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Global Energy Perspectives: the Role of Nuclear Energy

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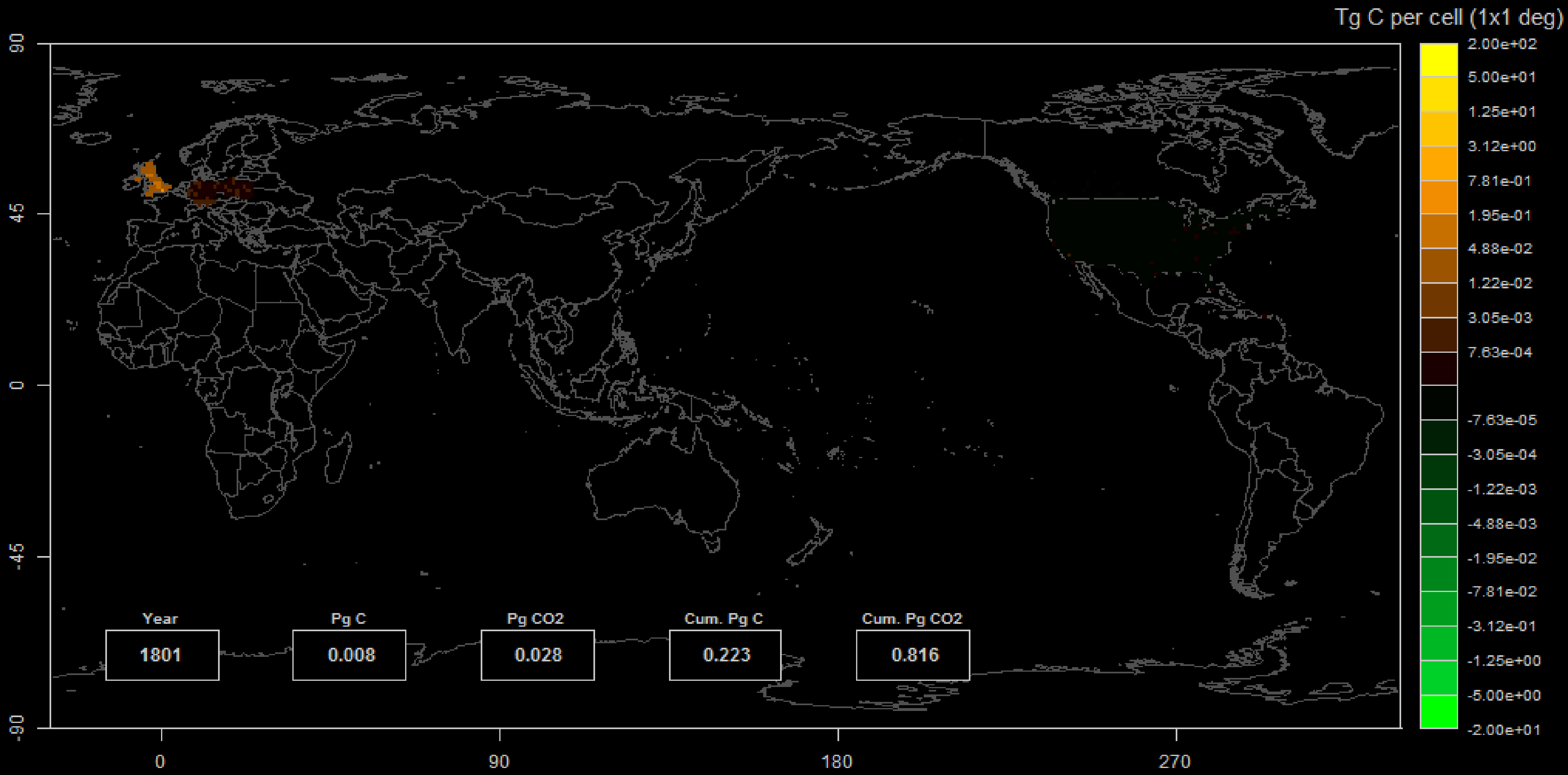
International Institute for Applied Systems Analysis (IIASA)

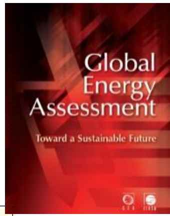
- **International, independent, interdisciplinary science**
- **Research & big-data on major global problems**
- **Solution & policy oriented, integrated systems analysis**

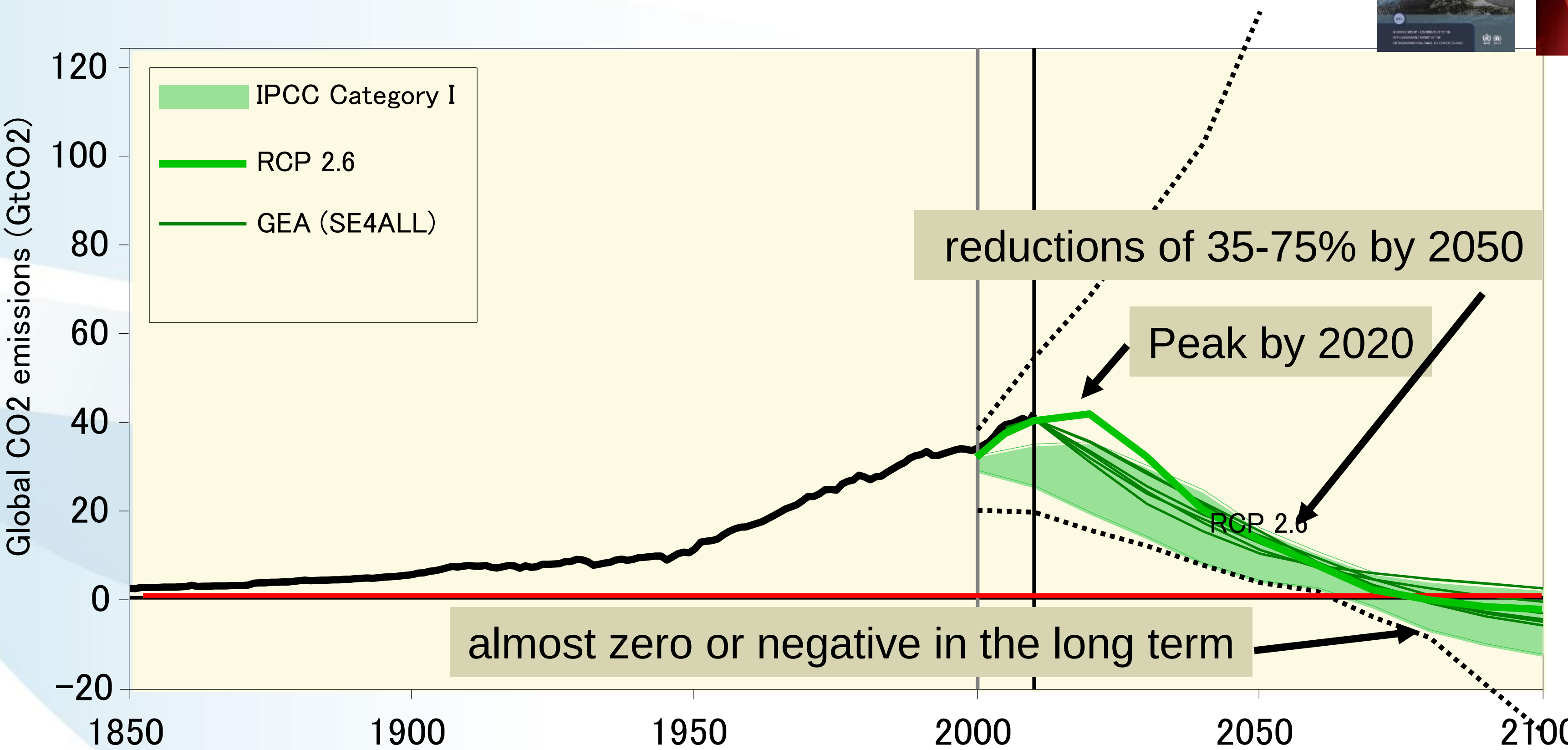
Global mean temperature increase

Global CO_2 Emissions



Global CO2 Emissions





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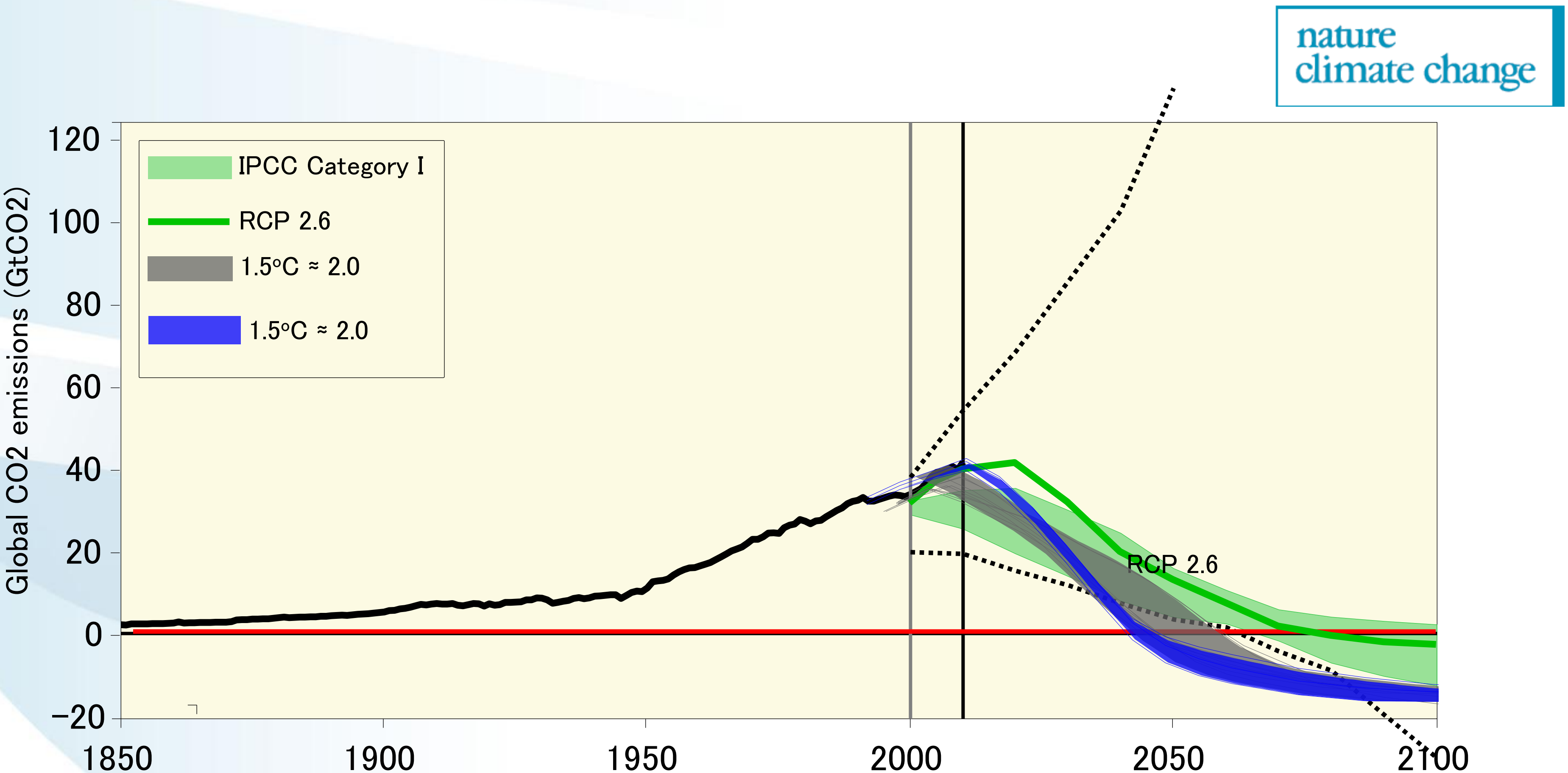


