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**Title:** Affordable and Secure Nuclear Energy Development: DOE Investments and Laboratory R&D Challenges - A Review

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# Affordable and Secure Nuclear Energy Development: DOE Investments and Laboratory R&D Challenges – A Review

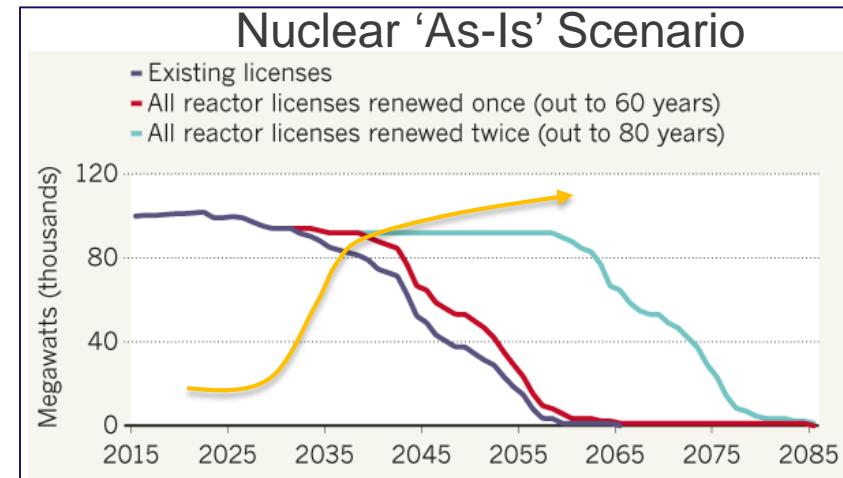
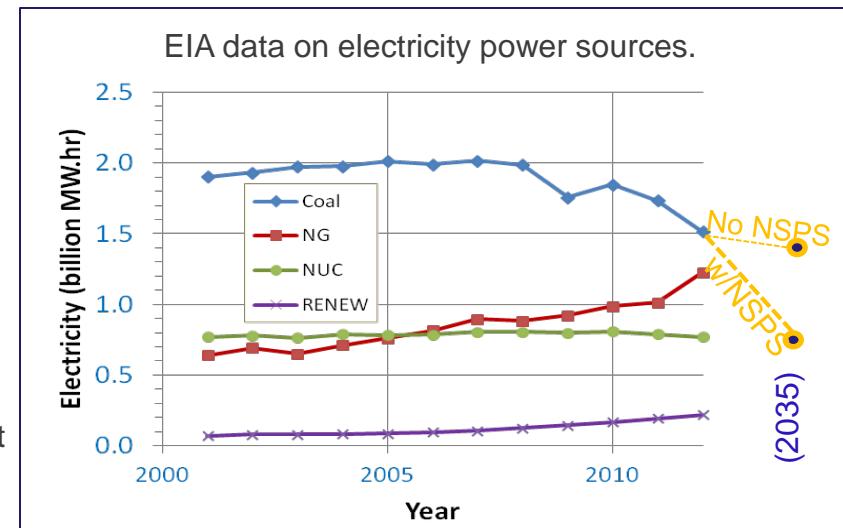
Dasari V. Rao, Program Director  
Civilian Nuclear Power Office

12/1/2016

# BACKGROUND

## OPTIONS FOR BASELOAD

- Coal electricity has steadily declined since 2008
  - Emissions regulations and fracking
  - EIA projected coal to stabilize @ 1.5 billion MW.hr
- EPA New Source Performance Standard (NSPS) impacted this
  - It limits CO<sub>2</sub> to 1000 lbs per MW.hr
  - Existing coal plants don't meet this standard without major refits
- Three 'Scalable' Options exist
  1. Super Critical IGCC Coal plant with Carbon Capture and Sequestration for higher efficiency (overnight capital \$5000 per kWe)
  2. Replace plants with Natural Gas Combined Cycle that can achieve EPA target (@ \$1107 per kWe); couples with Solar PV; halves water use
  3. Increase generation capacity with Nuclear units.
- Nuclear must be made affordable
  - National Academies
  - Sec of Energy Advisory Board
  - Aspen Institute
  - IEA/OECD Economics Forum

