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Gaps in the Design Process

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Business Network for Offshore Wind 2016 International Offshore Wind Partnering Forum

Newport, Rhode Island

October 4, 2016

NREL/PR-5000-67279

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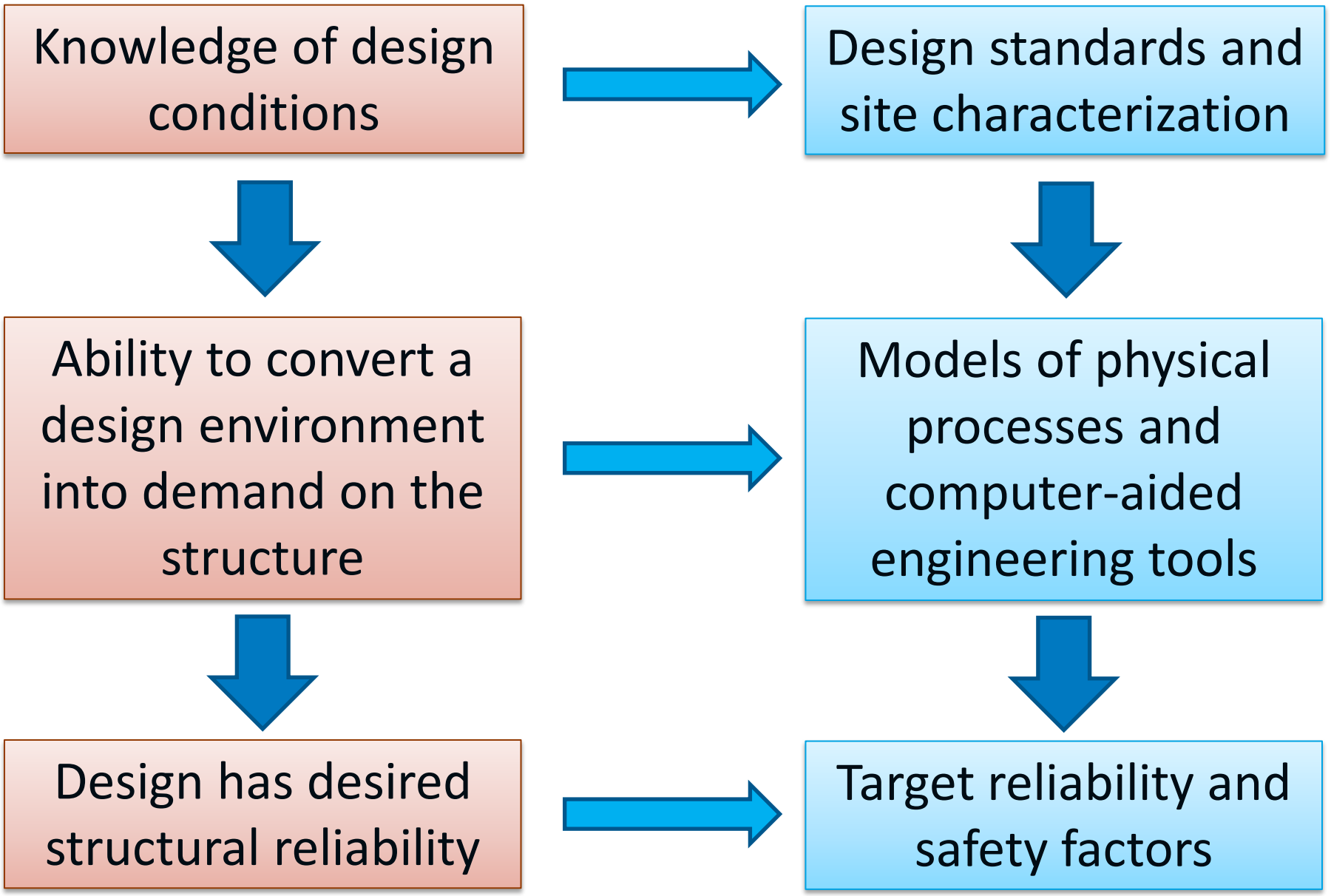
High-Level View—Where are the Needs (Gaps)?



