Global Prospects for Wind Energy

Addressing The Challenges of an Intermittent Energy Source

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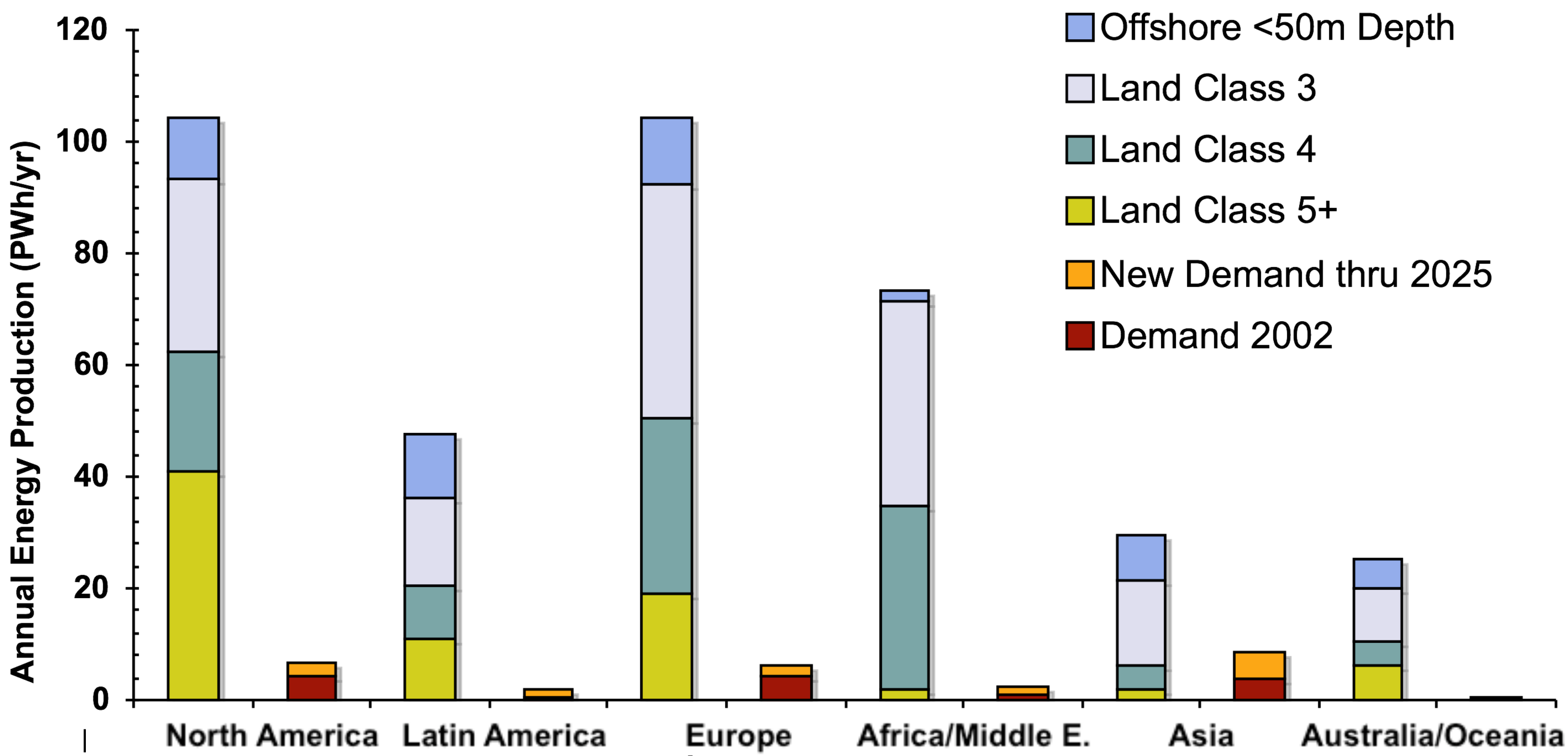
Outline

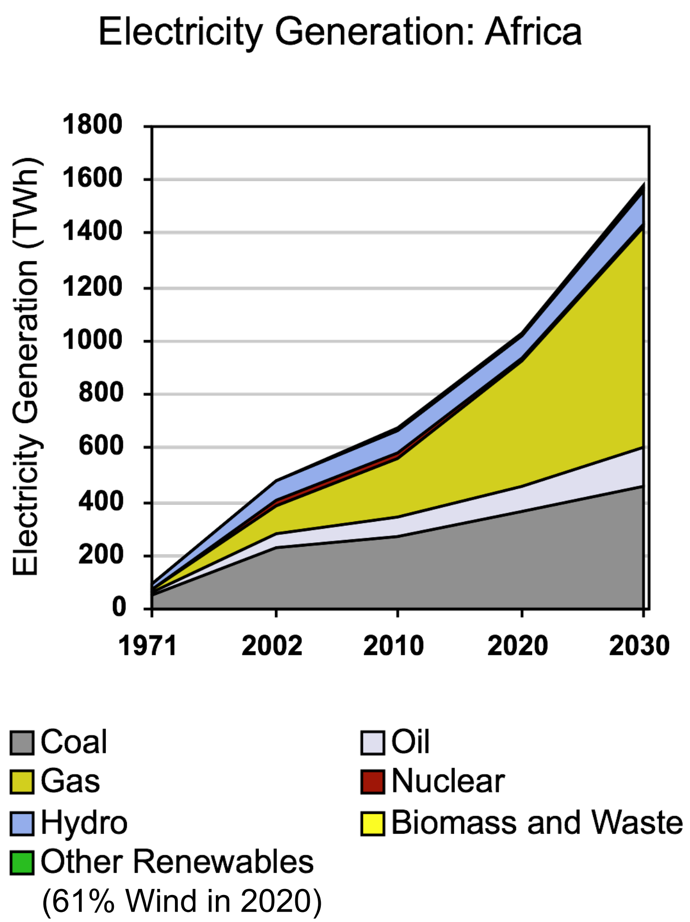
- Wind Energy Resources
  - Size of the Global Resource
  - Projected Growth of Wind in Global Energy
  - Remoteness
  - Intermittency
- Large-Scale Wind with Energy Storage
  - Wind with Energy Storage
  - Competition with Coal
- The Picture of Wind In Africa
  - Current Progress and Resource Estimates
  - Exploitation of Low Wind Classes
  - Small Turbine Technology

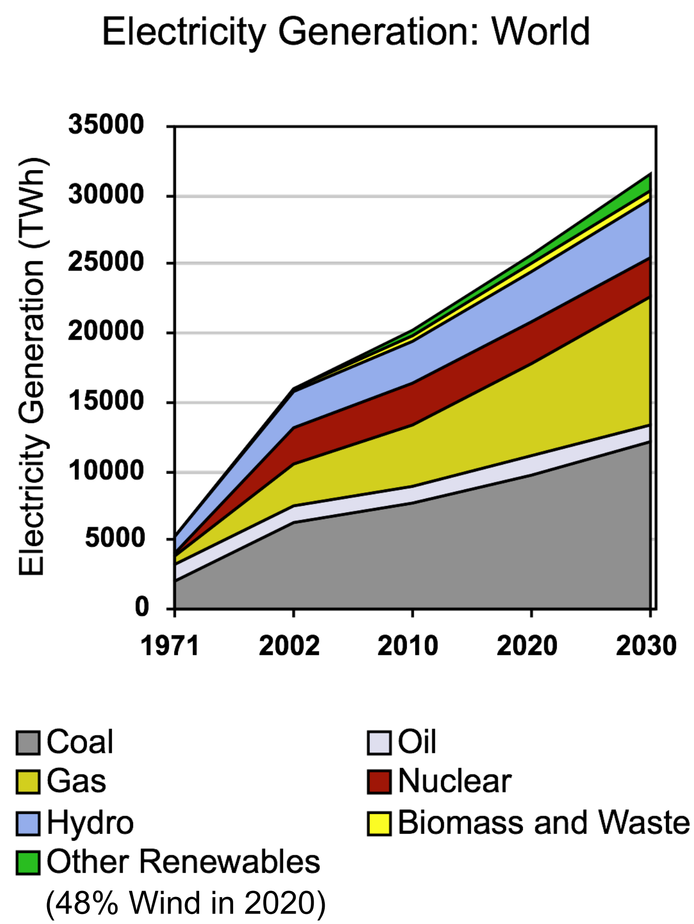
Global Wind Resource vs. Total Electricity Demand



50% Exclusion Basis

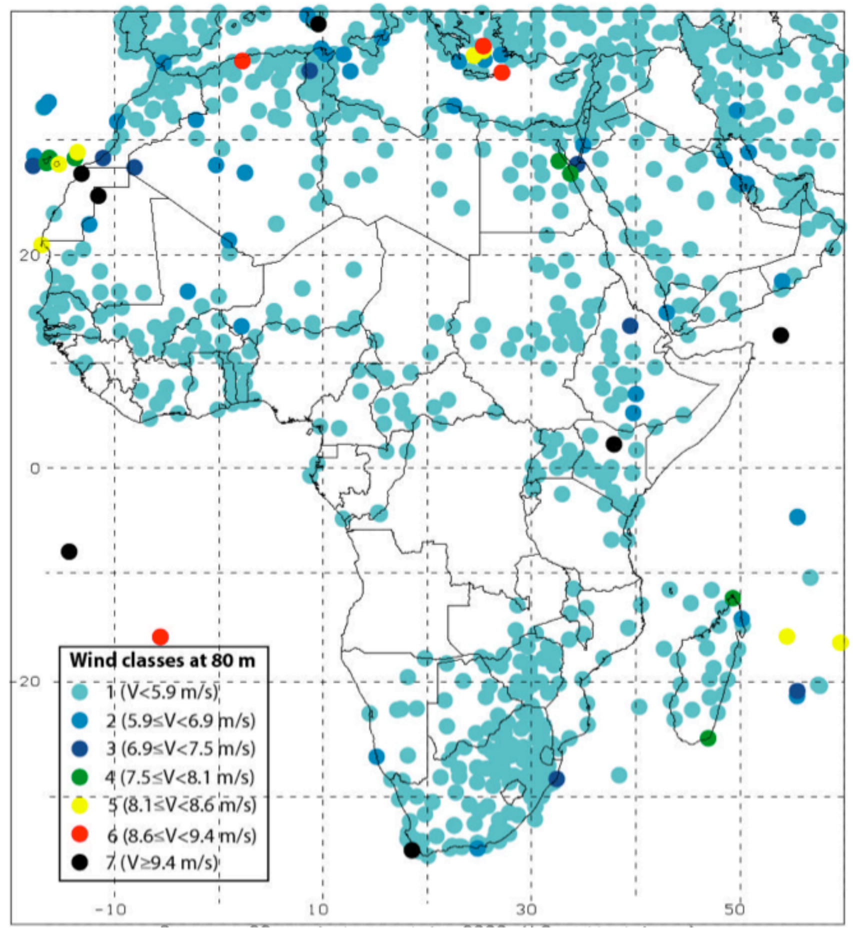
Current Forecasts For Electricity Generation Mix



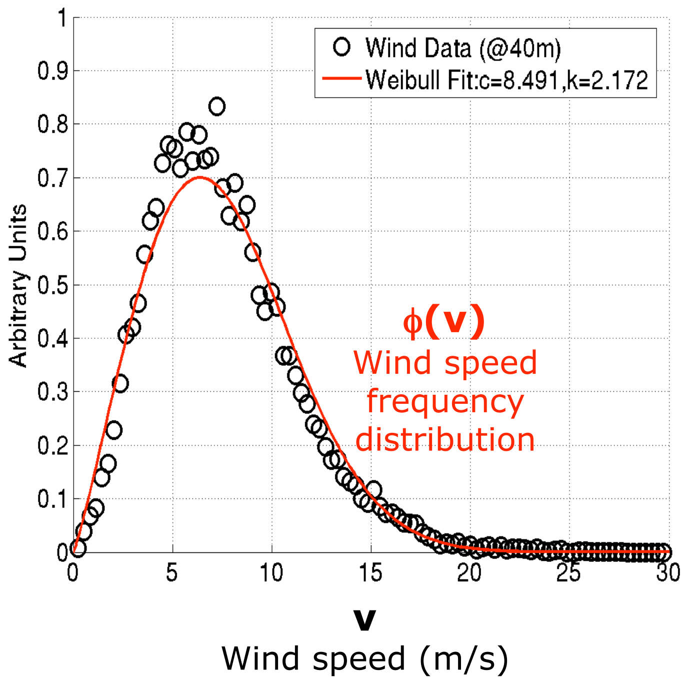


Resource Remoteness

- Location of best resources may not be proximal to demand centers
- Additional transmission infrastructure may be required to bring wind energy to market
- Expensive long distance transmission lines represent a large fixed capital investment
- Optimal utilization is necessary to justify cost



