Role of Washington State in Developing Advanced Nuclear Energy Options

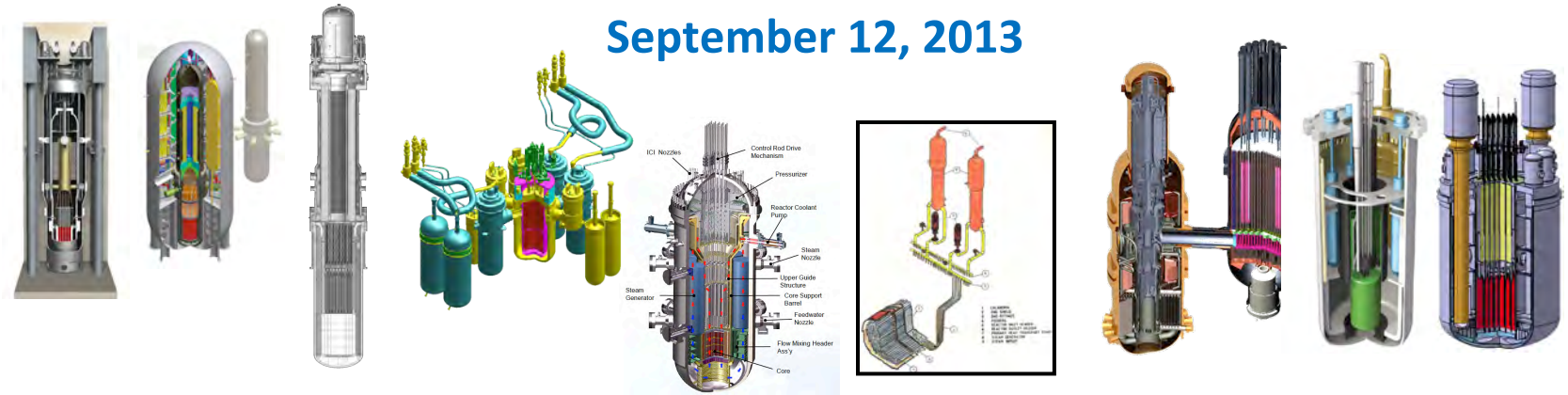
Alan Waltar

Past President, American Nuclear Society

Washington State Academy of Sciences

6th Annual Meeting and Symposium

September 12, 2013



Outline

I. Current Nuclear Energy International

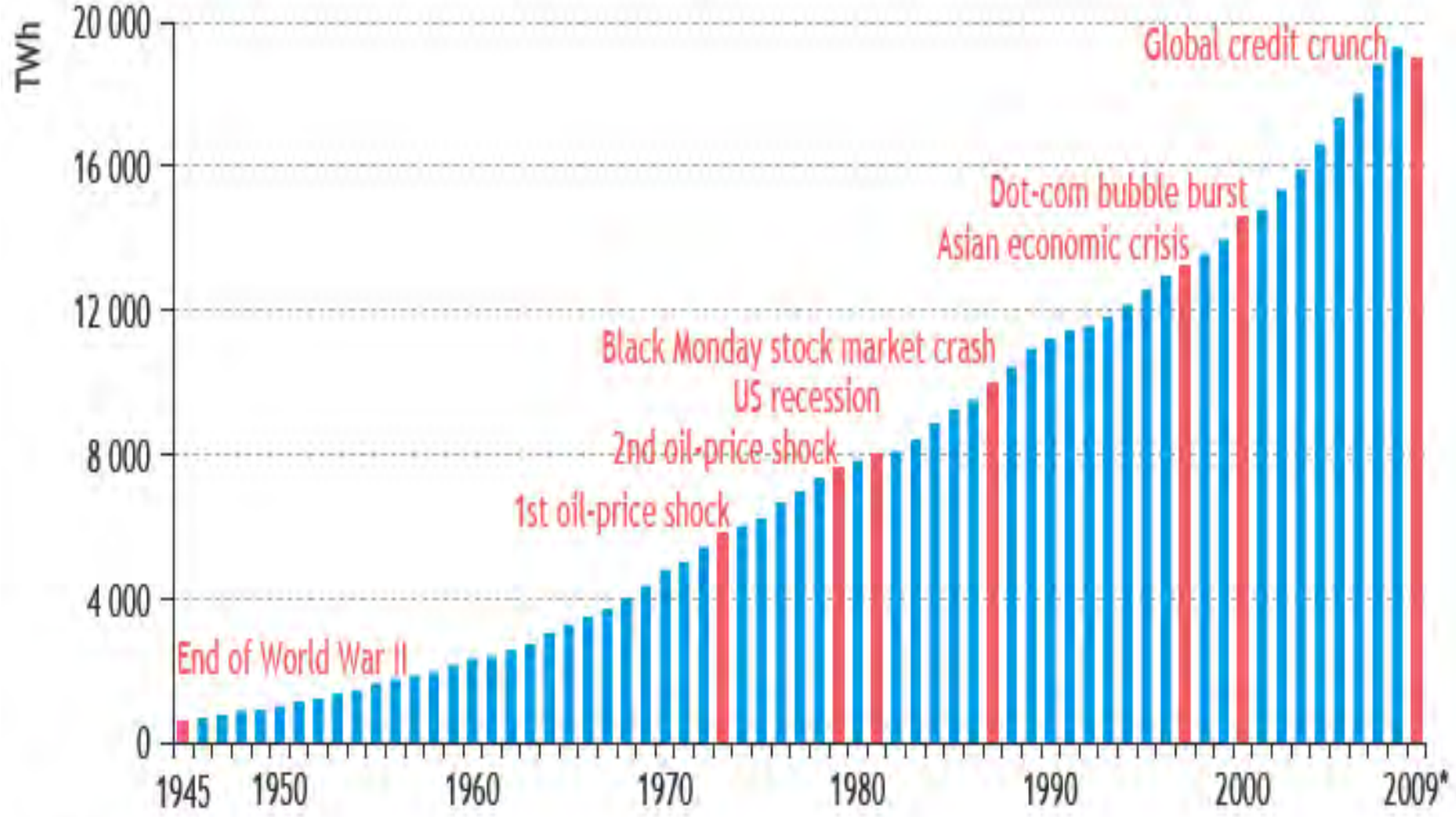
