Nuclear Power One Year After Fukushima

Where is it Heading?

Alexander Glaser

CMI Annual Conference
Princeton University, April 17, 2012

Revision 8x

Fukushima-Daiichi Plant

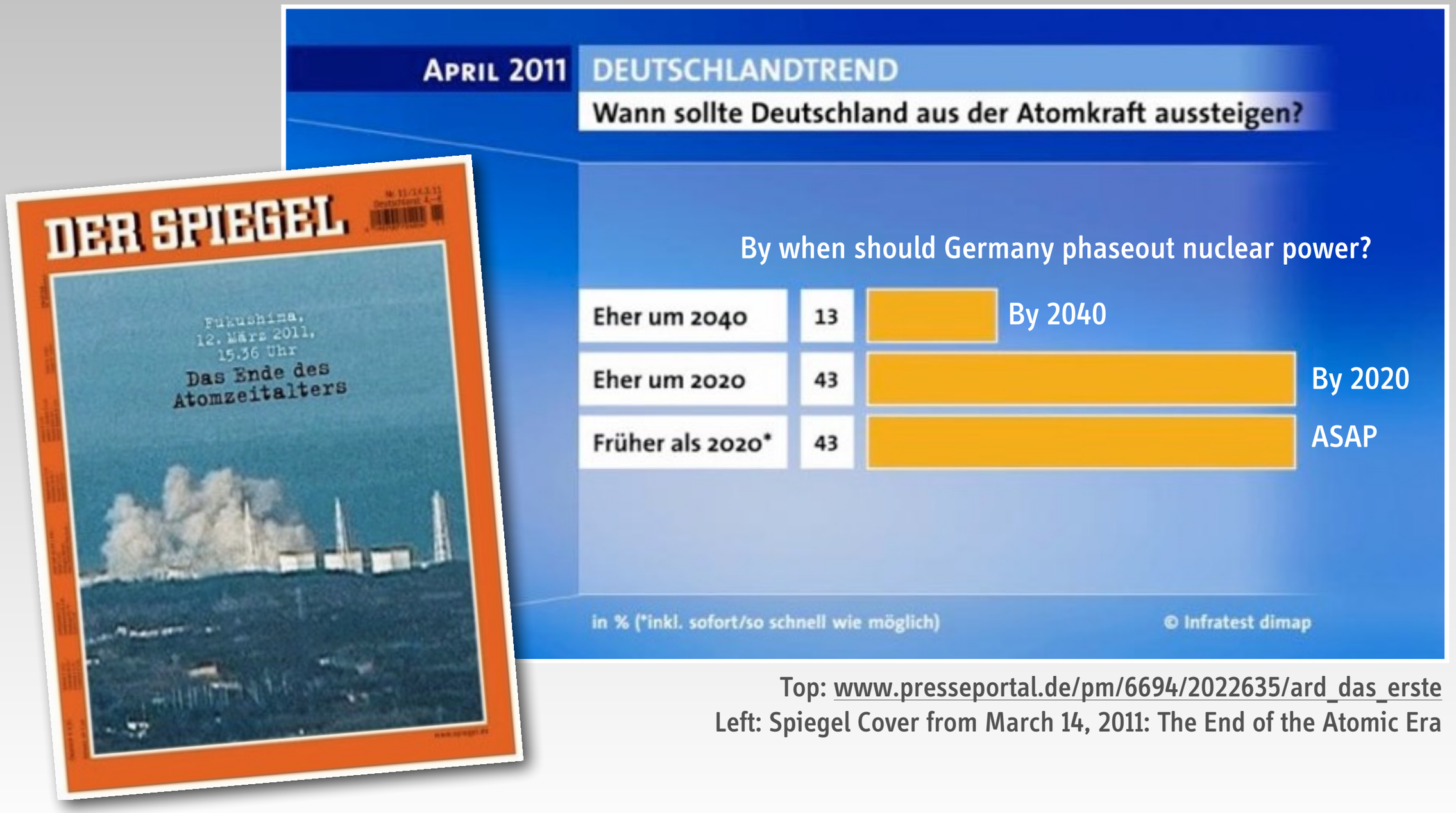
Source: TEPCO, undated

March 14, 2011 - DigitalGlobe

International Responses To Fukushima

In Germany, the Fukushima Accidents Consolidated Support Overnight for Nuclear Phaseout

