AAPA
ENVIRONMENT COMMITTEE MEETING

Brett Oakleaf, NREL - Ports/Airports Collaboration Leader

April 10, 2018
Topics

1) Electrification Progression

2) Electrification Needs

3) Renewable Energy Trends
   • Off-Shore Wind
   • Solar PV
   • Energy Storage

4) Growing areas of interest with Ports
   • Visualization/Collaboration with City
   • Increasing resiliency
   • Growing collaboration with Federal Agencies
Hybrid (Diesel/Electric) propulsion

Easy integration
Greater fuel efficiency
Lower emission
Wartsila, Rolls-Royce, Siemens

All Electric propulsion

Dutch company: Port-Liner
Carrying capacity: 280 containers
ISD: Fall 2018
Routes: Between ports in Europe
Marine Electrification

All Electric propulsion

*Hauling up to 2,000 tons of coal*

2.4 MWh Battery/Super-Capacitors
~ 24 Tesla Model 100D car batteries
~ 50 Mile range

*Maiden voyage – November 2017*

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All Electric propulsion

*Sweden company: HH Ferries*

~ 800 ft long/~ 8,500 tons

*Projected: 7.4M people/1.9M cars*

*Routes: ~2.5 miles (Sweden – Denmark)*
Autonomous/Electric

Norwegian: Yara Birkeland
Carrying capacity: 100 – 150 containers
Cost: $25M (3x conventional), but offset by 90% annual operating cost savings
~ 37 Mile range
Maiden voyage – 2018
Transition to full autonomous by 2020

Bottom line:

=> Competitive Advantage to Ports that have these capabilities
Semi (Class 8) Trucks

**Natural Gas (LNG/CNG)**
*Freightliner, Mack*
*Lower cost fuel*
*Lower emissions*
*~500 mile range*

**Hydrogen Fuel Cell**
*Toyota, Nikola*
*Toyota ~ 200 miles*
*Nikola ~ 1200 miles (2020)*
**Semi (Class 8) Trucks**

**Electric**
*Cummins, Thor, Tesla*
*Lower cost of ownership*
*No emissions*
*~300 - 500 mile range*

**Port Implications**
- Significant charging demands
- Need for regional, nation-wide fast charging network
Growing Inventory of Port Electric Vehicles

**EV Yard Tractors**

**EV Drayage**

**Electric Catenary**

**Automated Guided Vehicles...**

**Challenges / Opportunities**

**Charging Infrastructure**
**Charging Protocols**
**Charge Management**
**Battery Secondary Use**
**Grid Services**
**Extreme Fast Charging...**
Electrification Needs

- **Need for Shore Power**
  - Coordinating infrastructure needs
  - Significant load growth (10MW/Cruise ship)

- **Load control/growth**
  - Don’t want simultaneous charging (new higher peak demand)
  - 5x – 8x load growth

- **Opportunities**
  - Ship 2 Grid (S2G)
  - Opportunities for real time pricing – low cost energy capture
  - Reefer units – load control

- Could this be a negotiation tool for Port to work with Electric Utility to implement?
  - Utility perspective (low/declining low growth, new business model)
  - Port Perspective (valuable customer with unique energy characteristics)
  - Win-win for Port and Utility
Where is this power going to come from?
Oil and Gas Experience Helped Accelerate First Generation

• Floating wind is based on oil & gas technology and reliability criteria that have resulted in successful but expensive designs

• Unit October 2017 there were only 6 utility-scale floating wind systems

• First multi-turbine project: October 2017 in Scotland – 30-MW Statoil

• System engineering approach is needed to lower cost
Scaling Turbines to 15-MW - New Technology Challenges

- Key system cost reduction driver is turbine size (5x land-based)
- Component weight minimization a strong imperative; blades, generators, towers, substructures
- 110-m blade lengths: more modular designs, lighter materials, sub-component testing, innovative manufacturing
- Larger test facilities and alternative test methods
- Reduced dependence on vessels

Will mature large-scale offshore wind turbines be adapted for future land-based wind plants?