II. WA State Electricity Futures

III. Washington State's Unique Design

IV. New Interest in Small Modular Reactors (SMRs)

V. Potential WA State Leadership Role

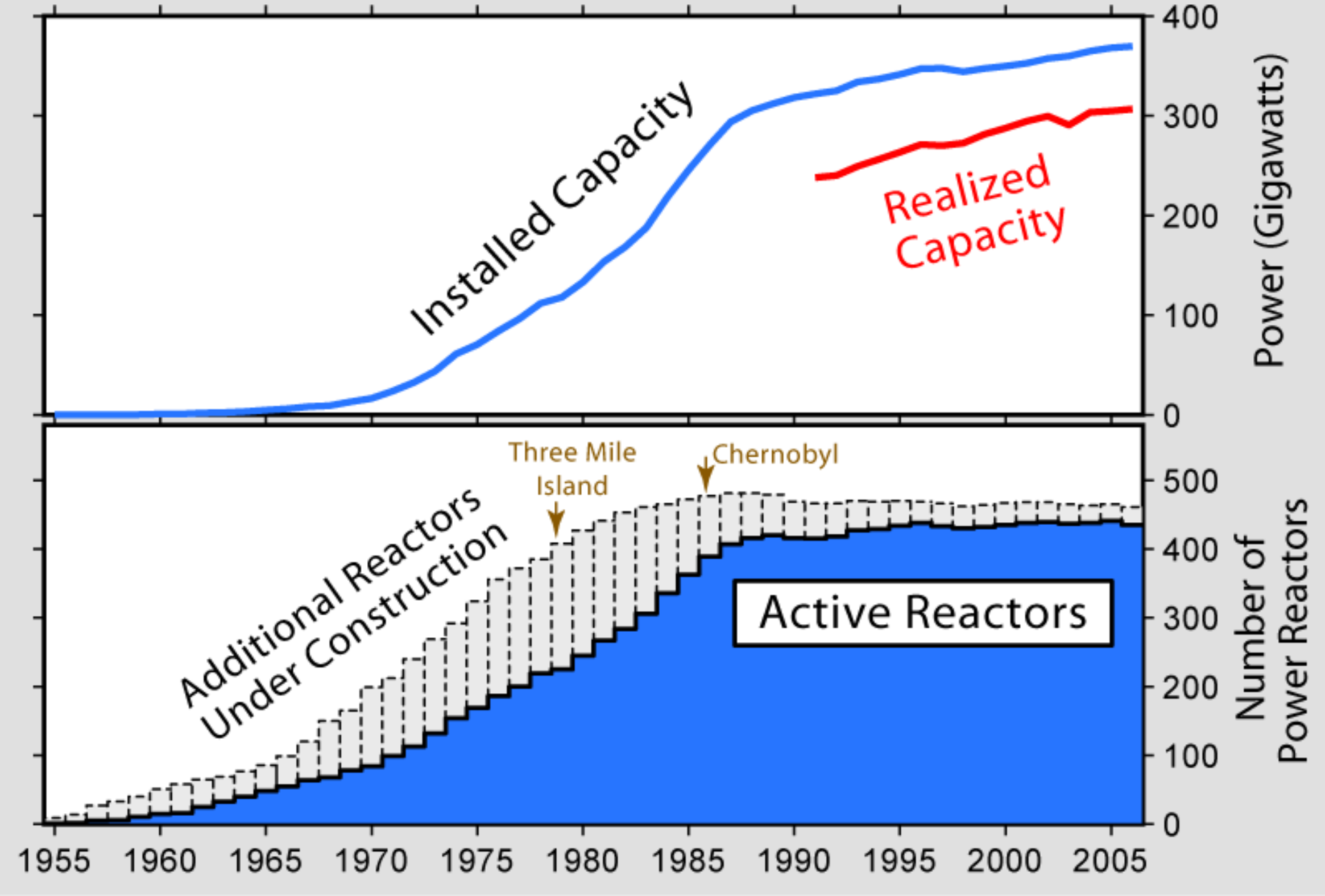
Historical world electricity consumption



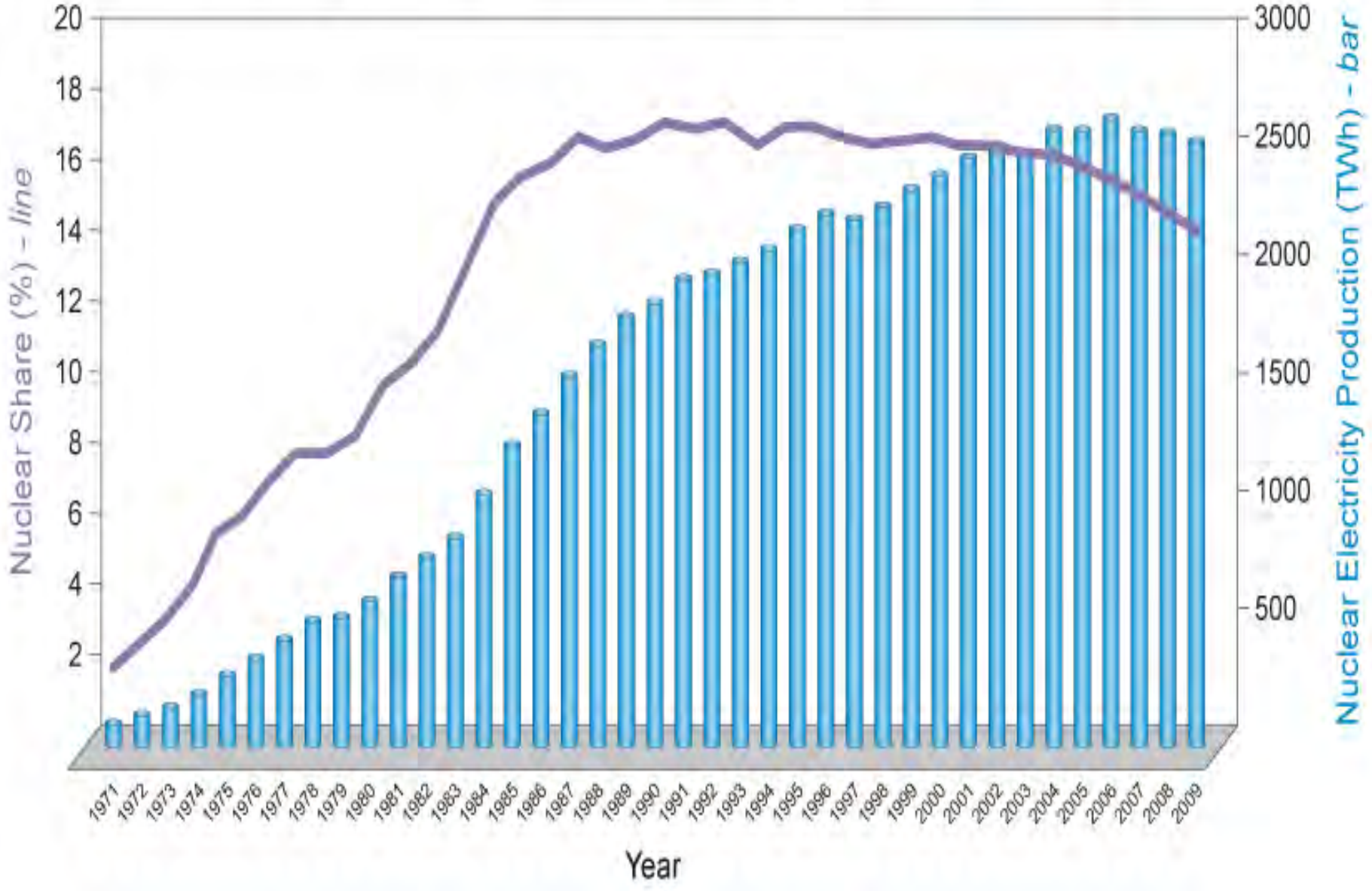
* IEA estimate.

Source: IEA databases and analysis.