Resource Intermittency



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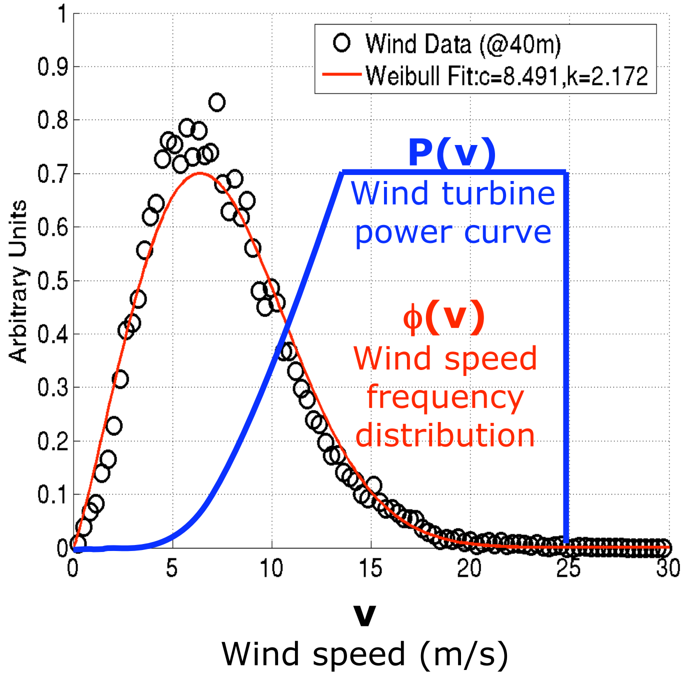
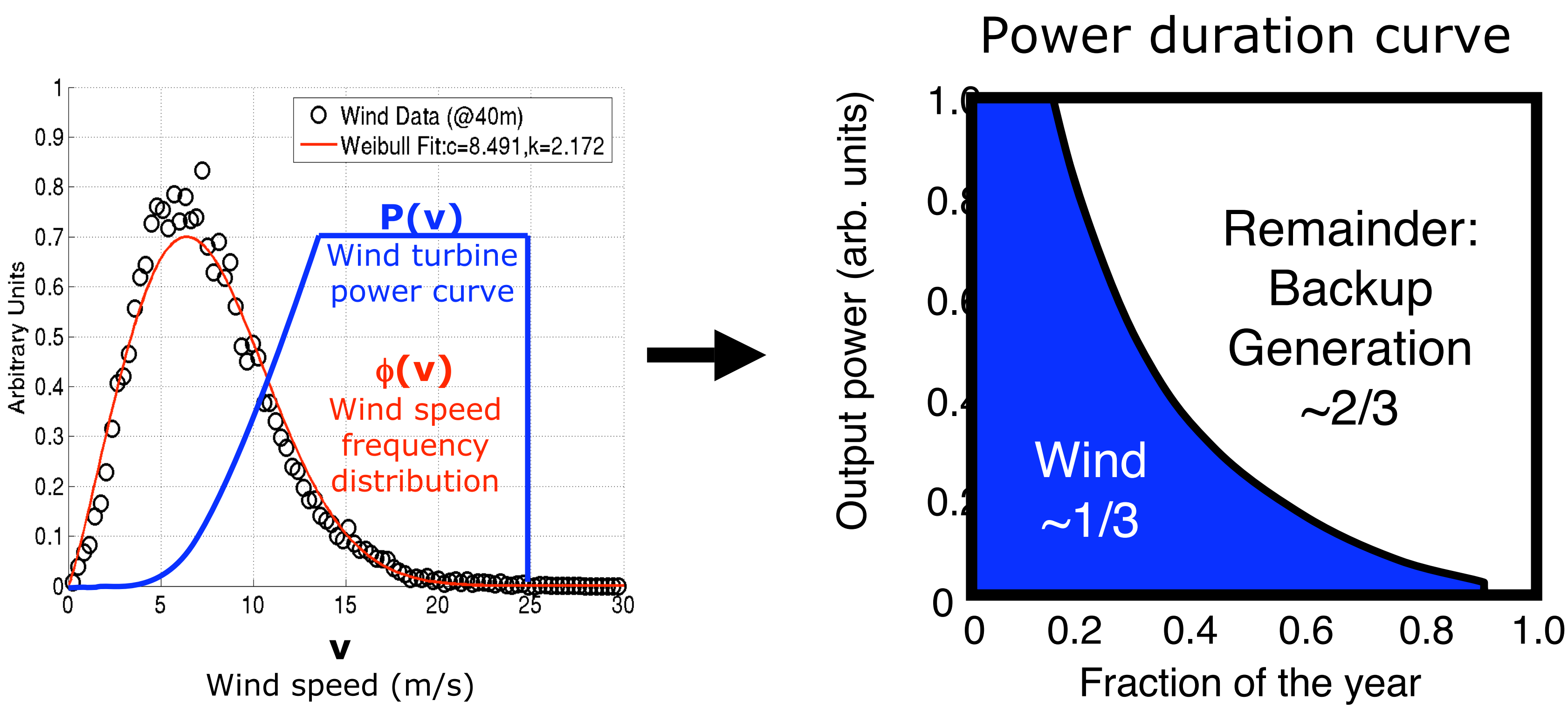


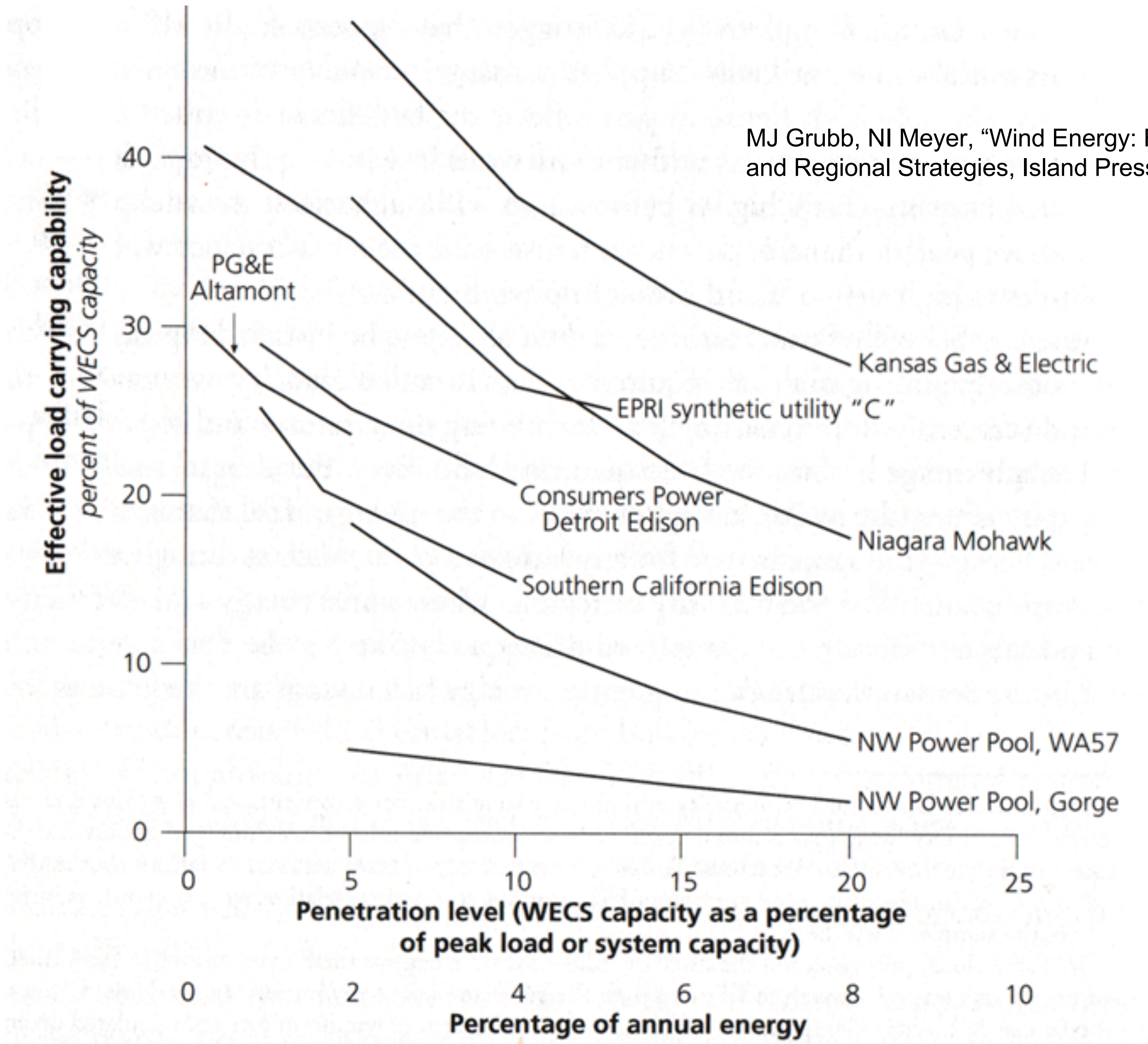
Resource Intermittency



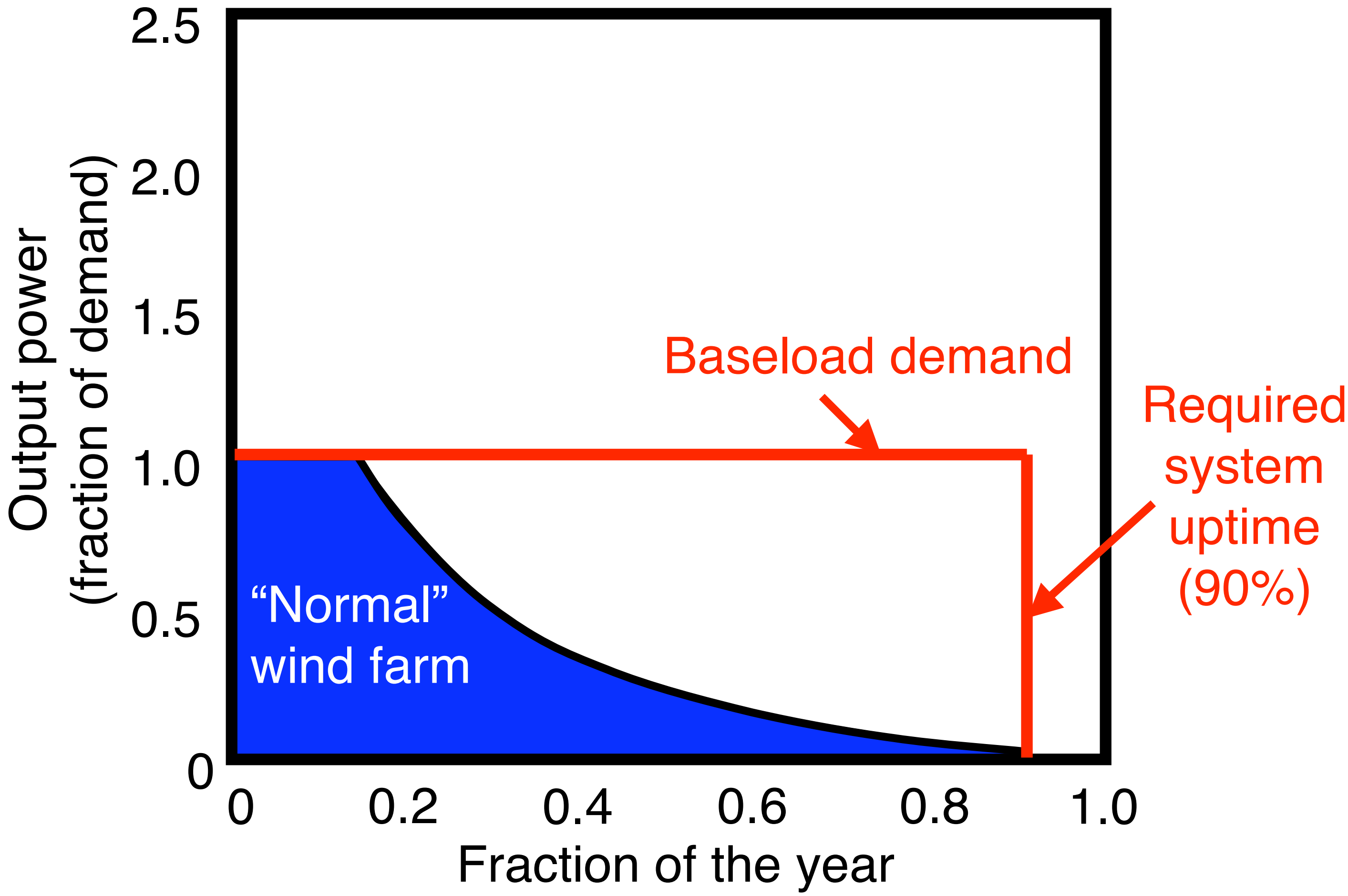
- Rated Power Delivered 20% of the Year
- Typical Capacity Factor ~ 30%

