Recent Developments in the Levelized Cost of Energy from U.S. Wind Power Projects

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Background and Motivation

- Some recent focus has been placed on the increasing capital cost of wind projects observed from the early 2000s to 2010, and the apparent flattening of fleet-wide capacity factors in recent years
- These trends are important, but ignore other developments:
  - Continued improvements in capacity factors within individual wind resource classes (if not fleet-wide) due to hub height and rotor diameter scaling
  - Significant recent improvements in low-wind-speed technology, resulting in increased capacity factors and increased land area open to development
  - Steep reductions in turbine prices negotiated in last 2 years, and some evidence of reductions in balance of plant costs → expected (with some lag) to lead to sizable near-term reductions in project-level capital costs
  - Possible longer-term (i.e., since early 2000s) reductions in the cost of operating and maintaining as well as financing wind projects, as well as potentially improved turbine/project availability
  - Incentive choice with respect to 30% ITC/1603 Treasury grant in lieu of PTC

Background and Motivation

- Exclusive focus on *historical capital cost* and *fleet-wide capacity factor* trends fails to convey recent improvements in the levelized cost of energy (LCOE) from wind projects, the opening of new lower-wind-speed areas for development, and the fundamental interdependency of capital costs and capacity factors
- Wind turbine manufacturers, wind project developers, and wind power purchasers are not focused solely on optimizing capital costs and capacity factors, individually, but are more interested in:
  - Levelized cost of wind energy across all wind resource classes
    - Lower LCOE → lower power sales prices → greater demand for wind energy
  - Amount of land area that might be reasonably developed
    - Transmission/siting/policy influences can constrain development in high-wind-resource regimes → opening new lower-wind-resource regimes for development can significantly increase potential development opportunities

Objectives of Present Work

(1) Develop consistent ***levelized cost of energy*** estimates for wind in the U.S. in various wind resource regimes for:

- Projects installed in 2002-2003: The low-point of wind capital costs
- Projects installed in 2009-2010: The likely peak of wind capital costs
- Projects to be installed in 2012-2013: When current turbine pricing is likely to more-fully make its way into observed capital costs

Focus on direct costs, accounting primarily for **capital cost** trends and trends in estimated **capacity factors**; conduct analysis with/without PTC/ MACRS; emphasize, only as an example, GE turbines

(2) Estimate the amount of **available land area** that would exceed certain capacity factor and LCOE thresholds using the same assumed technology, assumptions, and time periods as above

(3) Conduct two side-case analyses: (1) impact of **incentive choice** between PTC and ITC/Section 1603; and (2) impact of possible **O&M, financing, and availability trends**

Caveats

- This is a preliminary assessment of the impact of various trends on LCOE; the analysis does not consider all factors, and the results have not undergone rigorous peer-review or been published
- The analysis uses GE turbine technology only as an example to facilitate assessment
- This work only seeks to understand and estimate recent and near-term developments
- LCOE estimates for 2012-2013 are based on current turbine pricing, but are nonetheless speculative
- This work has not attempted to track developments over a longer historical record or to forecast longer-term future trends
- The present analysis is focused on the U.S., though the basic findings should hold for other regions of the world as well

Presentation Outline

Recent Trends

Analysis Assumptions

Analytical Results

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Datasets Used To Explore Recent Capital Cost and Performance Trends

Project- and Turbine-Level Capital Costs

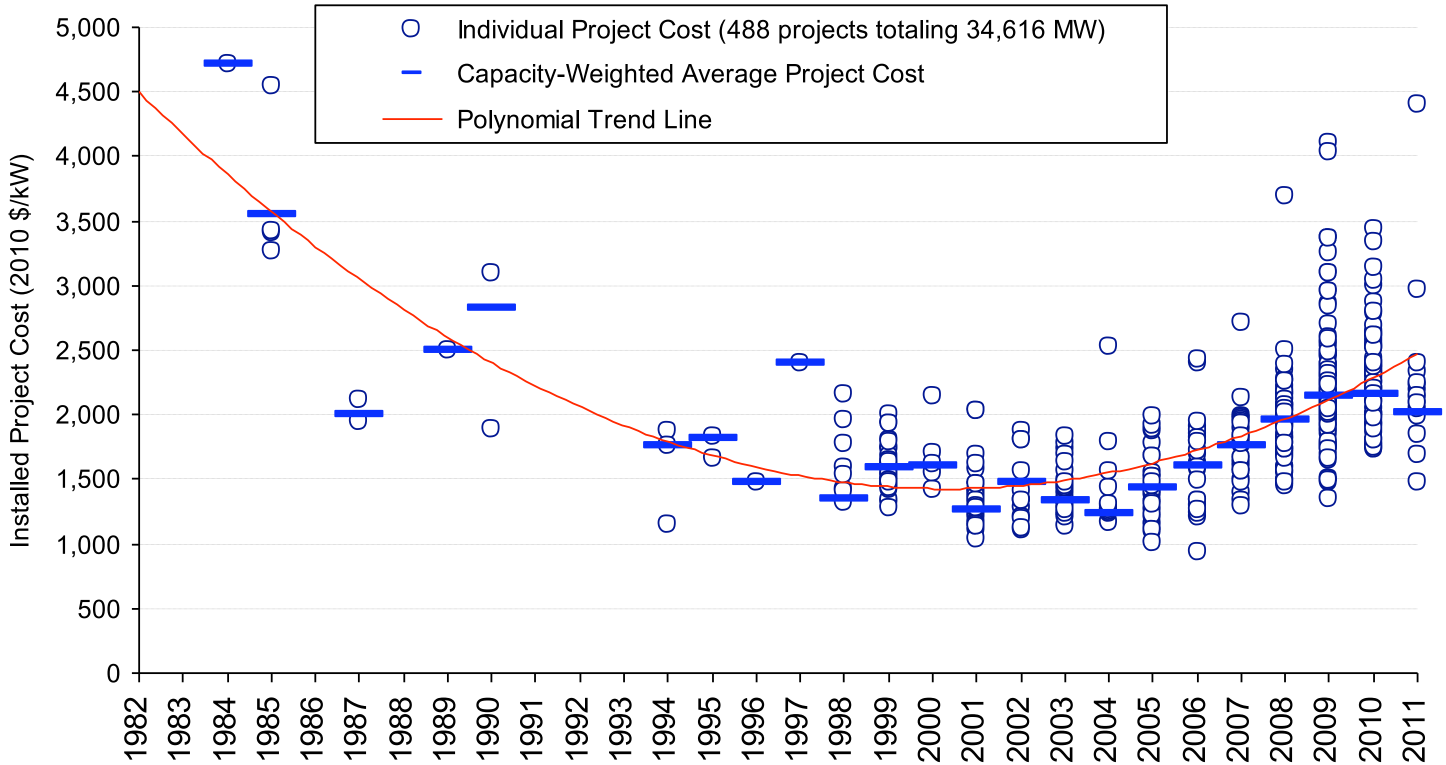
- 488 projects built from 1983-2011, 34.6 GW
- 81 turbine transactions from 1997-2011, 23.9 GW

Project-Level Performance / Capacity Factors

- 338 projects built from 1983-2009, 32.0 GW

Data shown here are primarily from the U.S. DOE's *2010 Wind Technologies Market Report ("U.S. DOE 2011")*

