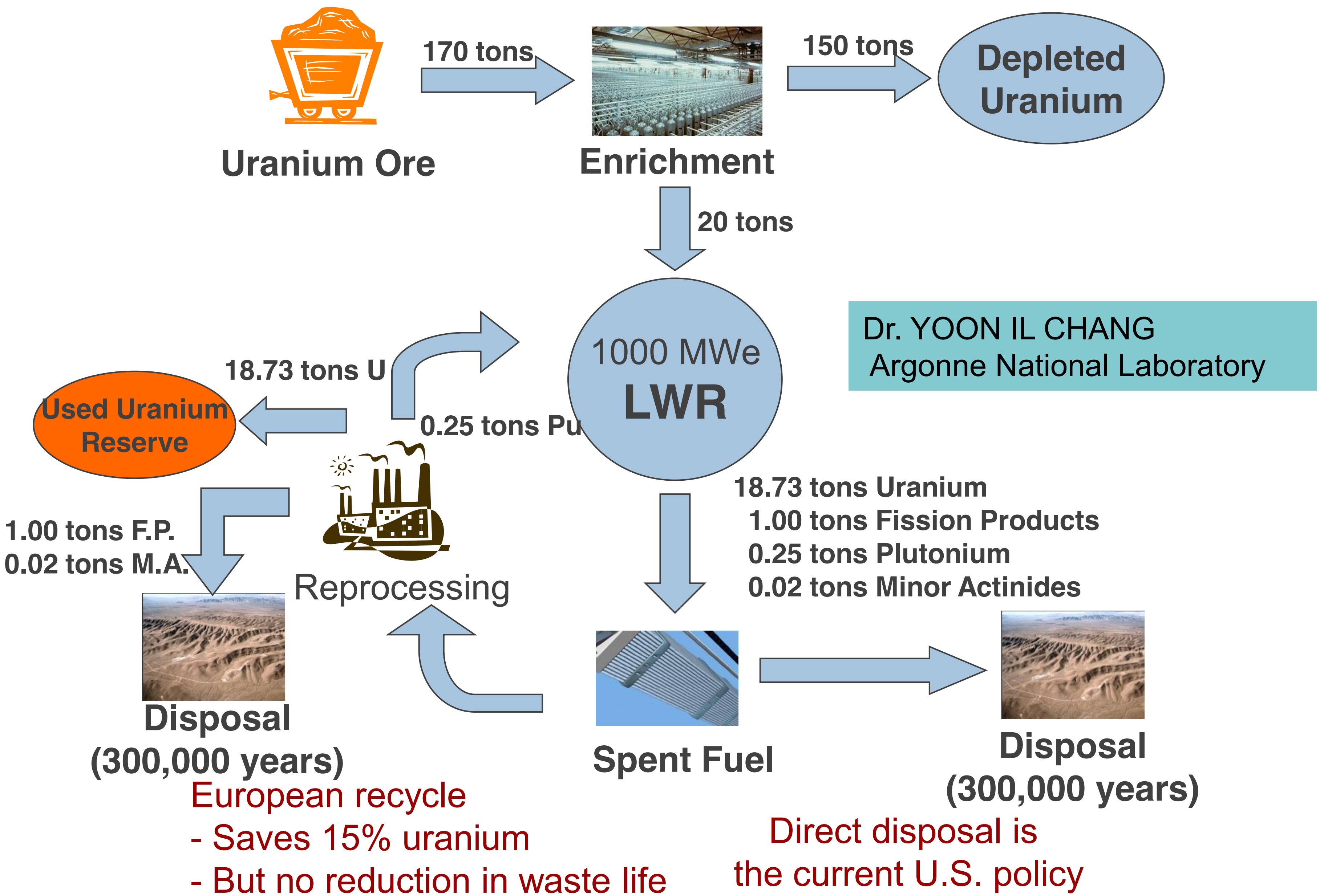
- Inexhaustible Energy Supply
- Inherent Passive Safety
- Long-term Waste Management Solution
- Proliferation-Resistance
- Economic Fuel Cycle Closure

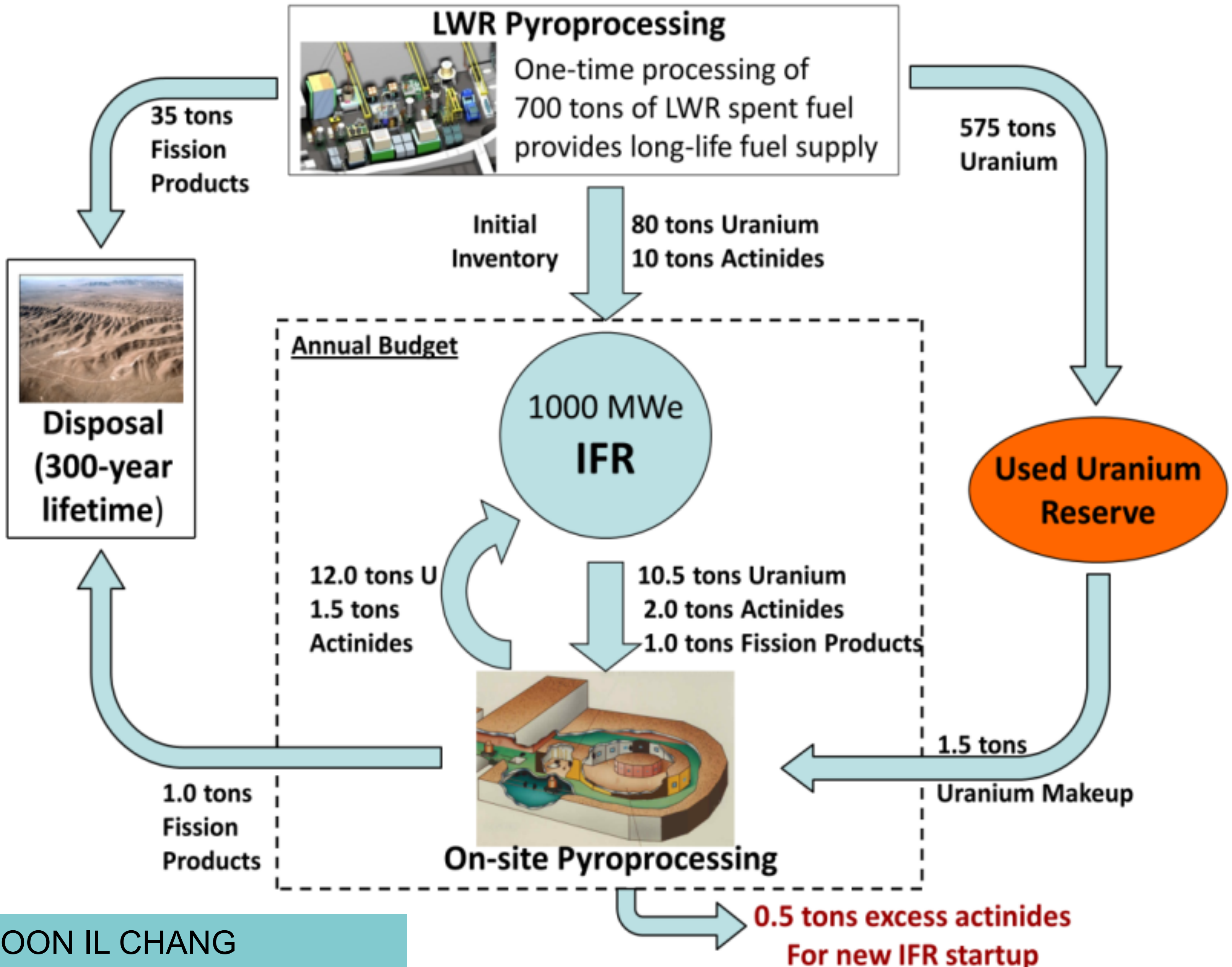
✓Metal fuel and pyroprocessing are key to achieving these revolutionary improvements.