The Key Energy Challenges

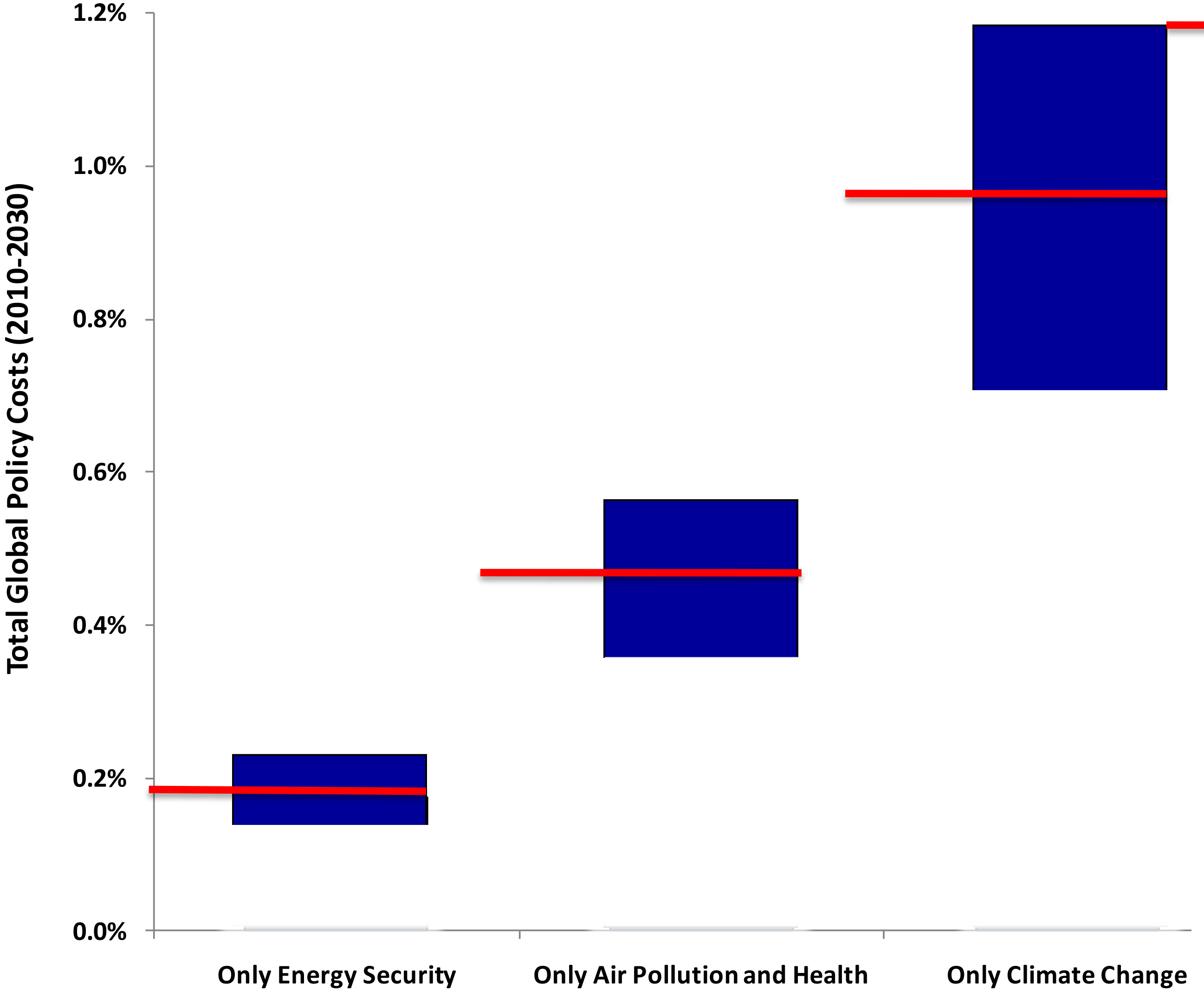
Energy Access

Climate Change

Energy Security

Air Pollution
Health Impacts

Multiple Benefits of Integrated Policies



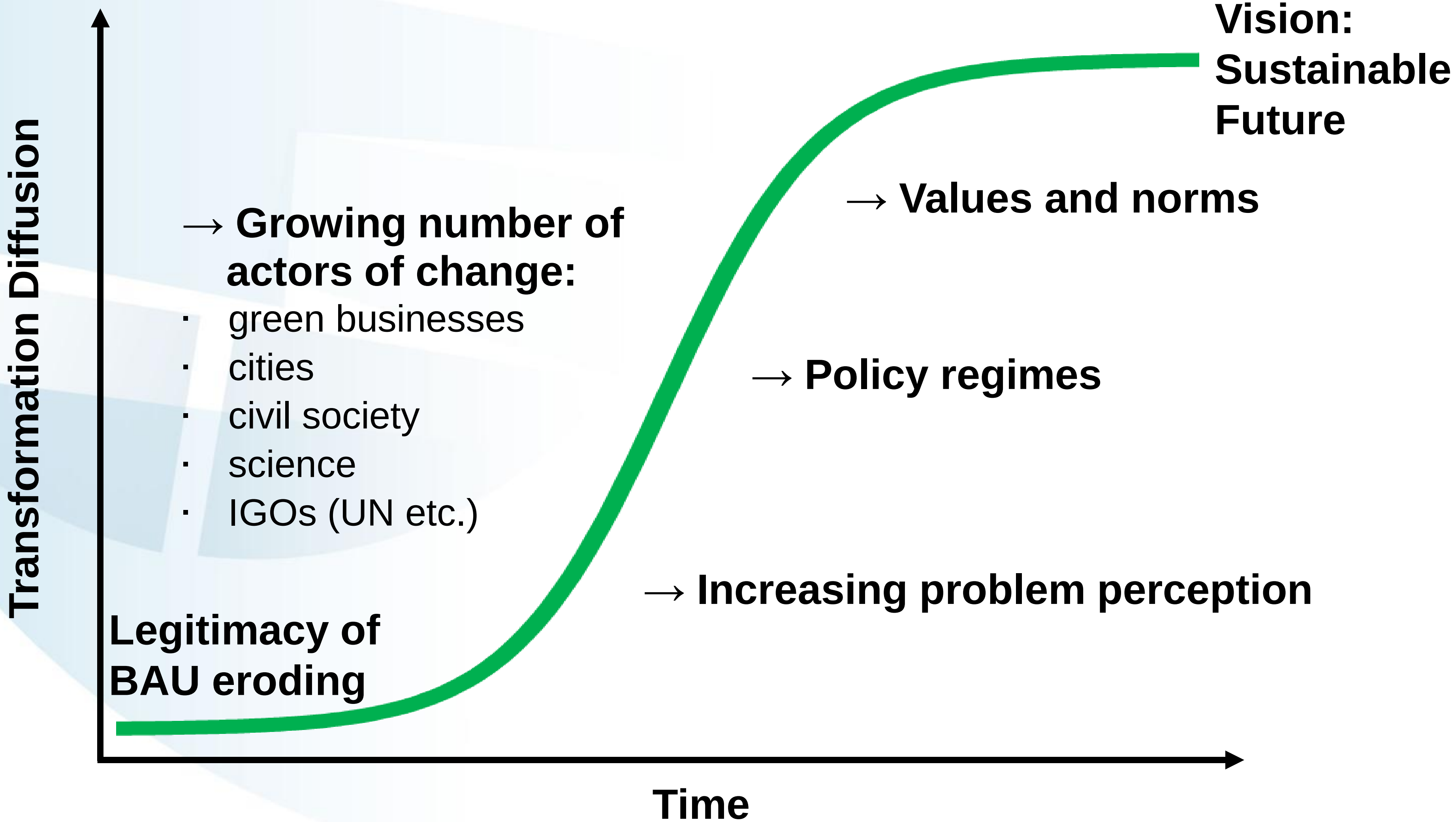

SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

The World in 2050 (TWI2050)

- How to achieve global development within a safe and just operating space
- "Safe space" of interaction among SDGs: sustainability narratives and integrated models
- Sustainable Development Pathway based on existing literature e.g. SSP1, GEA, DDPP
- Multiple-benefits and tradeoffs of transformation toward the "safe space" and how to achieve sustainable futures

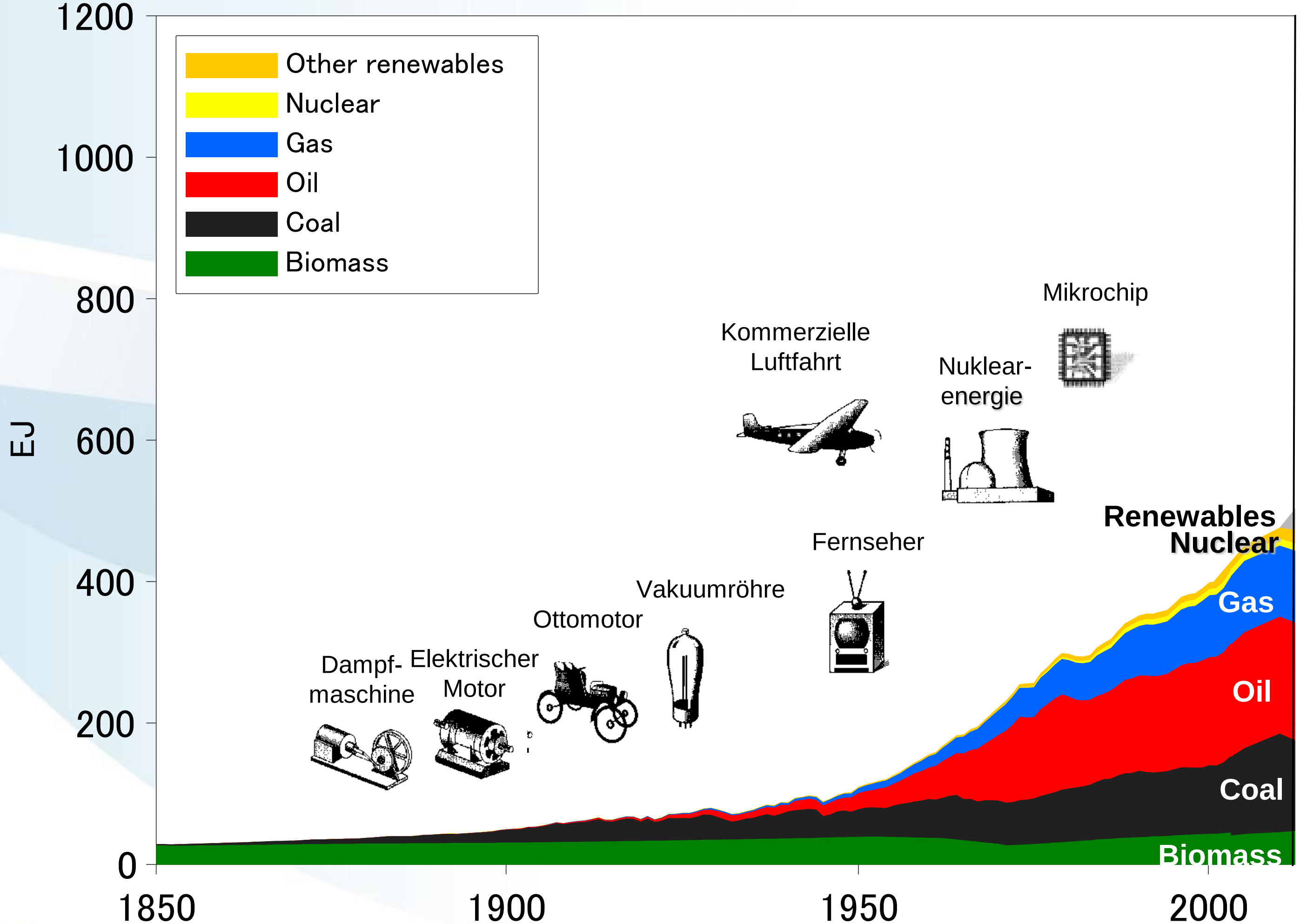
Sustainability Transformation

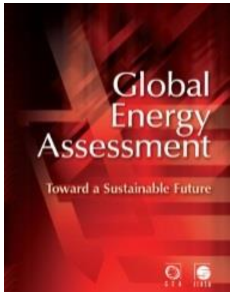
"Doing More with Less" within Planetary Boundaries



Global Primary Energy

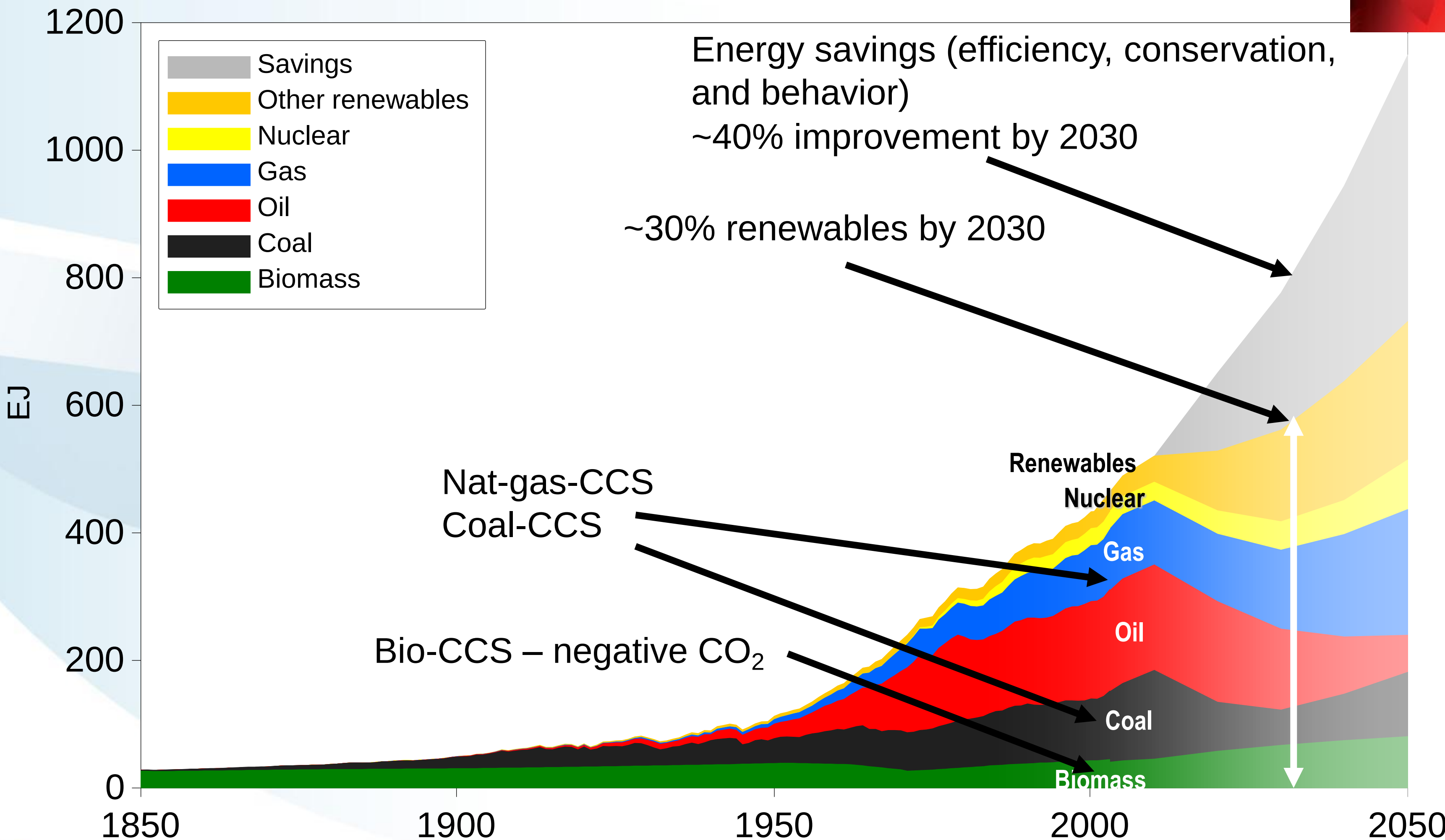
Historical Evolution

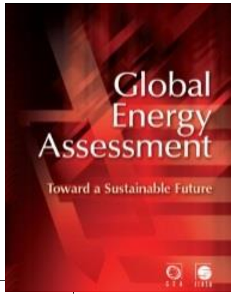




Asia-Pacific Primary Energy

A Transformational Pathway (I)