History of the Global Nuclear Power Industry



Nuclear Electricity Production and Share of Total Electricity Production



Current Global Nuclear Power Scene

EUROPE

- Finland: Building a new plant
- Russia: Doubling planned by 2020
- France: Building new plants
- UK: Going back to nuclear
- Sweden: Going back to nuclear
- Japan: Reassessing
- Germany: Phasing out

ASIA

- China: 5-fold growth planned by 2020
- India: 100-fold growth planned by mid-century

CHINA: 29 Nuclear Power Plants Now Under Construction!

Table from 4 years ago

NPP	Type	Power (MWe)	Status
Qinshan-1	PWR	300	Operation
Qinshan-2	PWR	2×600	Operation
	PWR	2×600	Construction
Qinshan-3	PHWR	2×720	Operation
Daya Bay	PWR	2×900	Operation
Lingao	PWR	2×944	Operation
	PWR	2×944	Construction
Tianwan	PWR	2×1000	Operation
Sanmen	PWR	2×1000	Planned
Yangjiang	PWR	2×1000	Planned
Hongyanhe	PWR	2×1000	Construction
Haiyang	PWR	2×1000	Planned
Fuqing	PWR	6×1000	Suggestion
Ningde	PWR	6×1000	Suggestion




INDIA: 17 Operating Stations

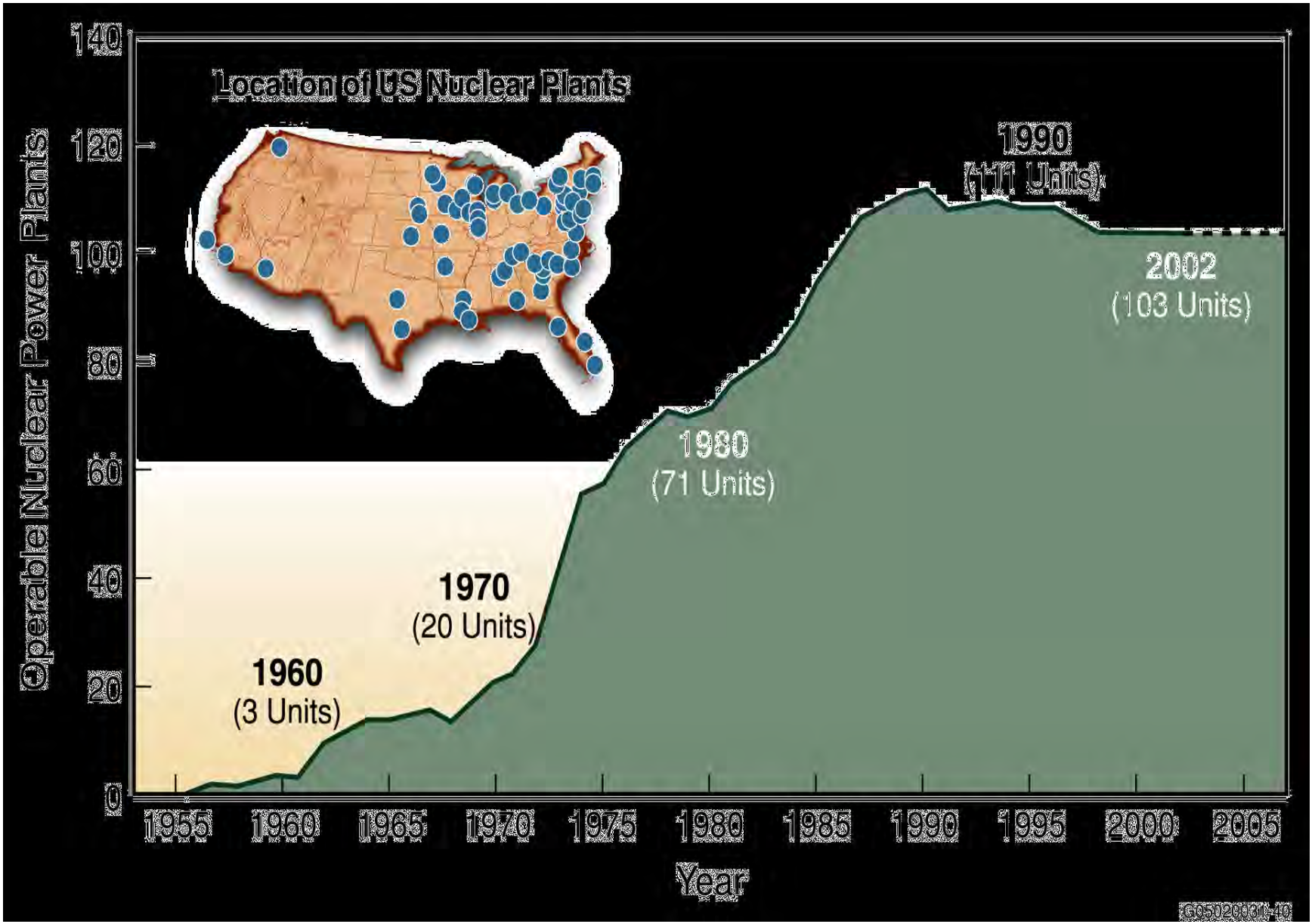
TAPS-1&2 (2 x 160 MWe)	Oct., 1969/ Oct., 1969
TAPS-3&4 (2 x 540 MWe)	Jul., 2006/ Sept., 2005
RAPS-1&2 (100 & 200 MWe)	Dec., 1973/ April 1981
RAPS-3&4 (2 x 220 MWe)	Jun., 2000/ Dec., 2000
MAPS-1&2 (2 x 220 MWe)	Jan., 1984/ Mar., 1986
NAPS-1&2 (2 x 220 MWe)	Jan., 1991/ Jul., 1992
KAPS-1&2 (2 x 220 MWe)	May, 1993/ Sept., 1995
KGS-1&2 (2 x 220 MWe)	Nov., 2000/ Mar., 2000
KGS-3 220 MWe	MAY 2007

6 NPPs Under Construction



The American Scene

History of U.S. operating plants prior to Fukushima



What About the State of Washington? Should We Consider More Nuclear?

- **After the WPPSS debacle**
  - -- Largest default in history
  - -- You've got to be kidding!

…and then Fukushima…

- **Just one nuclear power plant is now operating in the State (Energy Northwest)**
  - -- Output equivalent to power all of Seattle

So What are our Options?

- **HYDRO:**
  - --We are very fortunate to have vast amounts of hydroelectric power (Lowest power rates in the nation)
  - --But, large future electricity blocks from hydropower are very limited
- **COAL:**
  - --Being phased out—Huge environmental issues
- **Natural gas**
  - --very cheap (due to new fracturing techniques)
  - -- but not environmentally compatible
  - -- cheap prices will not last forever (finite resource)
- **Renewables (wind and solar power)**
  - -- currently the favored options

Can Renewables Solve our Future Electricity Growth Challenges?

- **Short answer: NO---Not Alone!**
- **Utilities can only accept ~ 20% of intermittent power on the grid (without huge, expensive storage systems)**
- **Substantial Base Load Power is Essential**

German Example with Solar

- Renewables championed in Germany for over a decade
- **Ave. cost for electricity now 32 cents/KW-hr**
  --10 times the cost in our State!
- **~800,000 Germans have cut off power**
  -- too expensive
- **Siemans planning to close its solar division**
  --loss of $1.5 billion

Do we want this for our State?

