U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Vision and Strategy for the Development and Deployment of Advanced Reactors

John E. Kelly
Deputy Assistant Secretary for Nuclear Reactor Technologies
Office of Nuclear Energy
U.S. Department of Energy

June 7, 2016

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Delivering Clean Energy: Nuclear has to be part of the solution

2011

"By 2035, 80% of America's electricity will come from clean energy sources. Some folks want wind and solar, others want **nuclear**, clean coal, and natural gas. To meet this goal we will need them all.

President Barack Obama, 2011 State of the Union address

2014

"All-of-the above is not merely a slogan, but a clear-cut pathway to creating jobs and … reducing carbon emissions. President Obama has made clear that he sees **nuclear** energy as part of America's low carbon energy portfolio . . .

Energy Secretary Ernest Moniz, 2014 National Press Club speech

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Evolving Policy Drivers that support Clean Energy

- **Climate Action Plan – June 2013**
  - Reduce greenhouse gas emissions by 30% by 2030
- **Executive Order #13693 - March 19, 2015**
  - Reduce Federal facility greenhouse gas emissions 40% by 2025
  - Defines "clean energy" to include alternative energy
    - Definition of “alternative energy” includes “small modular nuclear reactor technologies”
- **Clean Power Plan – August 3, 2015**
  - Sets CO_2 emissions performance goals for every State in U.S.
  - Provides flexibility to States to choose how to meet carbon standards
    - Include renewables, energy efficiency, natural gas, **nuclear** and carbon capture and storage
- **COP21 – December 12, 2015**
  - International agreement to limit average temperature rise to <2°C
  - Reaffirmed U.S. commitment to carbon reduction goals

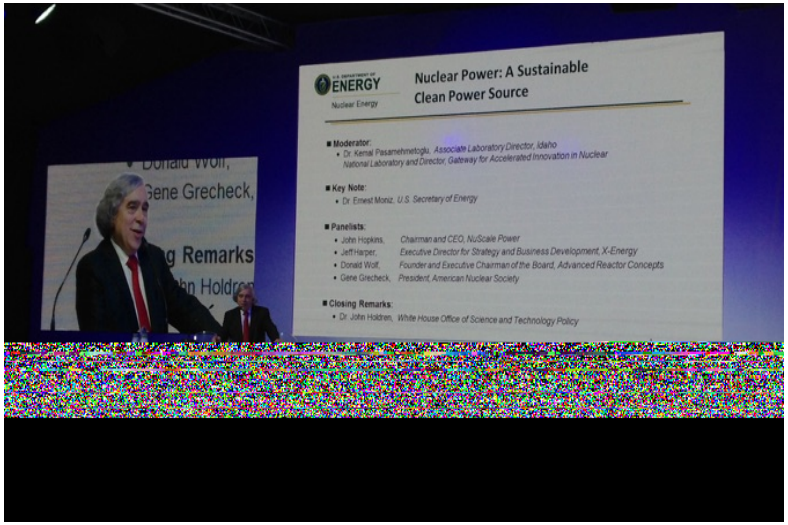
President Obama speaks at the Department of Energy on Mar 19, 2015

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Nuclear Power: A Sustainable Clean Power Source

"To meet our emissions reduction targets and avoid the worst effects of climate change, we need to dramatically reduce power sector emissions. Switching from coal to natural gas is already reducing the U.S. carbon footprint, but it's not enough to get the deep CO_2 cuts envisioned in the President's Climate Action Plan. ***Reducing emissions by 80% will likely require the complete decarbonization of the power sector….***



We know nuclear can provide 24-hour baseload power, because it already does. Worldwide, nuclear power produces more energy than hydro, solar, wind, and geothermal power combined.

The bottom line is that to achieve the pace and scale of worldwide carbon reductions needed to avoid climate change, nuclear must play a role."

