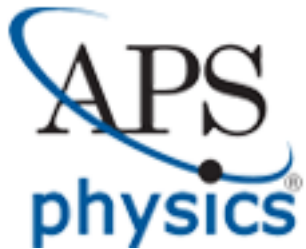
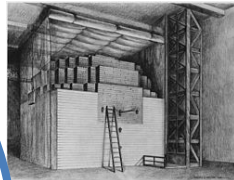


APS ENERGY RESEARCH WORKSHOP PROGRAM



A Strategy for U.S. Nuclear Power: Changing the Game with Small Modular Reactors- Is this a “Sputnik Moment?”



Fermi

Small Modular Reactors



Fubini



Victor H. Reis
Senior Advisor
Office of Undersecretary for Science
U.S. Department of Energy
victor.reis@science.doe.gov

Examples

1. Space: Sputnik, Apollo and U.S. Manned Space
 - Develop a Strategic Planning Perspective
2. Nuclear Deterrence: Stockpile Stewardship
3. Global Nuclear Energy Partnership (GNEP)

A Strategic Planning Perspective

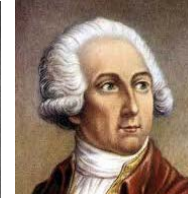




President Obama State of the Union January 25, 2011



Newton



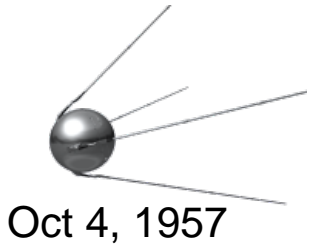
Lavoisier

“Half a century ago, when the Soviets beat us into space with the launch of a satellite called Sputnik, we had no idea how we would beat them to the moon. The science wasn't even there yet. NASA didn't exist. But after investing in better research and education, we didn't just surpass the Soviets; we unleashed a wave of innovation that created new industries and millions of new jobs. This is our generation's Sputnik moment.”

“Some 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.”

“We're telling America's scientists and engineers that if they assemble teams of the best minds in their fields, and focus on the hardest problems in clean energy, we'll fund the Apollo Projects of our time.”

A Strategic Planning Perspective: Sputnik & Apollo



A Cold War Strategy

Vision



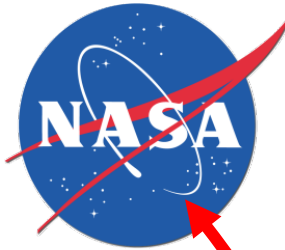
Юрий Гагарин
April 12, 1961



Strategy



Feb 1958



Focus &
Align

July 20 1969
Timely
Goal



May 25, 1961

First, I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth.

Maintain Nuclear Deterrence Without Nuclear Testing:

(Science Based) Stockpile Stewardship

To assure that our nuclear deterrent remains unquestioned under a test ban, we will explore other means of maintaining our confidence in the safety, the reliability, and the performance of our own weapons.



July 1993

Vision



Strategy

Validated Simulation

Validation Experiments

Timely Goal

~ 100 teraflops



Congress



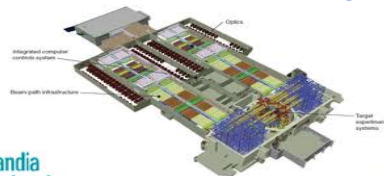
DoD

DOE

Lab Partner with High Performance Computer Industry

Lawrence Livermore National Laboratory

By 2004



NIF



MESA

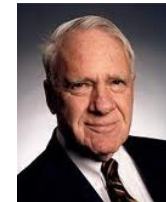
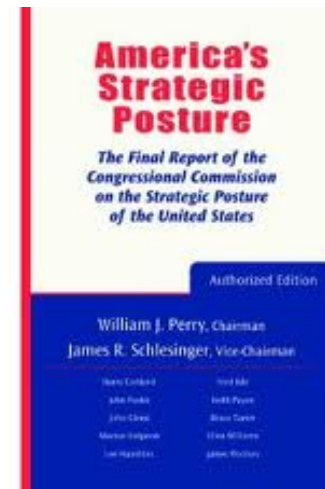