New Nuclear Plant in Finland

- **Most expensive nuclear plant ever built**
  - **Estimated total cost ~ $15 billion**
- **Still only 7 cents/KW-hr**

  --One-fourth Germany's cost
- **By the way: *NOBODY* killed or injured from radiation release from the Fukushima accident!**

Implications of the Near Halt in Construction of New Nuclear Power Plants in Last Couple Decades

- **Key Professionals Retired or Lost to Industry**
- **Few Professionals Coming into the Industry**
- **Manufacturing Plants Shut Down**

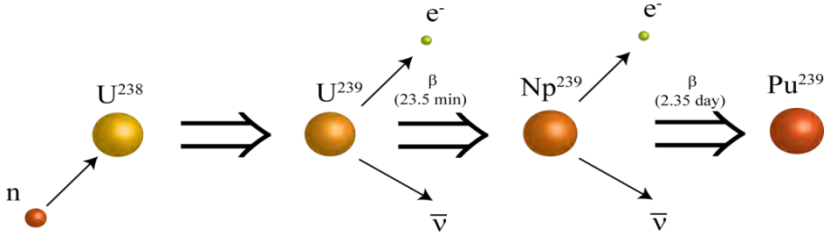
- **Hence, New Construction Cost Much Higher in the Renaissance that began about 5 years ago**
- **Utilities now strapped to spend ~$5B on new, large plants**

Washington State's Unique Design
The Traveling Wave Approach

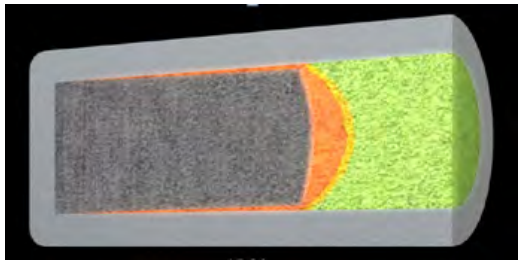
- **A Concept Originally Proposed by**
  Edward Teller

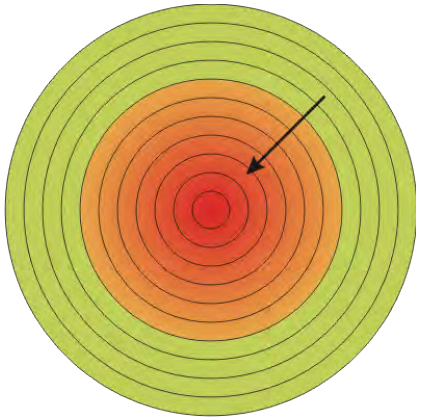
- **Substantially Developed by TerraPower in Seattle, Washington (USA)**
  --- Funding Supplied by Bill Gates

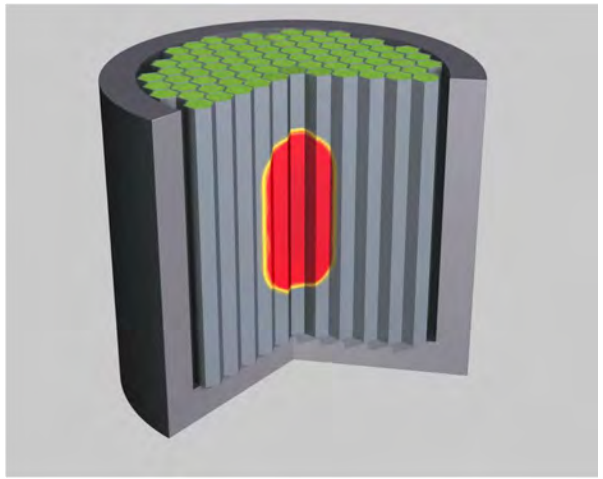
What is the TWR?
Fuel from Available *Depleted* Uranium



Breeds and burns depleted uranium or discharged LWR fuel
Fueled once and can burn up to 40+ years
Weapons proliferation resistant.







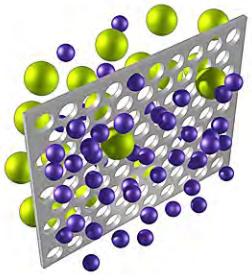
The "Traveling Wave" evolved to a conventional geometry
Assemblies are shuffled within a reactor vessel, limited access

Compliments of Doug Adkisson, TerraPower Corp.