✓Implications on LWR spent fuel management

Dr. YOON IL CHANG
Argonne National Laboratory

Uranium utilization is <1% in LWR





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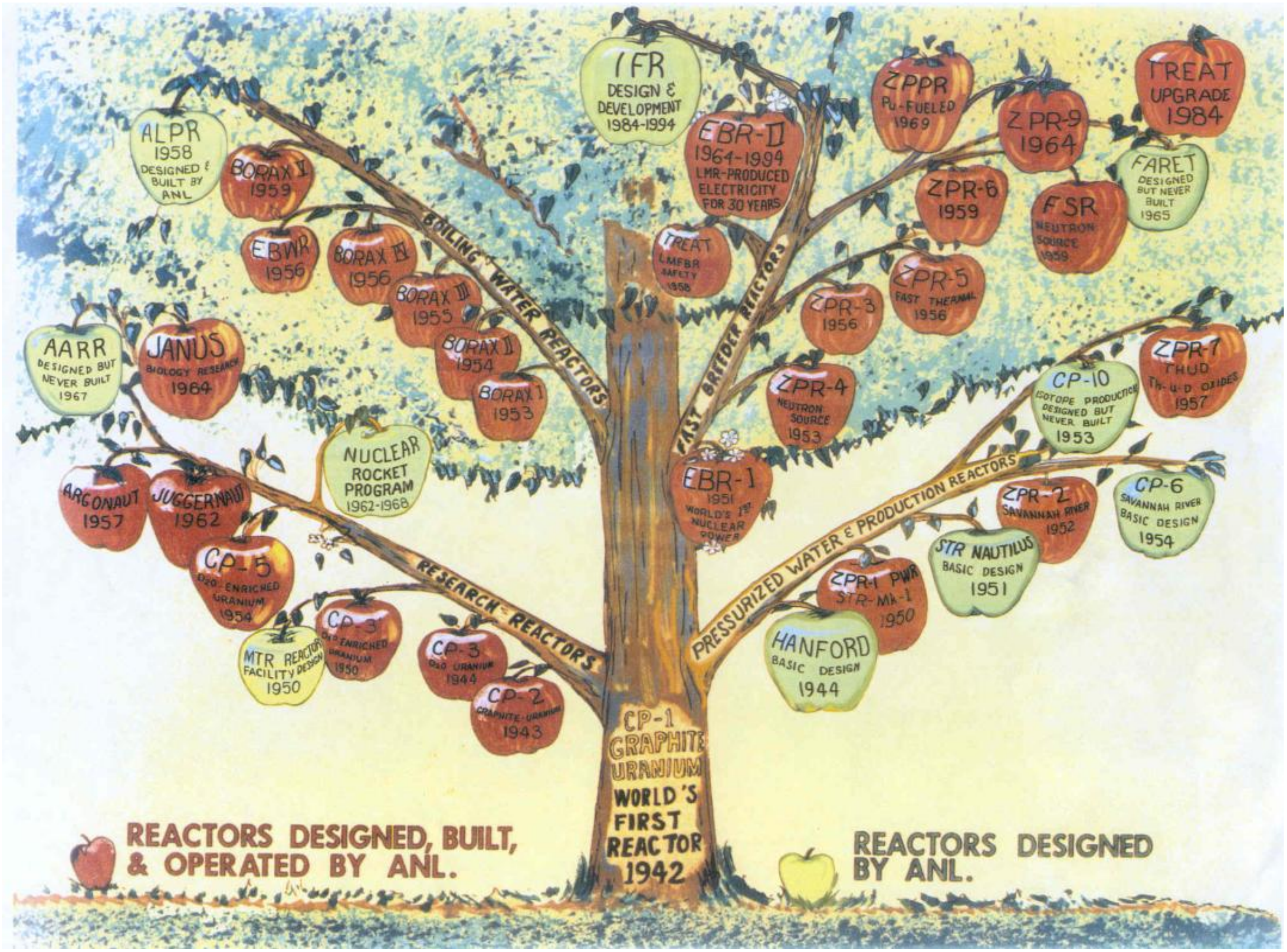

Figure 1-8. Reactors developed by Argonne

Legend of Admiral Rickover

経済観測

前国際エネルギー機関事務局長　田中　伸男

リッコーバー提督の伝説

2014.[redacted].[redacted]

ロバート・ストーン監督のドキュメンタリー映画「パンドラの約束」に興味深い場面が出てくる。海軍士官が初の原子力潜水艦ノーチラス号の模型を前に原子力の素晴らしさを説明しているところだ。若い頃のハイマン・リッコーバー提督である。米海軍の原潜乗りで彼の名前を知らないものはいない。

加圧水型軽水炉（ＰＷＲ）は、酸素を必要としない動力源として潜水艦用に開発された。蒸気発生器も乗組員を被ばくから守るための技術だ。提督は乗組員に原子炉知識の共有と安全管理を徹底した。小さくてもミスを犯したものは原潜から放逐されたという。１人の間違いが全乗組員の死に直結するからだ。これが海軍でリッコーバー提督の伝説となり、今もその安全ルールが徹底されていると聞く。

退役した乗組員が米原子力規制委員会の委員やスタッフになり、原子力発電所にも派遣されて原子炉の安全を守っている。水を冷却材とする軽水炉は、原潜に載せるのに都合の良い技術だ。万が一の事態が起こっても海中に投棄すれば原子炉は停止するからだ。それを陸に上げれば冷却水が途絶えるリスクがあることは福島で明らかになった。

軍事技術の転用として商業用軽水炉の普及が急速に進んだのはリッコーバー提督の功績である。しかし軽水炉と同時に開発されていた高速炉は、原子力利用の本命と言われながら過渡的な技術のはずの軽水炉との実用化競争に敗れいまだに研究段階にある。問題は軽水炉実用化を急ぎすぎ、炉の安全性や使用済み核燃料処理などバックエンド技術が未完のまま走り始めたことだ。福島事故後の日本こそ、安全で核不拡散型かつ廃棄物処理の楽な「統合型高速炉」を平和利用の伝説にする責任があるのではないか。


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映像提供：フイルムヴォイス

Joint Program on Pyroprocessing with Japan

- ✓Central Research Institute of Electric Power industry (CRIEPI): $20 million cost sharing signed in July 1989.
- ✓CRIEPI and Japan Atomic Power Company jointly representing Federation of Electric Power Companies (FEPC): Additional $20 million added in October 1992.
- ✓Tokyo, Kansai, and Chubu Electric Power Companies: $6 million for LWR feasibility study signed in July 1992.
- ✓Power Reactor and Nuclear Fuel Development Corporation (PNC): $60 million cost sharing program agreed to in February 1994, but canceled by DOE.
- ✓These joint programs ended when the IFR Program was terminated in October 1994.

Dr. YOON IL CHANG
Argonne National Laboratory

Importance of LWR Pyroprocessing Demonstration

- ✓ The public views adequate nuclear waste management as a critical linchpin in further development of nuclear energy.
- ✓ The backend of the nuclear fuel cycle cannot be addressed independent of the next-generation reactor options. A systems approach is required.
- ✓ Basically, three options exist:
  - LWR once-through only and direct disposal of spent fuel
  - PUREX reprocessing and MOX recycle in LWRs in interim
  - LWR once-through, followed by pyroprocessing and full recycle in fast reactors
- ✓ A key missing link for decision making is a pilot-scale demonstration of pyroprocessing for LWR spent fuel.

Dr. YOON IL CHANG
Argonne National Laboratory

A Plausible Path forward Option

✓As an immediate step, develop a detailed conceptual design and cost/schedule estimates for a pilot-scale (100 ton/yr) pyroprocessing facility to treat LWR spent fuel.

- This will provide data for industry to evaluate viability.

✓Follow with a construction project for 100 ton/yr LWR pyroprocessing facility to validate economics and commercial viability.

✓In parallel, initiate an IFR demonstration project based on GEH's PRISM Mod-B (311 MWe).

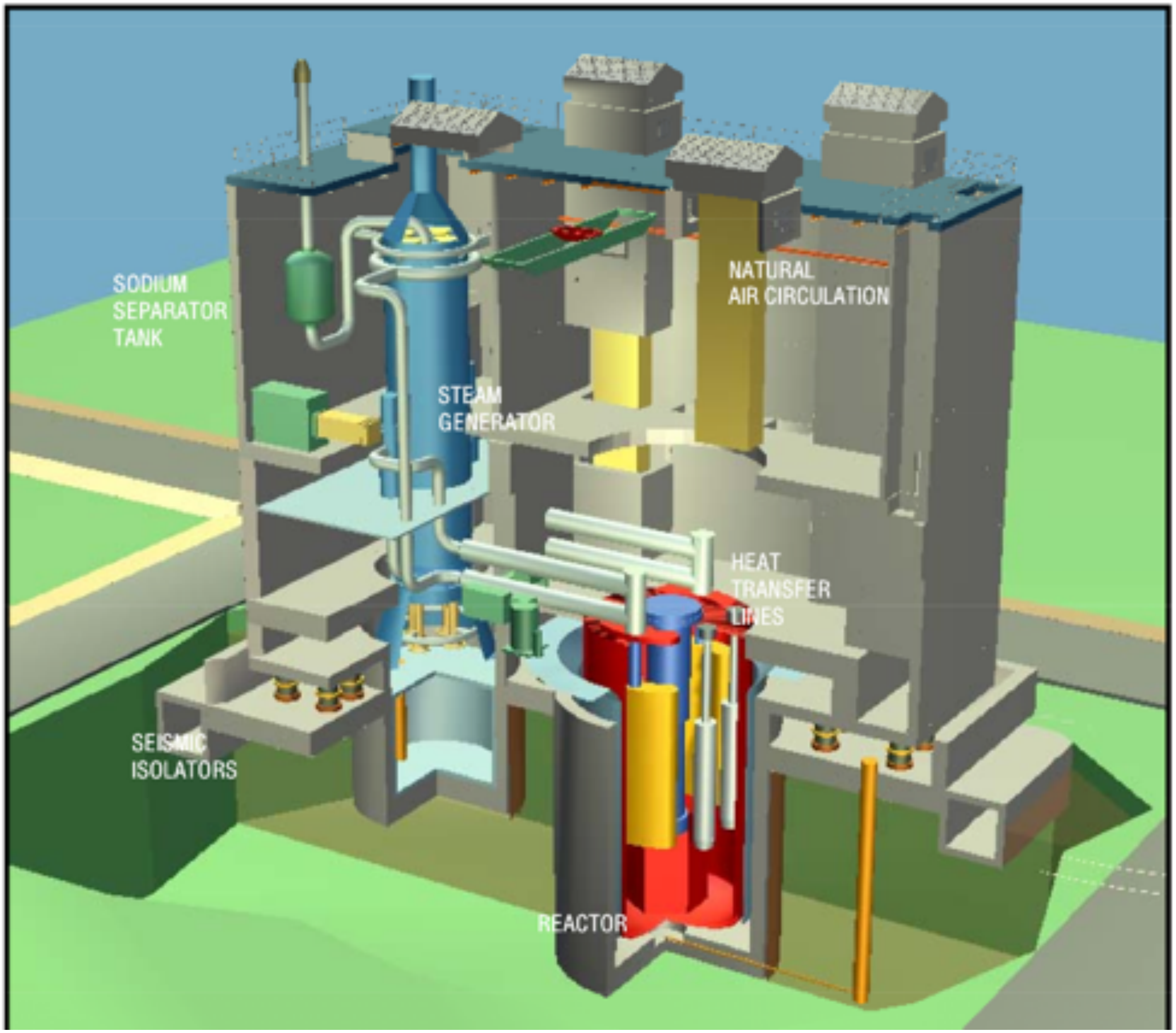
- Licensing preparations
- Negotiations with the U.S. industry and international partners

✓A modest sized prototype demonstration project on a DOE site can be done at a fraction of the cost.