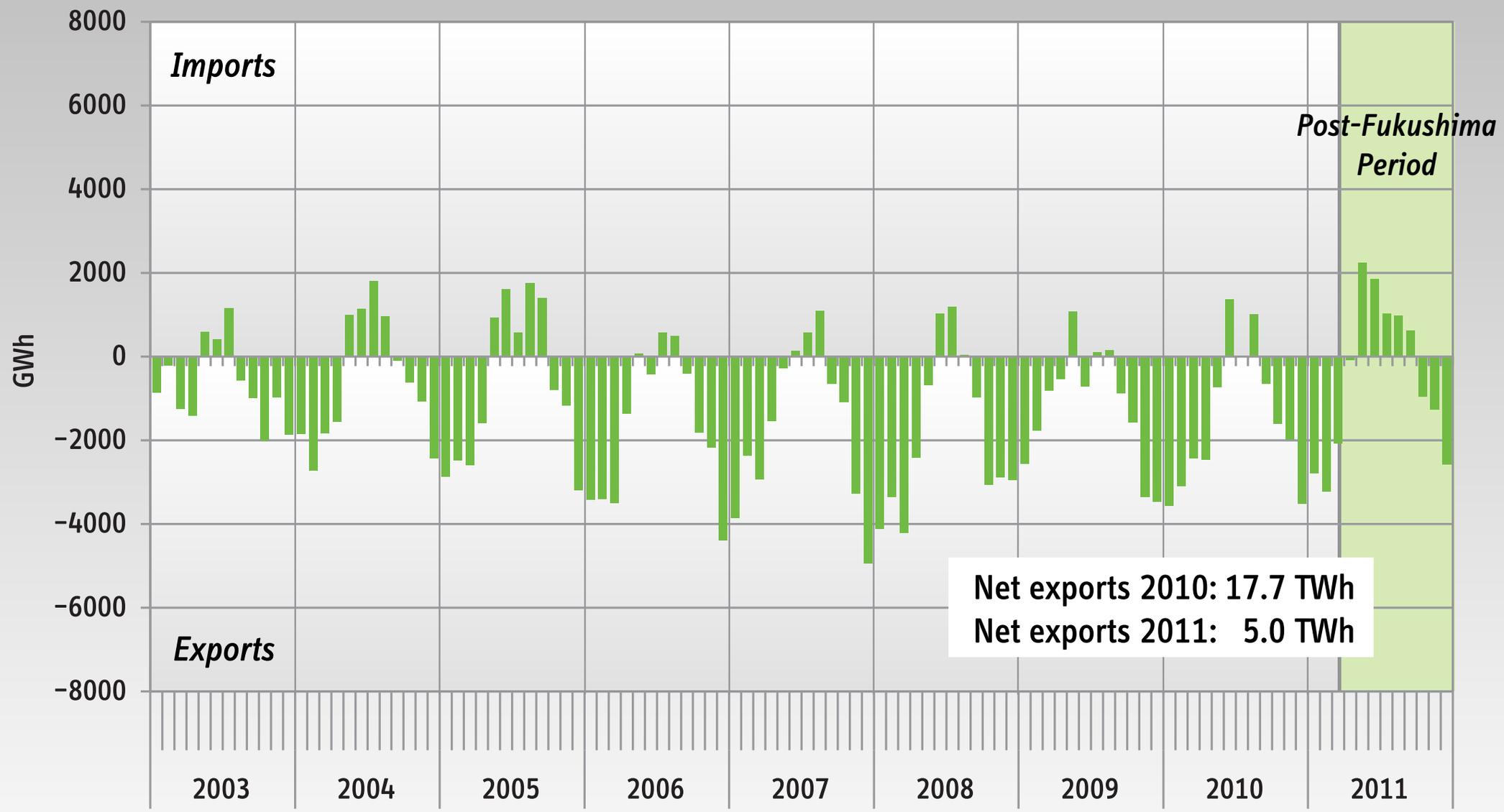
86% support nuclear phaseout by 2020 (Polling data from April 4-5, 2011)



Top: www.presseportal.de/pm/6694/2022635/ard_das_erste
Left: Spiegel Cover from March 14, 2011: The End of the Atomic Era

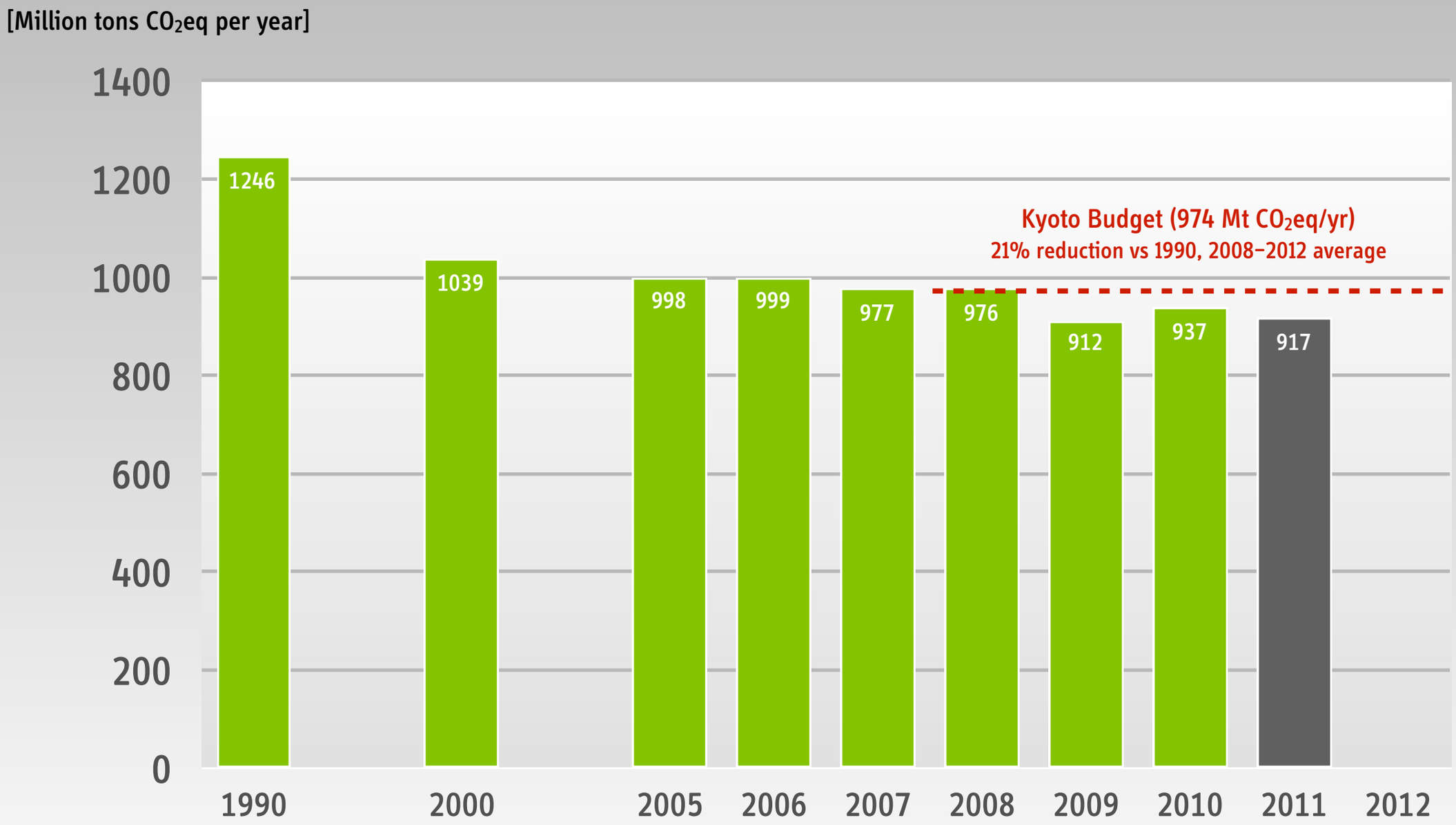
Germany's Electricity Imports/Exports

The Impact of Post-Fukushima Shutdowns is Visible but not Dramatic



Charlotte Loreck, *Atomausstieg in Deutschland*, Institute of Applied Technology, Darmstadt, March 2012

