U.S. DEPARTMENT OF ENERGY | Nuclear Energy

International Perspectives on Nuclear Power

San Diego Section of the American Nuclear Society

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U.S. Department of Energy

September 4, 2014

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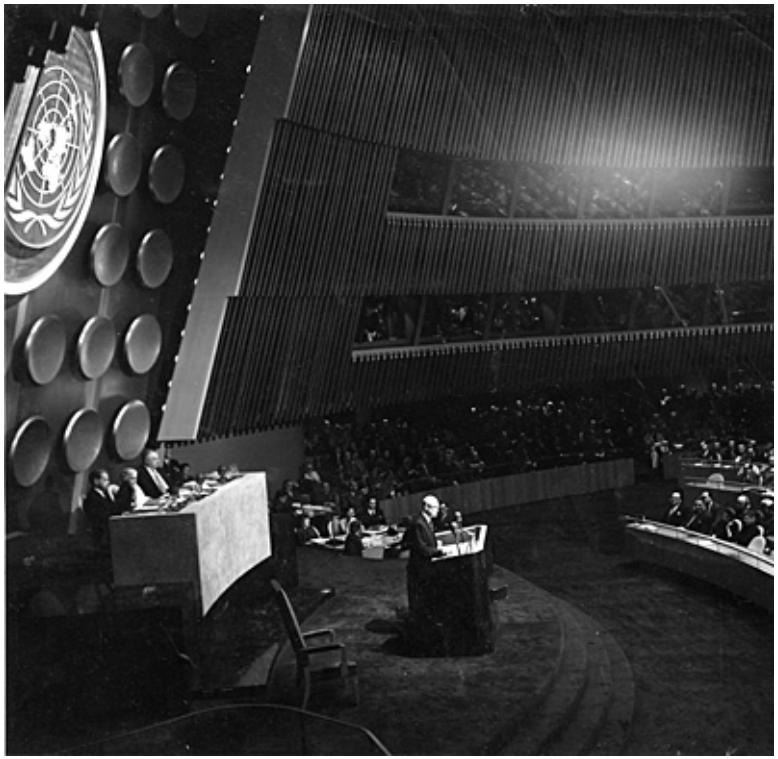
Atoms for Peace

The First Wave of Nuclear Power Deployment



"Peaceful power from atomic energy is no dream of the future. That capability, already proved, is here – now – today."

~ President Dwight D. Eisenhower, December 8, 1953, to the 470th Plenary Meeting of the United Nations General Assembly

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Drivers that Influenced the First Wave of Nuclear Power Deployment

Encouraging drivers

- Post World War II: Re-emerging economies required increased energy
- 1970s - Oil Crisis
- Strong Government Backing

Neutral drivers

- Acid Rain
- Air Pollution
- 1971- **Inadvertent Climate Modification**. *Report of the Study of Man's Impact on Climate*

Discouraging drivers

- High Interest Rates
- Fear of Radiation
- Fear of Nuclear Weapons
- Three Mile Island Accident
- Chernobyl Accident
- Waste Management Impasse

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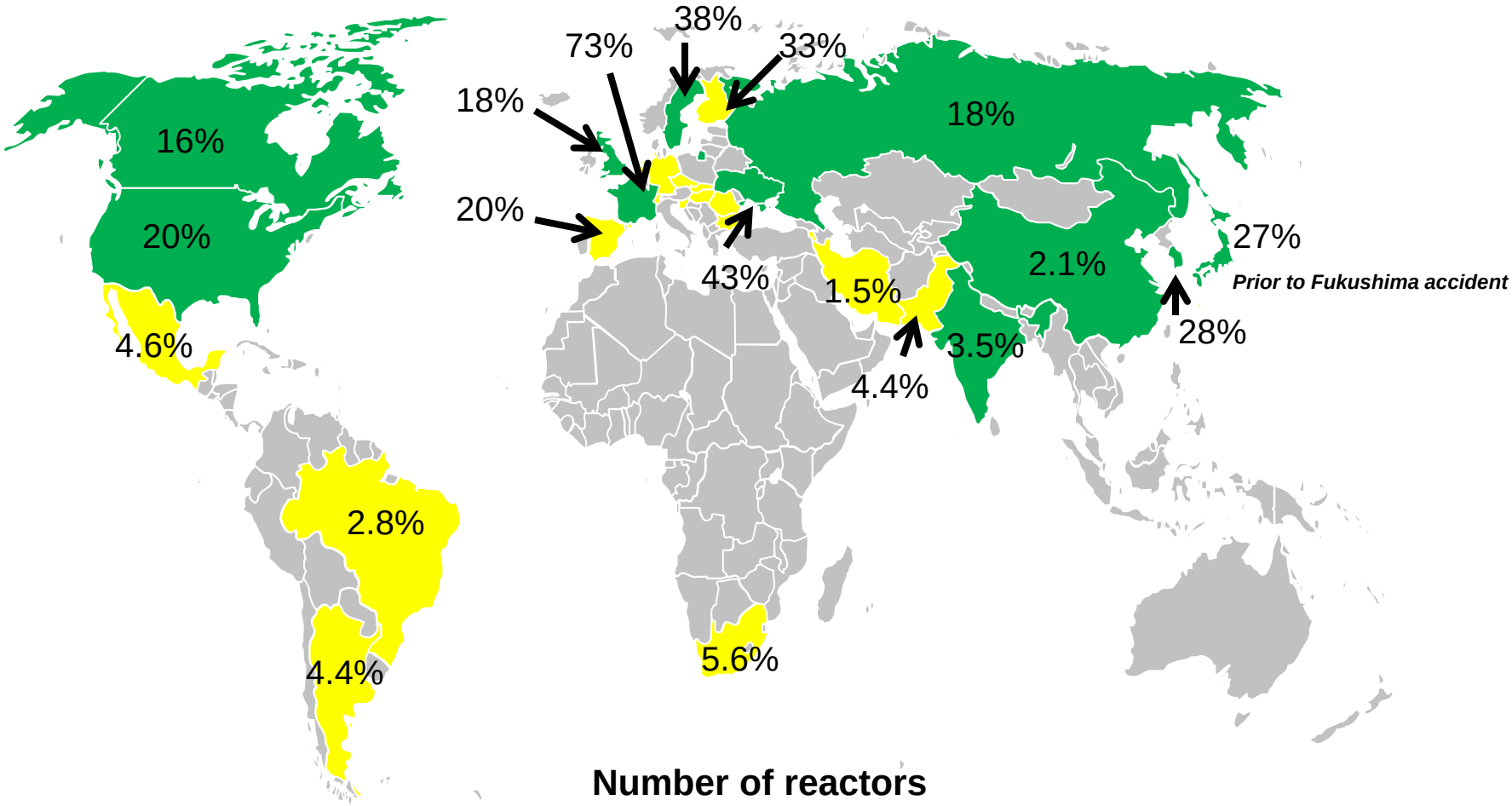
Existing Nuclear Commercial Power Reactors *(13.8% World Wide / 21.4% OECD)*