Declining Capacity Credit

MJ Grubb, NI Meyer, "Wind Energy: Resources, Systems, and Regional Strategies, Island Press, 1993



Making wind dispatchable with storage: Think "baseload"



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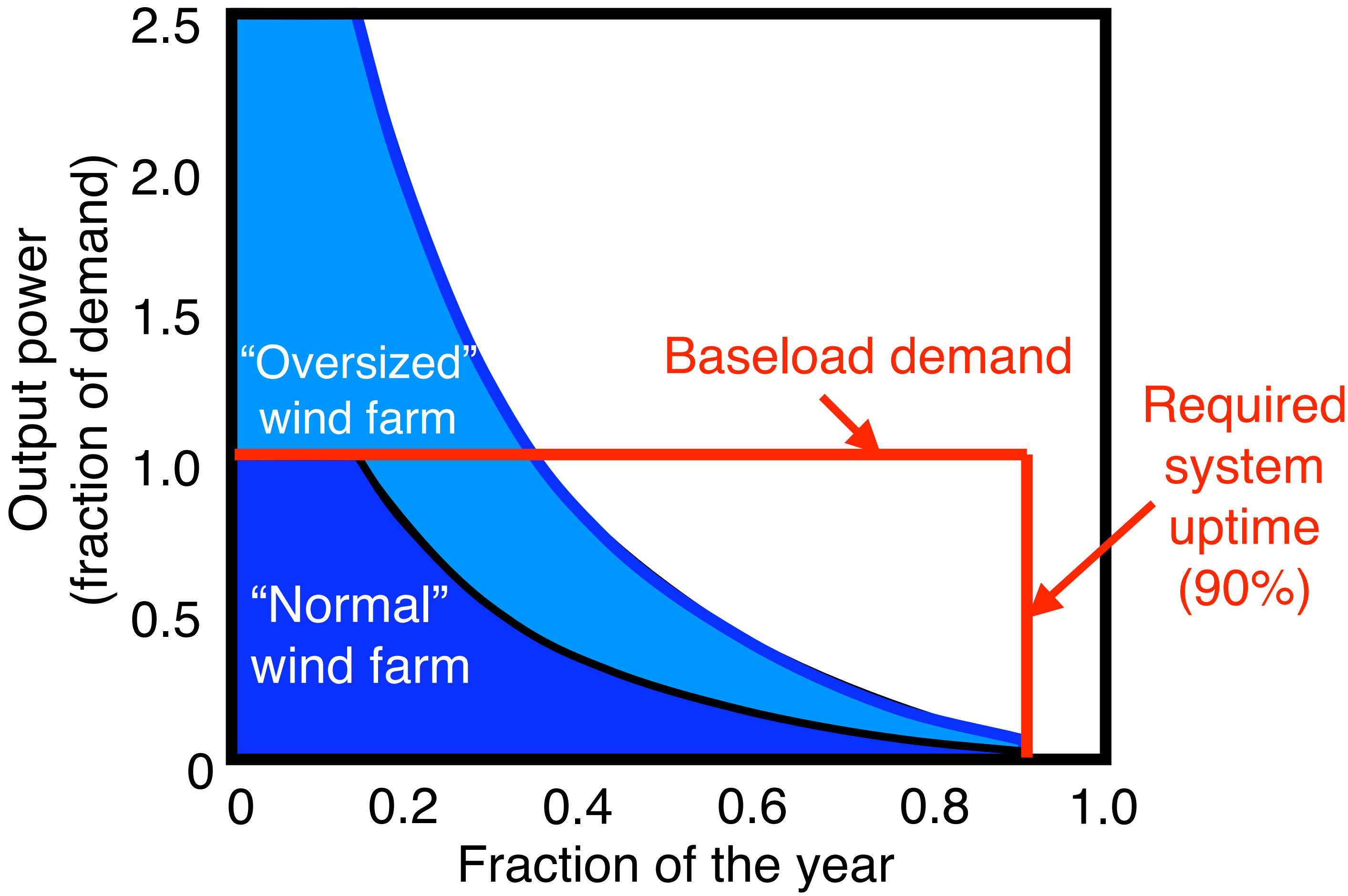

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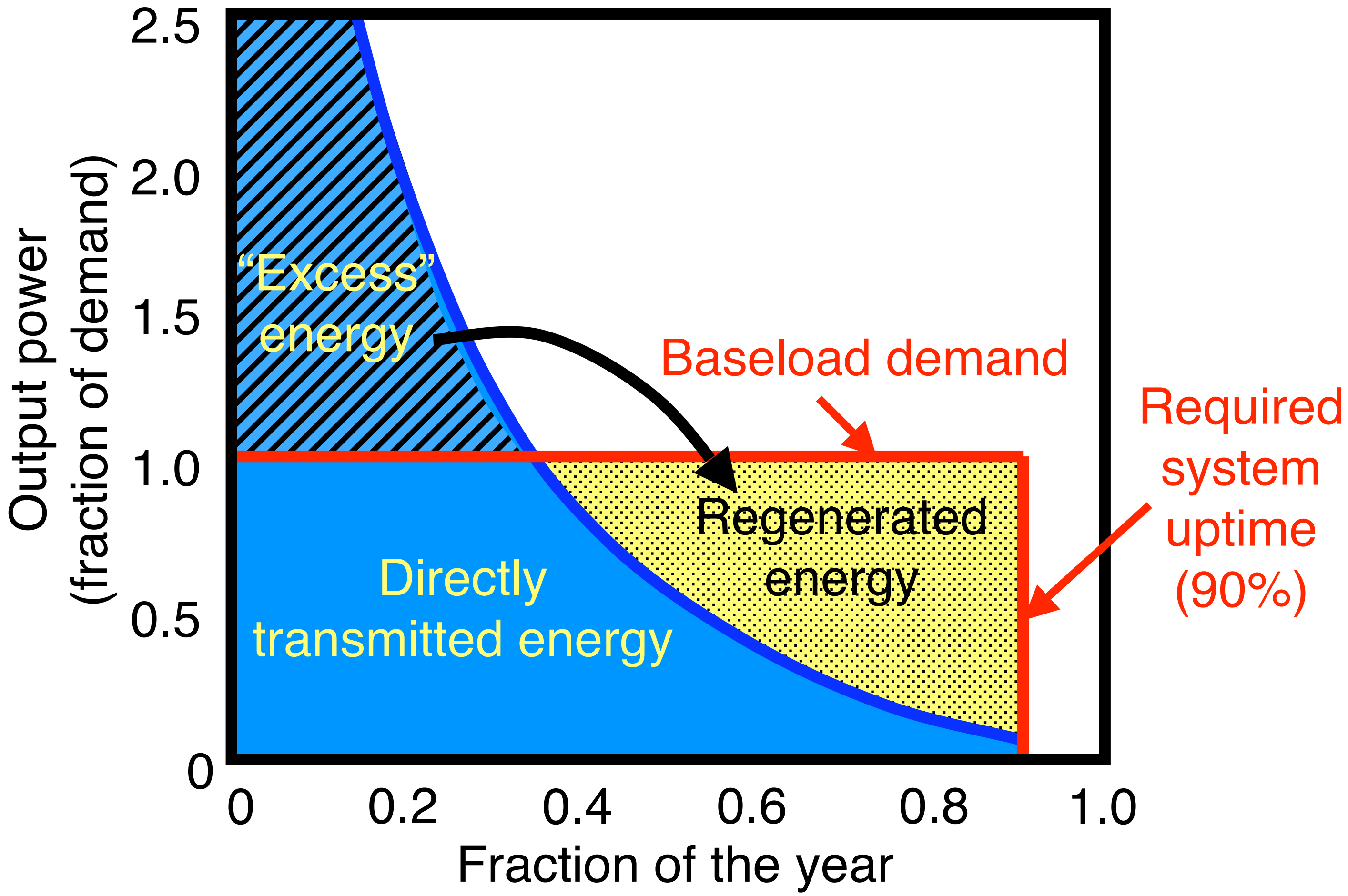


Energy Storage for Wind

- Exploit high quality remote resources with optimal utilization of dedicated transmission infrastructure
- Achieve high penetrations of wind on the grid without cost penalties associated with intermitent generation
- Install large amounts of wind energy with little or no added spinning reserves or backup thermal generation
- Allow wind energy to compete in baseload energy markets

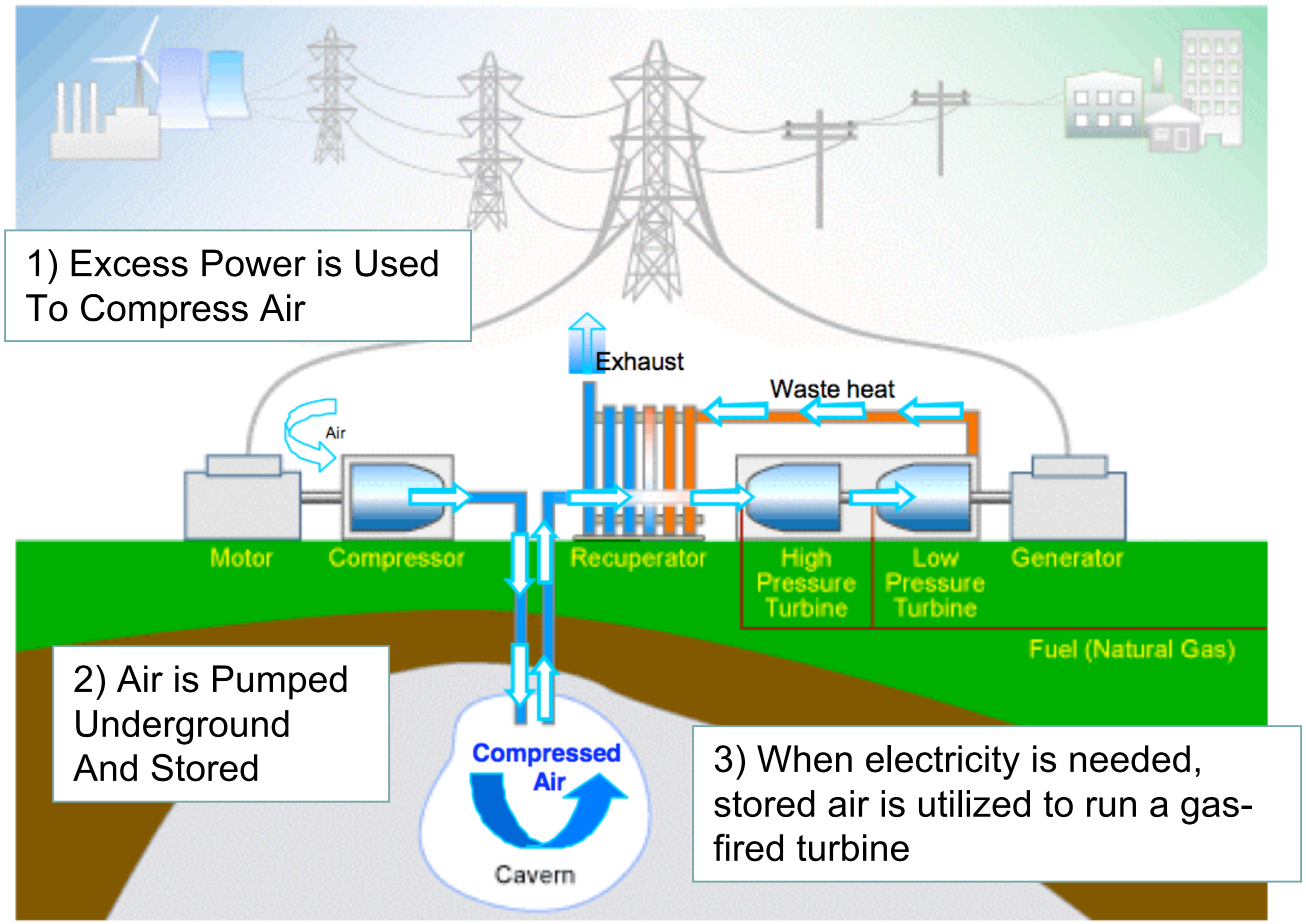
Energy storage options

Source: PCAST, 1999 and EPRI/DOE, 2003

Technology	Capacity ($/kW)	Storage ($/kWh)	**Cost of 20 hrs. storage ($/kW)**
→ **Compressed Air Energy Storage (CAES) (300 MW)**	**440**	**1**	**460**
Pumped hydroelectric	900	10	**1100**
Advanced battery (10 MW)	120	100	**2100**
Flywheel (100 MW)	150	300	**6200**
Superconductor (100 MW)	120	300	**6100**