Secretary Moniz
COP21, Paris 2015

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Decarbonization of Electricity Production by 2050

	2010		2035			2050
Source	**Elect (TWhr)**	**CO_2 (Gton)**	**Elect (TWhr)**	**CO_2 (Gton)**		**Elect (TWhr)**
Natural Gas	1000	0.44	~~1520~~	~~0.51~~	~0	
Coal	1730	1.58	~~1800~~	~~1.66~~	~0	
Coal (CCS)	0	0	0	0		1400
Nuclear (Large)	790	0	870	0		900
Nuclear (SMR)	0	0	0	0		700
Hydro	325	0	300	0		300
Renewable	200	0	440	0		2200
Petroleum/Other	50	0.04	~~40~~	~~0.03~~	~0	
TOTAL	4095	**2.05**	4970	~~2.2~~	~0	5500

2013 U.S Electricity Consumption and CO_2 Emissions. ***EIA*** ***CE=32%***

Projections to 2050
CE= 100%

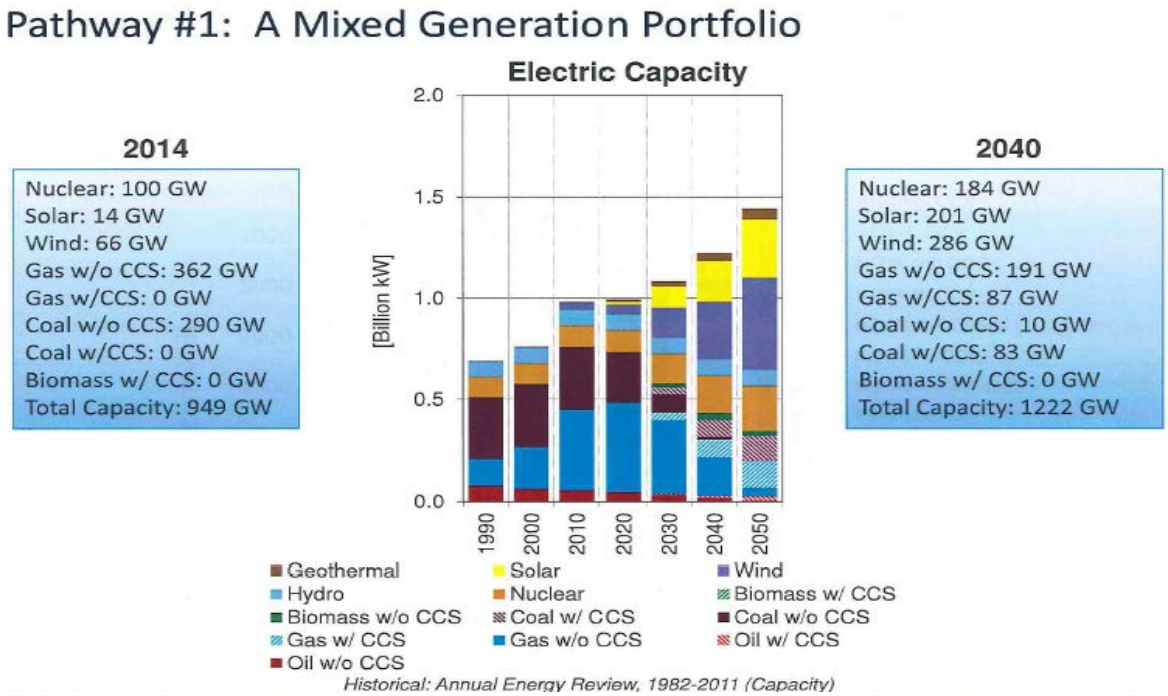
Source: EIA, Annual Energy Outlook 2013

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

EPSA Nuclear Growth Projections

- **DOE's Office of Energy Policy and Systems Analysis (EPSA) held a Low Carbon Energy Futures Workshop in January 2016**
  - Workshop explored various energy sector scenarios to meet 80% greenhouse-gas (GHG) reduction goal by 2040
  - Beginning with 100 GW of nuclear capacity in 2014, several proposed pathways showed nuclear projections between 160-238 GW by 2040 to meet GHG reduction goals



