The Impact of Research on Cost Reductions in Wind Power

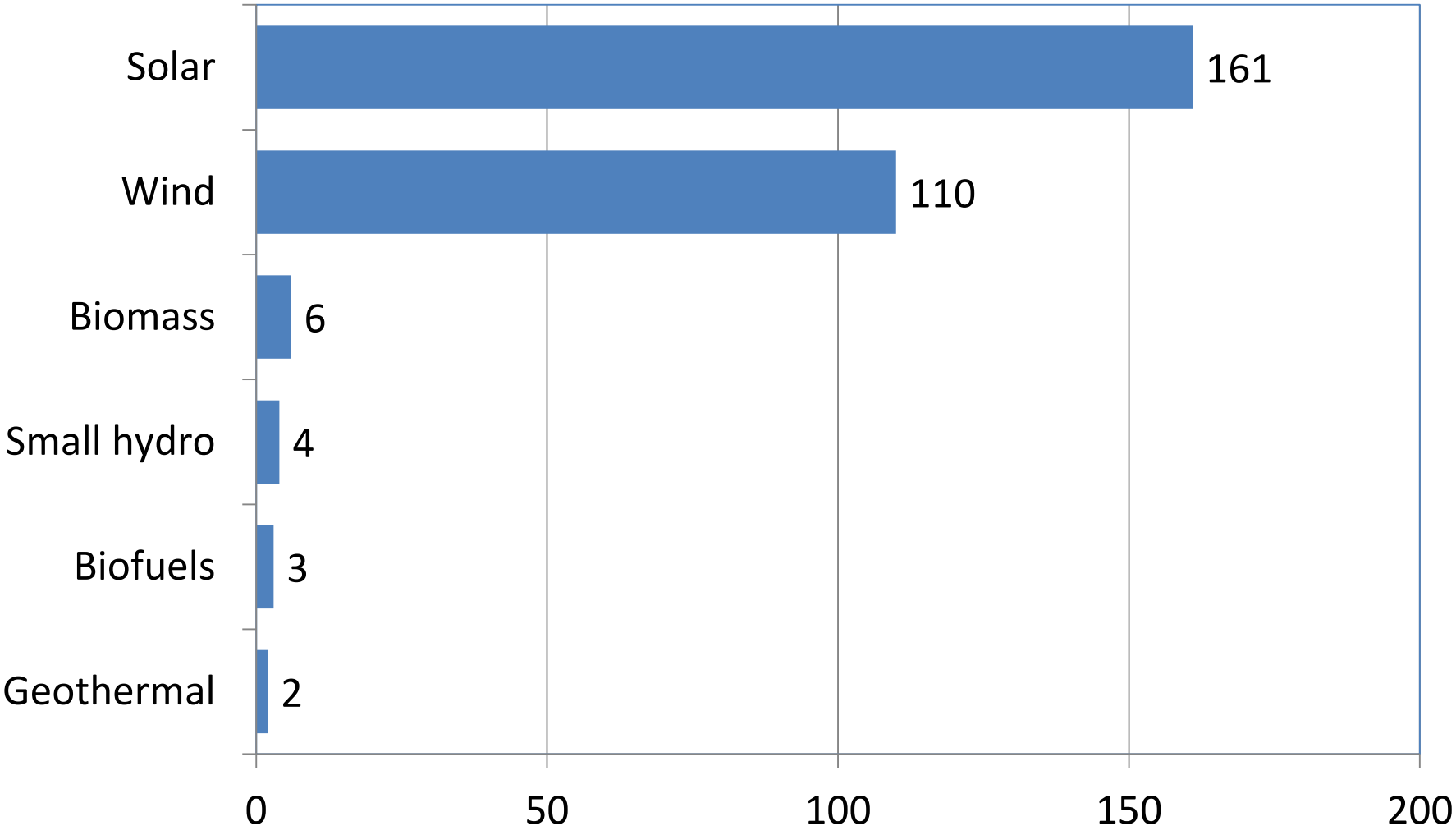
Henrik Stiesdal, April 29, 2019

The baseline –

The Mission and Vision of EERE

- The mission of EERE is to create and sustain American leadership in the transition to a global clean energy economy.
- The vision of EERE is a strong and prosperous America powered by clean, affordable, and secure energy.

Distribution of new renewables capacity, 2015, $Bn



Source: UNEP, Bloomberg New Energy Finance

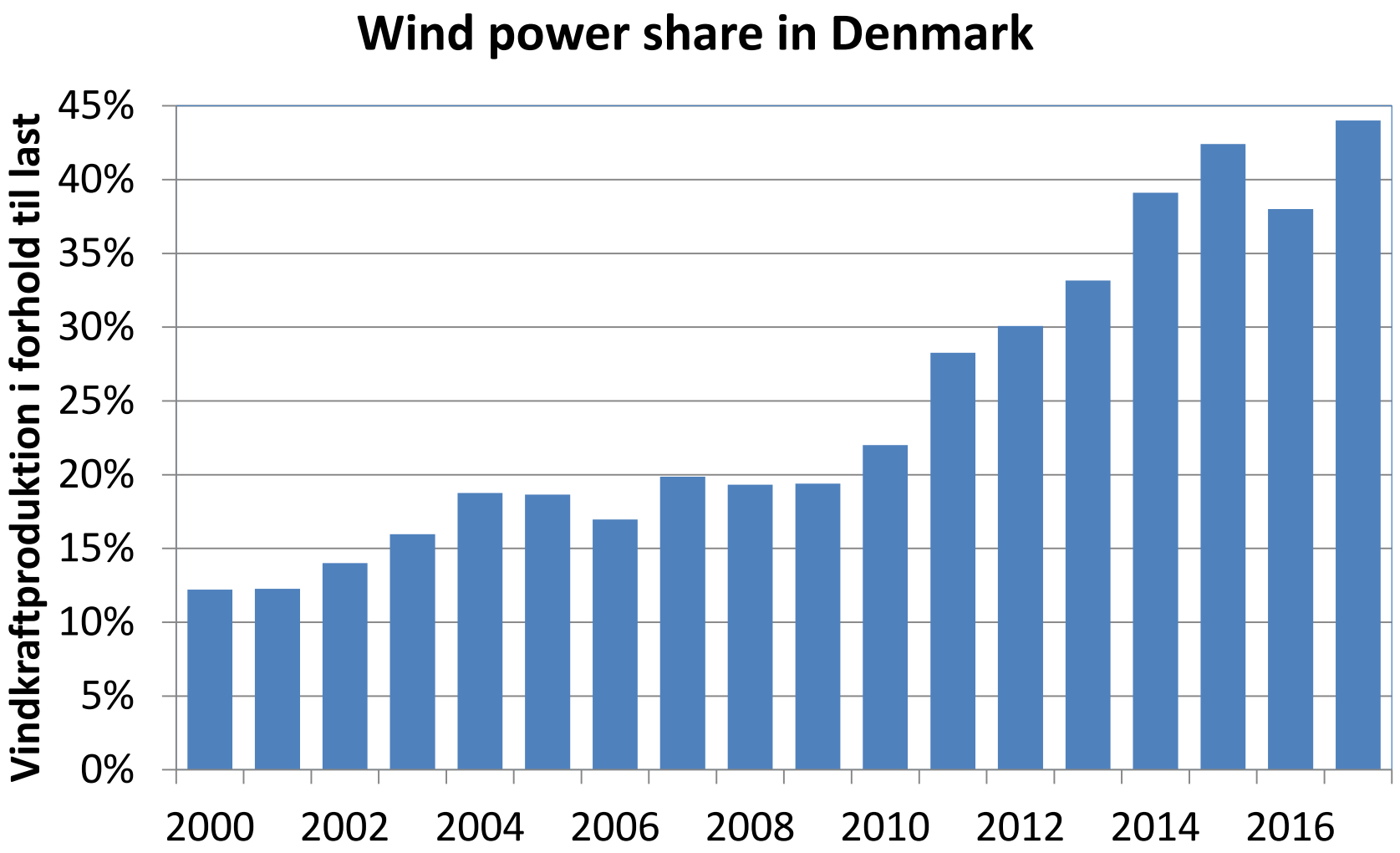
Powered by clean, affordable and secure energy …

A preferred source of electricity must be able to deliver the desired electric energy -

- ? to the necessary extent,
- ? without destroying the climate,
- ? without excessive public opposition,
- ? at an affordable cost, and
- ? securely, and when it is needed

Let us check it out for wind power

To the necessary extent ...



Source: Energinet.dk

Area use for offshore wind at 100% of load in Europe (pre-Brexit)

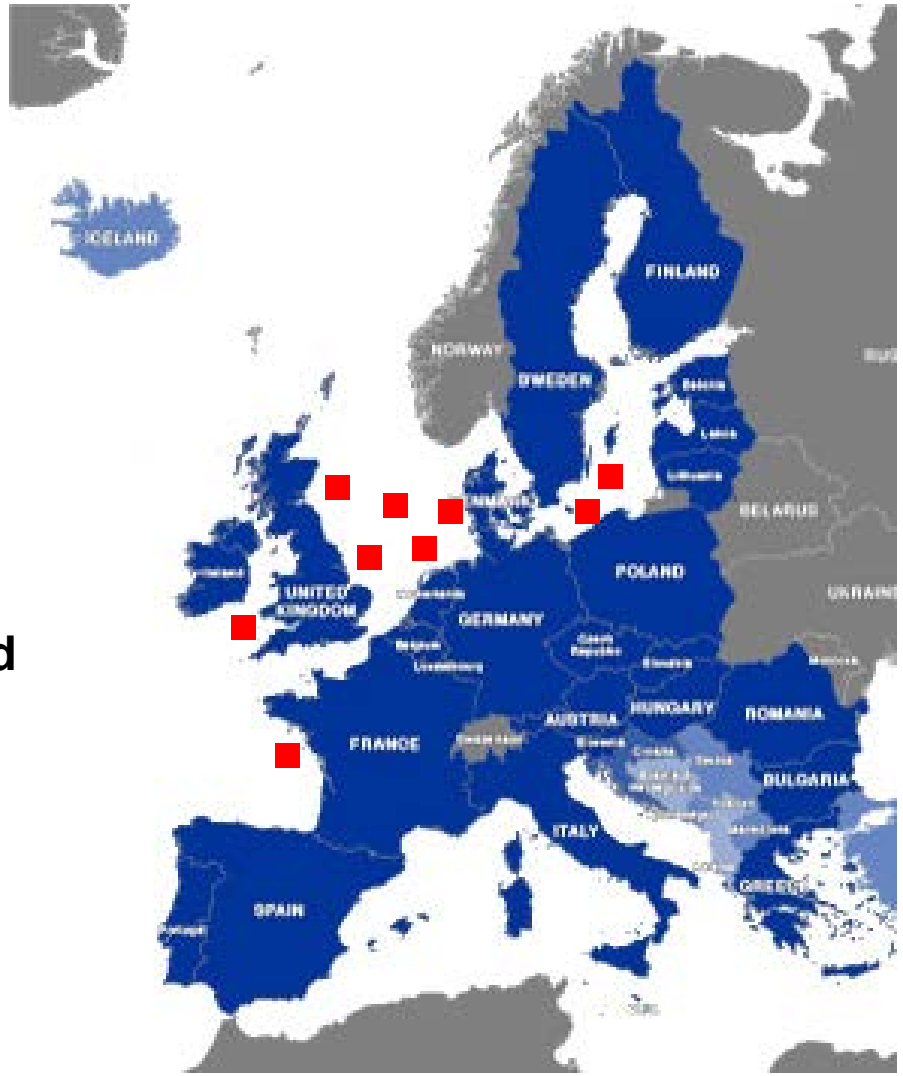
Area use. Denmark

- DK load: 35 Bn. kWh/year
- Energy: 30 kWh/m^2/year
- Area required: 1115 km^2
- **Corresponds to one offshore wind farm measuring 35 km x 35 km**

Area use, EU

- EU load: 2.800 Bn. kWh/year
- Energy: 30 kWh/m^2/year
- Area required: 90.000 km^2
- **Corresponds to nine offshore wind farms, each measuring 100 km x 100 km**

Still plenty of sea available for shipping and fishing!



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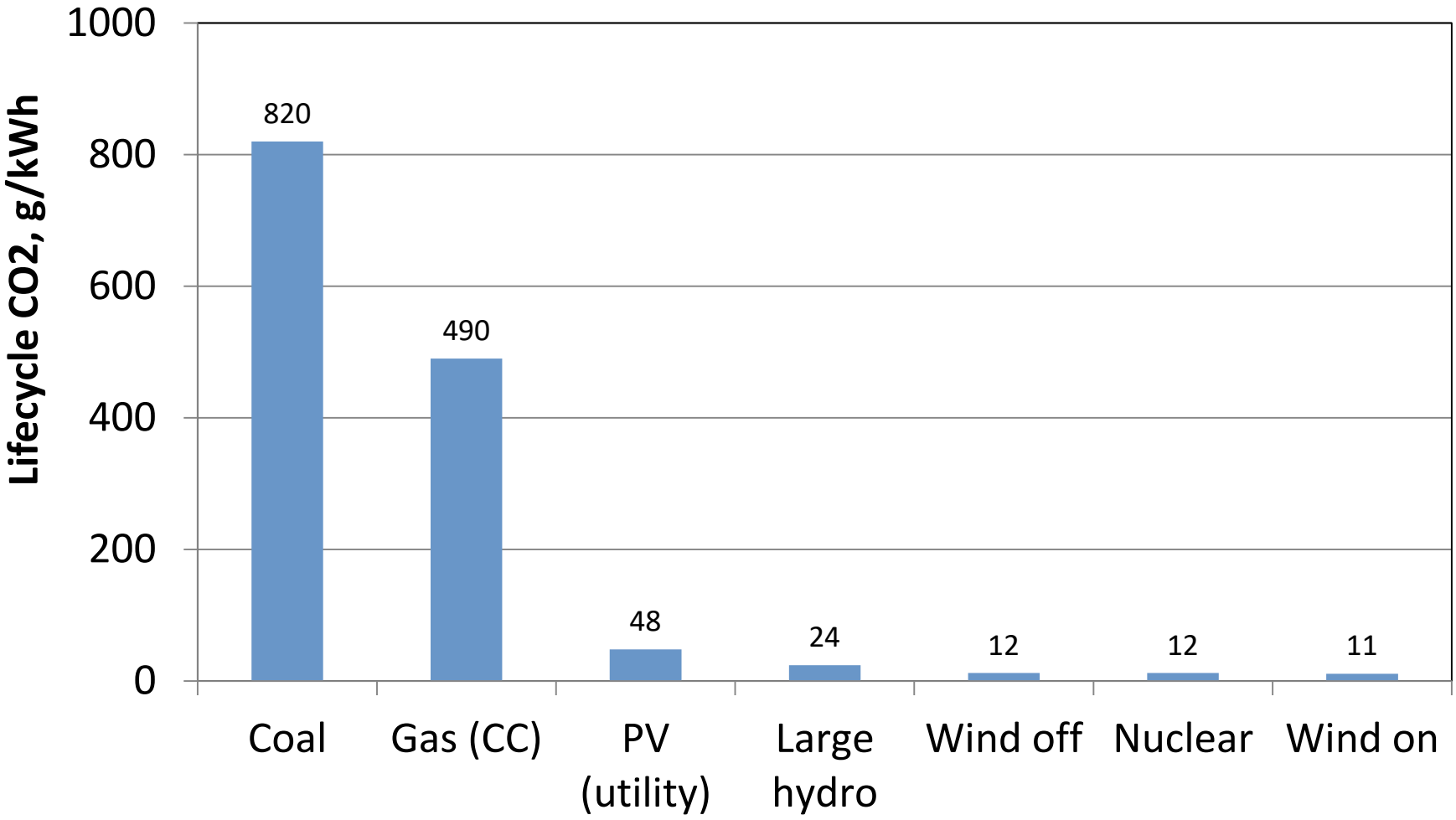
Without impacting the climate …



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Without creating unnecessary public opposition ...