~ Source: IAEA information & news reports

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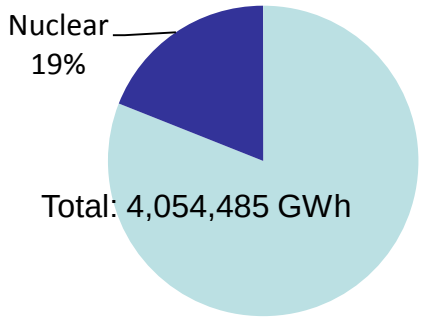
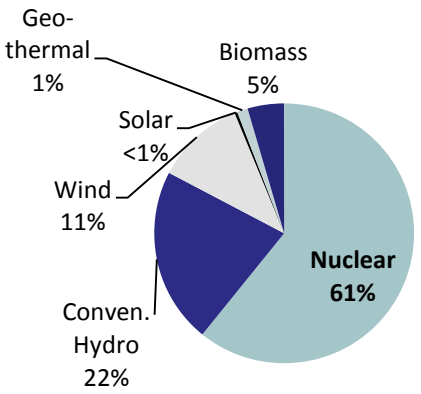
Nuclear Energy Plays an Important Role in US Energy Supply

- **Nuclear power is a clean, reliable base load energy source**
  - Provides 19% of U.S. electricity generation mix
  - Provides 61% of U.S. emission-free electricity
  - Avoids about 700 MMTCO2 each year
  - Helps reduces overall NOx and SOx levels
- **U.S. electricity demand projected to increase ~28% by 2040 from 2011 levels**
- **100 GWe nuclear capacity - 100 operating plants**
  - Fleet maintaining close to 90% average capacity factors
  - Most expected to apply for license renewal for 60 years of operation
  - Some plants may be vulnerable to premature closure

Electricity Production, 2012



Net Non-Carbon Emitting Sources of Electricity, 2012



Source: Energy Information Administration

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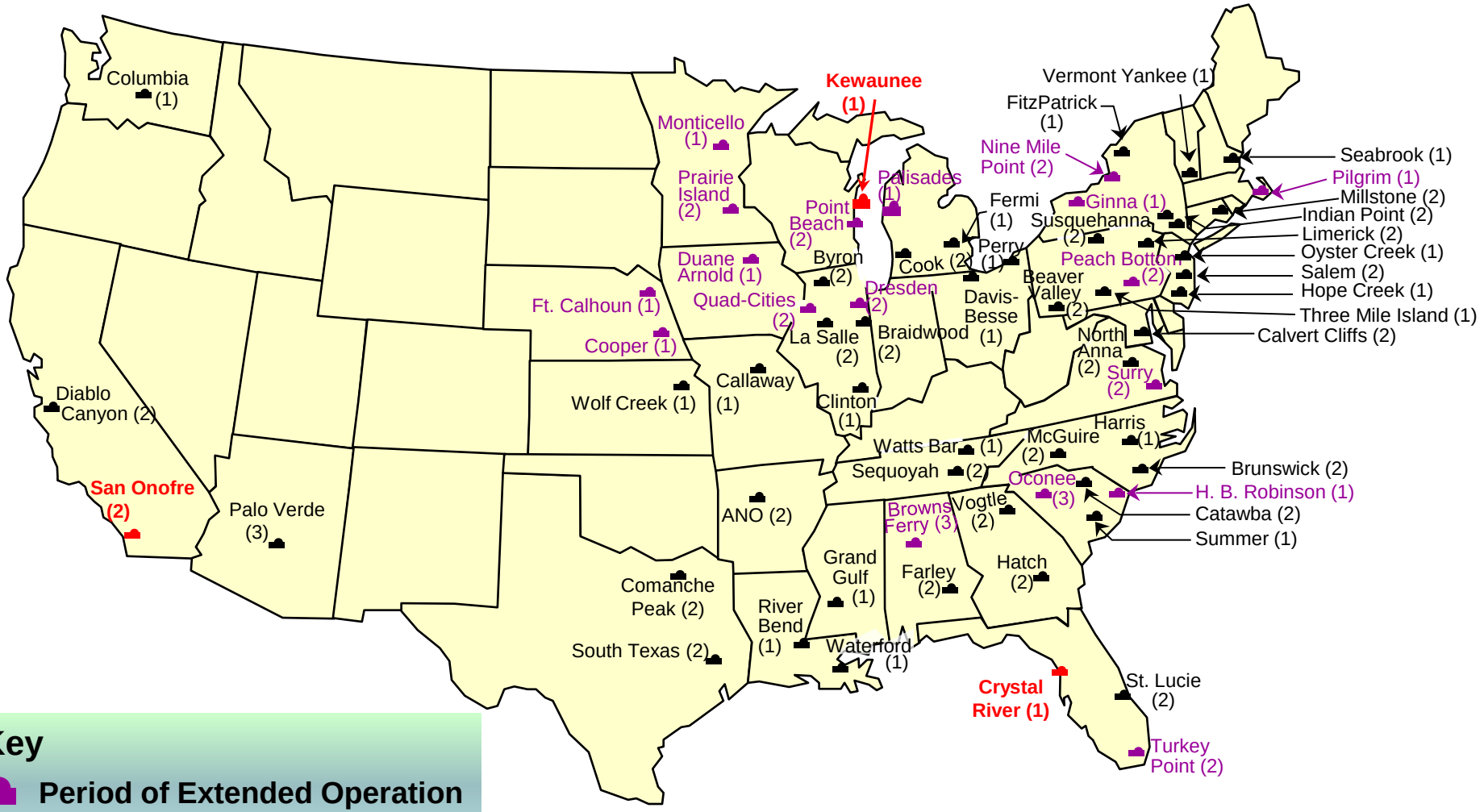
U.S. Nuclear Power Plants in Operation



