A Strategy for U.S. Nuclear Power:
"Changing the Game" with Small Modular Reactors (SMR)

Secretary of Energy's Advisory Board
July 20, 2011

Bill Perry
Chairman

Victor H. Reis
Office of Undersecretary for Science
(Matthew Crozat)
Nuclear Energy
U.S. Department of Energy

Origins of this SMR "Small" Study

Poneman

Can you do an ASCI (Stockpile Stewardship) for Energy?

(Stockpile Stewardship "changed game" in Nuclear Weapons: Underground Testing to Validated Simulation)

Koonin

- Will SMRs "change the game" for U.S Nuclear Power? If so, what is the role of DOE?

Outline

1. Stockpile Stewardship
2. Administration Energy Policy
3. U.S. Nuclear Energy
4. SMR Characteristics
5. US Nuclear Game Changing
6. DOE/NE/SMR Program Update J.Kelly

Miller Lyons

[Pete & Re-Pete]

- OMB questions on DOE SMR Program & Budgets - Why DOE?

SMR Conference July 2010

- Develop the "story" for DOE SMR Program

Changing the Game in Nuclear Weapon Deterrence: Stockpile Stewardship (ASCI)

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.

President Clinton July 1993

President's Vision

Los Alamos NATIONAL LABORATORY EST. 1943

sgi

ASCI Accelerated Strategic Computing Initiative

Sandia National Laboratories

intel

Lawrence Livermore National Laboratory Science in the National Interest

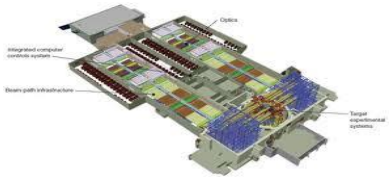
IBM

Strategy

Validated Simulation

Lab **Partner** with HPC Industry

Validation Experiments



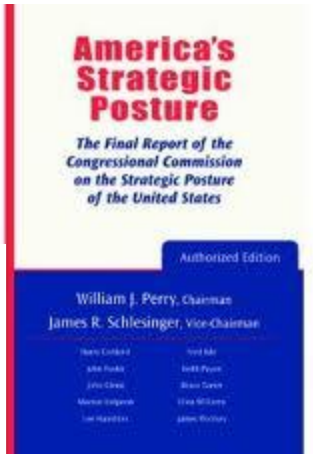
NIF

Specific (Time Urgent) Goal

~ 100 teraflops by 2004

Change from Test to Simulation: Stockpile Stewardship

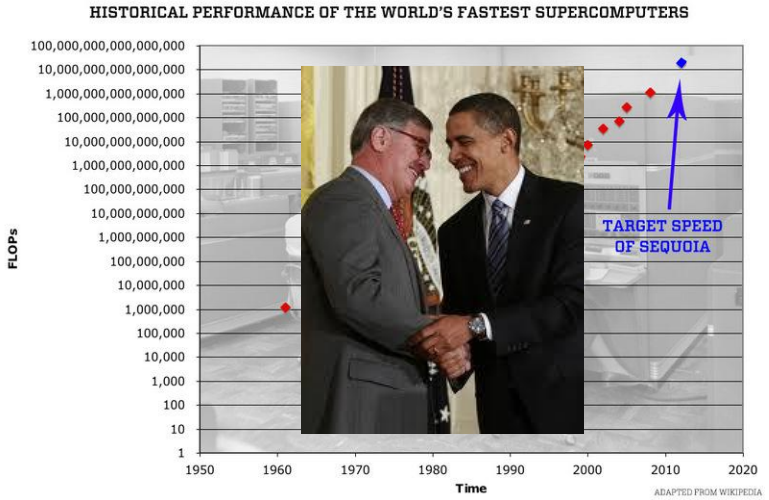
"The Stockpile Stewardship Program has been a remarkable success, much more than originally expected." *America's Strategic Posture: Final Report of the Congressional Commission on the Strategic Posture of the United States.* William Perry (Chairman) & James Schlesinger (Vice Chairman), 2009



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



"Changing the Game" with SMR
A Top-Down Systems Analysis
(Strategic Planning Model)

Recent Events

Fukushima

President's Vision

Energy & Nuclear Goals

Strategy

Alignment of U.S. Electricity Sector Goals with National Goals

Specific (Time Urgent) Goals

- Role Nuclear Power in meeting US Electricity Sector and National Goals
- Role of SMR in meeting Nuclear Power Goals
- Role of DOE in SMR

