

Wind Energy: Retrospective, Prospective and the Role of Universities

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Over the last hundred years...

- More people
- More fossil fuel use, more CO₂
- Higher temperatures
- More need for renewable energy
 - Solar
 - **Wind**
 - Marine
 - Hydro
 - Biomass

Where Are We Now?

- Compared to 40 years ago (the beginning of modern wind energy)
 - Wind turbines are far more reliable
 - Wind turbines are larger
 - Cost to produce electricity from wind is much lower
 - Wind supplies ~3% of world's electricity
 - Climate change recognized as major concern
 - There is still a long way to go!

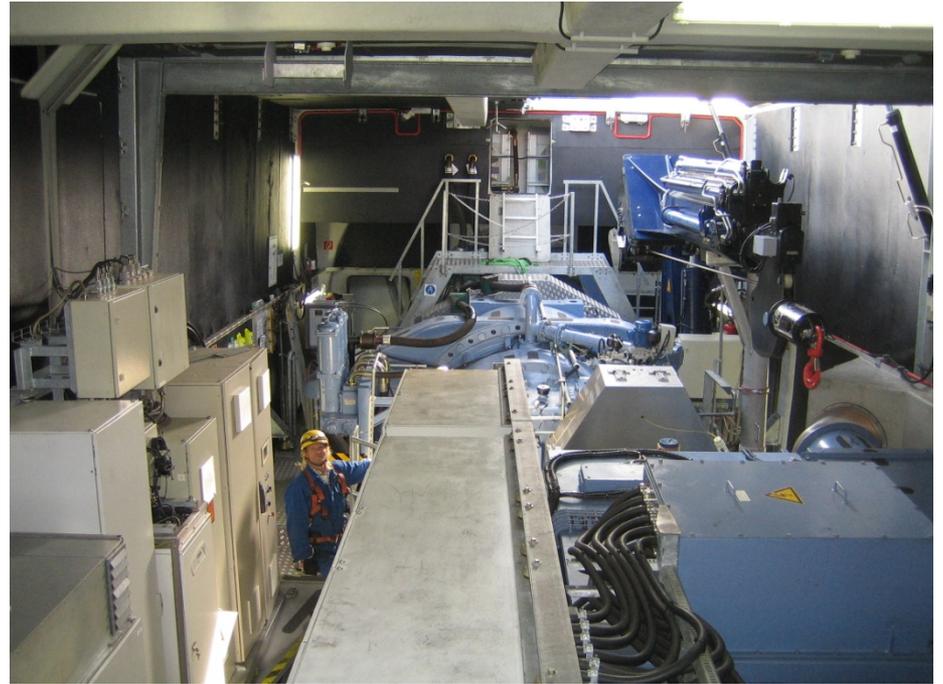
Evolution of Modern Wind Turbines

- US, Denmark, Germany
- Initially characterized by range of concepts, small size, low availability, high cost of energy
- Now: highly engineered and improved devices

