• Who uses nuclear energy
• Current Trends
  – US Nuclear industry improvements
• The Next Decade
  – New nuclear construction for a balanced energy portfolio
• Beyond
  – Sustainable nuclear fuel cycles for a secure global nuclear future
Who uses nuclear energy?

- 16% of world’s electricity production
Who uses nuclear energy?

<table>
<thead>
<tr>
<th>Country</th>
<th>Total Nuclear Generation (Billion kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>787</td>
</tr>
<tr>
<td>France</td>
<td>429</td>
</tr>
<tr>
<td>Japan</td>
<td>292</td>
</tr>
<tr>
<td>Germany</td>
<td>159</td>
</tr>
<tr>
<td>Russia</td>
<td>144</td>
</tr>
<tr>
<td>S. Korea</td>
<td>141</td>
</tr>
<tr>
<td>China</td>
<td>93.1</td>
</tr>
<tr>
<td>Canada</td>
<td>92.4</td>
</tr>
<tr>
<td>Ukraine</td>
<td>84.8</td>
</tr>
<tr>
<td>UK</td>
<td>69.2</td>
</tr>
</tbody>
</table>

2006
Current Trends

**Generation I**
Early Prototype Reactors

- Shippingport
- Dresden, Fermi-I
- Magnox

**Generation II**
Commercial Power Reactors

- LWR: PWR/BWR
- CANDU
- VVER/RBMK

Capacity Factors Improve

- 90.1% in 2004
- 89.3% in 2005
- 89.8% in 2006

Source: NEI

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Nation’s Lowest Production Costs

- Coal
- Gas
- Nuclear
- Petroleum

Total Production Cost (¢/kWh)

Source: NEI
Record U.S. Nuclear Electricity Production

1000MWe = 7.9 billion kWh

Source: EIA

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Extending Assets: Power Uprates

- Expected Applications 1,473 MWe
- Applications Under Review 1,017 MWe
- Approved 4,900 MWe

Source: NEI
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Extending Assets: License Renewals

- **License Renewals**
  - 20 year license renewals
  - Must demonstrate continued safe operation

- **48 units renewed**
- **19 units pending**
- **26 plants considering**

93 out of 104 operating reactors
... the Next Decade ...

**Generation I**
Early Prototype Reactors
- Shippingport
- Dresden, Fermi-I
- Magnox

**Generation II**
Commercial Power Reactors
- LWR: PWR/BWR
- CANDU
- VVER/RBMK

**Generation III**
Advanced LWRs
- System 80+
- AP600
- EPR
- ABWR

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Nuclear Power 2010

Goal
New Advanced LWR operating in 2010’s

• New Licensing Process (1992)
  – Three steps
    • Design Certification (5 certified designs)
    • Early Site Permit (3/4 ESP applications granted)
    • Construction & Operation License
• Renewal of Price-Anderson Act (2005)
• Federal loan guarantees (2005)
# New Nuclear Plant Status

30+ reactors planned, 17 COLAs for 26 reactors

<table>
<thead>
<tr>
<th>Company</th>
<th>Site(s)</th>
<th>Early Site Permit (ESP)</th>
<th>Design, # of units</th>
<th>Construction/Operating License Submittal Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVA (NuStart)</td>
<td>Bellefonte (TN)</td>
<td>W: AP1000 (2)</td>
<td>October 2007</td>
<td></td>
</tr>
<tr>
<td>South Carolina E &amp; G</td>
<td>Summer (SC)</td>
<td>W: AP1000 (2)</td>
<td>March 2008</td>
<td></td>
</tr>
<tr>
<td>Duke</td>
<td>Cherokee County, SC</td>
<td>W: AP1000 (2)</td>
<td>Dec 2007</td>
<td></td>
</tr>
<tr>
<td>Progress Energy</td>
<td>Harris (NC)</td>
<td>W: AP1000 (2) AP1000 (2)</td>
<td>Feb 2008 July 2008</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Levy County, FL</td>
<td>Will go to COL with early submittal of siting info</td>
<td>Areva: EPR (1) EPR (1) EPR (1)</td>
<td>March 2008 Oct 2009 TBD</td>
</tr>
<tr>
<td>Constellation (UniStar)</td>
<td>Calvert Cliffs (MD) Nine Mile Point (NY) + one other sites</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NRG Energy (STP)</td>
<td>South Texas Project (TX)</td>
<td>GE: ABWR (2)</td>
<td>Sep 2007</td>
<td></td>
</tr>
<tr>
<td>Luminant</td>
<td>Comanche Peak (TX)</td>
<td>Straight to COL MHI: APWR (2)</td>
<td>Sep 2008</td>
<td></td>
</tr>
<tr>
<td>Detroit Edison</td>
<td>Fermi (MI)</td>
<td>Not yet determined GE: ESBWR (1)</td>
<td>Sep 2008</td>
<td></td>
</tr>
</tbody>
</table>