Installed Wind Project Capital Costs Increased from Early 2000s through 2010



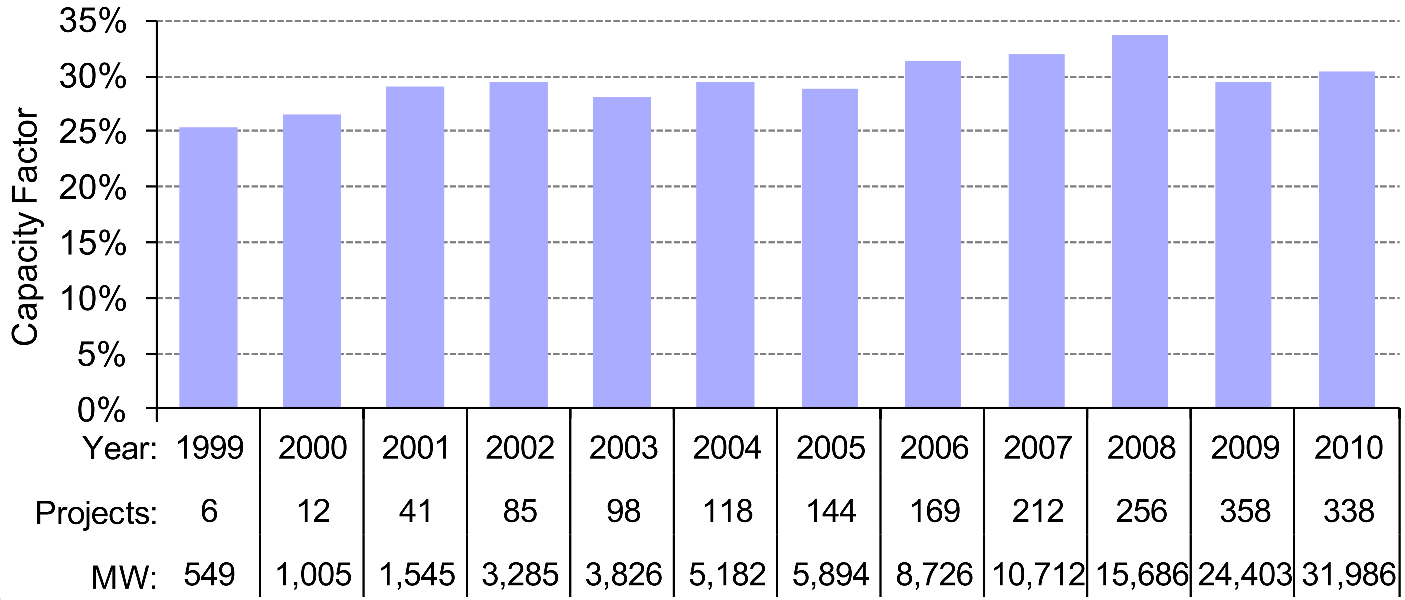
Source: U.S. DOE 2011

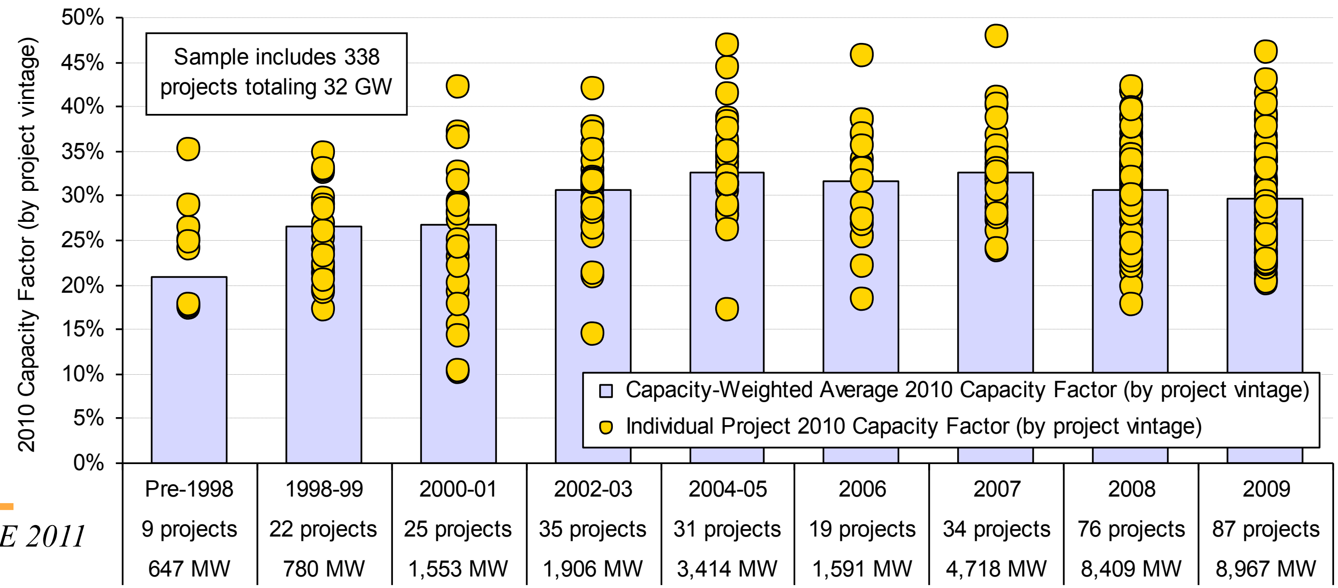
Project costs bottomed out in 2001-2004; rose by $850/kW on average through 2009; held steady in 2010 ($2,155/kW); based on limited available data, may have dropped in 2011

Fleet-Wide Capacity Factors (CF) Have (Generally) Increased Over Time

<u>**BUT:**</u>

Some leveling off in ***fleet-wide*** capacity factors in recent years is also apparent





Source: U.S. DOE 2011

Historical Trends Important, But Ignore Other Notable Developments

Project Performance	• Sizable historical/continued increases in hub heights and rotor swept area (in proportion to nameplate capacity), leading to improvements in capacity factors within individual wind resource classes, especially in lower-wind-speed sites
Installed Capital Costs	• Steep reductions in wind turbine prices negotiated over the last 2 years, with some evidence of a simultaneous reduction in balance of plant costs, which are expected to lead to sizable near-term capital cost reductions
Other Possible Advancements (since early 2000s)	• Operation and maintenance: Potential reduction in the cost of O&M for newer wind power projects • Financing: Notwithstanding the impact of the financial crisis, generally improved financing terms over the *longer-term* as the sector and technology have matured • Availability: Potential reduction in losses due to improved turbine/project availability

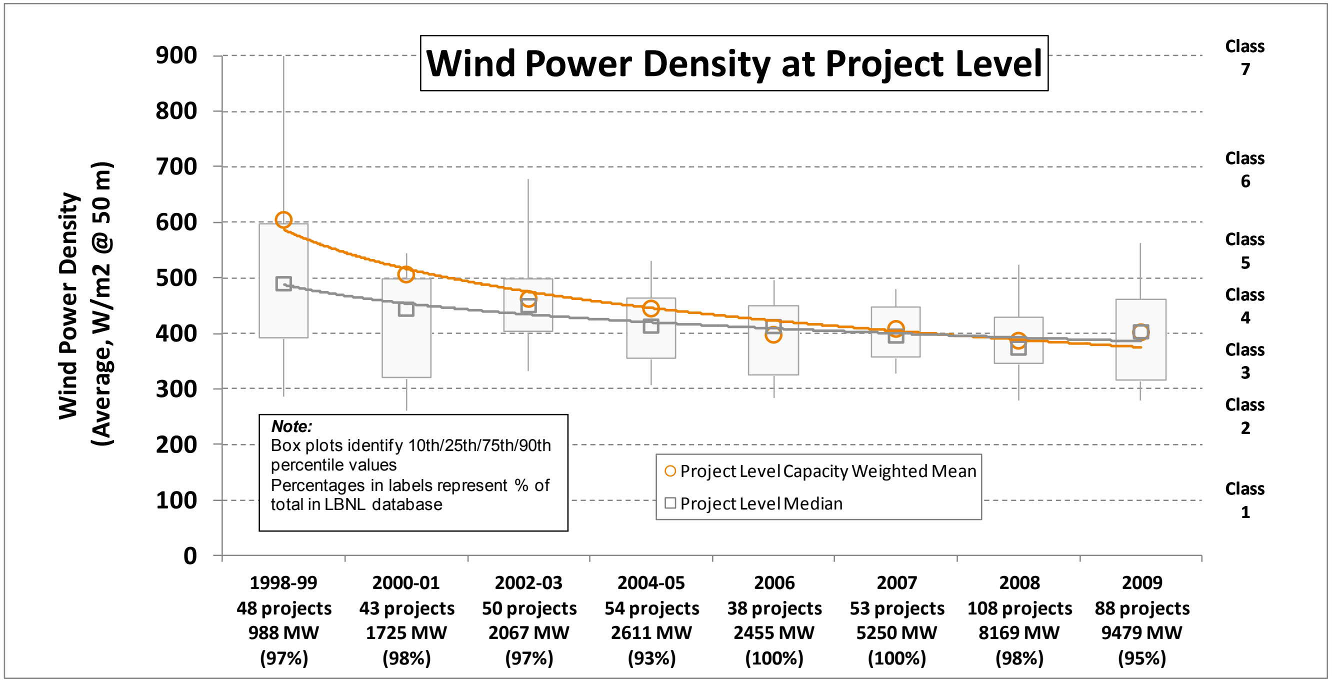
See following slides for more details…

Recent Moderation of CF Increase Driven In Part By Move Towards Lower Wind Speed Sites…

Projects increasingly sited in poorer wind regimes at 50m:

- **1998-2001: Class 4-5 common**
- **2006-2009: Class 3-4 common**

Trend likely driven by transmission/siting limitations and policy influences, as well as improvement in low wind speed technology



Source: Lawrence Berkeley National Laboratory

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…and Growing Amounts of Wind Energy Curtailment in Some Regions

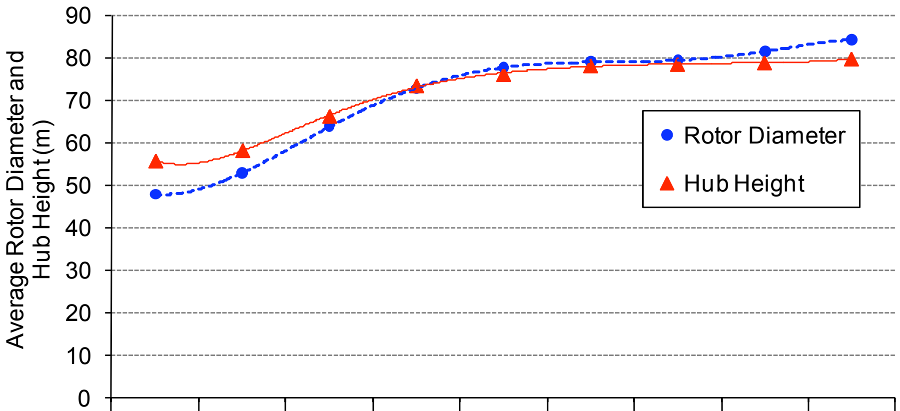
Wind Curtailment, GWh (percent potential generation)	**2007**	**2008**	**2009**	**2010**
Electricity Reliability Council of Texas	109 (1.2%)	1,417 (8.4%)	3,872 (17.1%)	2,067 (7.7%)
Southwestern Public Service Co.	N/A	0 (0.0%)	0 (0.0%)	0.9 (0.0%)
Public Service Company of Colorado	N/A	2.5 (0.1%)	19.0 (0.6%)	81.5 (2.2%)
Northern States Power Co.	N/A	25.4 (0.8%)	42.4 (1.2%)	42.6 (1.2%)
Midwest ISO, less NSP	N/A	N/A	250 (2.2%)	781 (4.4%)
Bonneville Power Administration	N/A	N/A	N/A	4.6 (0.1%)
Total Across These 6 Areas:	**109 (1.2%)**	**1,445 (6.4%)**	**4,183 (10.4%)**	**2,978 (5.1%)**