First wind farm: US Windpower 50 kW turbines, New Hampshire, 1980



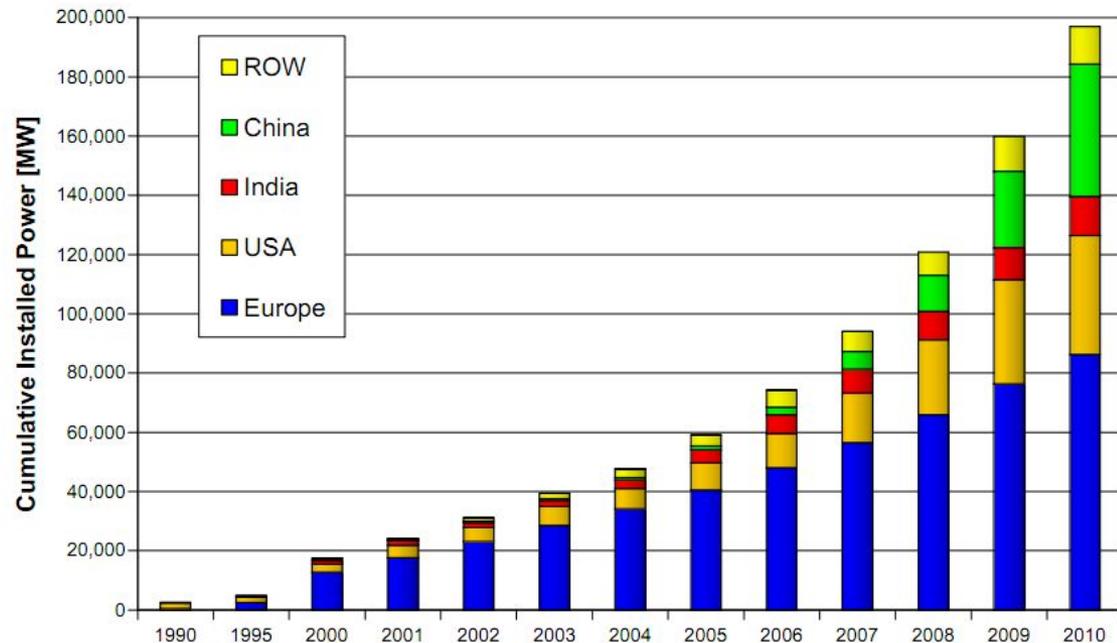
Contemporary Large Turbine



REpower 5M, model for NREL 5MW

Growth in Wind Energy Capacity

- World capacity as of 2014: 270,000 MW
- Rapid growth since 1990



How Did This Happen?

- Experience
- Data
- Analysis
- Modeling
- Design standards

Universities played a major role →

- **Vision**
- **Direct research**
- **Educating the participants**

Challenges for the Future

- Wind could produce much more of the world's electricity
- But:
 - We will need many more turbines
 - Lower cost
 - More reliable
 - Easier to service
 - We must integrate them with the energy supply
 - Public acceptance
 - Electrical load management
 - Energy storage
 - Fuel production

**More vision and research
and more educated
people will be needed!**

DOE's A2E Research Framework

- Change the research paradigm from individual wind turbines to entire wind plant cost and performance optimization
- Engage the national labs, **universities**, and industry in a collaborative consortia...

Resource Characterization

- Forecasting
- Complex terrain (hills and mountains)
- Weather fronts and turbulence
- Long term measurements
- Wind + waves (for offshore)

Excellent topics for universities, research institutes and industrial collaborations!

Wind Plant Technology

- Wind plant and array aerodynamics
- Fluid structure interaction
- Advanced controls
- Component R&D
- Wind plant reliability
- Design & systems engineering tools

Excellent topics for universities, research institutes and industrial collaborations!

Wind Integration

- Issues are related to the desired penetration level (average wind power/average load)
- At low levels (<20%), issues are minimal
- At moderate levels (<40%), coordinated dispatch of other generators is usually sufficient
- At high levels (>50%), more sophisticated load management, energy storage, fuel production may be useful

Excellent topics for universities, research institutes and industrial collaborations!

Some Examples

Flow in Wind Farms is Complex!



Two-Bladed Rotors Again?



Challenge of Fabricating Large Blades



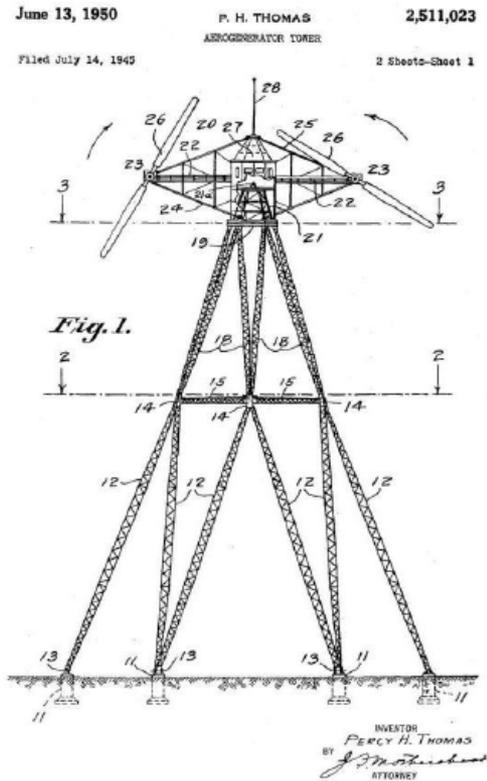
<http://www.technologyreview.com/sites/default/files/images/blade.innovationsx519.jpg>

