NIC Global Summit
Outlook on Decommissioning Market

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State of Play - Nuclear Energy Worldwide

- At mid-year 2016, worldwide there are 444 operating power reactors with a combined capacity of 388 GWe and which accounted for 11% of world’s electricity
- Some 80% of existing nuclear capacity is in OECD countries. Of that more than three-quarters is over 30 years old
- By contrast, around half of the capacity in non-OECD countries (excluding Russia) is less than 15 years old
- Currently, worldwide there are 62 power reactors under construction with a combined capacity of 66 GWe, 16 reactors in OECD countries and 46 in non-OECD countries
DECOMMISSIONING OVERVIEW

• Over the next 20 years and beyond, the IEA estimates that 150 GWs, or more than 200 nuclear plants, are expected to be retired, primed for or begin decommissioning.

• To date, over 160 nuclear power plants have been shutdown and/or are undergoing decommissioning worldwide (not including test reactors).

• Top drivers for plant retirements include:
  - 75% - Units that have achieved their expected economic lifetime
  - 20% - Units which are closed prematurely by political decision or due to regulatory reasons and/or economic difficulties
  - 5% - Units that are closed following an accident

• Other key market drivers include:
  - Stringent regulations post-Fukushima
  - Rising cost of nuclear plant O&M and cap ex
  - Low electricity demand growth
  - Falling cost of renewables and combined with low natural gas prices
DECOMMISSIONING OVERVIEW

• Bulk of worldwide retirements are in the mature markets, i.e. oldest fleets first, reflecting the age profile of their fleets, particularly the by the United States followed by the European Union (led by France, Germany and UK), Japan and Russia.

• Rate of retirements picks up in the first half of the 2020s as reactors built in 1970s are taken off-line, and then again in the 2030s, particularly if life extensions in the U.S. are not re-extended for another 20 years.

• Average rate of retirements is about 5 GWs per year, compared with new additions of 15 per year
# Worldwide Estimated Market Size – Near Term

<table>
<thead>
<tr>
<th></th>
<th>2016 Market Size</th>
<th>2020 Market Size</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>•</strong></td>
<td>8,217 MWe</td>
<td>20,604 MWe</td>
</tr>
<tr>
<td><strong>•</strong></td>
<td>$6,163 - $12,326 Billion</td>
<td>$15,453 - $30,906 Billion</td>
</tr>
</tbody>
</table>

**Annual Average Growth Rate:** 23 PERCENT
Worldwide Age Profile of Operating Reactors

- Over 20+ years, there are 356 reactors
- Over 30+ years, there are 220 reactors
- Over 40+ years, there are 65 reactors
Around 150 GW of nuclear capacity is retired thru 2040, equivalent to 38% of the current installed capacity or 44% of the existing operating world fleet.
U.S. Nuclear Plant Age Distribution

- US nuclear fleet is the oldest in the world and averages 33 years
- 75 U.S. reactors have a 20 year life extension
Recent news reports indicate that first candidates for a second 20-year extension to 80 years are Dominion Resources Surry Plant in Virginia, Exelon’s Peach Bottom Plant in Pennsylvania and Duke Energy’s Oconee plant in South Carolina.
• Without additional new builds beyond those currently underway, total U.S. installed capacity begins to decline starting around 2027
EU Nuclear Capacity Outlook

- EU nuclear fleet has a current average age of 30 years, all most half is expected to be retired by 2040
U.S. License Renewal Efforts

- Forty reactors have passed 40-year mark
- Approximately 31,000 MW of nuclear capacity will reach 60 years between 2029 and 2035
- Approximately one-half U.S. nuclear capacity will reach 60 years by 2040
- For second license renewal, NRC regulatory process stable, well-understood; existing regulations adequate
- In November 2015, Dominion Virginia Power announced intent to file second license renewal application for Surry nuclear plant. Exelon has followed and announced its attention at Peach Bottom
- Decision to renew a second time depends on whether market conditions justify capital investment required

