Nuclear Energy: A National Strategic Asset

• Recognition of the importance of nuclear – today and in the future
  – Energy Security
  – Economic Prosperity
  – Global Security
  – Environmental Sustainability

• Concern about the financial viability of some currently operating plants, yet benefits from keeping them running

• Increased interest in nuclear in some domestic and international markets

• Innovators and utilities looking at advanced nuclear as a way to move beyond electricity

• Secretary Perry: Make Nuclear Energy Cool Again!

“If you really care about this environment that we live in… then you need to be a supporter of this [nuclear energy] amazingly clean, resilient, safe, reliable source of energy.”
Secretary Rick Perry at Press conference, May 10th

• 20% of electricity (56% of non-emitting)
• 92% capacity factor
• Supports 475,000 jobs
• $10B in federal & $2.2B in state taxes annually
Global Growth and Market Opportunity

Potential Nuclear Power Expansion

- 35 countries taking steps to develop nuclear power
- 30 countries with operating reactors developing expansion plans

- ~60 reactors under construction in 15 countries (20 in China)
- ~170 reactors planned in over 25 countries, worth as much as $700 billion over the next 5-10 years
- ~370 reactors proposed in 36 countries, worth as much as $1.6 trillion over the next 10-25 years

~450 reactors operating
11% of electricity / 40% of clean electricity

Source: IAEA/PRIS & WNA
Office of Nuclear Energy Mission Pillars

- Existing Fleet
- Advanced Reactor Pipeline
- Fuel Cycle Infrastructure
A private-public partnership framework aimed at rapid and cost-effective development of innovative nuclear energy technologies towards market readiness

**Mission**
Provide the nuclear energy industry with access to **technical, regulatory and financial support** necessary to move innovative nuclear energy technologies toward **commercialization** in an accelerated and cost-effective fashion
Small Modular Reactors

Greater affordability
  – Easier financing for public power entities
  – Lower capital investment
  – Factory fabrication, shorter construction times

New standard of passive nuclear safety

Energy and environmental benefits
  – Greenhouse gas and air pollution avoided
  – Grid benefits: stability, security, quality, availability, reliability
  – Siting flexibility
  – Hybrid energy systems and flexible integration with renewables

Importance to National Security

Economic development and job growth
  – Manufacturing jobs and supply chain opportunities in the United States
Non-Water Advanced Reactor Designs Being Developed By Industry

**Gas Reactors**
- X-Energy Xe-100
- General Atomics Energy Multiplier Module, EM2

**Fast Reactors**
- GE Hitachi PRISM
- TerraPower TWR
- Advanced Reactor Concepts LLC ARC-100

**Molten Salt Reactors**
- Terrestrial Energy USA IMSR
- TerraPower MCFR
- Elysium USA MCSFR
- Kairos Power UCB PB-FHR
Micro Reactors

Designed for Specialized Applications

- Siting flexibility including near population centers
- Micro-grids
- Remote Operating Bases
- Data Centers
- Disaster Relief (FEMA)
- Specialized Non-electric Applications

Courtesy HolosGen
Nuclear Beyond Electricity – Advanced Reactors

NOW

Baseload Electricity Generation

FUTURE

Flexible Electricity Generation

Advanced Reactors

Large LWRs

SMRs

Non-Water Reactors

Chemical Processes

Clean Water

Hydrogen Production

Industrial Applications

Heat
Nuclear-Renewable Hybrid Energy Systems: Program Overview

• **Modeling and Simulation**
  Tool development and associated analysis to assess technical and economic viability and to determine optimal system design and energy dispatch
  *FY-18 Focus: Pilot case studies for specific plants and regions with utility partners*

• **Demonstration / Experimental Systems**
  Electrically heated system testing to demonstrate hardware interfaces, control systems, dynamic operation
  *FY-18 Focus: Design review with key stakeholders for PWR-emulation loop*
  Design/build thermal energy distribution system (TEDS) to connect PWR loop to hydrogen electrolysis.

• **Stakeholder engagement**
  – **Federal**: DOE-EERE collaboration, complementary work in -OE, -FE, DOD
  – **Industry**: Utilities (incl. Utility Advisory Committee), developers, end users
  – **International**: Clean Energy Ministerial, various others

**H2@Scale is a complementary, collaborating program supported by the DOE EERE Fuel Cell Technologies Office.**
Evaluating Technical and Economic Feasibility with Utility Partners

Case I: Nuclear-Renewable-Water Integration in Arizona

- Electrical integration of existing nuclear generation and desalination in a region with significant solar generation
- Collaboration with Arizona Public Service (APS), operating owner of Palo Verde Generating Station, with consultation from Electric Power Research Institute (EPRI)

Case II: Nuclear-Industrial Process Variable Hybrid in the Midwest

- Retrofit of an existing LWR to support an industrial application and electricity production in a region with significant wind generation
- Focus on H2 generation and associated off-take industries (e.g., steel making or ammonia production)
- Collaboration with multiple industrial partners, led by Exelon, with consultation from EPRI
At the 9th Clean Energy Ministerial (May 2018, Denmark) NICE Future was launched by the United States, Canada and Japan to spotlight nuclear energy in the international clean energy community.