APT/DAHRT



Change from Test to Simulation: Stockpile Stewardship

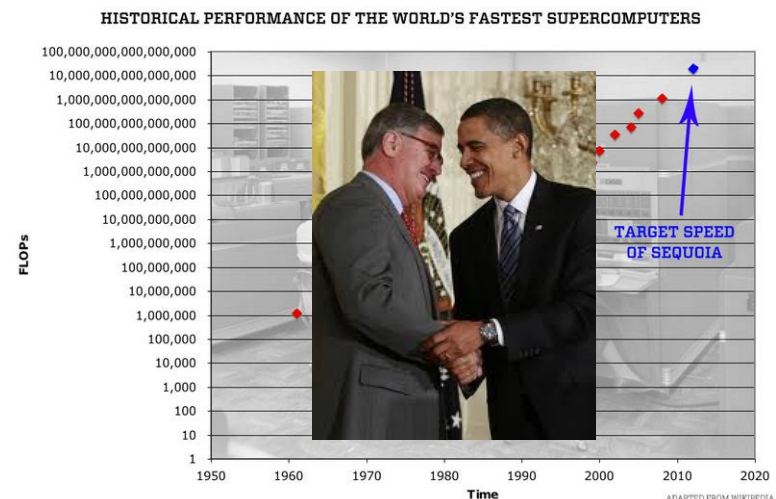
“The Stockpile Stewardship Program has been a remarkable success, much more than originally expected.” *America’s Strategic Posture: Final Report of the Congressional Commission on the Strategic Posture of the United States*. William Perry (Chairman) & James Schlesinger (Vice Chairman), 2009



Elements of “Success”

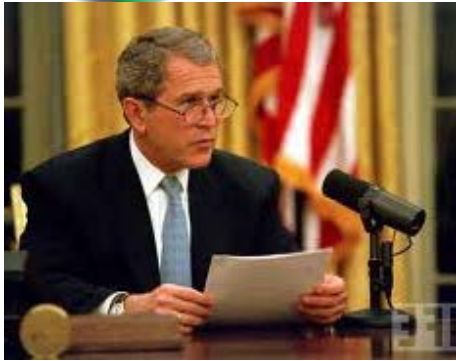
- U.S. Government “owned” the whole problem
 - Well Defined
 - Quantitative goals
- Alignment of Relevant Institutions/Leadership
 - Presidential Urgency
 - World class Labs
 - Commercial Spin-off
 - Top Computer Companies
 - DoD Partner
- Sustained Sufficient Funding
 - Executive
 - Congress

Changed the Game in HPC
Commercial MPP





Civil Nuclear Power Leadership: Global Nuclear Energy Partnership: GNEP



....my Administration has announced a bold new proposal called the **Global Nuclear Energy Partnership**. Under this partnership, America will work with nations that have advanced civilian nuclear energy programs, such as France, Japan, and Russia. Together, we will develop and deploy innovative, advanced reactors and new methods to recycle spent nuclear fuel.

President Bush Feb 18, 2006

National Security Leadership



April 15, 2009: US GNEP programme dead, DOE confirms

President's Vision

Not Aligned:

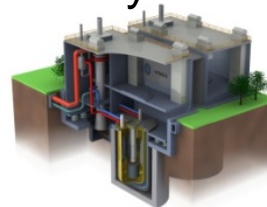
- U.S. Utilities
- U.S Spent Fuel Policy