Status of First License Renewal

- 81 Reactors Approved
- 12 Reactors Under Review
- 5 Reactors Intend to Renew

Source: Nuclear Regulatory Commission
## Premature Nuclear Plant Shutdowns

<table>
<thead>
<tr>
<th>Plant</th>
<th>MWe</th>
<th>Reason</th>
<th>Closure Year</th>
<th>Latest Electricity Generated (bkWh/year)</th>
<th>Latest CO2 Emissions Avoided (million tons/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal River 3</td>
<td>860</td>
<td>Mechanical</td>
<td>2013</td>
<td>7.0</td>
<td>5.3</td>
</tr>
<tr>
<td>San Onofre 2 &amp; 3</td>
<td>2,150</td>
<td>Mechanical</td>
<td>2013</td>
<td>18.1</td>
<td>8.8</td>
</tr>
<tr>
<td>Kewaunee</td>
<td>566</td>
<td>Market</td>
<td>2013</td>
<td>4.5</td>
<td>4.8</td>
</tr>
<tr>
<td>Vermont Yankee</td>
<td>620</td>
<td>Market</td>
<td>2014</td>
<td>5.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Fort Calhoun</td>
<td>479</td>
<td>Market</td>
<td>2016</td>
<td>3.5</td>
<td>3.7</td>
</tr>
<tr>
<td>FitzPatrick</td>
<td>852</td>
<td>Market</td>
<td>2017</td>
<td>7.4</td>
<td>3.9</td>
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<td>Clinton</td>
<td>1,065</td>
<td>Market</td>
<td>2017</td>
<td>8.7</td>
<td>9.2</td>
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<tr>
<td>Quad Cities 1 &amp; 2</td>
<td>1,819</td>
<td>Market</td>
<td>2018</td>
<td>15.6</td>
<td>13.2</td>
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<tr>
<td>Pilgrim</td>
<td>678</td>
<td>Market</td>
<td>2019</td>
<td>5.0</td>
<td>2.6</td>
</tr>
<tr>
<td>Oyster Creek</td>
<td>610</td>
<td>Policy</td>
<td>2019</td>
<td>5.3</td>
<td>4.4</td>
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<td>Diablo Canyon 1 &amp; 2</td>
<td>2,240</td>
<td>Combination</td>
<td>2024-2025</td>
<td>18.5</td>
<td>8.3</td>
</tr>
</tbody>
</table>

- 11,939 MWe of baseload capacity
- 67 million short tons of CO₂ avoided
- 16% of Clean Power Plan’s 2030 414-million-ton target
- Approximately 9,000 direct jobs
Plants Declared at Declared at Risk/or at Risk

• Additional plants that have been declared at risk include:
  ▪ Davis Besse: 894 MWe
  ▪ Three Mile Island 1: 805 MWe
  ▪ Ginna: 582 MWe
  ▪ Nine Point 1: 637 MWe

• Deemed at Risk:
  ▪ Indian Point 2: 1028 MWe
  ▪ Indian Point 3: 1041 MWe

• Total Capacity at Risk: 4,987 MWe
U.S. Announced Early Plant Retirements

Source: NECG
Decommissioning Costs

• Decommissioning cost estimates vary

• Based on U.S. data, decommissioning cost estimates are in the range of $750 million to $1 billion per 1000 megawatt plant

• Decommissioning options include:
  - Immediate dismantling is the prompt removal and processing of all radioactive material
  - Deferred dismantling (Safe Store) is the process of allowing radioactive decay to occur before starting the dismantling process
Decommissioning Costs as a function of time from shutdown

**Figure 8:** Decommissioning a nuclear power plant takes many years and costs vary widely. The highest costs will be incurred during the initial shutdown and final decommissioning and demolition. Any intervening period of standing by will be less expensive. These factors may influence decisions on how rapidly decommissioning will take place. Source United States Department of Energy (2010)
## Investor-Owned Decommissioning Per Plant Cost Estimates