Source: NEI/NRC 10/2008
## New Nuclear Plant Status

<table>
<thead>
<tr>
<th>Company</th>
<th>Site(s)</th>
<th>Early Site Permit (ESP)</th>
<th>Design, # of units</th>
<th>Construction/Operating License Submittal Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amarillo Power</td>
<td>Near Amarillo, TX</td>
<td></td>
<td>EPR</td>
<td>FY 2009</td>
</tr>
<tr>
<td>Florida Power &amp; Light</td>
<td>Turkey Point (FL)</td>
<td>TBD</td>
<td>TBD (2)</td>
<td>FY 2009</td>
</tr>
<tr>
<td>Alternate Energy Holdings</td>
<td>Bruneau, ID</td>
<td></td>
<td>EPR</td>
<td>FY 2009</td>
</tr>
<tr>
<td>AmerenUE</td>
<td>Callaway (MO)</td>
<td></td>
<td>EPR</td>
<td><strong>July 2008</strong></td>
</tr>
<tr>
<td>Exelon</td>
<td>Matagorda &amp; Victoria County, TX</td>
<td></td>
<td>ESBWR(2)</td>
<td><strong>September 2008</strong></td>
</tr>
<tr>
<td>Duke</td>
<td>Davie County (NC)</td>
<td>Under consideration</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Duke</td>
<td>Oconee County (SC)</td>
<td>Under consideration</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Exelon</td>
<td>Clinton (IL)</td>
<td><strong>Approved 03/2007</strong></td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>PPL Corp</td>
<td>Susquehanna, (PA)</td>
<td>TBD</td>
<td>EPR</td>
<td><strong>October 2009</strong></td>
</tr>
</tbody>
</table>

Source: NEI/NRC 10/2008
Life-cycle Emissions

<table>
<thead>
<tr>
<th>Emissions [kg CO₂ eq./MWhₑ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (Boiler)</td>
</tr>
<tr>
<td>Gas CCGT</td>
</tr>
<tr>
<td>PV (battery storage)</td>
</tr>
<tr>
<td>Wind (air storage)</td>
</tr>
<tr>
<td>PV (no storage)</td>
</tr>
<tr>
<td>Fission</td>
</tr>
<tr>
<td>Wind (no storage)</td>
</tr>
</tbody>
</table>

- Coal (Boiler): 974 kg CO₂ eq./MWhₑ
- Gas CCGT: 469 kg CO₂ eq./MWhₑ
- PV (battery storage): 136 kg CO₂ eq./MWhₑ
- Wind (air storage): 109 kg CO₂ eq./MWhₑ
- PV (no storage): 39 kg CO₂ eq./MWhₑ
- Fission: 15 kg CO₂ eq./MWhₑ
- Wind (no storage): 14 kg CO₂ eq./MWhₑ

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Nuclear Supplies Most Low-Emission Electricity

- **Nuclear**: 69.2%
- **Hydro**: 29.1%
- **Geothermal**: 1.3%
- **Photovoltaic**: <0.1%
- **Wind**: 0.34%

Source: EIA 2000
Issues: Waste
The 3 C’s of Used Nuclear Fuel

Compact ... Contained ... Cared for

• Imagine all your electricity for an entire lifetime was generated by nuclear energy
  – About 1 million kWh (2004 EIA)

• About 1 soda-can of used nuclear fuel
The 3 C’s of Used Nuclear Fuel

Compact    ...    Contained    ...    Cared for

- Fuel itself is **solid**
- Wrapped in metal
- Stored in pool/cask
The 3 C’s of Used Nuclear Fuel

- Compact ... Contained ... Cared for

- Carefully tracked
- Decades of experience in safe handling
- Easy to detect and monitor
- Paid for in Nuclear Waste Fee
Yucca Mountain Timeline

- 1957: National Academy recommends deep geologic disposal as preferred solution
- 1978: Study begins @ Yucca Mtn
- 1982: Nuclear Waste Policy Act
  - 63,000 metric tonnes of spent nuclear fuel in first repository
- 1985: Three sites approved for intensive study
- 1987: Yucca Mtn selected as preferred site
- 2002: Yucca Mtn suitability affirmed by President & Congress
- 2006: New Senate Majority leader
  - Sen. Harry Reid (D-NV)
- 2008: Application for license expected at US Nuclear Regulatory Commission for 2017 opening
  - Current funding level means schedule in question (2021?)
Estimated Dose from Yucca Mtn
Estimated Dose from Yucca Mtn

Projected Annual Dose (mrem)

Time (years)

Mean
Median
95th Percentile
5th Percentile

Ref: DOE Supplemental Environmental Impact Statement
... and Beyond!