Strategy

Global Partnership



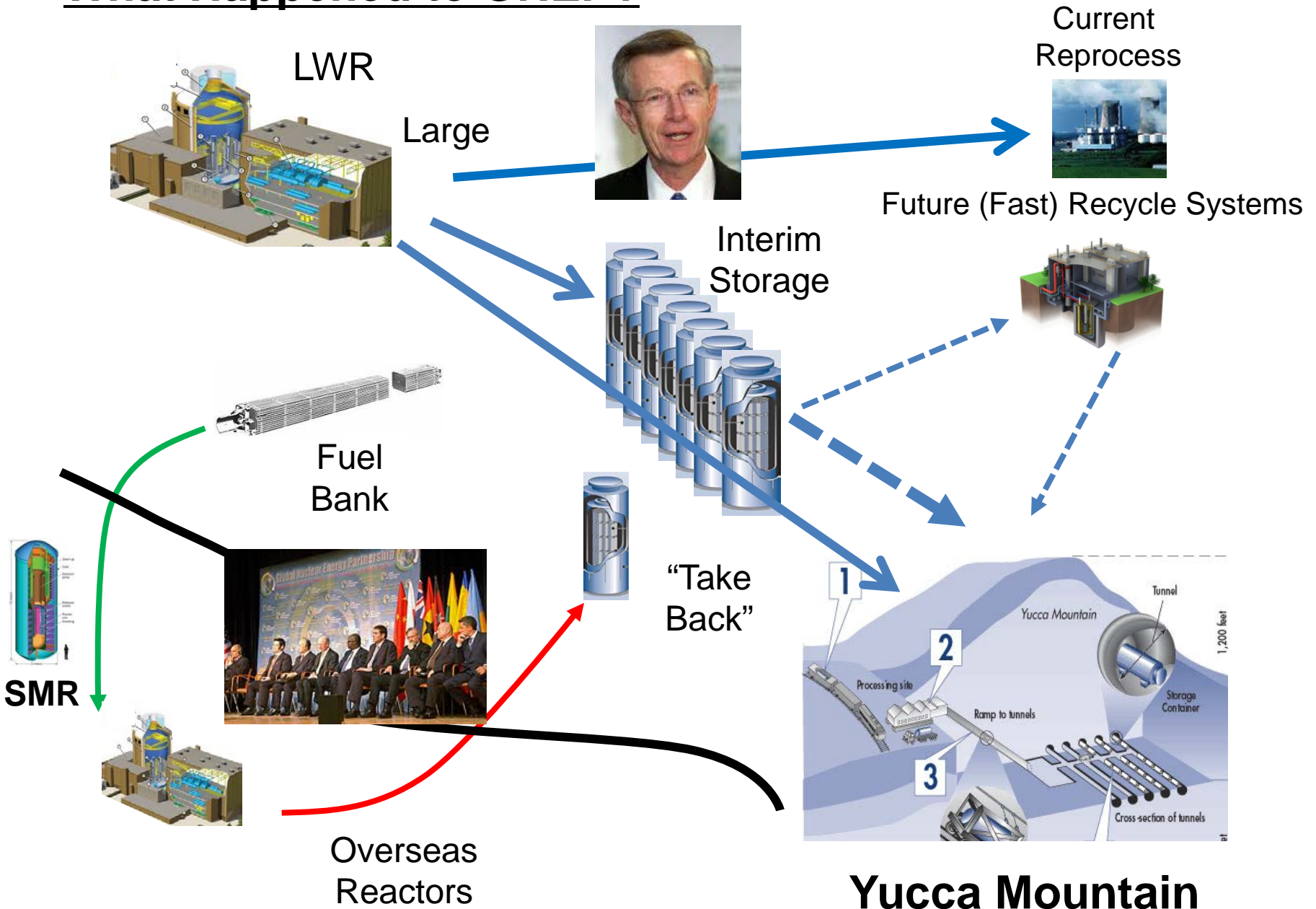
Advanced Reactors/Fuel Cycle



Timely Goal

?

What Happened to GNEP?



Secretary Chu on Small Modular Reactors

•“one of the most promising areas is small modular reactors (SMRs). If we can **develop this technology in the U.S. and build these reactors with American workers, we will have a key competitive edge.** Small modular reactors would be less than one-third the size of current plants. They have compact designs and could be made in factories and transported to sites by truck or rail. SMRs would be ready to "plug and play" upon arrival.

•If commercially successful, SMRs would significantly expand the options for nuclear power and its applications. Their small size makes them suitable to small electric grids so they are a good option for locations that cannot accommodate large-scale plants. **The modular construction process would make them more affordable by reducing capital costs and construction times.**

•Their size would also **increase flexibility for** utilities since they could add units as demand changes, or use them for **on-site replacement of aging fossil fuel plants.** Some of the designs for SMRs use little or no water for cooling, which would reduce their environmental impact.”