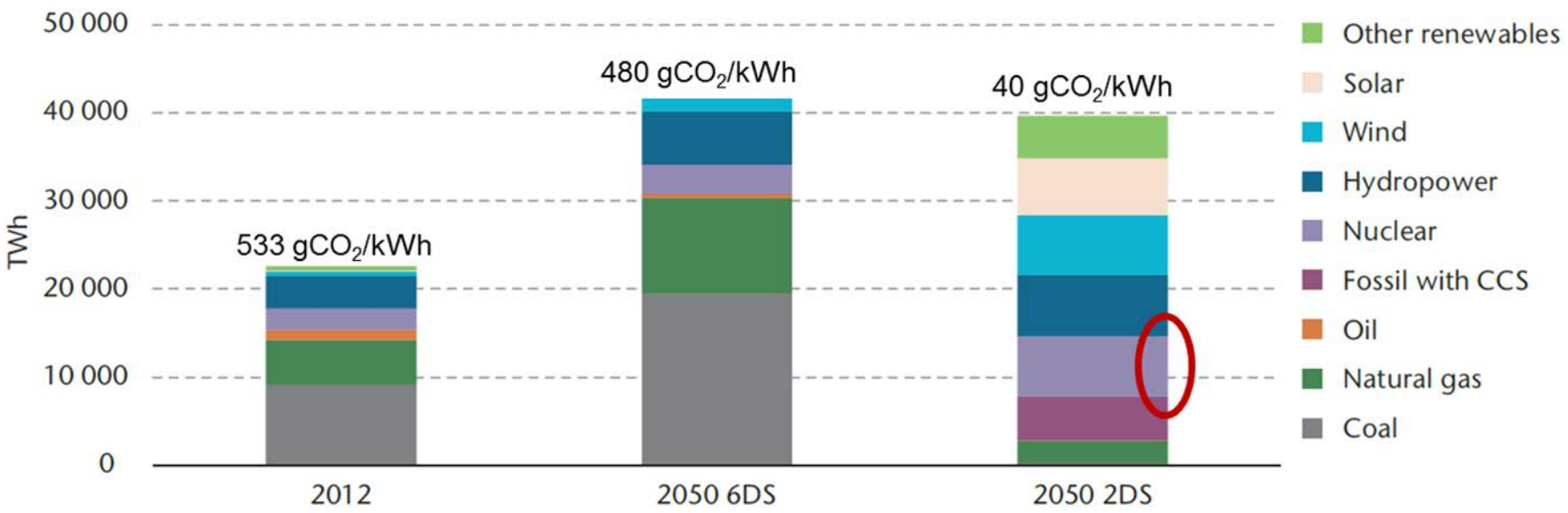
U.S. DEPARTMENT OF ENERGY

Nuclear Energy

OECD/IEA Nuclear Growth Projections

- **The International Energy Agency's (IEA) 2ºC Scenario (2DS) projects current nuclear capacity of 390 GW to more than double by 2050 to reach 930 GW (gross capacity)**
- **Share of nuclear electricity would increase from 11% to 18%**

Shares of different technologies in global electricity production until 2050 in the 2DS