A typical modern offshore wind farm as seen from the beach

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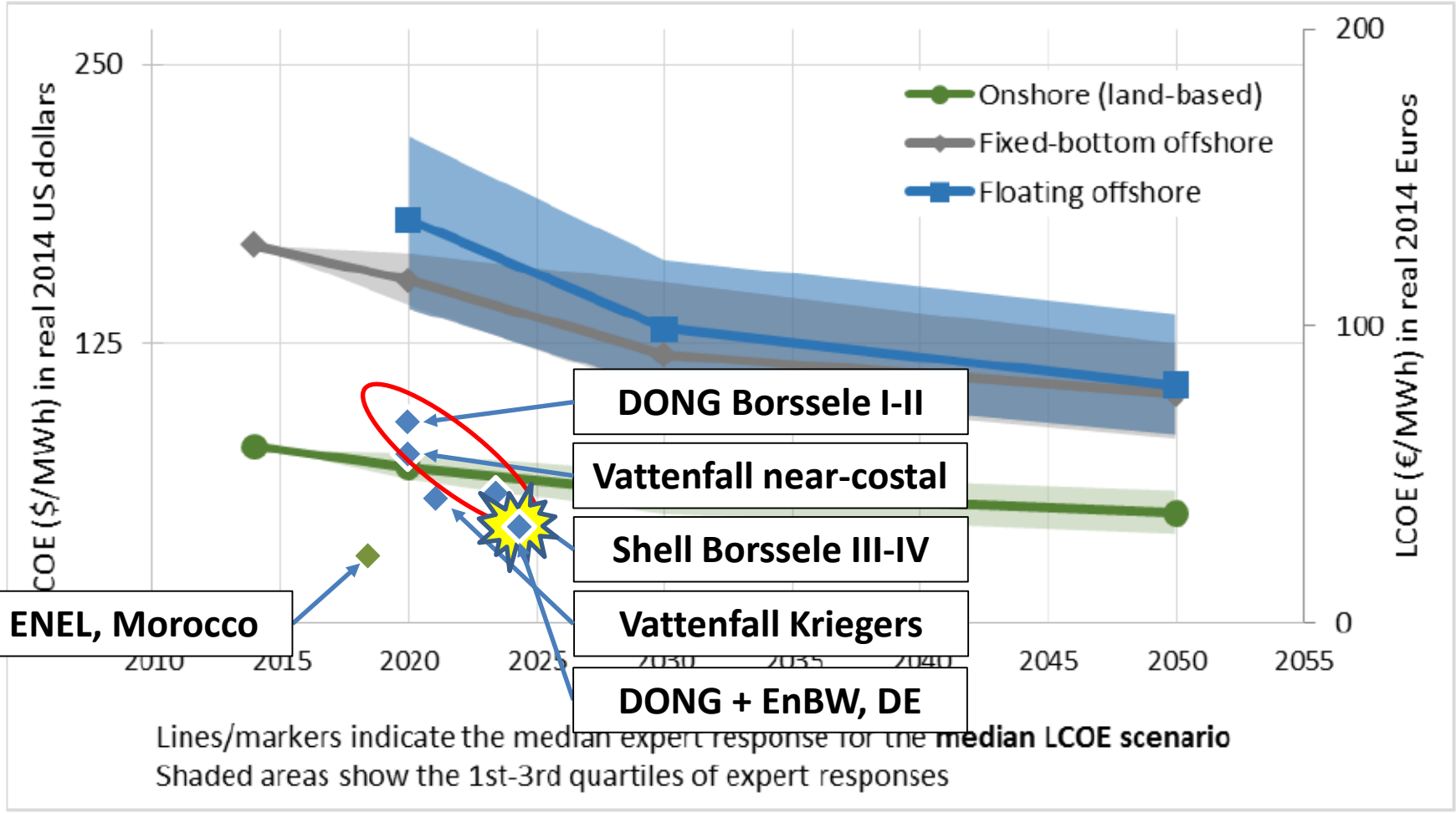
Disruptive 2016 cost reductions in bottom-fixed offshore wind



Source: Berkeley National Lab

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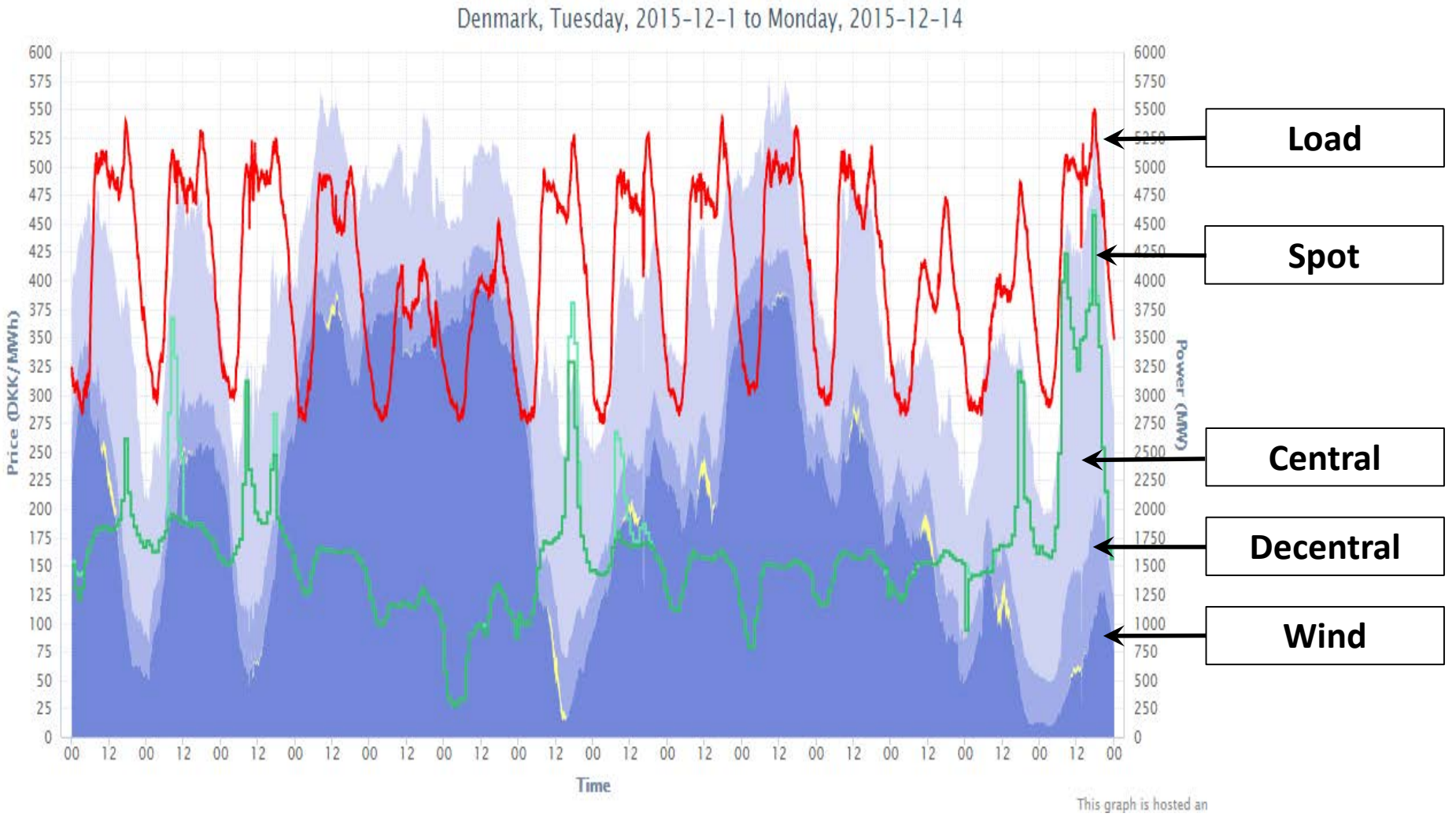
A classical picture of production and load



Source: EMD

Powered by clean, affordable and secure energy …

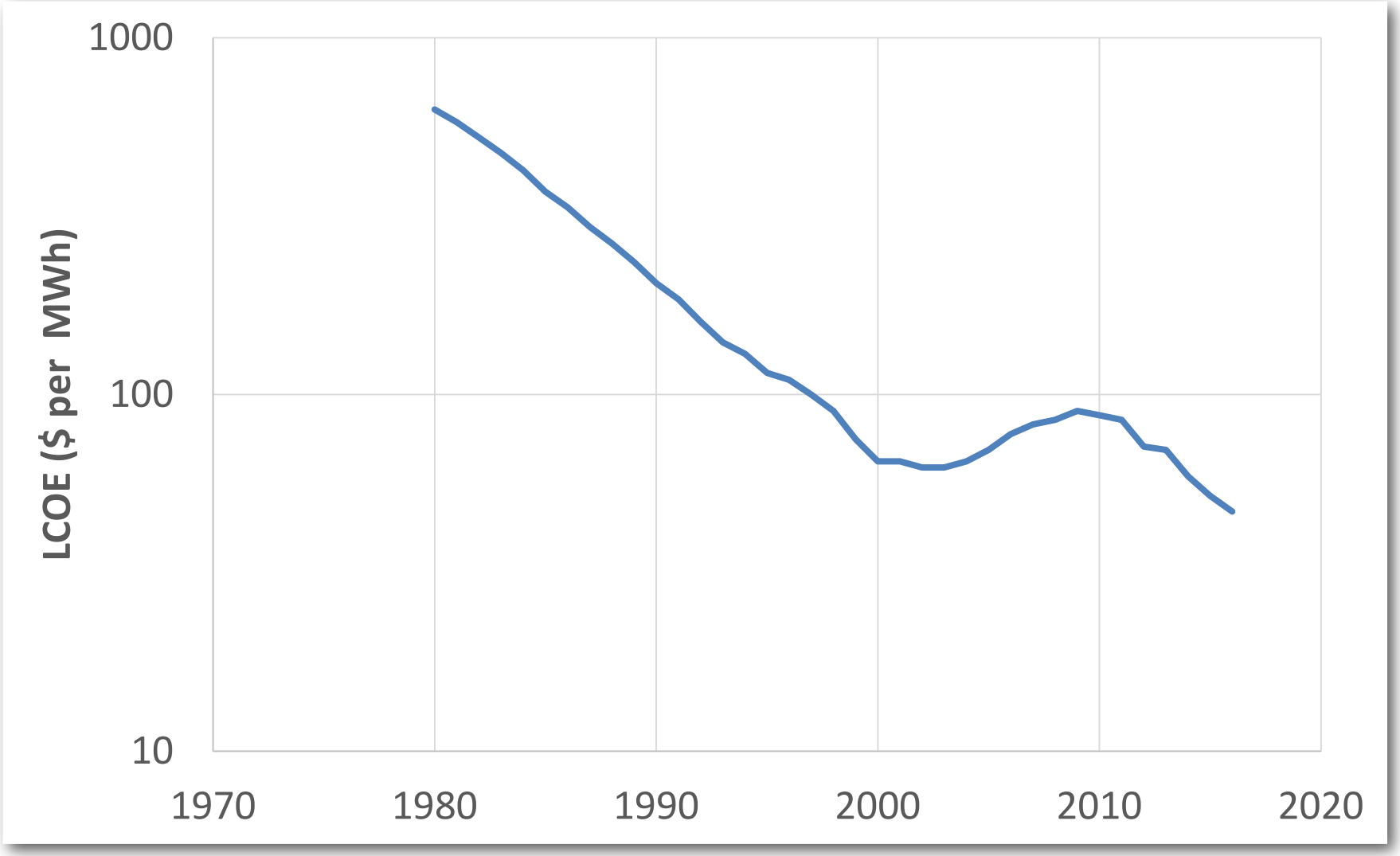
A preferred source of electricity must be able to deliver the desired electric energy -

- ✓ to the necessary extent,
- ✓ without impacting the climate,
- ✓ without excessive public opposition,
- ✓ at an affordable cost, and
- ÷ when it is needed

Wind can deliver - but

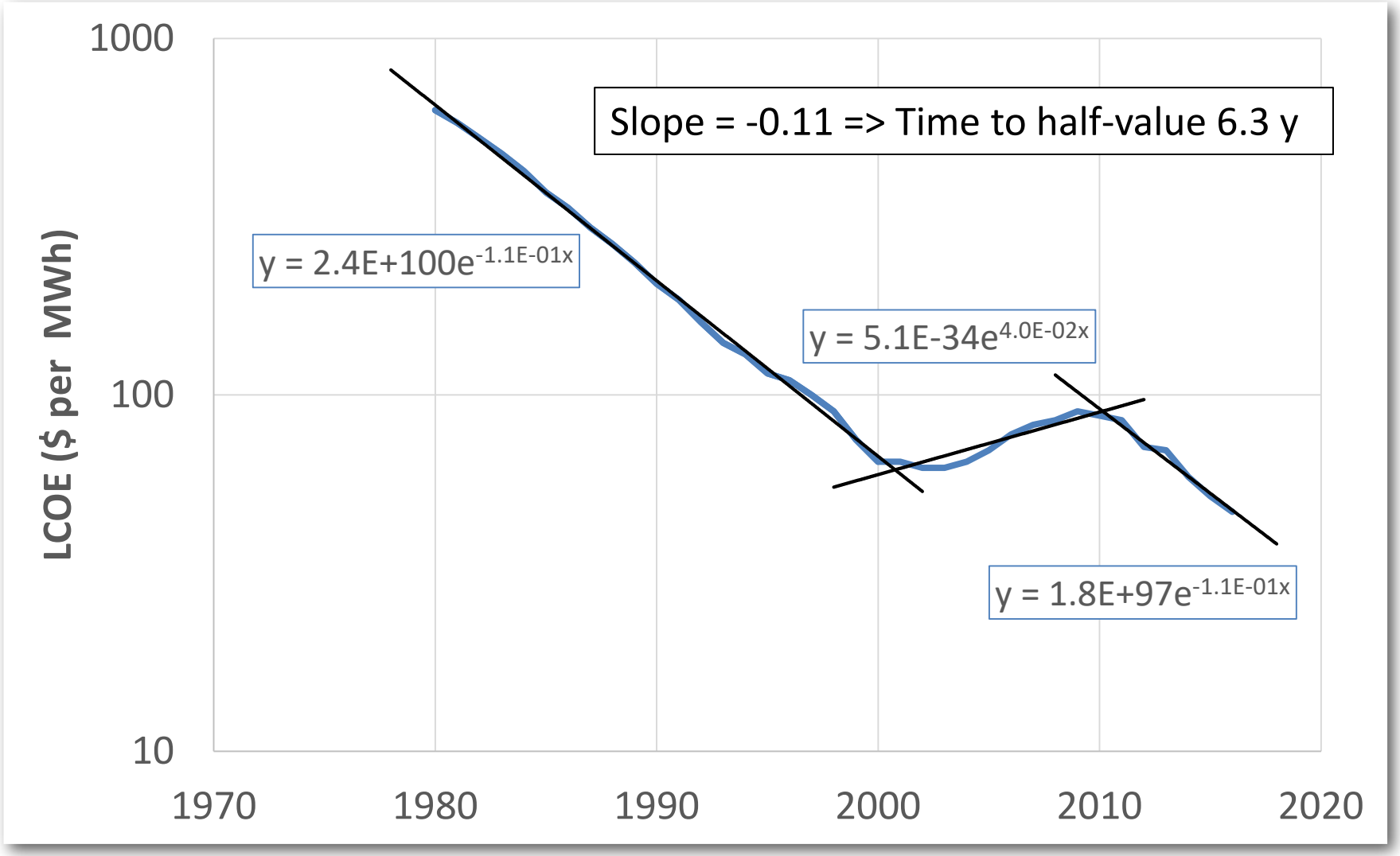
- We need to continue cost reductions in wind power, and
- We need to develop energy storage