Germany's GHG Emissions Have Not Spiked Despite the Shutdown of Eight Reactors in March 2011



"Weniger Treibhausgase mit weniger Atomenergie," Press Release, 17/2012, Umweltbundesamt, April 12, 2012
See also European Central Data Reposoitory, cdr.eionet.europa.eu/de/eu/ghgmm/envtw7blw

The International Response to the Fukushima Accidents Has Been Very Uneven

Germany

Consolidating a national consensus on phaseout of nuclear power

- Immediate shutdown of eight oldest (out of a fleet of seventeen) reactors
- Complete phaseout by 2022

Japan

Fundamental review of energy policy underway

- As of April 2012, 53 out of 54 reactors shut down; several units are unlikely to come back online
- Strong public support for significantly reduced role of nuclear power in the future

France

Minor adjustments to government policy

but nuclear energy now salient issue (again) for political opposition and public debate

- Discussions about reducing nuclear power's of electricity generation from almost 80% down to 50%
- Major life-extension program underway: EUR 40 billion plus EUR 10 billion post Fukushima

The International Response to the Fukushima Accidents Has Been Very Uneven

several

Reconsidering a new or more important role of nuclear power

- Mostly relevant for non-committed "newcomer" countries
- Also includes countries with existing small programs (Belgium, Switzerland, the Netherlands, ...)

China

Ambitious expansion plans largely unaffected

- Safety review of all current plants; possible new licensing requirements for future plants
- Target for 2020: add 35–45 GW to existing 12 GW (Share of nuclear electricity in 2011: 1.85%)

USA

Continued commitment to nuclear power

but only few new construction projects moving forward despite government support

United States: The Market is Deciding

Federal Loan Guarantees

as part of the Energy Policy Act of 2005, up to $18.5 billion
Obama Administration has sought to increase amount to $54.5 billion

Most proposed construction projects have stalled

some before and some after the Fukushima Accidents

Vogtle-3 and -4 Project (Waynesboro, GA) moving forward

2 x Westinghouse AP-1000, 2200 MWe, expected for 2016 and 2017
Combined Construction and Operating License issued in February 2012
$14 billion investment; $8.3 billion in Federal loan guarantees

"Let me state unequivocally that I've never met a nuclear plant I didn't like;
Having said that, let me also state unequivocally that new ones don't make any sense right now."

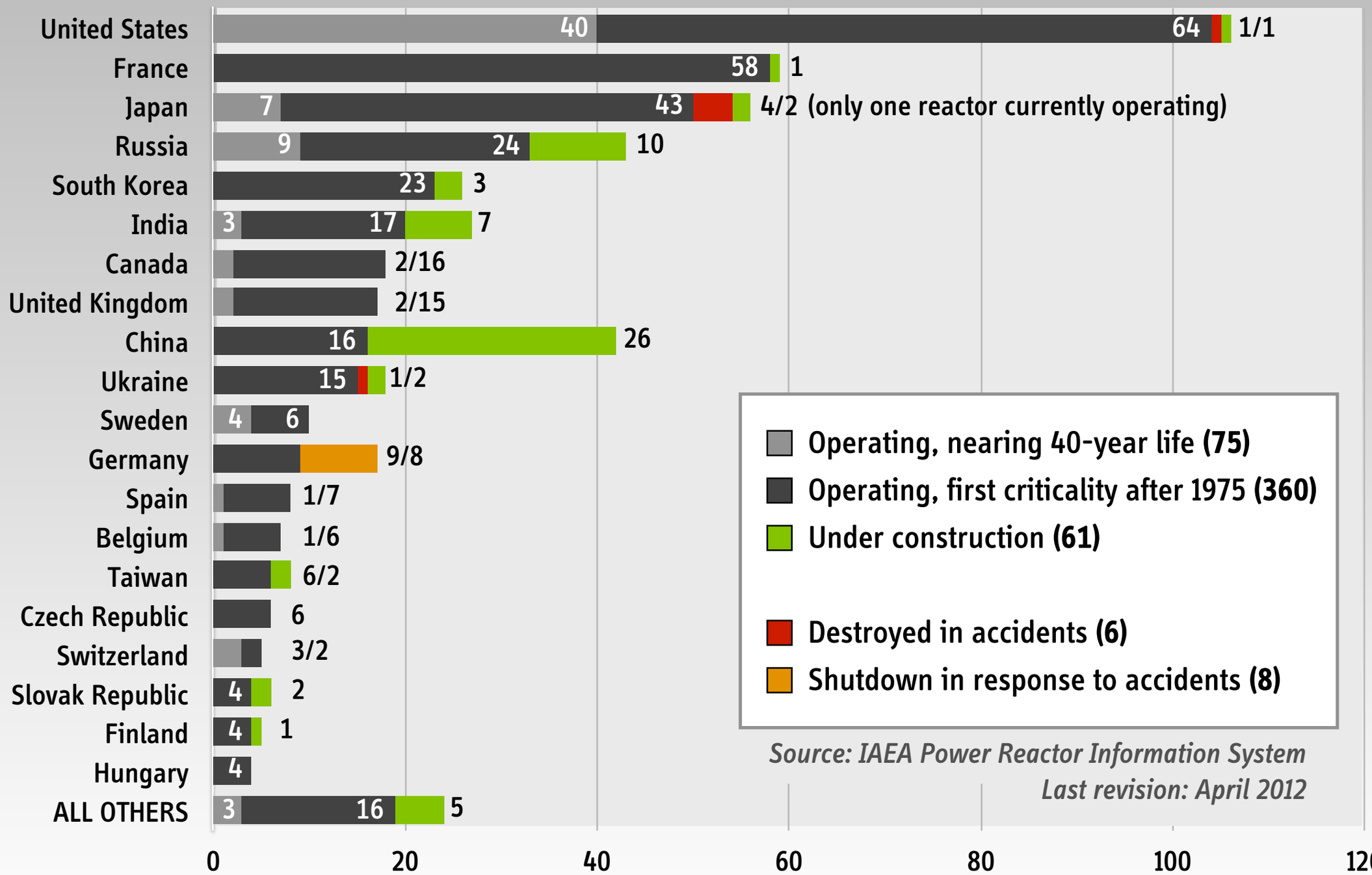
John Rowe, Former CEO Exelon, March 29, 2012

quoted in www.forbes.com/sites/jeffmcmahon/2012/03/29/exelons-nuclear-guy-no-new-nukes