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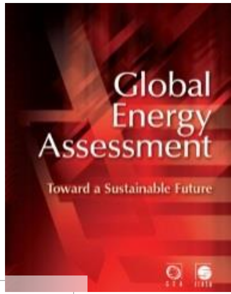
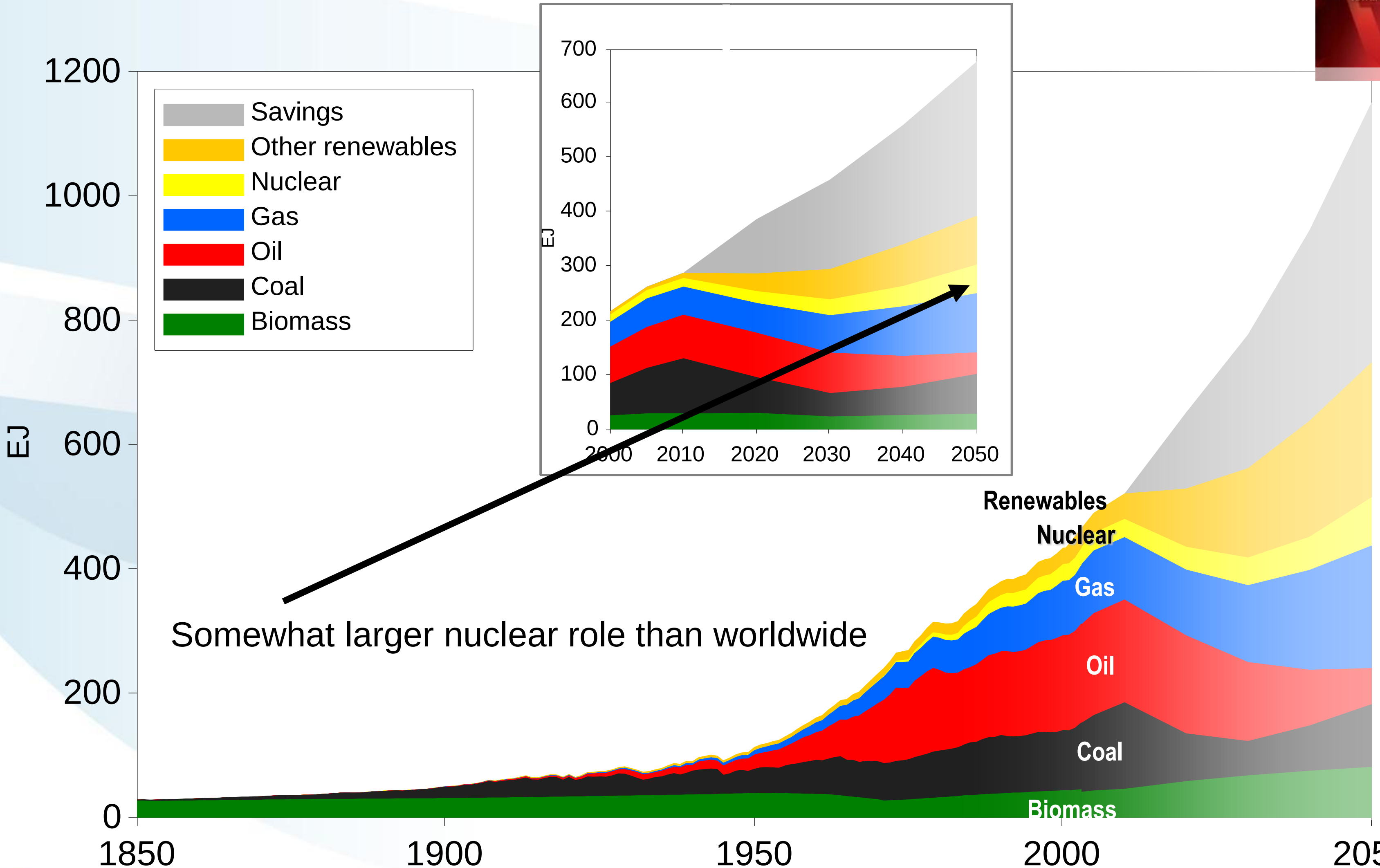
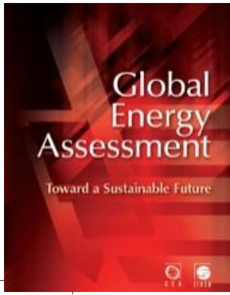
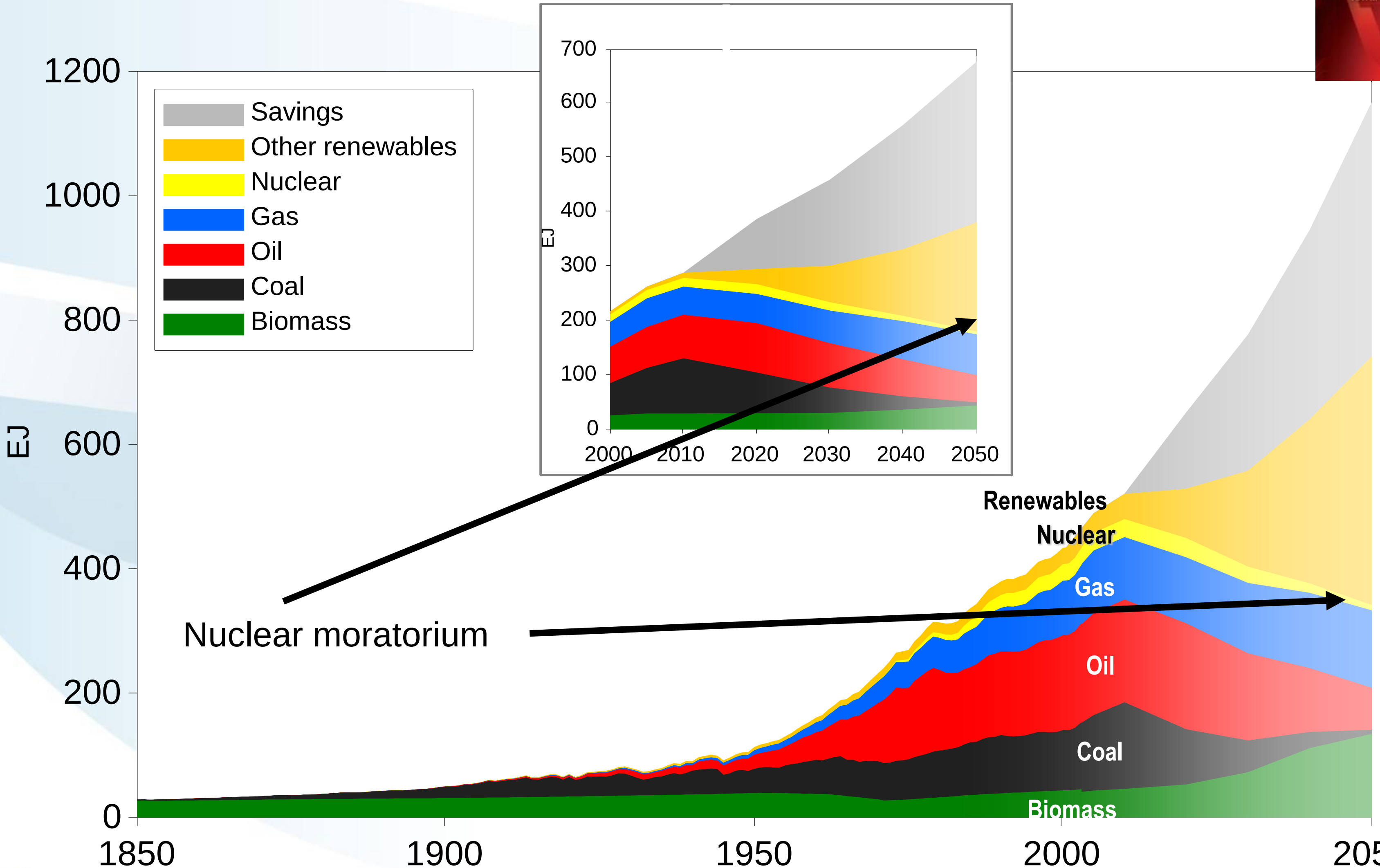




Asia-Pacific Primary Energy

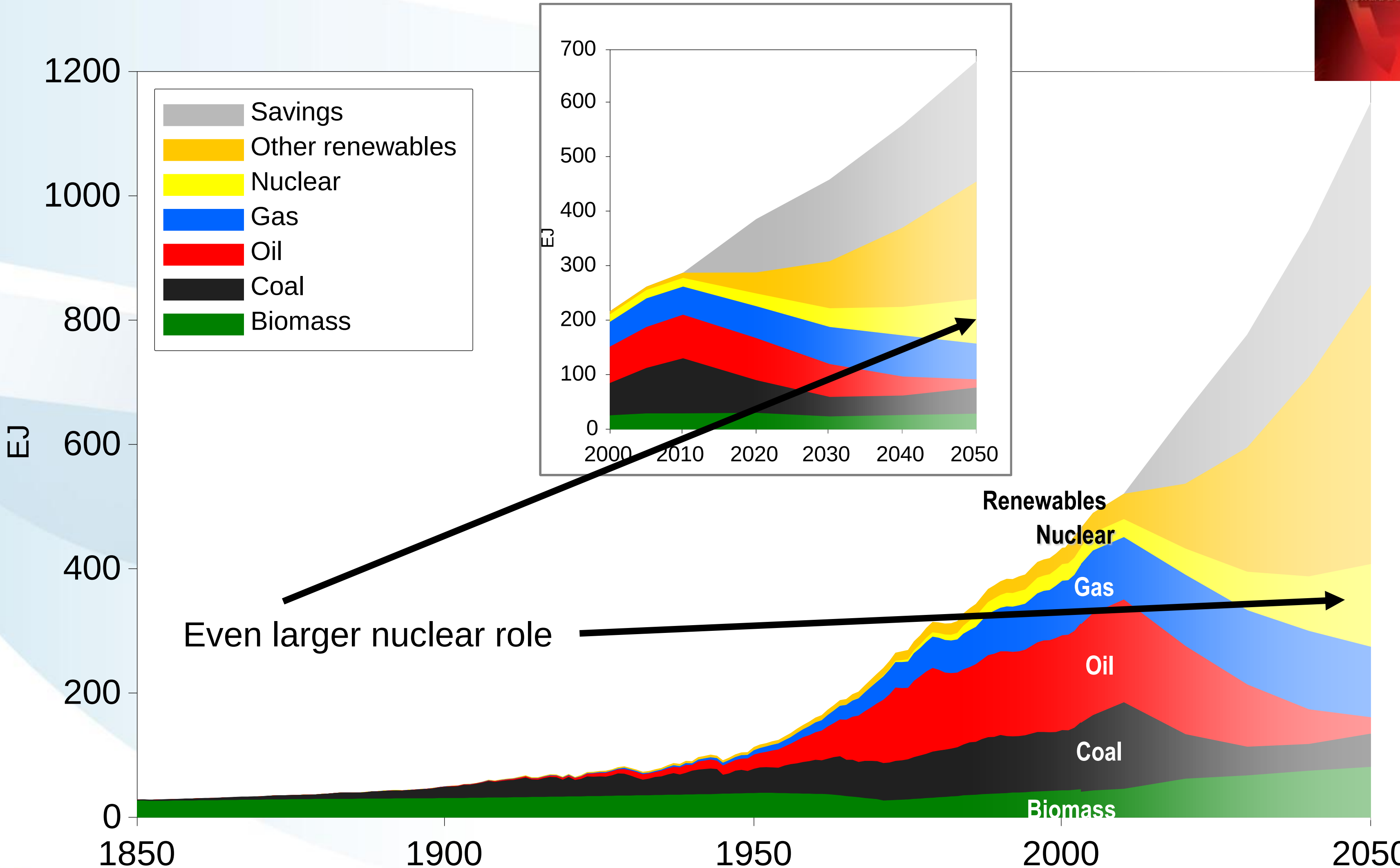
A Transformational Pathway (II)

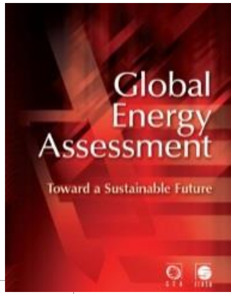




Asia-Pacific Primary Energy

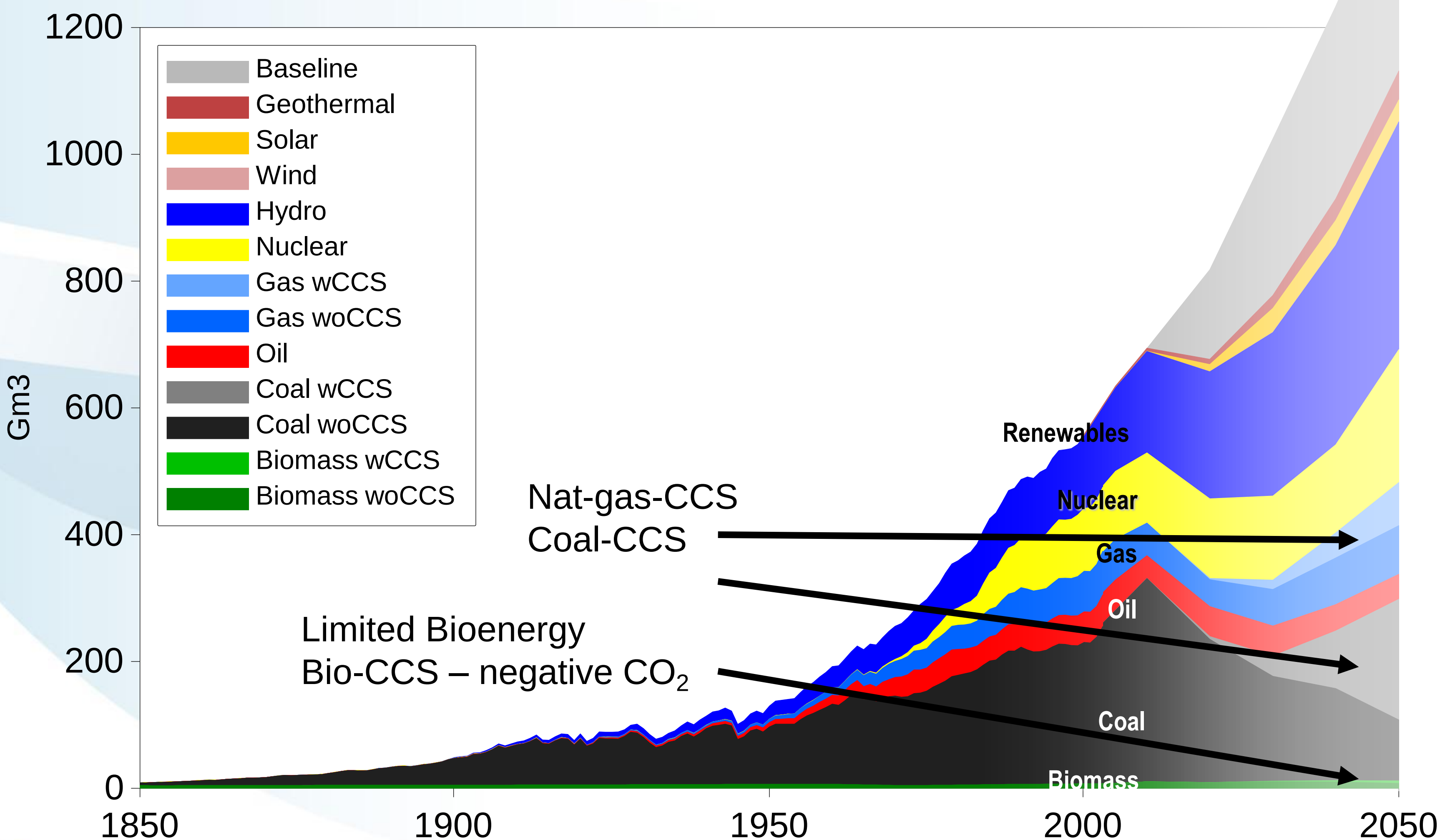
A Transformational Pathway (III)