The development in cost of wind energy, US market, average



Source: 1980-2011: “Revolution Now”, DoE, 2016; 2012-2016: Lazard

The development in cost of wind energy, US market, average



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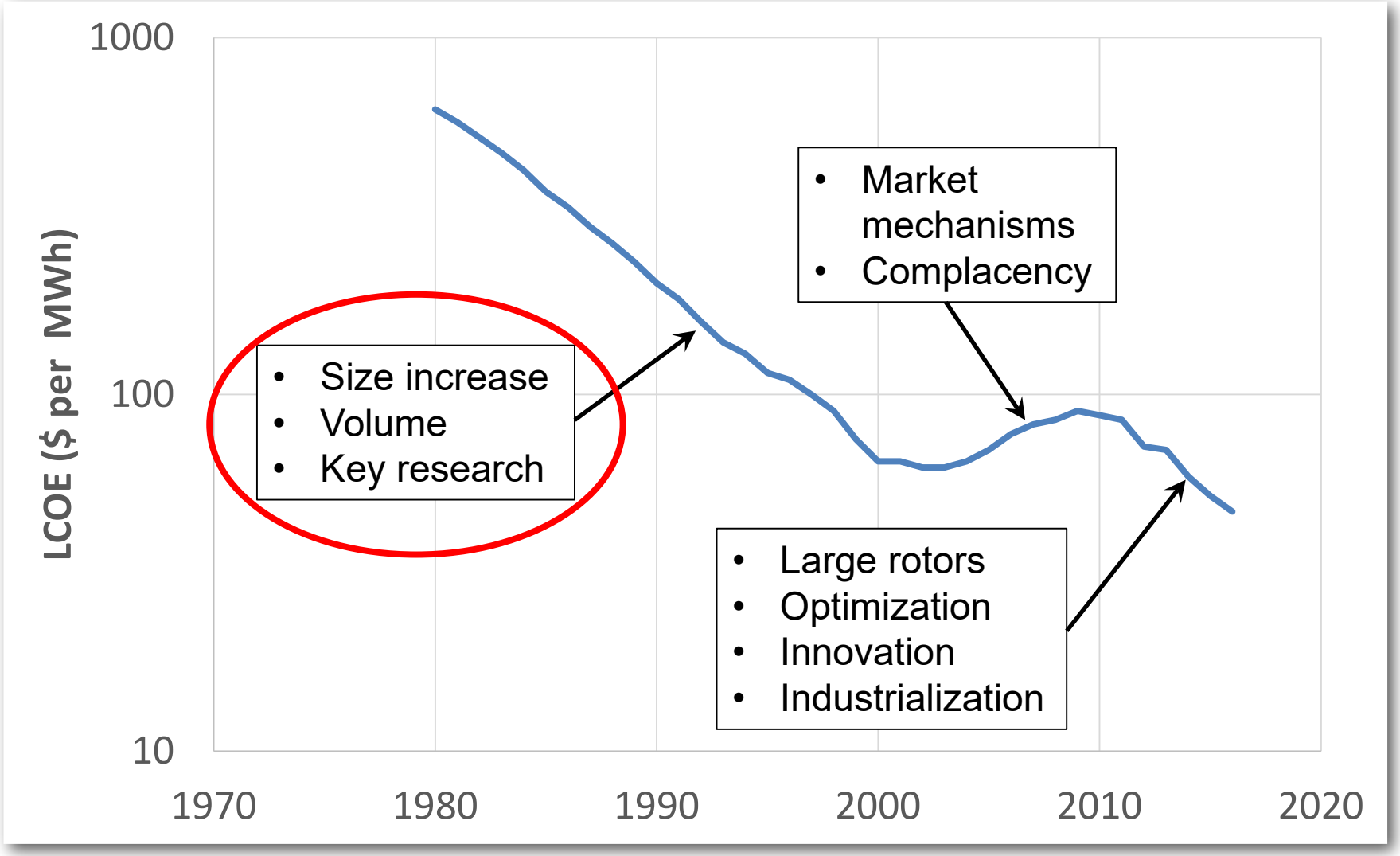
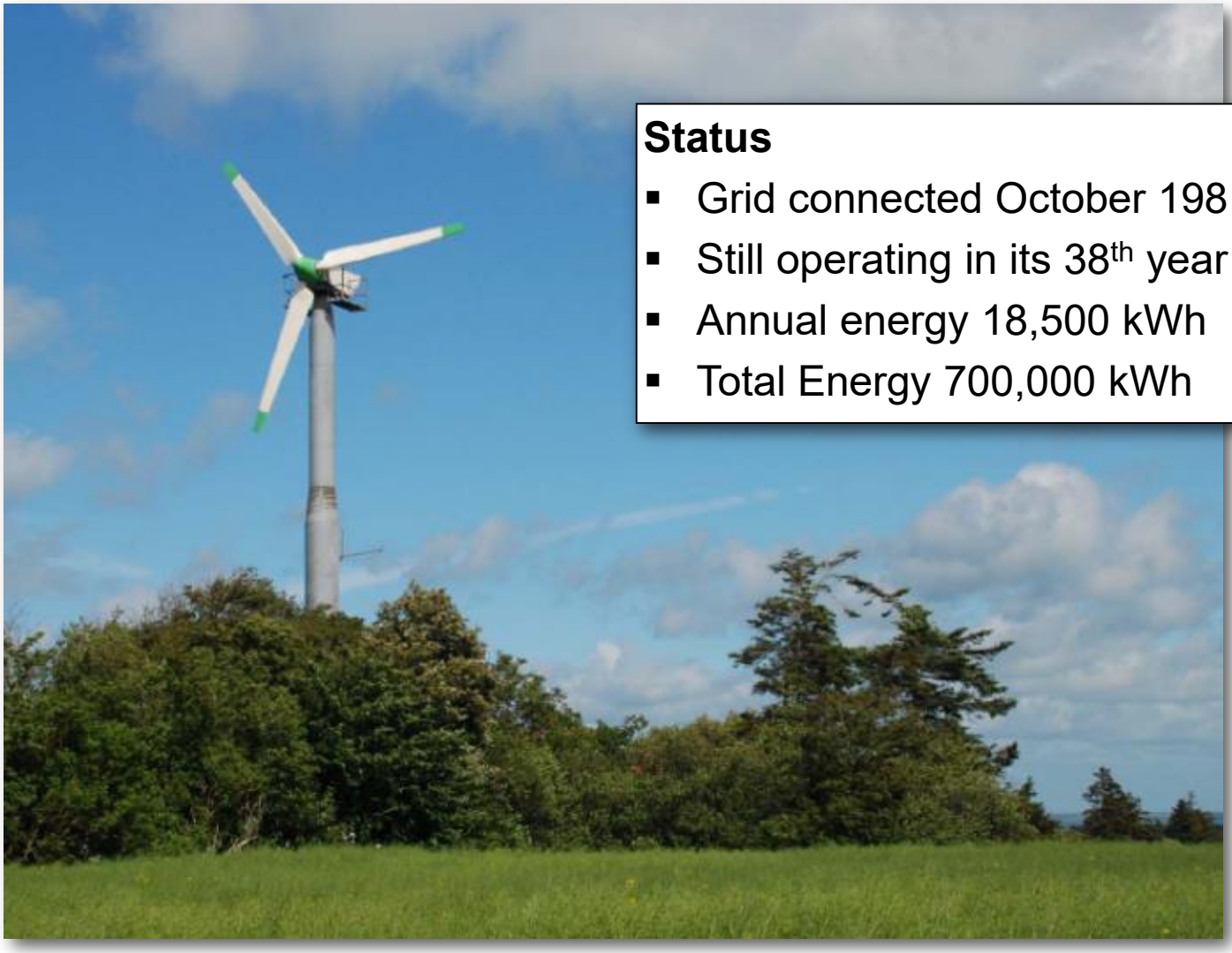
The development in cost of wind energy, US market, average



Source: 1980-2011: “Revolution Now”, DoE, 2016; 2012-2016: Lazard

The first Bonus turbine – 30 kW, Tambohuse, 1981



Status

- Grid connected October 1981
- Still operating in its 38th year
- Annual energy 18,500 kWh
- Total Energy 700,000 kWh

Picture credit: Siemens Gamesa

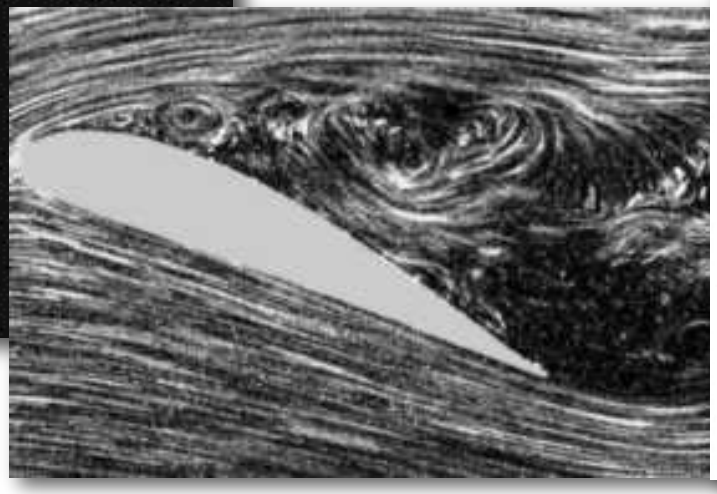
A modern wind turbine, Siemens Gamesa 8 MW, Beatrice

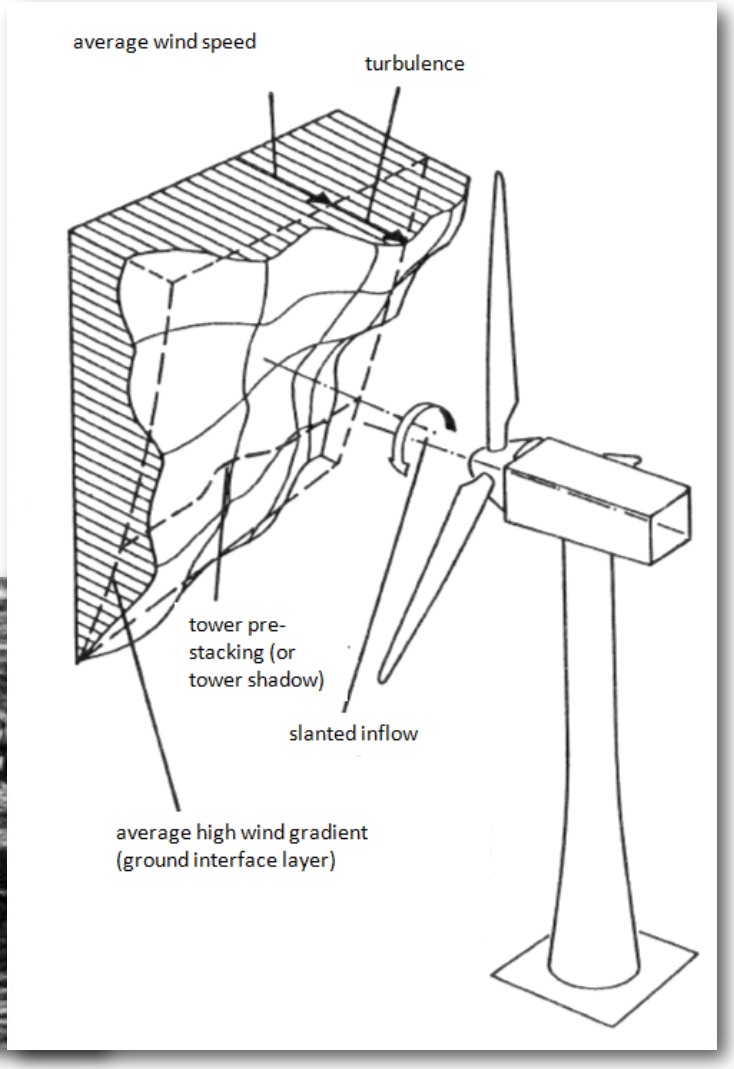
Status

- Commissioned 2019
- Calculated lifetime 25 years
- Annual Energy 30.000.000 kWh
- Produces in 8.5 days same energy as the first turbine did in 38 years

Picture credit: Siemens Gamesa

Key research area: The character of the wind





Key research area: The character of the wind

Picture credit: Bel-Air

Research with Impact – The Resource

Challenge

- How do we improve the prediction of energy production from wind turbines?

Starting point

- Historical meteorological mast wind measurements at a small number of locations in Denmark

Task given by

- Danish Government

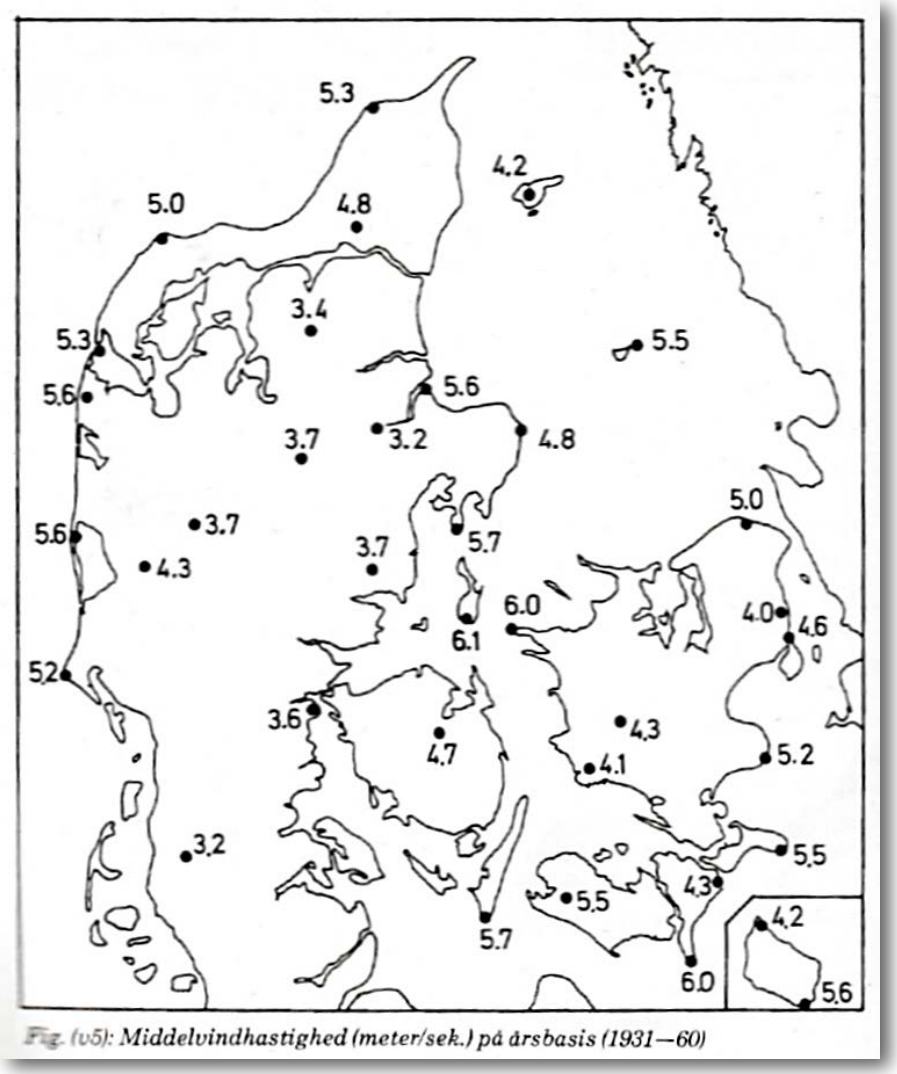


Fig. (v5): Middelvindhastighed (meter/sek.) på årsbasis (1931—60)