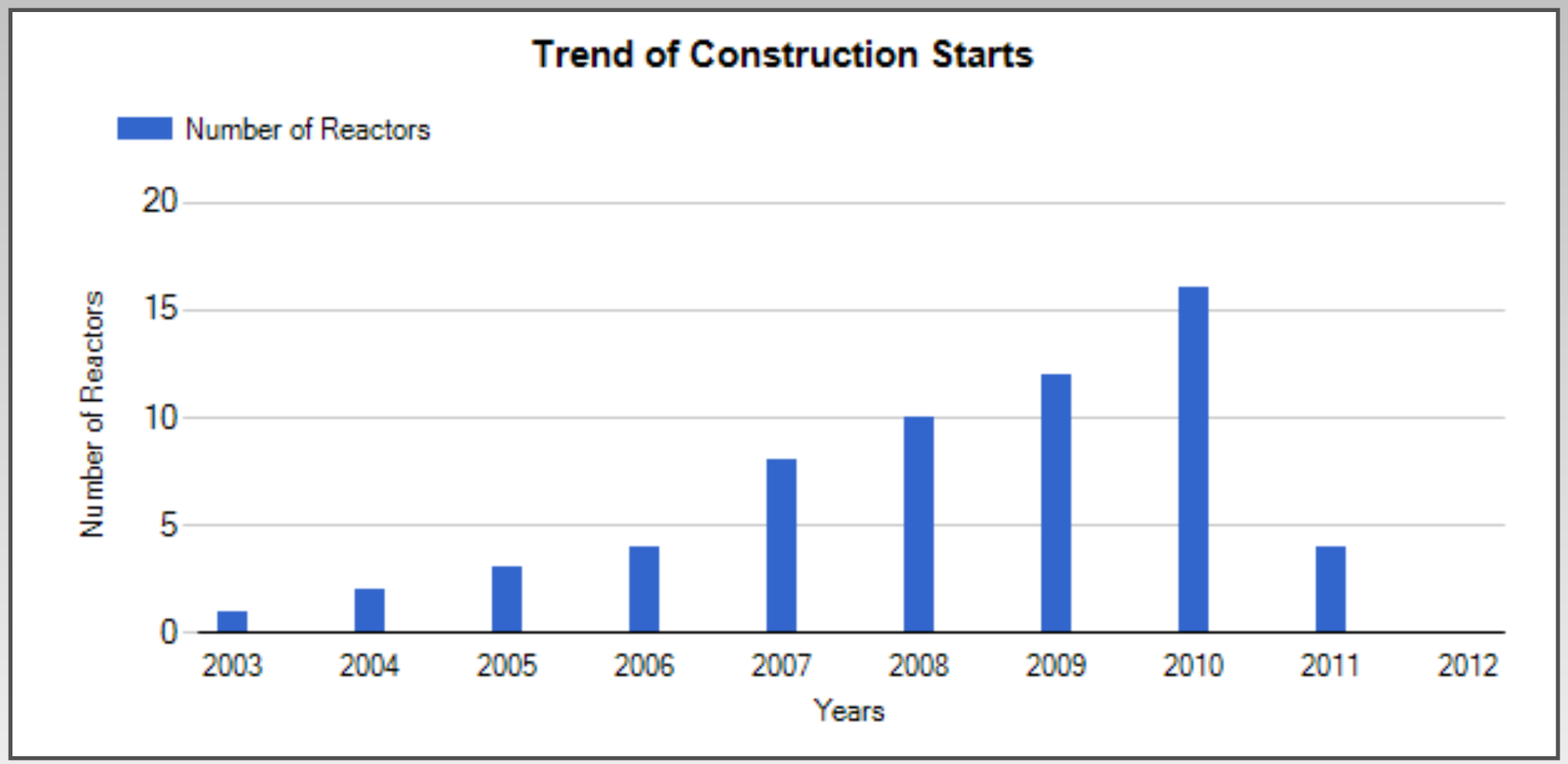
Looking Forward

The Existing Fleet of Power Reactors is Aging

(20-year life-extensions have already been granted for most U.S. reactors)

