Renewable Generation
Update on Trends and Challenges in the Electric Enterprise

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Laufer Energy Symposium
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Presentation Outline

• About EPRI

• Key Industry Technical Challenges

• Renewables
  – Drivers
  – Update / Trends
  – Challenges for the Grid

• Summary
  – R&D Opportunities and Gaps
About EPRI …

• Founded in 1972
• Independent, nonprofit center for public interest energy and environmental research
• Collaborative resource for the electricity sector
• 450+ participants in more than 40 countries
• International funding of more than 20% of EPRI’s research, development and demonstrations
The Challenge

Provide society with . . . while transforming to a cleaner, more efficient, modern generation fleet with an interactive electrical grid.
Key Strategic Industry Technical Challenges

- Smart Grid
- Energy Efficiency
- Long-Term Operations

- Renewable Resources and Integration
- Near Zero Emissions
- Water Resource Management

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Wind Generation
Rapid growth in renewables ... in places ...

~50% of global operating wind capacity in U.S. and China

~50% of global operating solar capacity in Germany and Italy

Source: Renewables Global Status Report 2011
Growing Global Wind Capacity

- Currently $1500 - $1800/kw turn key cost

$40 - $50 billion annual market

Globally diversified
- US/North America: 20%
- Europe: 25%
- China/Asia Pac: 50%
- ROW: 5%
China Was 1\textsuperscript{st} and the U.S. Was 2\textsuperscript{nd} in Both New and Cumulative Wind Power Capacity

<table>
<thead>
<tr>
<th>Annual Capacity (2011, MW)</th>
<th>Cumulative Capacity (end of 2011, MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>17,631</td>
</tr>
<tr>
<td>U.S.</td>
<td><strong>6,816</strong></td>
</tr>
<tr>
<td>India</td>
<td>3,300</td>
</tr>
<tr>
<td>Germany</td>
<td>2,007</td>
</tr>
<tr>
<td>U.K.</td>
<td>1,293</td>
</tr>
<tr>
<td>Canada</td>
<td>1,267</td>
</tr>
<tr>
<td>Spain</td>
<td>1,050</td>
</tr>
<tr>
<td>Italy</td>
<td>950</td>
</tr>
<tr>
<td>France</td>
<td>875</td>
</tr>
<tr>
<td>Sweden</td>
<td>763</td>
</tr>
<tr>
<td>Rest of World</td>
<td>5,766</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>41,718</strong></td>
</tr>
<tr>
<td>China</td>
<td>62,412</td>
</tr>
<tr>
<td>U.S.</td>
<td><strong>46,916</strong></td>
</tr>
<tr>
<td>Germany</td>
<td>29,248</td>
</tr>
<tr>
<td>Spain</td>
<td>21,350</td>
</tr>
<tr>
<td>India</td>
<td>16,266</td>
</tr>
<tr>
<td>U.K.</td>
<td>7,155</td>
</tr>
<tr>
<td>France</td>
<td>6,836</td>
</tr>
<tr>
<td>Italy</td>
<td>6,733</td>
</tr>
<tr>
<td>Canada</td>
<td>5,278</td>
</tr>
<tr>
<td>Portugal</td>
<td>4,214</td>
</tr>
<tr>
<td>Rest of World</td>
<td>34,453</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>240,861</strong></td>
</tr>
</tbody>
</table>

Source: BTM Consult; AWEA project database for U.S. capacity

- Global wind power capacity additions in 2011 up 6\% from 2010 level
- U.S. additions = 16\% of global additions in 2011, up from 13\% in 2010 but down from 26-30\% from 2007 through 2009

Source: R.Wiser and M. Bolinger LBL, July 2012 Report
Wind Turbine Technology Trends

Evolution of Commercial Wind Technology

The 1980's
- Altamont Pass, CA Kenetech 56-100kW 17m Rotor
- San Clemente, CA Micon 700-225/40 29.6m Rotor

The 1990's
- Mehuku, Norway Vestas V52-850kW 52m Rotor
- 500kW
- 300kW

2000 & Beyond
- Liverpool Bay, UK Siemens SWT-3.6MW 107m Rotor
- 750kW
- 2.5 MW
- 1.5 MW
- Medicine Bow, WY Clipper 2.5MW 93m Rotor
- Hagerman, ID GE 1.5 MW 77m Rotor

Land Based
- Aberdeen, Scotland North Sea (45m water depth) REpower 5MW 126m Rotor

Offshore
Driver for Renewable Adoption in the U.S.