Key

Period of Extended Operation

Recently shut-down plants

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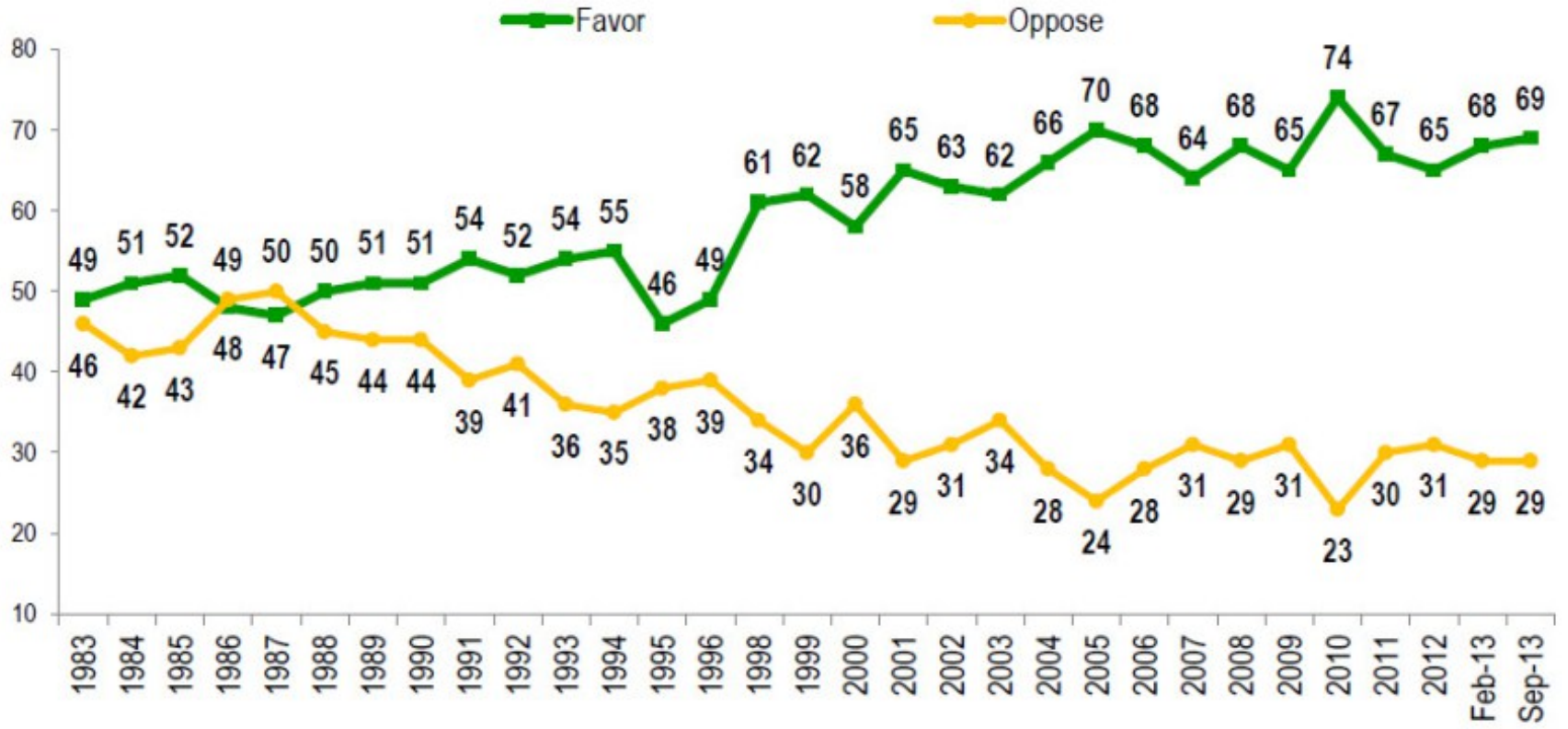
Public Support Increases

Figure 1. Percent Who Favor and Oppose Nuclear Energy: 1983 to 2013

"Overall, do you strongly favor, somewhat favor, somewhat oppose, or strongly oppose the use of nuclear energy as one of the ways to provide electricity in the United States?"