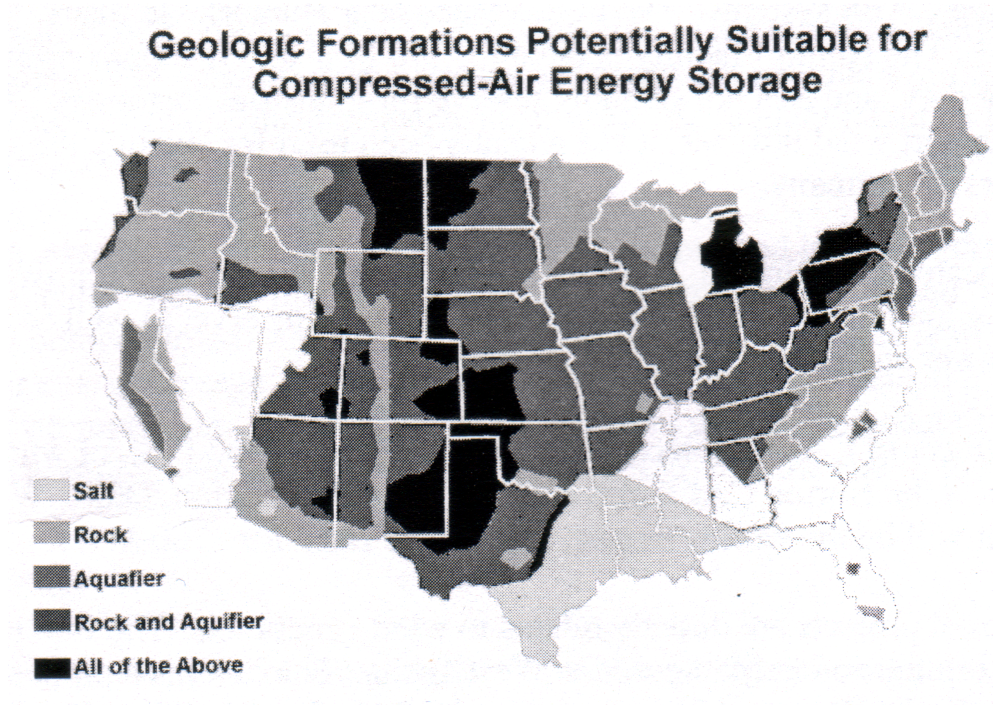
CAES is clear choice for:
Several hours (or more) of storage
Large capacity (> ~100 MW)

Compressed Air Energy Storage (CAES)



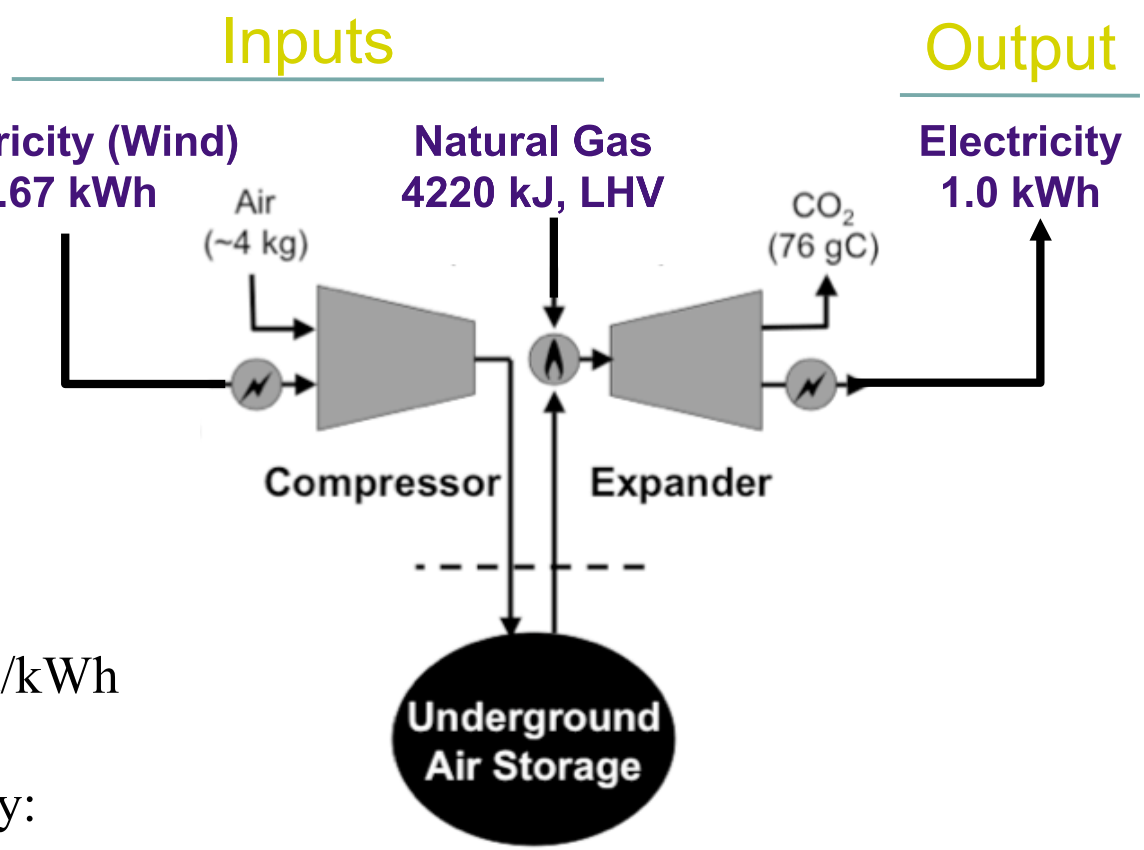
Availability of CAES

- Suitable geology for compressed air storage found over 80% of the area of the USA
- Locations coincident with high quality wind resources
- Availability of fuel source is an additional constraint for wind/CAES implementation



CAES Efficiency

Round-Trip Efficiency: ~ 82%



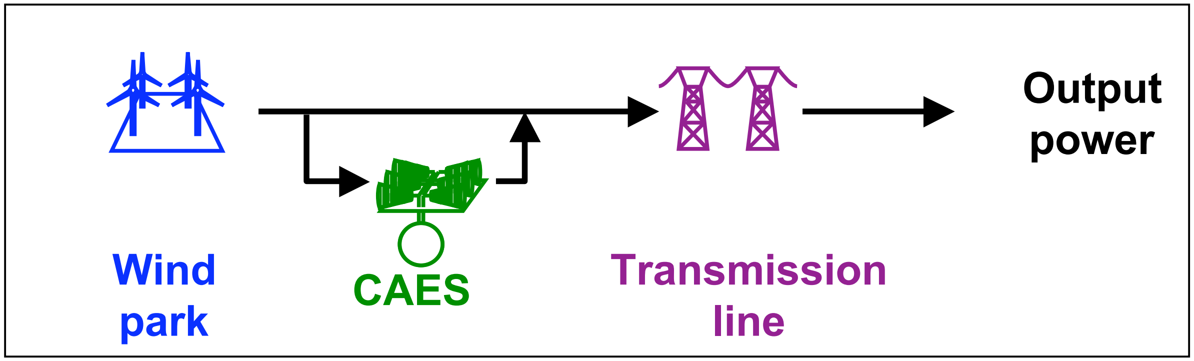
$E_o/E_i = 1.0/0.67 = 1.5$

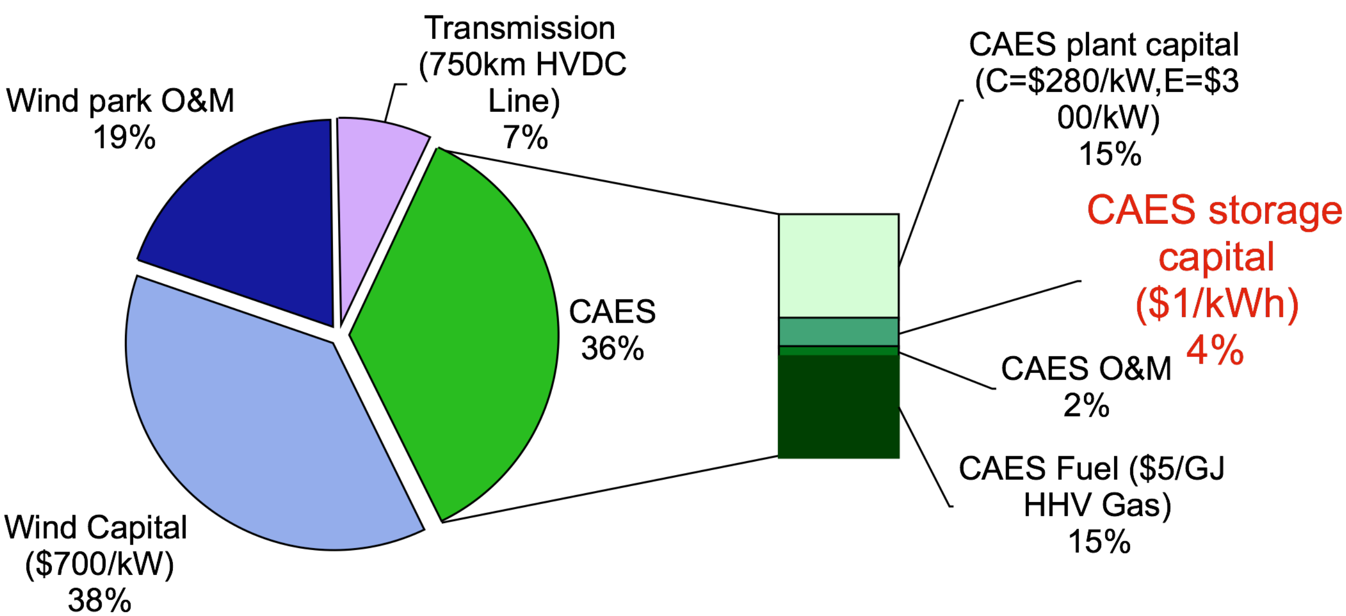
Heat Rate = 4000 Btu/kWh

Round-Trip Efficiency:

$$\frac{1.0kWh}{(4220/3600)*Eff_{NG}+0.67} = 54\%(Eff_{NG}1.00), 77\%(Eff_{NG}0.54, NGCC), 89\%(Eff_{NG}0.385, GT)$$