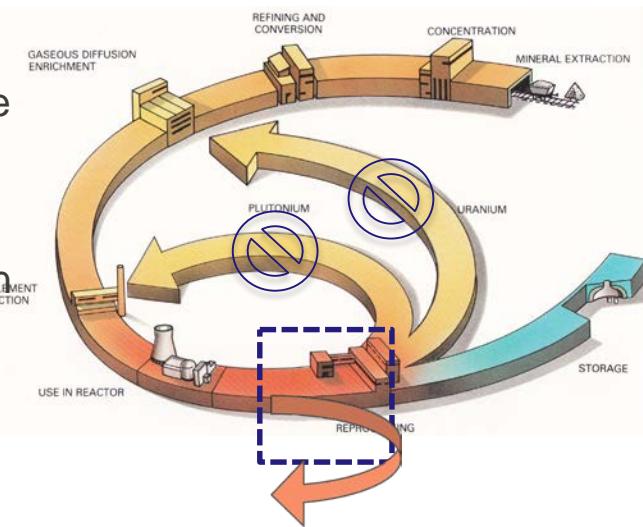


# TWIN GOALS OF ADVANCED NUCLEAR ENERGY

URGENT ALIGNMENT OF THESE OFTEN COMPETING GOALS IS REQUIRED

## What is needed for sustainable nuclear energy?

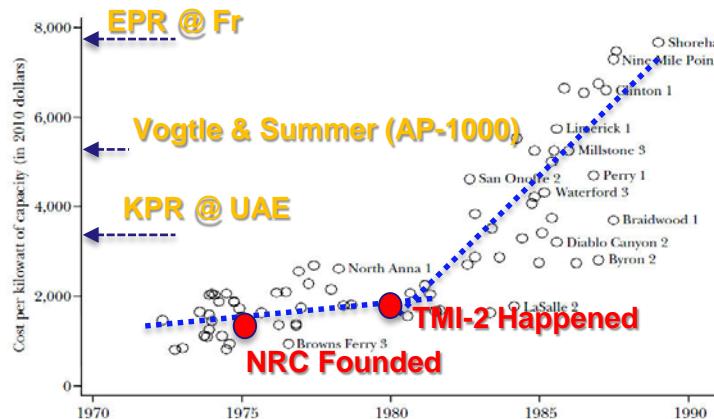
- New reactor and fuel designs that are more **economical** (less capital intensive) and inherently safe
  - Affordable approaches to development
- New countries and regions to counter GHG
- New separation technologies to increase fuel utilization



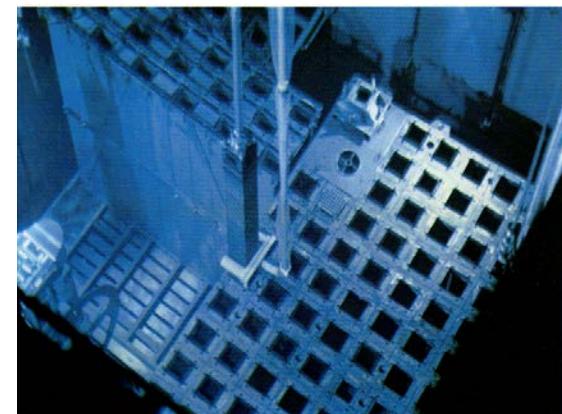
## What is Needed for secure nuclear energy?