*Steven Chu,
Wall Street Journal,
March 23, 2010*



Dec 8, 1997,

Civil Nuclear Power Leadership: Small Modular Reactors

“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's Vision



*President Obama,
Prague, April 2009*



Miller Lyons
June 2010

National Energy & Nuclear Goals

- Climate/Clean Energy
- Energy Security
- Competiveness
- National Security

Strategy

Align U.S. Electricity Sector Goals to National Goals

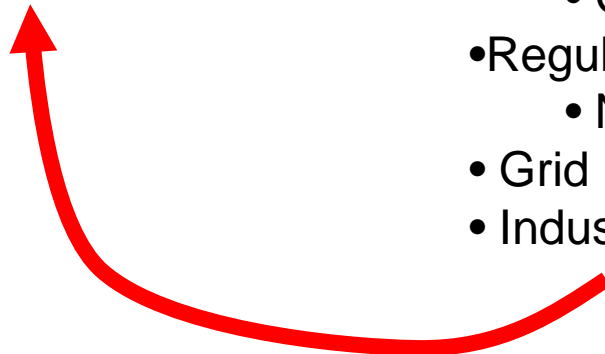
- Consumers
- Utilities
 - Generators
- Regulators
 - NRC
- Grid
- Industrial Base



Timely Goal

“ **By 2035, 80 percent** of America's electricity will come from clean energy sources”

2011
State of the Union



Recent (Strategic) Events

Climate?



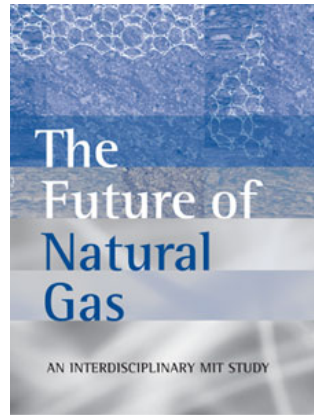
2010 Election



*President Obama
November 3, 2010*

“There's been discussion about how we can restart our nuclear industry as a means of reducing our dependence on foreign oil and reducing greenhouse gases. Is that an area where we can move forward?”

Competition?



SAFETY?

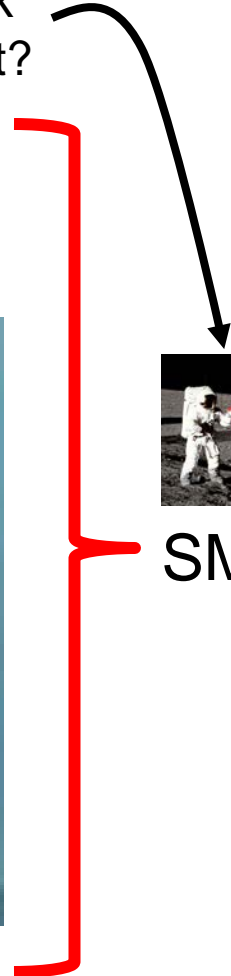


Fukushima
March 11, 2011

Sputnik Moment?



SMR?



Meeting Administration's 2035 80% Clean Energy Standard

Assume: • Weighted Emission Standards: $F_{CE} = 1 - \left[\frac{\sum_i \phi_i E_i}{\sum_i E_i} \right]$

$\Phi = \text{Coal} = 1, \text{Gas} = 0.5, \text{CCS} = 0.1$

• Renewable and CCS goals met

<u>Source</u>	Elect (TWhr)	CO₂ (Gton)	Elect (TWhr)	CO₂ (Gton)	Elect (TWhr)	CO₂ (Gton)	
Coal	1800	1.85	2100	2.1	400	0.4	Replace Coal
Coal (CCS)	0	0	0	0	200	0.02	
Natural Gas	785	0.4	1030	0.5	1200	0.5	
Nuclear (Large)	800	0	870	0	1000	0	
Nuclear (SMR)	0	0	0	0	1000	0	A lot ~130 GW Fast ~ 10 GW/yr
Hydro	250	0	250	0	250	0	LWR, LEU
Renewable	130	0	320	0	650	0	
Petroleum	40	0.04	0	0	0	0	
TOTAL	3800	2.3	4570	2.9	4600	0.92	

2010 U.S Electricity Consumption and CO₂ Emissions. *EIA, Fce = 0.42*

EIA Reference Projections 2035 Fce=0.43

Assumed 2035 electricity production to meet “clean energy” standard, *Fce = 0.8*

Align Civil Nuclear Sector with National Goals

Currently: 104 Reactors 100 GW 800 TWhrs

Last Ground Breaking - 1973

U.S. Utilities' Strategy: A Culture of Prudence

- Maintain (extraordinary) High Performance
- Extend Lifetime of Current Reactors
- Buy New (Gen 3) Reactors when Licensed & Cost Competitive
 - Westinghouse (Toshiba) : 1150 MW
 - GE/Hitachi : 1350 MW, 1600 MW
 - AREVA: 1650 MW
 - Mitsubishi: 1540 MW