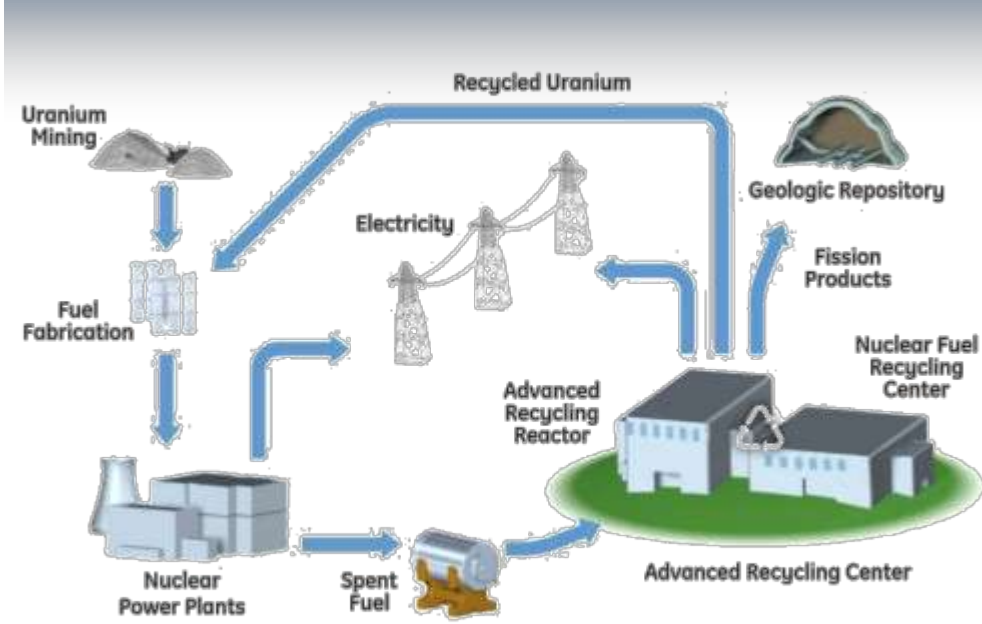
- A vital project to preserve the technology base and develop next-generation engineers for the future.

Dr. YOON IL CHANG
Argonne National Laboratory

S-PRISM Nuclear Steam Supply System

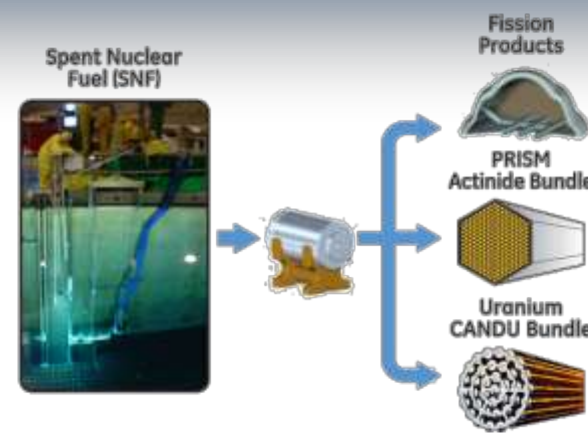


Extending PRISM… recycling used LWR fuel closes the nuclear fuel cycle with two technologies . . .

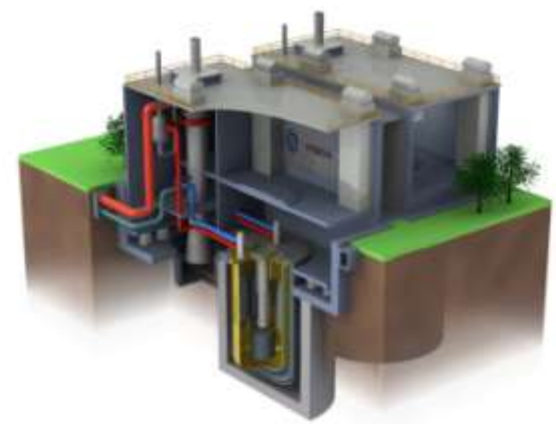


Benefits include:

- Waste half-life … 300-500 years
- Uranium energy … extracts 90%
- Non-proliferation … no plutonium separation
- Environmentally responsible … dry process