Source: U.S. DOE 2011

U.S. fleet-wide capacity factors from 2008-2010 would have been 1-2 percentage points higher absent curtailment

(curtailment largely caused by inadequate transmission and minimum load)

Move to Lower Wind Speed Sites and Increased Curtailment Hide the Very Real Increases in CFs Witnessed in Individual Wind Resource Classes

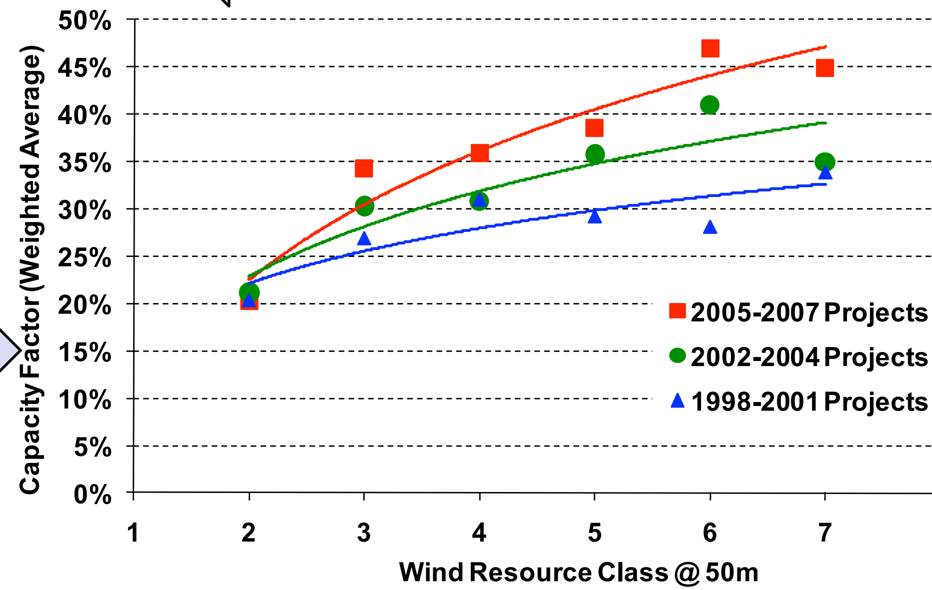


COD:	1998-99	2000-01	2002-03	2004-05	2006	2007	2008	2009	2010
Turbines:	1,418	1,982	1,686	1,942	1,515	3,190	5,004	5,733	2,855
Capacity:	1,014 MW	1,756 MW	2,080 MW	2,779 MW	2,440 MW	5,249 MW	8,348 MW	9,993 MW	5,113 MW

Source: U.S. DOE 2011

Historical increases in avg. hub height and rotor diameter have been substantial

Leading to sizable increases in avg. capacity factors within specific resource classes



Source: Lawrence Berkeley National Laboratory

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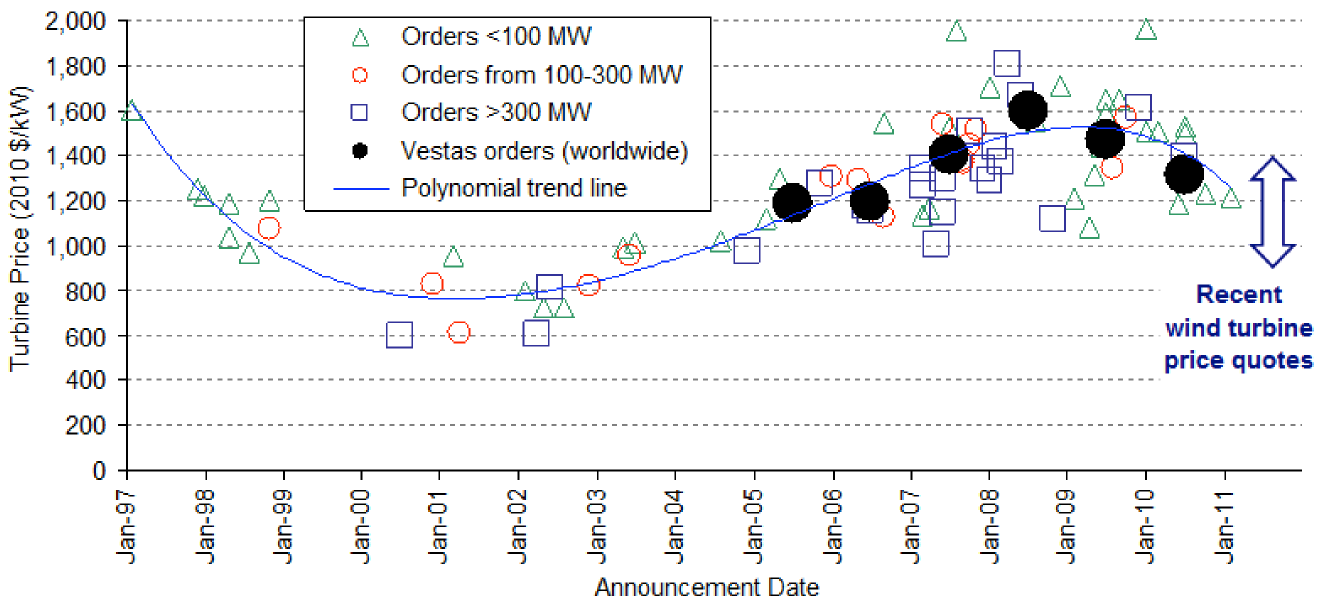
Wind Turbine Prices Have Softened Since Their Highs in 2008



Source: Bolinger and Wiser 2011

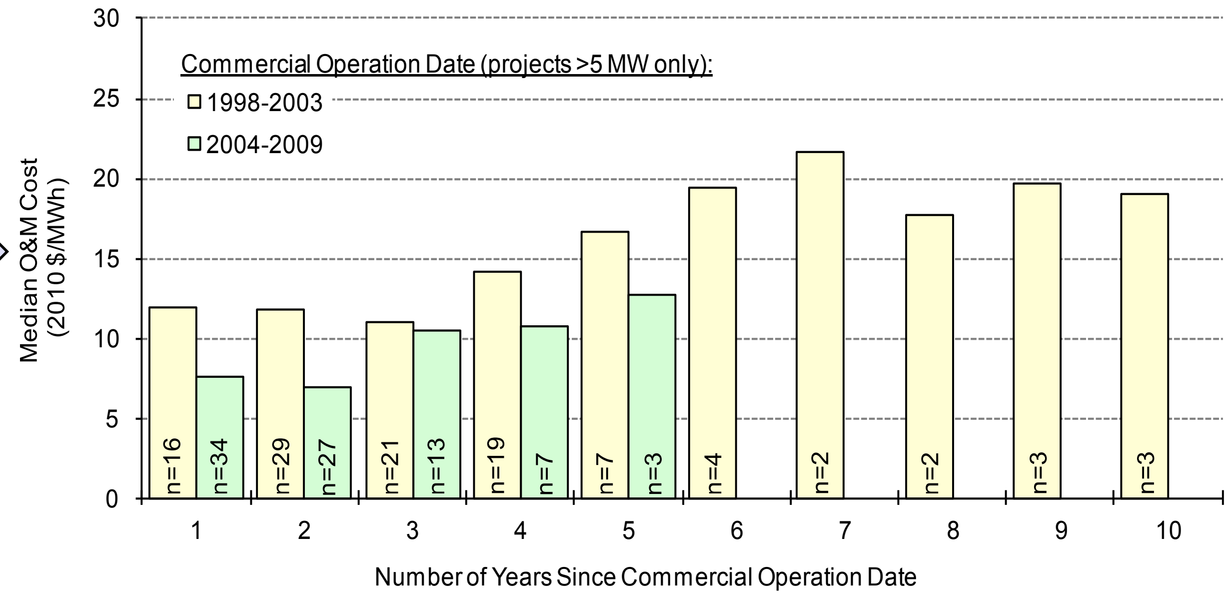
Lag between turbine prices and project costs should lead to substantial project-level installed capital cost reductions by 2012-2013

Turbine price quotes in 2011 for "standard" technology are reportedly <u>as low as</u> $900/kW (Tier 1: ~$1,100-1,250/kW, with average at ~$1,100/kW); higher costs typical for smaller orders, larger rotors/towers, etc.

(also more-favorable terms for buyers and improved technology; balance-of-plant costs also reportedly lower than in recent past)

Some Evidence of Lower O&M Costs, Higher Availability, Improved Financing

O&M costs from limited sample of US wind power projects (U.S. DOE 2011)



GE's reported median availability by model year (Mesh et al. 2011, "GE Wind Turbine Availability)

Figure 1: Americas 1.5SLE/XLE Model Year: Median Lifetime Availability, excluding first 12 weeks of operation

Strength of evidence supporting specific improvements in O&M, availability, and financing somewhat lower than trends in capacity factor and capital cost

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Recent “Chatter” Suggests that, As a Result of These Trends, Delivered Wind Energy Costs Have Declined Substantially

BNEF 2011: "The cost of wind generation has been driven to record lows by declines in turbine prices and the cash grant, which eliminates the cost of securing tax equity financing.”