Passive
Safety

U.S. Government: Multiple Agencies – Mixed History

- Spent Fuel - DOE/NRC/EPA
- Safety/Security- NRC
- Environment - EPA
- Proliferation - DOE/NNSA



Yucca Mountain

Blue Ribbon Commission on
America's Nuclear Future



Scowcroft

- DOE Nuclear Power 2010
 - Cost Share Design Certification & License (Completed)
- Loan Guarantees
- R&D on Advanced Concepts

DOE/SMR
Program

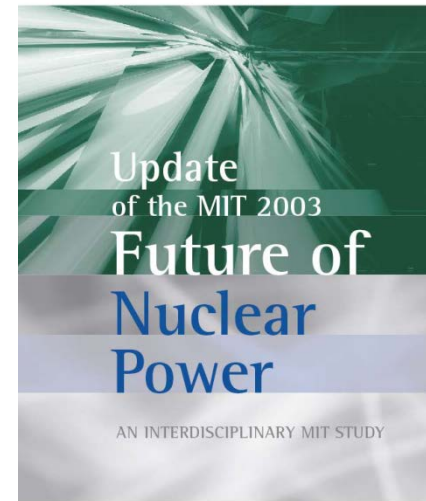


Align with Utilities Strategy:

Affordable (Consumers), Reliable and Profitable

Large Plant Investment
\$10B, >5yrs ???

“Nuclear power can be economically competitive under appropriate market conditions”



“Levelized Cost of Electricity” Cost of Carbon

	Overnight Cost	Fuel Cost	Base Case	\$25/Ton CO ₂	= Cost of Capital
\$2007	\$/KW	\$/MBTU	¢ KWhr	¢ KWHR	¢ KWhr
Nuclear	4000	0.67	8.4		6.6
Coal	2300	2.6	6.2	8.3	
Gas	850	4/7/10	4.2/6.5/8.7	5.1/7.4/9.6	

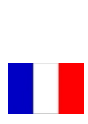
Loan Guarantees for large plant “first movers”

Current Deployment of Nuclear Power in U.S.

Ownership of Publicly Listed U.S Nuclear Reactors

Holding Company	MWe	unit	maj	own	Mkt Cap B	Revenue	Debt	Assets
Exelon Corp.	16,715	19	17	13	\$ 28.5	\$ 18.6	\$ 12.9	\$ 52.2
Entergy Corp.	10,129	11	11	10	\$ 12.0	\$ 11.5	\$ 11.8	\$ 38.7
Dominion Resources, Inc.	5,691	7	7	4	\$ 28.4	\$ 15.2	\$ 17.6	\$ 42.8
NextEra Energy, Inc.	5,470	8	8	5	\$ 24.4	\$ 15.3	\$ 20.8	\$ 53.0
Duke Energy Corp.	5,173	6	5	5	\$ 25.4	\$ 14.3	\$ 18.4	\$ 59.1
FirstEnergy Corp.	3,862	12	2	0	\$ 18.5	\$ 13.3	\$ 14.8	\$ 34.8
Progress Energy								\$ 33.1
Southern Company								\$ 55.0
Public Service								\$ 29.9
PG&E Co.								\$ 46.0
Edison International								\$ 45.5
PPL Corp.								\$ 32.8
American Electric Power								\$ 50.5
Constellation Energy Group	1,338	3	4	0	\$ 7.7	\$ 14.0	\$ 4.0	\$ 20.0
Xcel Energy, Inc.	1,668	3	3	3	\$ 11.9	\$ 10.3	\$ 9.8	\$ 27.4
Ameren Corp.	1,190	1	1	1	\$ 7.0	\$ 7.6	\$ 7.7	\$ 23.5
Pinnacle West Capital Corp.	1,147	3	0	0	\$ 4.9	\$ 3.3	\$ 3.7	\$ 12.4
NRG Energy, Inc.	1,126	2	0	0	\$ 5.8	\$ 8.8	\$ 9.2	\$ 26.9
DTE Energy Co.	1,122	1	1	1	\$ 8.6	\$ 8.6	\$ 8.2	\$ 24.9
SCANA Corp.	644	1	1	0	\$ 5.1	\$ 4.6	\$ 4.9	\$ 13.0
El Paso Electric Co.	623	3	0	0	\$ 1.4	\$ 0.9	\$ 0.9	\$ 2.4
Great Plains Energy, Inc.	545	1	0	0	\$ 2.9	\$ 2.3	\$ 3.8	\$ 8.8
Westar Energy, Inc.	545	1	0	0	\$ 3.1	\$ 2.1	\$ 3.0	\$ 8.1
Berkshire Hathaway, Inc.	434	2	0	0	\$ 189.4	\$ 136.2	\$ 58.6	\$ 372.2
Sempra Energy	430	2	0	0	\$ 12.7	\$ 9.0	\$ 9.5	\$ 30.3
PNM Resources, Inc.	402	3	0	0	\$ 1.5	\$ 1.7	\$ 1.8	\$ 5.2