“Changing the Game” with SMR
A Top-Down Systems Analysis

Administration Energy Goals

- Climate
- Clean Energy
- Competitiveness
- Energy Security
- National Security

U.S. Electricity Sector

- Consumers
- Utilities
- Regulators
  - NRC, State PUC
- Grid
- Industrial Base
- DOE
  - Nuclear R&D
  - Nuclear Spent Fuel
  - National Security

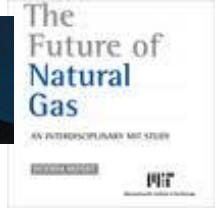
Blue Ribbon Commission on America's Nuclear Future

Recent Events

Climate?

2010 Election

Competition?



SAFETY?

Fukushima

SMR?

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

" 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."

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

President's Science Advisor on SMR

John Holdren
NPR, Feb 18,2011

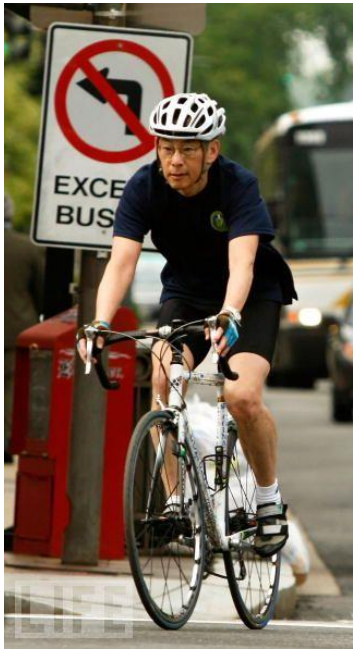
"I think a more interesting idea, which is reflected with a modest amount of money in the president's 2012 budget proposal, are the small modular nuclear reactors which could be manufactured in, basically, assembly-line way, would have the potential for getting the cost down, are potentially economically attractive in much smaller sizes than the nuclear reactors we've been relying on. That makes them applicable in a wider variety of places."

Secretary Chu on Small Nuclear 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

Specific Administration Goal:
(Quantifiable) Emission Reduction

President's Vision

Strategy

Time urgency
LWR/LEU fuel for SMR

LWR SMR

DOE (DoD)
LWR SMR
"first user"

Specific
(Time Urgent)
Goal

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

2011 State of the Union

The Federal Government will reduce its greenhouse gas (GHG) pollution by **28 % by 2020**.
Executive Order 13514, January 29, 2010

Meeting Administration's 2035 80% Clean Energy Standard

Assume:

- Weighted Emission Standards: Coal = 1, Gas =1/2, CCS = 1/10
  - Renewable and CCS goals met

Source	**Elect (TWhr)**	**CO_2 (Gton)**	**Elect (TWhr)**	**CO_2 (Gton)**	**Elect (TWhr)**	**CO_2 (Gton)**	
Coal	1800	1.85	2100	2.1	400	0.4	
Coal (CCS)	0	0	0	0	200	0.02	
Natural Gas	785	0.4	1030	0.5	1000	0.5	
Nuclear (Large)	800	0	870	0	1000	0	
Nuclear (SMR)	0	0	0	0	1100	0	A lot fast
Hydro	250	0	250	0	250	0	
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 CO_2 Emissions. *EIA*		***EIA Reference Projections 2035***		**Assumed 2035 electricity production to meet "clean energy" standard**		

Current U.S. Nuclear Power "Strategy":

104 Reactors 100 TW 800 TWhrs
Last Ground Breaking - 1973

Utilities: A Culture of Prudence

- Maintain (extraordinary) High Performance
- Extend Lifetime of Current Reactors

} LWR

- Buy New (Gen 3) Reactors when Licensed & Cost Competitive
  - Westinghouse (Toshiba) : 1150 MW
  - GE/Hitachi :1350 MW
  - AREVA: 1650 MW
  - Mitsubishi:1540 MW