NFRC - Electrometallurgical

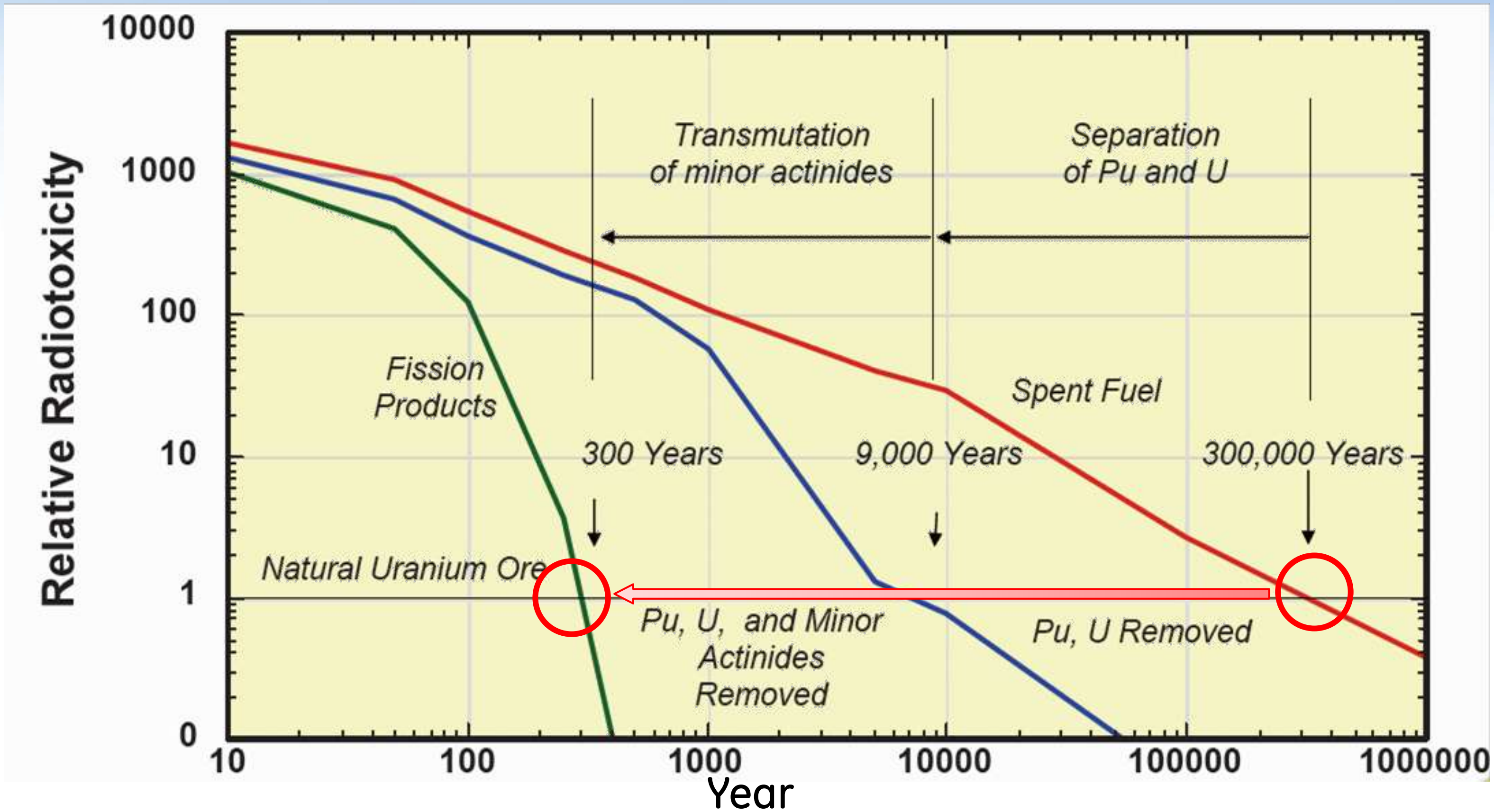


Advanced Recycle Reactor - PRISM

HITACHI

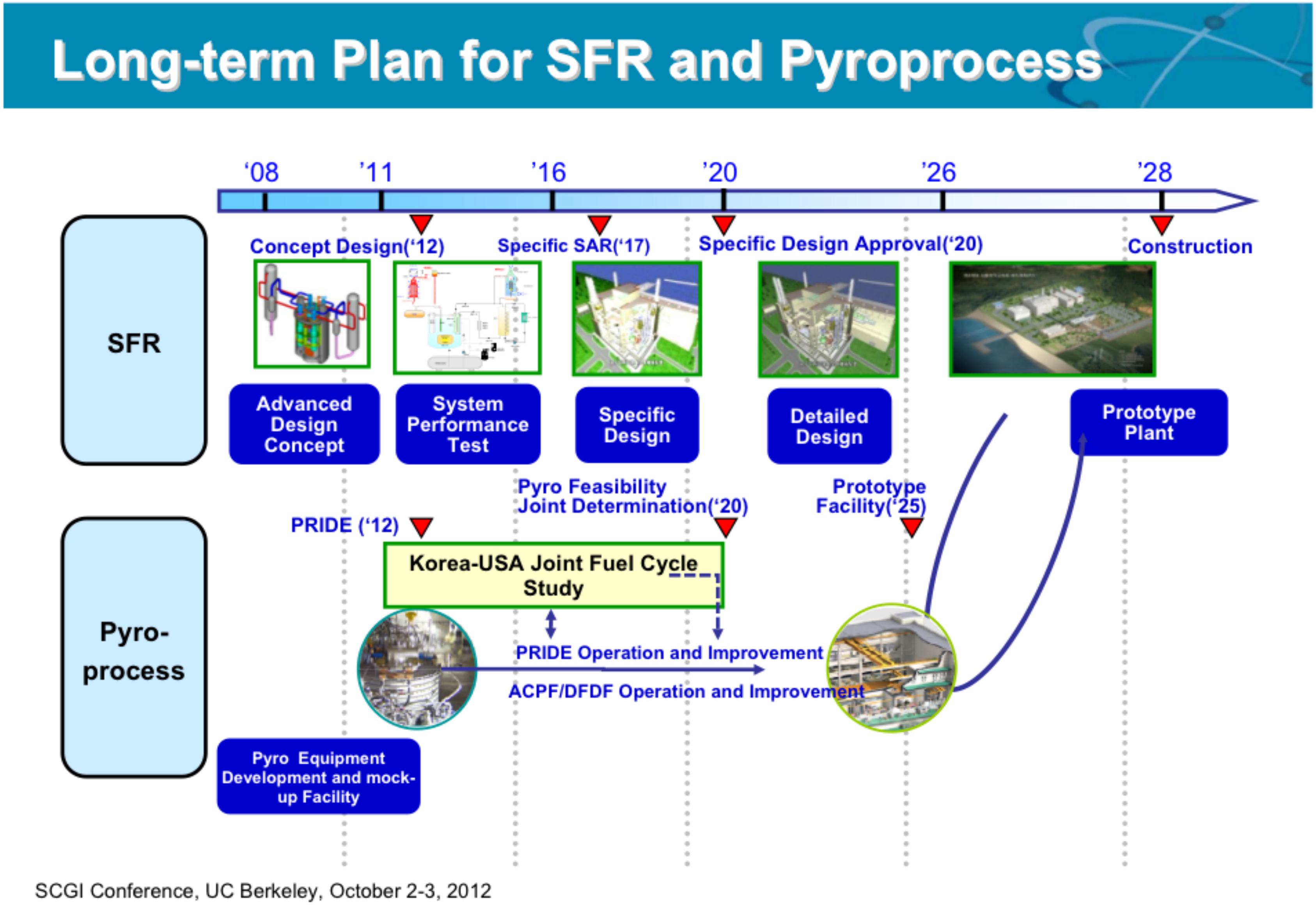
Transuranic disposal issues

The 1% transuranic (TRU) content of nuclear fuel is responsible for 99.9% of the disposal time requirement and policy issues



Removal of uranium, plutonium, and transuranics makes a 300,000 year problem a 300 year problem

Korea seeks to change the 1-2-3 Agreement



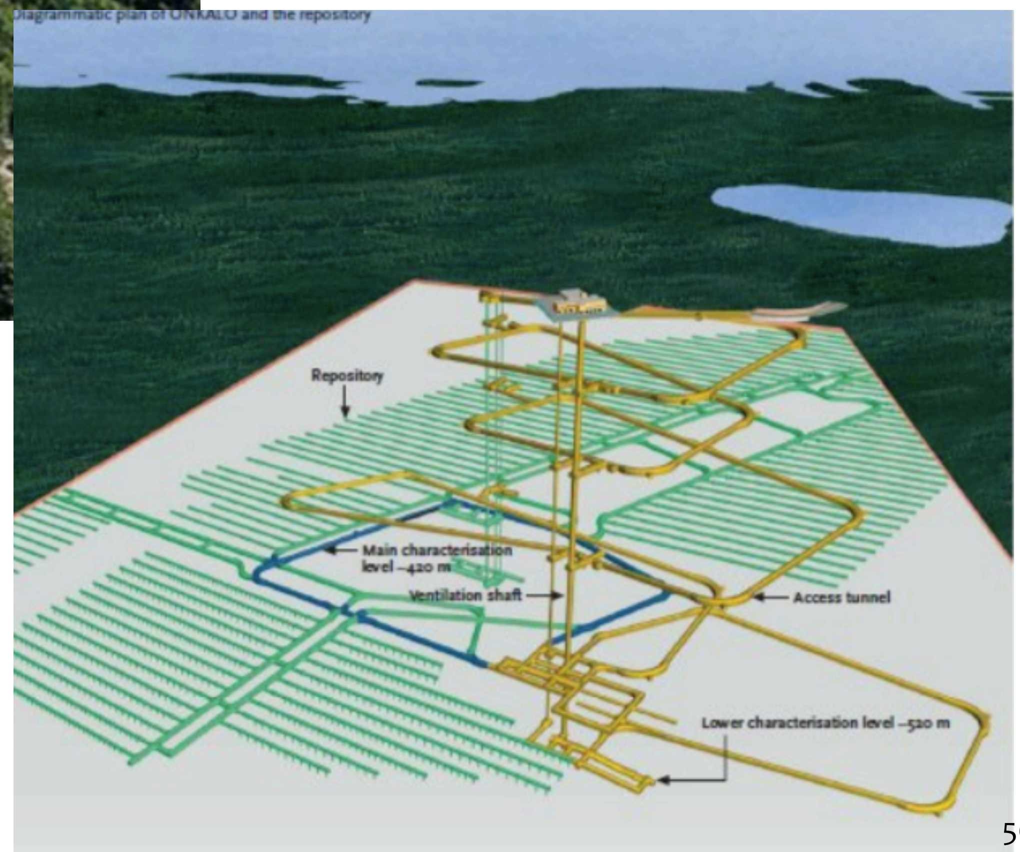
U.S.-Japan Alliance Report by Nye & Armitage (2012/8/10)

For such an alliance to exist, the United States and Japan will need to come to it from the perspective, and as the embodiment, of tier-one nations. In our view, tier-one nations have significant economic weight, capable military forces, global vision, and demonstrated leadership on international concerns. Although there are areas in which the United States can better support the alliance, we have no doubt of the United States' continuing tier-one status. For Japan, however, there is a decision to be made. Does Japan desire to continue to be a tier-one nation, or is she content to drift into tier-two status?

Energy Security
（Nuclear）
Understandably, the Fukushima nuclear disaster dealt a major setback to nuclear power. The setback reverberated not only throughout Japan, but also around the world. Japan has made tremendous progress in boosting energy efficiency and is a world leader in energy research and development. While the people of Japan have demonstrated remarkable national unity in reducing energy consumption and setting the world's highest standards for energy efficiency, a lack of nuclear energy in the near term will have serious repercussions for Japan.

Issue of High-level Waste Disposal

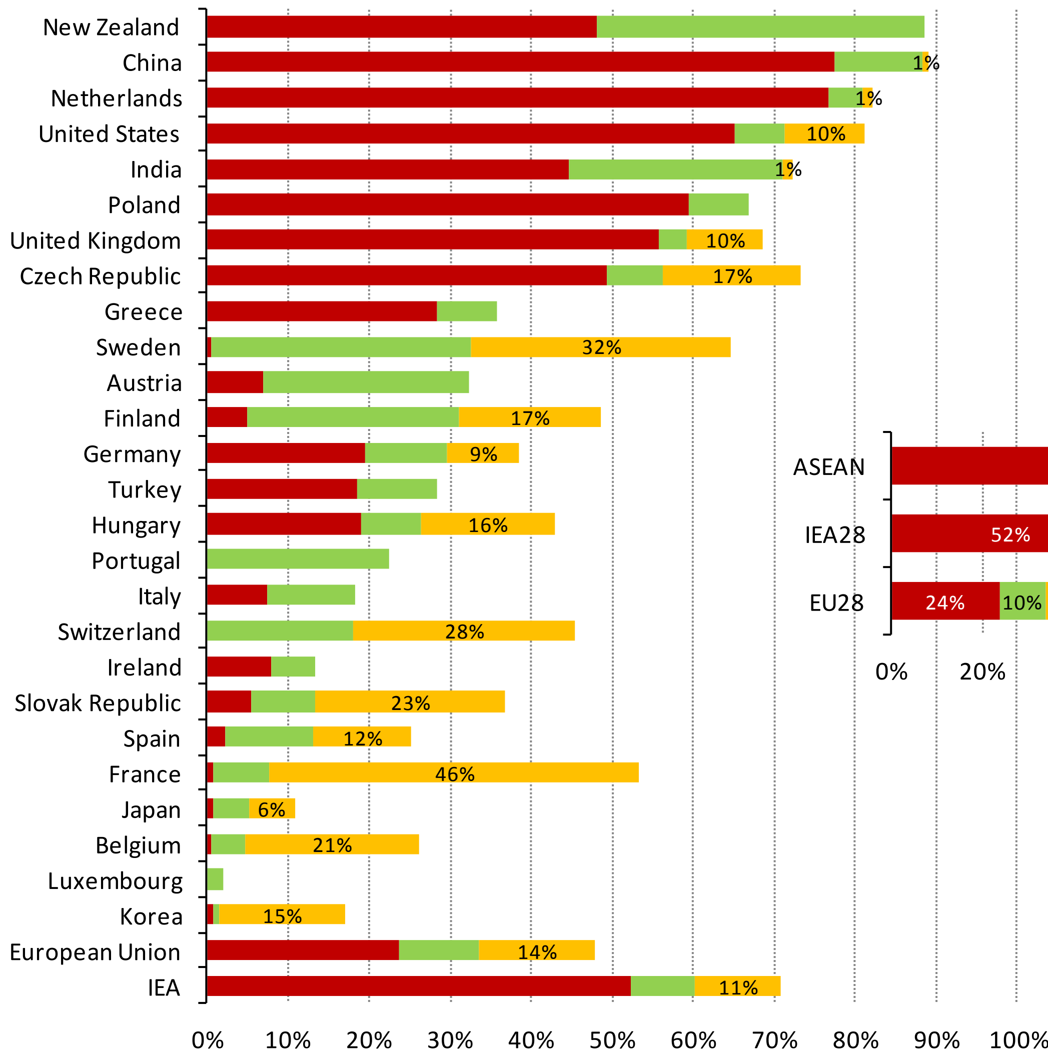
Finland Model:
Olkiluotp Nuclear Power Plant and Onkalo nuclear spent fuel repository