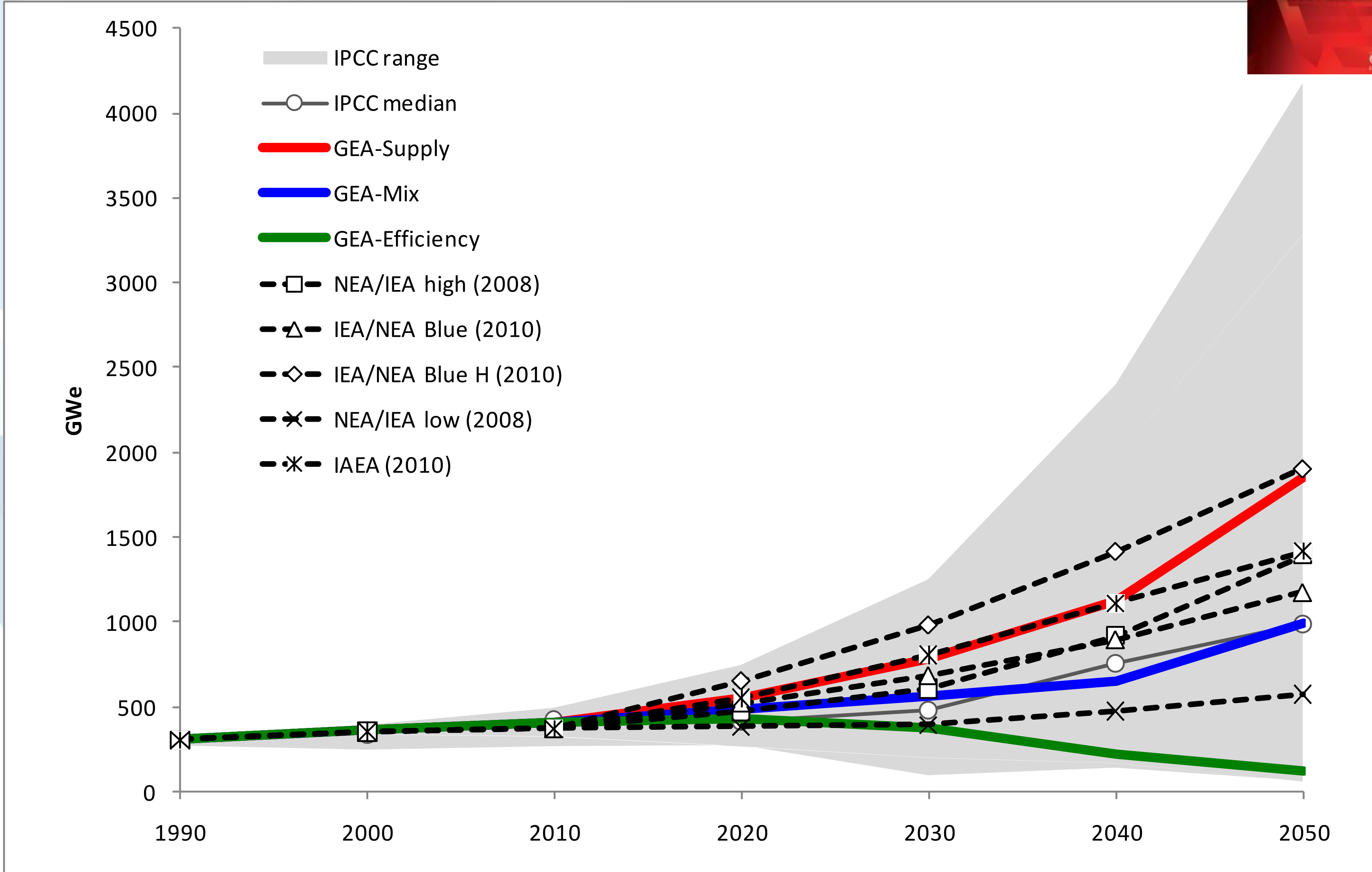
Global Water Withdrawals

A Pathway with Full Portfolio



Nuclear in GEA pathway

Global Energy Assessment
Toward a Sustainable Future



Four stages of nuclear development

			Construction starts		Grid connections	
	Stage	Period	Reactors per year	MW per year	Reactors per year	MW per year
1	Early growth	1954-1965	7.4	1,332	4.2	432
2						
3						
4						
5						

Four stages of nuclear development

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4	Rising expectations	2005-2010	8.8	8,722	2.7	1,996
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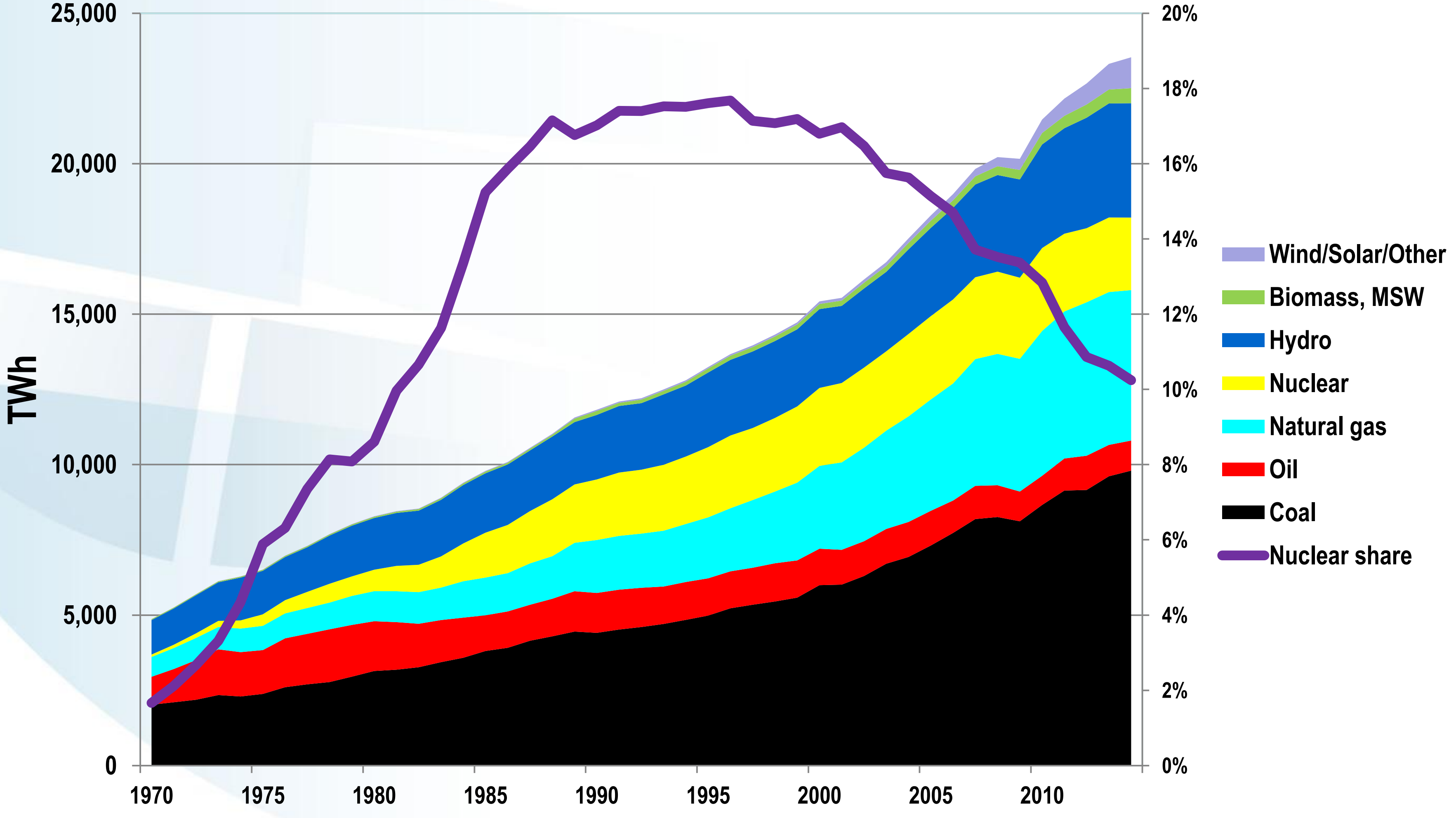
4	Rising expectations	2005-2010	8.8	8,722	2.7	1,996
5	Post Fukushima	2011-	6.2	6,014	5.7	5,279

Nuclear power before Fukushima

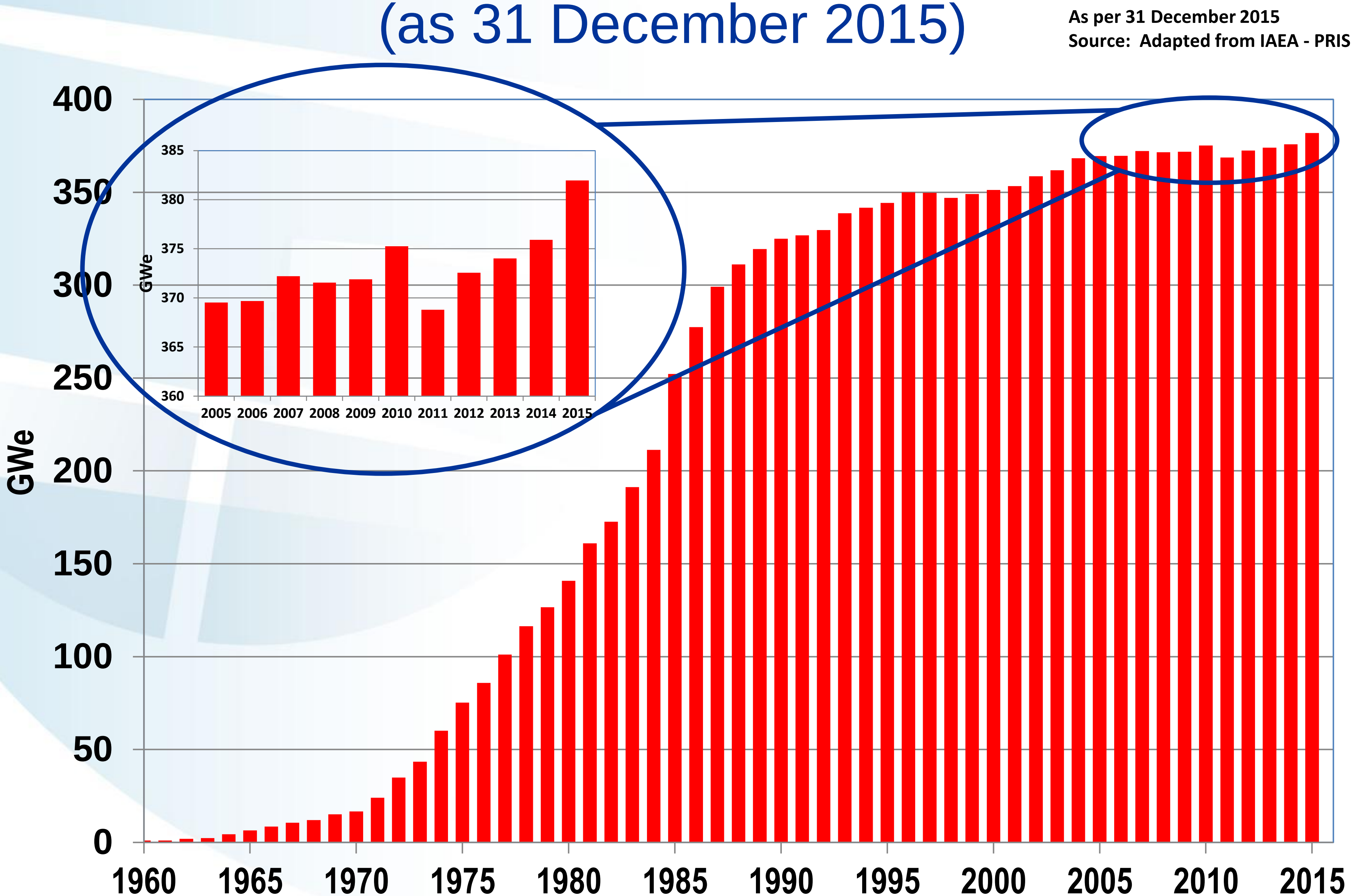
- Dramatic improvement in operating performance between 1990 and 2005
- Higher capacity factors
- Power up-rates
- Licence extensions
- Market in “used” reactors
- “Money printing” machines

- Previous “hopes/fears” that NPPs would be victims of electricity liberalization have not materialized!
- Market liberalization proved difficult for new NPPs

Global electricity and the nuclear share

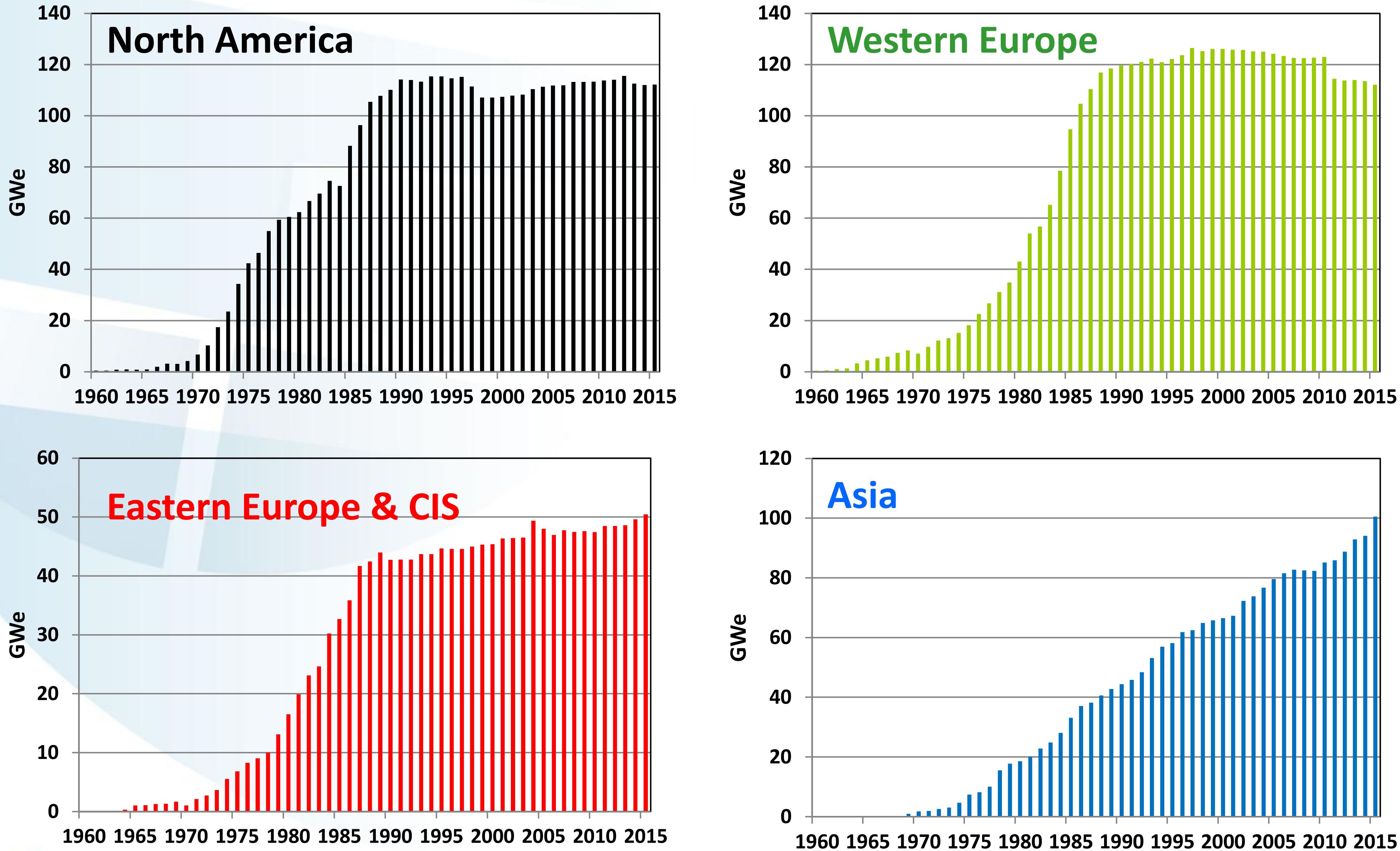


Global nuclear power generating capacity (as 31 December 2015)