Source: ”Sol og Vind”, Claus Nybroe, 1976

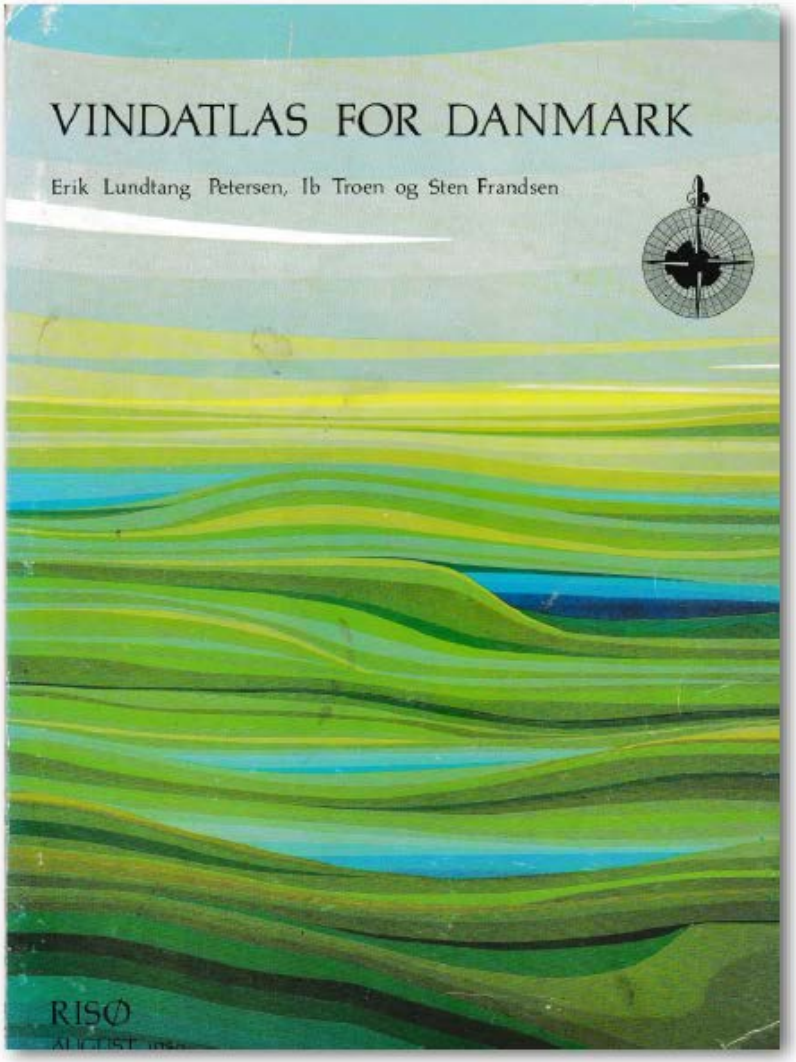
Project and deliverables

Research institution
- Risø

Lead researchers
- Erik Lundtang Petersen, Ib Troen

Effort
- Man-years, 1978-95

Deliverables
- Vindatlas for Denmark
- European Wind Atlas
- WaSP method



Source: Risø

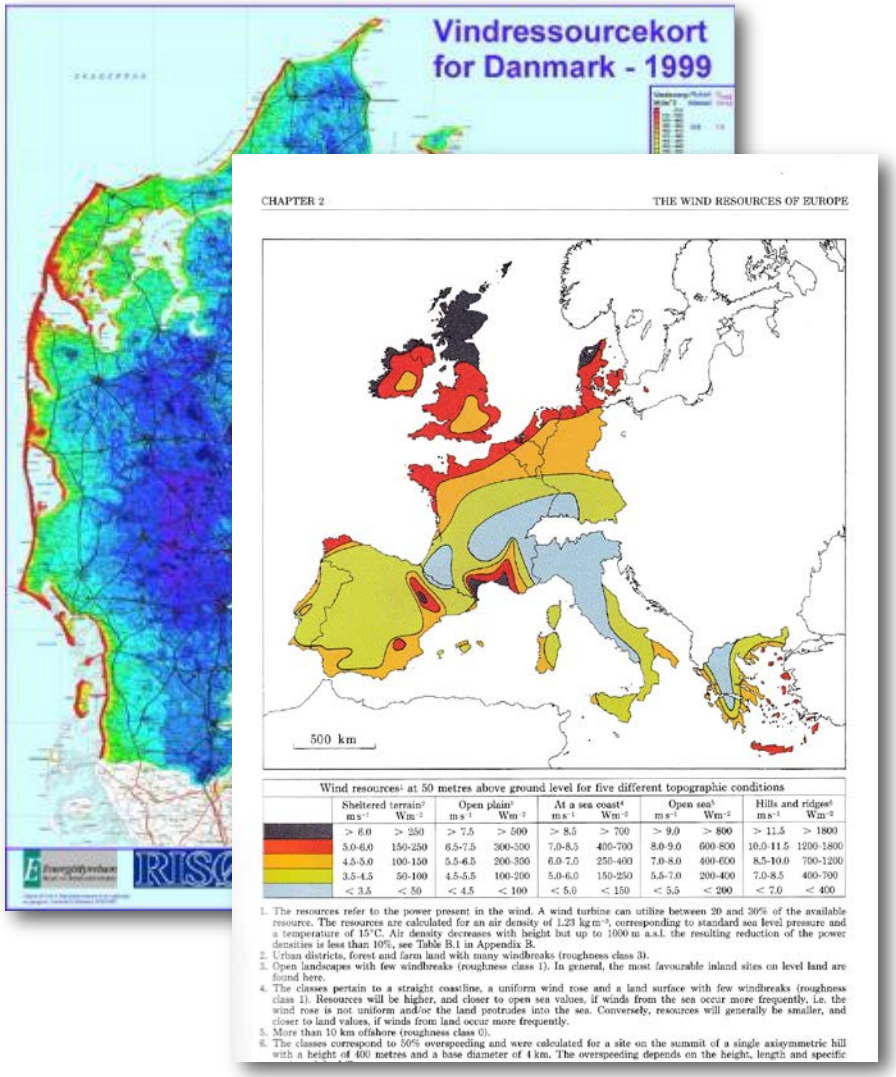
Impact and consequences

Main impact

- Huge reduction in reduction of uncertainty of resource prediction

Consequences

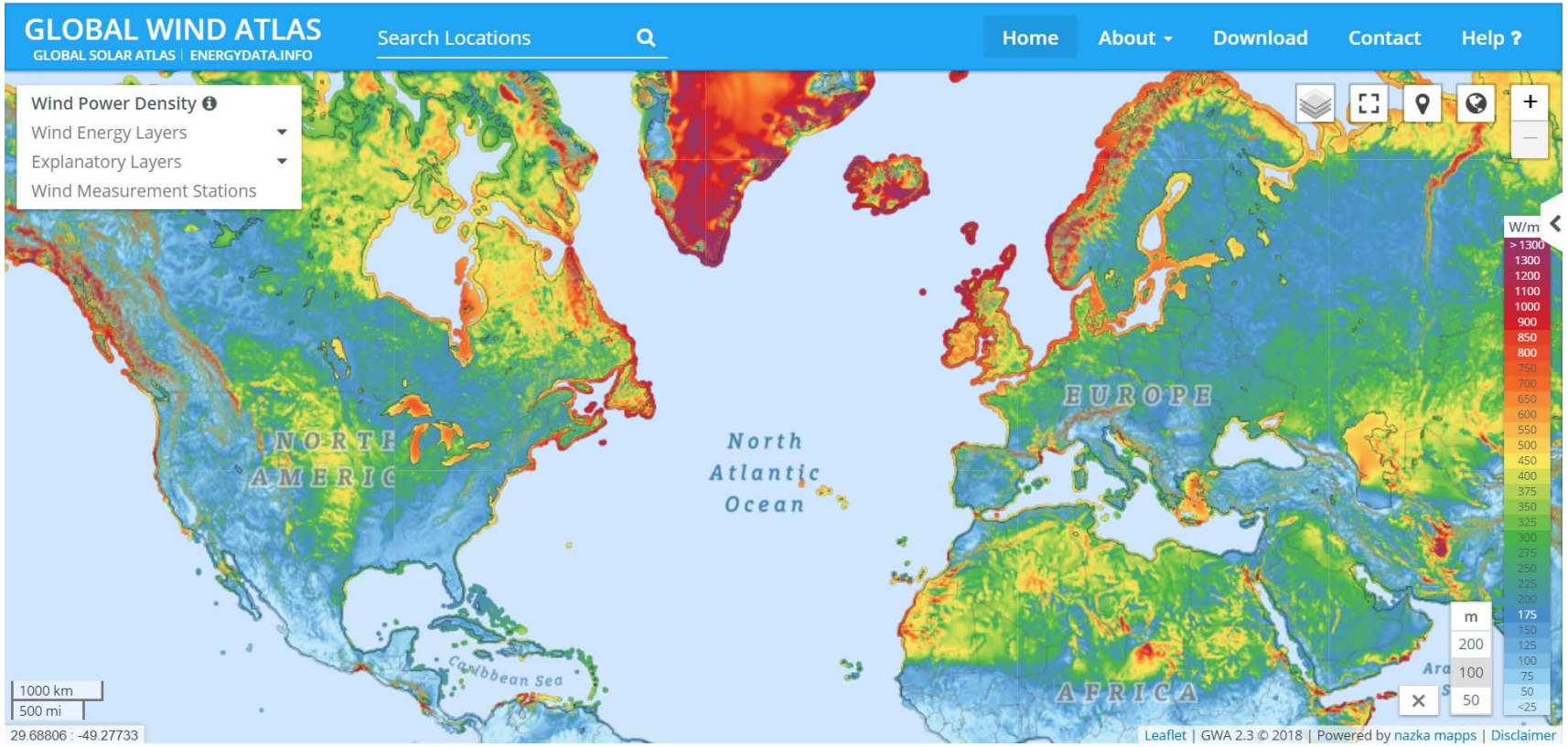
- Solidifying basis for industry
- Bankability
- Solid basis for consulting
- Inspiration



Source: Risø

Impact and consequences

Global wind atlas



Source: World Bank

Research with Impact – The turbulence itself

Challenge

- How do we model turbulence for use in load calculations?

Starting point

- Quite good qualitative and statistical understanding of turbulence, but no acknowledged method to model

Task given by

- Researcher self

Navier-Stokes momentum equation (*convective form*)

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\frac{1}{\rho}\nabla \bar{p} + \nu \nabla^2 \mathbf{u} + \tfrac{1}{3}\nu \nabla(\nabla \cdot \mathbf{u}) + \mathbf{g}.$$

Poetic interpretation

Bigger swirls have smaller swirls
That live on their velocity
Smaller swirls have smaller swirls
And so on, to viscosity

Lewis Fry Richardson

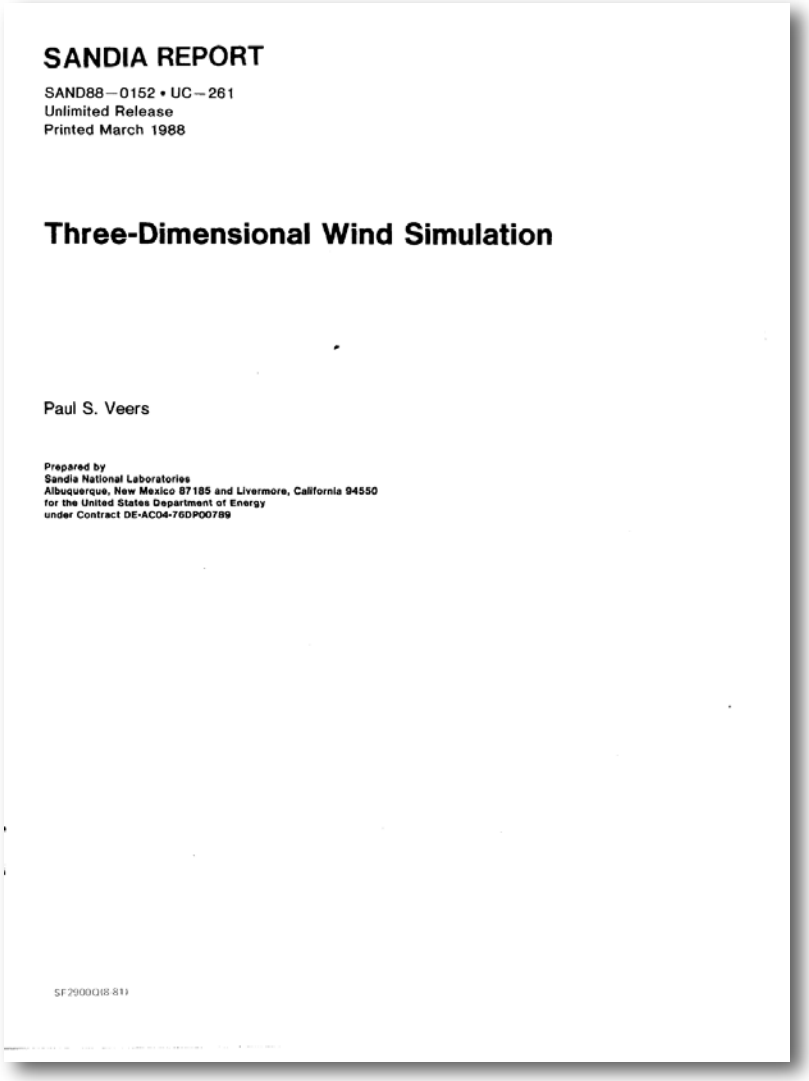
Project and Deliverables

Research institution
- Sandia National Labs

Lead researchers
- Paul Veers

Effort
- Man-year, 1988

Deliverables
- Algorithm for computer coding



SANDIA REPORT

SAND88–0152 • UC–261
Unlimited Release
Printed March 1988

Three-Dimensional Wind Simulation

Paul S. Veers

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

SF2900Q18:811

Source: Sandia National Lab

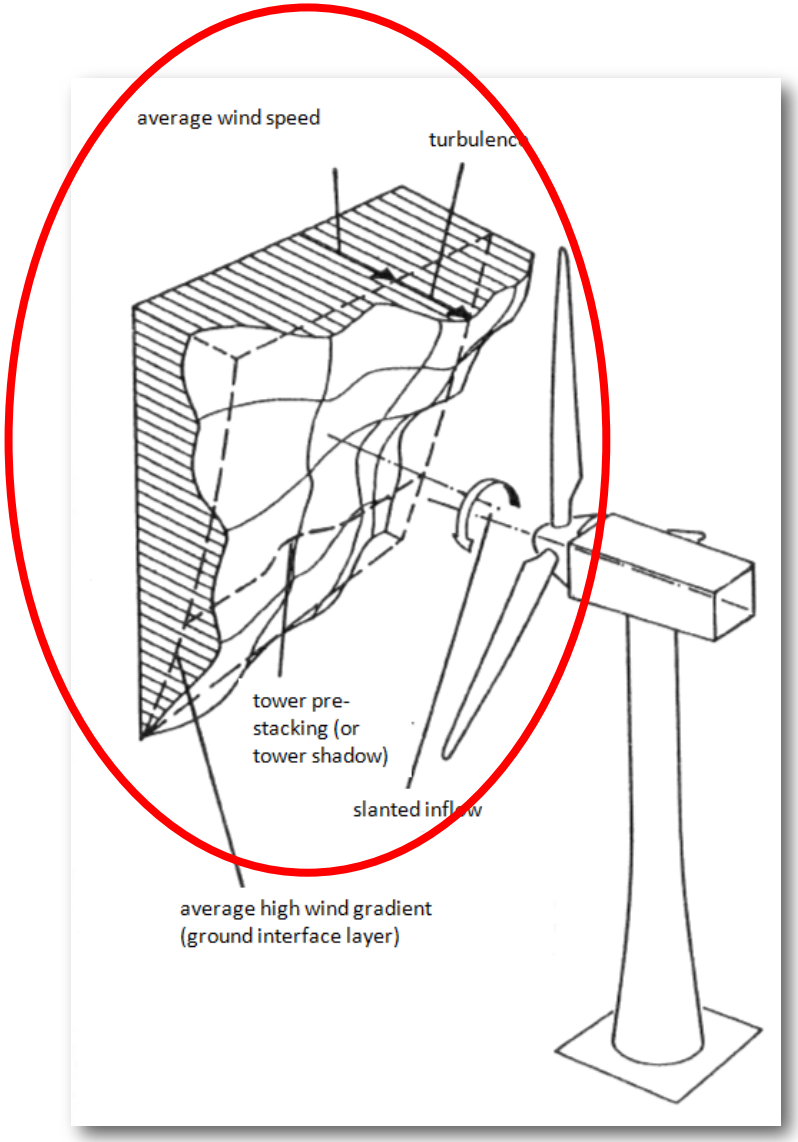
Impact and consequences

Main impact

- Removed guesswork on turbulence input to turbine dynamic modelling

Consequences

- Enabled next-generation load calculations



Research with Impact – The Loads

Challenge

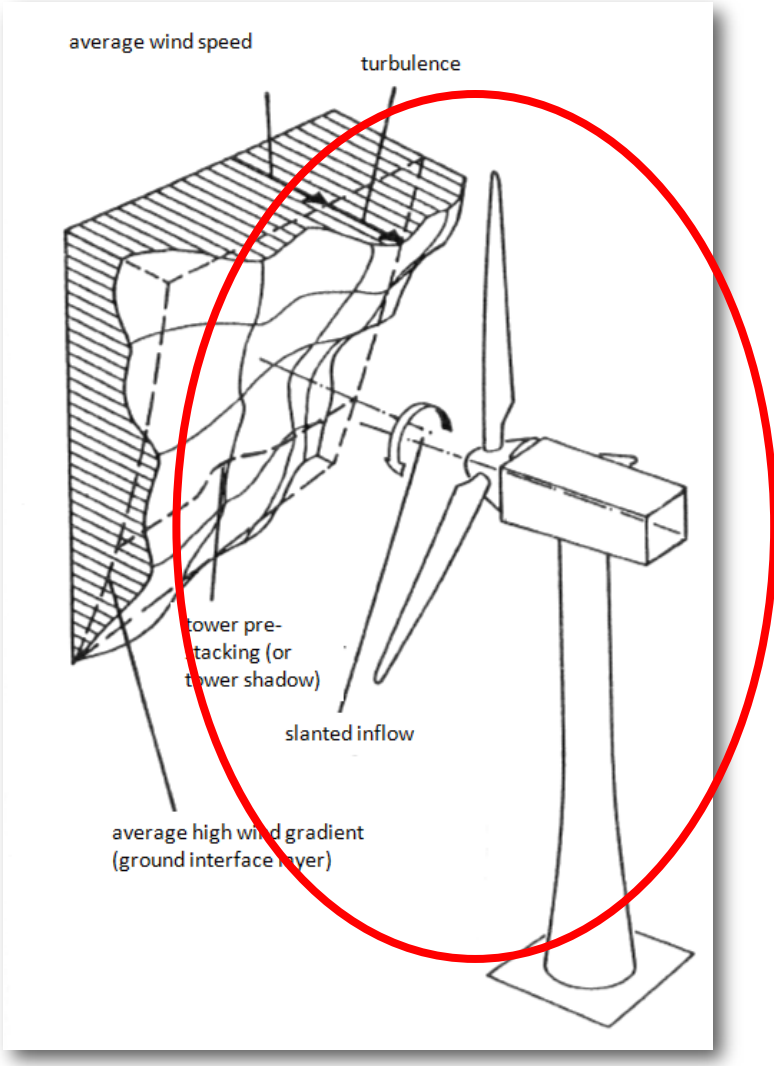
- How do we improve the prediction of structural loads on wind turbines?

