Key Message

• IEC wind class for design, application space for siting

• OEMs knowledge of design limits enabler for full utilization of turbine potential

• OEMs can benefit turbine layout and performance optimization
OEM Engagement

Wind Analysis

Turbine Selection & Layout Optimization

Customer typically has options
Can benefit from OEM detail design knowledge

Final AEP & Loads Assessments

Turbine suitability analysis and power curves for AEP

Plant Construction

Turbine installation or turn key

Wind Plant Operation

O&M
Can benefit from OEM detail design knowledge

AEP Annual energy production
### Turbine Selection – IEC Wind Classes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Label</th>
<th>IEC Example</th>
<th>Site Example</th>
<th>Site vs. IEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference wind speed [m/s]</td>
<td>Vref</td>
<td>37.5</td>
<td>32</td>
<td>&lt;</td>
</tr>
<tr>
<td>Average wind speed [m/s]</td>
<td>Vavg</td>
<td>7.5</td>
<td>8</td>
<td>&gt;</td>
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<tr>
<td>Turbulence intensity at 15 m/s [%]</td>
<td>TI15</td>
<td>16%</td>
<td>12%</td>
<td>&lt;</td>
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<tr>
<td>Air density [kg/m$^3$]</td>
<td>$\rho$</td>
<td>1.225</td>
<td>1.16</td>
<td>&lt;</td>
</tr>
<tr>
<td>Wind shear exponent [-]</td>
<td>$\alpha$</td>
<td>0.2</td>
<td>0.23</td>
<td>&gt;</td>
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<tr>
<td>Flow inclination angle [deg.]</td>
<td>$\theta$</td>
<td>8</td>
<td>4</td>
<td>&lt;</td>
</tr>
<tr>
<td>Weibull shape parameter [-]</td>
<td>$k$</td>
<td>2</td>
<td>2.4</td>
<td>&gt;</td>
</tr>
</tbody>
</table>

All site conditions < design → **suitable but optimum?**
All site conditions > design → **not suitable**
Otherwise (most common) → can’t conclude
Turbine Selection – Application Space Example – Fatigue Loads

Design air density, wind shear, flow inclination, Weibull k

Increased application space from lower air density

Turbine application space is best for siting
Layout Optimization - Method

- Multi-objectives, multi-constraints problem
- Loads analysis in optimization loop

Customer Objectives
Max. AEP
Min. cost

Project Constraints
Site boundaries
Exclusion zones
Existing turbines
Turb. suitability
Noise

Design Space

Turbine Suitability (Mech. Loads)

Energy Production

Optimized Layout(s)

Ref.: 2009 EWEA Conf. Poster entitled “Turbine Layout Optimization - A Manufacturer’s Perspective”
Layout Optimization – Sample Results

- 6 projects

<table>
<thead>
<tr>
<th>Project #</th>
<th># Turbines</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>41</td>
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<tr>
<td>2</td>
<td>80</td>
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<tr>
<td>3</td>
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<td>4</td>
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<tr>
<td>5</td>
<td>160</td>
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<td>6</td>
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</tbody>
</table>

- Site conditions and baseline layout from customer

- Turbine loads within design limits

- Average AEP gain of 2.8%

- Multi-objective optimization AEP-BOP Pareto front

Ref: 2009 EWEA Conf. Poster entitled “Turbine Layout Optimization - A Manufacturer’s Perspective”
Turbine Performance Optimization

OEMs can “move” the power curve within design limits
- Address performance variations
- Take advantage of design margins
- Compensate for winds << predicted

Loads & controls modeling are enablers
Challenges

Pre-construction

- Wind resource assessment preferences vary, no standard
- Wake modeling preferences vary & accuracy
- Balance of plant cost modeling
- Due diligence of OEM loads

Post-construction

- Post-warranty turbine data access
- Nacelle wind speed accuracy (absolute)
- Turbine wakes impacting met mast measurements
- Due diligence of turbine upgrade
Conclusions

• Site turbines per application space

• Design limits knowledge enabler for full utilization of turbine potential

• OEMs can benefit turbine layout and performance optimization