Current Nuclear Fuel Cycle

Uranium mining and milling

Conversion to uranium hexafluoride

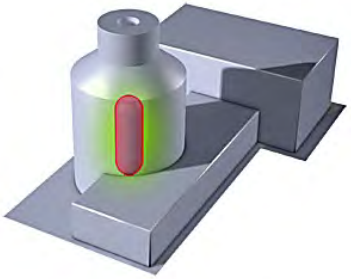


Uranium enrichment

Fuel fabrication

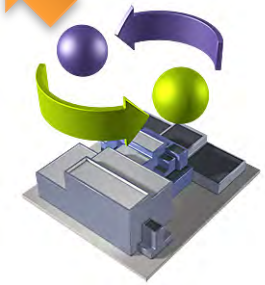
Depleted uranium storage

Nuclear power generation

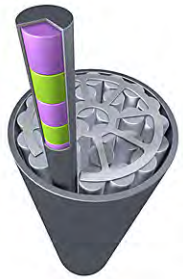


Spent fuel storage

Reprocessing



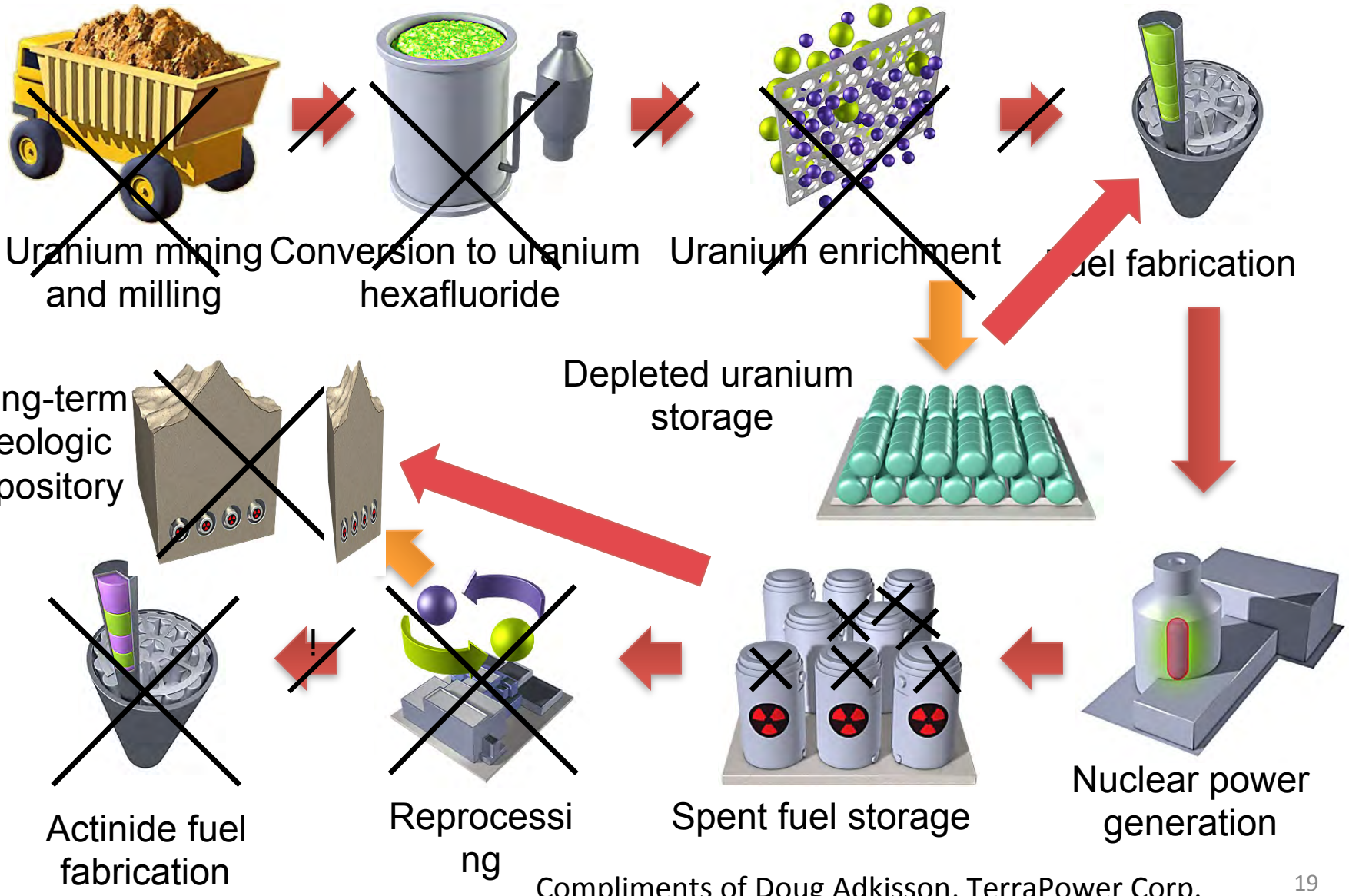
Actinide fuel fabrication



Long-term geologic repository

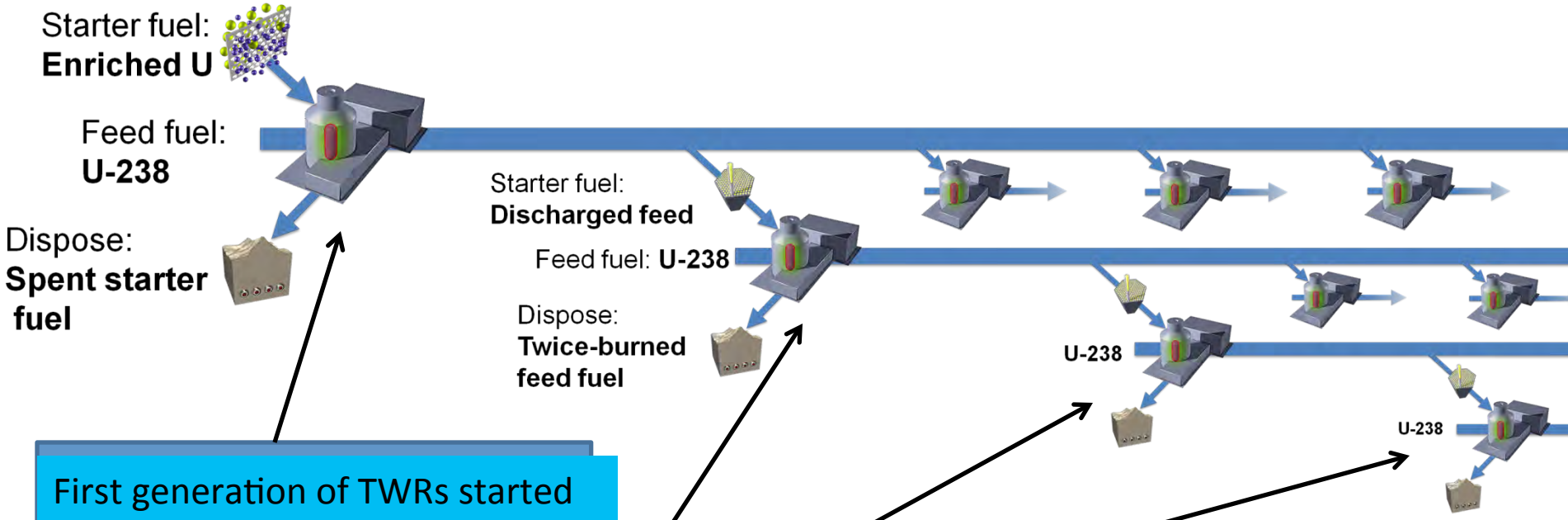
Compliments of Doug Adkisson, TerraPower Corp.

TWR Simplified Fuel Cycle



Compliments of Doug Adkisson, TerraPower Corp.

The TWR can Create Starter Fuel for Subsequent Plants



First generation of TWRs started with **enriched uranium**

Second and subsequent generations started with **recycled feed fuel** from previous generations

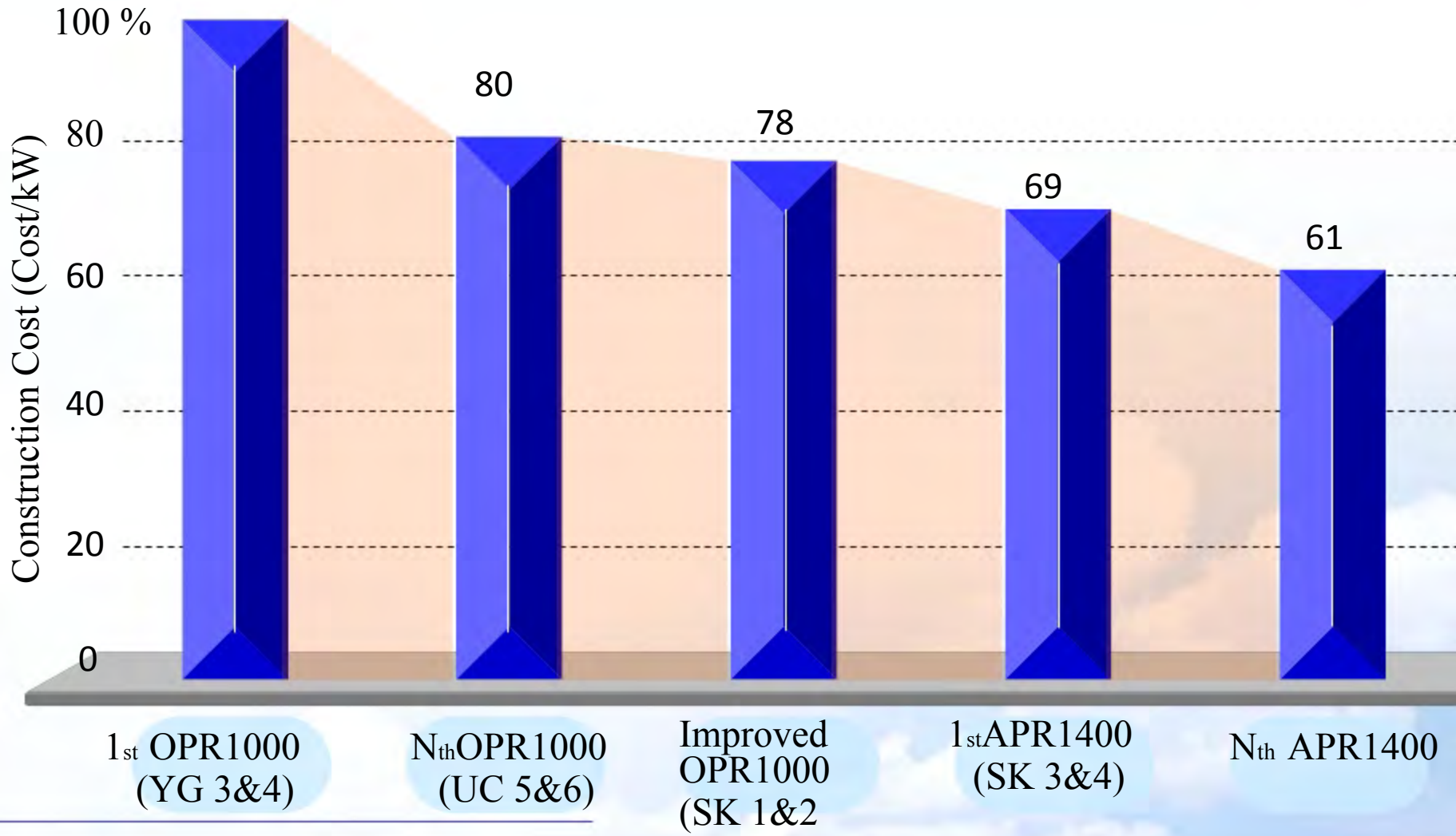
Every reactor is capable of running indefinitely on depleted uranium