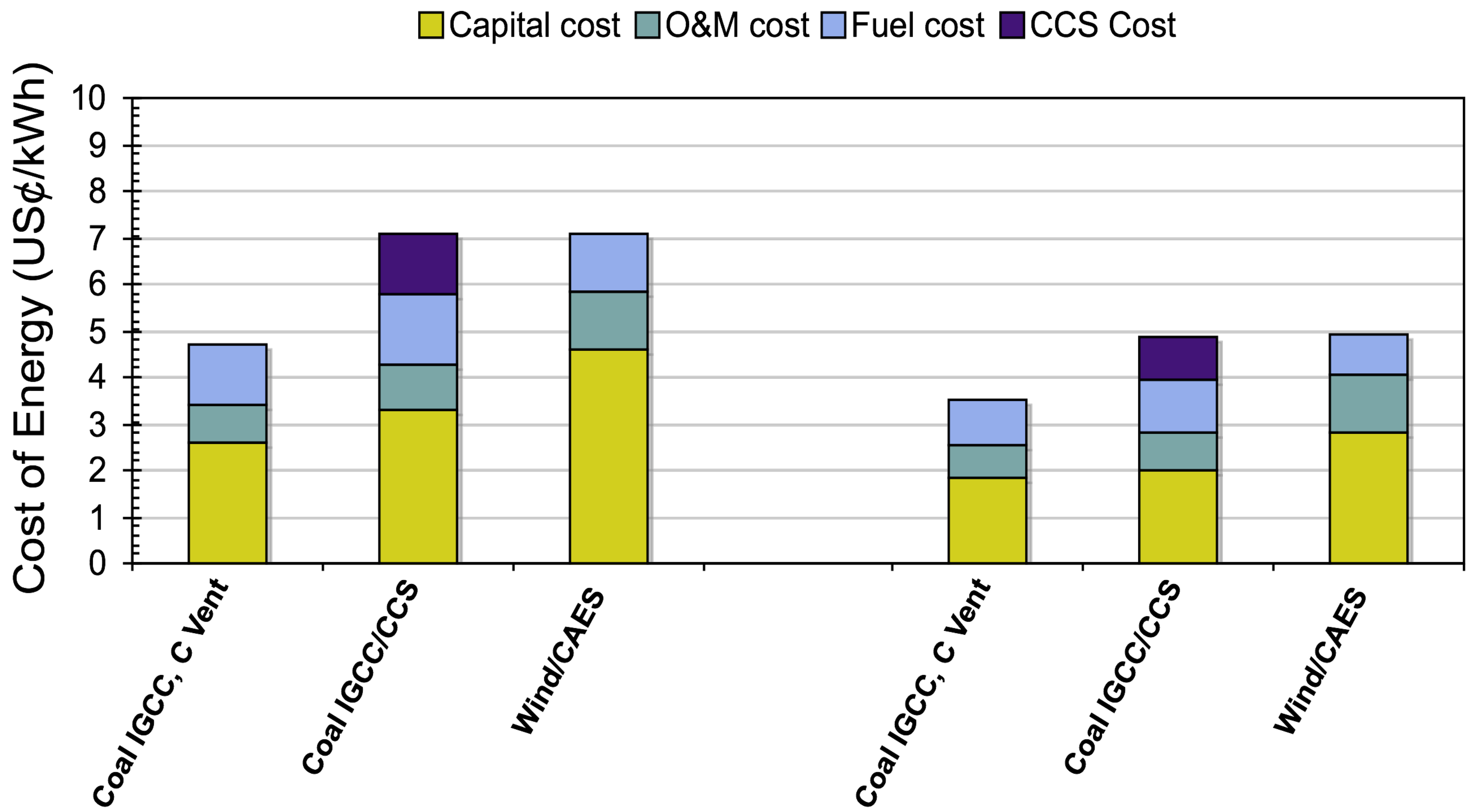
Wind with CAES: Cost of Energy Breakdown





CAES costs are dominated by turbo-machinery and fuel **not** storage capital

Economic Viability of Wind

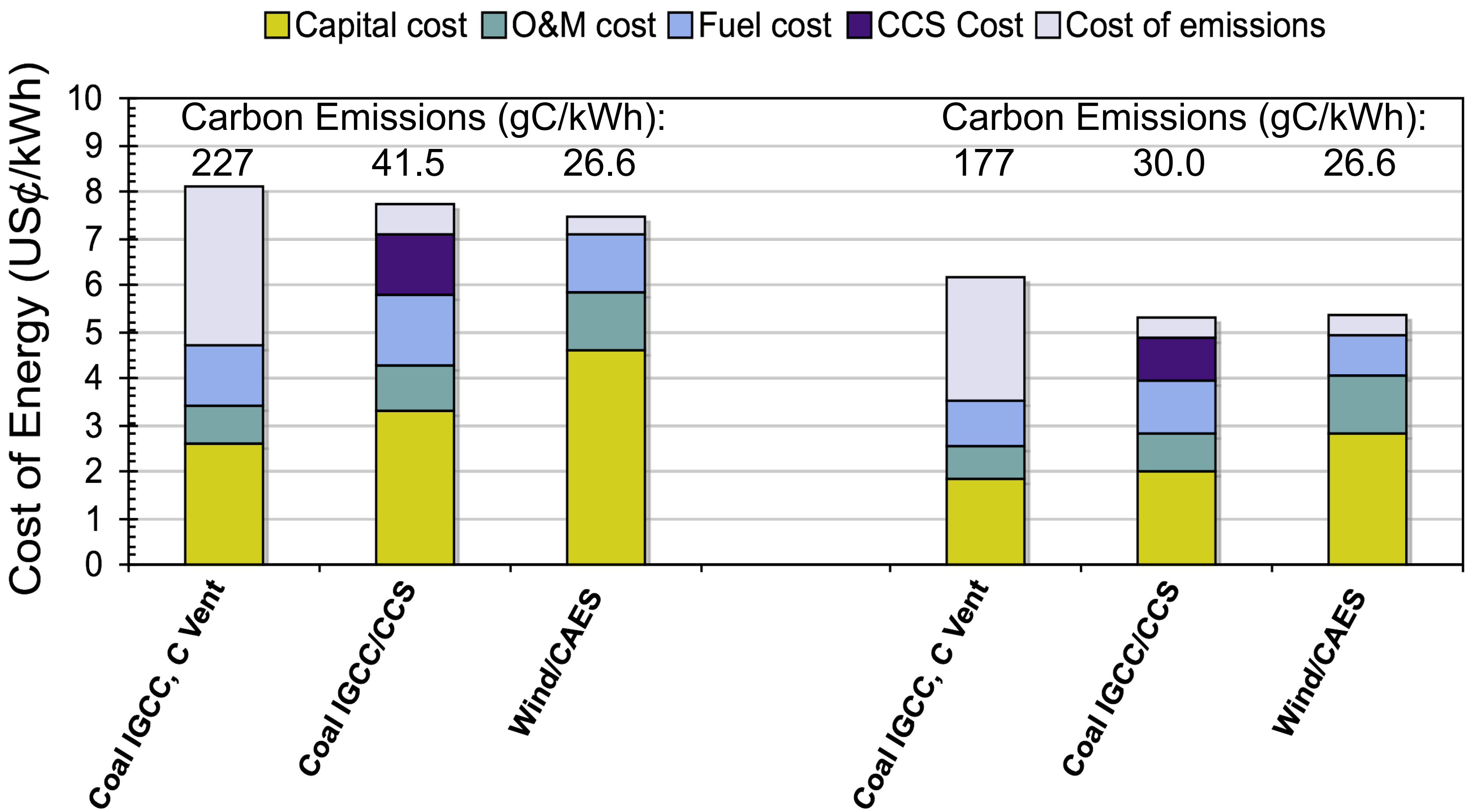


Current Technology
Wind $900/kW, Class 5, NG $7/GJ, 15% CCR

2020 Scenario
Wind $600/kW, Class 5, NG $5/GJ, 11% CCR

Economic Viability of Wind

Carbon Price:$150/tC or €34/t$CO_2$ (24 Oct 2005 Price: $94.6/tC)



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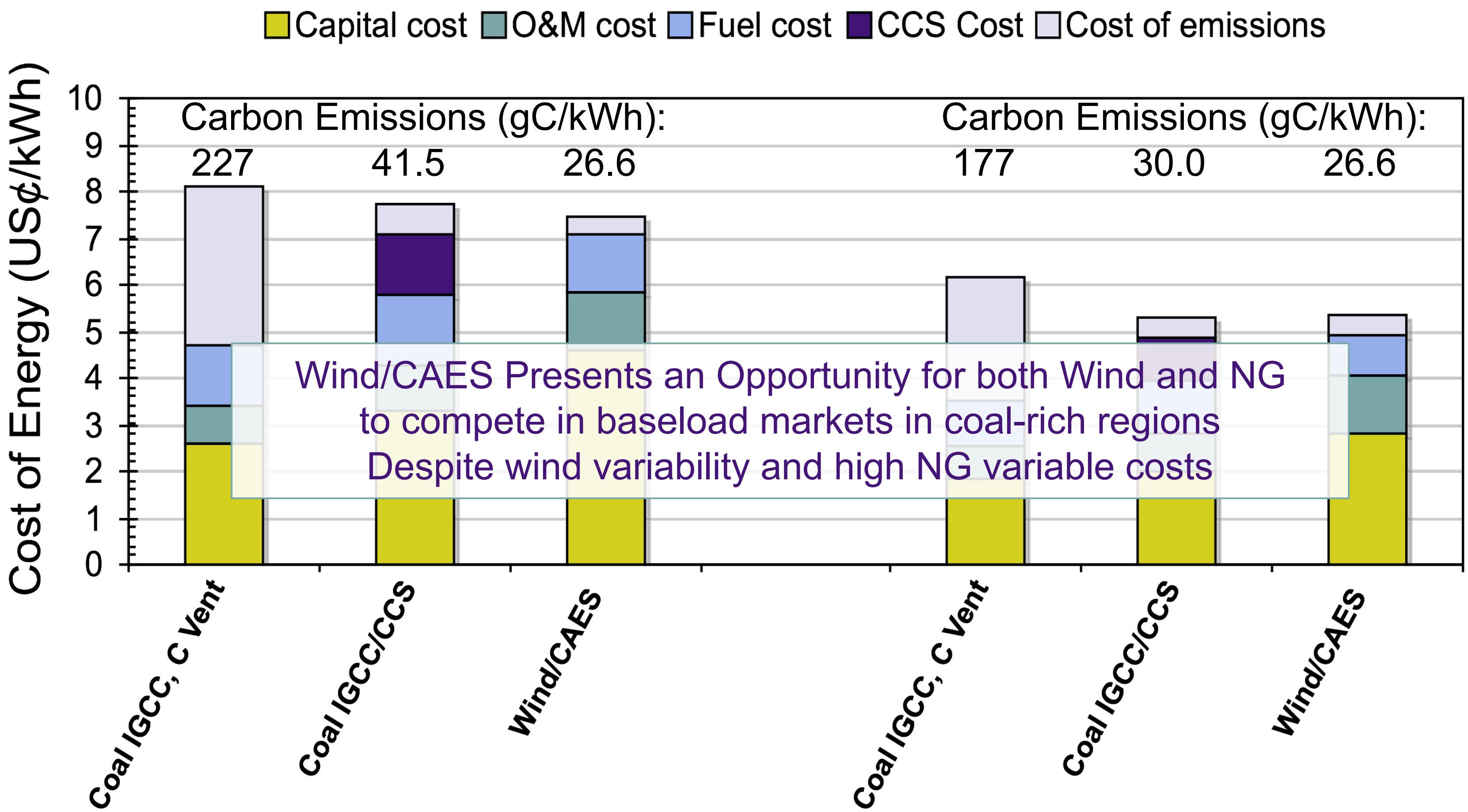