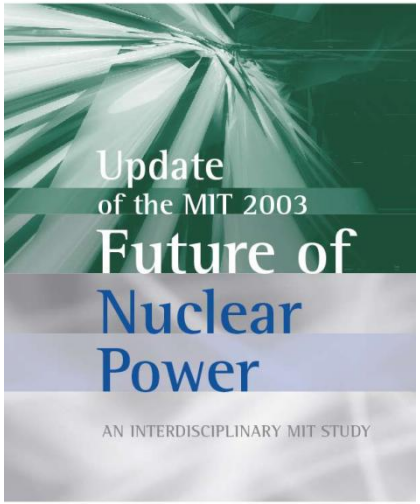
Passive Safety

U.S. Government: Multiple Agencies – Mixed History

- Spent Fuel - DOE/NRC/EPA
- Safety/Security- NRC
- Environment - EPA
- Proliferation - DOE/NNSA
- Cost Share Design Certification/License (DOE/NE/NP2010)
- Loan Guarantee: First Movers- DOE
- R&D on advanced concepts – DOE/NE

Program complete

Affordable (Consumers) and Profitable (Utilities) Electricity



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								$ 33.1
Southern								$ 55.0
Public S								$ 29.9
PG&E C								$ 46.0
Edison I								$ 45.5
PPL Cor								$ 32.8
America								$ 50.5
Constell								$ 20.0
Xcel Ene								$ 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.

MidAmerican ENERGY

	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 emission reduction goals

- **Potential LEU/LW Designs /Concepts**
  - mPower – 125 MW(e) [x4] B&W + Bechtel
  - NuScale – 45 MW(e) [x12] + Newport News + Electric Boat + …
  - Westinghouse - 200 MW(e)
  - Holtec – 140 MW(e)

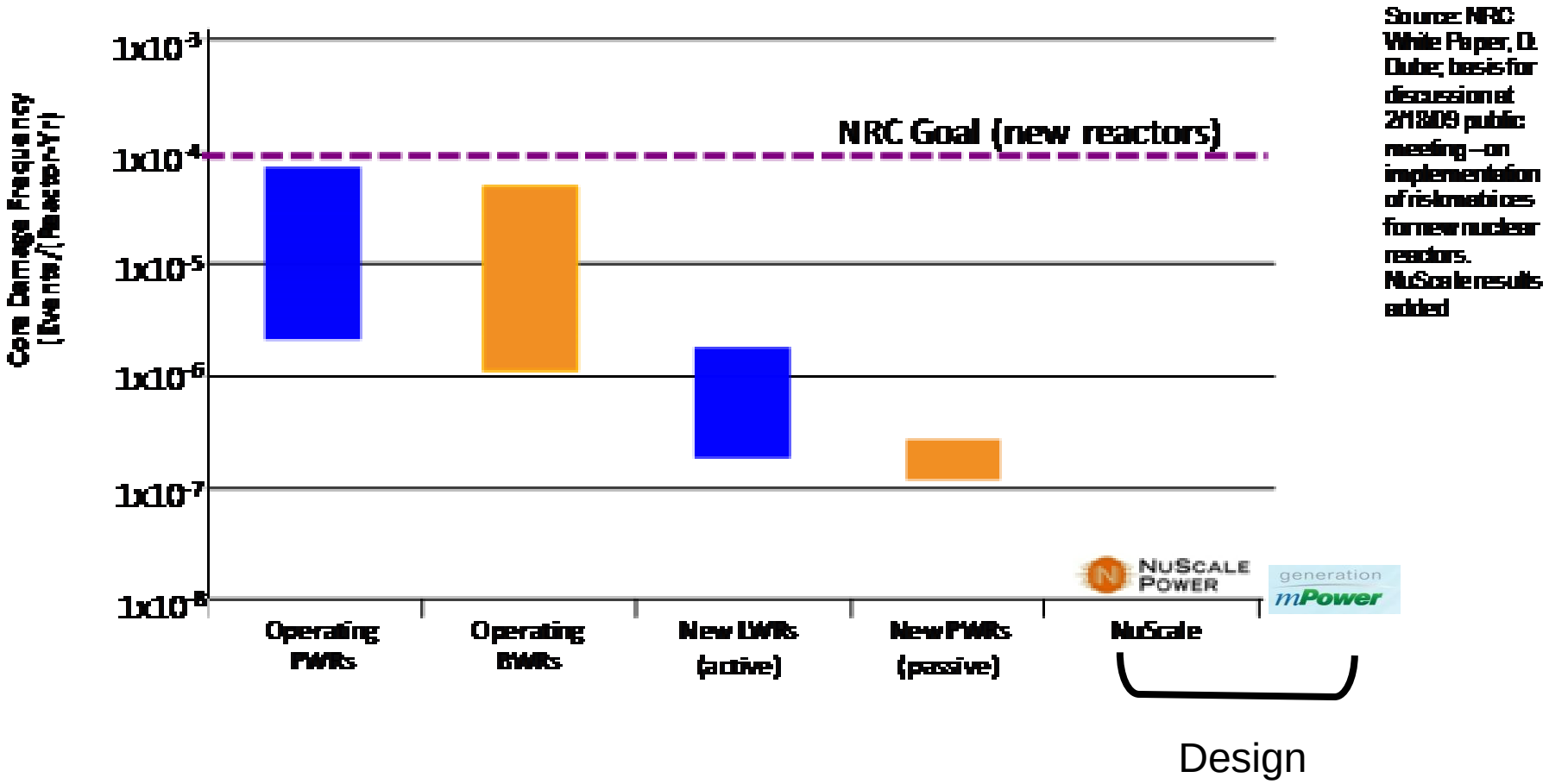
- **U.S Industrial & Regulatory Base**
  - Commercial (LWR,LEU) fuel
  - Factory Built Modules ["learning vs. economy of scale"]
    - Potential High Throughput
    - Quality Control