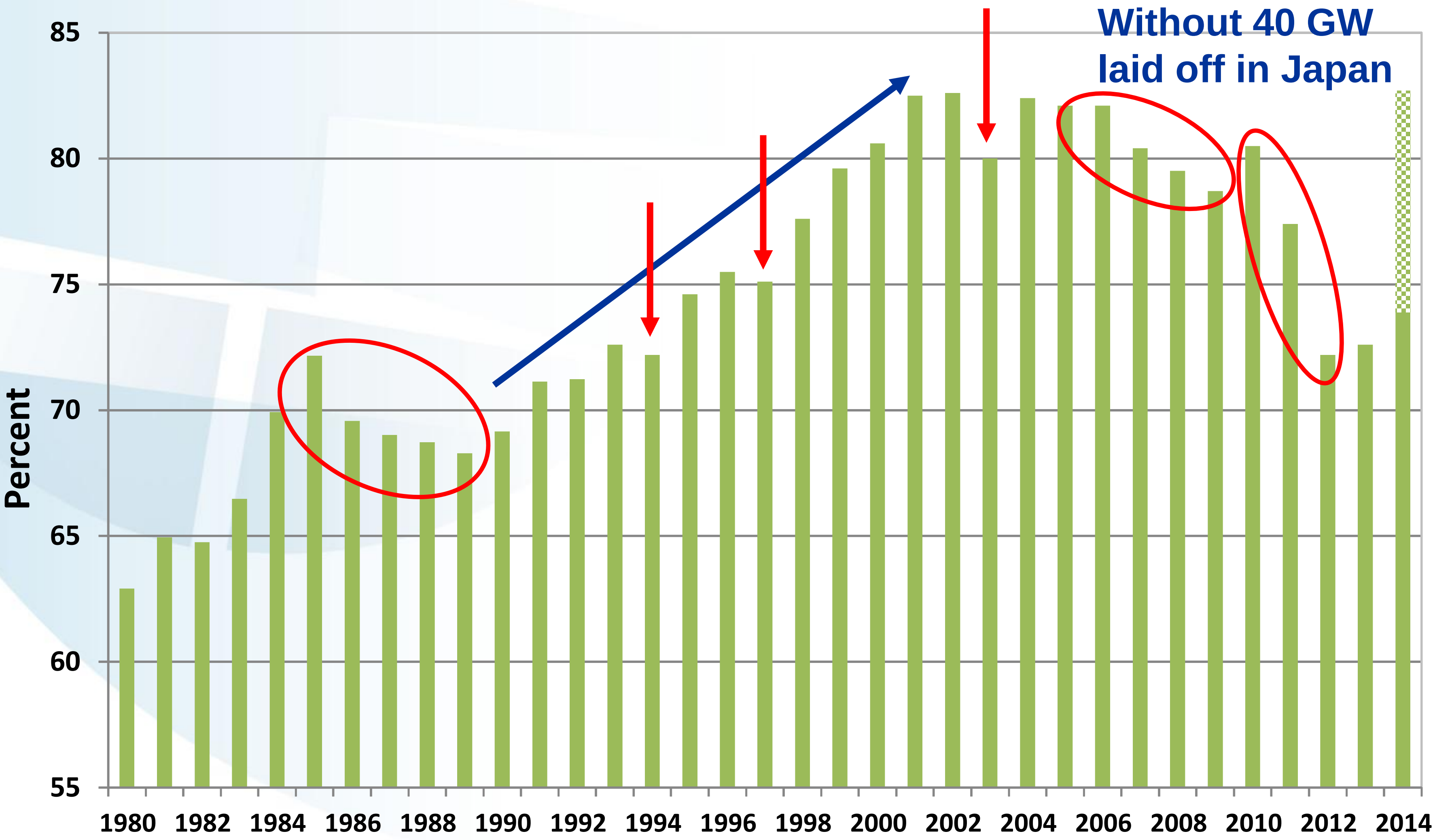
Regional nuclear generating capacities

As per 31 December 2015
Source: Adapted from IAEA - PRIS



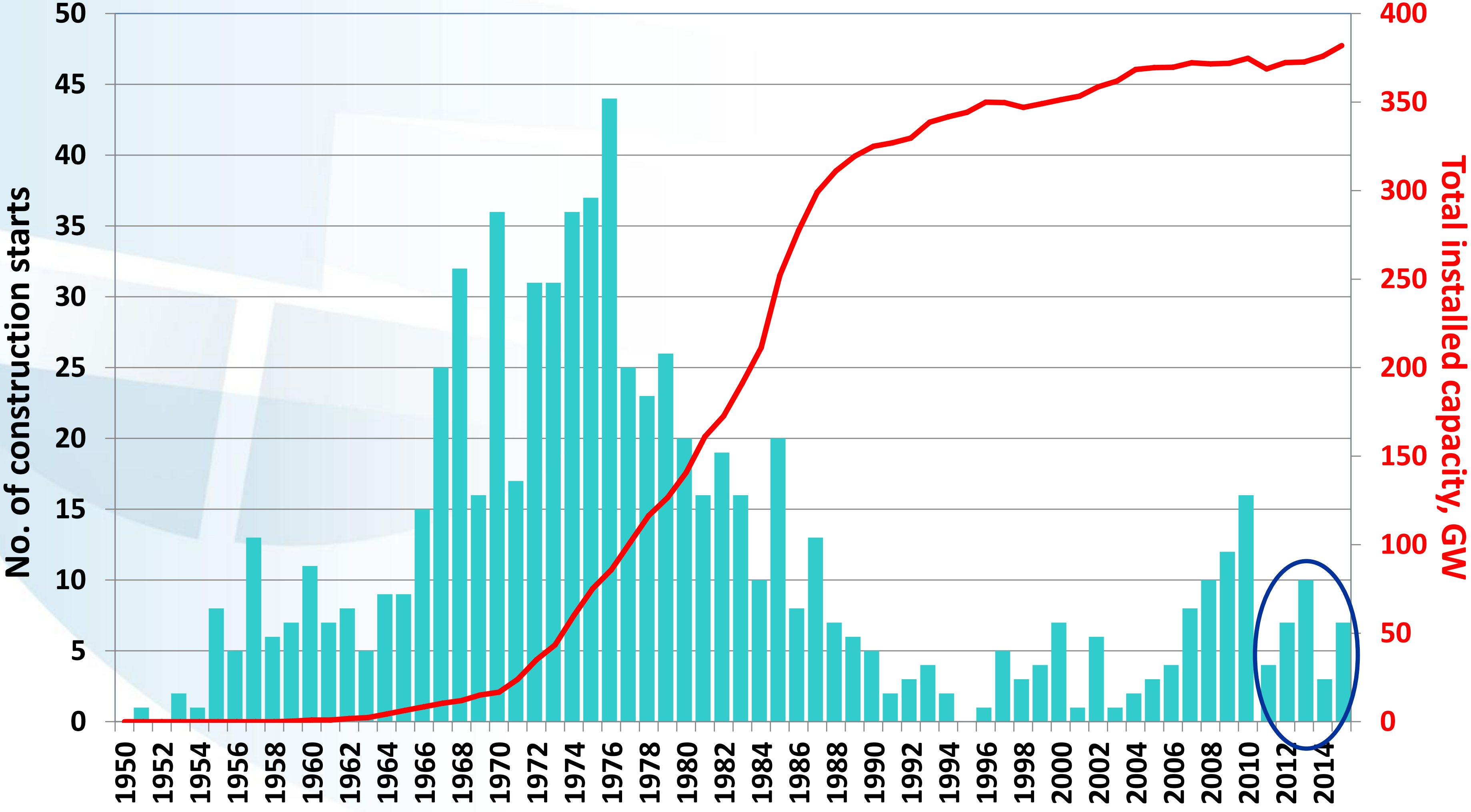
Load factor: Global fleet of nuclear reactors

1990 – 2000: Performance improvements correspond to a virtual construction of 34 NPPs of 1,000 MW each

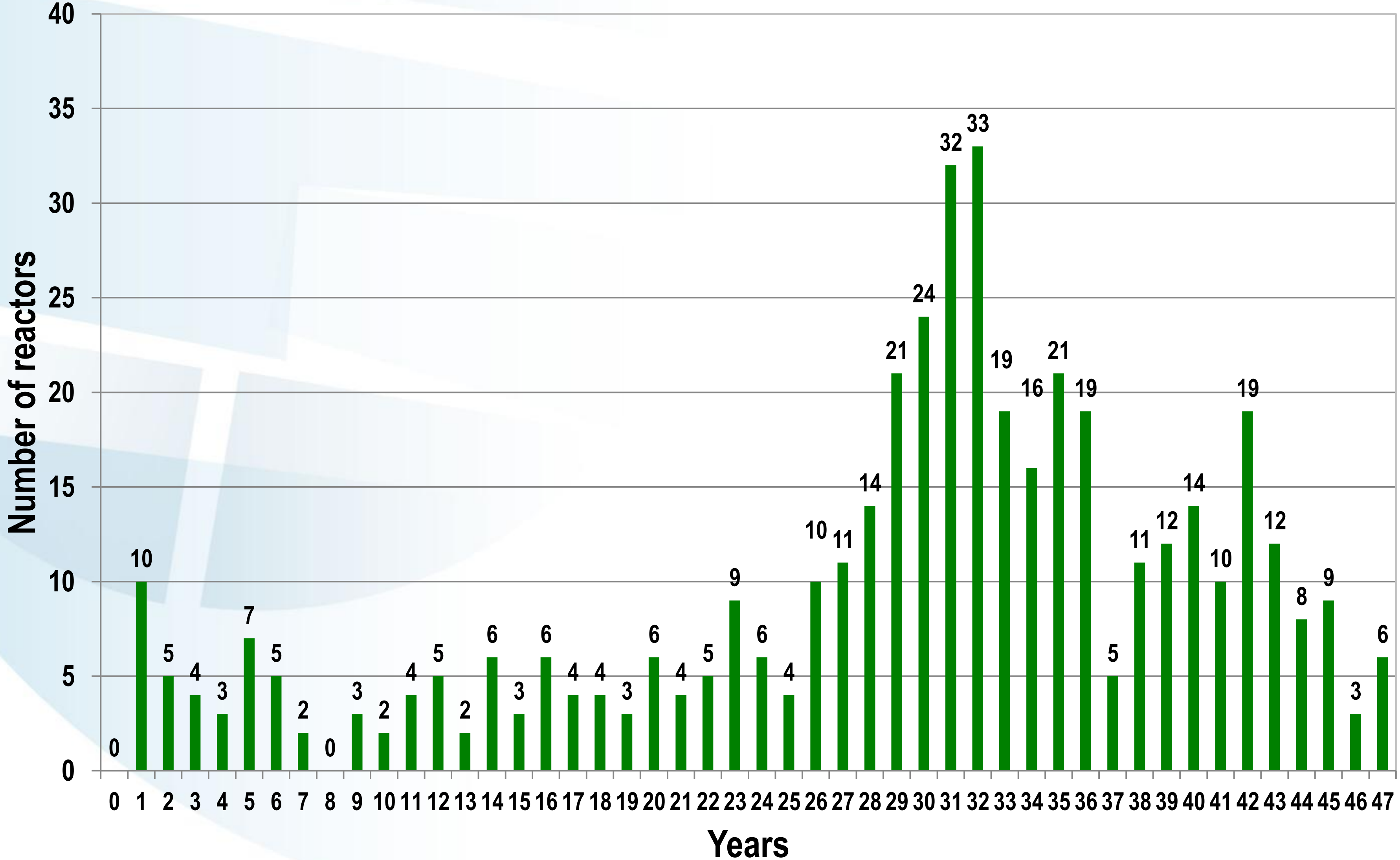


Construction starts 1950 to 2015

As per 31 December 2015
Source: Adapted from IAEA - PRIS



Age structure of nuclear power plants

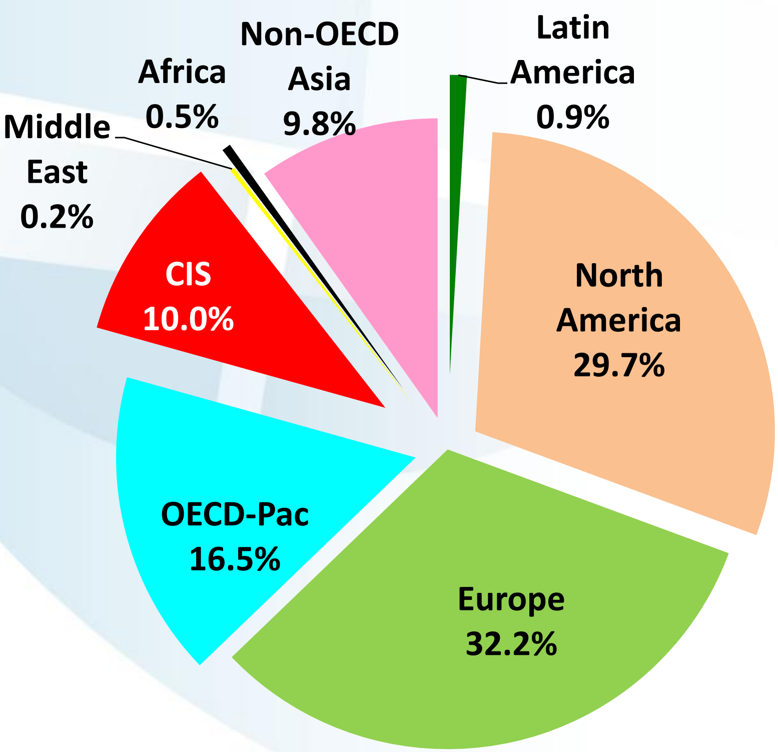


Note: Age of reactor is determined by its first grid connection. Reactors connected in current year are assigned with the age 0 years.