- Advanced architecture for real-time 'full' duty-cycle wide awareness of the fuel
- Multi-Scale Science Based Safeguards

### Economies of Scale: Bigger is Better! (70's economics)



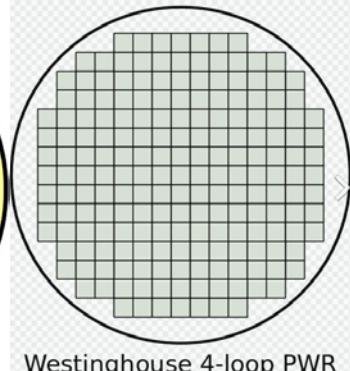
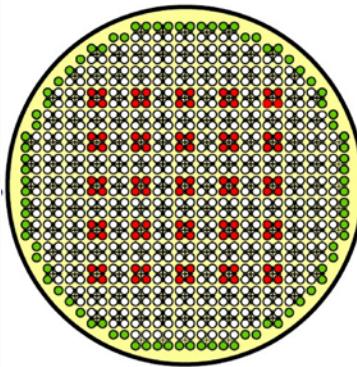
### No YMP: Large Used Fuel Inventory



# GLOBAL NUCLEAR LANDSCAPE IS UNDERGOING A MAJOR CHANGE

## DRIVEN BY ECONOMICS AND PUBLIC-PRIVATE SPONSORSHIP TECHNOLOGY IS EVOVLING

### Workhorses of Present & Near Future Deployment in US/OECD Countries

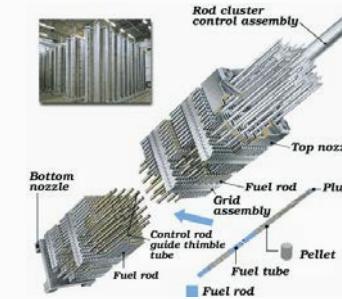


Westinghouse 4-loop PWR

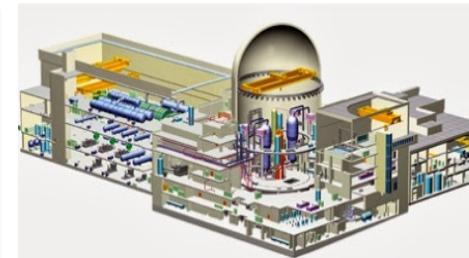
GE-BWR Design



Westinghouse Bundle



LWR Sustainability (DOE)



KPR-1400 in UAE



Westinghouse Electric Company LLC

1. Fuel-handling Area
2. Concrete Shield Building
3. Reactor Building
4. Reactor Coolant Pumps (RCP)
5. Reactor Coolant Pumps (RCP)
6. Reactor Coolant Pumps (RCP)
7. Reactor Vessel
8. Integrated Head Package
9. Heat Exchangers
10. Heat Exchangers
11. Feedwater Pumps
12. Turbine Generator



EPR-1200 Fr, UK(?)

AP-1000: US (4),  
China (8), and India (6)

**Loan Guarantee  
Prod Tax Credit  
Six to 8 years**

Cost: \$5300 per KWe

Accident Tolerant Fuels (DOE)

U<sub>3</sub>Si<sub>2</sub>.UN

U-Th-Zr Metal

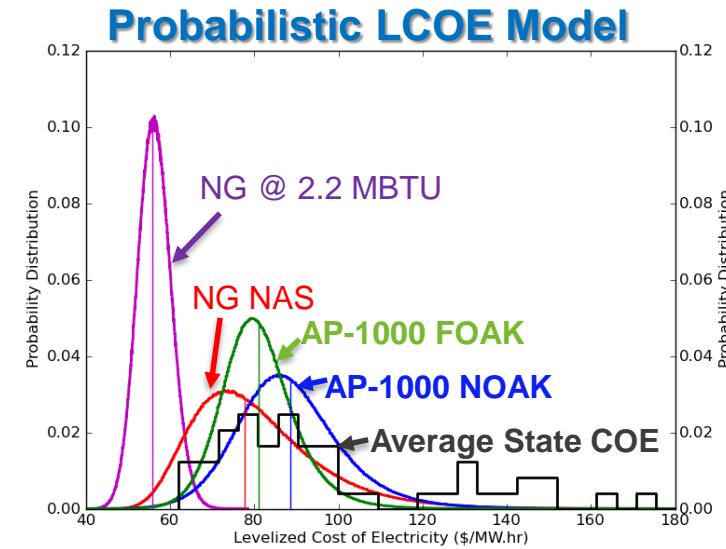
# WHAT'S NEEDED FOR NUCLEAR RENAISSANCE?