Floating Offshore Turbines

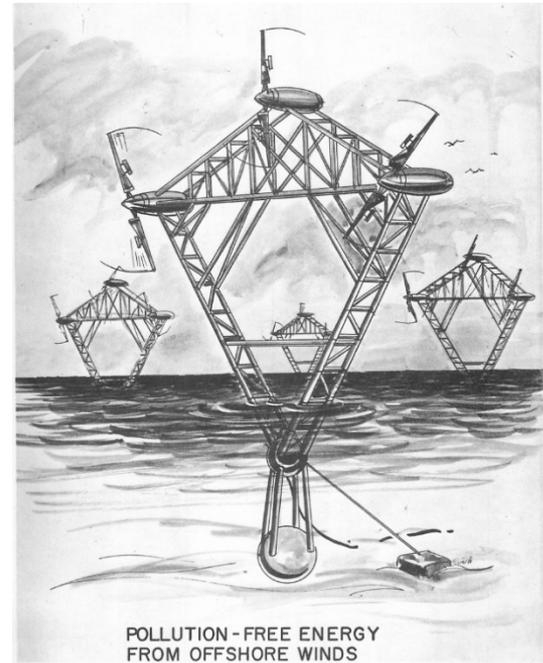


Multiple Rotors?

- A new life for an old idea?



Thomas, 1940



Heronemus, 1972

Hybrid Power Systems

- Models for the future?

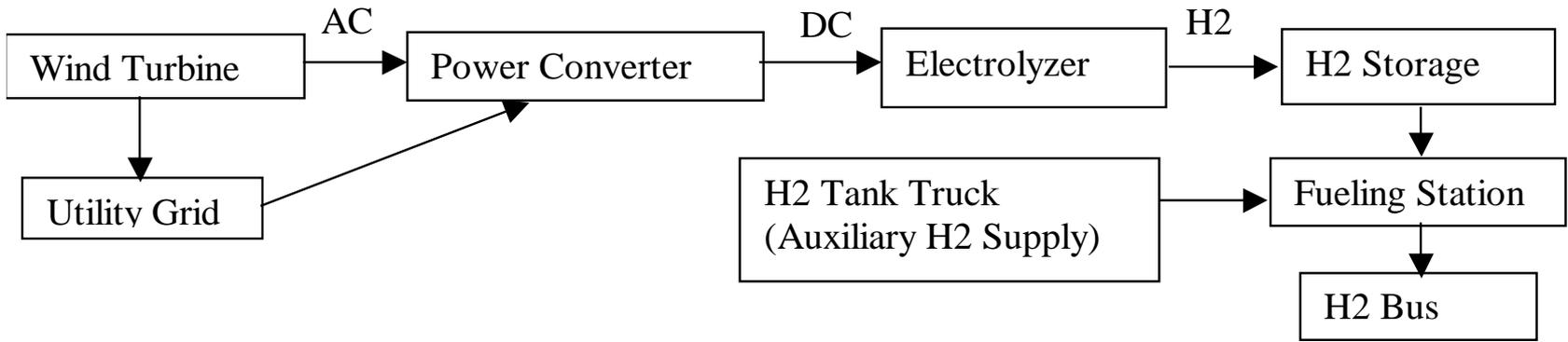


Diesel plant and wind turbines in Alaska

Wind + Water

- Using wind avoids use of water for cooling thermal power plants
- Wind can supply energy for sea water desalination by reverse osmosis
- Variability of wind provides an interesting opportunity and impetus for innovation
- Storage of water simpler and cheaper than storing electricity

Envision the Future: Wind for Fuel



Precedent: H₂ powered buses in Iceland; "Prof. Hydrogen" at Univ. Reykjavik

Deniers and Skeptics

- Climate change deniers and wind power skeptics often have a vested industry in delaying the transition
- Cogent rebuttals often required

Conclusion

- Great progress in wind technology so far
- Wind at very high penetration is possible and desirable but also challenging
- Many opportunities for innovation
- Concerted, multidisciplinary action will be needed
- Need for scientists, engineers and educated people of all types!