“Austin Energy officials say those wind contracts are among the cheapest deals available, when the cost of building power plants is taken into account, and comparable to what the historically volatile natural gas market has been offering recently.” *(Statesman.com article)*

“Our contract with NextEra Energy Resources is one of the lowest we’ve ever seen and results in a savings of nearly 40 percent for our customers,” said David Eves, president and CEO of Public Service Company of Colorado. “The addition of this 200-megawatt wind farm demonstrates that renewable energy can compete on an economic basis with more traditional forms of generation fuel, like natural gas, and allows us to meet the state’s Renewable Energy Standard at a very reasonable cost to our customers.” *(Reuters article)*

Consumers Energy, Michigan: "Lower wind power costs mean $54m saving for Consumers Energy.“ *(newspaper article)*

Westar, Kansas: Signed more wind contract than needed "...because pricing is so attractive now and to minimize tax risk to our investors" *(Westar Q4 earnings call)*

Presentation Outline

- Recent Trends
- **Analysis Assumptions**
- Analytical Results

Analysis Objective

Estimate Capacity Factors, LCOE, and Developable Land Area By Selecting Representative Assumptions for Turbines Used in U.S. Wind Projects

Installed in 2002-2003	• The low-point of wind project capital costs
Installed in 2009-2010	• The likely peak of wind project capital costs
(To be) Installed in ~2012-13	• When current turbine pricing is likely to more-fully make its way into observed capital costs

Basic Approach

In each period, account for common actual/expected trends in:

(1) installed capital costs (based on actual/estimated cost)

(2) capacity factors in different wind resource classes (estimated based on available power curves, assuming sea level air density of 1.225 kg/m^3)

For simplicity, in most cases hold constant: O&M costs; financing structure and costs; project/turbine availability and other losses; project life, income taxes, decommissioning, etc.

Estimate LCOE: (1) <u>without</u> PTC or 5-yr MACRS (depreciation assumed to be 12-yr straight line); and (2) <u>with</u> PTC and 5-yr MACRS

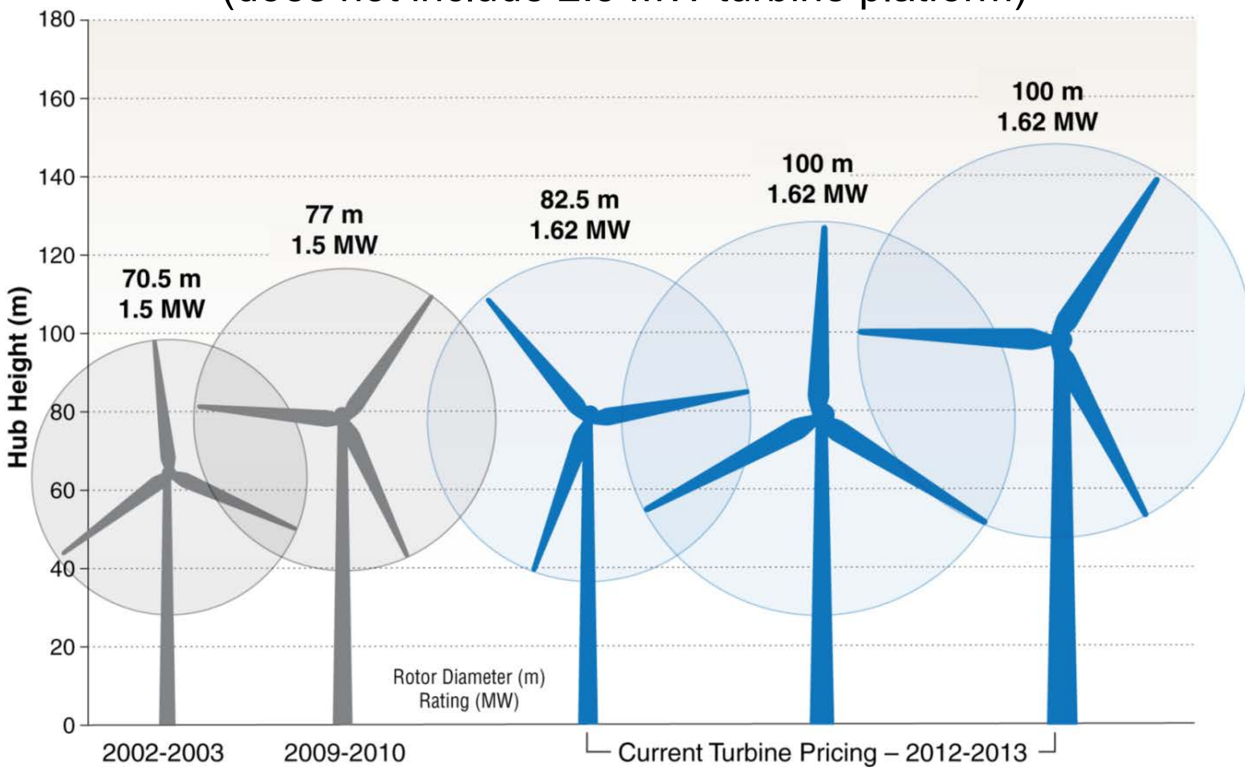
Conduct two side analyses: (1) impact of <u>incentive choice</u> between PTC and ITC/Treasury Grant; and (2) impact of possible <u>O&M, financing, and availability</u> trends

Use IEA Task 26 Work-package 1 LCOE model

For Analytical Simplicity, Focus on GE Turbine Evolution

Typical GE Turbine Offerings Over Time

(does not include 2.5 MW turbine platform)



GE has been the dominant supplier of turbines to the U.S. market over this timeframe, ensuring that a focus on GE *as an example* of the evolution of cost, performance, and LCOE trends is appropriate

Summary of Core Input Assumptions

Characteristics	2002-2003	2009-2010	Current Turbine Pricing: ~2012-2013		
Technology type	Standard	Standard	Standard*	Low Wind*	Low Wind*
Nameplate capacity	1.5 MW	1.5 MW	1.62 MW	1.62 MW	1.62 MW
Hub height (HH)	65 m	80 m	80 m	80 m	100 m
Rotor diameter (RD)	70.5 m	77 m	82.5 m	100 m	100 m
Installed capital cost	$1,300/kW	$2,150/kW	$1,600/kW	$1,850/kW	$2,025/kW
Operating costs	$60/kW-yr	$60/kW-yr	$60/kW-yr	$60/kW-yr	$60/kW-yr
Losses (availability, array, other)	15%	15%	15%	15%	15%
Financing (nominal)	9%	9%	9%	9%	9%

- Dollar values are all real 2010$
- Financing cost / discount rate reported in nominal terms
- Air density = 1.225 kg/m^3 (sea level wind speed)
- Weibul K Factor = 2 in all scenarios
- 1/7th power law scaling to estimate hub height wind speed
- 20-year assumed project/economic life in all scenarios
- Aggregate income taxes assumed to equal 38.9%

All assumptions intended to reflect representative actual/common conditions; installed costs, operating costs, losses and other assumptions can vary considerably from one project to the next

**These turbines are assumed viable in sites up to the respective IEC Class II and Class III reference average annual wind speed. Depending on site specific gust, turbulence, and air densities these turbines in actuality may be reasonably placed in sites with higher average annual wind speeds than applied in this analysis.*

Basis For Core Assumptions

Turbine Characteristics (capacity, hub height, rotor diameter)

- Common GE designs for relevant installation years

Installed Capital Cost

- 2002-2003 and 2009-2010: based on actual average costs for installed projects
- 2012-2013: assumes \$550/kW drop in turbine/BOP costs since high-point for 80 m HH / 82.5 m RD turbine based on earlier data on turbine cost trends, BNEF (2011), and discussions with wind developers/manufacturers; \$250/kW assumed increase for 100 m RD upgrade and additional \$175/kW increase for 100 m HH upgrade based on discussions with wind developers/manufacturers; result is an **estimate** of the average installed cost of projects based on current turbine orders; actual project costs will have a large spread around the average, with both lower- and higher-cost projects anticipated

Other Costs and Characteristics

- Operating costs: Assumed to be exclusively denominated in \$/kW-yr, though, in practice, some costs may be more-appropriately denominated in \$/MWh; all-in operating costs assumed to equal \$60/kW-yr in core analysis based on review of available data/literature
- Losses: 15% losses assumed in core analysis based on review of available data/literature, as well as matching actual and estimated project-level capacity factors
- Financing: 9% assumed in core analysis based on review of available data/literature

Summary of Side-Case Input Assumptions

Incentive Choice

- Assumes that project owners choose between the PTC and ITC/Treasury Grant based only on the face-value of those incentives (i.e., the incentive that minimizes the LCOE with no additional changes and ignoring any ancillary benefits of the ITC/Treasury Grant)

O&M, Financing, Availability

- **O&M:** Cost reduction from $64/kW-yr in 2002-2003 → $57/kW-yr in 2012-2013 based on review of available data/literature, including 2010 Wind Technology Market Report, BNEF (2011), etc.
- **Financing:** All-in cost of finance decreases as technology matures from 10.5% in 2002-2003 → 9% in 2012-2013 based on review of available data/ literature and discussions with wind developers
- **Availability:** Reduction in average project-level losses from 16.5% in 2002-2003 → 14% in 2012-2013 based only on assumed improvement in availability, itself based on review of limited available data/ literature and discussions with wind consultants and developers