Starting point

- “Load Paradigm” with conservative rules of thumb for blade and rotor loads

Task given by

- Researcher self



Project and deliverables

Research institution
- Risø

Lead researchers
- Jørgen Thirstrup Petersen

Effort
- Man-years, 1986-88

Deliverables
- HAWC Model

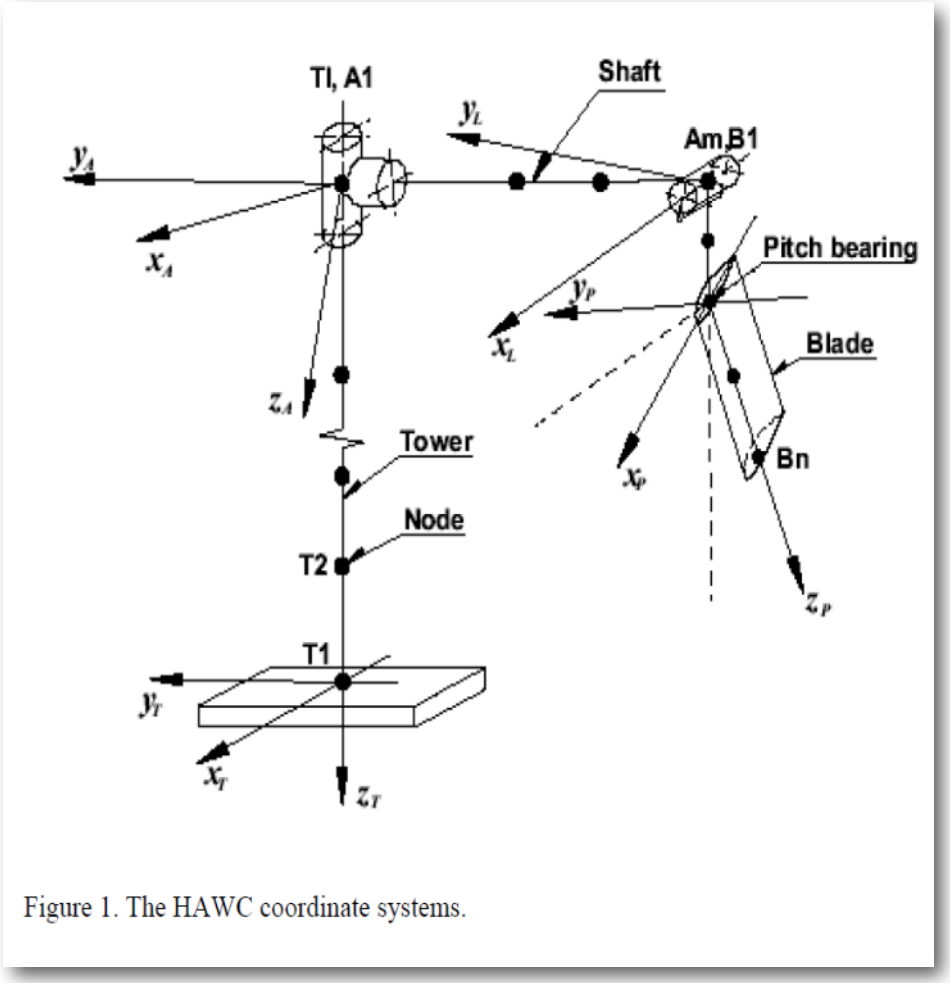


Figure 1. The HAWC coordinate systems.

Source: Risø

Research with Impact – The Flow

Challenge

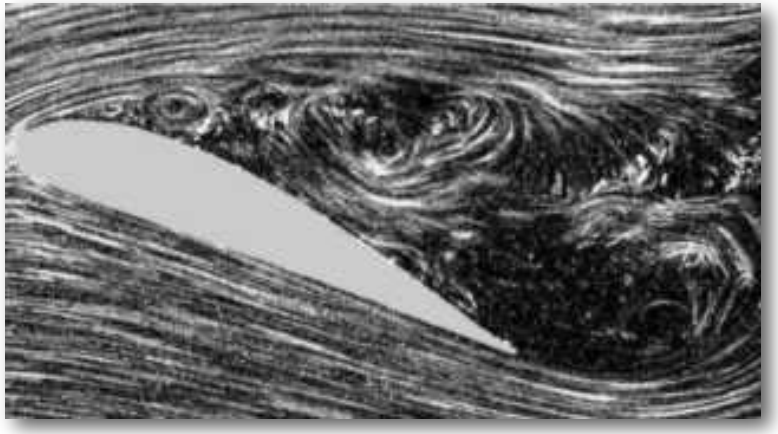
- How do we improve the modelling and understanding of flow around structures?

Starting point

- Existing, but expensive and slow tools for Computerized Fluid Dynamics

Task given by

- Researchers self



Source: Risø

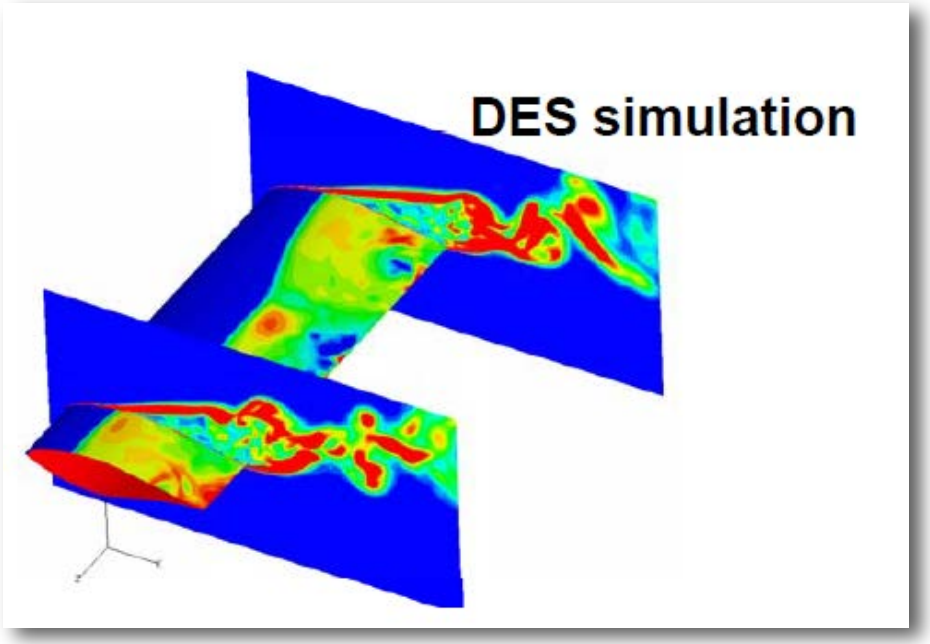
Project and deliverables

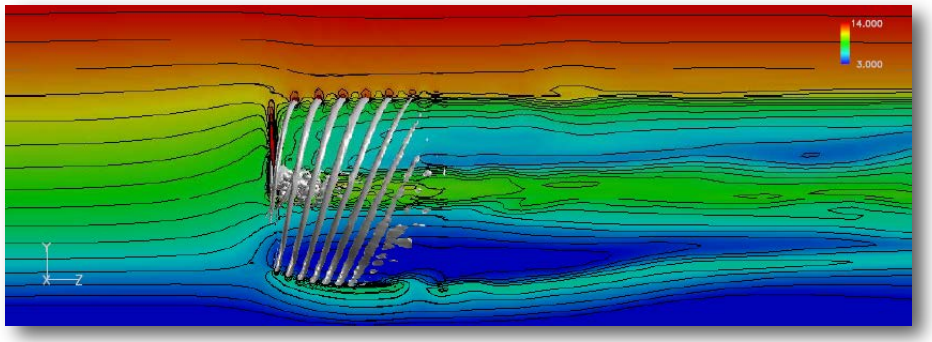
Research institution
- Risø / DTU

Lead researchers
- Niels N. Sørensen, Jess Michelsen

Effort
- Man-decades, from 1992

Deliverables
- Ellipsys 2D and 3D models





Source: Risø

Research with Impact – The Structure

Challenge

- Now that we know the loads, how do we get to dimension wind turbine blades on a rational basis?

Starting point

- Very limited data on composite fatigue properties available

Task given by

- Researchers self

Source: Anonymous

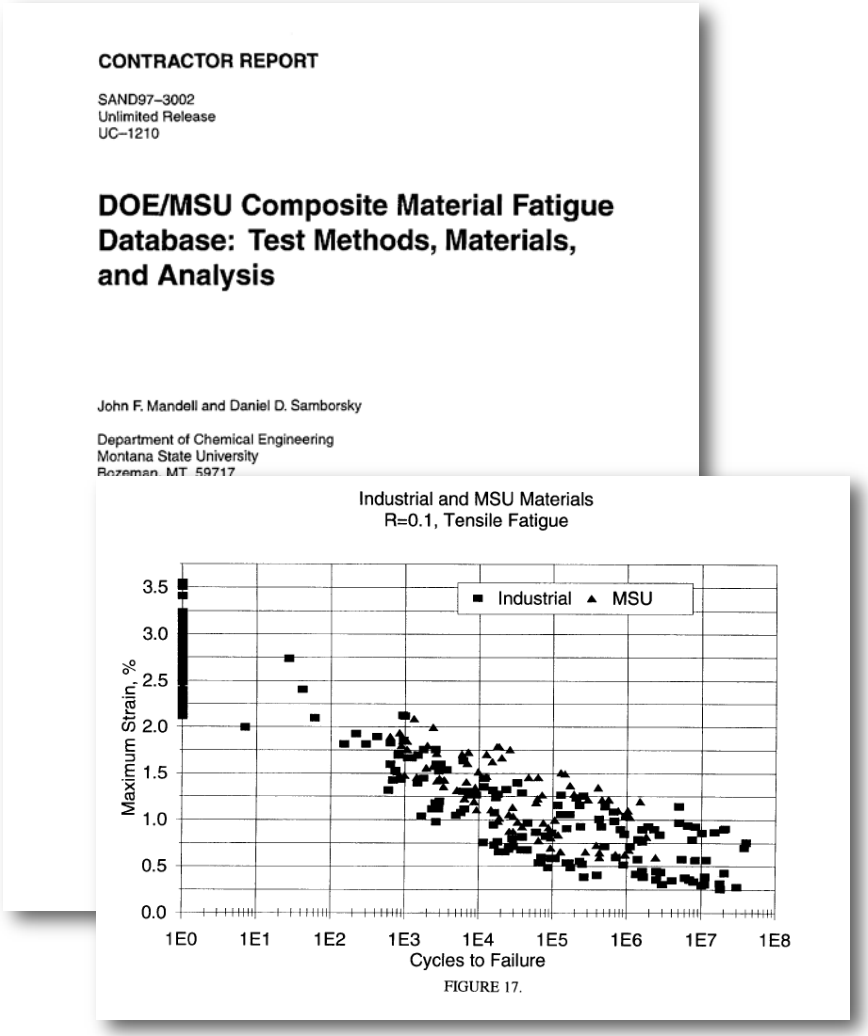
Project and deliverables

Research institution
- University of Montana / Sandia

Lead researchers
- John Mandell and Daniel Samborsky

Effort
- Man-years, 1990s

Deliverables
- Fatigue data for a large range of composites



CONTRACTOR REPORT

SAND97–3002
Unlimited Release
UC–1210

DOE/MSU Composite Material Fatigue Database: Test Methods, Materials, and Analysis

John F. Mandell and Daniel D. Samborsky

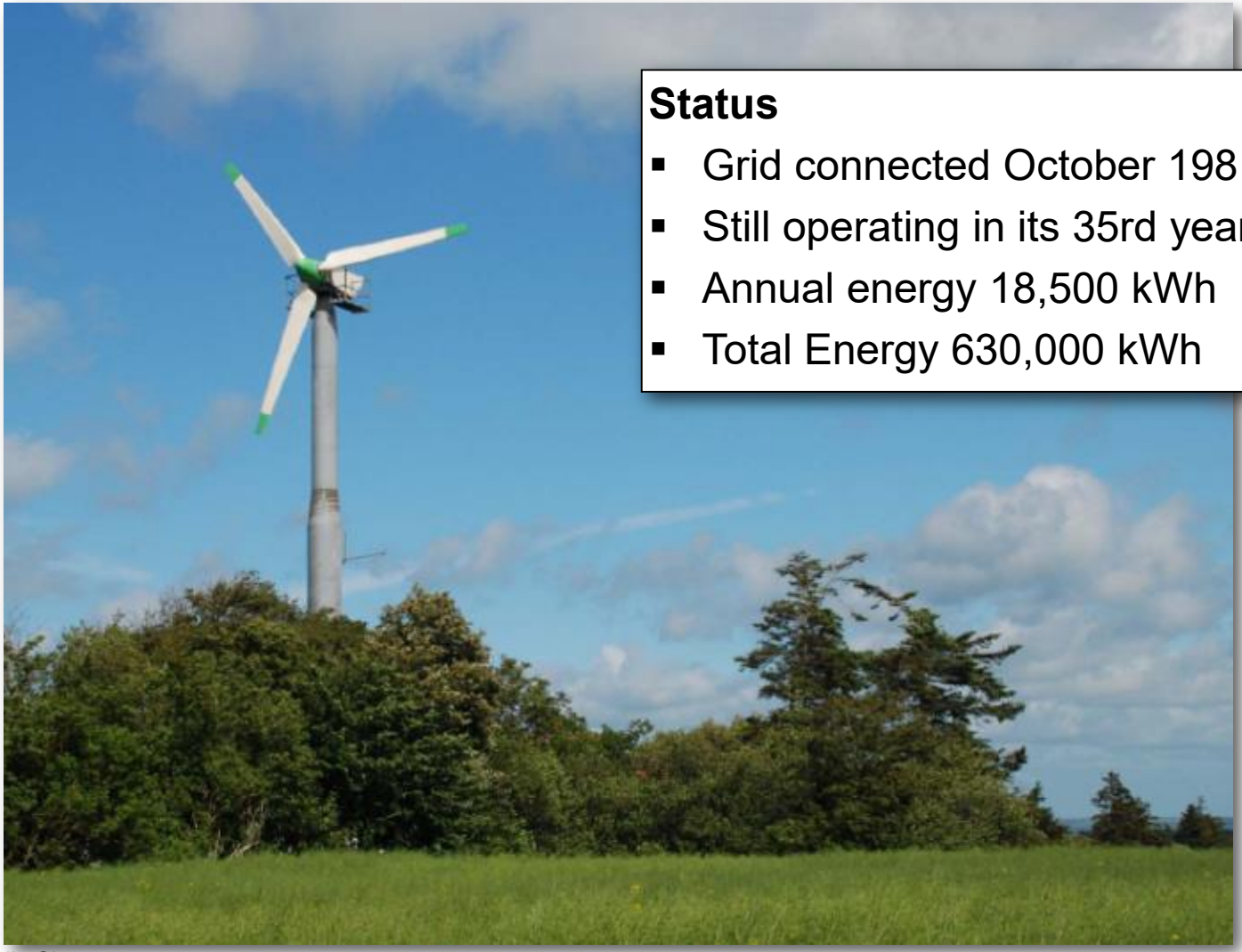
Department of Chemical Engineering
Montana State University
Bozeman, MT 59717

Industrial and MSU Materials
R=0.1, Tensile Fatigue

FIGURE 17.

Source: Sandia National Lab

So, now we have high-quality models – then what?