Knowledge of Design Conditions

- In traditional wind turbine design there are two stages to definition of design conditions
  - Design class for product line specification
  - Site assessment for selection of the appropriate product

IEC 61400-1 Ed. 3

Table 1 – Basic parameters for wind turbine classes[2]

Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values
A	I_{ref} (-)	0,16			specified
B	I_{ref} (-)	0,14			by the
C	I_{ref} (-)	0,12			designer

In Table 1, the parameter values apply at hub height and

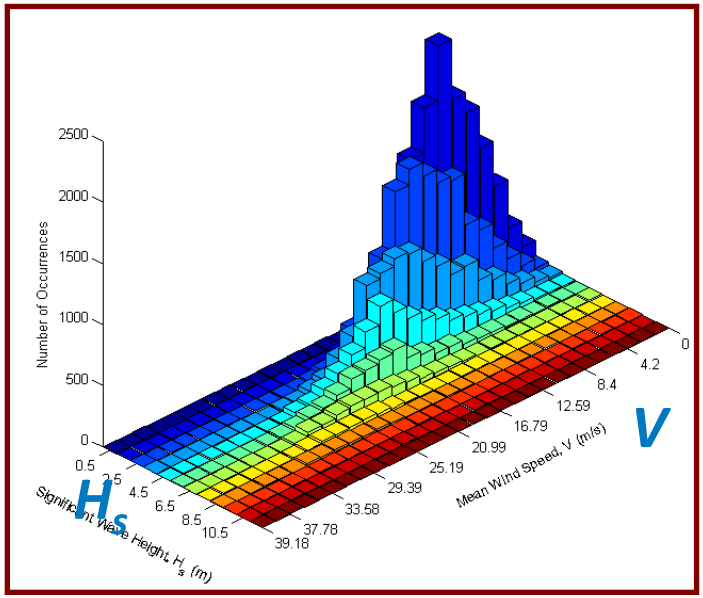
V_{ref} is the reference wind speed average over 10 min,

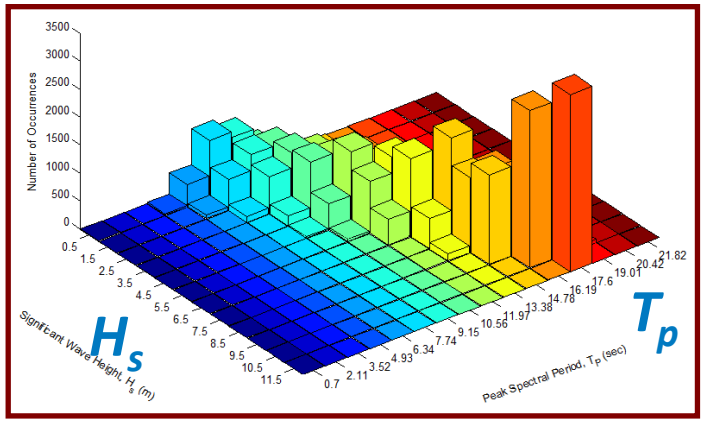
A designates the category for higher turbulence characteristics,