Renewable Portfolio Standards Exist in 29 States and D.C
7 More States Have Non-Binding Goals

Source: Berkeley Lab
Notes: Compliance years are designated by the calendar year in which they begin. Mandatory standards or non-binding goals also exist in US territories (American Samoa, Guam, Puerto Rico, US Virgin Islands)
Renewable Electricity Production from Wind and Solar Has Increased Dramatically in the US

<table>
<thead>
<tr>
<th></th>
<th>2001 (GWh)</th>
<th>2011 (GWh)</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. Wind Generation</td>
<td>6.7</td>
<td>119.7</td>
<td>1,777%</td>
</tr>
<tr>
<td>U.S. Solar Generation</td>
<td>0.5</td>
<td>1.8</td>
<td>334%</td>
</tr>
</tbody>
</table>

But Their Contribution to Total US Electricity Production is Modest

Year 2011 Total Electricity Net Generation = 4,106 GWh

Source: U.S. Energy Information Administration
US Trends: Wind Power Additions Increased in 2011, but Remained Below 2008 and 2009 Levels

- 6.8 GW of wind power added in 2011 in U.S., 31% higher than in 2010
- $14 billion invested in wind power project additions
- Cumulative wind power capacity up by 16%, bringing total to 47 GW

Source: R.Wiser and M. Bolinger LBL, July 2012 Report
US Trends: Wind Power Comprised 32% of Electric Generating Capacity Additions in 2011

- Wind power in 2011 was again the 2\textsuperscript{nd}-largest resource added (after gas, and for the 6\textsuperscript{th} time in the past seven years)

Source: R.Wiser and M. Bolinger LBL, July 2012 Report
Geographic Spread of Wind Power Projects in U.S.

Note: Numbers within states represent cumulative installed wind capacity and, in parentheses, annual additions in 2011.

Source: R.Wiser and M. Bolinger LBL, July 2012 Report
Electric Utilities Are Still the Dominant Off-Takers of Wind Power

- Scarcity of power purchase agreements drove continued merchant development, though at somewhat lower levels than in recent years.

Source: R. Wiser and M. Bolinger LBL, July 2012 Report
Wind Turbine Prices Continued to Decline in 2011, After Rising from 2002-2008

- Recent turbine price quotes reportedly in the range of $900-1,270/kW, with more-favorable terms for buyers and improved technology

Source: R.Wiser and M. Bolinger LBL, July 2012 Report
Some Regional Differences in Wind Power Project Costs Are Apparent

- Different permitting/development costs may play a role; it’s easier to build in TX and the Heartland and more difficult in New England and CA

Source: R. Wiser and M. Bolinger LBL, July 2012 Report
Average Capacity Factors Have Improved Over Time, But Leveled Off in Recent Years

- General improvement reflects increase in hub height and rotor diameter
- Drop in 2009 and 2010, and rebound in 2011, driven in part by:
  (1) inter-annual wind resource variation, and (2) wind power curtailment

Source: R.Wiser and M. Bolinger LBL, July 2012 Report
Curtailment a Growing Issue in Some Areas

Estimated Wind Curtailment (GWh and % of potential wind generation)

<table>
<thead>
<tr>
<th>Area</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Reliability Council of Texas (ERCOT)</td>
<td>109 (1.2%)</td>
<td>1,417 (8.4%)</td>
<td>3,872 (17.1%)</td>
<td>2,067 (7.7%)</td>
<td>2,622 (8.5%)</td>
</tr>
<tr>
<td>Southwestern Public Service Company (SPS)</td>
<td>N/A</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>0.9 (0.0%)</td>
<td>0.5 (0.0%)</td>
</tr>
<tr>
<td>Public Service Company of Colorado (PSCo)</td>
<td>N/A</td>
<td>2.5 (0.1%)</td>
<td>19.0 (0.6%)</td>
<td>81.5 (2.2%)</td>
<td>63.9 (1.4%)</td>
</tr>
<tr>
<td>Northern States Power Company (NSP)</td>
<td>N/A</td>
<td>25.4 (0.8%)</td>
<td>42.4 (1.2%)</td>
<td>42.6 (1.2%)</td>
<td>54.4 (1.2%)</td>
</tr>
<tr>
<td>Midwest Independent System Operator (MISO), less NSP</td>
<td>N/A</td>
<td>N/A</td>
<td>250 (2.2%)</td>
<td>781 (4.4%)</td>
<td>657 (3.0%)</td>
</tr>
<tr>
<td>Bonneville Power Administration (BPA)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>4.6* (0.1%)</td>
<td>128.7* (1.4%)</td>
</tr>
<tr>
<td>Total Across These Six Areas:</td>
<td>109 (1.2%)</td>
<td>1,445 (5.6%)</td>
<td>4,183 (9.6%)</td>
<td>2,978 (4.8%)</td>
<td>3,526 (4.8%)</td>
</tr>
</tbody>
</table>

*A portion of BPA’s curtailment is estimated assuming that each curtailment event lasts for half of the maximum possible hour for each event.