Presentation Outline

Recent Trends

Analysis Assumptions

Analytical Results

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Outline of Key Results

Estimated Capacity Factors in Varying Resource Classes

Levelized Cost of Energy in Varying Resource Classes

Side Analysis: Impact of Improvements in O&M, Financing, and Availability

Designing Turbines for Low Wind-Speed Sites: Narrowing the Gap in LCOE

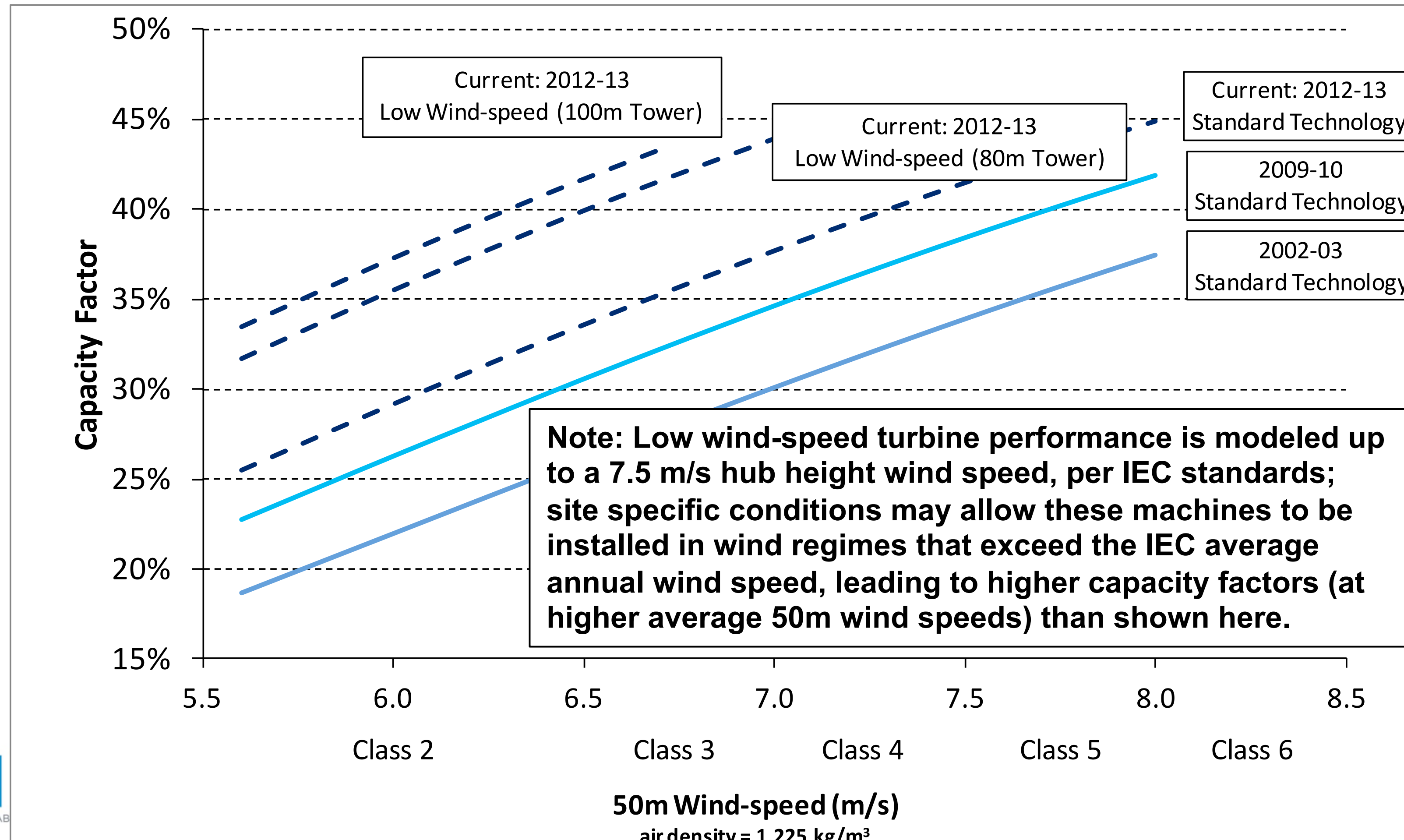
Side Analysis: Impact of ITC/Treasury Grant Option In Lieu of PTC

Increased Land Area Exceeding Capacity Factor Thresholds

Increased Land Area Exceeding LCOE Thresholds

Turbine Design Advancement Leads To Enormous Increase in Capacity Factors

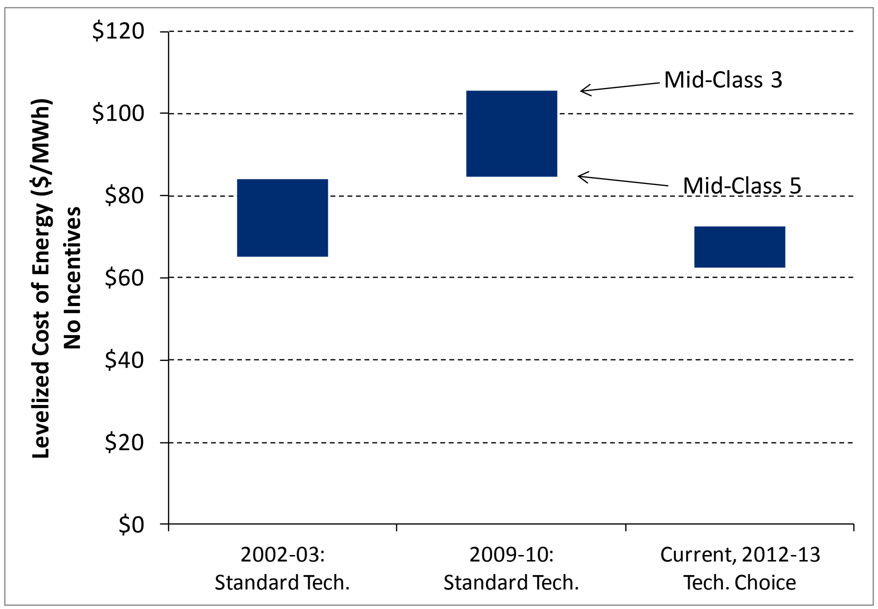
Estimated capacity factor improvement driven by larger rotor swept area in proportion to nameplate capacity, as well as higher hub heights; increase is especially apparent with newest batch of low-wind-speed turbines



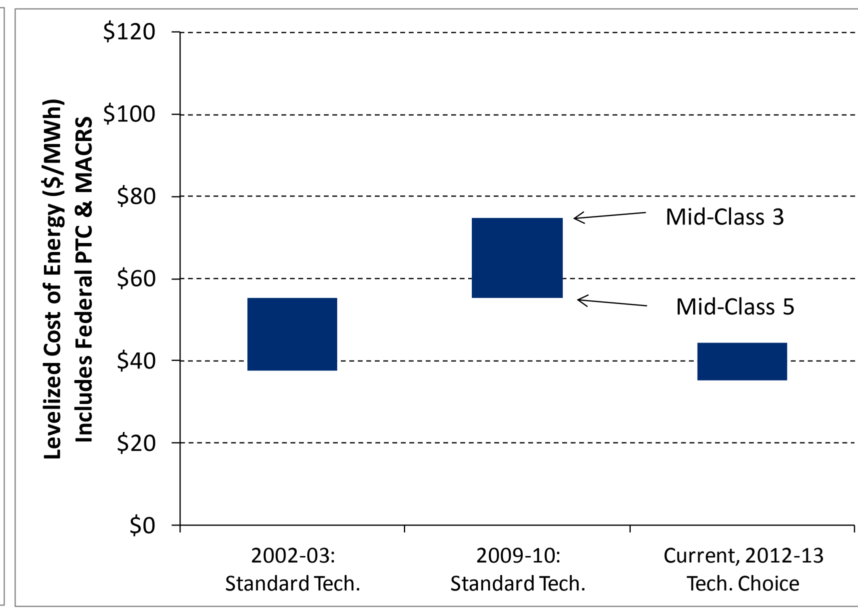
Levelized Cost of Wind Energy Is Estimated To Be at An All-Time Low for 2012-2013

Accounting only for assumed capacity factor and capital cost trends, LCOE increased substantially from 2002-2003 to 2009-2010 because capital cost increases were not fully compensated by CF improvements; estimated LCOE has since dropped below its earlier lows within individual wind resource classes because capital cost increases from 2002-2003 to the present have been more-than offset by CF improvements, yielding a lower LCOE than at any time in the past within individual resource classes

Without Federal Incentives



With Federal PTC/MACRS



Note: "Tech. Choice" assumes that IEC Class III machines are only available for sites up to 7.5 m/s average wind speed at hub height (sea level air density)