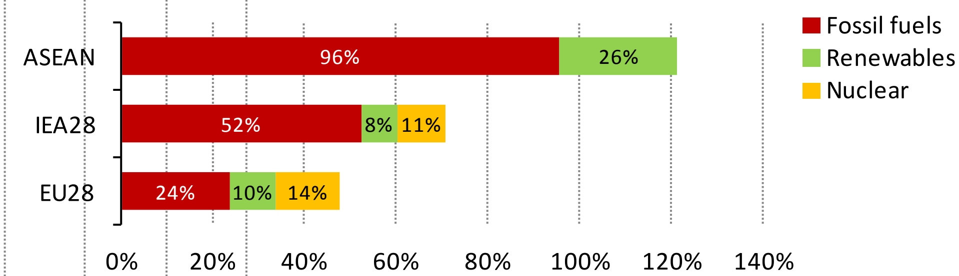


HQ of Teollisuuden Voima Oyj   Utility which owns Olkiluoto Nuclear Power Plant exists in the Plant site.

Collective Energy Security and Sustainability by Diversity, Connectivity and Nuclear

Energy self-sufficiency* by fuel in 2011





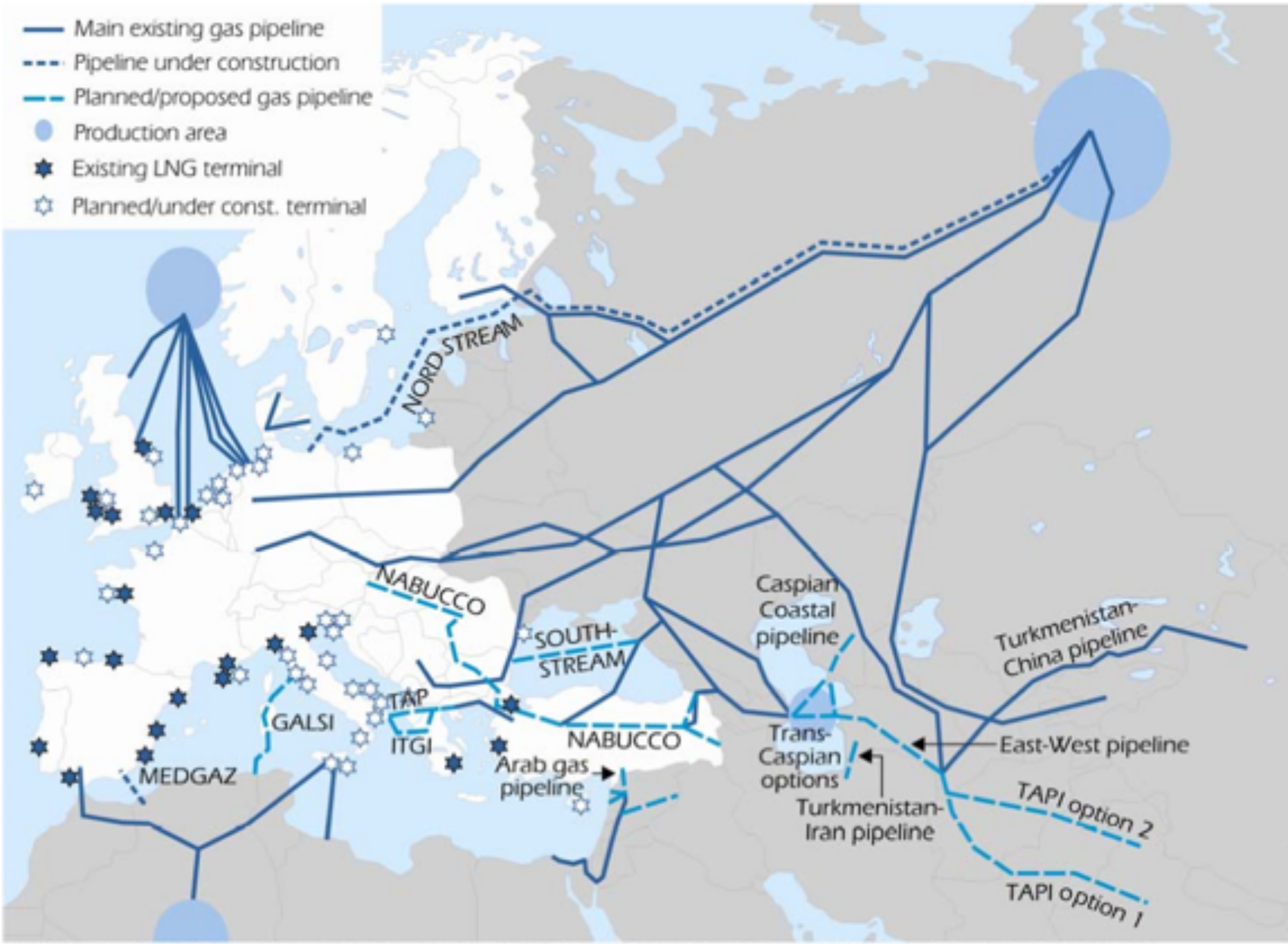
* Self-sufficiency =
domestic production /
total primary energy supply

Source: Energy Data Center, IEA.

Note: Does not include fuels not in the fossil fuels, renewables and nuclear categories.

Natural Gas Import Infrastructure in Europe

European Import Infrastructure



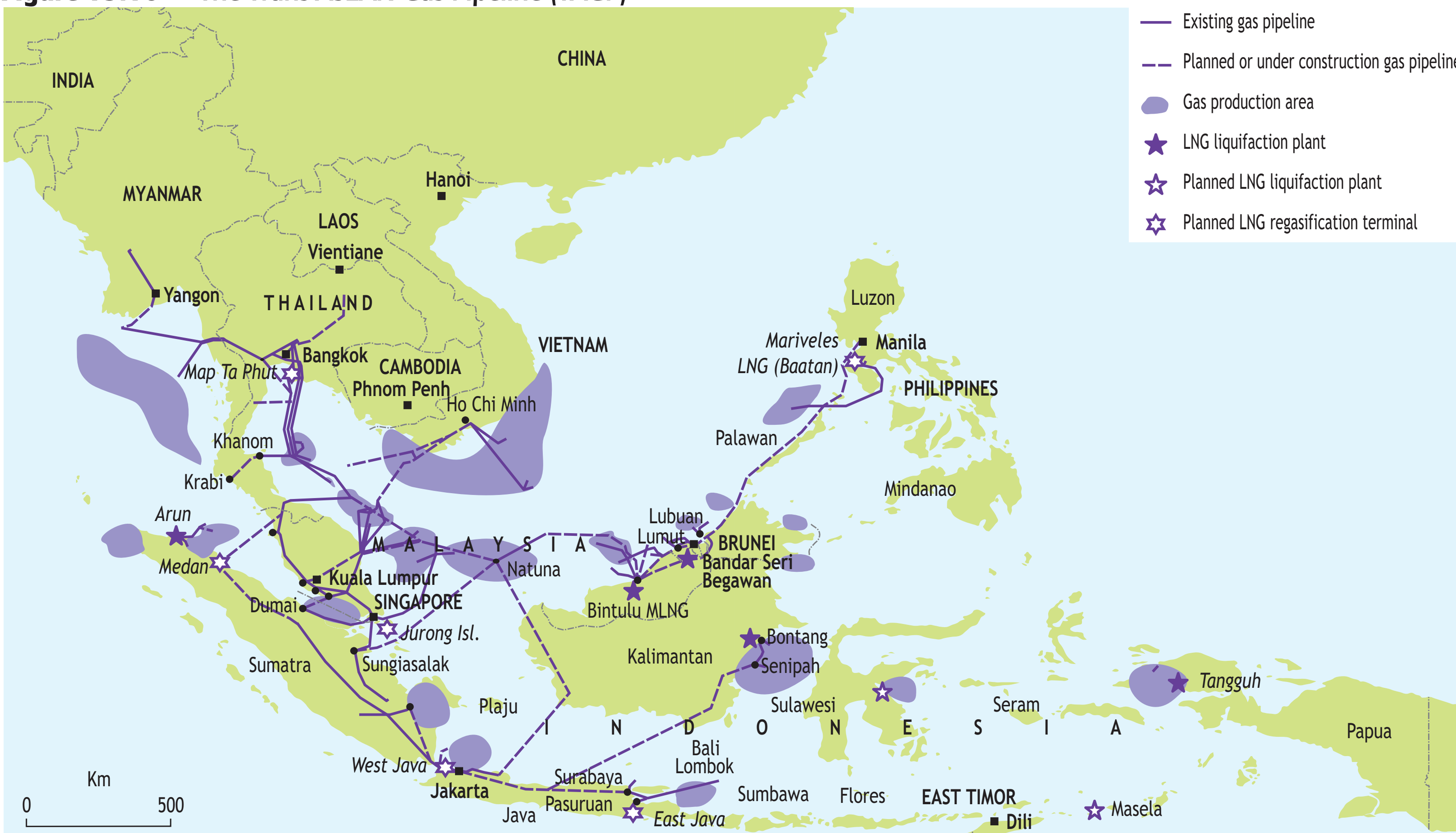
The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

Source: IEA.

IEA Medium Term Oil and Gas Markets 2010

ASEAN is working on Gas Pipeline System.