Nuclear Energy Institute-commissioned national public opinion surveys from 1983 to 2013

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U.S. Public See Vital Role for Nuclear Energy

Nuclear Energy Institute Survey

- National survey of public opinion conducted March 2014
- Positive Findings
  - 74% believe nuclear energy will play an important role in meeting the country's future electricity needs, and half believe this importance will increase with time
  - 63% favor the use of nuclear energy as one of the ways to provide electricity in the United States
  - 70% agree that nuclear power plants operating in the United States are safe and secure
  - 82% of respondents favor renewing operating licenses for nuclear power plants that continue to meet federal safety standards
- Misconceptions
  - 25% believe nuclear energy releases no greenhouse gas
  - 28% associate nuclear energy with "climate change solution"

NEI
NUCLEAR ENERGY INSTITUTE

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10-Year Trend of U.S. Nuclear Plant Costs (2012 $ per MWh)

Source: Electric Utility Cost Group (EUCG)

Year	Fuel	Capital	Operating	Total
2002	5.57	3.76	18.58	27.91
2003	5.47	5.02	20.27	30.75
2004	5.10	6.12	19.56	30.78
2005	4.89	6.56	20.27	31.73
2006	4.81	6.42	20.71	31.94
2007	4.98	6.34	20.31	31.62
2008	5.24	7.27	20.78	33.29
2009	5.89	10.58	22.46	38.92
2010	6.67	10.53	22.49	39.69
2011	7.01	11.50	23.34	41.85
2012	7.35	12.96	23.86	44.17

Step Changes: Post-Davis Besse vessel head replacements (esp. 2003), license upgrades and power uprates

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Baseload Power Generation Issues

- **Findings from recent *American Consumer Institute Center for Citizen Research* seminar**
  - Capacity Markets are broken
    - Grid operators are increasing reliance on intermittent sources of energy
    - Investment in baseload generation discouraged
  - Energy markets are distorted
    - Wholesale electricity prices are low and subsidies for other clean sources have further suppressed prices
    - Larger renewable penetration with limited transmission capability will further distort the market

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Today, International Interest in New Nuclear Power is Strong

Energy security
- Nuclear shelters countries from import of costly fossil fuels
- Replacing retired nuclear or coal generation plants

Economic incentives
- Nations rich in fossil fuel would prefer to export those fuels and use nuclear for domestic electricity production

Environmental protection
- Replacing coal with nuclear can alleviate air pollution problems

Climate change concerns
- Nuclear is the “Emission-free” base load generation technology
- Dry condenser cooling possible with SMRs when water usage is restricted

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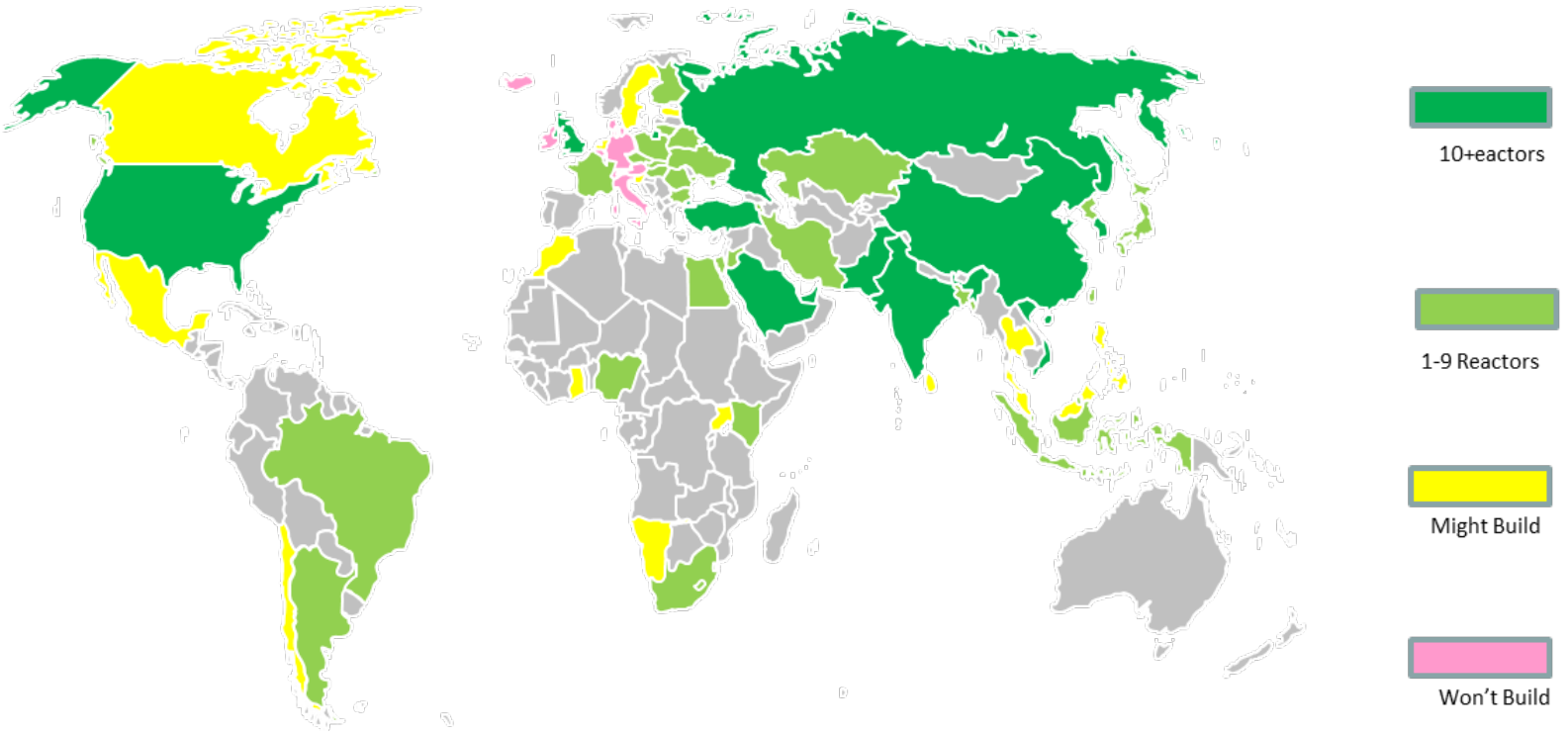
Global Nuclear Construction Plans