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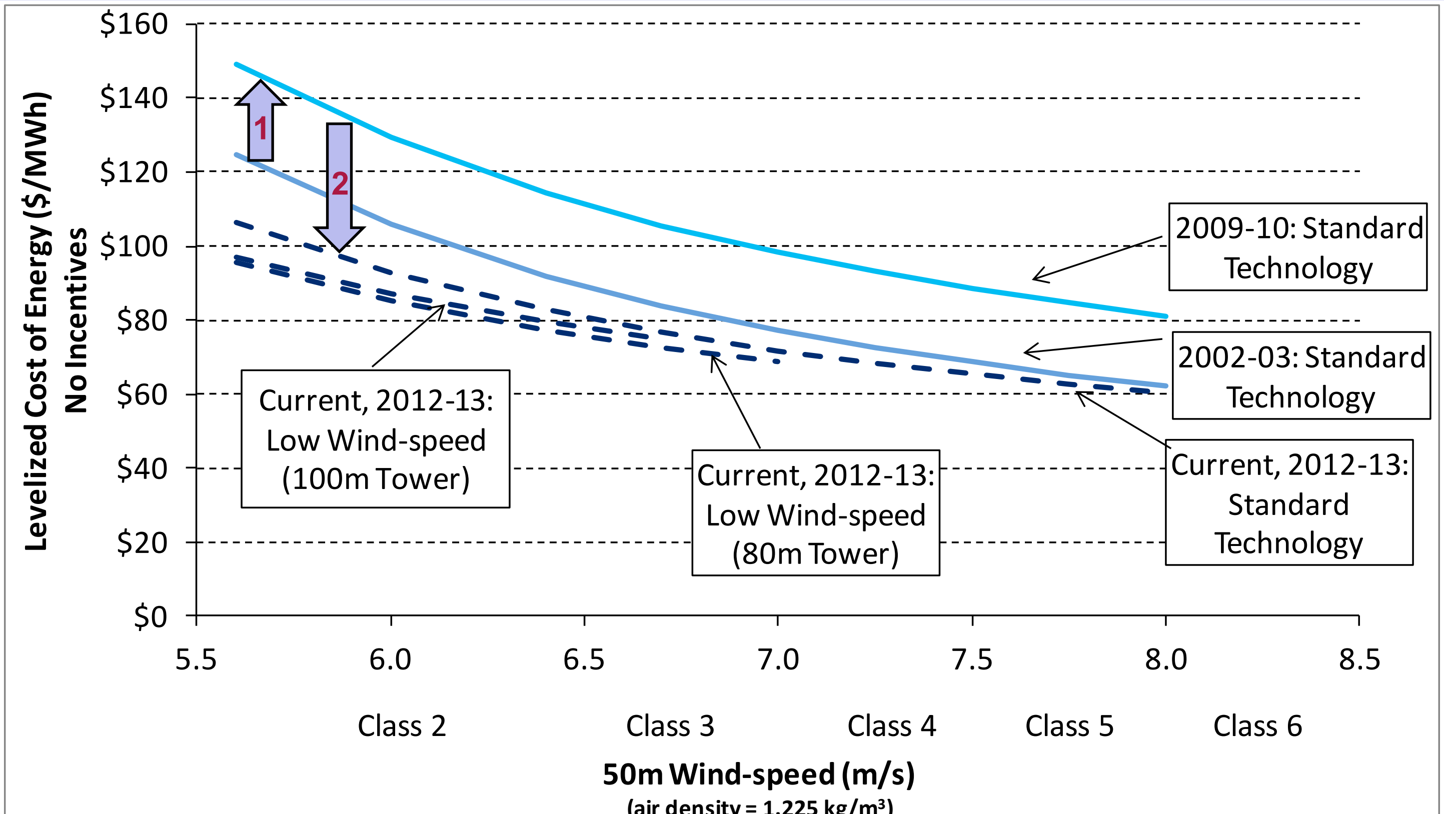
Levelized Cost of Energy in Varying Resource Classes (*without* PTC/MACRS)

Based on current pricing and assumptions: 100m rotor diameter is found to be economically attractive in comparison to 2012-2013 'Standard Technology' where it can be deployed; a wind sheer higher than 1/7th is found to be needed for the 100m tower to be least cost in comparison to the 80m option (with the 100m rotor)



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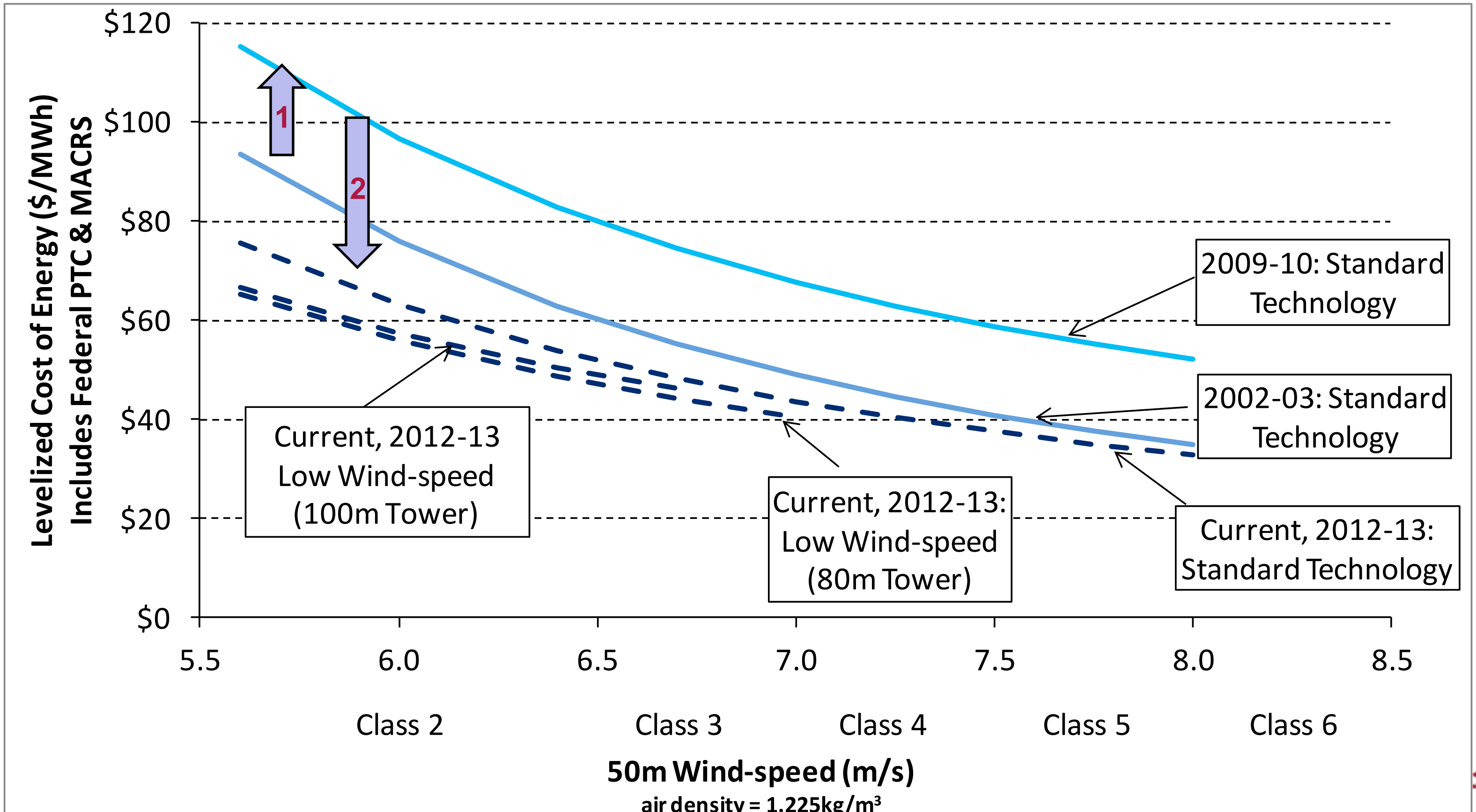
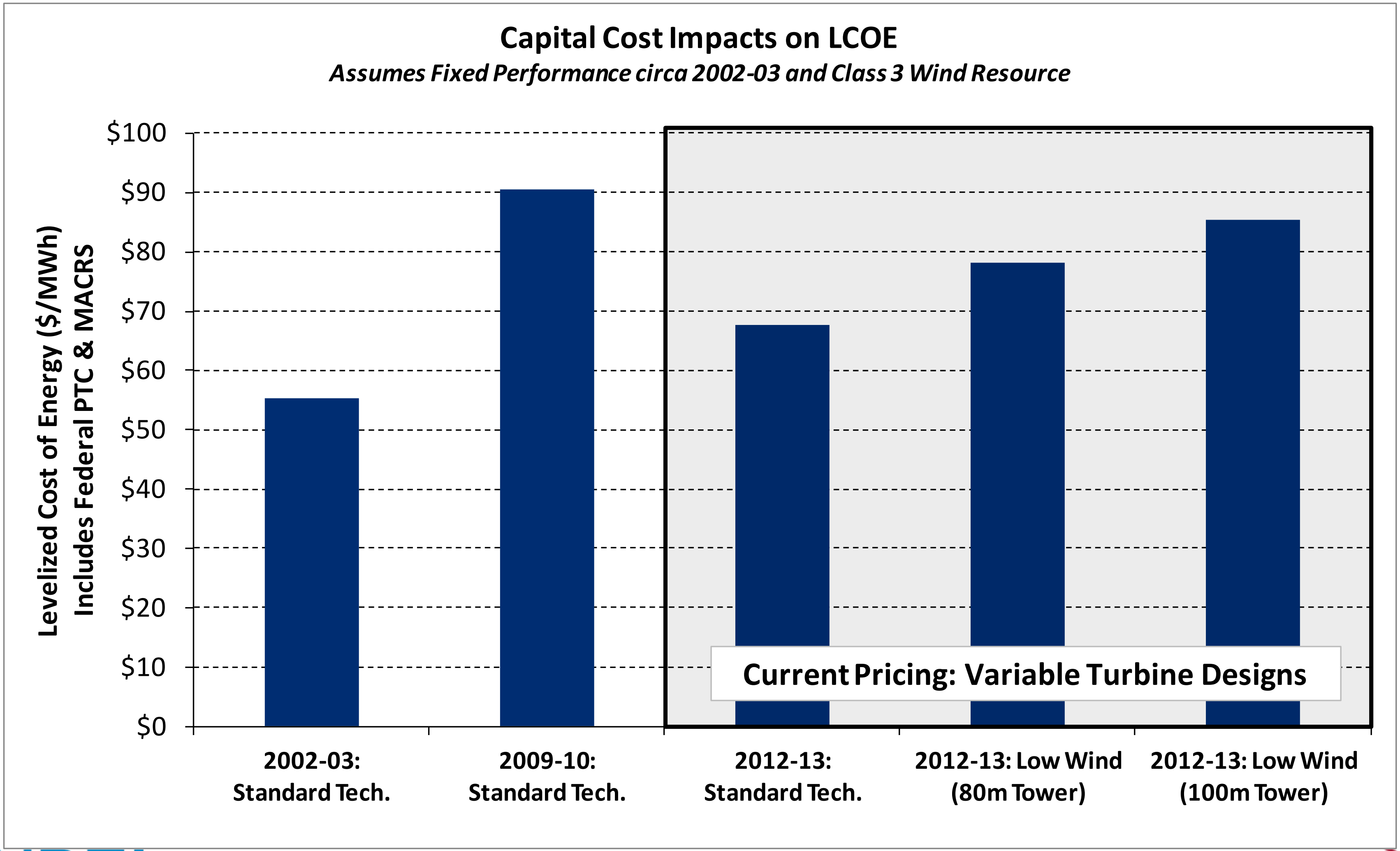
Levelized Cost of Energy in Varying Resource Classes (*with* PTC/MACRS)