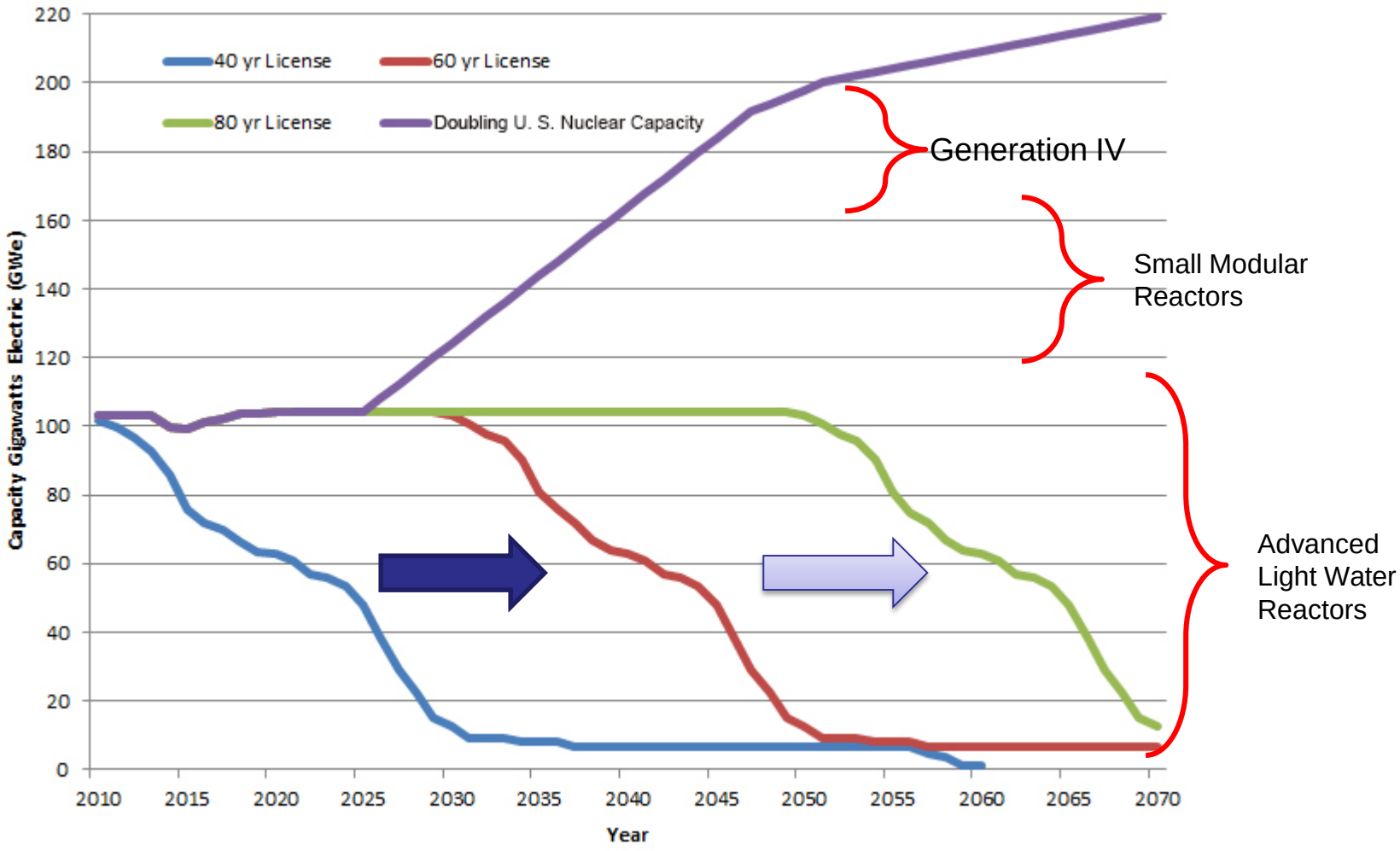


Source: IEA

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Nuclear Power Capacity needed to meet Clean Power Goals



U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Over 30 Advanced Reactor Designs in the United States

- **Sodium Fast Reactor**
  - TerraPower, General Electric, etc
- **High Temperature Gas Reactor**
  - X-Energy, AREVA, TerraPower, Hybrid Energy, Ultra Safe, etc
- **Molten Salt Reactor**
  - TerraPower, Transatomic, Terrestrial, Elysium, FLIBE Energy, etc
- **Lead Fast Reactor**
  - Westinghouse, Gen IV Energy, Lake-Chime, etc
- **Gas Fast Reactor**
  - General Atomics

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Observations on the Nuclear Start-up Designers in the United States

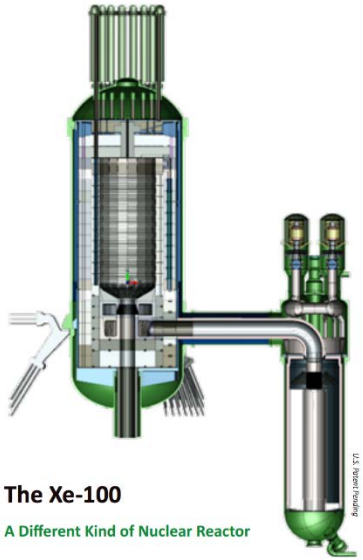
- **Private sector investing in Clean Energy Technologies**
  - Nuclear is part of the mix
- **Startups have diverse concepts**
  - Uranium utilization, Thorium as a “fuel”, remote siting
- **Need to help focus investments on providing clean energy generation capacity for the electric sector**
- **However, before large-scale deployment can occur, advanced reactors still need:**
  - Further demonstration of their performance characteristics
  - Further validation of their “value proposition”