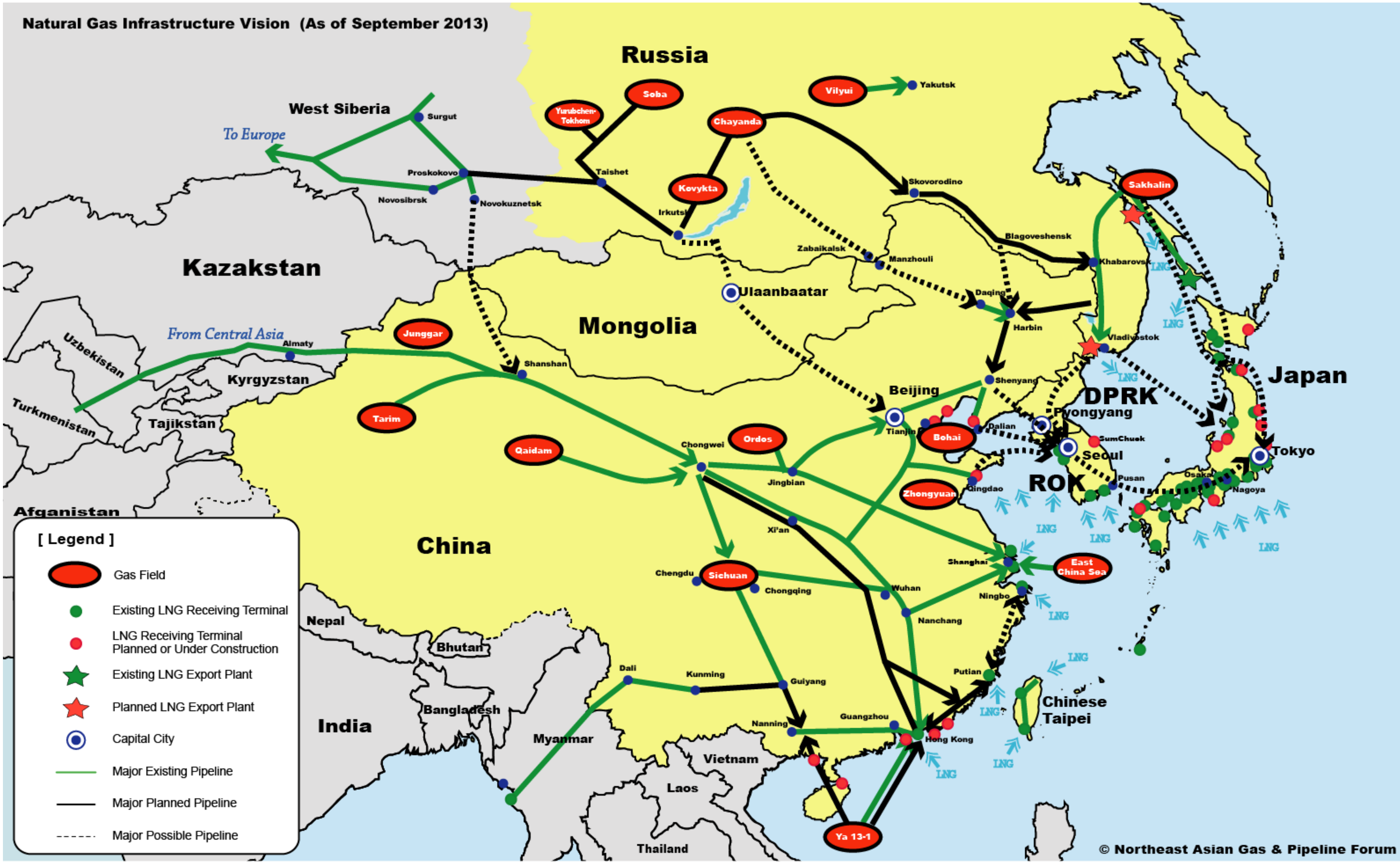
Figure 15.16 ● The Trans-ASEAN Gas Pipeline (TAGP)