Compliments of Doug Adkisson, TerraPower Corp.

Principal Challenges of TWR

- **Very High Burnups and dpa Required**
  (approximately twice the current data base)
- **High Sodium Void Worth**
- **Sophisticated Fuel Shuffling Required**
- **Large Size Necessary to Support Breeding**

Nuclear Power Plant Construction Costs in Korea



Why?
How is Korea Different?

Two Main Reasons:

- **Top Federal Support for past half-century**
- **Stayed the Course after Chernobyl**

UAE Nuclear Power contract

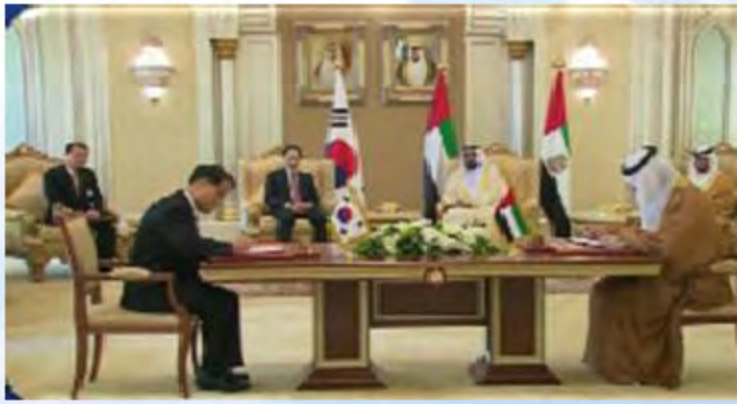
- **NPP turnkey package contract**




Contract worth

- **$ 20 billion +**

- **Completion schedule**
  - **2017 - 2020**



But for most other nations, including the United States…

- **New Construction Cost Much Higher in the Renaissance that began about 5 years ago**
- **Utilities now "bet the farm" on new, large plants**

Hence, Small Modular Reactors (SMRs) now of Current Interest

- Reduced capital costs per plant
- Meet electrical growth incrementally
- Shorter construction schedules (modular construction)
- Enhanced safety and security (some Fukushima influence)
- Improved quality (in-factory construction)
- Replace aging coal plants
- Re-establish U.S. leadership (largely lost during last two decades)
- Create good domestic jobs
- Serve international markets (with limited electrical infrastructure)

Drivers for utility interest in SMRs

Affordability

- Smaller up-front cost
- Better financing options

Load demand

- Better match to power needs
- Incremental capacity for regions with low growth rate
- Allows shorter range planning

Site selection

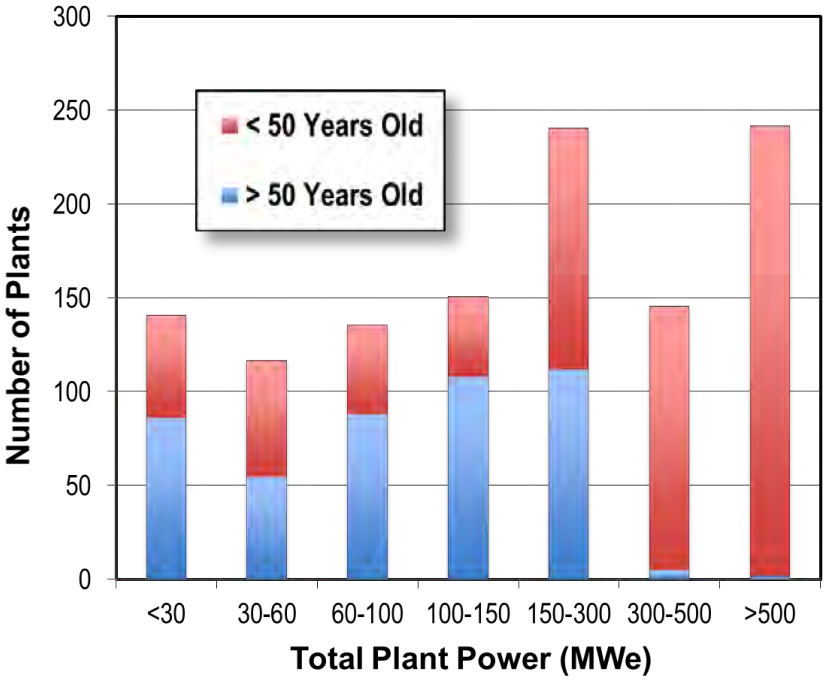
- Lower land and water usage
- Replacement of older coal plants
- Potentially reduced emergency planning

Grid stability

- Closer match to traditional power generators
- Smaller fraction of total grid capacity
- Potential to offset non-dispatchable renewables

U.S. Coal Plants

Plants >50 yr old have capacities Less than 300 MWe



Economic Challenges Facing SMRs

- Significant investment needed to reach commercialization
  - On the order of $500 M + per design
- Can the plants be built cheaply enough?
  - Economies of replication > economies of scale?
  - Need a factory to make the price attractive
  - Need an attractive price to produce the orders to warrant building the factory
- Can the operations and maintenance costs be kept down?
  - Will simplified "inherently safe" designs translate into smaller workforce & operation cost & comply with regulatory requirements?