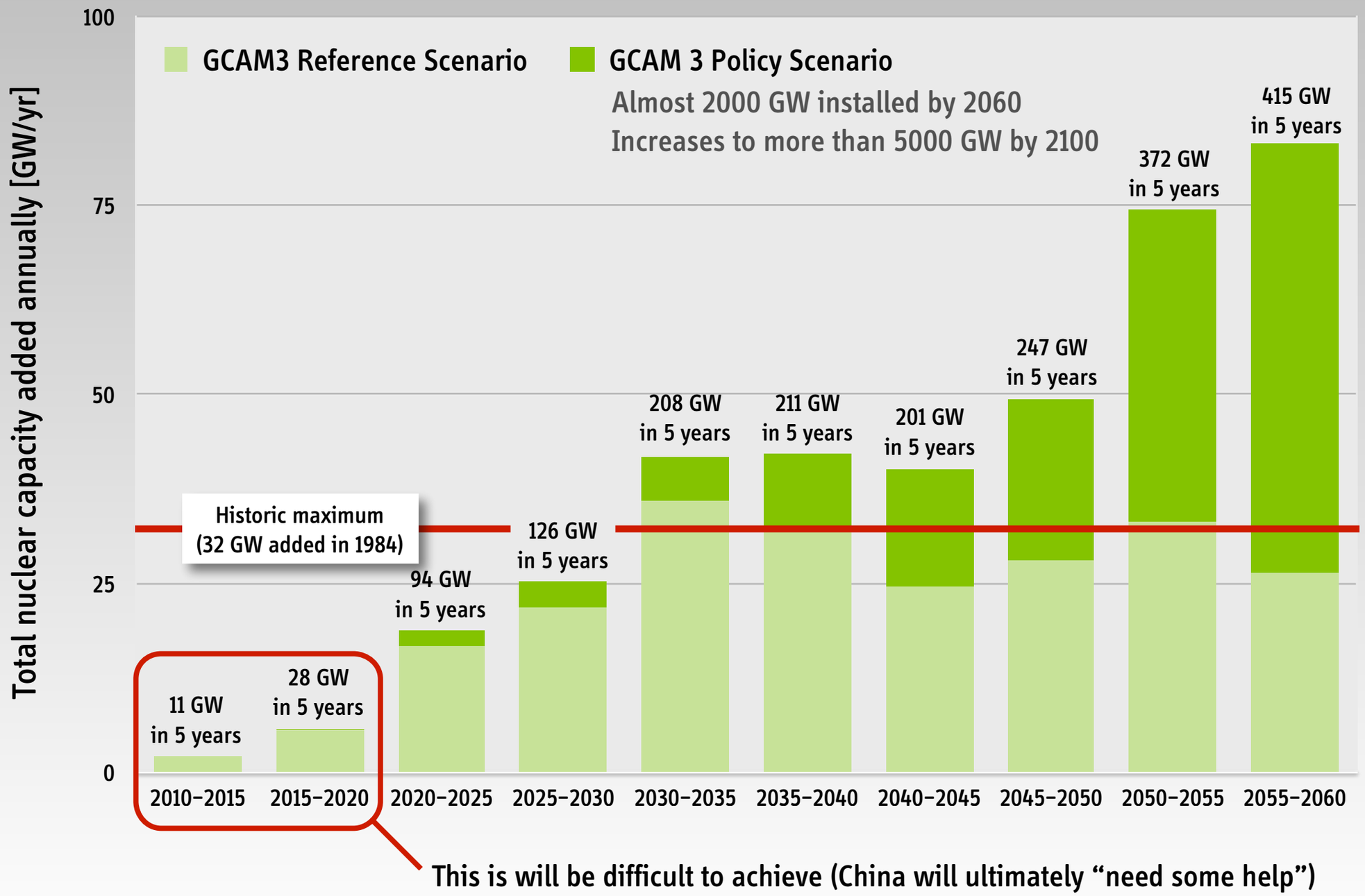


Construction Starts By Year



Source: Power Reactor Information System (PRIS), International Atomic Energy Agency, http://pris.iaea.org/public/
Information retrieved: April 16, 2012

Energy Scenarios for 2060 and Beyond Still Envision a Massive Global Expansion of Nuclear Power



Are New Technologies on the Horizon?

The Case of Small Modular Reactors

Why Consider Small Modular Reactors?

- **Substantially lower investment risks**
  $1 billion vs $10 billion projects; combined with shorter construction times
- **Better suited for electricity markets with low growth rates**
  Modules can be added to existing facilities "on demand"
- **Promise of enhanced safety and security**
  Almost all designs envision underground siting
- **Potential nonproliferation benefits**
  Long-lived cores

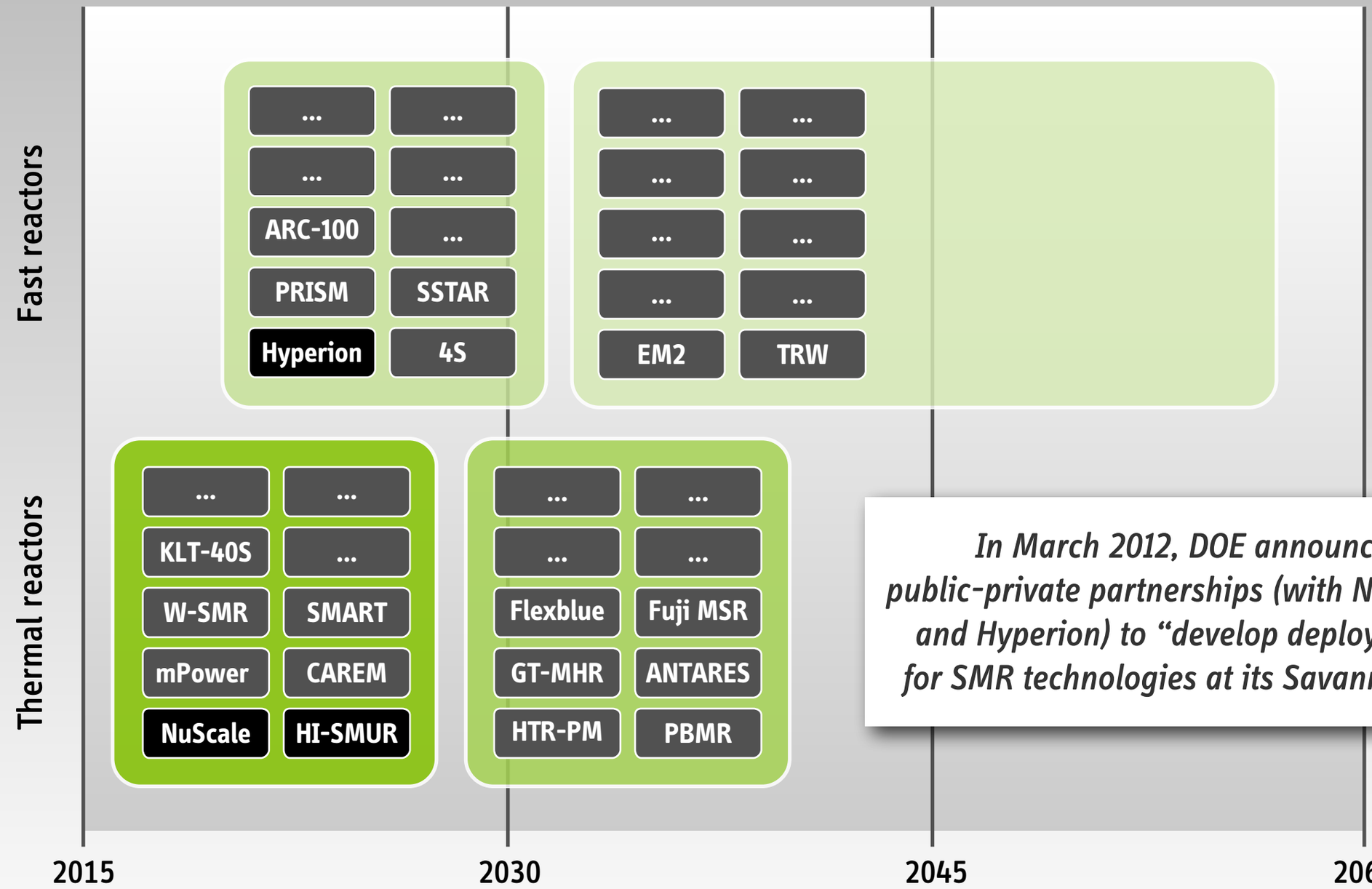
BUT: Ultimately, everything will hinge on the economics