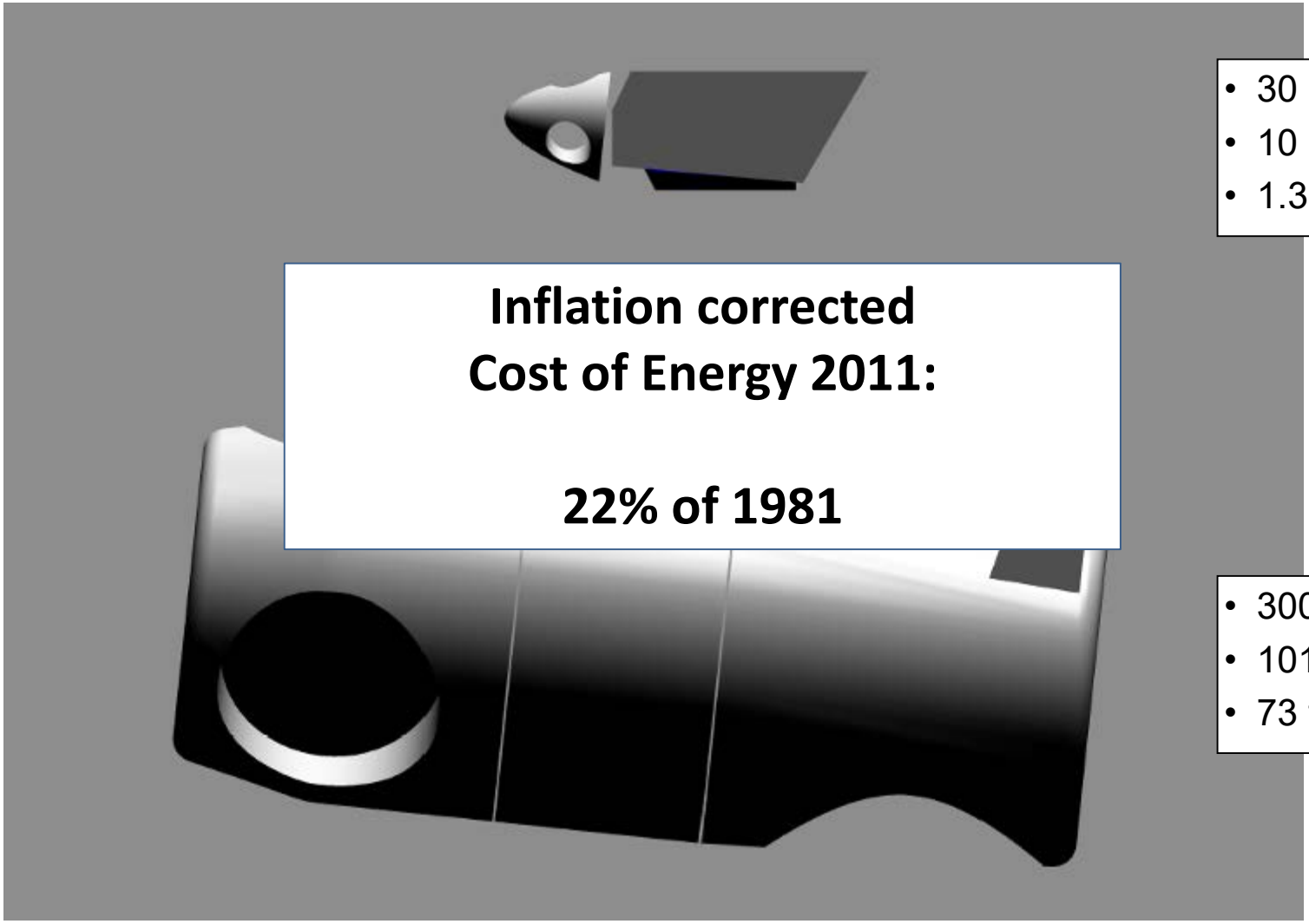


Status

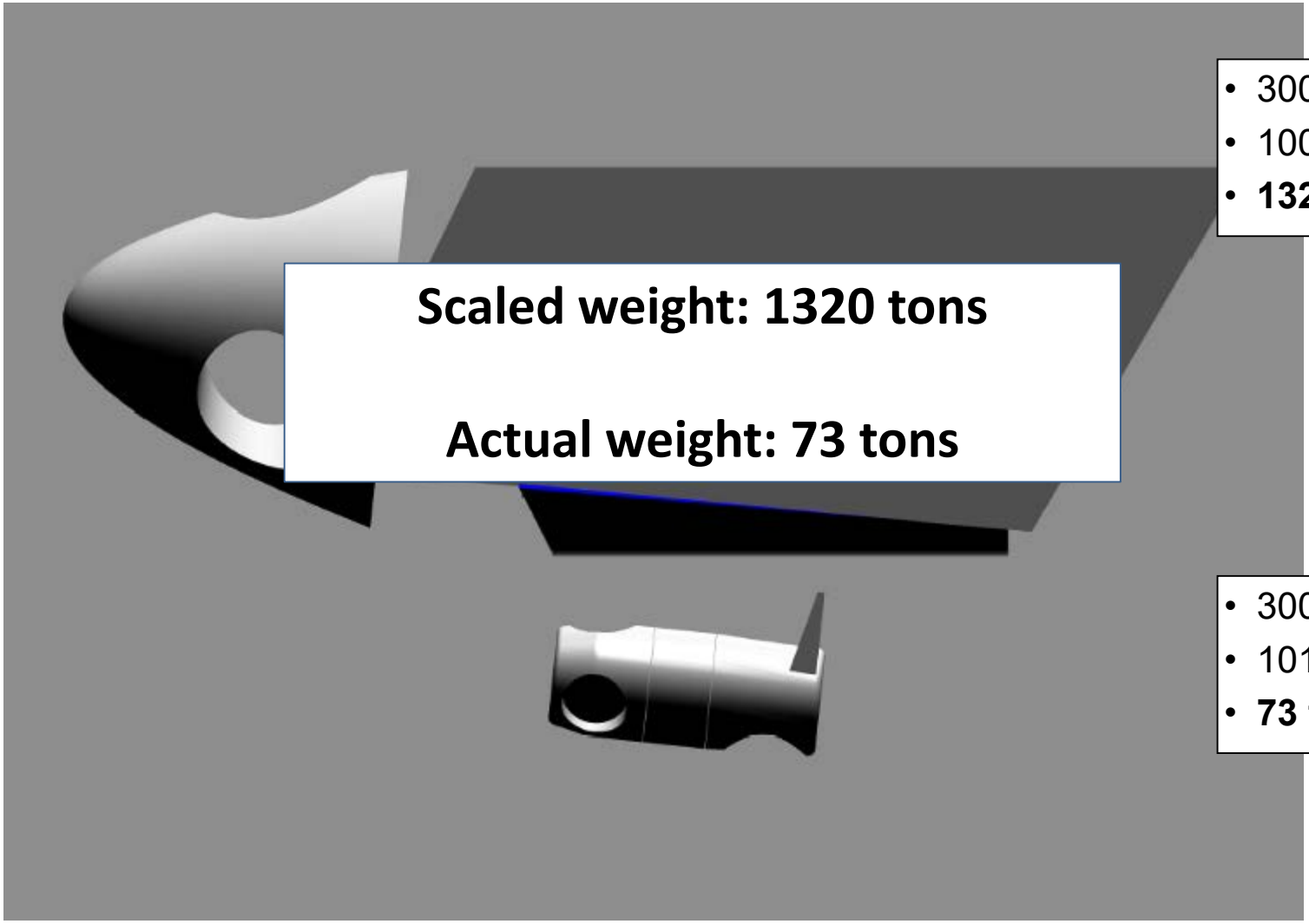
- Grid connected October 1981
- Still operating in its 35rd year
- Annual energy 18,500 kWh
- Total Energy 630,000 kWh

Picture credit: Siemens

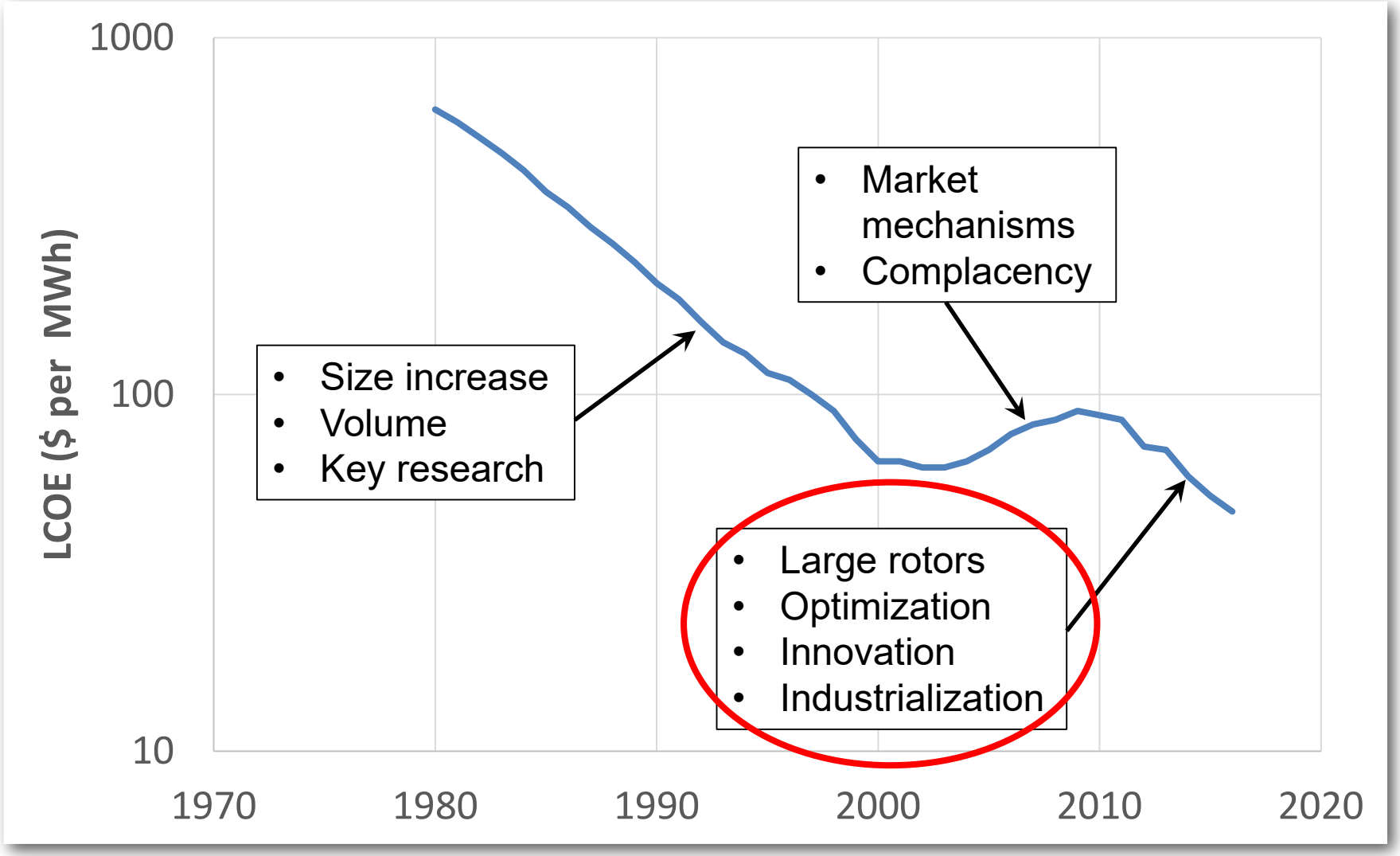
The effect of innovation based on high-quality models



If the 1981 turbine had just been enlarged

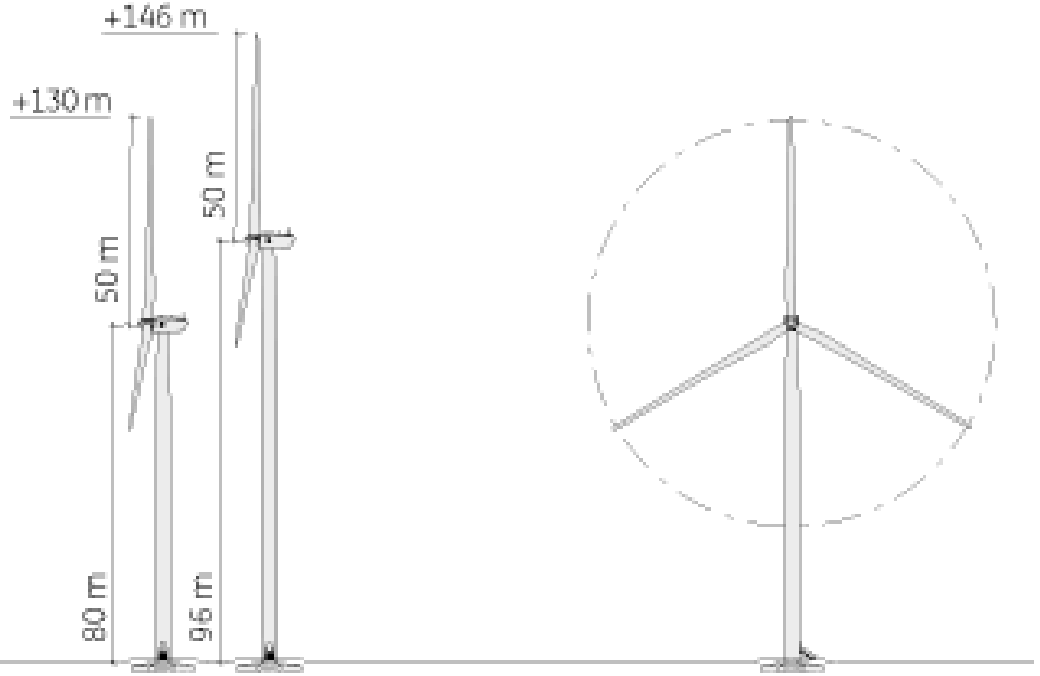


The development in cost of wind energy, US market, average

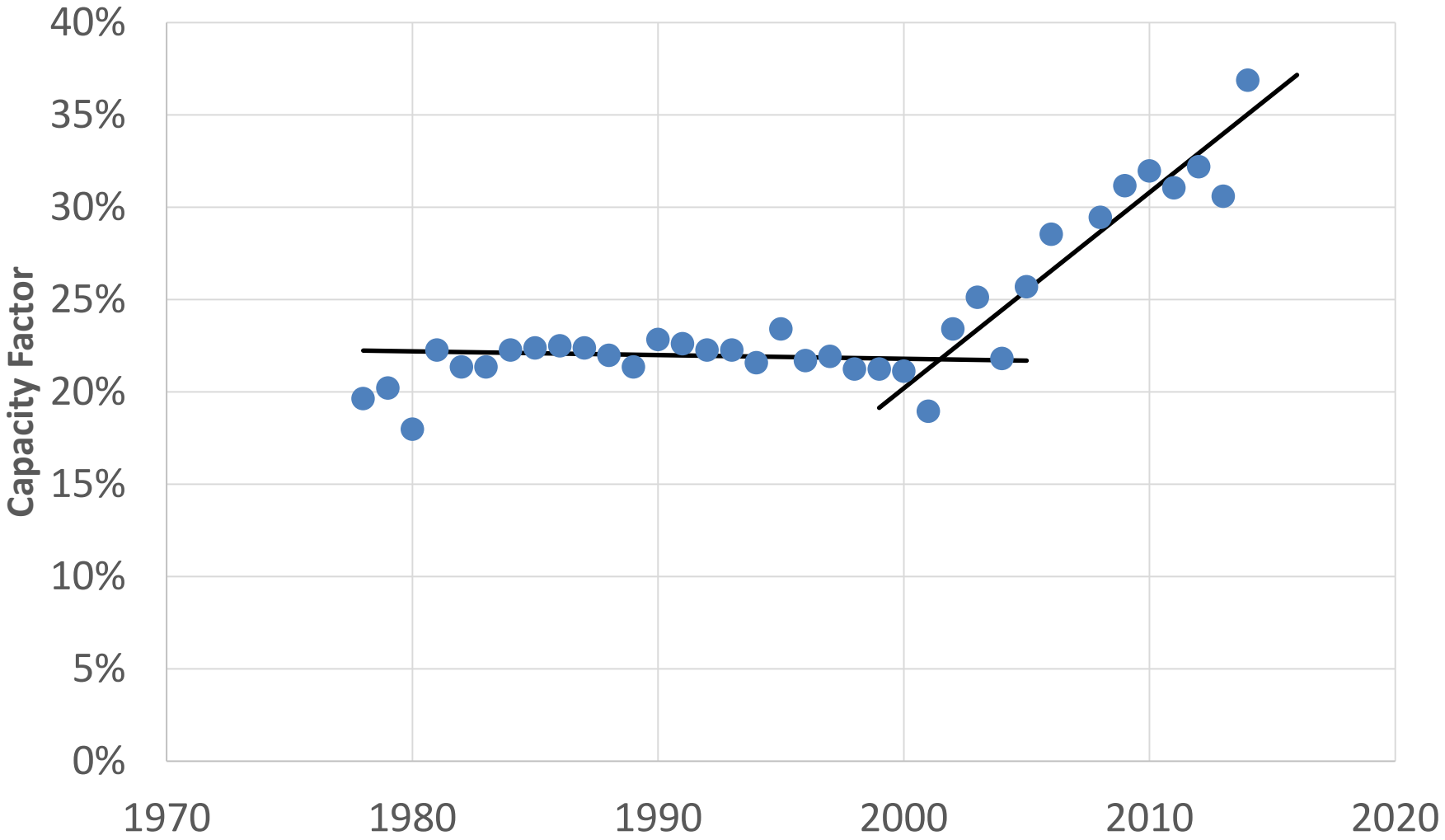


Source: 1980-2011: “Revolution Now”, DoE, 2016; 2012-2016: Lazard

The large rotors



The effect of the larger rotors on DK wind productivity



Source: Naturlig Energu

Research with Impact – The Example

Challenge

- How do we make researchers speak about the same things when considering the impact of models and tools, regulation, etc.?