Data Source: MAKE Consulting 2017
PV Record Cells – Current Status

Best Research-Cell Efficiencies

**Multijunction Cells** (2-terminal, monolithic)
- LM = lattice matched
- MM = metamorphic
- IMM = inverted, metamorphic
- Three-junction (concentrator)
- Three-junction (non-concentrator)
- Two-junction (concentrator)
- Two-junction (non-concentrator)
- Four-junction or more (concentrator)
- Four-junction or more (non-concentrator)

**Thin-Film Technologies**
- CIGS (concentrator)
- CIGS
- CdTe
- Amorphous Si:H (stabilized)

**Emerging PV**
- Dye-sensitized cells
- Perovskite cells (not stabilized)
- Organic cells (various types)
- Organic tandem cells
- Inorganic cells (CZTS/Se)
- Quantum dot cells (various types)

**Crystalline Si Cells**
- Single crystal (concentrator)
- Single crystal (non-concentrator)
- Multicrystalline
- Silicon heterostructures (H/HT)
- Thin-film crystal

**NREL**
- National Renewable Energy Laboratory

**Samsung**
- Solar Cells

**SunPower**
- Solar Cells

**Sharp**
- Solar Cells

**Kyocera**
- Solar Cells

**First Solar**
- Solar Cells

**Ametek**
- Solar Cells

**ARCO**
- Solar Cells

**RCA**
- Solar Cells

**NREL**
- Solar Cells

**IBM**
- Solar Cells

**LG Electronics**
- Solar Cells

**Fraunhofer ISE**
- Solar Cells

**Solarex**
- Solar Cells

**Suntech**
- Solar Cells

**SunPower**
- Solar Cells

**Sanyo**
- Solar Cells

**Sempa**
- Solar Cells

**Japan Energy**
- Solar Cells

**Enel**
- Solar Cells

**Elta**
- Solar Cells

**First Solar**
- Solar Cells

**Solaronix**
- Solar Cells

**SunPower**
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### 2017 Xcel Energy (Colorado) RFP Bid Responses

#### RFP Responses by Technology

<table>
<thead>
<tr>
<th>Generation Technology</th>
<th># of Bids</th>
<th>Bid MW</th>
<th># of Projects</th>
<th>Project MW</th>
<th>Price or Equivalent Units</th>
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</thead>
<tbody>
<tr>
<td>Combustion Turbine/IC Engines</td>
<td>30</td>
<td>7,141</td>
<td>13</td>
<td>2,466</td>
<td>$4.80/kW-mo</td>
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<tr>
<td>Combustion Turbine with Battery Storage</td>
<td>7</td>
<td>804</td>
<td>3</td>
<td>476</td>
<td>$6.20/kW-mo</td>
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<tr>
<td>Gas-Fired Combined Cycles</td>
<td>2</td>
<td>451</td>
<td>2</td>
<td>451</td>
<td>$6.20/kW-mo</td>
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<tr>
<td>Stand-alone Battery Storage</td>
<td>28</td>
<td>2,143</td>
<td>21</td>
<td>1,614</td>
<td>$11.30/kW-mo</td>
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<tr>
<td>Compressed Air Energy Storage</td>
<td>1</td>
<td>317</td>
<td>1</td>
<td>317</td>
<td>$11.30/kW-mo</td>
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<tr>
<td>Wind</td>
<td>96</td>
<td>42,278</td>
<td>42</td>
<td>17,380</td>
<td>$18.10/MWh</td>
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<tr>
<td>Wind and Solar</td>
<td>5</td>
<td>2,612</td>
<td>4</td>
<td>2,162</td>
<td>$19.90/MWh</td>
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<tr>
<td>Wind with Battery Storage</td>
<td>11</td>
<td>5,700</td>
<td>8</td>
<td>5,097</td>
<td>$21.00/MWh</td>
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<tr>
<td>Solar (PV)</td>
<td>152</td>
<td>29,710</td>
<td>75</td>
<td>13,435</td>
<td>$29.50/MWh</td>
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<tr>
<td>Wind and Solar and Battery Storage</td>
<td>7</td>
<td>4,048</td>
<td>7</td>
<td>4,048</td>
<td>$30.60/MWh</td>
</tr>
<tr>
<td>Solar (PV) with Battery Storage</td>
<td>87</td>
<td>16,725</td>
<td>59</td>
<td>10,813</td>
<td>$36.00/MWh</td>
</tr>
<tr>
<td>IC Engine with Solar</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>$5/MWh</td>
</tr>
<tr>
<td>Waste Heat</td>
<td>2</td>
<td>21</td>
<td>1</td>
<td>11</td>
<td>$5/MWh</td>
</tr>
<tr>
<td>Biomass</td>
<td>1</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td>$5/MWh</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>430</td>
<td>111,963</td>
<td>238</td>
<td>58,283</td>
<td></td>
</tr>
</tbody>
</table>
Energy Storage