U.S. DEPARTMENT OF ENERGY

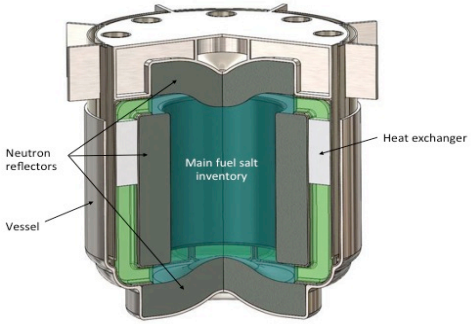
Nuclear Energy

Addressing the Growing National Interest in Advanced Reactors

- **DOE is currently supporting innovative reactor technologies and improving their economic competitiveness by:**
  - Targeted laboratory R&D
  - Advanced Test/Demonstration Reactor Study
  - Industry projects to develop advanced reactor concepts
    - X-Energy (Pebble Bed High Temperature Gas Reactor)
    - Southern Company Services (Molten Chloride Fast Reactor)
  - Facilitating industry access to DOE expertise through the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative
    - Streamlining processes
    - Voucher program
    - Test bed
    - Regulatory advice



Pebble Bed Reactor Concept
http://nextbigfuture.com/



Molten Chloride Salt Reactor Concept
(https://hdiac.org/)

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Regulatory Framework for Advanced Reactors

- **DOE is also currently supporting the Nuclear Regulatory Commission (NRC) on its efforts to develop an Advanced Reactor Regulatory Framework**
  - Next Generation Nuclear Plant project tackled several important regulatory issues
  - Joint project with NRC to develop Advanced Reactor General Design Criteria
    - NRC issued draft for public comment
  - Conducting joint workshops to solicit input from stakeholders
    - September 1-2, 2015
    - June 7-8, 2016
  - Exploring new regulatory review processes that are step-wise in nature

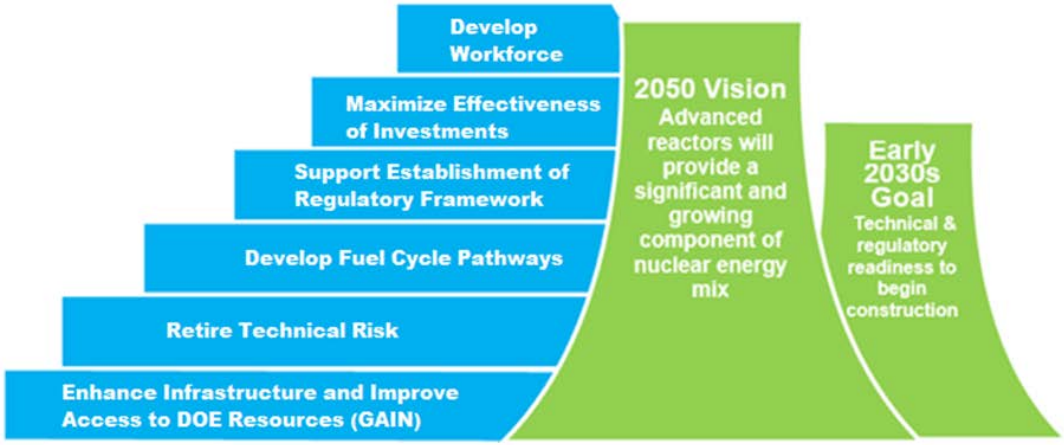
U.S.NRC

U.S. DEPARTMENT OF ENERGY

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Vision and Strategy for Advanced Reactors

- **To meet the challenge, DOE has developed the *Vision and Strategy for Development and Deployment of Advanced Reactors***
  - Final draft publically available at http://energy.gov/ne/downloads/draft-vision-and-strategy-development-and-deployment-advanced-reactors
- **The Vision and Strategy will complement DOE efforts to:**
  - Support the current Light Water Reactor fleet
  - Pursue the construction/operation of Generation III+ reactors
  - Support the development/licensing/deployment of Small Modular Reactors



Vision and Strategy for Advanced Reactors

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Vision and Goal

VISION

By 2050, advanced reactors will provide a significant and growing component of the nuclear energy mix both domestically and globally, due to their advantages in terms of improved safety, cost, performance, sustainability, and reduced proliferation risks.