Starting point

- Everybody calculating on their own design, comparison difficult

Task given by

- Researchers self

Source: NREL

Research with Impact – The Example

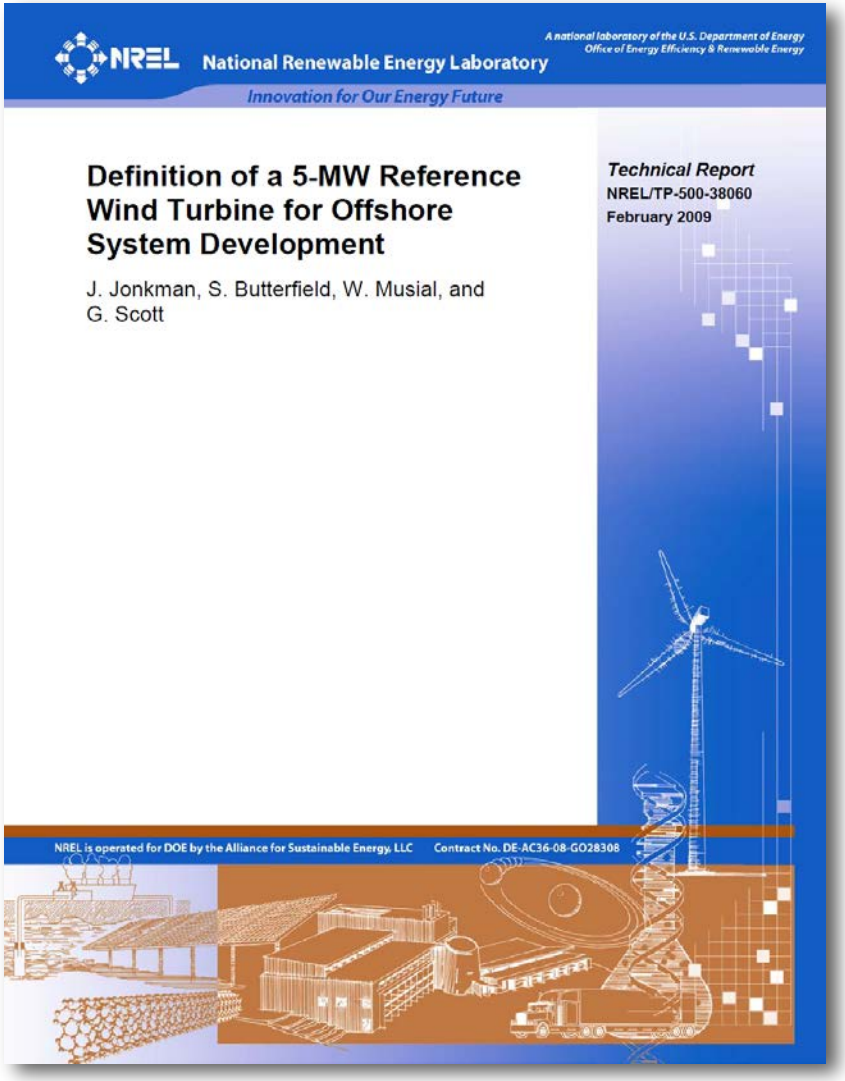
Research institution
- NREL

Lead researchers
- Walt Musial, Jason Jonkman

Effort
- Man-months, 2009

Deliverables
- 5 MW reference turbine

Impact
- Babel replaced with common language



Source: NREL

Research with Impact – The Bend-Twist Coupling

Challenge

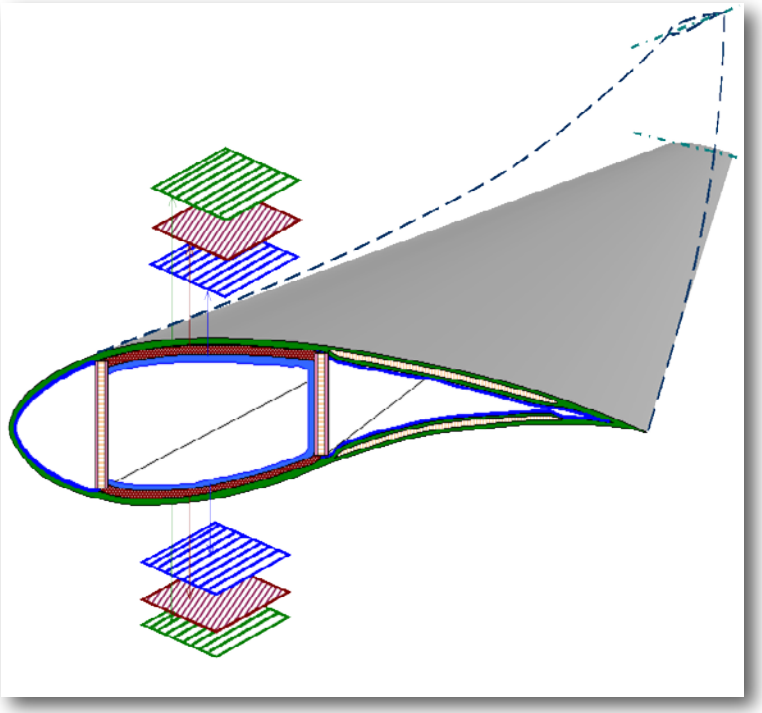
- How do we reduce the loads on wind turbine blades?

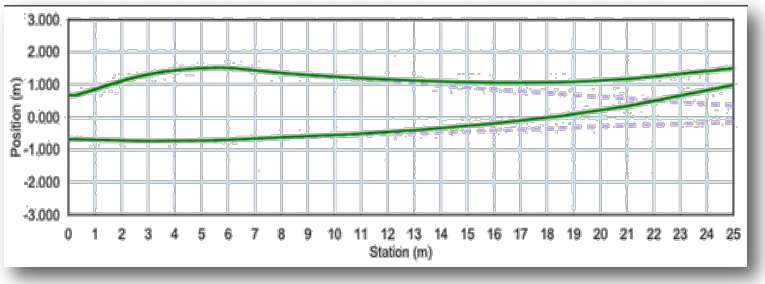
Starting point

- Blade flexibility is a liability; loads are more or less given by geometry and operational conditions

Task given by

- Researcher self





Source: Sandia National Lab

Project and deliverables

Research institution
- Sandia National Lab

Lead researchers
- Paul Veers

Effort
- Man-years, from 2004

Deliverables
- Validation of stable operation with bend-twist coupled blade

Source: Sandia National Lab

Impact of Veers project – and previous Risø / DTU projects

A fundamental change in size and operation – and opportunities

- A much more slender and lightweight blade
- Profiles changed from 1930s aircraft types to modern custom-made types
- Flexibility used for load control purposes

The other lever - industrialization

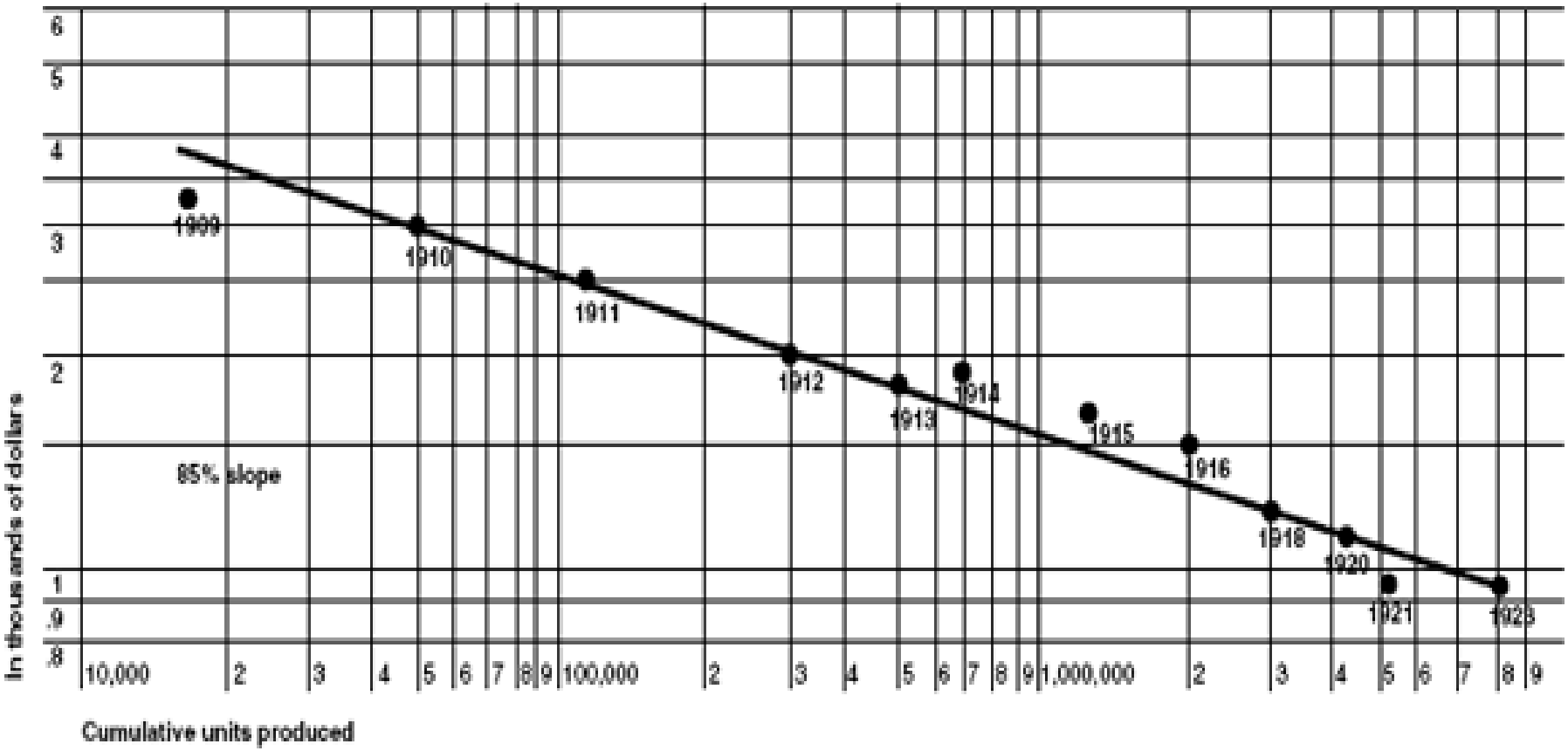
1909

1923

Source: Ford Motor Company

The money is also in industrialization!

EXHIBIT I Price of Model T, 1909–1923 (Average List Price in 1958 Dollars)



Source: Ford Motor Company

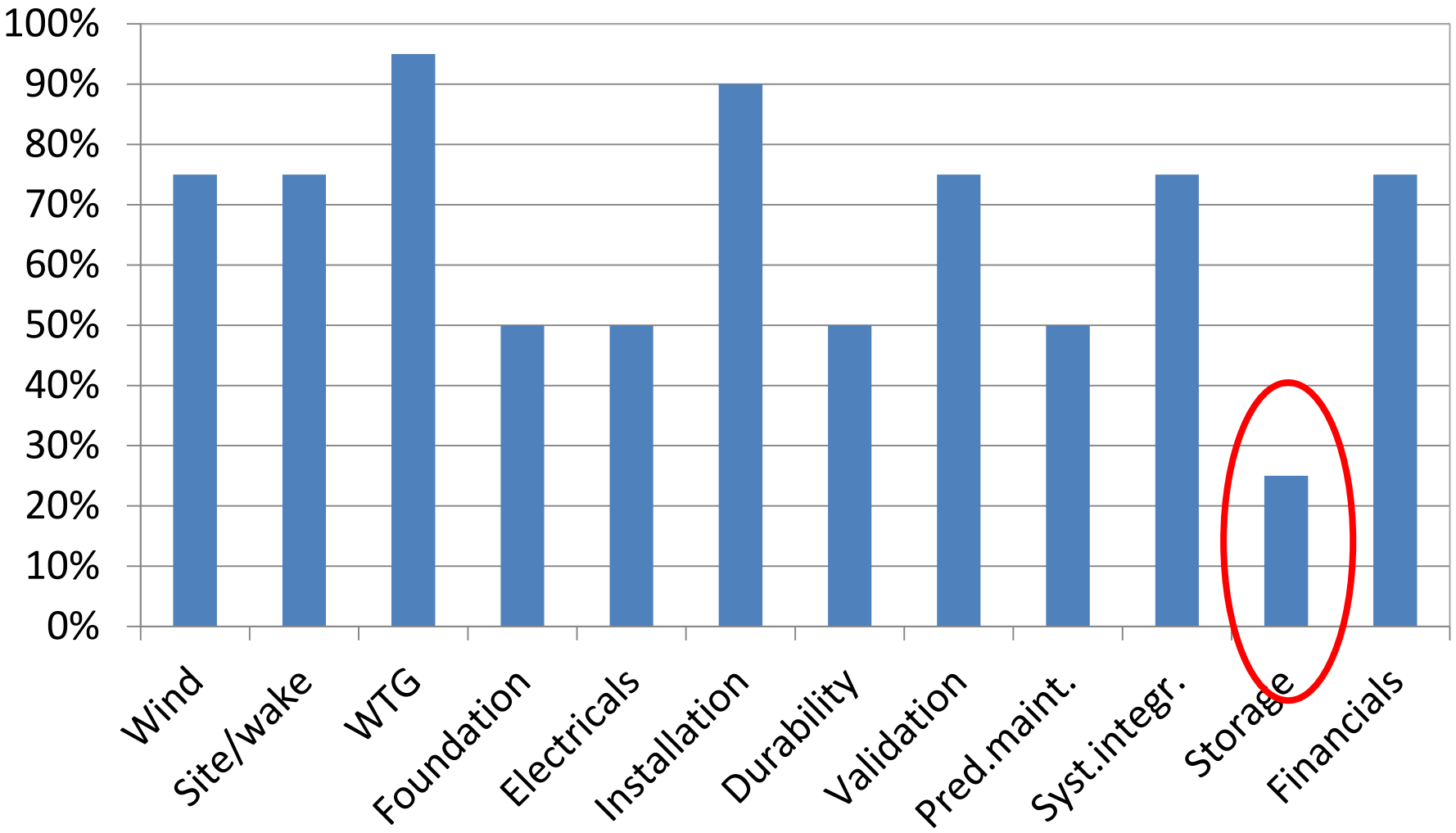
Shared characteristics of Research with Impact examples

My summary

- The Lead researcher (working individually or in a team) must have sufficient seniority / experience to be able to identify topics of genuine substance and real innovation potential.
- There must be a “pull” from key stakeholders (industry, developers, the overall research community)
- The research institution management must be sufficiently appreciative of the researcher status and/or the importance of the topic to give the work adequate priority
- Sufficient resources must be available throughout the project
- The research must be carried out in a not overly large team
- Industry participation or regular calibration / interaction with industry is often, but not always conductive to results that have maximum impact

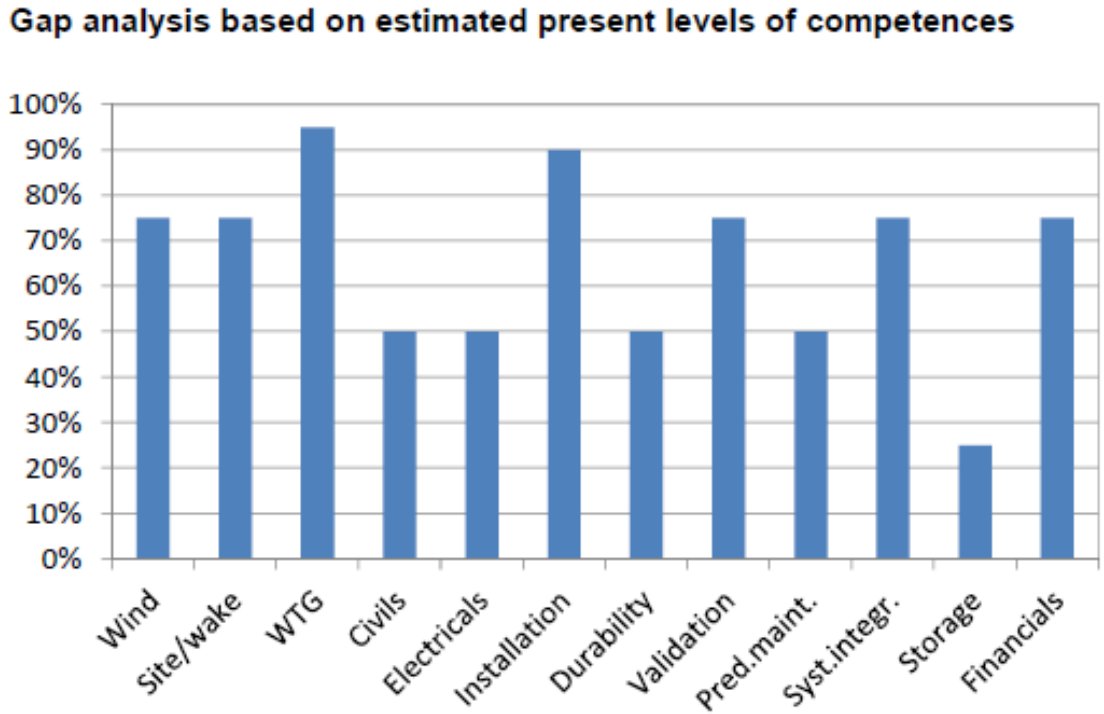
Come on – we just want to do our research!