Li-Ion Batteries

- Lithium-ion battery technology is expected to be the energy storage choice for (xEVs and grid storage) in the coming years
- Better (energy & power) performance than other existing technologies
- Trends toward large format cells
  - Higher volume & weight efficiencies and packaging
  - Lower # of connections and components
  - Lower system cost
Energy Storage

Li-ion Battery Cost is Falling

Rapidly falling costs of battery packs for electric vehicles
Björn Nykvist and Måns Nilsson (Nature Climate Change, March 2015)
Ports: Main Economic Engine for City/Region

Metropolitan Mobility Optimization through High Performance Computing
Driving Energy-efficiency and Productivity at the Nexus of Regional Mobility, Major Airports, and Autonomous Vehicles

Three HPC Project Concepts

Regional Mobility:
- Digital Twin
- Cyber Physical Control

Airport and Freight:
- Energy Productivity
- Disruptive Mobility Technologies

Connected and Autonomous Vehicle:
- Control Algorithms
- Deep Learning
- V2I Communication for Cyber Physical Mobility Control

HPC-Driven Transportation Optimization for:
- Energy Efficiency
- Productivity
- Mobility

Metropolitan Mobility Redefined by Confluence of Projects
Vision: Systems approach to integration with near real-time analytics

Map

Measure

Model

Real-time scenario interaction (what if?)

Communication infrastructure
Roads
Buildings
Water features
Power system
Topo

make changes

see impacts on other system layers
Vision: a systems approach to integration with near real time analytics
NREL evaluated thousands of random grid outages and durations throughout the year and compared the number of hours the site could survive with a diesel generator and fixed fuel supply vs. generator augmented with PV and battery.

<table>
<thead>
<tr>
<th></th>
<th>Generator</th>
<th>Solar PV</th>
<th>Storage</th>
<th>Lifecycle Cost</th>
<th>Outage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Base case</strong></td>
<td>2.5 MW</td>
<td>-</td>
<td>-</td>
<td>$20 million</td>
<td>5 days</td>
</tr>
<tr>
<td><strong>2. Lowest cost solution</strong></td>
<td>2.5 MW</td>
<td>625 kW</td>
<td>175 kWh</td>
<td>$19.5 million</td>
<td>6 days</td>
</tr>
<tr>
<td><strong>3. Proposed system</strong></td>
<td>2.5 MW</td>
<td>2 MW</td>
<td>500 kWh</td>
<td>$20 million</td>
<td>9 days</td>
</tr>
</tbody>
</table>

The diagram illustrates the probability of surviving outages of different lengths for the base case, lowest cost solution, and proposed system.
Growing collaborations with Federal Agencies

• Department of Transportation
  • Office of Port Infrastructure Development

• Department of Energy
  • Vehicle Technologies Office

• Department of Homeland Security
  • FEMA

➢ Themes
  • Resiliency
  • Economic growth
  • Innovation
Summary

• **Growing vehicle electrification & autonomy**
  • Growing collaboration/interdependency between Port, City, and regional freight movement

• **Could Port become virtual power plant?**
  • Solar PV (Perovskites)
  • Large amount of energy storage
  • Load control from buildings, reefer racks, cold warehouses

• **Opportunities for increasing Port wide resiliency**
  • Flexibility planning

• **Interest from federal, state, local level in collaborating with Ports**
• How will Ports change in the coming decade?
Thank you

www.nrel.gov

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Time for Boat Tour