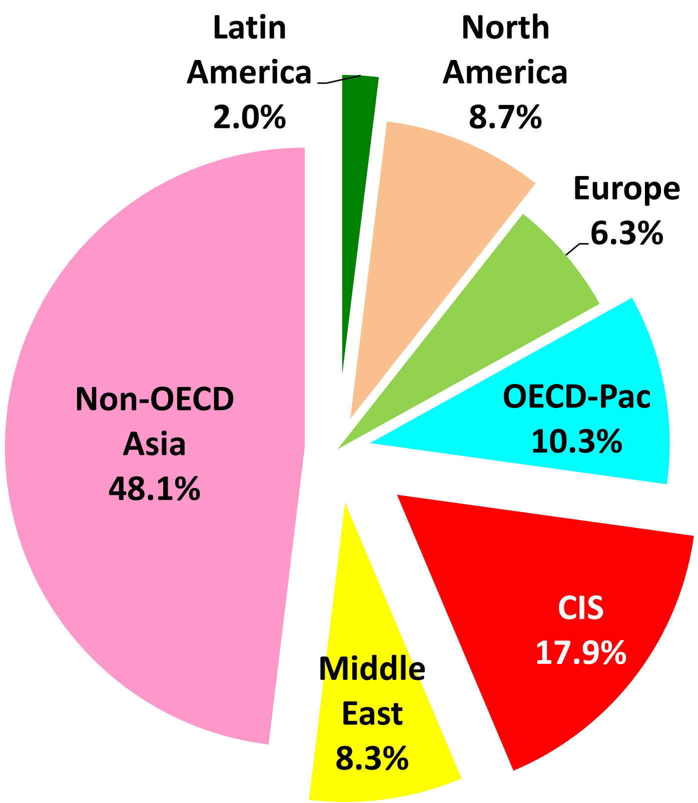
Status global nuclear power

As per 29 March 2016
Source: Adapted from IAEA - PRIS

Units in Operation: 442
384.2 GWe



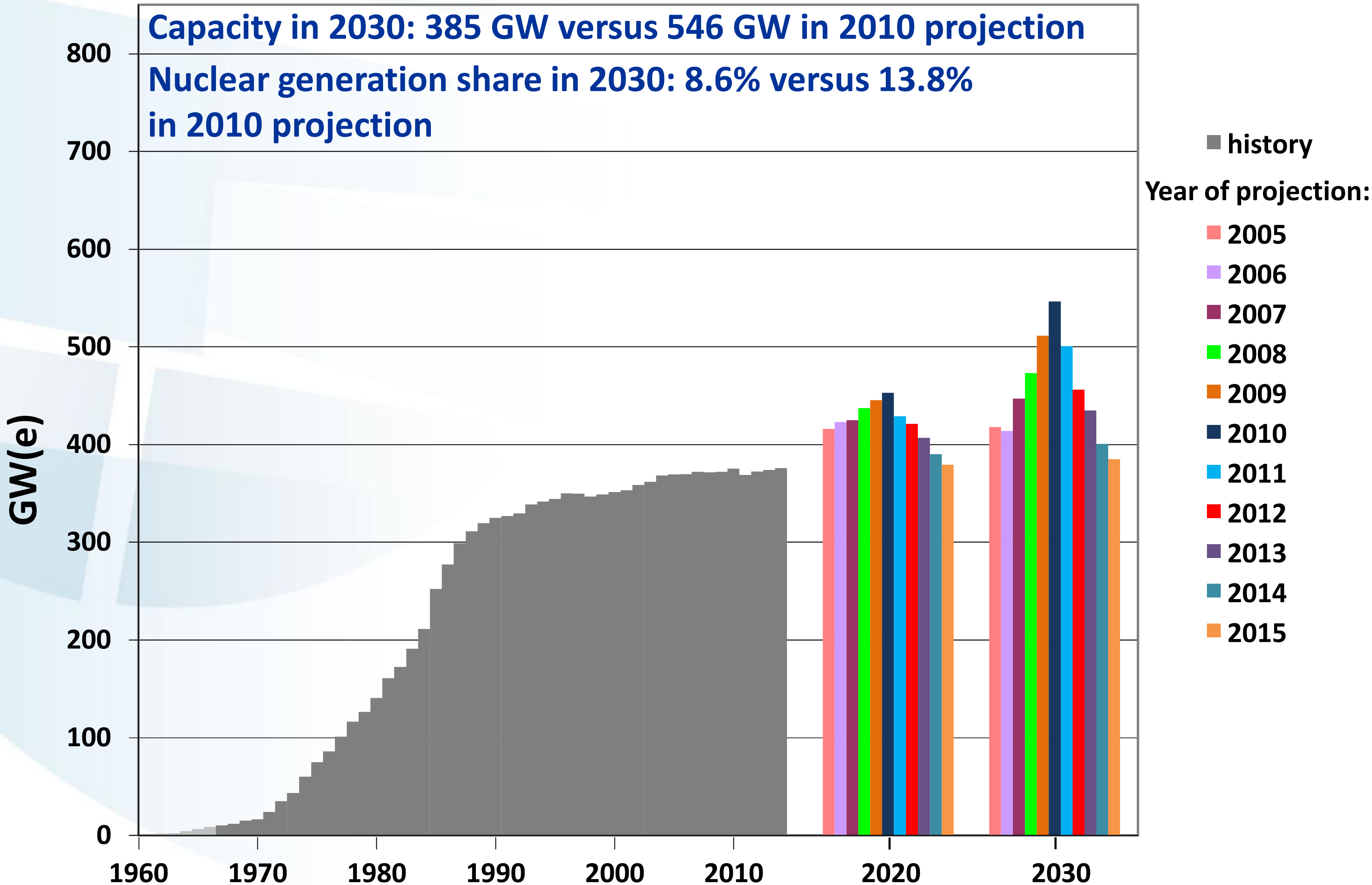
Units under construction: 66
65.0 GWe



Naval Reactors

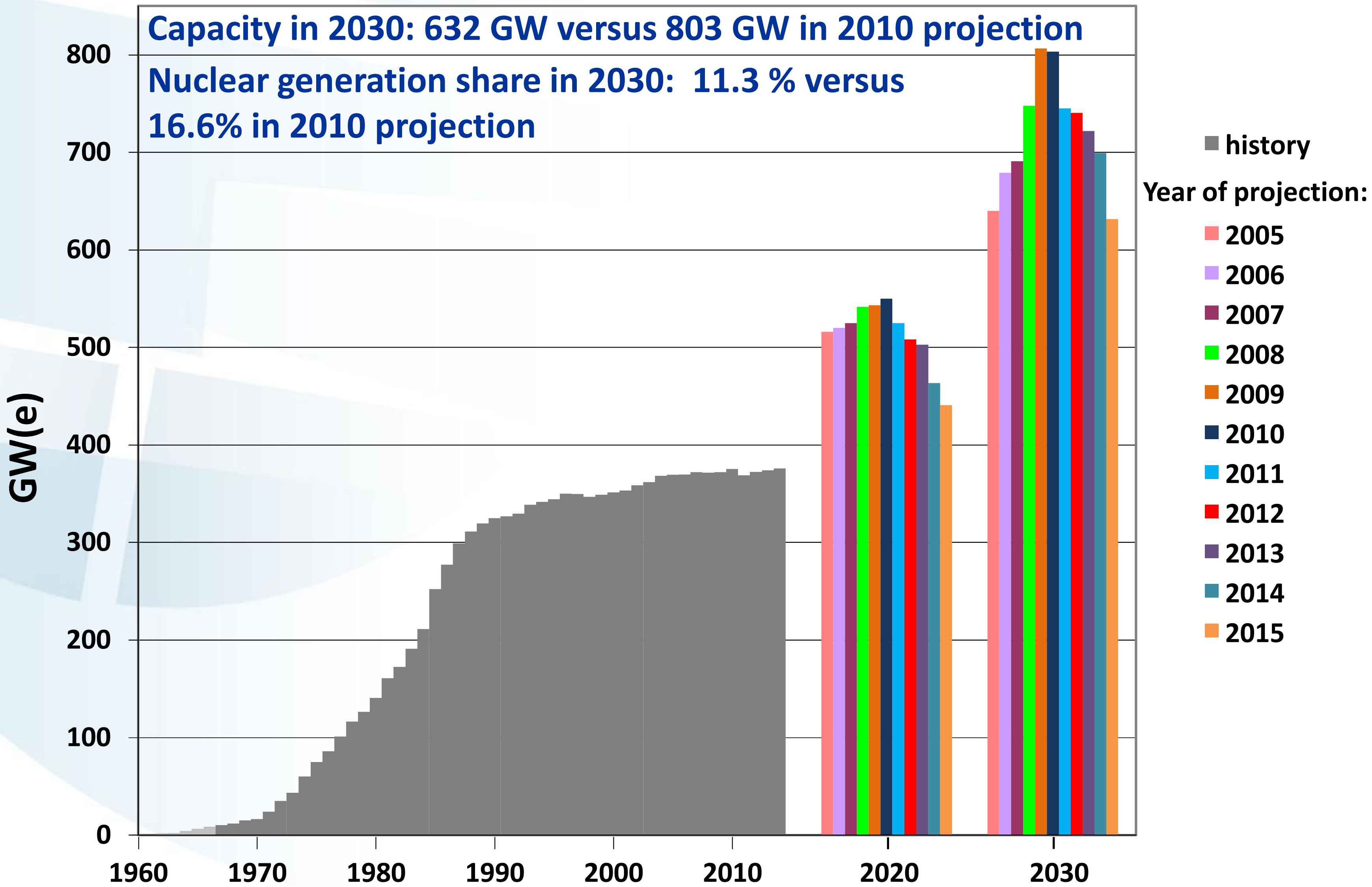
- U.S. ~130 reactors used as primary propulsion and electric power generation in submarines, aircraft carriers, a cruiser and a destroyer.
- Has safely accumulated over 5400 reactor-years of operation
- Uses more enriched fuel than commercial reactors
- Russia ~100; France ~20; UK ~20; and China ~ 6 reactors used as primary propulsion.
- Source of trained personnel in reactor operation.

IAEA – Low global nuclear scenarios



Source: Rogner, 2016

IAEA – High global nuclear scenarios

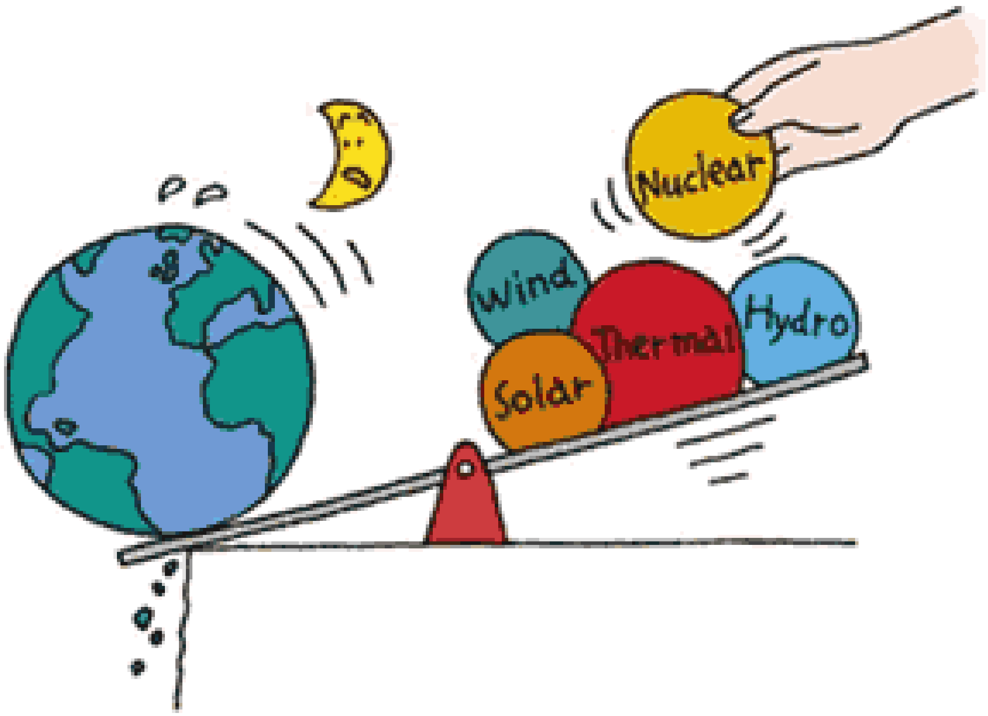


Source: Rogner, 2016

Drivers of the renaissance in interest

- Continued growth in global energy demand
- Energy security
- Fossil fuel price volatility
- Need for low-cost base load electricity
- Environment protection and climate change
- Nuclear power:

Improved operations, good economics and safety record starting in the early 1990s



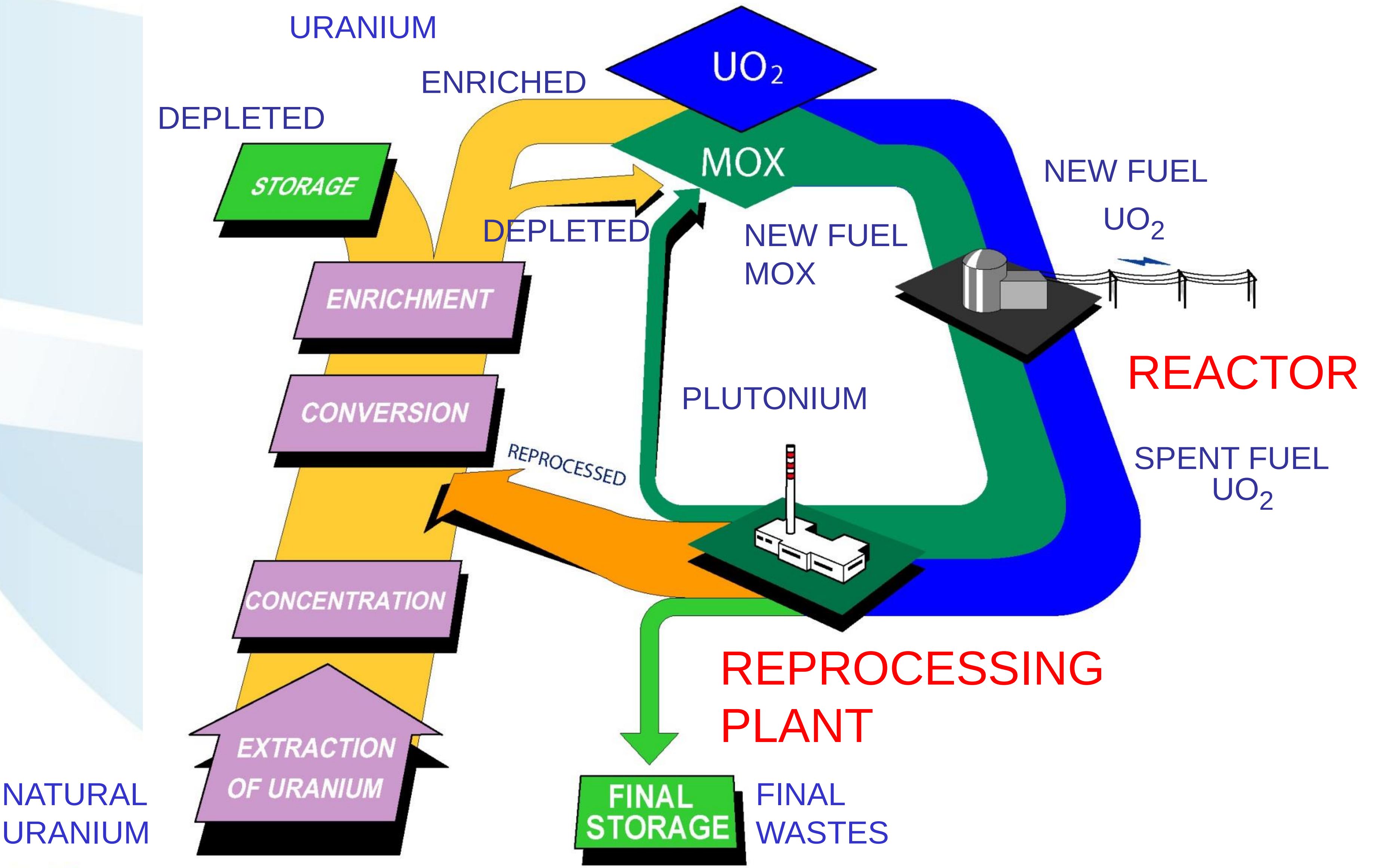
In spite of economic crisis:

- ➢ Prospects better than ever since the mid 1990s

R&D is needed for innovative solutions

- Safety, economics, storage, non-proliferation
- Advance modular, standard-design plants
- Easy and cheap ^{235}U reserves limited
- Once-through fuel cycle wastes 95% of energy
- Closed fuel cycle renders nuclear energy practically unlimited (for 10 000 years) with a considerable reduction of high-level radioactive wastes
- Radically new designs including nuclear fusion