Source: ERCOT, Xcel Energy, MISO, BPA

Assuming a 33% capacity factor, the total amount of wind generation curtailed in 2011 within just the six territories shown above equates to the annual output of roughly 1,220 MW of wind power capacity.

Source: R.Wiser and M. Bolinger LBL, July 2012 Report
Levelized Cost of Electricity Update for Generation Technologies ($/MWh)

- Natural Gas CC
- Nuclear
- Geothermal - Binary Plant
- Geothermal - Flash Plant
- Landfill Gas
- Biomass Anaerobic Digestion
- MSW - Combustion
- Biomass - Combustion
- Off-shore Wind
- On-shore Wind
- Solar Thermal + Storage
- Solar Thermal
- Solar Photovoltaic (c-Si, Tracking)
- Solar Photovoltaic (c-Si)

Source: BNEF, 1Q 2013

EPRI’s estimate
Forecasting Wind is key to optimal dispatching

Accuracy:
• Day ahead generally < 15%
• 2-hour < 5%
Wind Energy R&D Opportunities

- Wind Power Technology Assessment and Development
- Wind Power Asset Management
- Model Development and Validation
- Wind Environmental Issues

Power Converters  Retrofitting / Maintenance Options  Large Rotors for On-Shore
Photovoltaic – Solar Power Generation
Global PV Trends

Source: Bloomberg New Energy Finance, Global PV Market Update

Notes: 2012 and projected 2013 installs based on a range of estimates.

Figure 2: PV installation by year, historical and conservative forecast, 2007-2015 (MW)

Figure 3: PV installation by year, historical and optimistic forecast, 2007-2015 (MW)

Source: Grid operators, incentive programme administrators, industry associations, Bloomberg New Energy Finance
Note: Few countries have yet finalised their 2012 data, hence the spread here. A quartiling approach has been used to narrow the global spread for later years. Table with all major countries in Appendix, without quartiling. Data here.

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U.S. PV Trends

Figure 1: Conservative US PV demand forecast (GW)

<table>
<thead>
<tr>
<th>Year</th>
<th>Residential (0-10kW)</th>
<th>Commercial (10-1,000kW)</th>
<th>Utility (1,000kW+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>34%</td>
<td>30%</td>
<td>26%</td>
</tr>
<tr>
<td>2011</td>
<td>46%</td>
<td>39%</td>
<td>15%</td>
</tr>
<tr>
<td>2012</td>
<td>49%</td>
<td>38%</td>
<td>13%</td>
</tr>
<tr>
<td>2013</td>
<td>49%</td>
<td>37%</td>
<td>14%</td>
</tr>
<tr>
<td>2014</td>
<td>52%</td>
<td>13%</td>
<td>13%</td>
</tr>
<tr>
<td>2015</td>
<td>50%</td>
<td>13%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Figure 2: Optimistic US PV demand forecast (GW)

<table>
<thead>
<tr>
<th>Year</th>
<th>Residential (0-10kW)</th>
<th>Commercial (10-1,000kW)</th>
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<td>13%</td>
<td>14%</td>
</tr>
<tr>
<td>2015</td>
<td>48%</td>
<td>14%</td>
<td>38%</td>
</tr>
</tbody>
</table>

Source: Bloomberg New Energy Finance, Interstate Renewable Energy Council. For PV demand data, please see Appendix: Table 3 and Table 4.
Global Average Prices for PV Modules, 1992-2012

Source: SPV Market Research/Strategies Unlimited, The Solar Flare Newsletter
2012 Quarterly Average Selling Price (ASP) Trends, 2012
PV as Distributed Energy Resources
California now has 1 GW – goal is 12 GW by 2020

Signpost: Trends in PV panel and balance of system costs
Solar Energy R&D Opportunities

1. Solar Thermal Electric Research
2. Solar Technology Assessments
3. Photovoltaic Research
4. Inverter Technology to Ease Integration
5. Solar Environmental Issues
6. Operation and Maintenance

- Fact Book and Market Updates
- Recyclability
- O&M Guidelines
Today’s Power System …

Central generation, one-way power flow, passive consumers
Tomorrow’s Power System …

Distributed generation, two-way communications and power flow, active consumers
Challenges
Renewable Resources and Integration

Many questions remain regarding renewable costs, performance, impact and integration

Key Challenges

• Generation technology: cost and performance

• Grid reliability: Operating the system with variable resources

• Environmental impacts
Challenges for Grid Operations

High Levels of Wind and Solar PV Will Present an Operating Challenge!
A More Flexible Grid

...may be needed to accommodate more renewable generation

- Base Load Generation
- Load Following Generation
- Bulk Energy Storage
- Large-Scale Wind & Solar

Signpost: Challenges to Grid Operations from Variable Supply, Unpredictable Demand

- Built-in Demand
- Interruptible Load DR
- Price Responsive DR
- Distributed Generation
- "Demand-side" Resources
  Electric Vehicles and Battery Storage Systems

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Energy Storage Options may offer Flexibility
Bulk to Distributed Storage Solutions in the Smart Grid
Natural Gas Distributed Generation Options Can Support Grid Flexibility (Size Range and Electrical Efficiency LHV)

**50 MW - 1 MW**

Aero-derivative CT’s
- 25-60 MW
- 40+ % Eff.