## COST CONTROLS AND REGULATORY SIMPLIFICATION

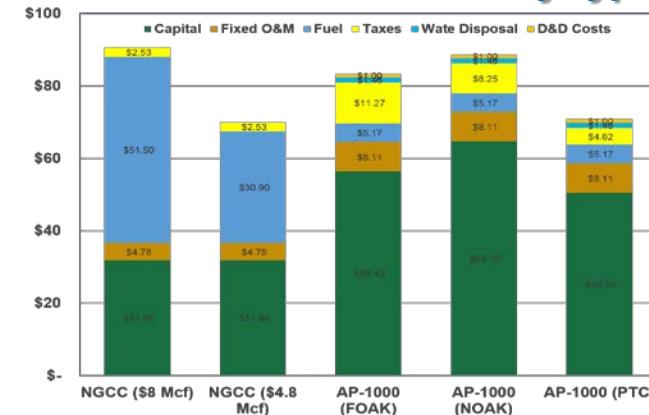
- **AP-1000 (Vogtle & Sumner)**
  - Construction costs (EPC): \$ 3700-4000 per kWe
  - Regulatory (Q&A Costs): \$ 750 per kWe
  - Financing on Capital: \$1600 per kWe
  - Total: \$ 6050 per kWe
- **Key**
  - Reduce length of construction
  - Reduce number of systems for Regulation and QA
  - Reduce EPC with simpler systems



### SMRs and Gen-IV



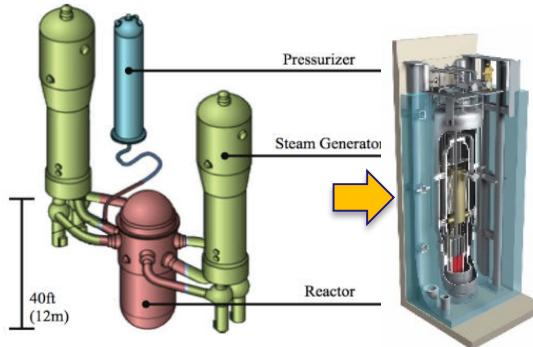
### Contribution to Costs by type



# SMALL MODULAR REACTORS

## SIMPLE, SCALABLE AND INHERENTLY SAFE

### NuScale



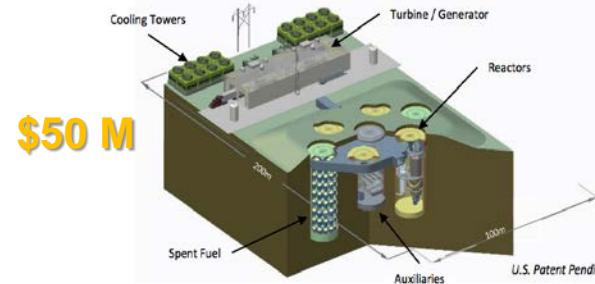
### NuScale SMR Strengths

- \$450 M Licensing Investment
- Existing NRC Regulatory Framework
- Existing Fuel Fab/Handling/ Disposal infrastructure
- SEAB recommends continued Loan Guarantee and PTC

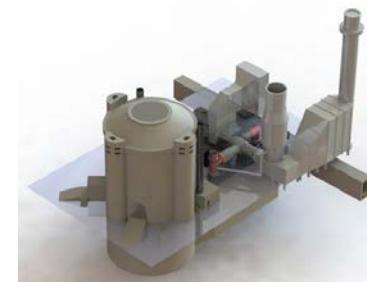
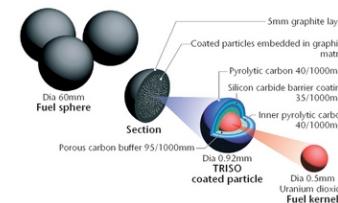
### TBD:

- NRC Licensing Burden Reduction
- Supply chain – QA and cost control

### X-Energy (B&W XT, Southern)

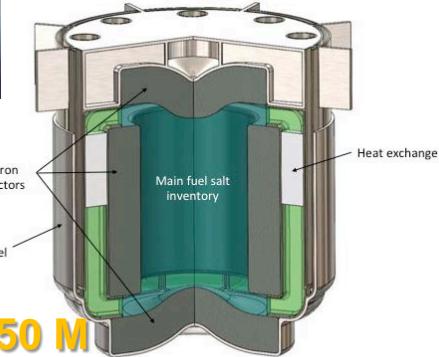


### TRISO



### Fluoride High Temperature

\$50 M  
Chloride Molten Salt Fast



# Backup slide

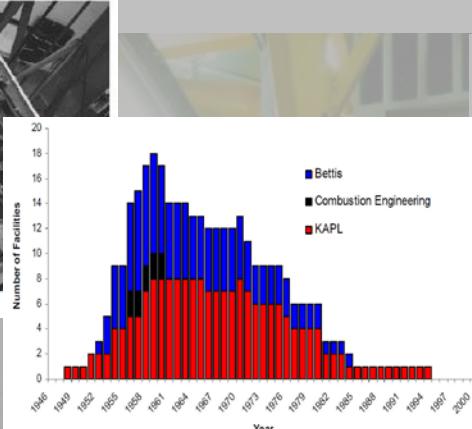
- Major investments required to make Advanced Reactors a Reality

# SCIENCE AND INFRASTRUCTURE TRANSFORMATION HAS BEEN SLOW

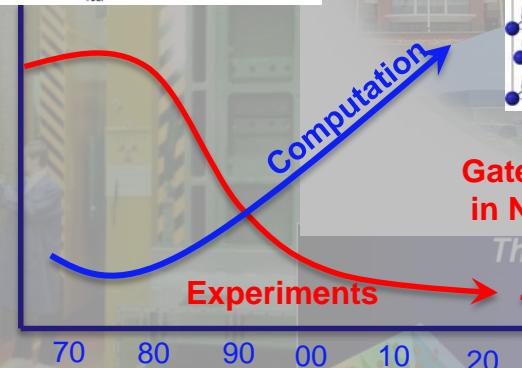
## STATE-OF-ART (DESIGNERS) VS STATE-OF-PRACTICE (REGULATORS)



Figure 2. Arranging Fuel Rods.



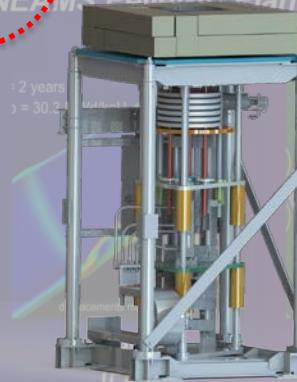
Adm. Rickover



“...Unless one has already built a reactor very similar to a proposed design, one cannot even be sure that it will go critical – based on calculation alone... It is clear that successful design and operation of new high power reactors must rely heavily on critical and experiments with the proposed design...” -- Adm. Rickover

Gateway for Accelerated Innovation  
in Nuclear Energy

The NEAMS Pellet-to-Plant Simulation

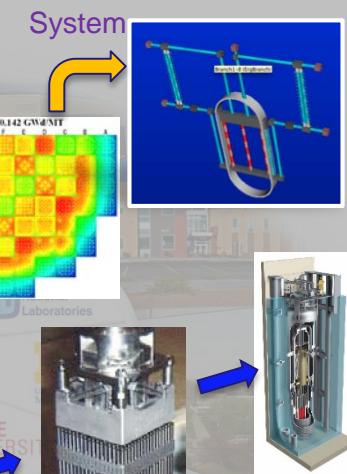
MARMOT  
(Pellet)

J.P. Uhle



M. Weber

GAIN is a great way to bring a new generation of designers and regulators along. But needs large investments

RELAP-7  
(Plant)

Safety-related or not!