    ~ 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 – (Post Fukushima)

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



Design

Safety & SMR – NuScale Power

Inherently Safe Reactor Modules

Natural Convection for Cooling

- Inherently safe natural circulation of water over the fuel driven by gravity
- No pumps, no need for emergency generators

Seismically Robust

- System is submerged in a pool of water below ground in an earthquake resistant building
- Reactor pool attenuates ground motion and dissipates energy

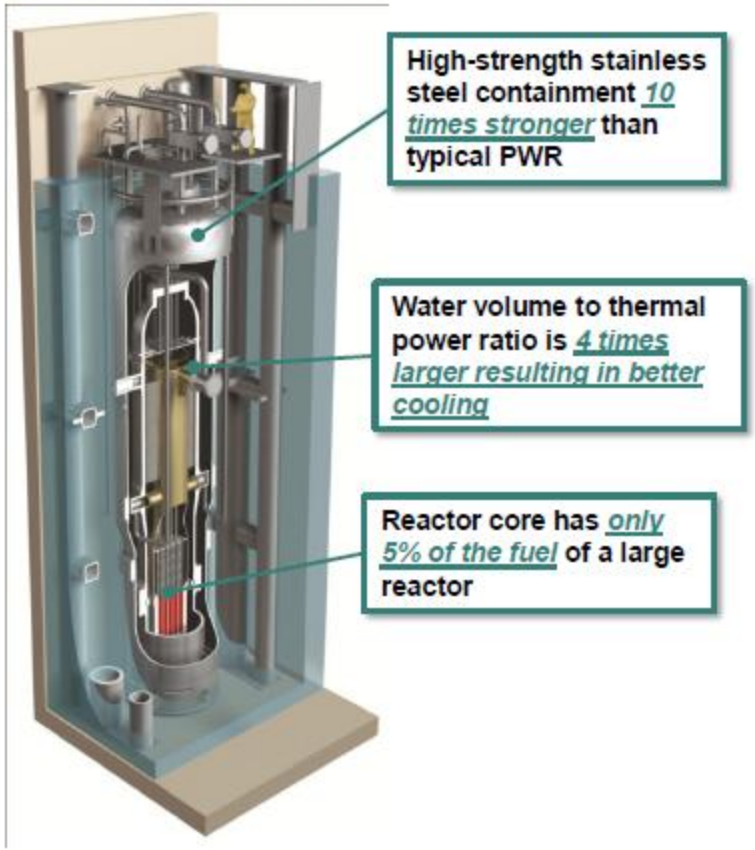
Simple and Small

- Reactor is 1/20th the size of large reactors
- Integrated reactor design, no large-break loss-of-coolant accidents

Defense-in-Depth

- Multiple additional barriers to protect against the release of radiation to the environment