In January 2012, DOE announced a 5-year $452 million cost sharing program to support engineering, design certification, and licensing for up to two first-of-a-kind SMR designs

www.grants.gov/search/search.do?mode=VIEW&oppId=138813

A Plethora of Small Modular Reactors Has Been Proposed

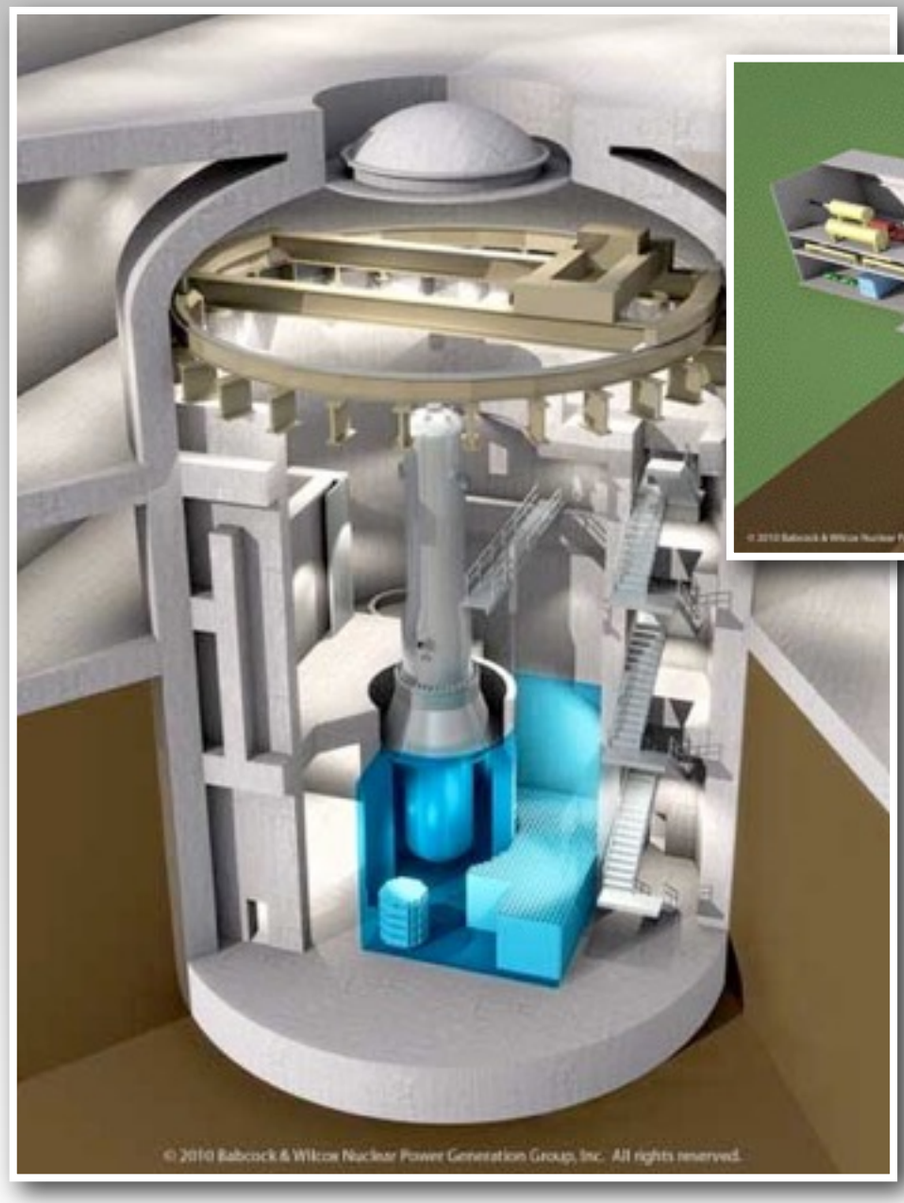
Some are based on proven technologies, some may be considered "science fiction"