Not a good impedance match between utilities financial structure and new large reactor's cost.

	TVA	6600	6
	EDF	62,400	58



(LEU Fueled Light Water) Small Modular Reactors

Potential for increasing the rate of introduction of ultra-safe affordable nuclear power in time to meet clean energy goals

• Potential LEU/LW Designs /Concepts

- mPower – 160 MW(e) [x4] B&W + Bechtel
- NuScale – 45 MW(e) [x12] + Newport News + Electric Boat + Fluor...
- Westinghouse - 200 MW(e)
- Holtec – 140 MW(e)

U.S Industrial & Regulatory Base

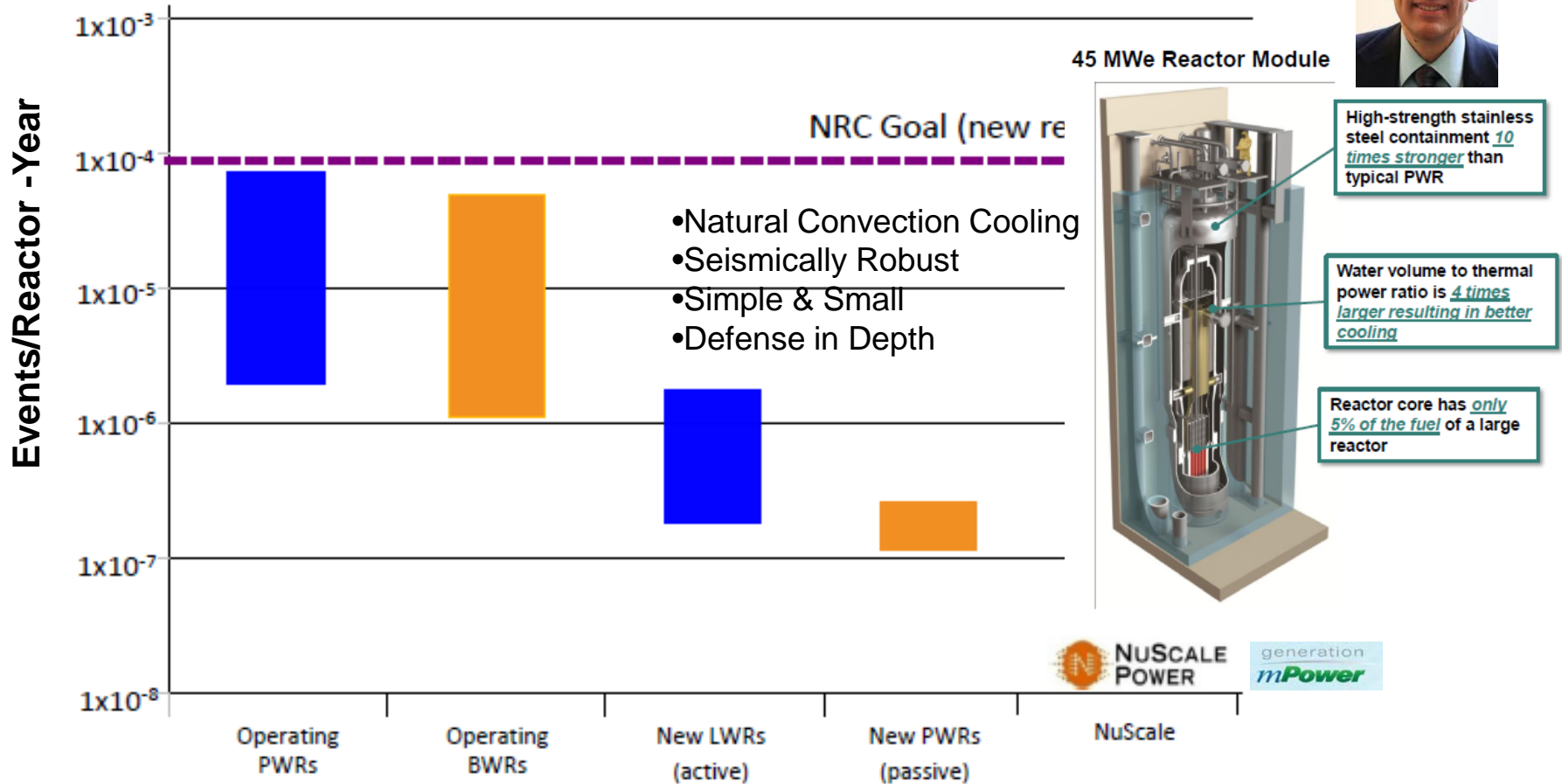
- Commercial (LWR,LEU) fuel
- Factory Built Modules [“learning vs. economy of scale”]
 - Potential High Throughput
 - Quality Control
- ~ U.S. Navy Industrial base
- NRC Licensable - LWR, LEU fuel, Safety, Security
- Lower early utility capital costs – reduce utility financial risk.
 - (1-3)\$B vs \$10B