Fabrication of nuclear fuel



ITER Design is Final

May 2001

Size: 3 times JET,

Plasma current: 15 MA

Plasma volume 837 m^3

Plasma surface 678 m^2

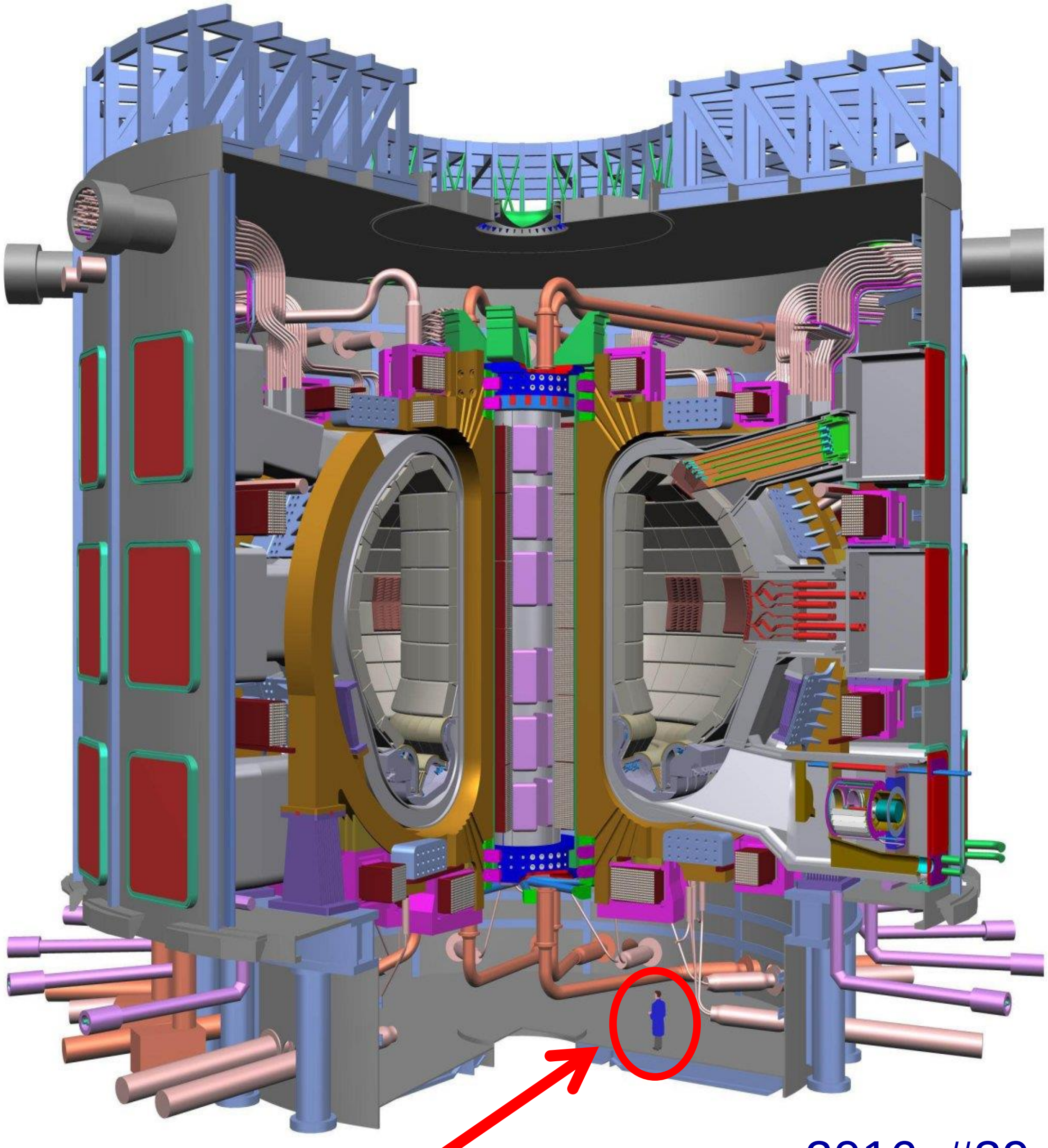
B = 5.3 T @ 6.2m

500 MW, 500 s, Q > 10

R = 6.2 m

Final scientific

demonstration

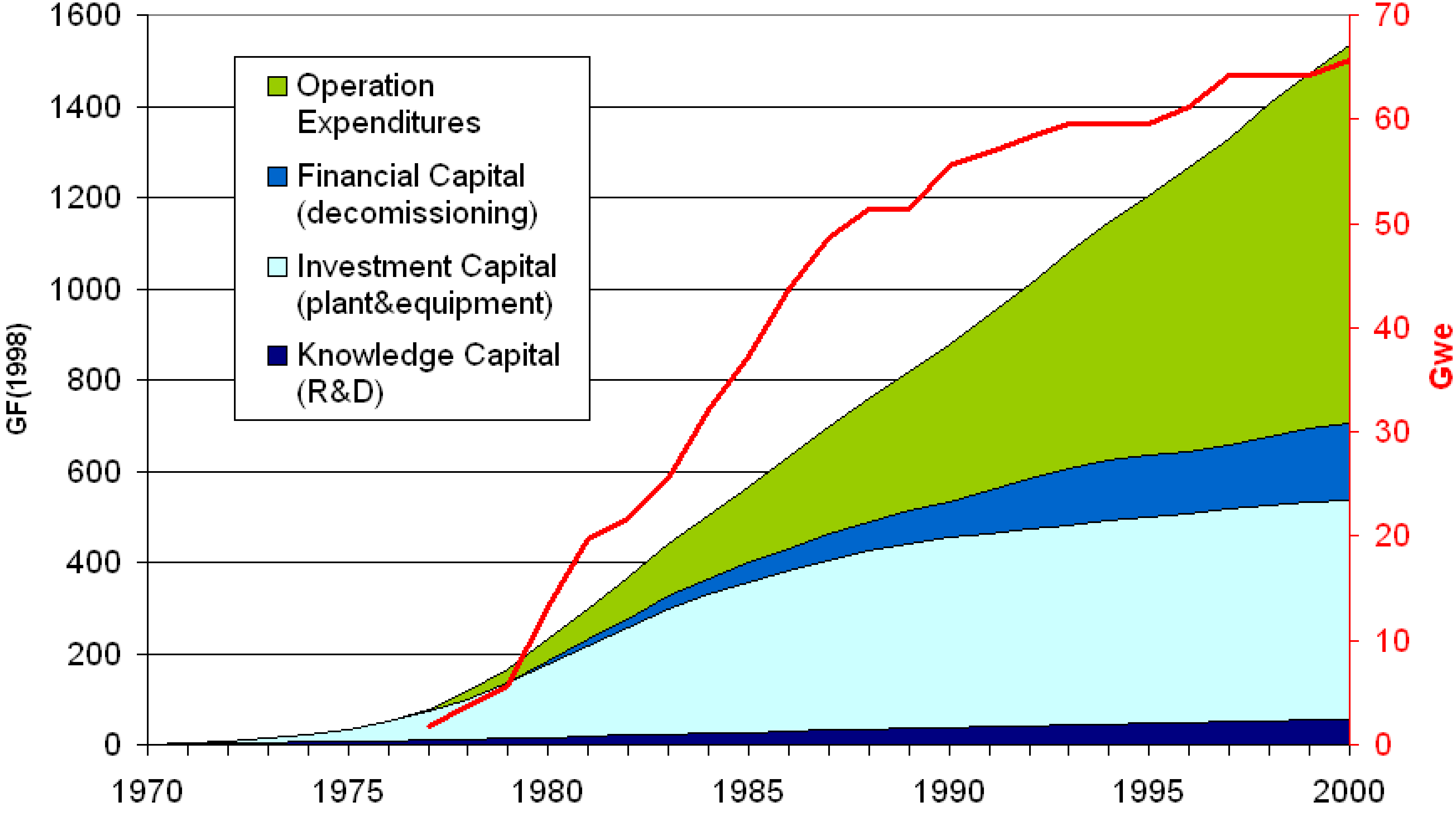


French Nuclear Reactors

- 58 reactors with 63 GWnet (66 GWgross)
- ~50 GW within 10 years (1980-1990)
- High degree of standardization:
  - 925 MW PWR Westinghouse license
  - 1350 MW PWR upscaled with maximized French equipment
  - 1550 MW PWR N4, precursor to 1650 EPR (lack of standardization)

French Nuclear Plants: Total Costs

1970-2000 = 1.5 1012 FF(1998) = ~$250 billion

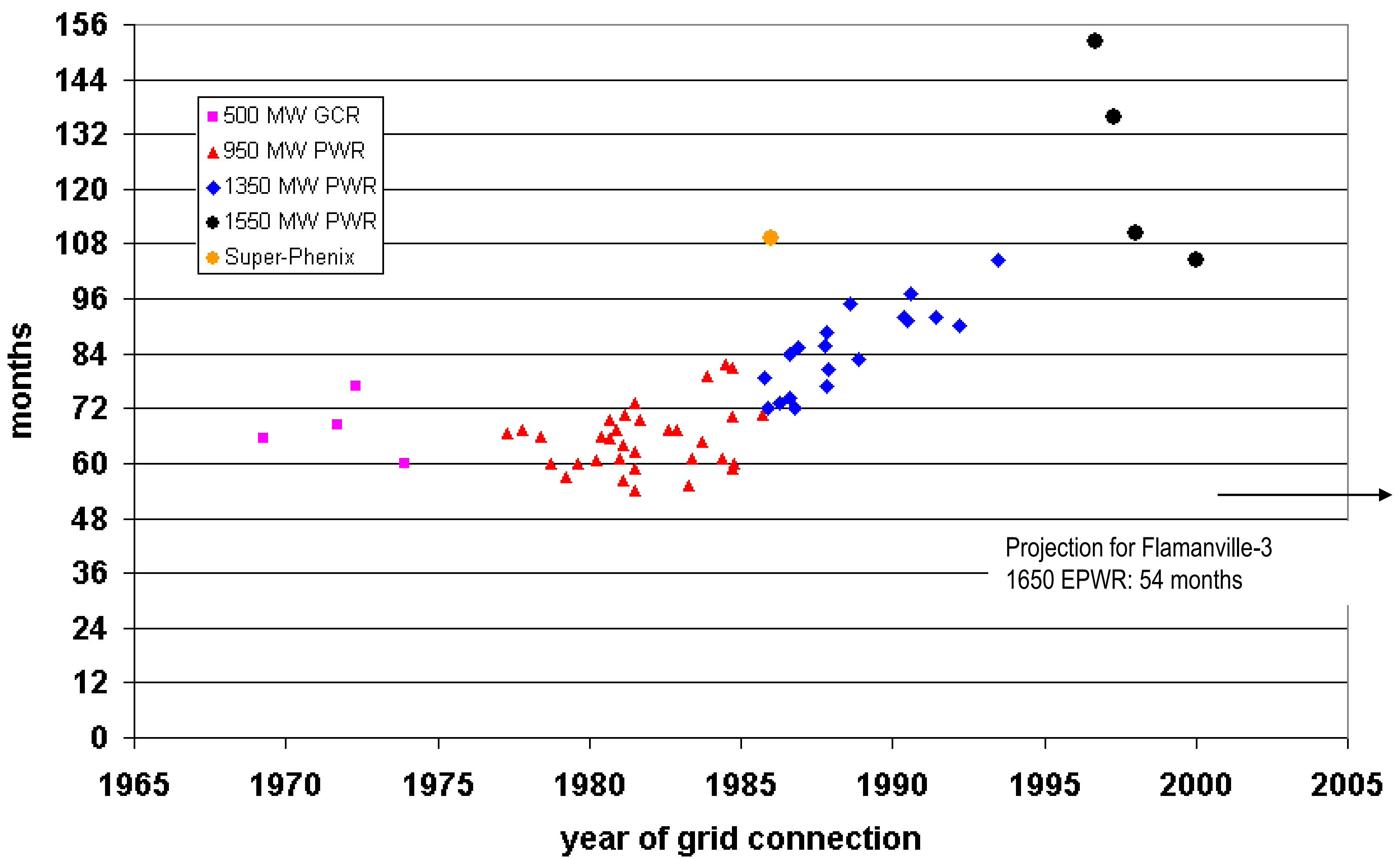


Anatomy of a Scale-up “Success”

- 80% nuclear electricity
- Load management and modulation
- No major accidents
- Little public opposition
- Stable regulatory environment (technocratic “grandes ecoles” elite)
- Continued development (scale-up) of technology
- Full-scale industry developed (incl. fuel cycle)

Source: Grubler, 2009

Construction Time
(construction start to grid connection)

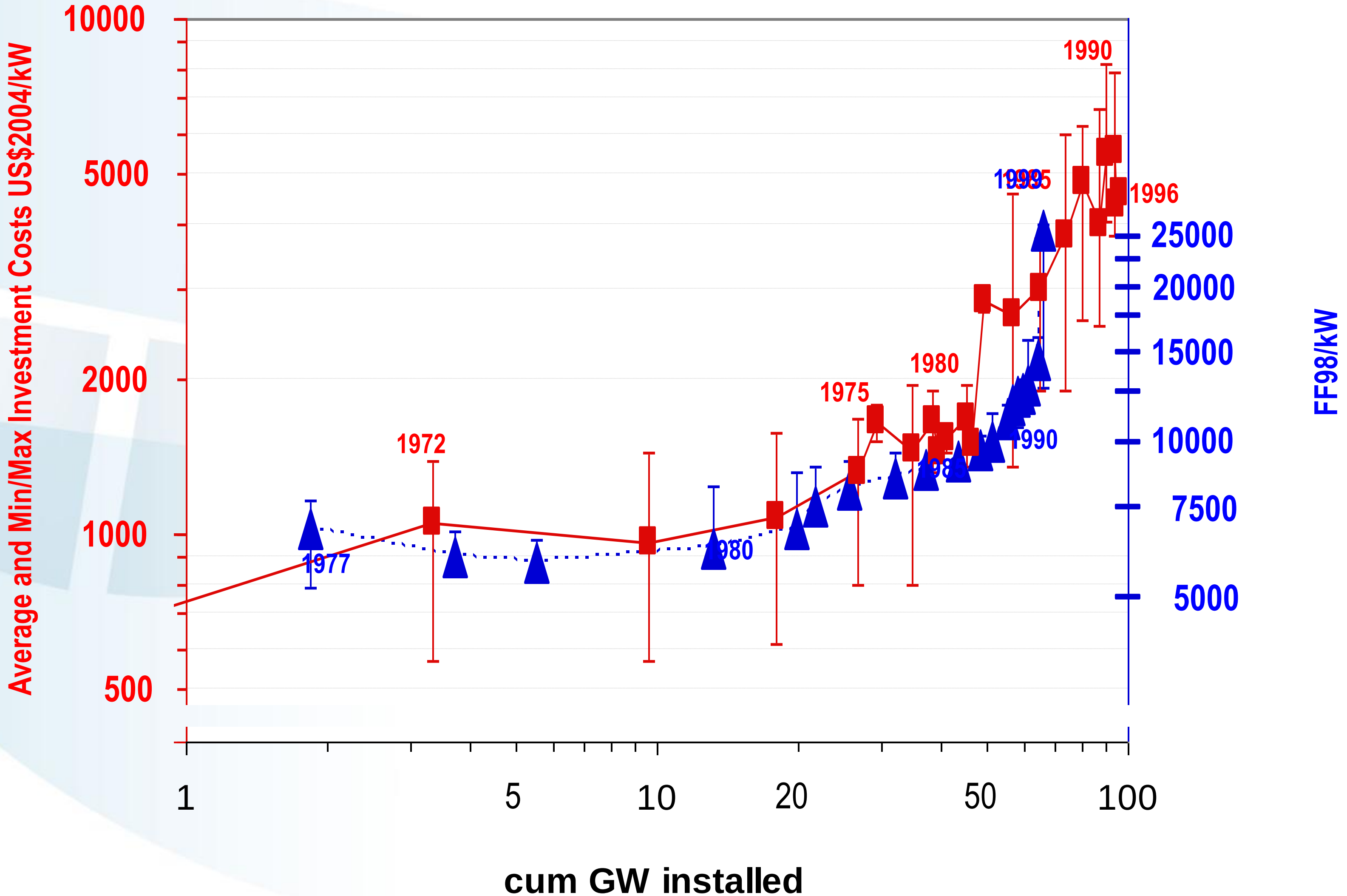


Data Source: IAEA PRIS, 2009

Beyond French Power Plants

- Similar pattern in the U.S. (albeit moderated)
- “Negative” learning: Cost escalation due to regulatory environment rather than intrinsic to technology
- Diseconomies of scale with increasing number and fewer plants being built
- Advantages of “granularity” (small unit-scale) and standard design