Gap analysis based on estimated present levels of competences



Recommendations to researchers

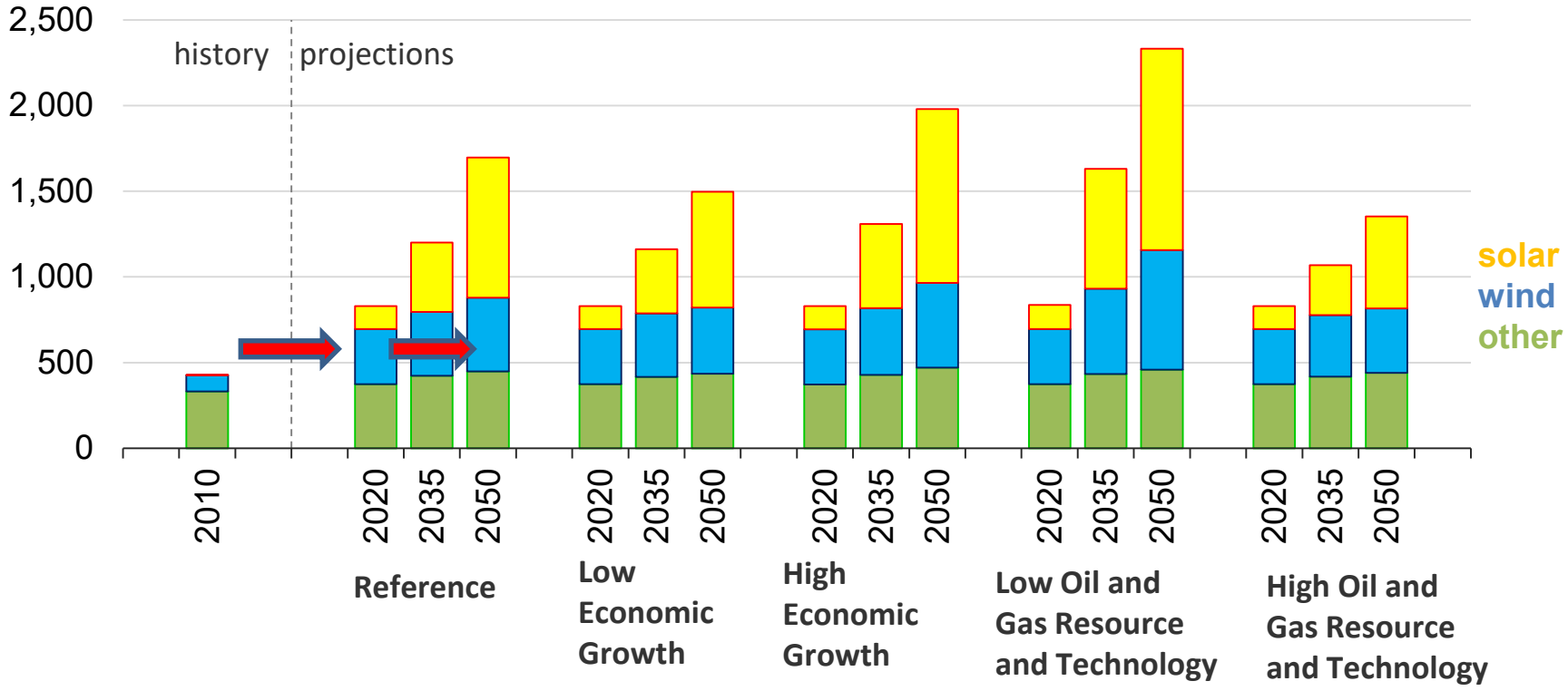
- Be extrovert. Push your research institute onto the key industrial players
- Balance the classical desire for scientific value creation against society's needs
- Take the gap analysis seriously, calibrate with industry



The ambition –

We can do better than this!

Renewables electricity generation (all sectors) by case
billion kilowatthours



Source: EIA

Where we are on wind power

Status

- We are less expensive than coal and are well on the path to be less expensive than gas on good wind sites
- We will ultimately beat gas on a cost basis even on sites with medium wind resources

What we need is research that fosters

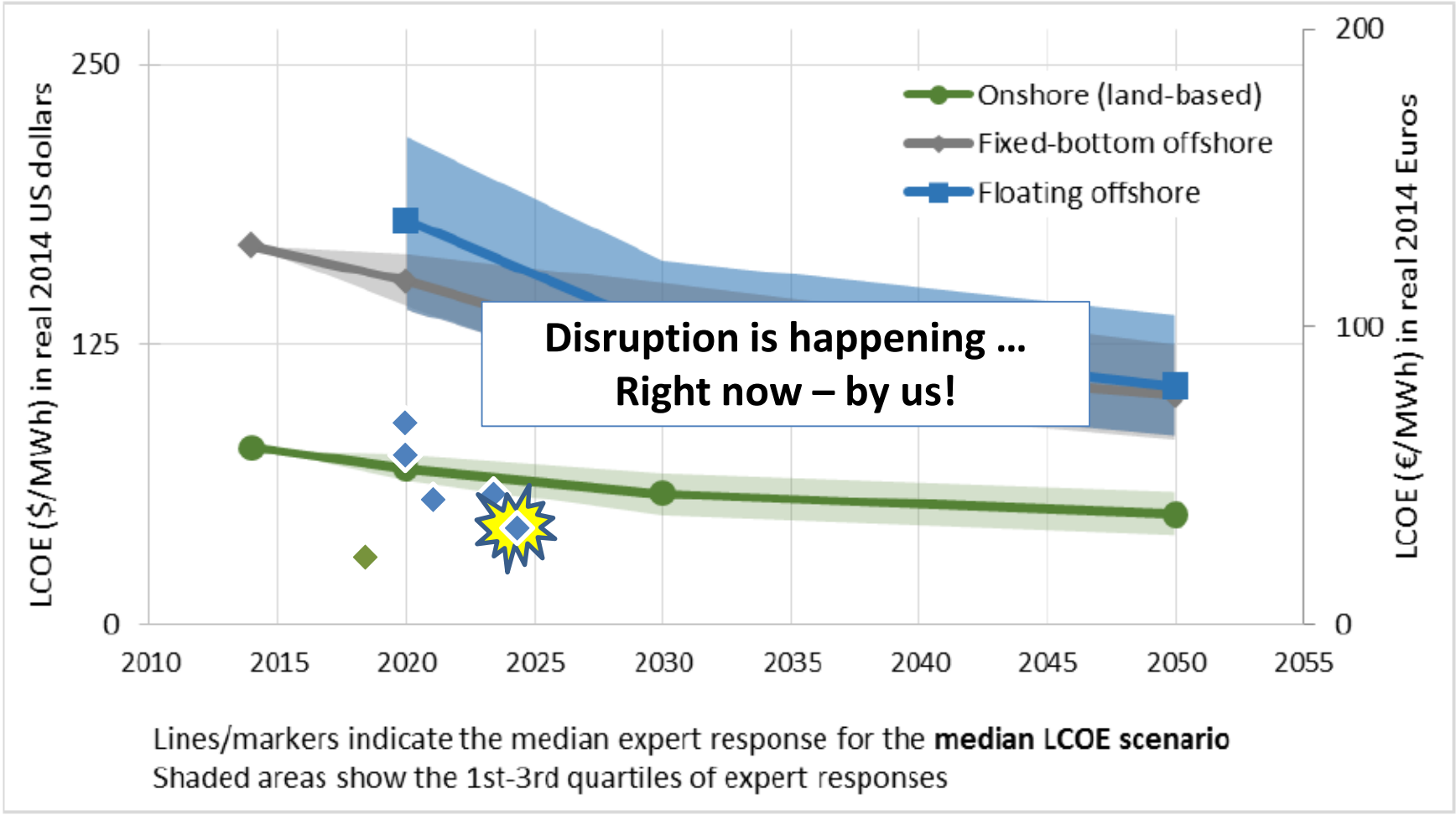
- Innovation
- Industrialization

If we succeed

- The question will change from
  - "How can we afford it"
- to
  - "How can we afford not to?"

Fortunately, this is already happening!

Disruptive 2016 cost reductions in bottom-fixed offshore wind

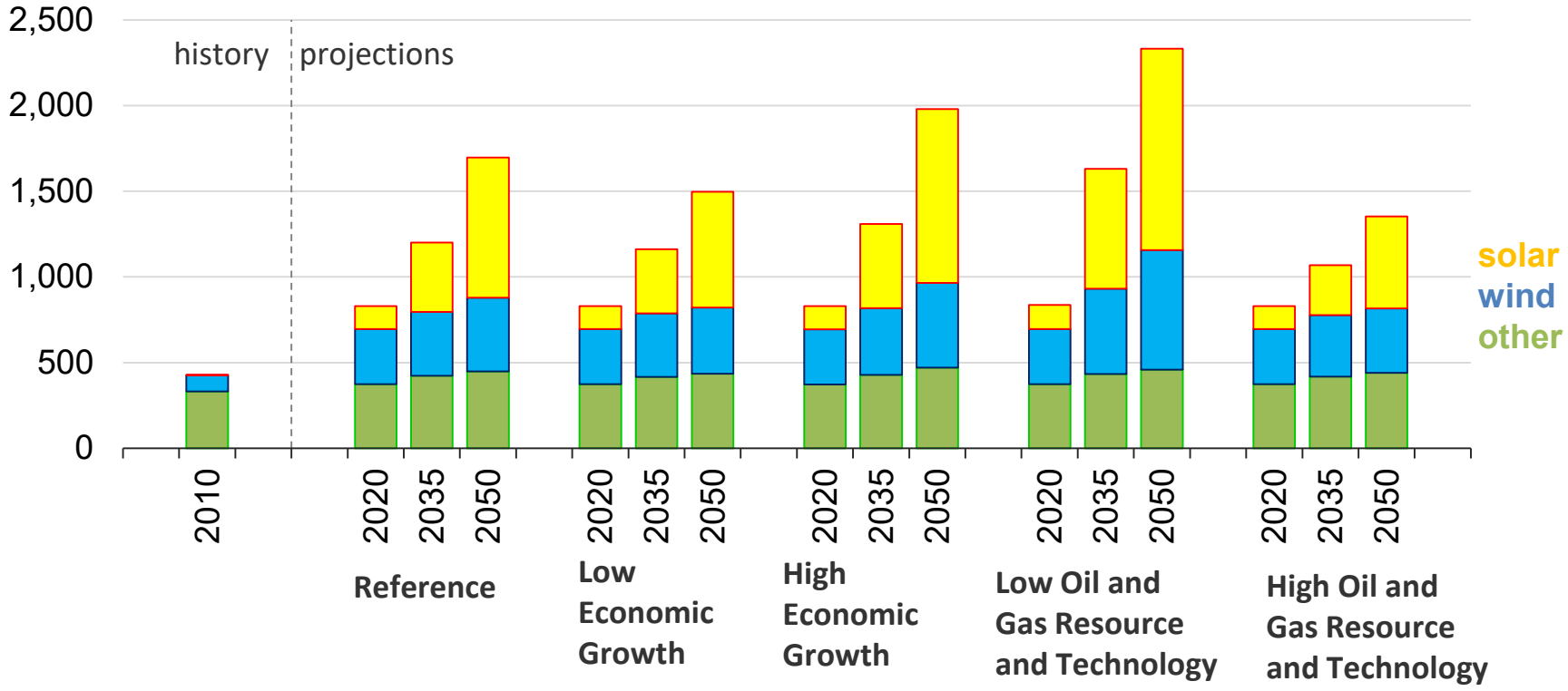


Source: Berkeley National Lab

The ambition –

We can do better than this!

Renewables electricity generation (all sectors) by case
billion kilowatthours

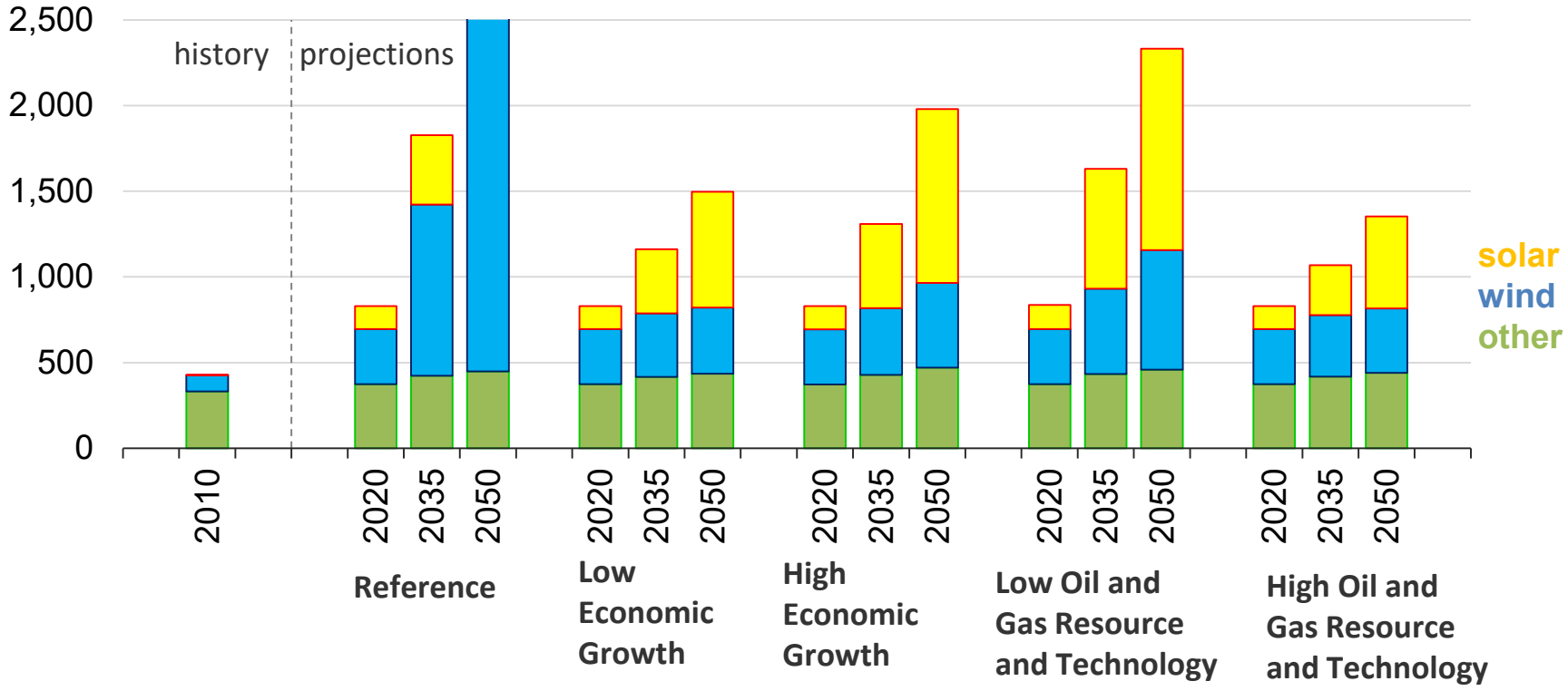


Source: EIA

The ambition –

We CAN do much better!

Renewables electricity generation (all sectors) by case
billion kilowatthours



Source: EIA

Disruption – 5th Avenue, New York City, Easter 1900

Source:New York City Library

Disruption – 5th Avenue, New York City, Easter 1913

Source:New York City Library

Your moment of Zen

Siemens 8.0-167

- A future offshore workhorse
- Annual Energy Production 30 million kWh at an offshore site, 350 turbines could supply the total electricity demand in Washington DC
- Likely to be the lowest cost source of green electricity from 2020 onwards
- Created on the basis of applied institutional and industrial research – by us!

That is kind of OK!