45 MWe Reactor Module



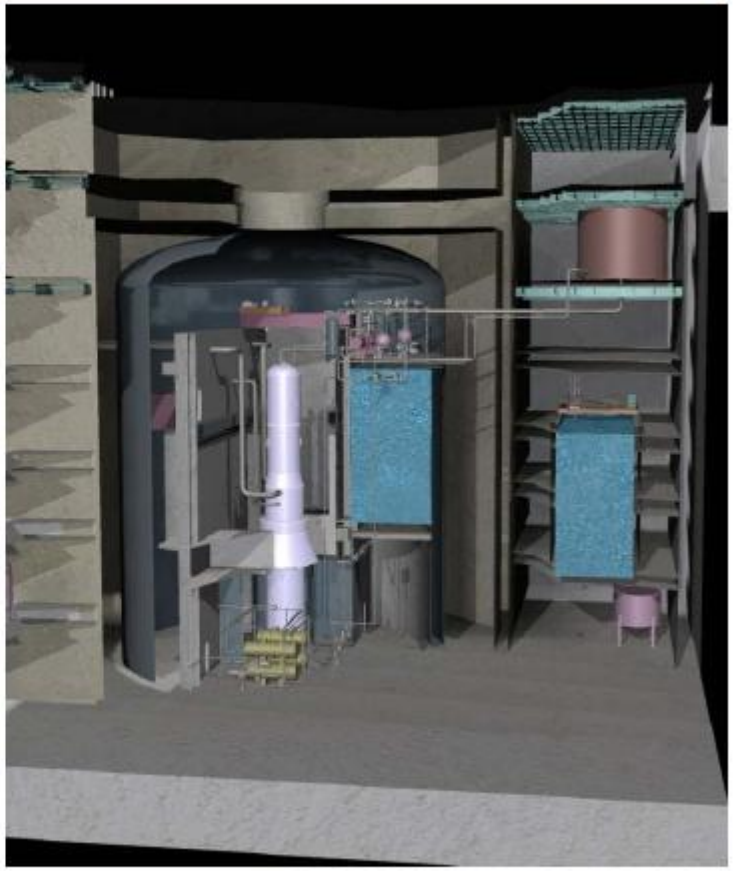
NuScale Power

Safety & SMR - MPower

generation mPower

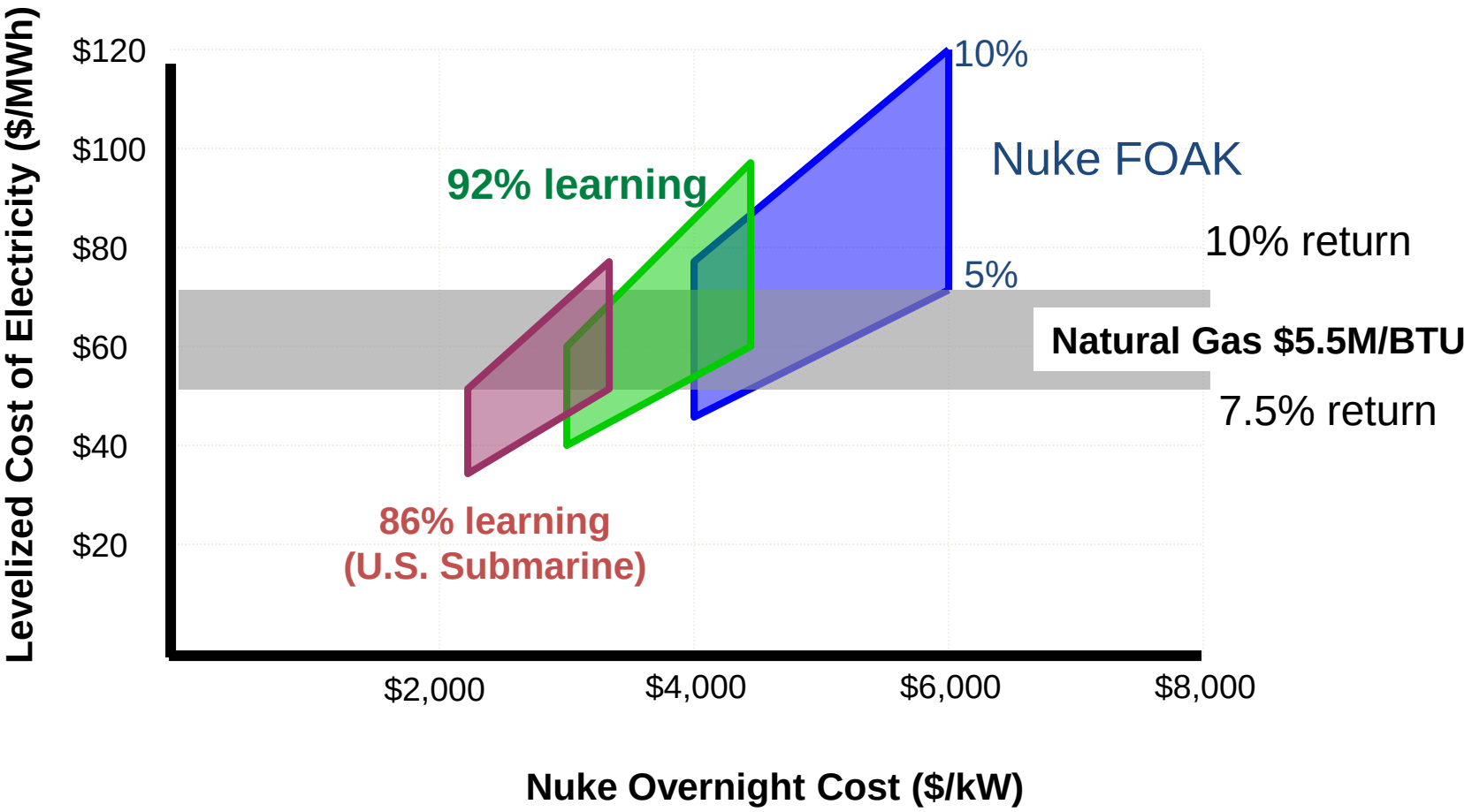
Robust Containment and Nuclear Island

- **Deeply embedded concrete reactor building**
  - Contains all water sources – RWST, UHS
  - Isolates all safety equipment from environment
- **Fully underground steel containment**
  - Favorable seismic response
  - Inherent aircraft crash & missile protection
- **Fully protected Spent Fuel Pool**