**Overview:**
NICE Future focuses on nuclear power as a clean energy option for reliable and resilient baseload electricity, and non-electric applications especially when deployed as hybrid nuclear-renewable systems.

**Areas of Work:**
1) Evaluations of innovative systems, technology, storage, uses
2) Policy-maker and Stakeholder Engagement
3) Economics
4) Communicating nuclear energy’s role in clean energy systems
Questions?

BACK-UP
American Innovation Can Capture the Global Market

Advanced Nuclear Industry: Next Generation

Reactor Design Types:
- Molten Salt Reactor
- Fluoride Salt-cooled High Temperature Reactor
- Liquid Metal-cooled Fast Reactor
- High Temperature Gas Reactor
- Pebble Bed Reactor
- Nuclear Battery Reactor
- Designs Advanced Nuclear Fuels
- Small Modular Reactor
- Fusion Reactor
- Super-Critical CO₂ Reactor
- Accelerator Driven System
# Quick Comparison

<table>
<thead>
<tr>
<th></th>
<th>Light Water Reactors</th>
<th>High-Temp Gas Reactors</th>
<th>Sodium Fast Reactors</th>
<th>Gas-Cooled Fast Reactor</th>
<th>Lead-Cooled Fast Reactor</th>
<th>Molten Salt Reactors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Power (MWe)</strong></td>
<td>600-1000</td>
<td>100-300</td>
<td>50-2000</td>
<td>1000</td>
<td>20-1200</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Coolant</strong></td>
<td>water</td>
<td>helium</td>
<td>sodium</td>
<td>helium</td>
<td>Lead or lead-bismuth eutectic</td>
<td>Fluoride or other salt</td>
</tr>
<tr>
<td><strong>Moderator</strong></td>
<td>water</td>
<td>graphite</td>
<td>--</td>
<td>--</td>
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<td>--</td>
</tr>
<tr>
<td><strong>System Pressure (MPa)</strong></td>
<td>8-16</td>
<td>4-7</td>
<td>0.3</td>
<td>7-9</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Coolant Temperature at Outlet (°C)</strong></td>
<td>325</td>
<td>700-1000</td>
<td>500-550</td>
<td>750-850</td>
<td>480-570</td>
<td>700-800</td>
</tr>
<tr>
<td><strong>Average Core Power Density (W/cm³)</strong></td>
<td>100</td>
<td>4-8</td>
<td>&gt;200</td>
<td>60-100</td>
<td>70-120</td>
<td>330</td>
</tr>
</tbody>
</table>
High Temperature GasReactors

**Prismatic or Pebble Bed Core**

This is the pressure boundary

TRISO-coated fuel particles (left) are formed into fuel compacts (center) and inserted into graphite fuel elements (right) for the prismatic reactor.

TRISO-coated fuel particles are formed into fuel spheres for pebble bed reactor.

5 mm Graphite Layer
Coated Particles Embedded in Graphite Matrix

Pebble

Prismatic
Fast Reactors

• Sodium-Cooled Fast Reactors
  – Fast neutron spectrum
  – Low pressure for simplified compact operation
  – Liquid metal coolant – high conductivity
  – Enhanced passive safety
  – High fuel utilization
  – Flexible fuel cycle applications that can be self-sustaining

• Lead-Cooled Fast Reactors
  – Liquid metal coolant that is not reactive with air or water
  – Lead or lead-bismuth eutectic options
  – Fast neutron spectrum
  – Low operating pressure
  – High fuel utilization
  – Flexible fuel cycle applications that can be self-sustaining
Molten Salt Reactors

- Two major types – salt cooled and salt fueled
  - High temperatures for non-electric applications
  - Low operating pressures

- Fluoride salt-cooled high temp reactor (FHR)
  - Molten fluoride salt as coolant; typically FLiBe
  - Solid fuel; typically TRISO in pins, pebbles

- Liquid Fueled Molten Salt Reactor
  - Molten salt used as both coolant and fuel
  - Salts typically fluoride or chloride
  - Thermal or fast spectrum
  - No fuel fabrication – online refueling
  - On-line waste Management