B designates the category for medium turbulence characteristics,

C designates the category for lower turbulence characteristics and

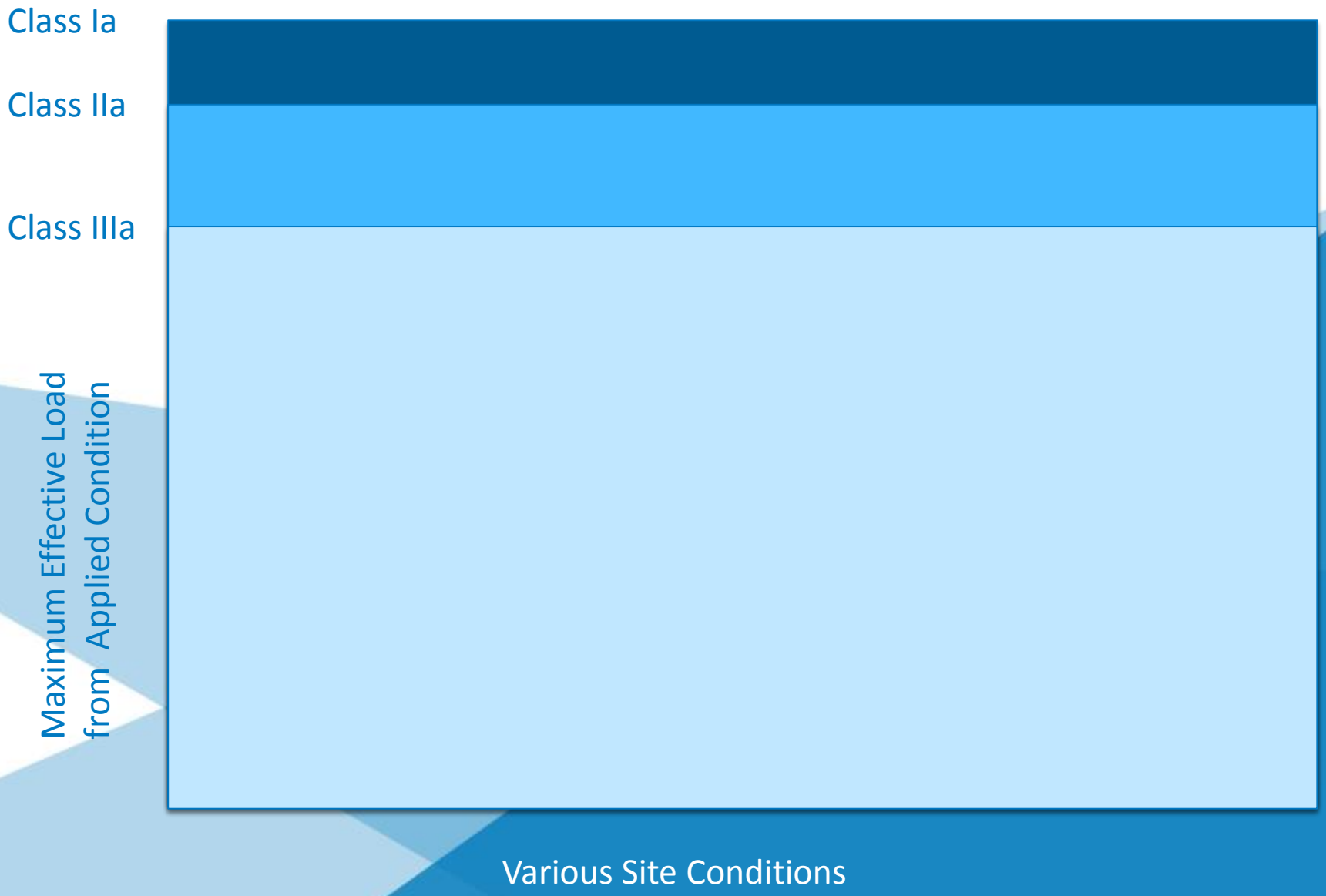
I_{ref} is the expected value of the turbulence intensity[3] at 15 m/s.