Licensing Challenges Facing SMRs

- **The Nuclear Regulatory Commission (NRC) not currently staffed with the required technical expertise**
  - **Time and money required to develop staff**
  - **Potentially very long licensing time**

- **Difficult for the NRC to allocate the resources if there is no serious utility buyer**
  - **"Chicken and the egg" syndrome**
  - **May need Congressional direction and funding**

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Office of Advanced Reactor Concepts
Small Modular Reactor Program

DOE Small Modular Reactor Program

--Enable the deployment of a **fleet of SMRs** in the United States

– SMR Program is a new start program for FY 2011

– Conduct needed R&D activities to advance the understanding and demonstration of innovative reactor technologies and concepts

SMR Program Elements:

– **LWR SMR Licensing Technical Support ($452M/5-year program)**

- **Public-Private Partnerships for design certification & licensing activities**

– **SMR Advanced Concepts R&D**

- **Conduct R&D on innovative technologies/systems/components and support Generic licensing work**
- **Collaborate with NRC on SMR licensing framework to support SMR commercialization**

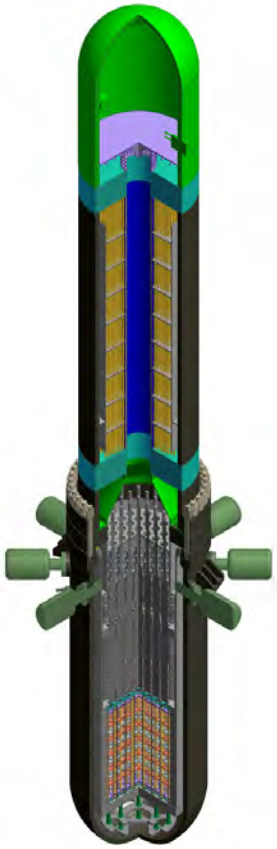
DOE Actions to date in funding SMRs

- mPower Reactor (Babcock and Wilcox design) to be sited at Clinch River); funded for up to $500K over 5 years

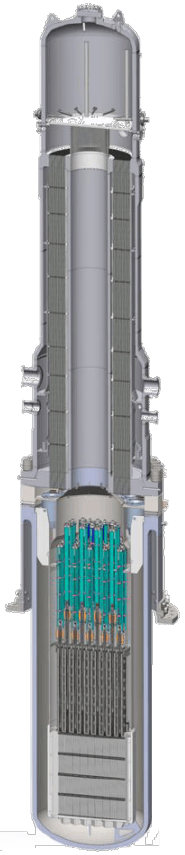
- A second Funding Proposal has been issued

U.S. LWR-based SMR designs for electricity generation

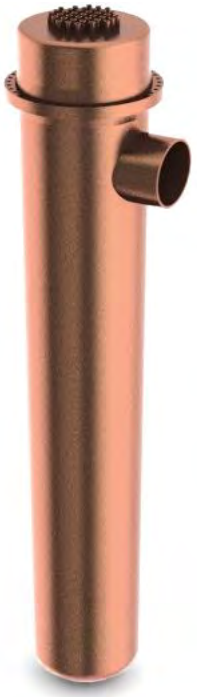
Light Water Reactor



SMR (Westinghouse)
225 MWe



mPower (B&W)
180 MWe



HI-SMUR (Holtec)
160 MWe

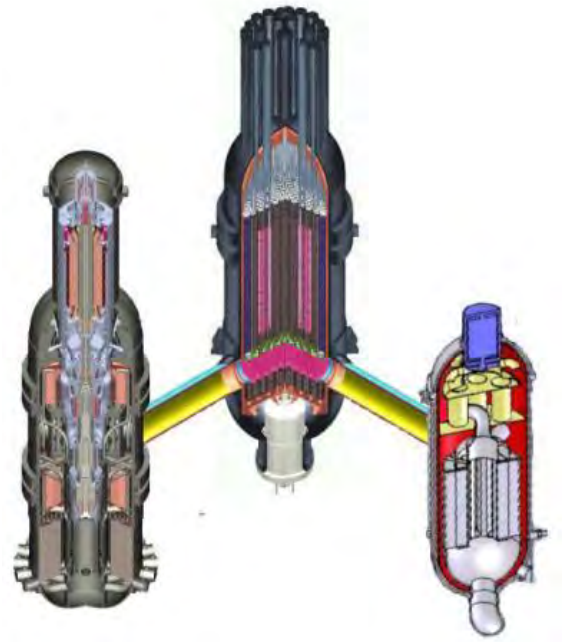
NuScale (NuScale)
45 MWe

Compliments of Dan Ingersoll

Gas-cooled reactor designs

Able to provide high-temperature process heat

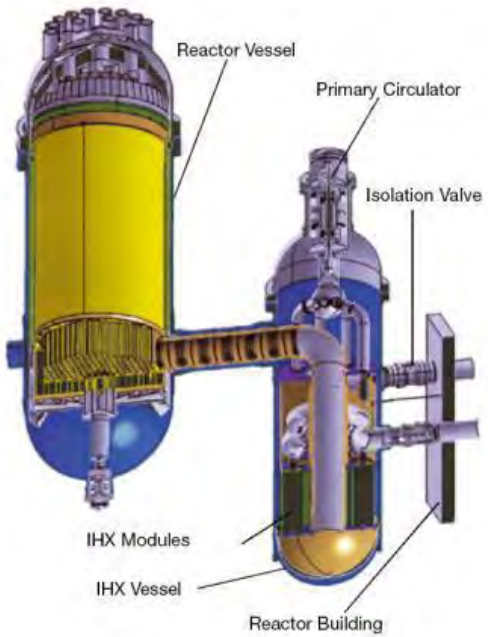
American Design



MHR (General Atomics)

280 MWe

French Design



ANTARES (Areva)

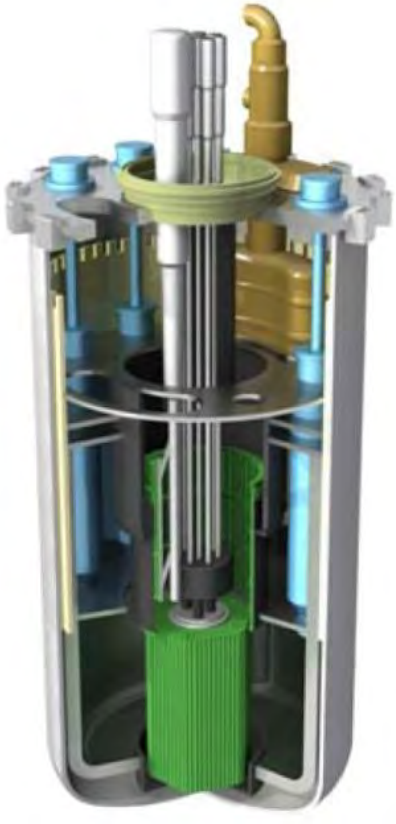
275 MWe

Fast spectrum reactor designs (Liquid Metal Cooled)

Able to provide improved fuel cycles

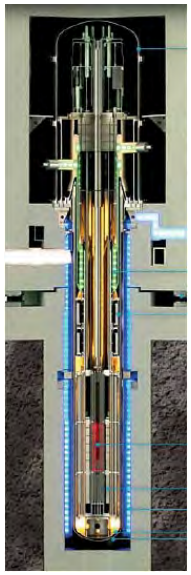
…….Sodium-Cooled……

…Lead-Bismuth Cooled…



PRISM (General Electric)

300 MWe



4S

(Toshiba, Japan)

10 MWe

SVBR-100

(AKME Engineering, Russian Federation)