<table>
<thead>
<tr>
<th>Company</th>
<th>Lic Exp [Aug Yr]</th>
<th>Mw Nuclear Capacity</th>
<th>Decommissioning Cost Estimate ($mm)</th>
<th>Feed Balance</th>
<th>Pro Forma Feed Shortfall</th>
<th>Current Amount</th>
<th>Pro Forma Amort Yr</th>
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</thead>
<tbody>
<tr>
<td>American Electric Power Co</td>
<td>2024</td>
<td>1,190</td>
<td>574</td>
<td>564</td>
<td>650</td>
<td>194</td>
<td>159</td>
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<tr>
<td>Constellation Energy Nuclear Gp</td>
<td>2024</td>
<td>2,069</td>
<td>3,175</td>
<td>665</td>
<td>1,651</td>
<td>1,932</td>
<td>-281</td>
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<tr>
<td>DTE Energy Co</td>
<td>2025</td>
<td>10.65</td>
<td>1,600</td>
<td>1,475</td>
<td>1,600</td>
<td>1,172</td>
<td>132</td>
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<tr>
<td>Duke Energy Co</td>
<td>2030</td>
<td>5,958</td>
<td>150,300</td>
<td>5,393</td>
<td>1,256</td>
<td>1,394</td>
<td>317</td>
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<tr>
<td>Great Plains Energy</td>
<td>2014</td>
<td>745</td>
<td>206</td>
<td>206</td>
<td>184</td>
<td>206</td>
<td>-1</td>
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<tr>
<td>Greens Mountain Power Co</td>
<td>2030</td>
<td>0.21</td>
<td>11</td>
<td>524</td>
<td>17</td>
<td>0</td>
<td>0</td>
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<tr>
<td>MidAmerican Energy Co</td>
<td>2032</td>
<td>444</td>
<td>329</td>
<td>740</td>
<td>334</td>
<td>394</td>
<td>0</td>
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<tr>
<td>NextEra Energy</td>
<td>2030</td>
<td>5,552</td>
<td>4,500</td>
<td>811</td>
<td>4,500</td>
<td>4,138</td>
<td>-208</td>
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<tr>
<td>NRG Energy</td>
<td>2027</td>
<td>1,126</td>
<td>554</td>
<td>492</td>
<td>551</td>
<td>48</td>
<td>25</td>
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<tr>
<td>Pacific Gas &amp; Electric Co</td>
<td>2024</td>
<td>2,303</td>
<td>3,690</td>
<td>1,559</td>
<td>3,590</td>
<td>2,665</td>
<td>925</td>
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<tr>
<td>Providence West Capital Co</td>
<td>2045</td>
<td>1,146</td>
<td>701</td>
<td>612</td>
<td>115</td>
<td>642</td>
<td>23</td>
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<tr>
<td>PPL Co</td>
<td>2042</td>
<td>2,378</td>
<td>1,245</td>
<td>549</td>
<td>1,810</td>
<td>594</td>
<td>0</td>
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<tr>
<td>Public Service Co of New Mex</td>
<td>2045</td>
<td>402</td>
<td>246</td>
<td>611</td>
<td>321</td>
<td>223</td>
<td>5</td>
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<tr>
<td>Public Service Ent Group</td>
<td>2033</td>
<td>3,622</td>
<td>2,180</td>
<td>602</td>
<td>2,890</td>
<td>1,701</td>
<td>1,189</td>
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<tr>
<td>San Diego Gas and Electric Co</td>
<td>2024</td>
<td>430</td>
<td>286</td>
<td>2,015</td>
<td>867</td>
<td>907</td>
<td>-40</td>
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<tr>
<td>Southern California Edison</td>
<td>2045</td>
<td>2,304</td>
<td>3,756</td>
<td>1,630</td>
<td>3,756</td>
<td>2,437</td>
<td>-481</td>
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<tr>
<td>Southern Co</td>
<td>2034</td>
<td>3,667</td>
<td>2,817</td>
<td>768</td>
<td>2,926</td>
<td>1,480</td>
<td>1,446</td>
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<tr>
<td>Westar Energy</td>
<td>2045</td>
<td>1,594</td>
<td>2,884</td>
<td>1,809</td>
<td>2,884</td>
<td>1,627</td>
<td>257</td>
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</table>

| Investor-Owned Utilities Total| 83,391           | 66,558              | 7,928                             | 74,234       | 50,475                   | 23,819         | 315               | 1,314           |
IEA Decommissioning Costs thru 2040

IEA estimate of $104 billion is based on 150 GW of plant retirements at $693 million per GW. At $1B per GW, estimate is 150 billion and at $1.5B per plant, the worldwide market is $225 billion.