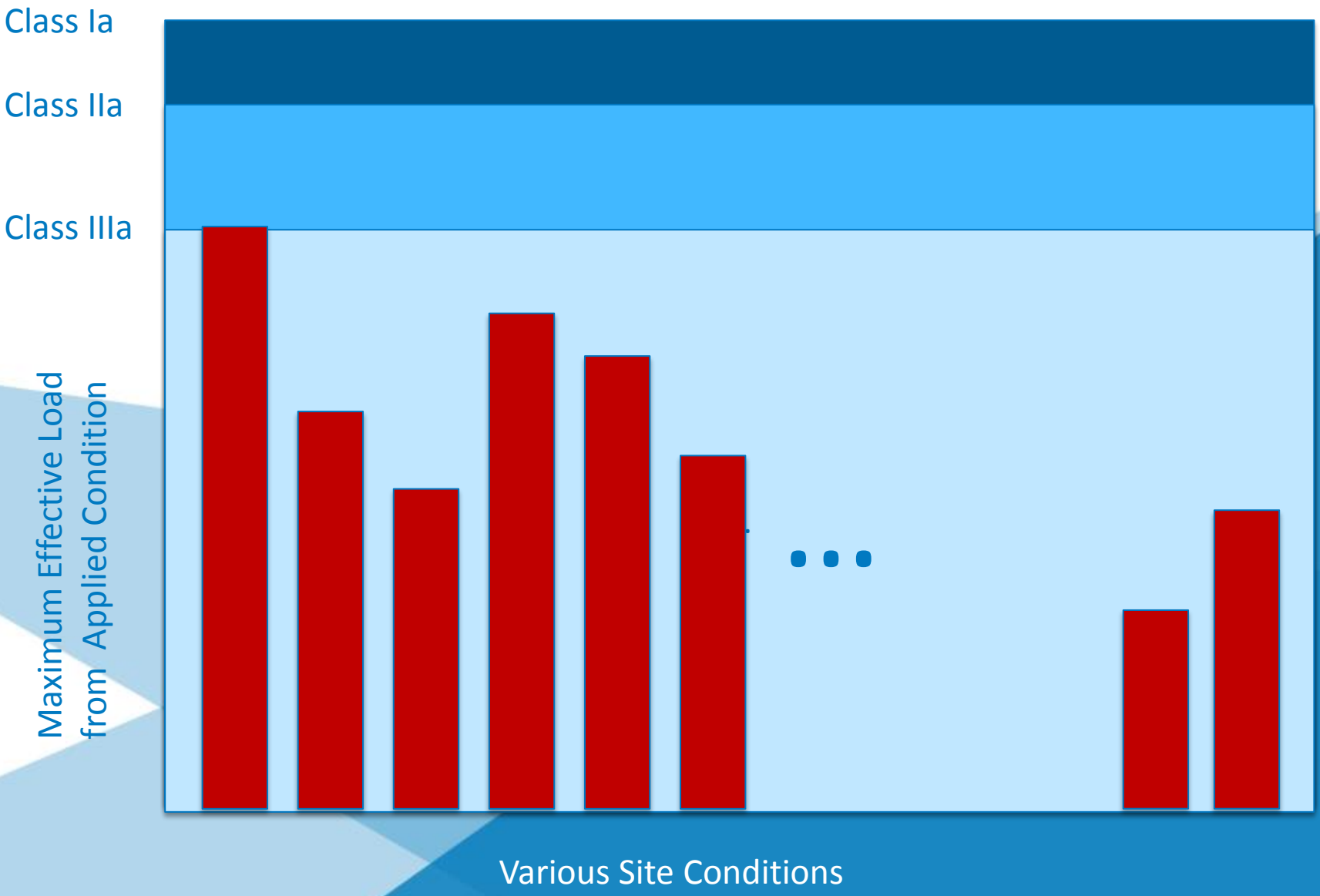


Courtesy Lance Manuel, UT

Standard Conditions are Intended to *Envelop* Actual Conditions



Site Suitability Assessment Defines Actual Conditions



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