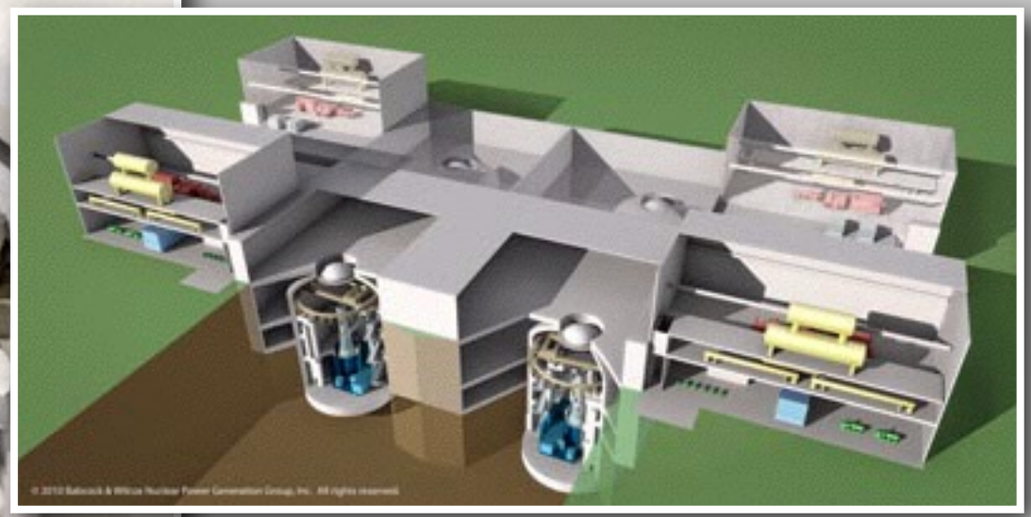


In March 2012, DOE announced three public-private partnerships (with NuScale, Holtec, and Hyperion) to "develop deployment plans" for SMR technologies at its Savannah River Site

Could Small Nuclear Reactors Play a Role?

Several designs are based on standard light-water reactor technology





Babcock & Wilcox mPower Concept

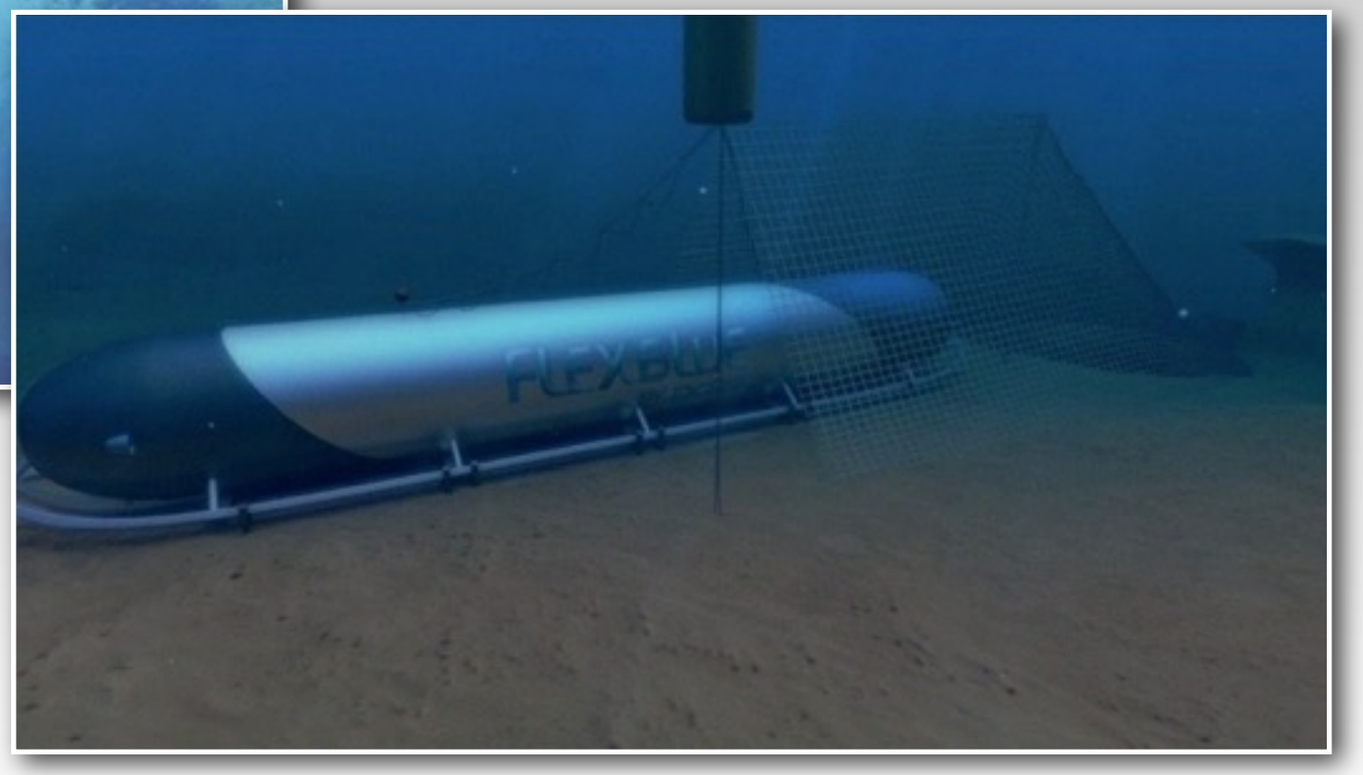
- Light-water cooled
- 125-750 MWe
- Underground construction
- 60-year spent fuel storage onsite
- Quasi-standard LWR fuel

Source: www.babcock.com/products/modular_nuclear/

Could Small Nuclear Reactors Play a Role?

Proposed new deployment options: underground, on barges, underwater

FlexBlue
DCNS (formerly *Direction des Constructions Navales*, DCN)
jointly with Areva, CEA, and EDF



Length: about 100 m
Diameter: 12–15 m
Power: 50–250 MWe
Siting: Seafloor mooring at a depth of 60 to 100 m
a few kilometers off coast

http://en.dcnsgroup.com/energie/civil-nuclear-engineering/flexblue/

Whenever You Read About a "Stunning" New Reactor

It Most Likely is a Fast Neutron Reactor Design

"The Energy Multiplier Module (EM^2) ... turns nuclear waste into energy."

"The current amount of used nuclear fuel waste in storage at U.S. nuclear plants is sufficient for 3,000 modules."

The design provides "the simplest possible fuel cycle, and it requires only one uranium enrichment plant per planet."

26 Advanced Recycling Centers "are capable of consuming the entire 120,000 tons of SNF. Additionally, they are capable of producing 50,000 MWe and avoiding the emission of 400,000,000 tons of CO_2 every year."