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

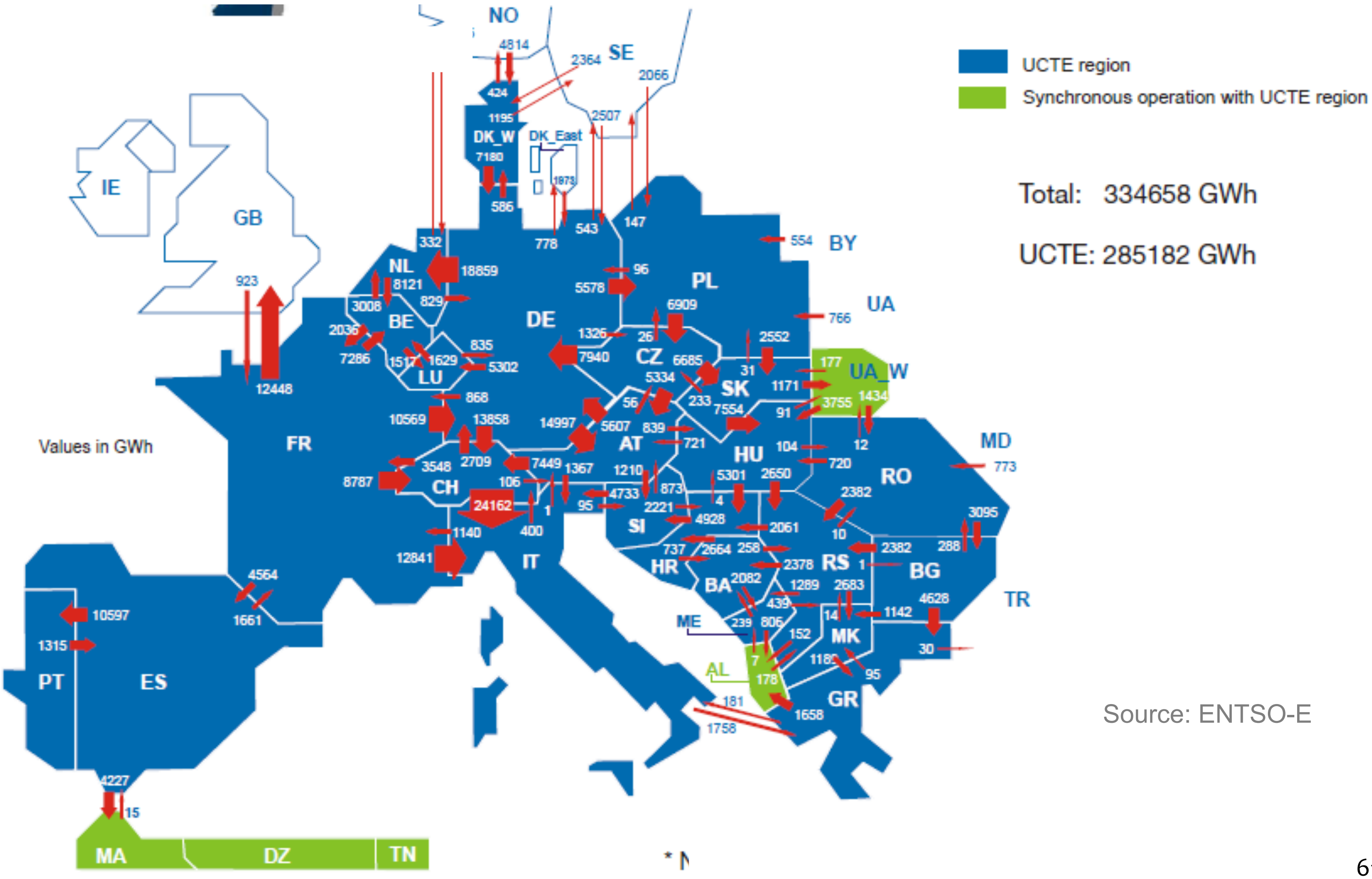
Source: ASCOPE Secretariat

Blue Print for North East Asia Gas & Pipeline Infrastructure



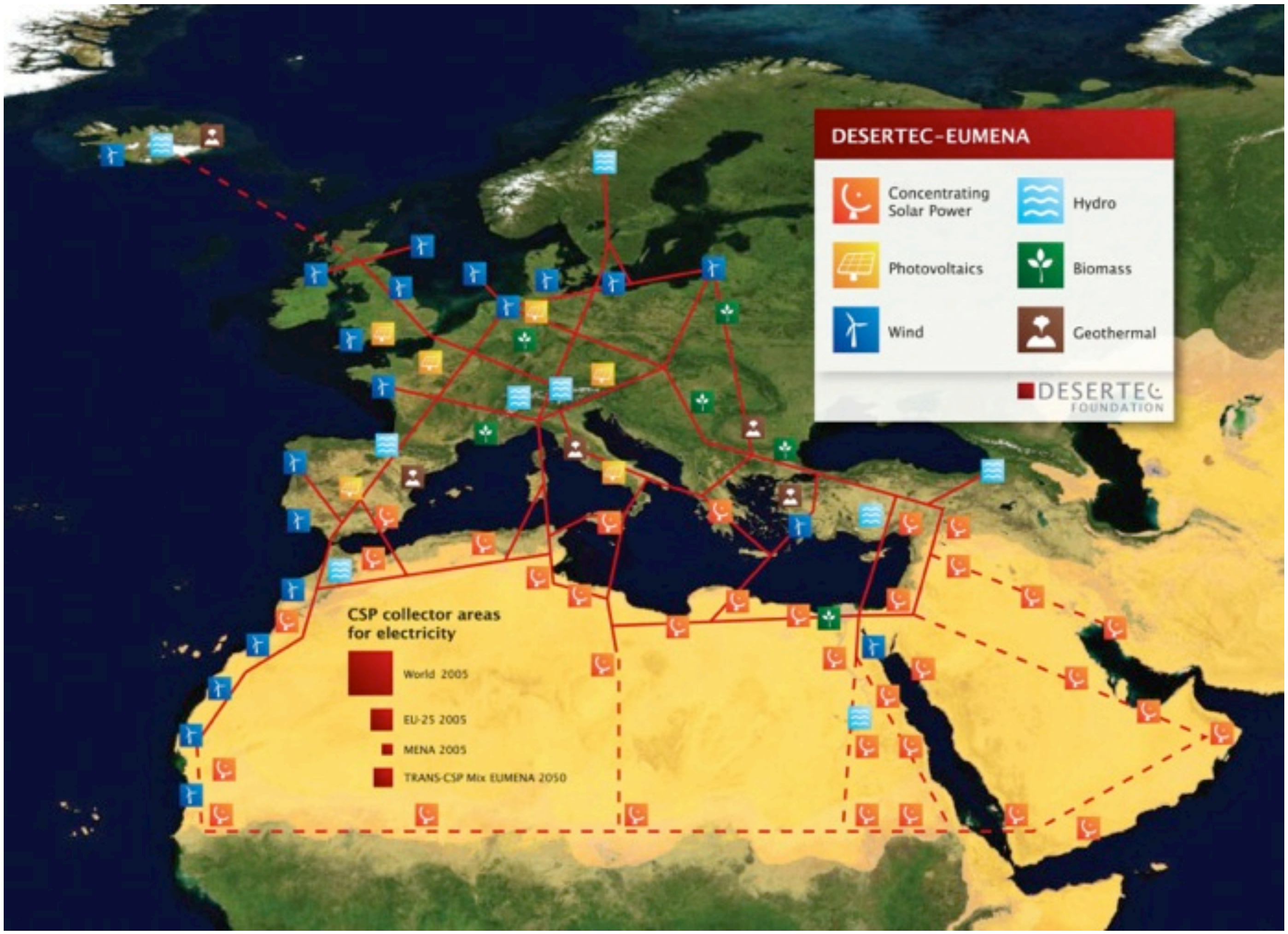
Power Grid Connection in Europe

Physical energy flows between European countries, 2008 (GWh)



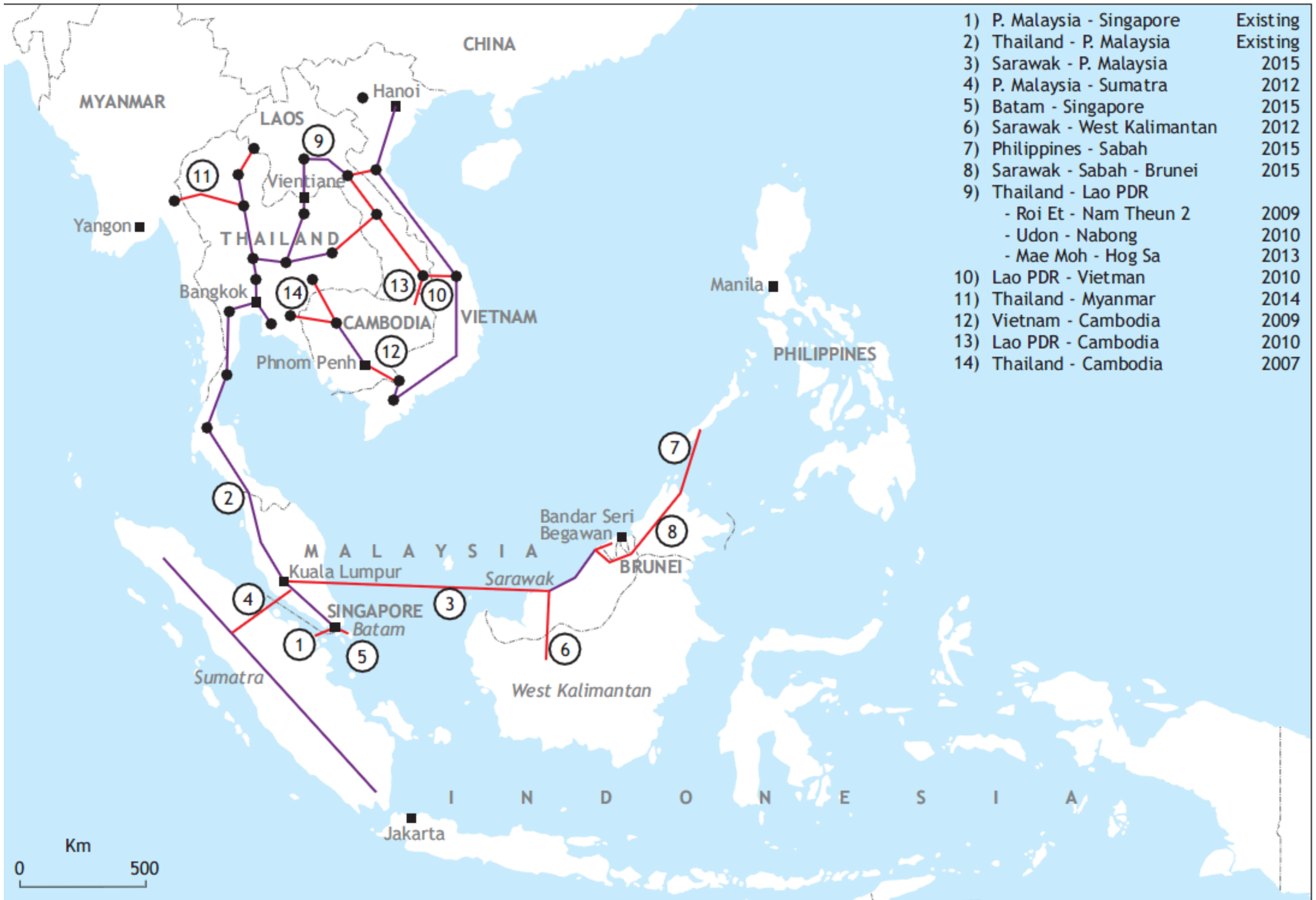
Source: ENTSO-E

Connecting MENA and Europe: " Desertec" as visionary “Energy for Peace"



Source: DESRETEC Foundation

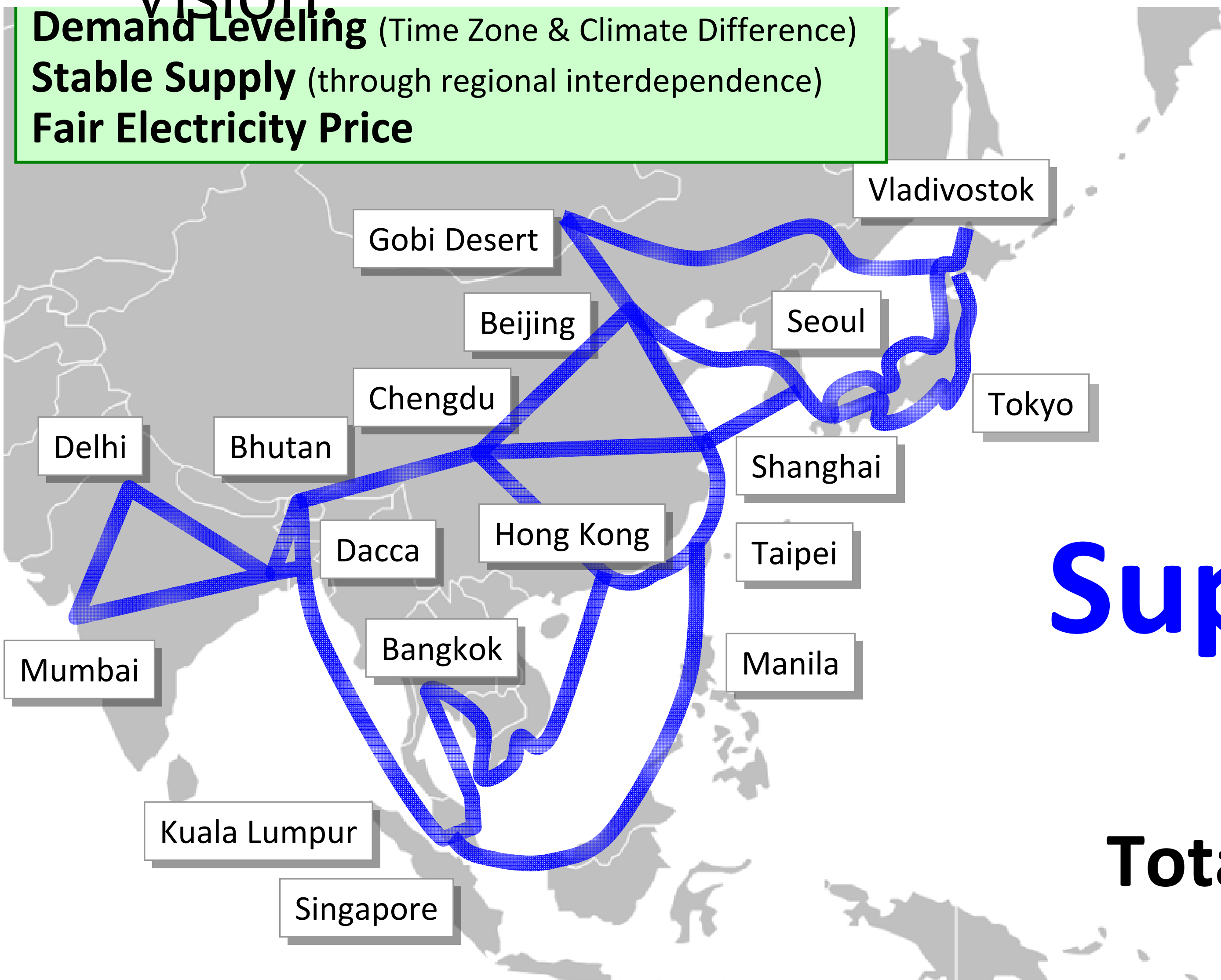
ASEAN power grid connection



The boundaries and names shown and the designations used on maps included in this publication do not imply official endorsement or acceptance by the IEA.