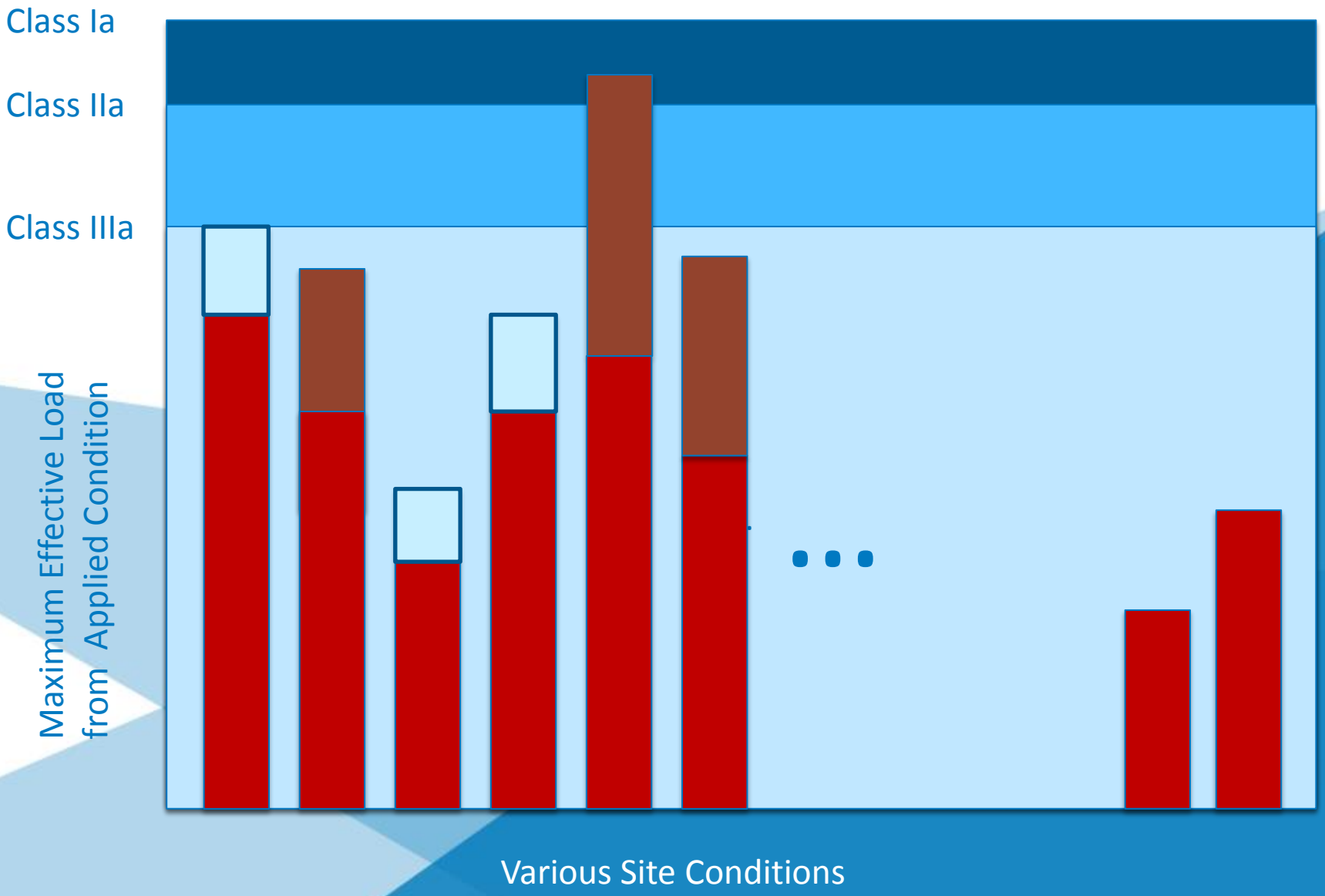
One Site Condition May Exceed the Class Definition



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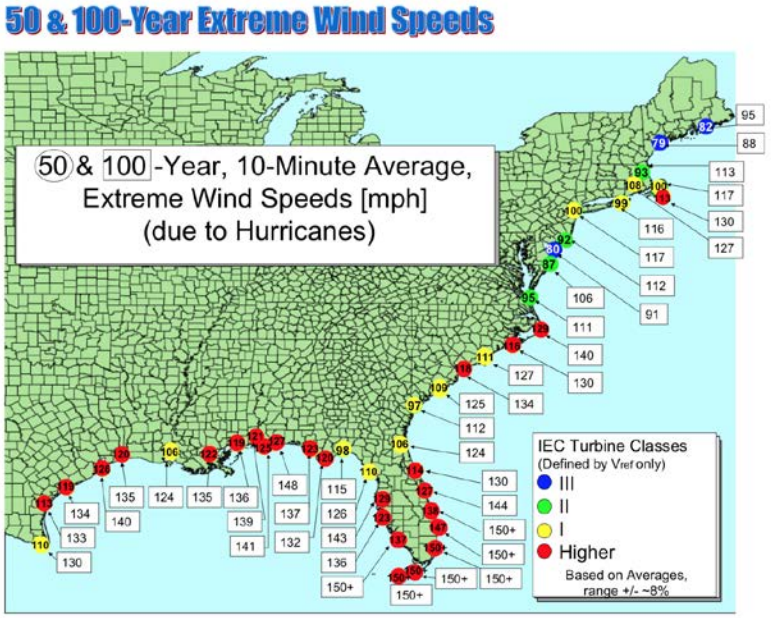
Knowledge of Design Conditions