Top: General Atomics, Technical Fact Sheet; Middle: C. Forsberg on Traveling Wave Reactor quoted in *Technology Review*, March/April 2009; Bottom: GE-Hitachi, ARC/PRISM Fact Sheet

CMI's "Re-Engineering the Nuclear Future" Project

Alex Glaser and M. V. Ramana, with Laura Berzak Hopkins

Review and analyze proposed SMR designs and their associated nuclear fuel cycles

Research supported by extensive neutronics calculations for notional SMR's

Examine the implications of a large-scale deployment of this technology with a particular focus on proliferation risk, nuclear waste generation, and economics

Research will include work with "Integrated Assessment Models" which are widely used to project energy futures and assess effectiveness of climate policies

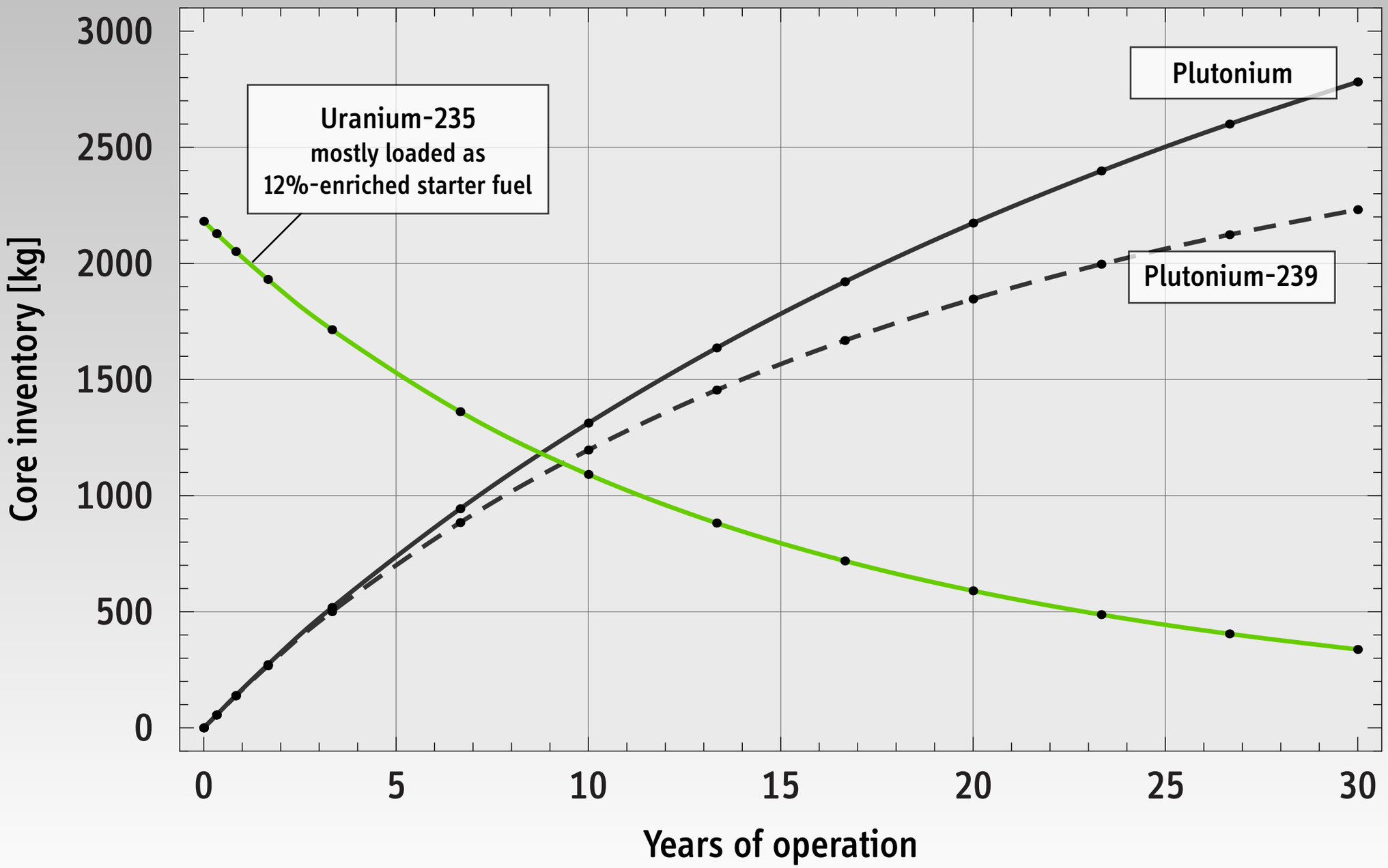
In the process, help improve the characterization of nuclear power in these models

Example

Notional Long-lived Small Modular Reactor in Once-through Mode

Fuel Inventory of a Long-lived Small Modular Reactor Operated in a Once-Through Mode

MCODE Simulations for Notional Design, 500 MW thermal, 30-year core life, 300 days per year



Resource and Fuel Cycle Requirements

500 MW thermal for 30 years (300 days per year, 9,000 effective full power days)

	Standard LWR (50 MWd/kg)	SMR TYPE F2 (fast spectrum, once-through)
Fuel demand	90 tons (5%-enriched fuel)	20 tons* (12%-enriched starter fuel)
Uranium requirements (to make fuel)	1050 tons (reference)	**570 tons (45% reduction)**
Enrichment	660,000 SWU (reference)	**430,000 SWU (35% reduction)**
Plutonium inventory in spent fuel	1.1–1.2 tons (10 kg per ton of fuel)	**2.8 tons (70 kg per ton of fuel)**
Waste	90 tons (reference)	40 MT (55% reduction)

*Does not include 20 additional tons of depleted uranium for blankets

In principle, some long-lived SMR concepts could be attractive for deployment in the 2020–2030 timeframe (but the "temptation" to reprocess the fuel from the used cores might be significant)

Where Is Nuclear Power Heading?

Some Concluding Observations

Many countries remain committed to nuclear power

but deployment and role of nuclear power is likely to be more uneven

Germany's phaseout will be a "game changer"

Small Modular Reactors

SMR attract significant attention; many innovative features; some prototypes will be built

Small may be beautiful … but it is small

Even under most optimistic assumptions, little generating capacity based on SMR technologies could be deployed by 2030

An early large-scale global nuclear expansion has become very unlikely

New thinking is needed about the potential (smaller) role of nuclear power in energy portfolios