"Energy for Peace in Asia" New Vision?

Demand Leveling (Time Zone & Climate Difference)
Stable Supply (through regional interdependence)
Fair Electricity Price



Phase 3

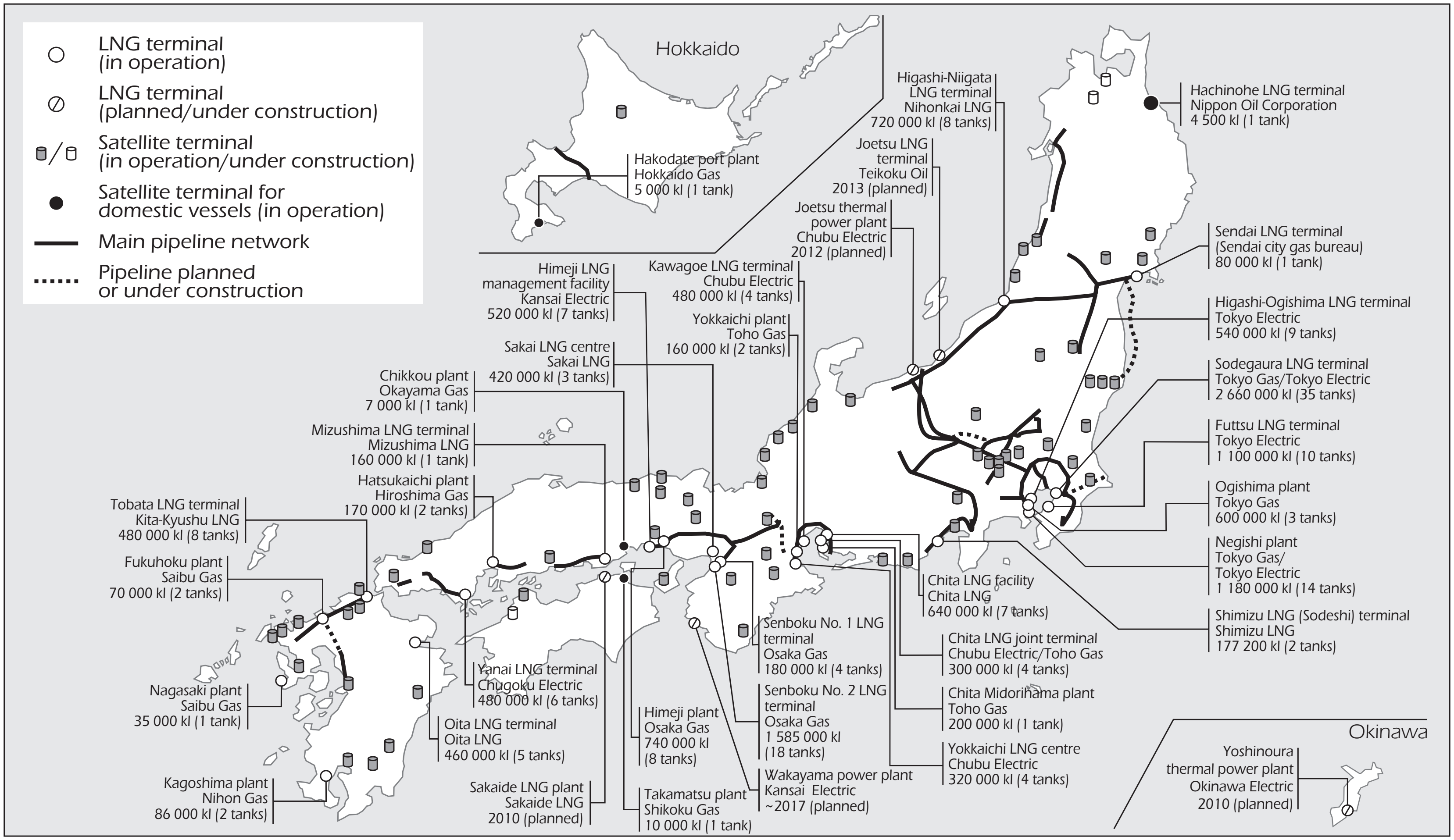
Asia Super Grid

Total 36,000km

Presentation by Mr. Masayoshi SON

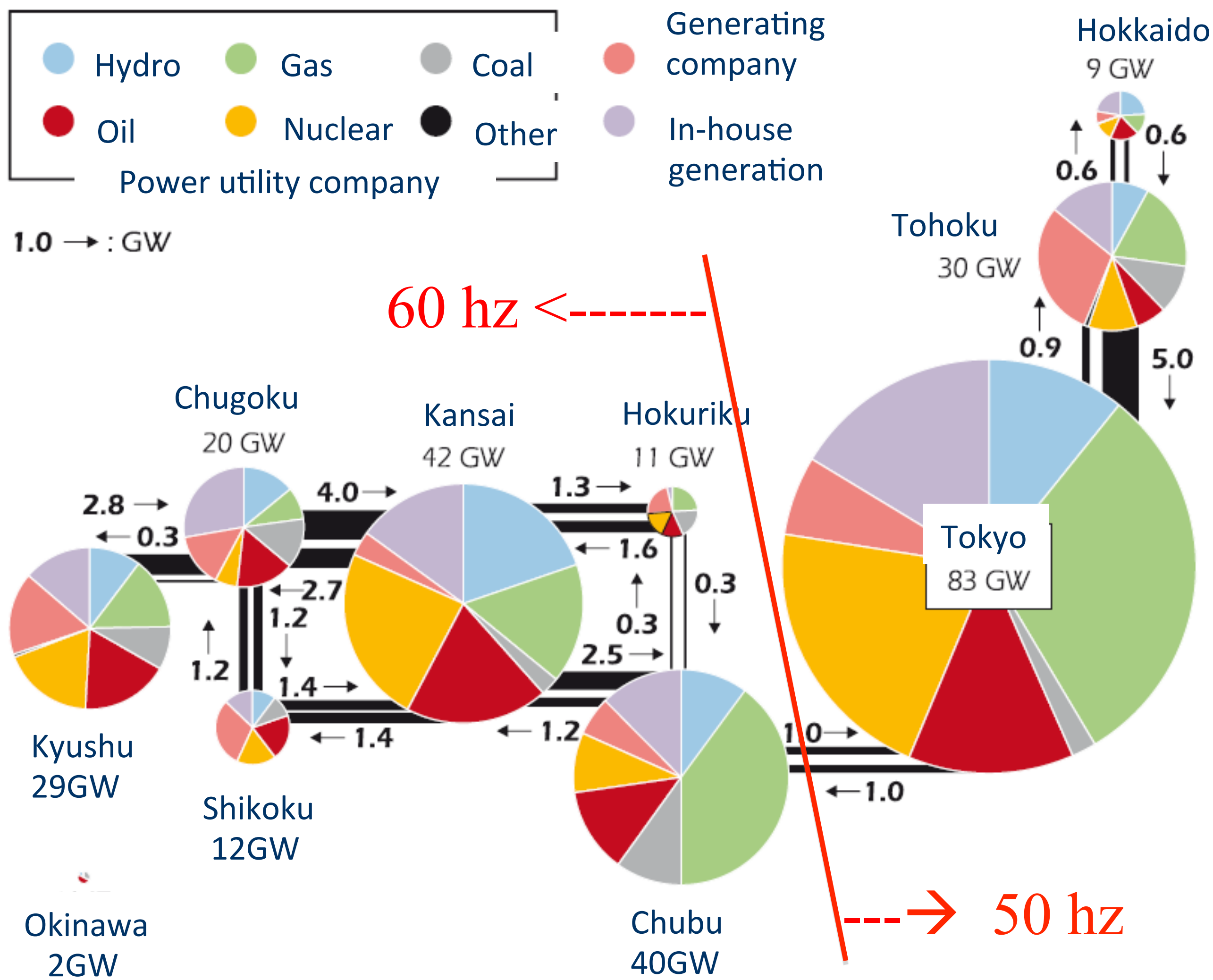
Japan’s Pipeline network

Map of the Japanese Gas Grid



Note: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the IEA.
Source: Country submission (compiled by ANRE from data provided by relevant companies).

Power grid in Japan



Source: Agency for Natural Resources and Energy, The Federation of Electric Power Companies of Japan, Electric Power System Council of Japan, The International Energy Agency

Conclusions

Comprehensive Energy Security and Sustainability

- Urgent need for restarting nuclear power plants. Prepare scenarios for Iranian Crisis.
- Nuclear Power will continue to play a major role in the world. Japan's role after Fukushima is to share the lessons learned for safer Nuclear Power deployment in Asia and elsewhere. (ex. rejection of B5b implementation) International collaboration on Integral Fast Reactor, Fuel cycle technology development at Fukushima.
- Energy Security for the 21st Century must be Collective and Comprehensive Electricity Supply Security under sustainability constraints. EU`s connectivity approach can be a model especially for Asia. Domestic reform issues of power market: 50-60 hrz problem, FIT reform, unbundling of utilities, international grid connection with Korea and Russia.
- Golden Age of Natural Gas will come with golden rules including sustainability requirements and a new pricing formula. Russia remains as a key player with pipelines and LNG facilities. LNG exports from North America including Alaska may be a game-changer.
- New technologies help; Hydrogen economy, Methane-hydrate , Super-conductivity grid., EVs, Smart Grids, Storage, CCS, Solar PV etc. .
- China and India should join the IEA. Need for the North East Asian Energy Security Forum

Thank you for your attention

エネルギーフォーラム社