GOAL

By the early 2030s, at least two non-light water advanced reactor concepts have reached technical maturity, demonstrated safety and economic benefits, and completed licensing reviews by the U.S. Nuclear Regulatory Commission (NRC) sufficient to allow construction to go forward.

U.S. DEPARTMENT OF ENERGY
Nuclear Energy

Strategic Objectives

1. **Enhance the innovation infrastructure for nuclear technologies and vastly improve access to DOE expertise and capabilities through the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative**
2. **Demonstrate performance and retire technical risks for advanced reactors**
3. **Support the development of fuel cycle pathways for advanced reactors**
4. **Support the establishment of an efficient and reliable regulatory framework for advanced reactors**
5. **Effectively leverage public/private sector resources and policy incentives to aid the private sector in accelerating advanced reactor deployment**
6. **Address human capital and workforce development needs**

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Enhanced Nuclear Innovation Infrastructure and Improved Access

- **Continue to enhance experimental, testing, and simulation capabilities while vastly improving access to DOE expertise and facilities. Key activities include:**
  - Implement the Gateway for Accelerated Innovation in Nuclear (GAIN)
    - Provides greater access to experimental, testing, and modeling and simulation capabilities
    - Facilitates use of the DOE nuclear technology database
    - Promotes broader engagement with industry to understand technical needs.
  - Restart the Transient Reactor Test Facility (TREAT)
  - Use the results of the advanced test/demonstration reactor planning study
  - Explore options for adding international collaboration elements to GAIN and the Nuclear Science User Facilities (NSUF) program

TREAT Facility

GAIN Gateway for Accelerated Innovation in Nuclear

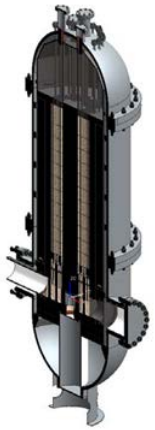
U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Retiring Advanced Reactor Technical Risk

- **DOE will pursue a multifaceted set of efforts to retire technical risks associated with advanced reactors including:**
  - Soliciting industry input on R&D needs
  - Supporting cost-shared, industry-led R&D for concept-level development and conduct research into high-temperature (HTR) reactor concepts, liquid metal cooled fast reactors (LMFRs) and molten salt cooled reactors (MSRs)
  - Conducting R&D in support of advanced reactor development
    - Efforts would include traditional laboratory R&D and relevant research projects selected through the DOE's Nuclear Energy University Program
    - Potential consideration to develop a test/demonstration reactor to further enhance its testing capabilities and support the timely deployment of advanced reactors
    - Pursuing technical solutions to support the changing role of nuclear energy as part of a diverse electricity generation mix and for non-electric uses

Mechanisms Engineering (Sodium) Test Loop at ANL



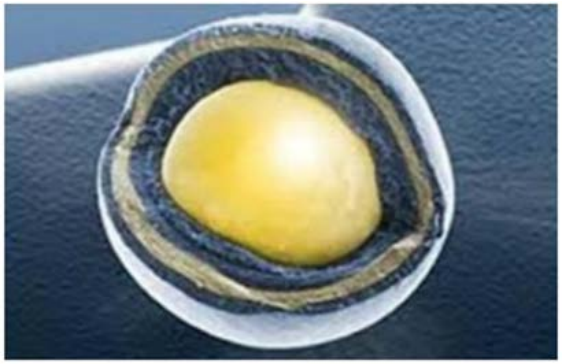
High Temperature Test Facility at Oregon State University

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Fuel Cycle Pathways for Advanced Reactors