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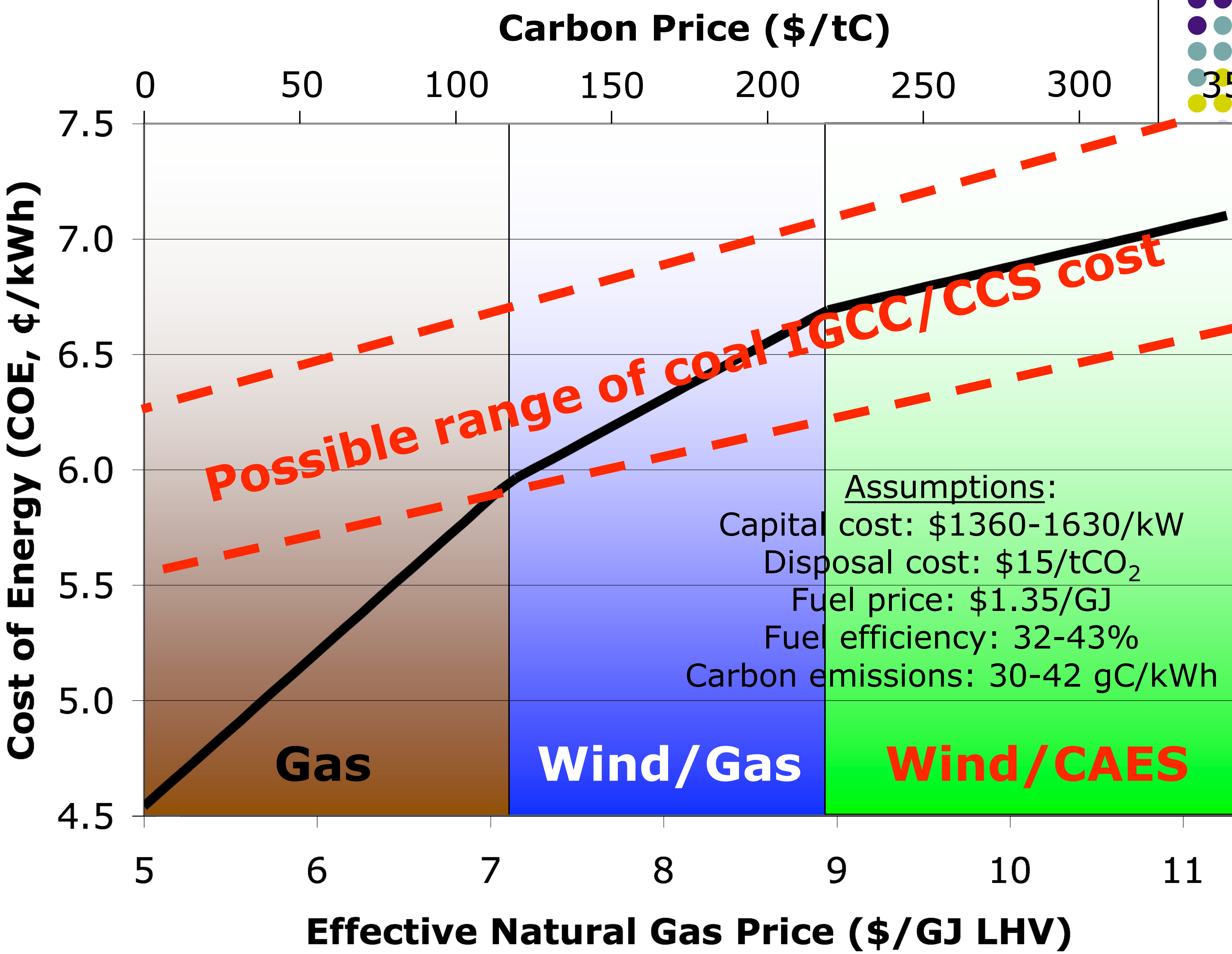
Comparison with coal IGCC/CCS



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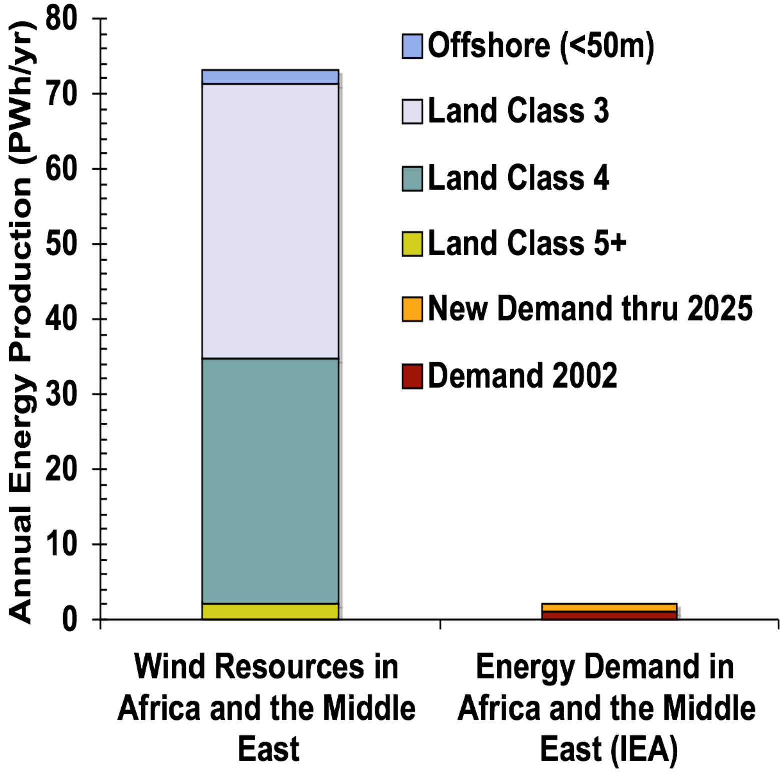
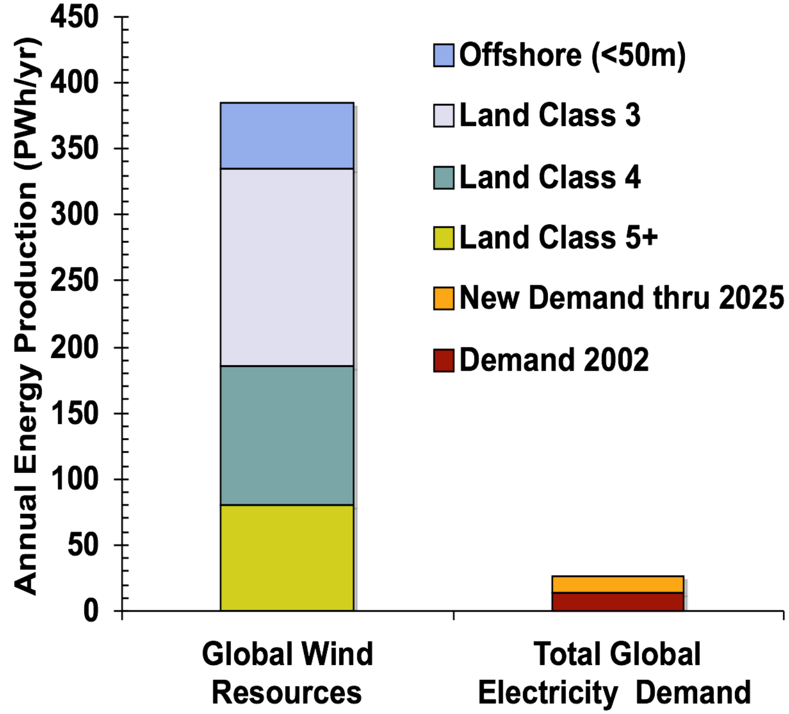
Wind Resources Revisited

Africa



World



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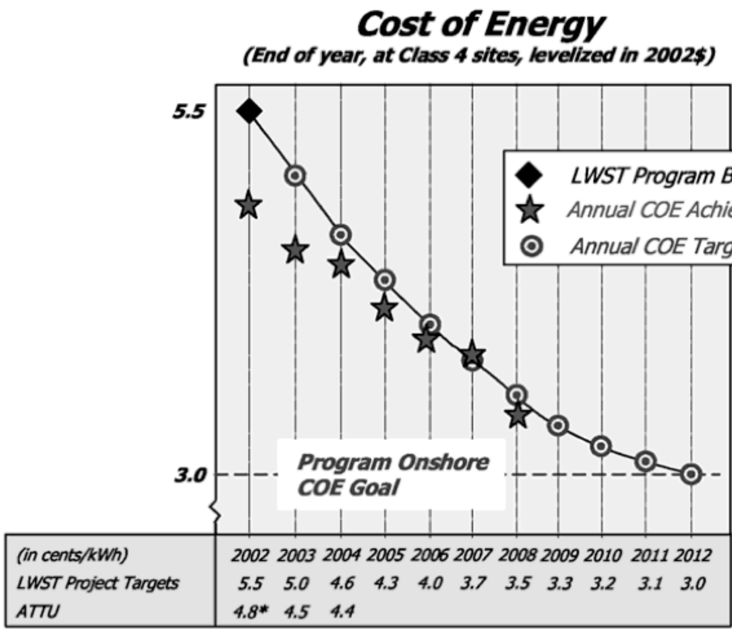
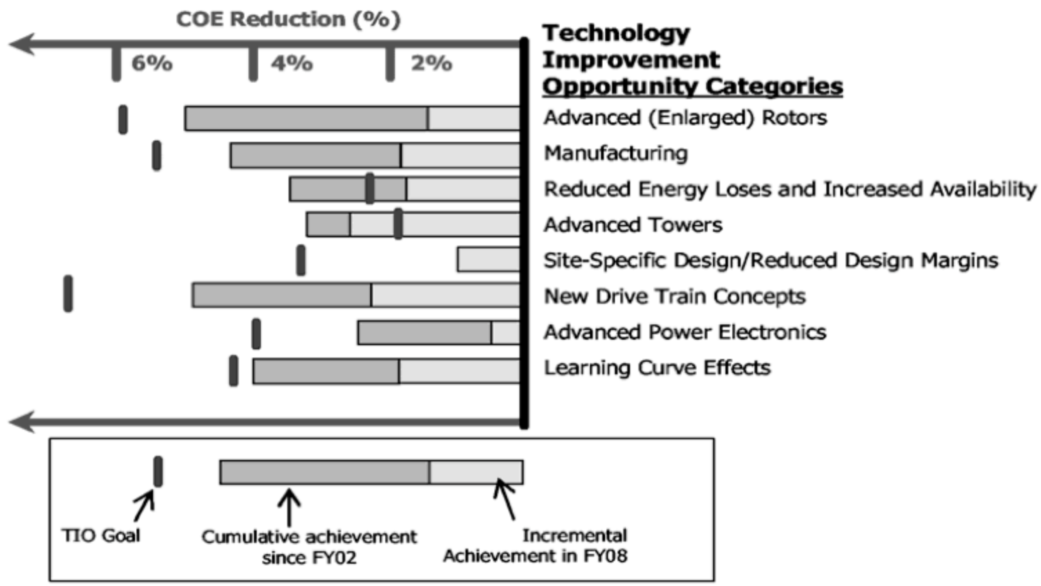
Cost Reductions for Low Wind Speed Turbines





- Hybrid Steel/Concrete Wind Turbine Towers
- Independent Pitch Control
- Advanced rotor design (hybrid carbon-glass)
- Manufacturing Improvements

Technical Report NREL/TP-500-37505 June 2005 Low Wind Speed Technologies Annual Turbine Technology Update (ATTU) Process for Land-Based, Utility-Class Technologies S. Schreck and A. Laxson

Resource Assessment - Africa

- Large scale wind energy resource assessments typically underestimate the actual resource
  - Source of data is low often existing low-altitude sites e.g. airports where wind is low
  - Other data sources such as global circulation models do not capture local effects well
- Programs to provide detailed resource assessments of African wind have been begun, but more work is needed
  - Solar & Wind Energy Resource Assessment (SWERA) is currently estimating wind potential in Kenya, Ghana and Ethiopia (funded by Global Environment Facility (GEF) and others)
    - 2,000 MW estimated potential in Ghana
  - Tanzania Electricity Supply Company is working with Danish firms to assess wind potential there
  - 1,000-10,000 MW estimated potential on the South African west coast

Large Scale Wind Power in Africa

	START 2004	START 2005	Growth	ANNOUNCED PROJECTIONS	Growth
	MW	MW	%	MW	%
EGYPT	69	145	110%	230	59%
MOROCCO	54	54	-	64.2	19%
TUNISIA	20	20	-	20	-
SOUTH AFRICA	3.2	3.2	-	8.4	163%
TOTAL - AFRICA	**146.2**	**222.2**	**52%**	**302.6**	**36%**
TOTAL - EUROPE	**28,835**	**34,630**	**20%**		

Sources: WindPower Monthly 2005, Republic of Egypt Ministry of Electricity and Energy http://www.nrea.gov.eg/

Small-Scale Wind for Distributed Generation

	Large Scale	Small Scale
Power	>1 MW	5-50 kW
Capital Cost ($/kW, 2002)	900-1000	3500-4000
Generation Cost (¢/kWh)	3-5	60-200

- Small scale windpower for numerous applications:
  - water desalination, water pumping, battery charging,
  - Hybrid mini grid with PV or diesel
- Research Issues:
  - Scaling Issues (low Reynolds number) leads to poor starting conditions
  - Inexpensive, robust, lightweight materials: thin blades for reduced blade inertia (starting) and withstand fatigue from increased rotational speed and low alt. turbulence
  - Replacement costs significant

CLAUSEN, P.D., and WOOD, D.H. (1999). Research and development issues for small wind turbines, Ren. Energy, 16, 922 - 927.
http://www.wind.newcastle.edu.au/