Small CT’s
- 1-5 MW
- ~ 40% Eff

IC Engines
- 1.6 MW
- 36% Eff.

**1 MW - 1.5 kW**

Microturbines
- 30-300 kW
- 25-30% Eff

Fuel Cells
- 400 -1000 kW
- 40-58 % Eff

Micro Generation
- 1-5 kW
- 30- 50% Eff.
Summary

• State Renewable Portfolio Standards, coupled with incentives, are driving the deployment of Renewable Generation in the U.S.
• Renewable Generation (Wind) has become a credible source of new generation in the U.S.
• Wind Turbine scaling has boosted wind project capacity factors
• Falling wind turbine prices have begun to push installed project costs lower
• Lower installed project costs, along with improved capacity factors, are enabling aggressive wind power pricing
• Distributed Solar deployment is also growing as PV panel prices have come down – enabling grid parity in certain regions today
• With higher penetration of both Wind and PV generation, more options for grid flexibility will be needed
• Future availability and price of natural gas will put pressure on future renewable deployment.
Summary -- What’s Needed for Renewables

Enable renewable technology options that are cost-competitive

Maintain electric grid reliability and stability

Minimize environmental impacts of renewable energy at utility scale

Technology advances can help renewables compete
EPRI’s Renewable Energy R&D Programs

Bulk Power System Integration

Energy Storage

Integration of Distributed Renewables

Economics and Technology Status

Reliable

Affordable

Environmentally Responsible

Electricity

Wind

Solar

Biomass

Hydro and Marine

Geothermal
R&D Gaps: Cost-Effective Technology Options

Wind O&M

Employ condition monitoring, NDE and reliability-centered maintenance (RCM)

Develop best practices and guidelines for wind turbine component maintenance

Solar PV Systems

Demonstrate lower-cost project designs and implementation approaches

Gain field experience and develop guidelines for PV system performance, reliability and economics

Concentrated Solar

Conduct technology pilots and demos of improved trough-based and tower-based CSP systems

Explore new materials and approaches for thermal storage
R&D Gaps: Grid Reliability and Stability

Wind/Solar Forecasting

Characterize the variability of wind and solar at multiple scales
Develop methods for incorporating forecasts into planning and operations processes

Grid Operator Tools

Create methods/tools for supporting operating reserve determination based on VG forecasts
Develop techniques to optimize dispatch schedules given inherent uncertainties

Energy Storage

Assess energy storage technologies and their applications
Determine how storage affects the cost, performance and reliability of renewables
The Power System of the Future

The electricity industry will likely see more changes in the next 10 years than it has in the last 100

Generation  Delivery  Customer

How will YOU respond?
Together…Shaping the Future of Electricity

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Supplemental Material
Electric Vehicles

Signpost: Batteries deliver range equivalent to gasoline

Energy Density (Wh/kg)

0 200 400 600 800 1000 1200 1400 1600 1800 2000

1860 1910 1960 2010 2020 2030

Lead-Acid 25 – 45
Nickel-Iron 30 – 40
Nickel-Cadmium 35 – 60
Nickel-Metal Hydride 50 – 75
Lithium Ion 110 – 140
Lithium Ion w/ Si Nanowire 400
Li-Air

Today’s Batteries

~2,000 Wh/kg
Comparative Levelized Costs – 2025

Source: EPRI, Generation Technology Options in a Carbon-Constrained World, October 2012

All costs are in constant Dec 2011$

- PC + CCS
- IGCC + CCS
- NGCC
- NGCC + CCS
- Nuclear
- Biomass
- Geothermal
- Onshore Wind*
- Offshore Wind*
- CSP*
- Solar PV*

Average LCOE values based on estimated capital cost ranges.
No investment or production tax credits are assumed for any technology.
No integration or backup costs assumed for wind and solar.
Is the Grid Ready for High Penetration of PV?

PV Plant Performance O&M

Feeder Hosting Capabilities

Smart-Grid-Ready Inverters

Readiness Screening
Opportunity to Integrate Smart Inverters

- Inverters are ready for participation in smart grid.
- However, too many manufacturer proprietary protocols.
- And, Grid is generally not ready to accept this help.