With PTC/MACRS and with current turbine pricing and other specific assumptions, the highest wind speed sites evaluated below can support LCOEs as low as ~$33/MWh (real$), while the lower wind speed sites have LCOEs of ~$65/MWh

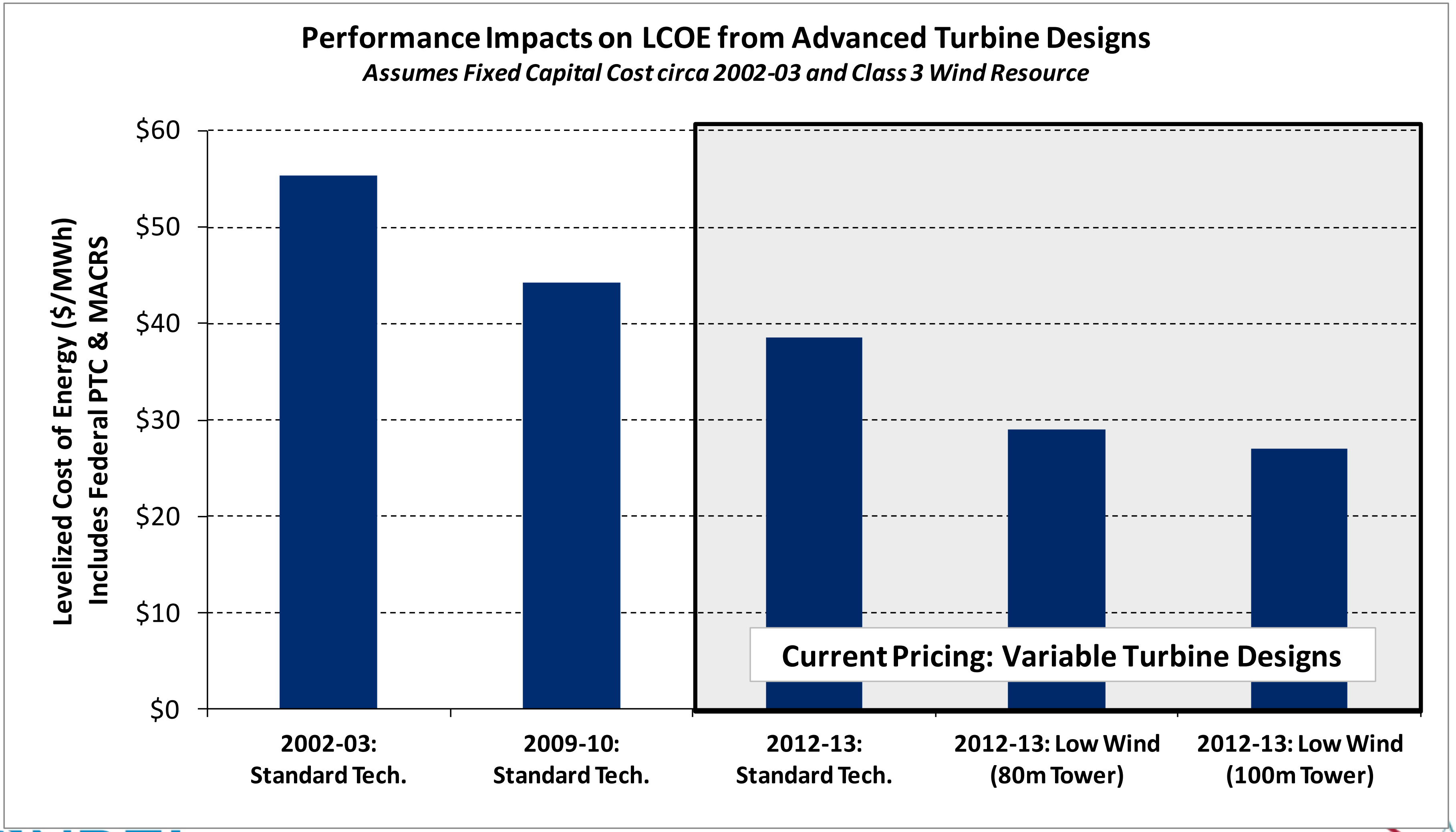


All Else Being Equal, Capital Cost Increases Would Have Led To Much Higher LCOEs
(Mid Class 3 Wind Resource, *with* PTC/MACRS)



All Else Being Equal, Performance Improvements Would Have Led To Much Lower LCOEs

(Mid Class 3 Wind Resource, *with* PTC/MACRS)



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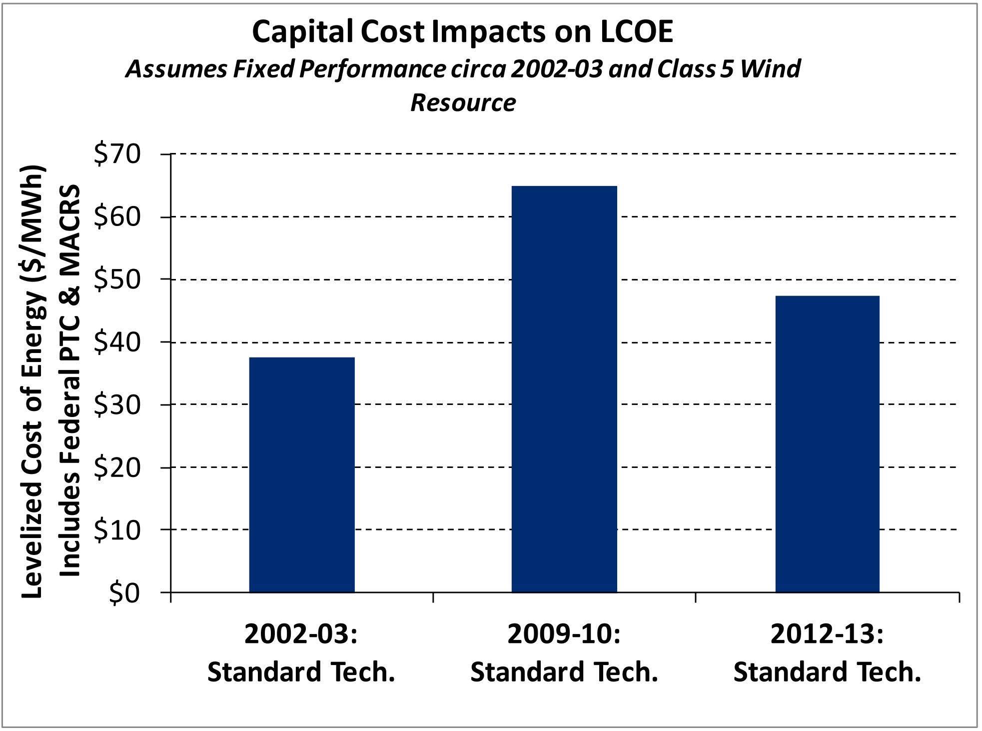
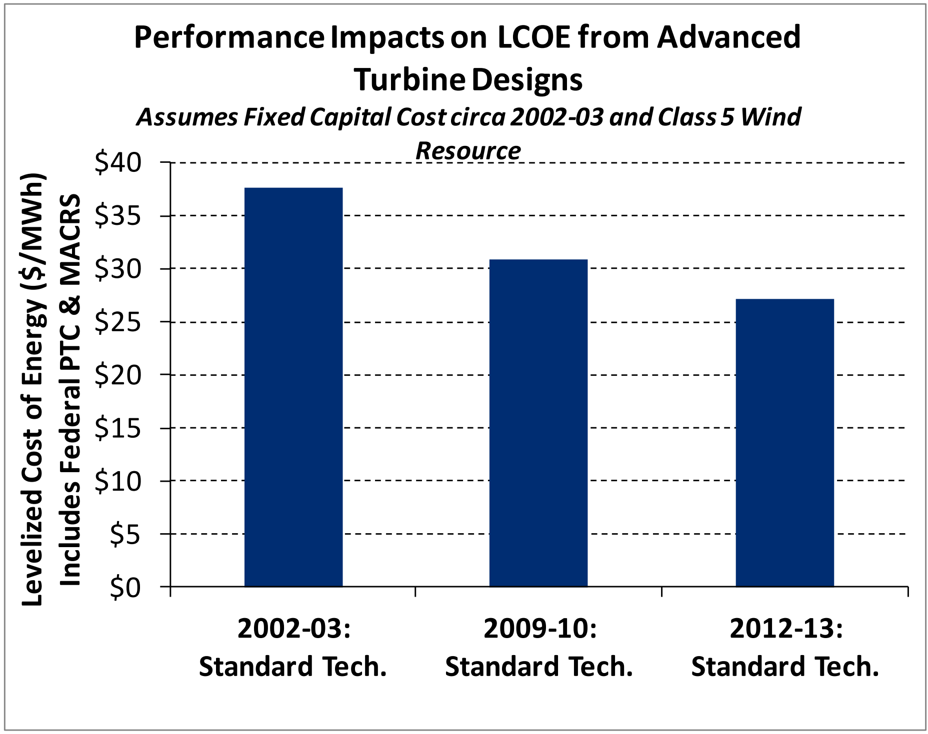
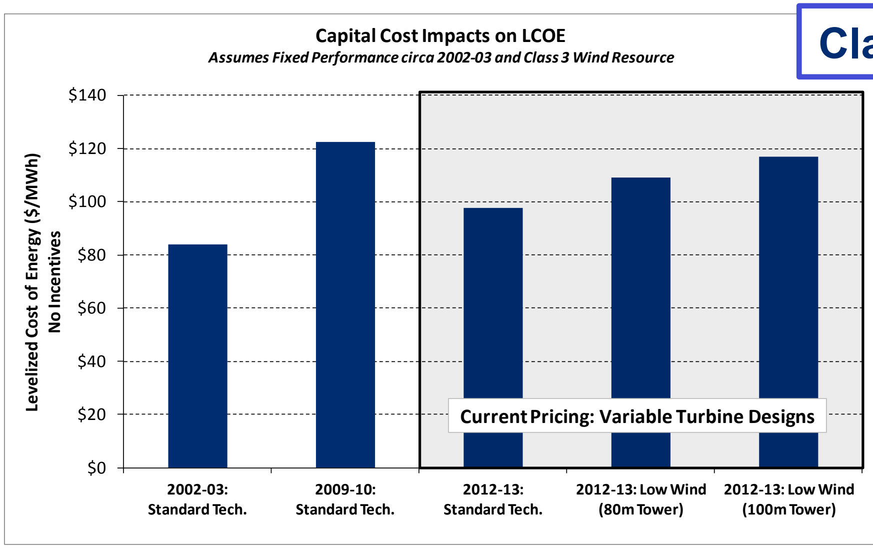
Same Tradeoff Between Capital Cost and Performance Exists in Other Wind Resource Classes
(Mid Class 5 Wind Resource, *with* PTC/MACRS)