**Generation I**
Early Prototype Reactors
- Shippingport
- Dresden, Fermi-I
- Magnox

**Generation II**
Commercial Power Reactors
- LWR: PWR/BWR
- CANDU
- VVER/RBMK

**Generation III**
Advanced LWRs
- System 80+
- AP600
- EPR
- ABWR

**Generation IV**
- Highly economical
- Enhanced Safety
- Minimized Wastes
- Proliferation Resistance


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Preparing for Global Energy Needs

• Improvement in global standard of living will require increased energy/electricity supply

• Even a modest nuclear share requires large global deployment:
  – Differing economic environments & energy products
  – Large spent fuel inventories
  – Proliferation concerns
  – Varying safety cultures
Global Nuclear Energy Partnership

- US Nuclear Power
- Proliferation-Resistant Recycling
- Advanced Burner Reactors
- Reliable Fuel Services
- Small-Scale Reactors
- Advanced Nuclear Safeguards

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Advanced fuel cycles

LWRs/ALWRs

Thermal Recycle

Fresh U

Full Recycle

Generation IV Reactors

Advanced Fuel Reprocessing w/o Pu Separation

Yucca Mountain, Nevada

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## Minimize Nuclear Waste

<table>
<thead>
<tr>
<th>Nuclear Futures</th>
<th>Legal Limit</th>
<th>Extended License for Current Reactors</th>
<th>Continued Constant Energy Generation</th>
<th>Constant Market Share</th>
<th>Growing Market Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Discharged Fuel by 2100, MTHM</td>
<td>63,000</td>
<td>120,000</td>
<td>240,000</td>
<td>600,000</td>
<td>1,300,000</td>
</tr>
<tr>
<td><strong>Current approach</strong></td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>21</td>
</tr>
<tr>
<td><strong>Expanded capacity</strong></td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td><strong>Thermal Recycle</strong></td>
<td>1</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Full Recycle</strong></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

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Reduce Proliferation Risk

- **Reliable fuel services**
  - Supplier states are most economically attractive option
  - Internationally guaranteed supply

- **Small-scale reactors**
  - Small size for growing economies with limited access to capital
  - Long life cores to minimize refueling

- **Advanced Safeguards**
  - Technology & diplomacy
On this day....

- Presidential election politics
- Credit crunch
- Economic slowdown
Paul Wilson
wilsonp@engr.wisc.edu

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Issues: Safety History

• 1979: Three Mile Island
  – Reactor valve malfunctions
  – Small radioactivity release
  – No radiation-related health impacts
  – Economic disaster for owner

• 1986: Chernobyl
  – Flawed reactor design & operations
  – Large radioactivity release
  – 50-1000 radiation-related deaths/illnesses
  – Regional socio-economic catastrophe
Issues: Safety

Current Trends

• Technology improvements continually reduce risk
  – Risk-based regulation

• Human training & performance critical
  – Safety culture
  – US nuclear industry one of the safest

• US Nuclear Regulatory Commission
  – Fee-based regulator
  – Credible & effective
• Price-Anderson Act
  – Group insurance policy
  – All reactor operators share liability for any accident
  – Total liability capped with US Gov’t as insurer of last resort
• Similar to other industries
Issues
Economics

• Large capital cost
  – $1500-2000/kWe
  – Construction delays

• Small fuel costs

• Regulatory uncertainty
  – 1989: Shoreham $6B
Advanced Light Water Reactors

• Evolutionary changes to current reactor designs
• Focus on passive safety systems
• Improved economics
  – Modern/modular construction practices
  – Standardized designs
• Currently being built in Pacific Rim, Finland & France
ALWR Example: Westinghouse AP1000

• Simplicity
  – 50 percent fewer valves
  – 83 percent less piping
  – 87 percent less control cable
  – 35 percent fewer pumps, and
  – 50 percent less seismic building volume than a similarly sized conventional plant

• Cheaper, Faster, Less Maintenance
Energy Recovery

- $\sim 1 \text{ MWd}_{th}/g$ of fissions
- Nat. abundance of $^{235}\text{U}$ is only 0.71%
- 140x as much energy in $^{238}\text{U}$ as in $^{235}\text{U}$
- 50 y (??) of energy in $^{235}\text{U}$
  \[= 7000 \text{ y of energy in } ^{238}\text{U} \text{ (and actinides)}\]

Note: we are ignoring Th