- Site-specific design conditions
  - Geotechnical conditions
  - Combination of wind and wave
  - Storm frequency and intensity
- As you move along the U.S. East Coast, the severity and frequency of storms varies continuously, as do soil conditions
- Traditional offshore foundation design often goes straight to the site conditions
- The gap between how turbines are designed and how foundations are designed will need to be narrowed
- Much depends on the size of the installation (5 or 100 turbines)



Note:
1. U.S. Offshore Extreme Wind Analysis (Susan W. Stewart, Penn State Applied Research Laboratory)

Class		I	II	III	T	S
V_{ref} [m/s]		50	42.5	37.5	57.5	Values specified by designer
I_{ref}	a	0.16				
	b	0.14				
	c	0.12				
	H	0.18				

Preliminary Proposal

Convert a Design Environment into Demand

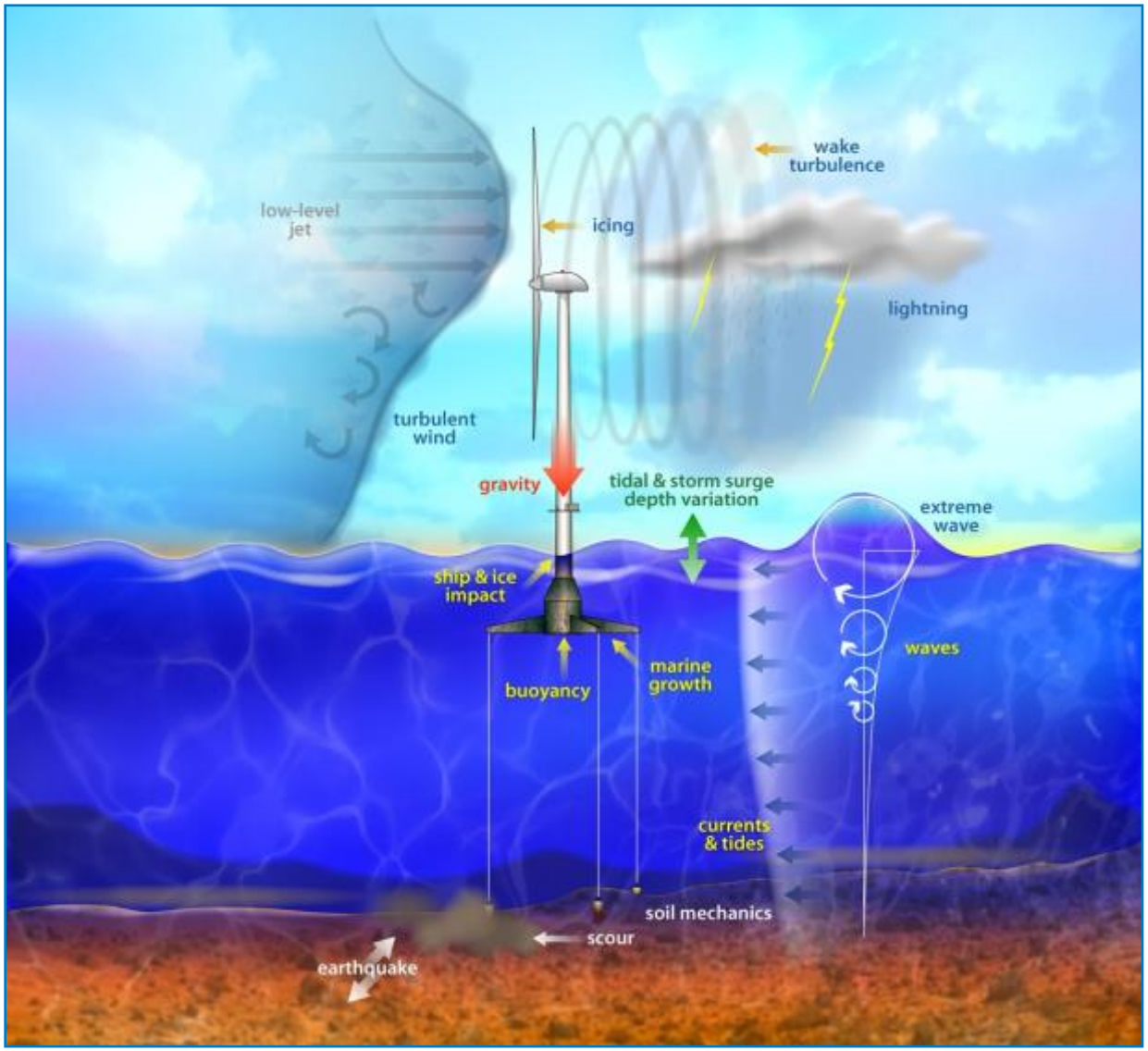


Illustration by Al Hicks, NREL

- Coupled aero-hydro-servo-elastic interaction
- Wind inflow
  - Discrete events
  - Turbulence
- Waves
  - Regular
  - Irregular
- Aerodynamics
  - Induction
  - Rotational augmentation
  - Skewed wake
  - Dynamic stall
- Hydrodynamics
  - Diffraction
  - Radiation
  - Hydrostatics
- Structural dynamics
  - Gravity/inertia
  - Elasticity
  - Foundations/moorings
- Control system
  - Yaw, torque, pitch

Modeling Gaps Identified

- BOEM held a workshop in April to ask a similar question about capabilities and gaps.
- There is a report summarizing the outcomes.

Design has Desired Structural Reliability

- The turbine design standard (IEC 61400-1) draws a **target reliability** of 5×10^{-4} failures per year
  - Safety factors throughout the standard are calibrated to achieve the target reliability
    - [K6] John Dalsgaard Sørensen and Henrik Stensgaard Toft, Safety Factors – IEC 61400-1 ed. 4 - background document DTU Wind Energy-E-Report-0066(EN) (ISBN 978-87-93278-08-0) November 2014.

A target value for the nominal failure probability for structural design for extreme and fatigue failure modes for a reference period of 1 year is

$$P_F^t = 5 \cdot 10^{-4} \qquad \text{(K.2)}$$

The corresponding target value for the reliability index is β^t = 3,3. Application of this target value assumes that the risk of human lives is negligible in case of failure of a structural element, see [K6]. The target reliability level is assumed to correspond to component class 2.

IEC 61400-1, Edition 4, Draft CDV

Check Against Desired Structural Reliability

- Design load cases are defined
- *Characteristic loads* are defined (return period)
- Appropriate *safety factors* are applied
- Result is intended to meet a *target reliability*