- **436 nuclear reactors operating in 30 countries (373 GWe capacity)**
- **71 reactors currently under construction in 15 countries (28 in China)**
- **172 reactors planned in 26 countries over next 8-10 years**
- **309 reactors proposed in 35 countries over next 15 years**

~ Source: IAEA information & news reports

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China is Driving the Nuclear Renaissance

- **Most of China's electricity is produced from fossil fuels**
  - 2014 data shows 80% coal, 2% oil, 1% gas, 15% hydropower & 2% nuclear
- **China has 21 nuclear power reactors in operation, 28 under construction, and more about to start construction**
- **Additional reactors are planned to increase nuclear capacity**
  - Goal is for 58 GWe by 2020, 150 GWe by 2030, and much more by 2050
- **China is largely self-sufficient in reactor design and construction, and other aspects of the fuel cycle, but is making full use of western technology to adapt and improve**
- **China will complete Gen II reactors already under construction, but any new reactors will be at least Gen III**

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Countries with Commercial Reactors Considering New Builds

Country/ market	Reactors (Under construction and planned)	GDP (2013 est) Billions US$ (PPP)	Grid (installed capacity, 2011)	Earliest Deployment (Operational)	Note
China	88	$13,390	1,100 GWe	Ongoing	Construction
India	28	$ 4,990	237 GWe	Ongoing	Construction
Czech	2	$ 286	20 GWe	2026	Discussion
Brazil	1+	$ 2,416	119 GWe	2015+	Construction
Argentina	1	$ 771	33 GWe	2018	Construction
U.K.	4+	$ 2,387	93 GWe	2018+	Contracts
Bulgaria	1	$ 105	10 GWe	2023	Discussion
U.S.	5+	$16,720	1,052 GWe	2016	Construction
Lithuania	1	$ 67	3.6 GWe	2020+	Contracts

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Countries Planning or Considering Initiating Commercial Nuclear Energy (examples)

Country/ market	Reactors (Under construction and planned)	GDP (2013 est) Billions US$ (PPP)	Grid (installed capacity, 2011)	Deployment Target (Operational)	Note
UAE	4+	$ 270	26.1 GWe	2017	Construction
Vietnam	4+	$ 359	22.0 GWe	2023	Contracts
Turkey	4+	$1.167	53.9 GWe	2021	Contracts
Jordan	1	$ 40	3.4 GWe	2021	Contracts
Bangladesh	2	$ 325	6.4 GWe	2020	Contracts
Poland	6+	$ 814	34.3 GWe	2025	Target
Kenya	TBD	$ 80	1.8 GWe	TGD	Target
Malaysia	TBD	$ 525	28.4 GWe	2021+	Discussion
Morocco	TBD	$ 180	6.4 GWe	TBD	Discussion
Nigeria	TBD	$ 479	5.9 GWe	2025+	Target
Egypt	2+	$ 550	27.8 GWe	2025+	Tender planned
Saudi Arabia	16+	$ 928	51.2 GWe	2022	Tender planned
Namibia	TBD	$ 18	0.4 GWe	TBD	Discussion
Indonesia	TBD	$1,285	41.0 GWe	TBD	Discussion

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Status of New Builds in U.S.

- **Gen III+ designs are a major evolutionary step in large reactor technology**
- **First new reactors being built in U.S. in 30 years**
- **Nuclear construction**
  - Watts Bar 2015
  - Vogtle late 2017
  - V.C. Summer 2018 - 2020
- **Challenges of nuclear deployment**
  - High capital cost
  - Lower electricity demand
  - Low natural gas prices
  - Post – Fukushima safety concerns
  - Waste Management

Construction of Vogtle Unit 3,
August 2014 ©Georgia Power Company

SCE&G Places First Ring on V.C. Summer Unit 2
Containment Vessel, June 2014 ©SCE&G

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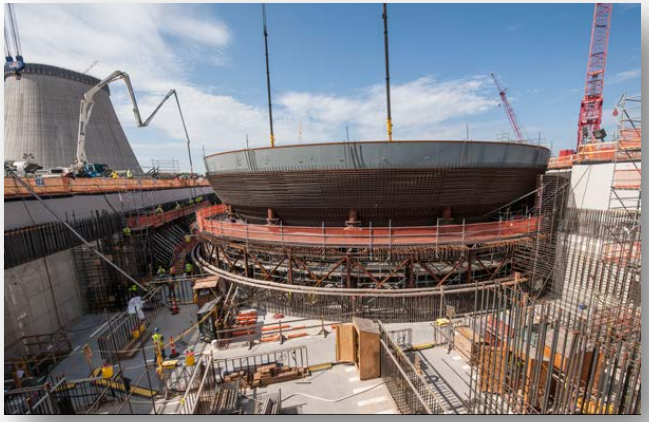
AP1000 Construction Worldwide

Sanmen – May 2014

Source: SNPTC

Haiyang – May 2014

Source: State Nuclear Power Engineering Feng Qingyi Wang Jinjie.



VC Summer – June 2014

Source: SCE&G

Vogtle – July 2014

Source: Georgia Power Co.

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Secretary Moniz Announces $6.5 Billion Vogtle Loan Guarantee

"The construction of new nuclear power facilities like this one - which will provide carbon-free electricity to well over a million American energy consumers - is not only a major milestone in the Administration's commitment to jumpstart the U.S. nuclear power industry, it is also an important part of our all-of-the-above approach to American energy as we move toward a low-carbon energy future…

The innovative technology used in this project represents a new generation of nuclear power with advanced safety features and demonstrates renewed leadership from the U.S. nuclear energy industry."