Conclusions

- Current estimates of global wind resources far exceed projected near term demand for electricity
- Resource remoteness and variability present challenges for attaining large penetrations of wind
- Energy storage mitigates variability costs and enables enhanced utilization of TL capital
- Wind/CAES allow both Wind and NG to compete in baseload markets in coal-rich regions
- Exploitation of lower wind classes and small scale turbine technology require further research to reduce costs

Backup Slides

Energy Storage Systems

Energy Storage for Wind Applications: 10 MW plant with 8 hours of storage, used 250 times a year						
	Expected Cycle Life (cycles)	Expected Service Life[1] (years)	AC Round-Trip Efficiency	Initial Capital Cost for a 10 MW / 80 MWh Installation[2]	Initial Capital Cost per kW ($/kW)	Initial Capital Cost per kWh ($/kWh)
Pumped Hydro	N/A	>25 years	80-85%	$9.0 M[3]	$900	$110
CAES	N/A	>25 years	>100%[4]	$8.2 M[3]	$820	$100
Batteries						
Lead-Acid Batteries[5]	1,250	5	50-65%	$35 M	$3,500	$450
Nickel-Cadmium Batteries	3,500	14	45-60%	$98 M	$9,800	$1,225
Sodium-Sulfur Batteries	4,500	15	65-75%	$23 M	$2,300	$300
Vanadium Redox Batteries	3,500	10	65-80%	$26 M	$2,600	$325
Zinc-Bromine Batteries	2,000	6	65-80%	$40 M	$4,000	$500
Hydrogen Storage[6]	500	2	20-45%	> $100 M	> $10,000	> $1,000
SMES	> 100,000	20	90%	> $100 M	> $100,000	> $100,000
Flywheels	> 100,000	20	90%	> $100 M	> $100,000	> $100,000
Ultracapacitors	> 100,000	20	90%	> $100 M	> $100,000	> $100,000

[1] Service life calculation is based on operating conditions and cycle life, and does not include refurbishment

[2] Costs include initial installed cost for battery, power conditioning, and balance of plant, but not O&M or life-cycle costs

[3] Costs for small pumped hydro and CAES systems are extrapolated from larger systems (hundreds of MW). These systems are unlikely to be cost effective at low power levels.

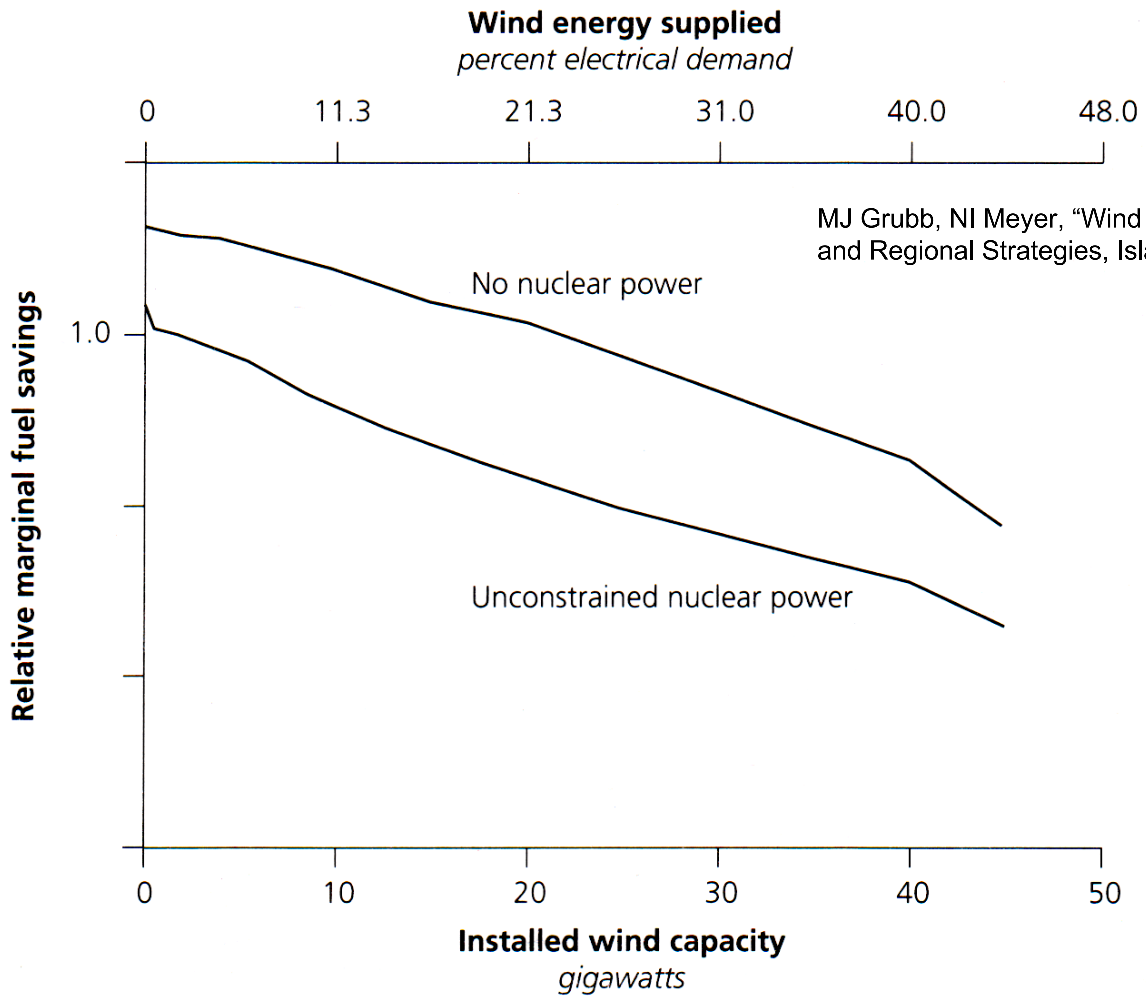
[4] Because most CAES systems have a natural gas input, efficiency can be greater than unity

[5] Assumes deep-cycle lead-acid batteries

[6] Hydrogen storage figures describe state of present art; future performance may be significantly better

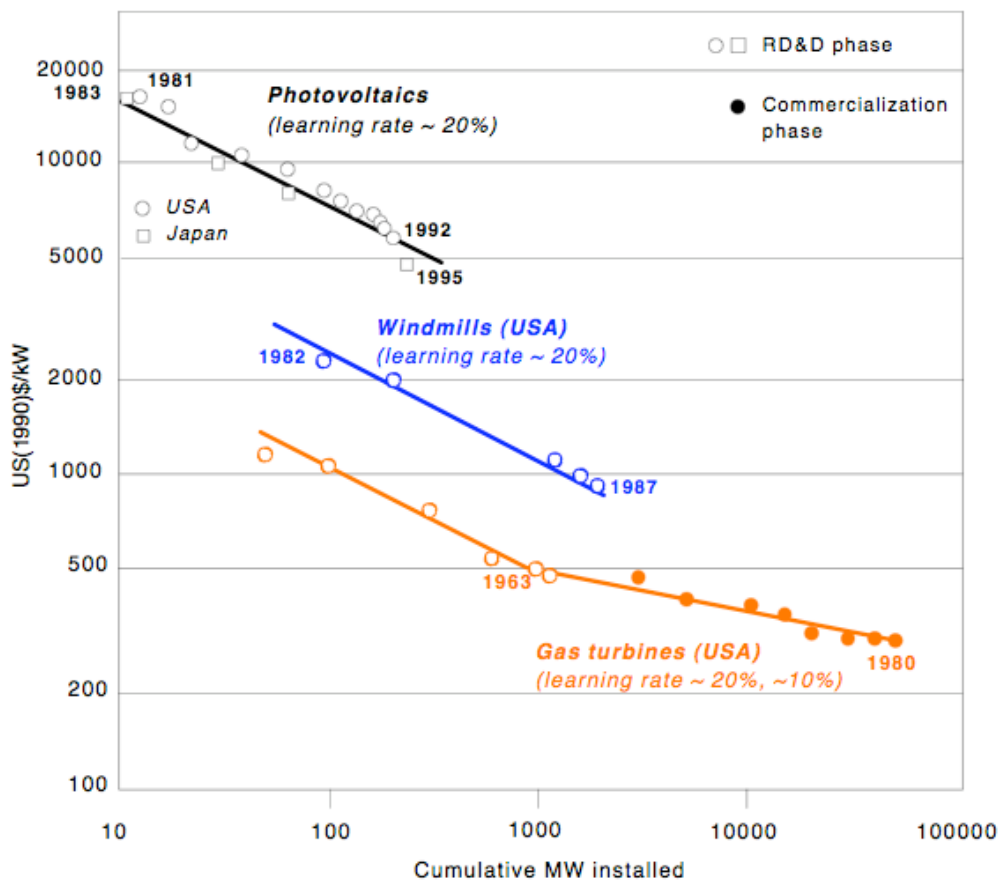
EPRI, Report 1008388, March, 2005

Value of Wind vs. Penetration

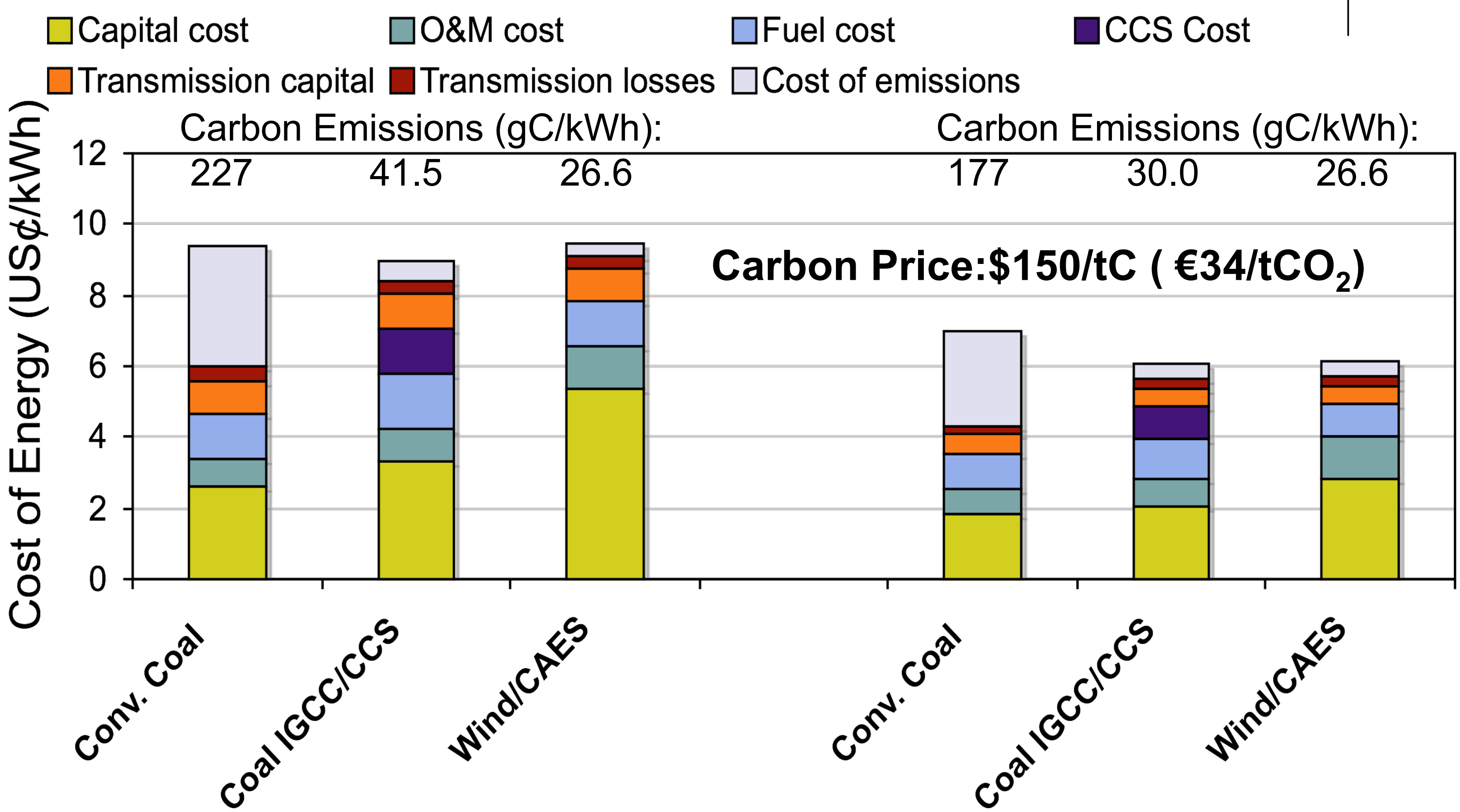


MJ Grubb, NI Meyer, “Wind Energy: Resources, Systems, and Regional Strategies, Island Press, 1993