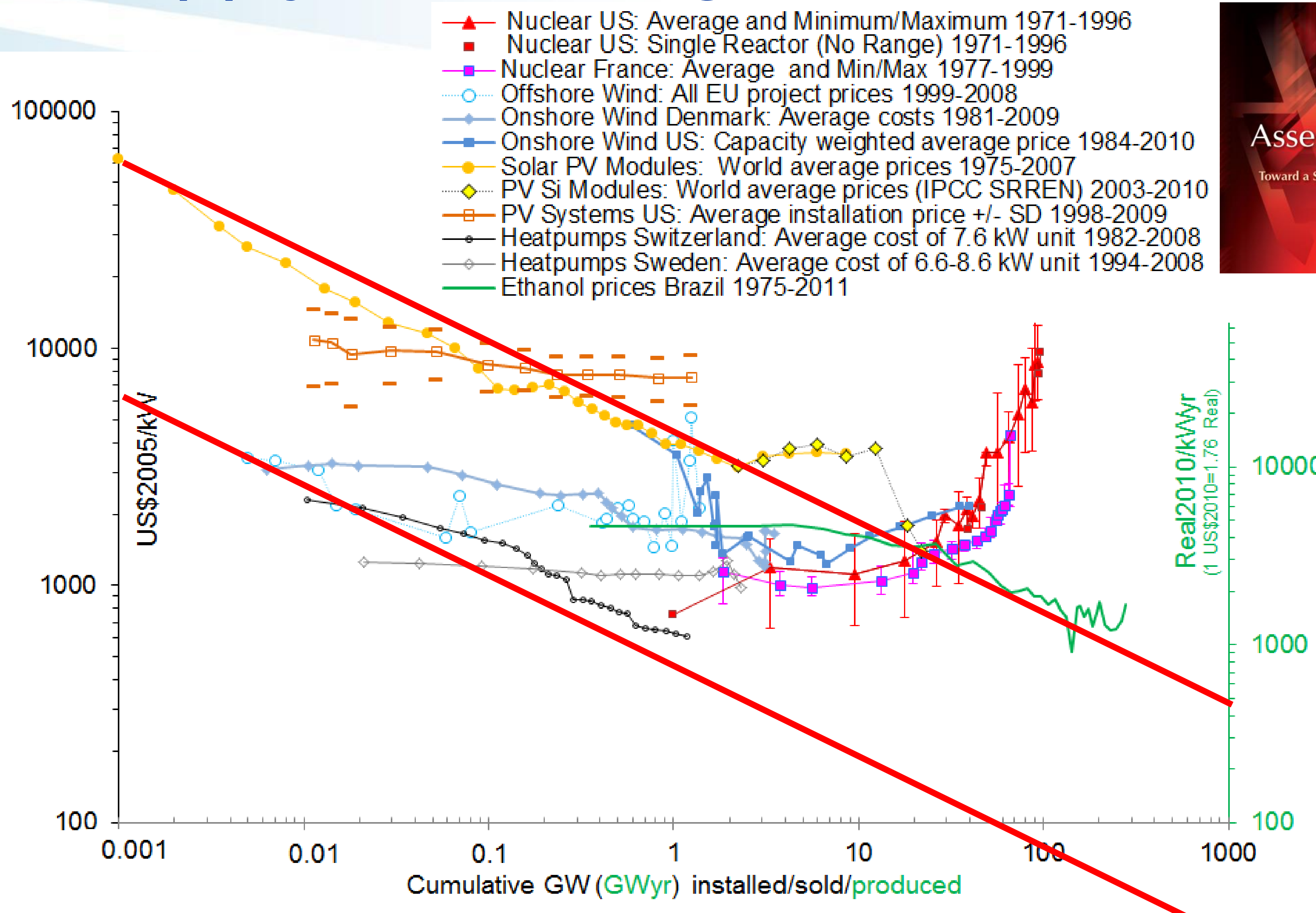
Nuclear Power Plants US & France:
"Negative" Learning by Doing

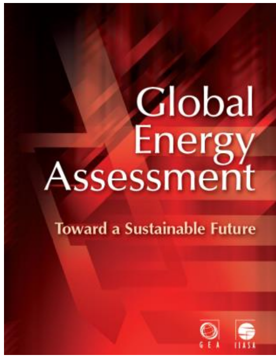


Summary

- Drastic cost escalation even for most successful OECD nuclear scale-up program
- Reasons for cost escallation:
  - Scaling-up in reactor size (negative economies)
  - Domestic production (low knowledge spillovers)
  - Departure from standardized design (N4/pre-EPR: CEA decides not EDF)
  - scale-back of expansion program (vs. exuberant forecasts and lengthened construction time)
- Lessons for the future – lack of cost certainty
  - Challenge for learning-by-doing paradigm
  - Need for granularity (standard, modular design)

Supply Technologies Cost Trends

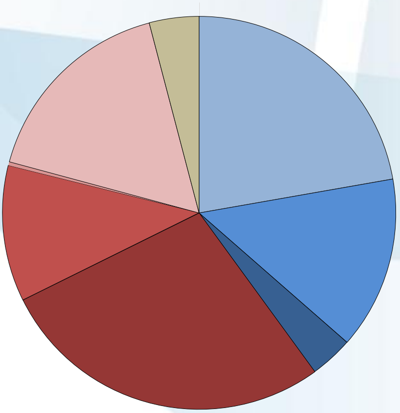




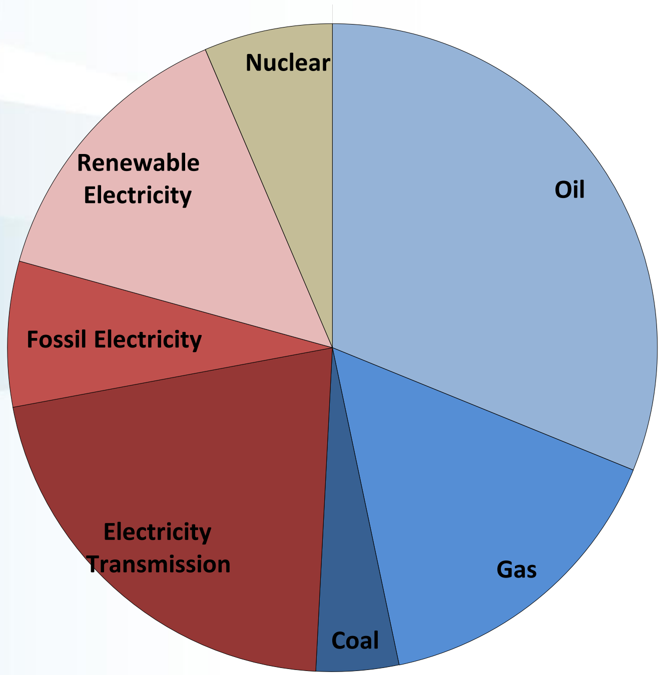
Investment Portfolios
World

No Sustainability Policies
(2558 bill.)

Today
(941bill.)

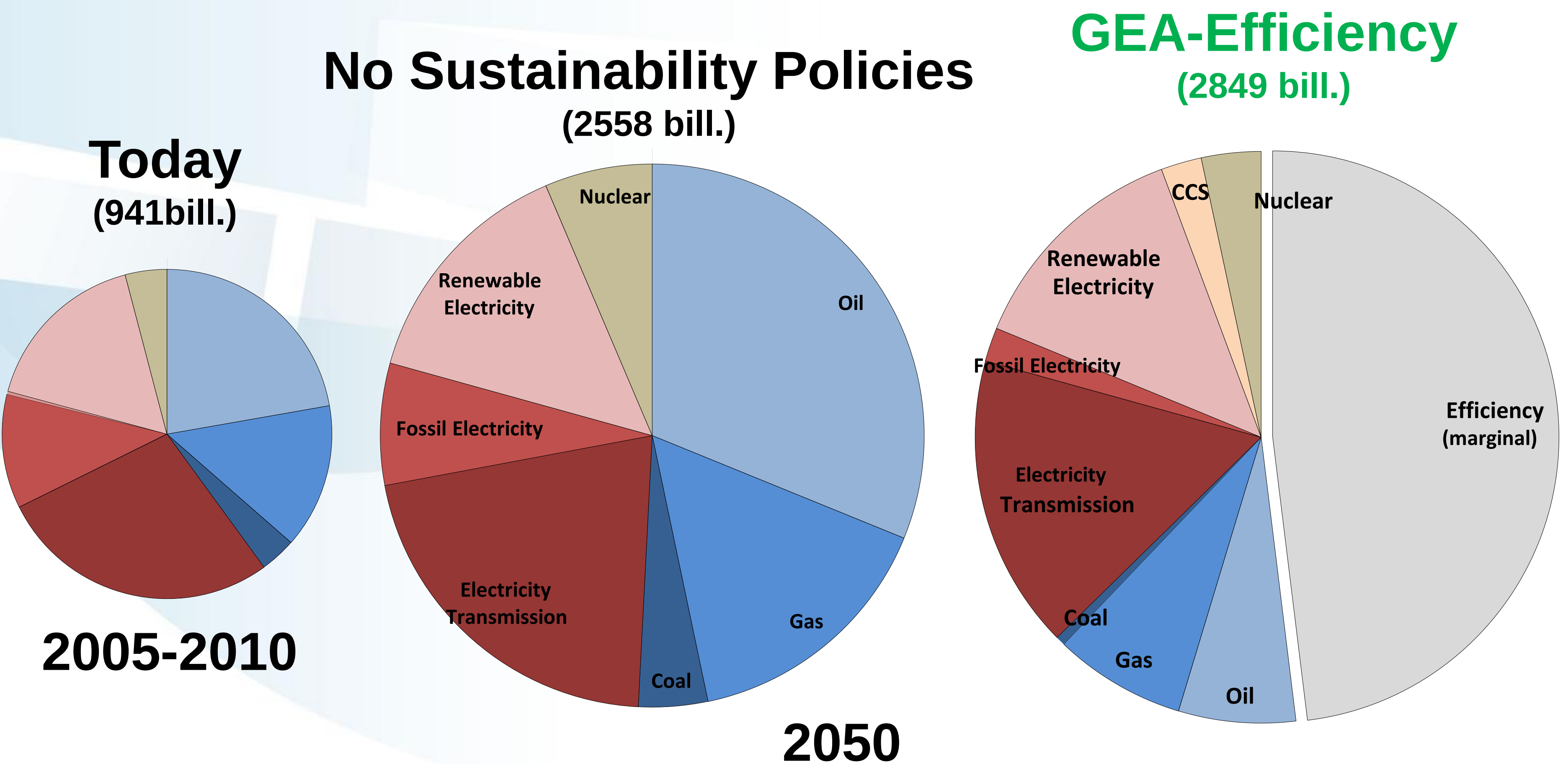


2005-2010



2050

Investment Portfolios World

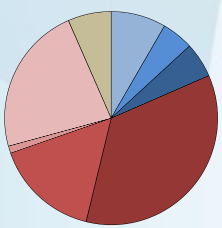


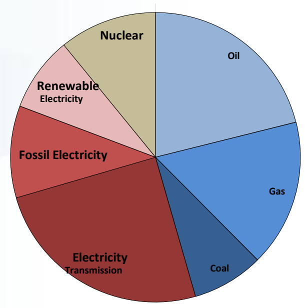
Investment Portfolios
Asia-Pacific

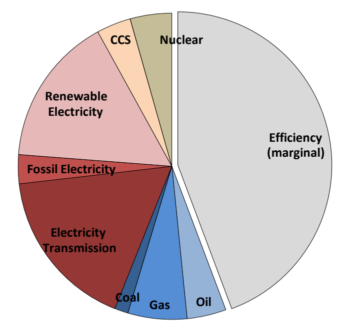
GEA-Efficiency
(579 bill.)

No Sustainability Policies
(516 bill.)

Today
(275 bill.)







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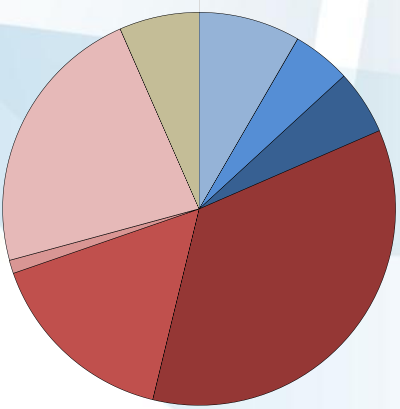

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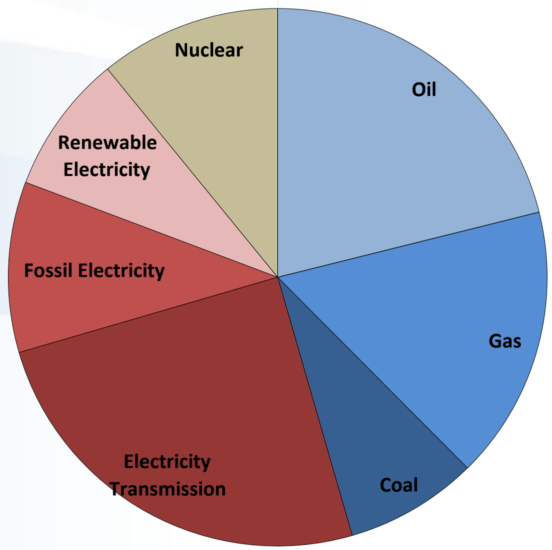

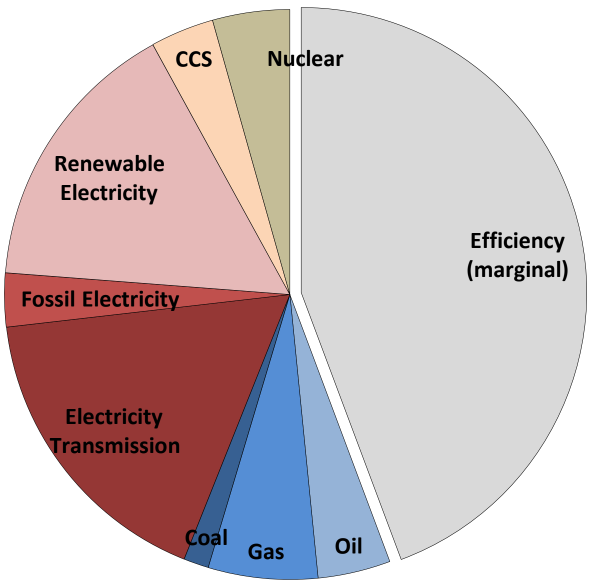

2050

Statement: Energy services are central for further development and a transformation toward sustainable future. It is important to increase RD&D and investments and establish stable regulatory mechanisms to achieve these development goals.

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THANK YOU

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