  - Located in auxiliary containment
  - Large volume supports extended SBO response
- **Inherently safe systems and features**
  - Gravity-powered ECCS
  - Dry containment with no debris entrainment
  - Dedicated safety-systems with no sharing
- **Significant Severe Accident mitigation**
  - Passive filtering
  - Passive hydrogen recombiners
  - NSSS water jacket capability



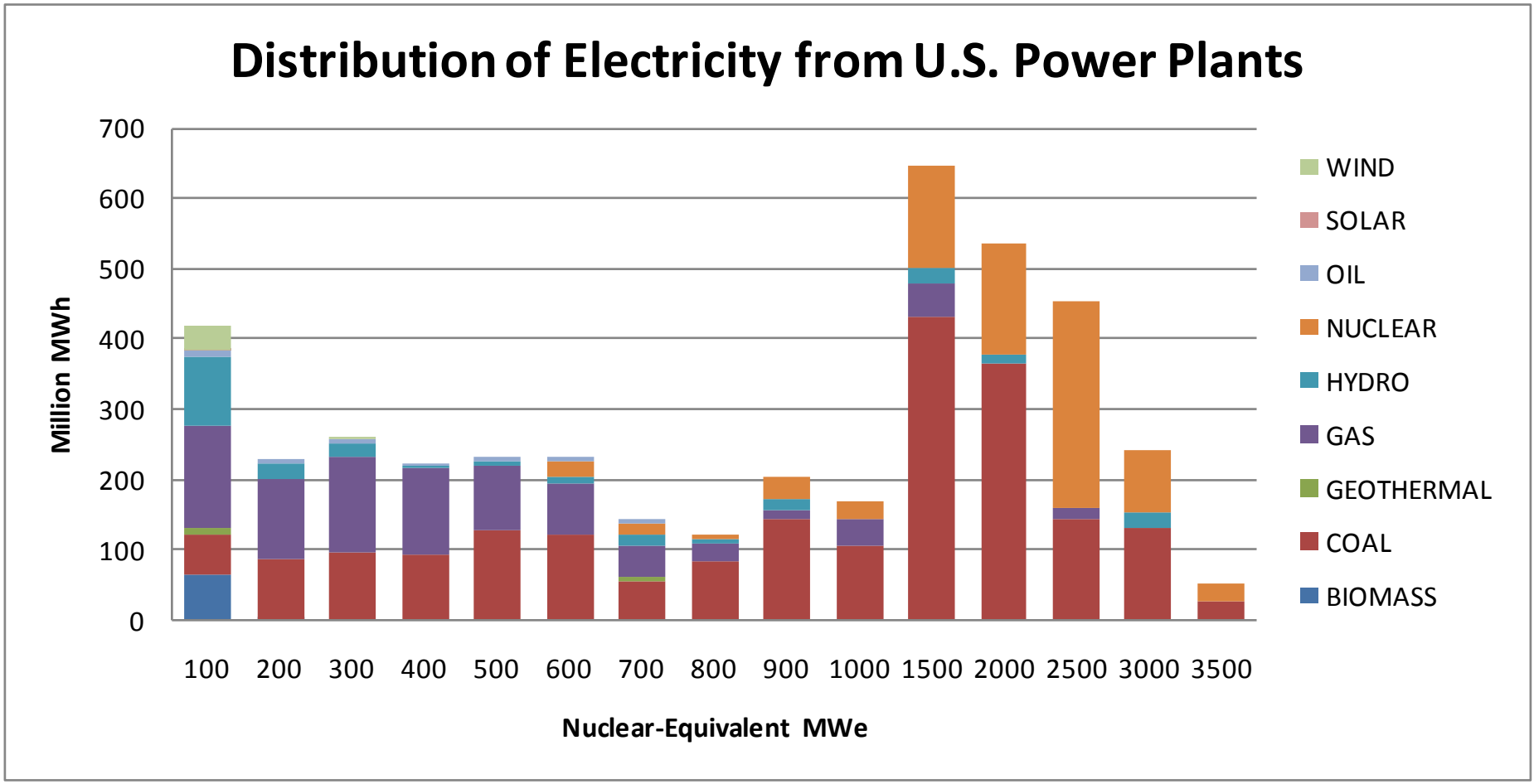
Risk informed design targets 10^{-8} CDF with fewer, inherently safe systems