<table>
<thead>
<tr>
<th>Country</th>
<th>Investment in nuclear plants*</th>
<th>Associated costs</th>
<th>Total capacity additions (GW)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fuel cycle</td>
<td>Decommissioning</td>
</tr>
<tr>
<td>China</td>
<td>345</td>
<td>191</td>
<td>-</td>
</tr>
<tr>
<td>European Union</td>
<td>301</td>
<td>220</td>
<td>51</td>
</tr>
<tr>
<td>United States</td>
<td>247</td>
<td>236</td>
<td>15</td>
</tr>
<tr>
<td>Korea</td>
<td>103</td>
<td>78</td>
<td>1</td>
</tr>
<tr>
<td>India</td>
<td>96</td>
<td>37</td>
<td>1</td>
</tr>
<tr>
<td>Japan</td>
<td>37</td>
<td>54</td>
<td>10</td>
</tr>
<tr>
<td>Rest of world</td>
<td>406</td>
<td>161</td>
<td>27</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,533</strong></td>
<td><strong>977</strong></td>
<td><strong>104</strong></td>
</tr>
</tbody>
</table>
Decommissioning market size is in the range of $100-$150 billion thru 2040.
Decommissioning costs are in the order of 10 percent of the investment in new nuclear capacity over the period.
SUMMARY

• Plant Decommissioning has become and will continue to be an increasing important segment of the nuclear energy industry

• Existing nuclear plant fleets are approaching “mid-life” and future nuclear plant retirements are “around-the-corner”, and are the logical consequence of plants reaching their economic life and design expectancies

• Nuclear plant decommissioning costs vary significantly and depend on decommissioning approach, in-country requirements and regulation and industry practices

• Nuclear plant decommissionings are expected to be concentrated in the oldest fleets, led by the U.S. and EU, as well as those underway in Germany and those that may take place in Japan as a resulted of the Fukushima accident

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Backup Slides
State of Play - Nuclear Energy Worldwide

- In 2015, WNA reports that 10 new reactors began commercial operations (+9497 MWe), while internationally eight reactors were shutdown for decommissioning (-4582 MWe)

- Four U.S. reactors (Crystal River 3, San Onofre 2&3, Vermont Yankee) were declared has permanently shutdown (-3479 MWe)

- Germany shutdown 1 reactor, Grefenrheingeld of 1345 MWe, Japan permanently closed 5 reactors: Genka 1, Mihama 1, Miahama 2, Shimane 1, and Tsuruga 1 representing a total of 2099, Sweden closed 1 reactor Oskarshamn of 648 MWe and Britain closed 1 reactor Wylfa of 490 MWe

- Total: 110 commercial reactors 46 experimental or prototypes, and 250 research reactors and number of fuel cycle facilities have been permanently shutdown. Some of these facilities have been fully dismantled.
### Figure 2

**New Nuclear Generating Capacity Needed If All Reactors Retire After 60 Years of Operation**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Electric Generation (bkWh)</th>
<th>Nuclear Capacity (GW)</th>
<th>Nuclear Generation (bkWh)</th>
<th>Nuclear Fuel Share</th>
<th>New Generation Needed to Meet Fuel Share (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>2025</td>
<td>4,622.3</td>
<td>104.0</td>
<td>820.0</td>
<td>17.7%</td>
<td>13.2</td>
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<td>42.6</td>
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<tr>
<td>2030</td>
<td>4,815.1</td>
<td>100.0</td>
<td>788.0</td>
<td>16.4%</td>
<td>22.2</td>
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<td>52.7</td>
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<tr>
<td>2035</td>
<td>5,004.3</td>
<td>72.4</td>
<td>570.4</td>
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<td>54.6</td>
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<td>2040</td>
<td>5,219.7</td>
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<td>453.2</td>
<td>8.7%</td>
<td>74.9</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>108.0</td>
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*Data Source: Energy Information Administration, Annual Energy Outlook 2014*