- **DOE will pursue R&D to develop improved fuels for existing reactor technologies and suitable fuels for advanced reactors. Working with industry, these efforts will likely focus on:**
  - TRISO-coated particle fuel for high temperature reactors, metallic fuel for fast reactors, and transmutation fuels for longer-term applications
  - Identifying and characterizing fuels and separations/enrichment technologies.
    - DOE would assess the need for and/or provide for the deployment of fuel cycle facilities.
  - Addressing the back end of the nuclear fuel cycle
    - DOE is pursuing R&D to develop the technologies and capabilities needed to enable the safe storage, transportation, and disposal of used nuclear fuel and wastes generated by existing and future nuclear fuel cycles



TRISO coated particle fuel

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

Supporting Regulatory Framework Development for Advanced Reactors

- **DOE and its stakeholders will collaborate with the NRC as the NRC develops a regulatory framework for advanced reactors. Potential efforts include:**
  - Providing assistance to the NRC as it develops
    - design criteria for advanced reactors
    - potential staged licensing and preliminary licensability review processes
  - Assisting the NRC in resolving key policy issues by
    - co-hosting joint workshops
    - exploring options for new fuel and fuel fabrication facilities
    - modifying existing guidance (such as the Standard Review Plan) to accommodate advanced non-light water reactor designs

U.S. DEPARTMENT OF ENERGY

Nuclear Energy

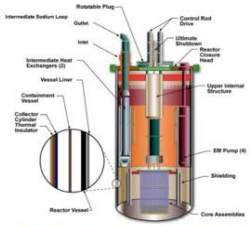
Maximizing the Effectiveness of Public and Private-Sector Investments to Accelerate Advanced Reactor Deployment

- **DOE will explore new ways to work with the private sector to accelerate advanced reactor deployment and support further development of advanced reactor concepts.**
  - DOE would use public-private partnerships and technology-specific working groups to identify opportunities for government investment that could help advance multiple reactor concepts
  - DOE and the Administration will explore the use of other appropriate policy or financial incentives to support advanced reactor deployment

- PWR
- BWR

- AP1000
- ESBWR

- NuScale
- B&W mPower
- Holtec SMR-160
- Westinghouse SMR



- Sodium Fast Reactor
- High Temperature Gas Reactor
- Lead Fast Reactor
- Gas Fast Reactor
- Molten Salt Reactor

GEN II	GEN III +	SMR	GEN IV Advanced Reactors
Leveraged Support	NP 2010	SMR Licensing Technical Support	Cost Shared and Potential Future Support for Advanced Reactors

U.S. DEPARTMENT OF ENERGY

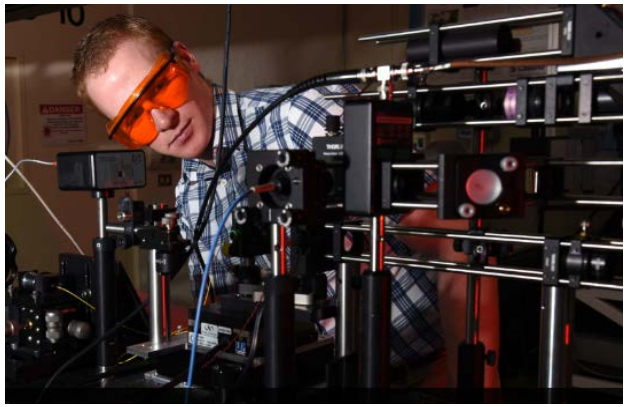
Nuclear Energy

Developing the Nuclear Energy Workforce of the Future

- **Continue funding nuclear-related research projects and scholarships and fellowships through its Nuclear Energy University Program (NEUP) and Integrated University Program (IUP)**
- **Promote advanced reactor technology training opportunities through workshops, curriculum development, and joint laboratory, university, and industry projects**
- **Seek opportunities to engage academic institutions in enhancing research efforts relevant to the development of advanced reactor technologies**

NEUP Nuclear Energy University Program

U.S. Department of Energy



Summary

- **Achieving our vision of a substantial role for nuclear power in our clean energy future requires:**
  - The continued long-term operation of the existing fleet of nuclear power plants
  - The deployment of new nuclear plants, including a mixture of
    - Large LWRs
    - SMRs
    - Advanced Reactors
- **Through the Vision and Strategy for Development and Deployment of Advanced Reactors and GAIN, DOE will work with key stakeholders, the NRC, and the private sector to lay the foundation for advanced reactor deployment.**