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



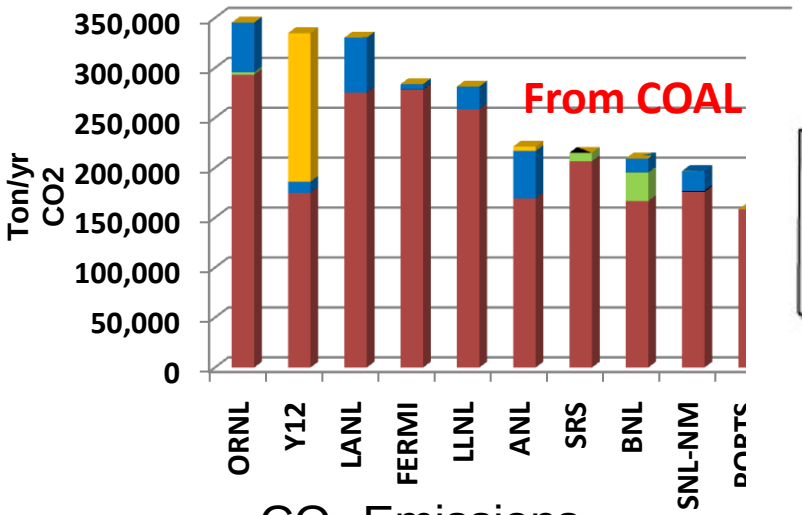
Flexibility of SMR within U.S Grid

“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.” S. Chu Wall Street Journal



Meeting 2020 28% Federal GHG Reduction Direction

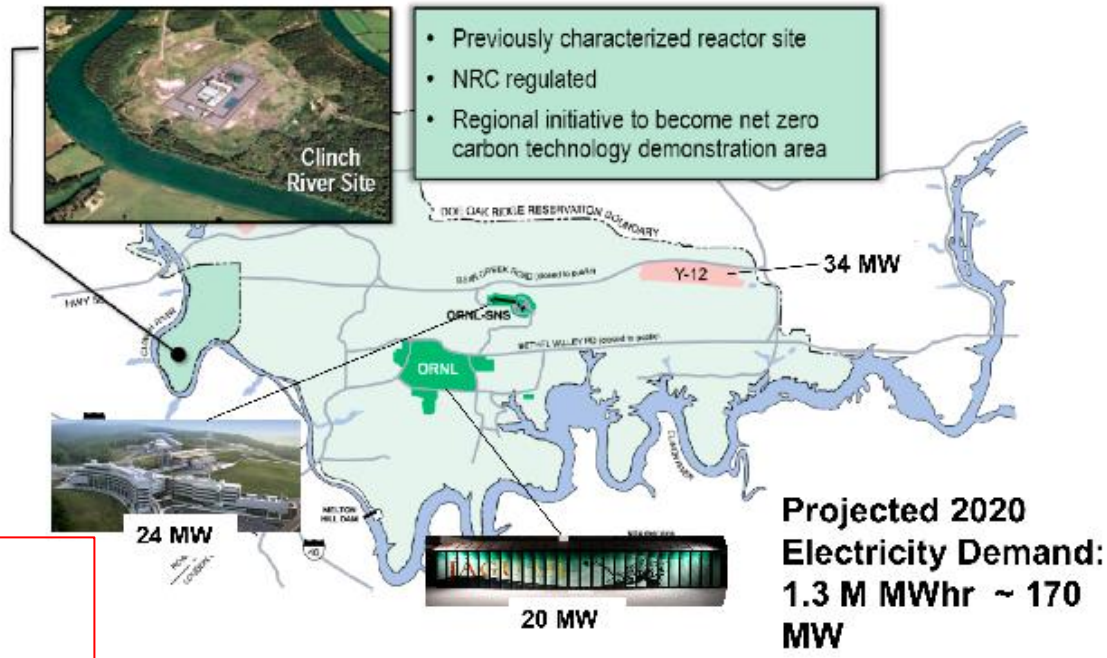
Marc Jones and Alexander Merola, "Sustainability and DOE High Energy Mission Specific Facilities"