CA20 module inside Vogtle Unit 3 nuclear island
August 2014 ©Georgia Power Company

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SMRs can be Game Changers

Secretary Moniz addresses the Intermountain Energy Summit, August 20, 2014

"Small Modular Reactors represent a new generation of safe, reliable, low-carbon nuclear energy technology and provide a strong opportunity for America to lead this emerging global industry."

"We are committed to fostering the safe and secure contribution of nuclear power to the global energy mix."

~ IAEA International Conference on Nuclear Security – July 1, 2013

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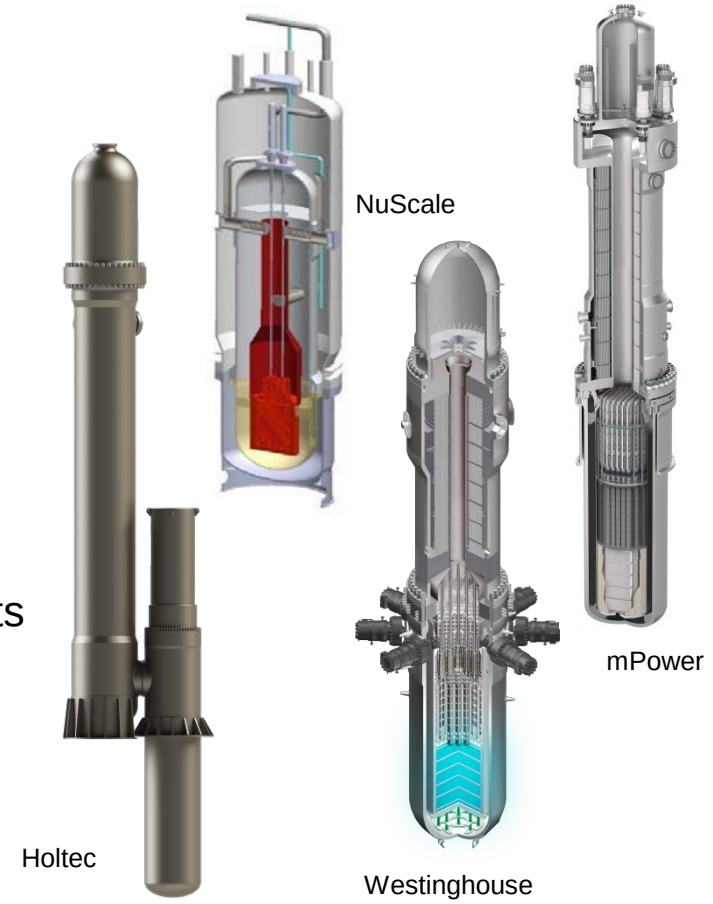
SMR Technologies are of Great Interest

Safety benefits

- Passive decay heat removal by natural circulation
- Simplified design eliminates/mitigates several postulated accidents
- Below grade reactor sites
- Potential for reduction in Emergency Planning Zone

Economic benefits

- Reduced financial risk
- Flexibility to add units
- Right size for replacement of old coal and other plants
- Frees up hydrocarbons for export or reduce need for fuel imports
- Job and skill creation



mPower and NuScale have been selected for the Department of Energy $452M SMR Licensing Technical Support Program

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Status of SMR Licensing Technical Support Program

B&W mPower

- Cooperative Agreement established with team consisting of B&W, Bechtel, and TVA in April 2013
- Initial DOE commitment of $101 M through March 2014
- DOE is working with B&W to establish a path forward for the mPower project

~Courtesy of B&W mPower

NuScale Power

- Selection of NuScale announced on December 12, 2013
- Cooperative Agreement signed May 27, 2014
- DOE to fund up to $217 M for NuScale SMR development
- DCA submittal currently planned for 2nd half of 2016

~Courtesy of NuScale

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SMRs are being Developed Globally

- **Russia**
  - KLT-40S is a 35 MWe barge mounted PWR - Available for commercial deployment
  - Other SMR designs: VBER-150/300, VK-300, ABV & SVBR-100 (lead-bismuth variant)
- **Korea**
  - SMART is a 90-100 MWe PWR
    - Plan to begin operation of a Demonstration plant in 2017
    - Would be used for electricity and/or non-electric applications such as desalination
- **China**
  - ACP100 is a 100 MWe PWR
    - Plan to begin construction of a 2 module plant in 2015
    - Would be used for electricity, heat or desalination
  - HTR-PM is a High Temperature Gas-Cooled Reactor
    - First nuclear concrete December 2012
- **Argentina**
  - CAREM-25 is a 27 MWe PWR
    - Plan to complete construction of a prototype in 2017
    - Would be used for electricity, desalination or as a research reactor
    - Full scale 200 MWe CAREM reactor to follow in early 2020's

~ How a power plant based on the CAREM reactor could look courtesy of Invap

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Generation IV International Forum

Generation I

Big Rock Point, GE BWR

Early prototypes

- **Calder Hall** (GCR)
- **Douglas Point** (PHWR/CANDU)
- **Dresden-1** (BWR)
- **Fermi-1** (SFR)
- **Kola 1-2** (PWR/VVER)
- **Peach Bottom 1** (HTGR)
- **Shippingport** (PWR)

Generation II

Diablo Canyon, Westinghouse PWR

Large-scale power stations

- **Bruce** (PHWR/CANDU)
- **Calvert Cliffs** (PWR)
- **Flamanville 1-2** (PWR)
- **Fukushima II 1-4** (BWR)
- **Grand Gulf** (BWR)
- **Kalinin** (PWR/VVER)
- **Kursk 1-4** (LWGR/RBMK)
- **Palo Verde** (PWR)

