# Innovating for a Sustainable Nuclear Future


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# Major Objectives of US Nuclear Industry

- ✓ Preserve the existing fleet
  - 98 reactors in operation
  - Providing 19.3% of total US electric generation and over 55% of country's emissions-free electricity
  - Achieving 92.3% average capacity factor
- ✓ Develop light-water small modular reactors (SMRs) and advanced reactors for commercial deployment

Momentum of current fleet is needed to ensure commercial viability of next generation of SMRs and advanced reactors

# Premature Nuclear Plant Closures and Announced Shutdowns

| Plant | MWe | Closure Year | Reason | Final Year Generation Generation (billion kWh per year) | Final Year CO2 Avoided (M tons/year) |
|---|---|---|---|---|---|
| Crystal River 3 | 860 | 2013 | Mechanical | 7.0 | 3.8 |
| San Onofre 2 & 3 | 2,150 | 2013 | Mechanical | 18.1 | 8.0 |
| Kewaunee | 566 | 2013 | Market | 4.5 | 3.8 |
| Vermont Yankee | 620 | 2014 | Market | 5.1 | 2.4 |
| Fort Calhoun | 478 | 2016 | Market | 3.4 | 3.3 |
| Oyster Creek | 625 | 2018 | Policy | 5.4 | 4.0 |
| TOTAL | 5,299 | | | 43.5 | 25.3 |
| Three Mile Island 1 1 | 803 | 2019 | Market | 6.9 | 5.0 |
| Pilgrim | 678 | 2019 | Market | 5.1 | 2.3 |
| Davis-Besse | 908 | 2020 | Market | 7.9 | 5.7 |
| Duane Arnold | 619 | 2020 | Market | 5.2 | 5.0 |
| Indian Point 2 & 3 | 2,061 | 2020-2021 | Market & Policy | 15.3 | 7.1 |
| Beaver Valley 1 & 2 | 1,872 | 2021 | Market | 15.3 | 11.1 |
| Perry | 1,268 | 2021 | Market | 9.8 | 7.1 |
| Palisades | 789 | 2022 | Market | 6.1 | 5.3 |
| Diablo Canyon 1 & | 2,240 | 2024-2025 | Policy | 17.9 | 2 6.9 |
| TOTAL | 11,238 | | | 89.5 | 55.5 |

Source: Emissions avoided are calculated using regional and national fossil fuel emissions rates from the **U.S. Environmental Protection Agency** and latest plant generation data from the **U.S. Energy Information Administration**. Updated: September 2018.

# Efforts to Prevent Premature Closure

## ✓Internal Focus

- Collaboration among operators through Delivering the Nuclear Promise initiative
  - Utilizing Minor Maintenance (EB 16-15b)
  - Critical Component Reduction (EB 16-25)
  - Value Based Maintenance (EB 17-03)
  - Standardized Performance Indicators (EB 17-24)
- Innovation
  - Electronic Work Packages
  - New Digital Worker

## ✓ External Focus

- State and federal level advocacy for policy changes
- Designed to level playing field among generation alternatives
- Rewards zero emissions attribute

# U.S. Nuclear Plant Costs ($/MWh in 2017 dollars)

| Year | Fuel | Capital | Operating | Total |
|---|---|---|---|---|
| 2002 | 5.93 | 4.06 | 19.25 | 29.24 |
| 2003 | 5.79 | 5.11 | 19.51 | 30.41 |
| 2004 | 5.47 | 5.85 | 19.19 | 30.51 |
| 2005 | 5.20 | 6.01 | 19.62 | 30.83 |
| 2006 | 5.22 | 5.76 | 19.90 | 30.88 |
| 2007 | 5.31 | 6.33 | 19.74 | 31.39 |
| 2008 | 5.54 | 7.00 | 20.21 | 32.75 |
| 2009 | 6.14 | 9.22 | 21.22 | 36.58 |
| 2010 | 7.00 | 9.48 | 21.37 | 37.84 |
| 2011 | 7.35 | 10.42 | 22.66 | 40.42 |
| 2012 | 7.77 | 11.21 | 22.37 | 41.35 |
| 2013 | 8.01 | 8.49 | 21.67 | 38.17 |
| 2014 | 7.47 | 8.47 | 21.67 | 37.60 |
| 2015 | 7.10 | 8.24 | 21.56 | 36.91 |
| 2016 | 6.90 | 6.89 | 20.87 | 34.65 |
| 2017 | 6.44 | 6.64 | 20.43 | 33.50 |
| 2002-2017 Change | 8.6% | 63.5% | 6.1% | 14.6% |
| 2012-2017 Change | -17.2% | -40.8% | -8.7% | -19.0% |