CO_2 Emissions DOE Sites

SMR?

- TVA buys SMR
- Installs at Clench River
- Electricity for Oak Ridge Site
- PPA with Site



DOE/DoD provide market for "first user" large enough for factory built SMRs

"Feasibility of Nuclear Power on U.S. Military Installations" CNA report March 2011

DoD requirement ~7GW
SMR "feasible and generally economical"

Elements of a U.S Nuclear Strategy

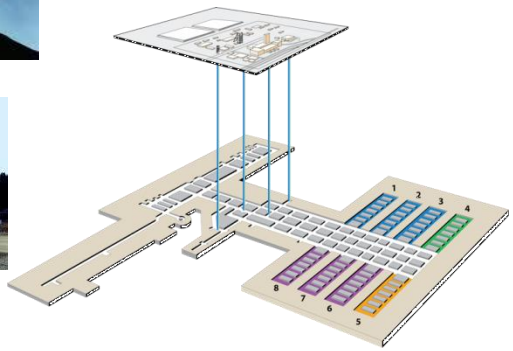
1. Rapid Growth of Affordable, Ultra-Safe, Nuclear Power - (SMR)

2. Resolve Spent Fuel issue

Blue Ribbon Commission on America's Nuclear Future

3. Lead Global Non-Proliferation
   - 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."

+ Crozat

Bottom Line

Small Modular Reactors Could Change the Game:
Restore U.S. Leadership in Nuclear Power

1. Nuclear Power Essential to Administration Commitment to Clean Energy
   - Time Urgency: Need a lot of new clean power in a short period of time
2. Light Water, Low Enriched Uranium SMR Characteristics
   - Ultra-Safe by design
   - Factory Manufacture [U.S (Navy) Industrial base]
     - Potential High Rate of Production
     - Learning to lower cost
   - Good Impedance match with U.S. utilities, grid, & NRC
     - Lower initial investment (~$2B vs ~$10B)
     - Grid flexibility
     - LWR, LEU Fuel (NRC licensable, available infrastructure)
   - Consistent with "proven" storage options & U.S. Nonproliferation policy

Game Change

3. Align with Consumer/Utility/ National Goals

“Obvious” Potential Barriers

- Post Fukushima Anti-Nuke Sentiment
  - Public
  - Politicians
- Perceived U.S. Government Policy Uncertainty
- Climate Politics
- U.S. Economic Climate
- Natural Gas “Boom”
- Utility “Prudence”
- NRC work load/expertise
- SMR Industrial Base Business Complexity
- U.S. Naval Reactor “Mission Creep”

DOE SMR Actions/Program
[John Kelly will describe]

- Cost share SMR design certification with potential vendors
  - Similar to Nuclear Power 2010 program

- A potential first buyer SMR generated electricity (with DOD?)
  - Federal GHG reduction directive
  - **Sufficient Market to start SMR factories**
  - Possible Power Purchase Agreement to reduce Government Costs

- R&D on Generic Concerns
  - Multiple Units
  - Advanced Systems

A vision without action is a dream,
Action without vision is a nightmare

Japanese Proverb

行為のない視野は夢、視野のない行為である不快感である