Generation III / III+

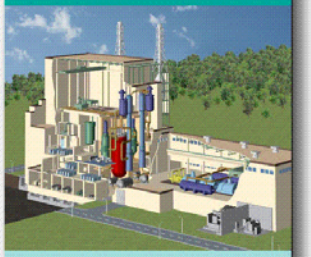
Kashiwazaki, GE ABWR

AP1000, Westinghouse PWR

Evolutionary designs

- **ABWR** (GE-Hitachi; Toshiba)
- **ACR 1000** (AECL CANDU PHWR)
- **AP1000** (Westinghouse-Toshiba PWR)
- **APR-1400** (KHNP PWR)
- **APWR** (Mitsubishi PWR)
- **Atmea-1** (Areva NP -Mitsubishi PWR)
- **CANDU 6** (AECL PHWR)
- **EPR** (AREVA NP PWR)
- **ESBWR** (GE-Hitachi BWR)
- **Small Modular Reactors**
  - Atomenergoproekt PWR
  - B&W mPower PWR
  - Holtec SMR-160 PWR
  - India DAE AHWR
  - KAERI SMART PWR
  - NuScale PWR
  - Westinghouse SMR PWR
- **VVER-1200** (Gidropress PWR)

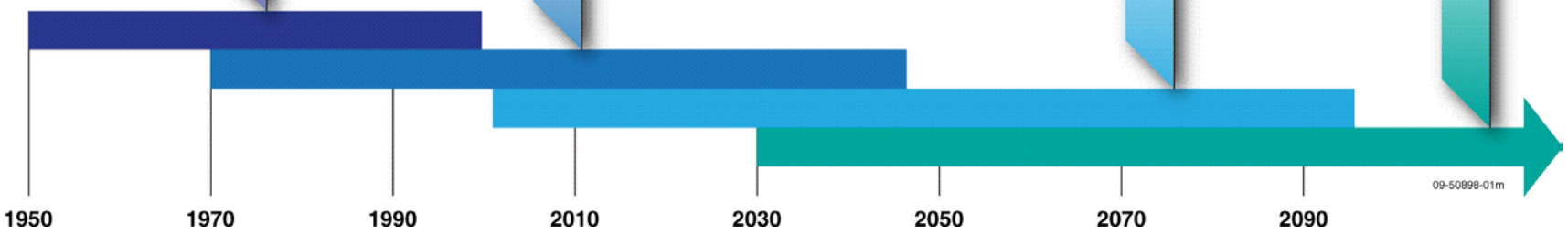
Generation IV



Japan Sodium Fast Reactor, ASTRID

Revolutionary designs

- **GCR** gas-cooled fast reactor
- **LFR** lead-cooled fast reactor
- **MSR** molten salt reactor
- **SFR** sodium-cooled fast reactor
- **SCWR** supercritical water-cooled reactor
- **VHTR** very high temperature reactor



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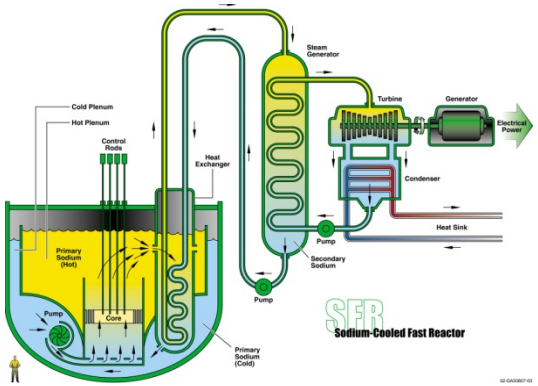
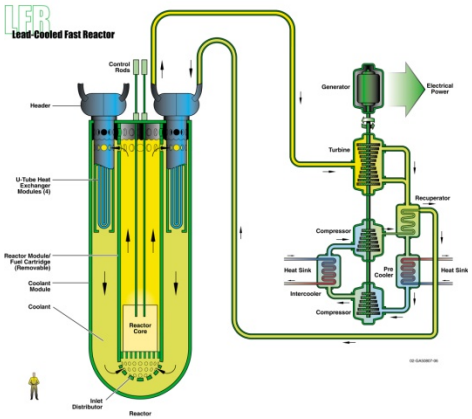
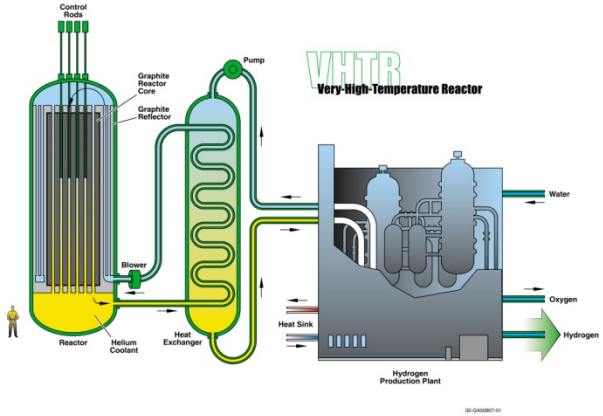
Generation IV Reactor Concepts