Experience Curves For Energy



Economic Viability of Wind



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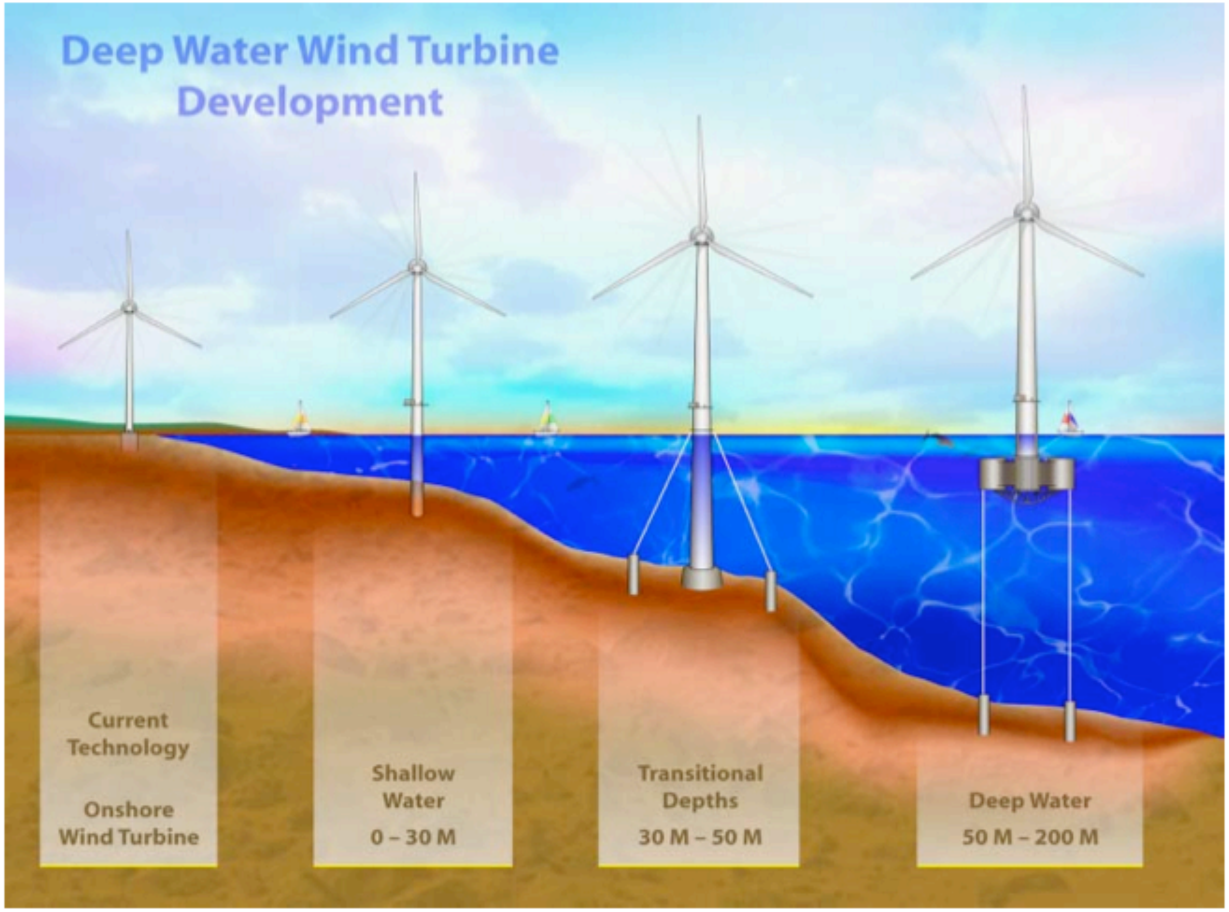
Sky wind power and Laddermills

- Eploitation of wind in the free troposphere (at ~10km) has several cost benefits
  - Energy denstities (~10kW/m^2) are an order of mag. higher than what is available from best wind @ 100m
  - Steady winds at high elevations yields less variable output

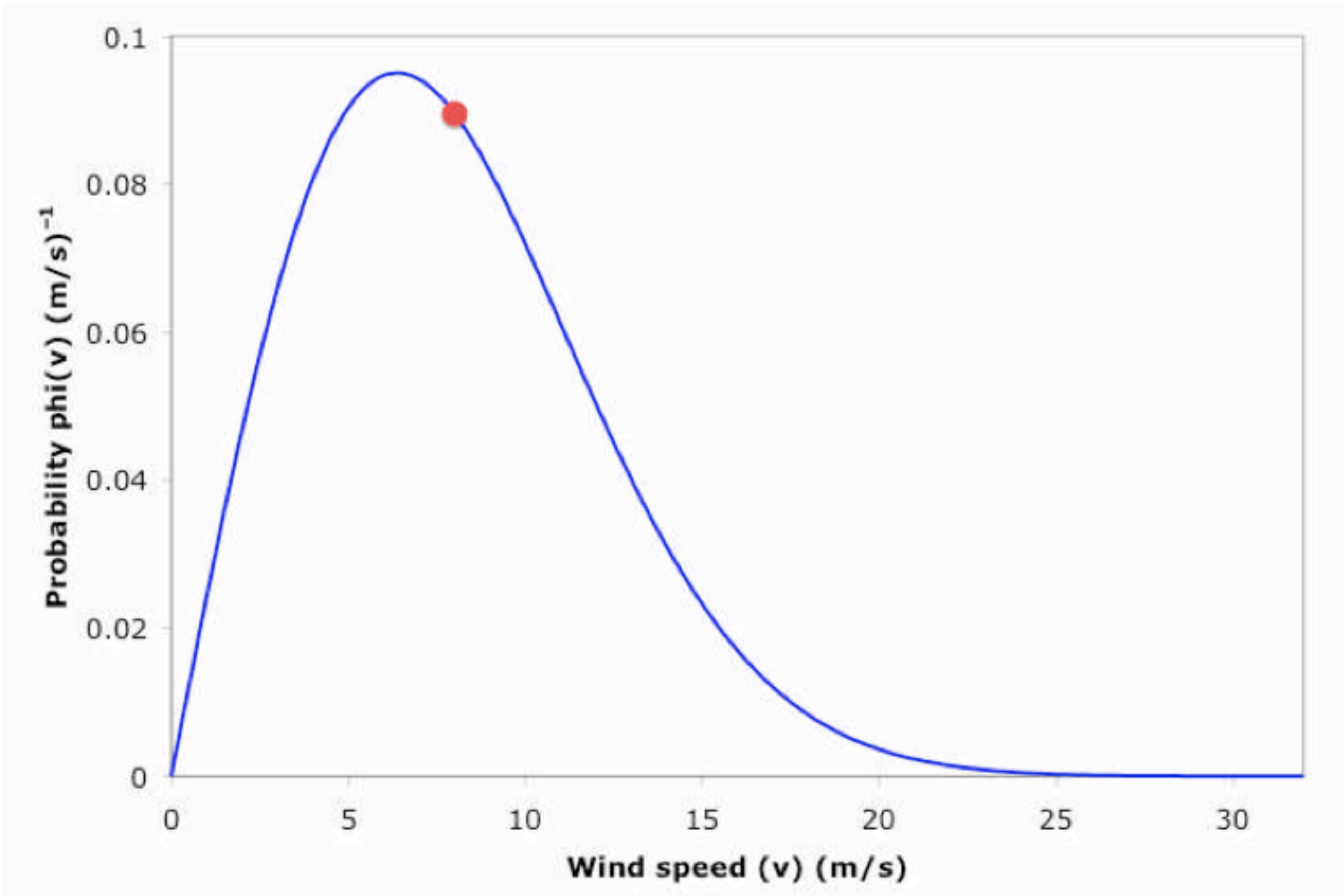
Meijaard, J. P., Ockels, W. J., Schwab, A. L., 1999. Modeling of the dynamic behavior of a laddermill, a novel concept to exploit wind energy, http://www.lr.tudelft.nl/asset/webpage/en/laddermill.php

Deep Offshore

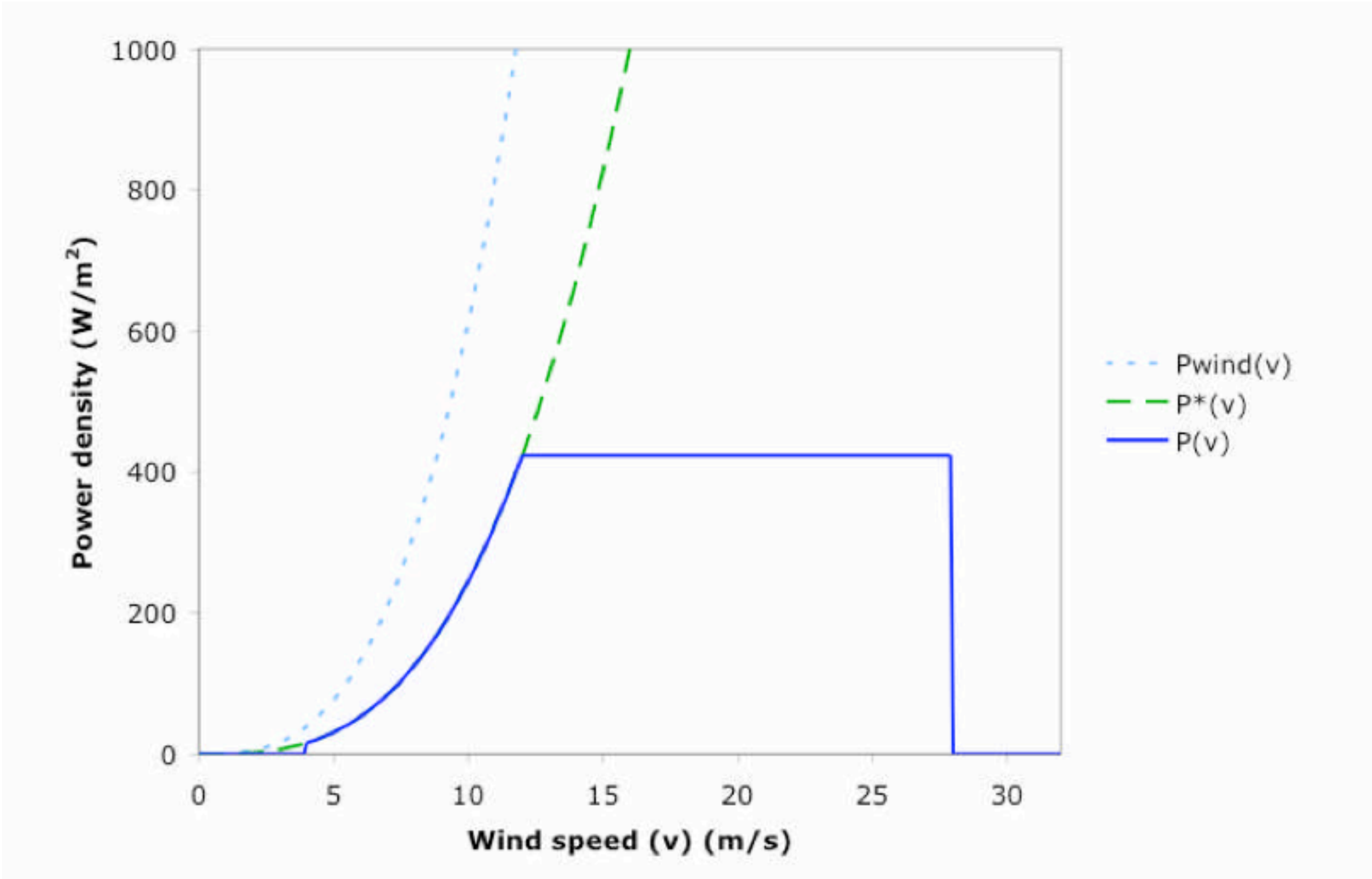


Musial, W., Butterfield, S., 2004. Future for offshore wind energy in the United States, conference paper preprint, *National Renewable Energy Laboratory*, report number NREL/CP-500-36313, Golden, Colorado.

Rayleigh Distribution



Wind Turbine Power Curve



Power Probability with Nominal Specific Rating