100 MWe

IAEA Report

Status of Small and Medium Sized Reactor Designs

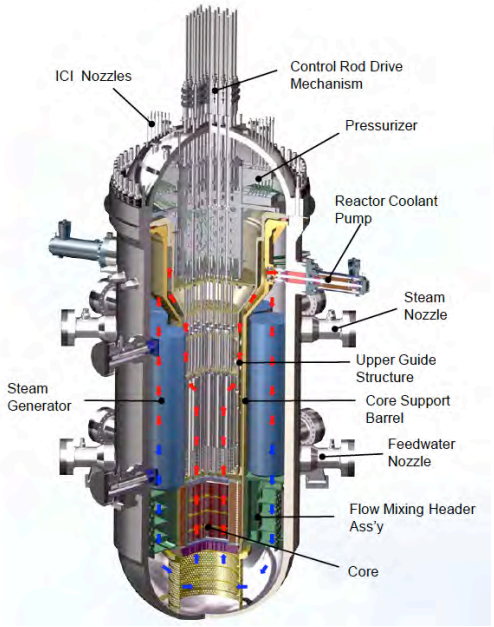
September 2012

- Light Water Cooled 18
- Heavy Water Cooled 3
- Gas Cooled 4
- Liquid Metal Cooled 7

TOTAL = 32

Two SMRs On Track to be Deployed

SMART



Korea

Integral PWR
100 MWe

Status: Approved by the Korean Licensing Authorities

ACP-100

China

Integral PWR
100-150 MWe

Status: Detailed design; construction starting in 2015

The World is Moving Ahead…
With or Without the United States!

How can we in Washington State benefit from SMRs?

- Add new base load power in small blocks
- Replace aging coal plants
- Eventually build the LargeTerraPower plants

MAIN NEAR-TERM GOAL:

- Utilize DOE Hanford site for demonstration
  - Letters of support from both senators
  - Letter of support from House legislative leaders
  - Letter of support from Governor

Hanford is an Ideal Location to Demonstrate a SMR

- Hanford has experience with "*First of a Kind Reactors*"
- DOE-RL needs additional 100 MWe from BPA by ~2020
- NRC Approved Site on DOE leased land with licensed operator
- $50M savings in existing infrastructure
- Qualified workforce
- Public support
- **Community Economic Stabilization**

Specific Opportunity at Hanford

Site a 100 MWe Fast Reactor

- Right size for Vit. Plant and PNNL needs in ~2020
- Build on an approved site (next to Energy Northwest)
- Utilize ~ $500 M funding from replacement of oil-fired unit originally envisioned for Vit. Plant

•Columbia Basin Consulting Group/SKBE Team

- Signed MOU/NDE to build upon Russian SVBK-100 technology
- Lead/Bismuth cooled reactor (8 Russian submarine experience)
- Demo plant now being built in Russia
- Impressive safety features
- Initial dialogue with DOE and NRC cautious but supportive

Overall Artist's View of SVBK-100 Being Built in in Dimitrovgrad

SOURCE: http://www.bellona.org/articles/articles_2011/volga_smallcapacity

Conclusions

- The interest in SMRs is growing rapidly throughout the world

- If the U.S. intends to remain a leader in the nuclear power field, it needs to become aggressive in developing and constructing SMRs

- Washington State could be a leader
  - Site a Demo Plant at Hanford
  - Produce many high-paying jobs
  - Develop a factory for numerous follow-on plants

BACKUP

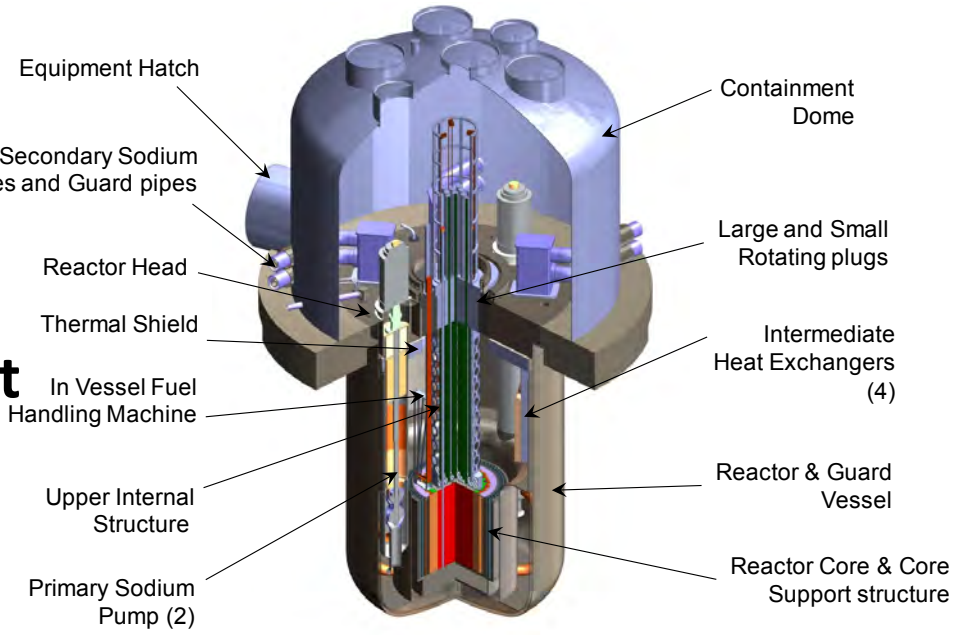
TWR-P Project

TWR prototype plant:

- First electricity producing TWR – Startup about 2023
- Demonstrates key plant equipment
- Verifies operational performance
- Bases for 600 & 1150 MW_e plants
- Last step of fuel and material qualification

Design features included for additional testing & development

- Lead test fuel assemblies
- Capability for post irradiation fuel examinations
- First-of-a-kind instrumentation, maintenance considerations



Compliments of Doug Adkisson, TerraPower Corp.

TWRs are More Environmentally Beneficial

Safety Cost **Environment** Proliferation Security

- Uses depleted uranium or waste from LWR
- Greatly reduced uranium mining
- Significantly less enrichment needed; none later
- No reprocessing facilities required
- At least 7X less high level waste relative to LWR
- Waste retained in the reactor; delayed external storage for up to 40 years
- Waste disposal footprint smaller and permanent

Compliments of Doug Adkisson, TerraPower Corp.

Nuclear Power:
Current status (as of July 2010)

- 437 nuclear power plants in 29 States
- 55 under construction
- expansion centered in Far East and South Asia

IAEA

President Obama: U.S. Nuclear Power

"We must harness the power of nuclear energy on behalf of our efforts to combat climate change, and to advance peace opportunity for all people."

President Obama, Prague, April 2009

folks want wind and solar. Others want nuclear, clean coal and natural gas. To meet this goal, **we will need them all** -- and I urge Democrats and Republicans to work together to make it happen."

President Obama, State of the Union, January 25, 2011

AFTER Fukushima… Administration continues to publicly support nuclear power

President Obama at Town Hall Discussion on Energy in Fairless Hills, Pennsylvania (April 6, 2011)

"I want us to double the amount of electricity that we draw from clean sources. I want us to double it. And that means by 2035, 80 percent of our electricity will come from renewables like wind and solar, as well as efficient natural gas, clean coal, nuclear power. We can do that."