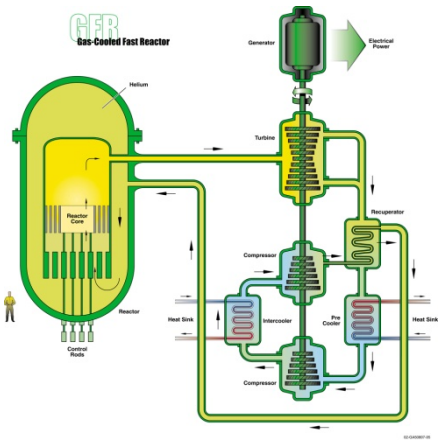
Sodium Fast Reactor



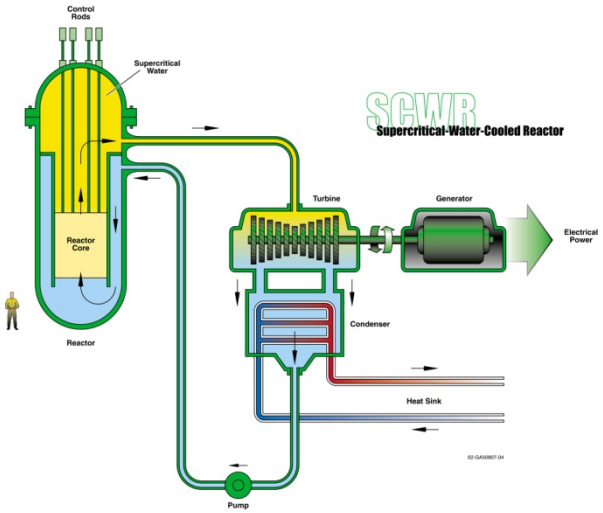
Lead Fast Reactor



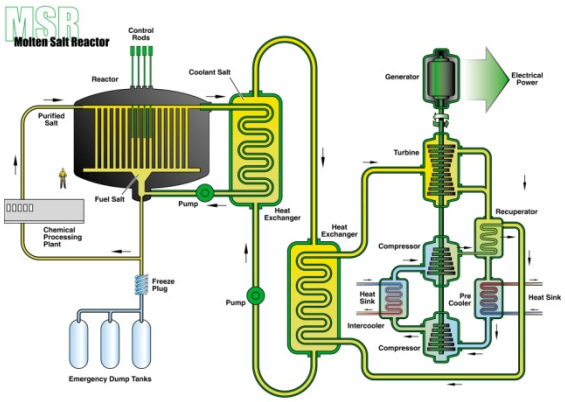
Very High Temperature Reactor



Gas Cooled Fast Reactor



Supercritical Water Cooled Reactor



Molten Salt Cooled Reactor

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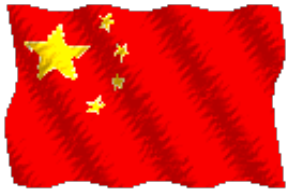
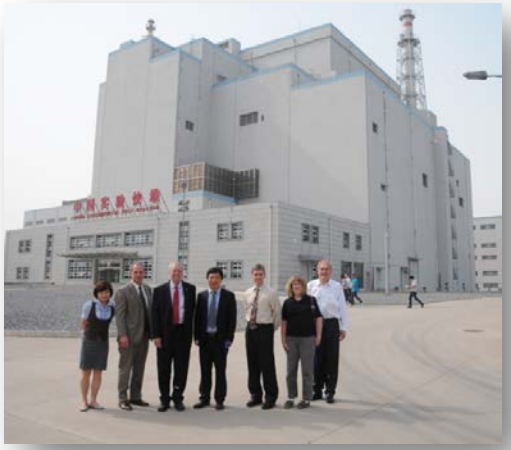
Gen IV Nuclear Construction in China

- **Operation of Chinese Experimental Fast Reactor (20 MWe Test Reactor)**
  - Startup in 2010 – 2011, Fully operational in 2014
- **Design of Chinese Prototype Fast Reactor**
- **Construction of demonstration High Temperature Gas Reactor**
  - 210 MWe Plant which consists of twin 250 MWt Pebble Bed HTR-PMs
  - Basemat pour completed March 29, 2014
  - Scheduled to start electricity generation by the end of 2017
- **Design of a small Fluoride Salt Cooled Reactor**





CEFR Finished

The construction site of the first HTR-PM at Shidaowan (Image: CNEC)

China's HTR-PM, Shidao Bay-1

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Gen IV Nuclear Construction in Russia

- **Completion of BN-800 Reactor**
  - First criticality date - June 27, 2014
- **Design of BN-1200 Gen IV SFR**
  - Competitive economics to LWRs
- **Design of MBIR test reactor to replace BOR-60**
- **Demonstration project on lead-bismuth LFR**

Beloyarsk-4 July 2014

Assembling a reactor in the 'clean area' of the BN-800 power unit at the Beloyarskaya NPP (RIA Novosti / Pavel Lisitsyn)

Refuel floor during the recent first-time fueling of BN-800 (Rosatom)

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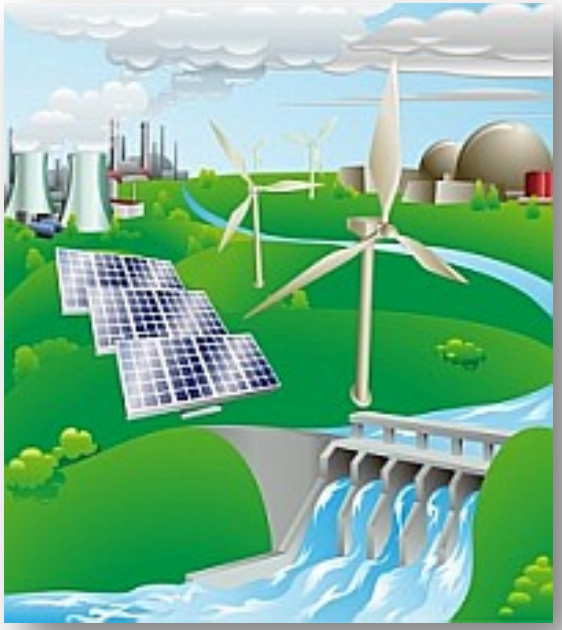
Summary

- **Strong international interest**
  - Energy
  - Climate & Environment
  - Economic
- **Current construction**
  - China is leading the nuclear renaissance
  - USA is making good progress in new builds
- **SMRs can be game changers**
- **Generation IV deployment is longer term**



"Investing in clean energy isn't a decision that limits our economic potential; it's an opportunity to lead the global clean technology markets that are forming right now."

~ Secretary Moniz at National Press Club, February 1, 2014