Game
Changer

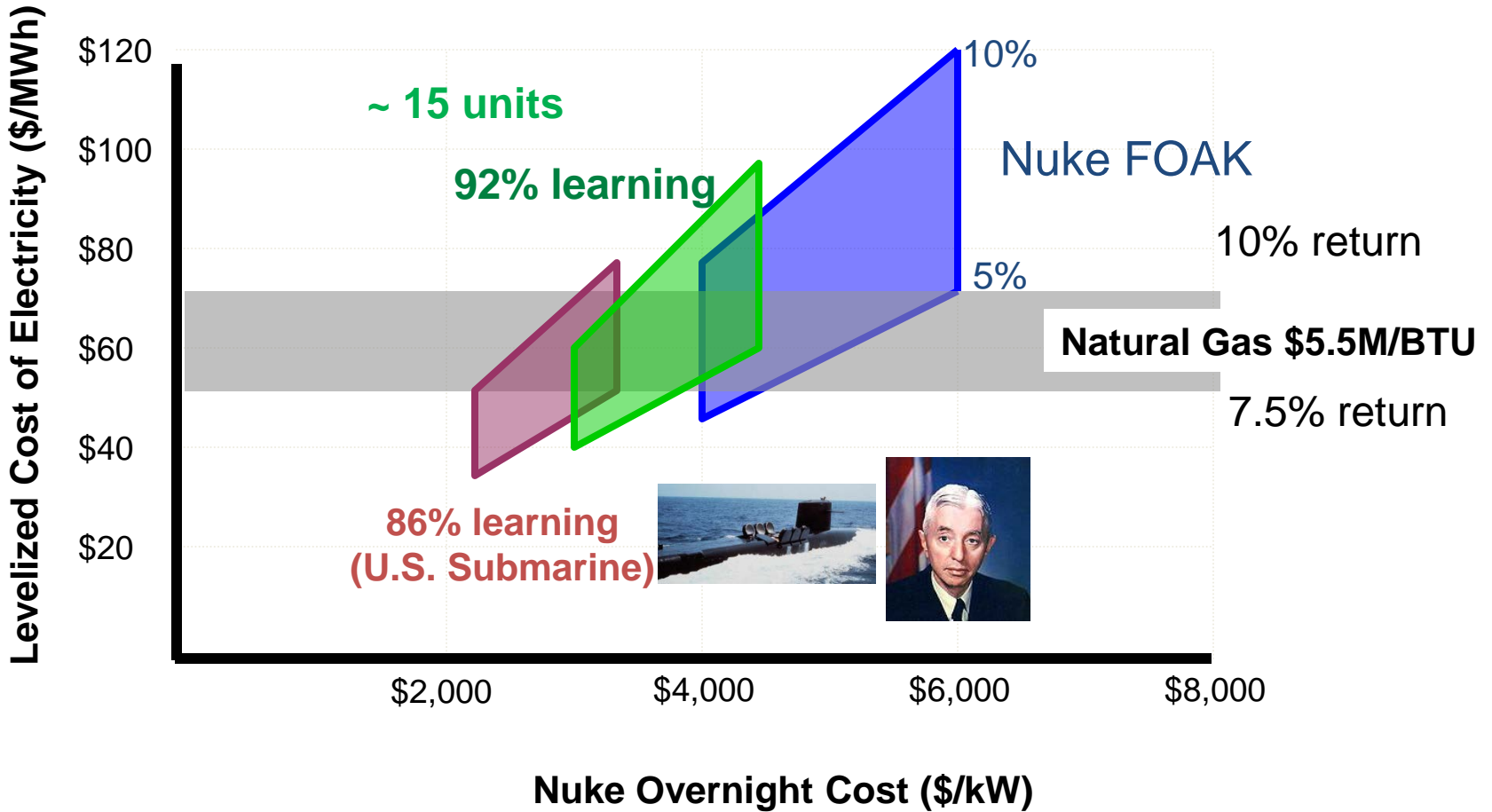


Safety Estimates for SMR

Probabilistic Risk Assessment (PRA) of Core Damage Frequency (CDF)



Can SMR's Compete with Natural Gas?: Effect of Manufacturing "Learning"





FY 2012 Budget



Small Modular Reactor Licensing Technical Support.

-The conference agreement includes \$67,000,000 to provide licensing and first-of-a-kind engineering support for small modular reactor designs that can be deployed expeditiously, to be administered as specified in the budget request. The Department is directed to consider applications utilizing any small modular reactor technologies. The conferees expect the program to total \$452,000,000 over five years.

Approach ~ DOE Nuclear Energy “Nuclear Power 2010”

- Instrumental in getting AP1000 certified and licensed
 - ABWR – ESBWR
 - Cost share with vendors/utilities (50/50)
- FOA January 23, 2012; Selection by end of FY.

Elements of a U.S Civil Nuclear Strategy

1. Rapid Growth of Affordable, Ultra-Safe, Nuclear Power - (SMR)

2. Resolve Spent Fuel issue

Blue Ribbon Commission on
America's Nuclear Future

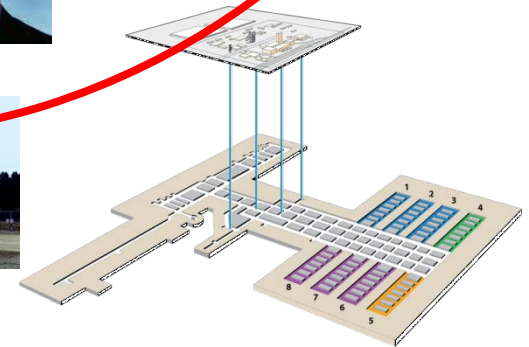


3. Lead Global Non-Proliferation

- Global Market Share
- Safeguards (SMR → LWR, LEU)
- Fuel Leasing



Dry Cask



Salt Repository

Pres BARACK OBAMA Prague April 9, 2009

“And we should build a new framework for civil nuclear cooperation, **including an international fuel bank**, so that countries can access peaceful power without increasing the risks of proliferation.”



Pres Bush NDU Speech: *New Measures to Counter WMD*, 2/11/04

The world's leading nuclear exporters should ensure that states have reliable access at reasonable cost to fuel for civilian reactors, so long as those states renounce enrichment and reprocessing



Small Modular Reactors for Civil Nuclear Power Leadership

“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.”

Prague, April 2009



Fukushima

President's Vision

National Energy & Nuclear Goals

- Climate/Clean Energy
- Energy Security
- Competiveness
- National Security
 - Non-proliferation

Strategy

Align U.S. Electricity Sector Goals to National Goals

- License 2 or more ultra-safe SMR designs
- Multiple Factory Manufacture
 - U.S. Navy Industrial Base
- Compete with Natural Gas to replace coal
 - Financial Incentives (?)
 - Government first user
- Global Market Leader
 - Safety, Security & Non-Pro Standard
- Spent Fuel Solution

“ By 2035, 80 percent of America's electricity will come from clean energy sources”

Timely Goal



2011
State of the Union