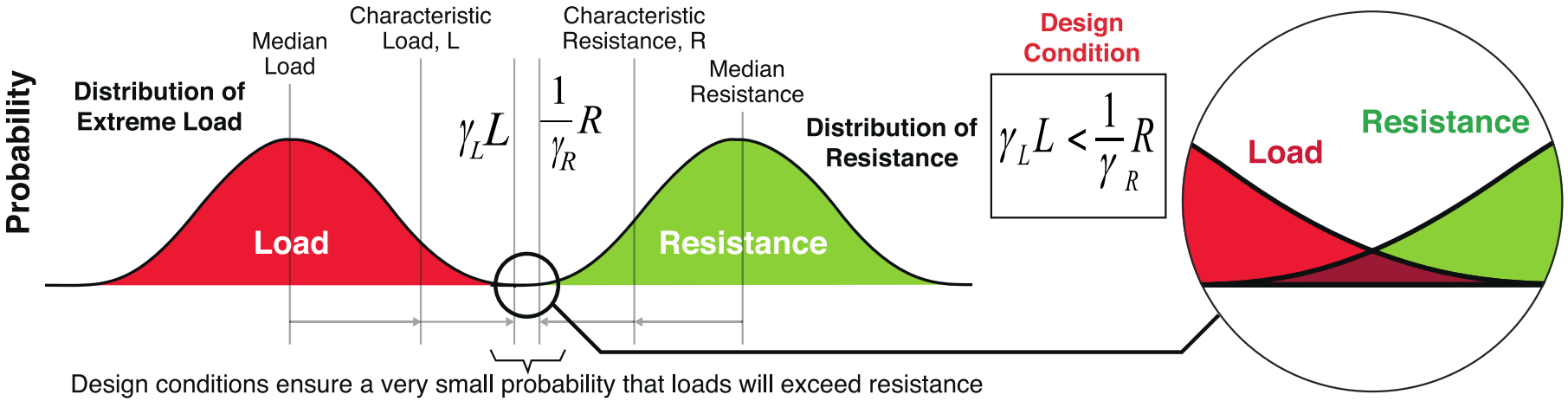
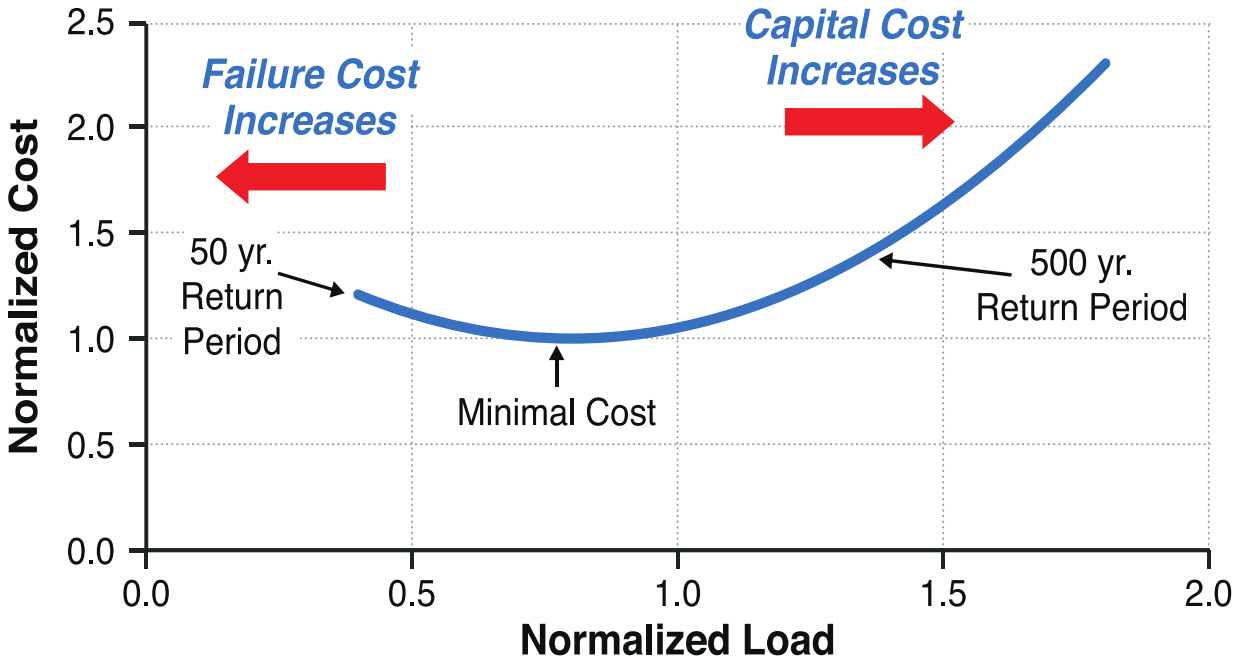


Illustration by Al Hicks, NREL

Agreement on a target reliability is a significant gap

- There has never been an economic analysis that establishes the trade-off between the high capital cost of low probability of failure and the cost of failure
- There is also a noneconomic factor in the consequences of an early failure on industry reputation



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Thank You!

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