Source: Electric Utility Cost Group
Updated: September 2018

# Nuclear Plants Saved from Premature Closure

| Plant | MWe | Projected Closure Year | Reason for Potential Shutdown | Electricity Generated in 2017 (billion kWh per year) | $CO_2$ Emissions Avoided in 2017 (Million metric tons/year) |
|---|---|---|---|---|---|
| Clinton | 1,065 | 2017 | Market | 8.3 | 8.1 |
| Fitzpatrick | 852 | 2017 | Market | 6.2 | 2.9 |
| Ginna | 582 | 2017 | Market | 4.7 | 2.2 |
| Hope Creek | 1,172 | ~2020 | Market | 10.6 | 7.7 |
| Millstone 2 & 3 | 2,096 | ~2020 | Market | 16.5 | 7.4 |
| Nine Mile Point 1 & 2 | 1,770 | 2017-2018 | Market | 16.0 | 7.4 |
| Quad Cities 1 & 2 | 1,819 | 2018 | Market | 15.4 | 11.2 |
| Salem 1 & 2 | 2,328 | ~2020–2021 | Market | 18.0 | 13.1 |
| **TOTAL** | **11,683** | | | **95.7** | **60.0** |

- 11,683 MWe baseload capacity
- More than 7,400 direct jobs saved
- More electricity generation than all U.S. utility solar in 2017
- 60.0 million metric tons of $CO_2$ avoided

Source: Emissions avoided are calculated using regional and national fossil fuel emissions rates from the **U.S. Environmental Protection Agency** and latest plant generation data from the **U.S. Energy Information Administration**. Updated: August 2018.

# Reactor Technology Evolution

## *Light Water Reactors (LWR)*

*Existing fleet*

## *Passive LWR*

***Developers***
Westinghouse
GE-Hitachi

## *LWR Small Modular Reactors (SMR)*

***Developers***
*NuScale*
*GEH*
*Holtec*

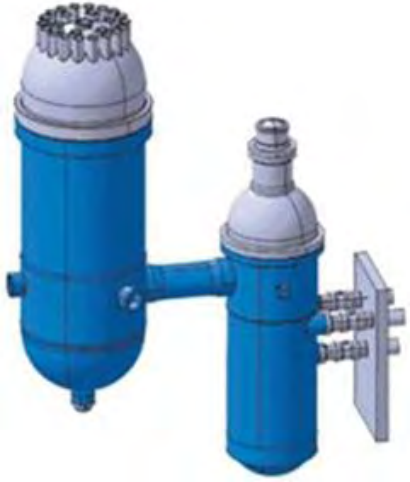
## *Fusion Reactors*

***Developers***
*Helion*
*Tri-Alpha*
*General Fusion*
*Lockheed Martin*
*FusionOne*

## *Molten Salt and Fast Reactors*

***Developers***
*Terrestrial*
*TerraPower*
*Flibe*
*Elysium*
*Oklo*
*Westinghouse*
*UPower*

## *High Temperature Gas-cooled Reactors (HTGR)*



***Developers***
*PBMR Ltd*
*Gen Atomics*
*Areva*
*Urenco*
*X-energy*

# Light-Water SMR Development

- ✓ NuScale Power
  - 12-pack of 60MWe reactors (720Mwe total)
  - Design Certification application under review by NRC
  - Potential construction by Utah-based municipalities
- ✓ GEH
  - 300MWe reactor
  - Based on approved design of ESBWR
  - Recently announce plans to pursue NRC approval
- ✓ Holtec
  - 160MWe
  - Expansion of dry cask expertise
  - Pursuing regulatory approval in Canada

# Advanced Reactor Activity

- ✓ Three Technology Working Groups (TWG)
  - High Temperature Reactors
  - Molten Salt Reactors
  - Fast Reactors
- ✓ Regulatory Challenges
  - Phased approach to licensing to support investment decisions
  - Regulatory framework changes needed to accommodate non-LWRs
- ✓ Federal Government Support
  - Gateway for Accelerated Innovation in Nuclear
  - Rolling funding opportunity from DOE
  - Strong, bi-partisan support in Congress
  - Department of Defense interest in microreactors

# Innovation and Collaboration

- ✓ Innovation
  - Optimizing combinations in salt formulas for MSRs
  - Customizing design to optimize operational staffing
  - Exploring additive manufacturing
- ✓ Collaboration
  - Among design competitors through TWG's
    - Addressing generic regulatory and technical issues
  - With international stakeholders
    - Exploring opportunities to share Virtual Test Reactor
    - Continuing communication between National Labs and international counterparts

Innovation and collaboration are key to ensuring that breakthrough technologies are competitive with other generation alternatives