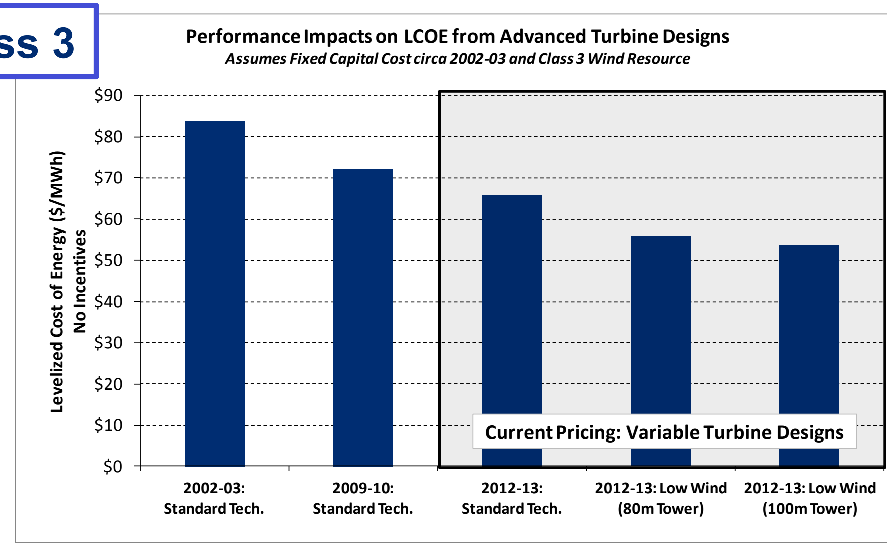




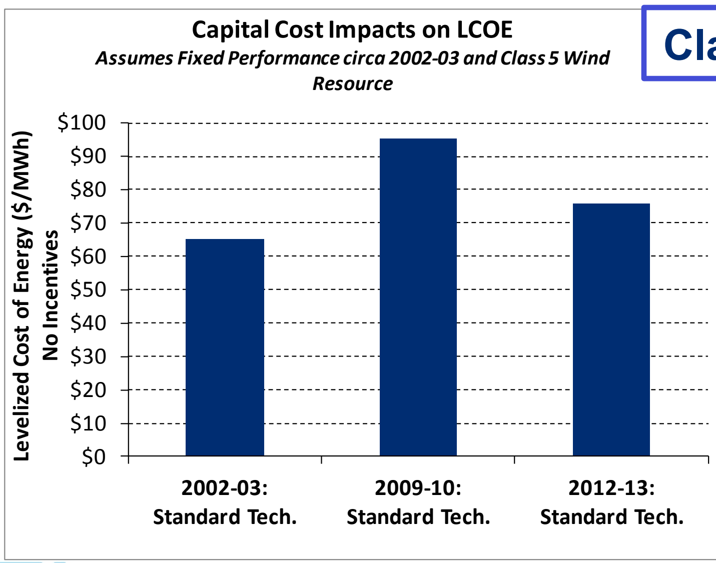
Same Tradeoff Between Capital Cost and Performance Exists *without* PTC/MACRS

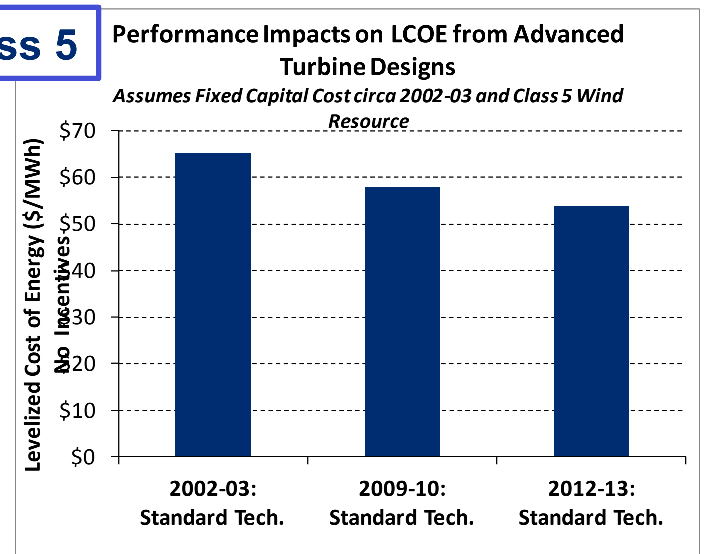
Class 3





Class 5



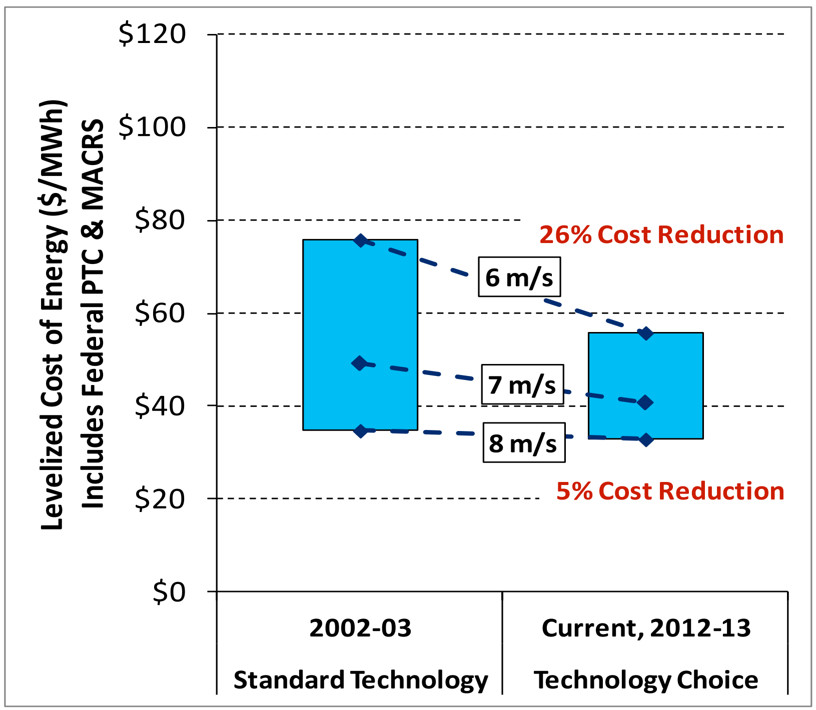


Side Analysis: Impact of Improvements in O&M, Financing, and Availability (*with* PTC/MACRS)

Assumed improvements in O&M costs, financing rates, and availability lead to substantial additional estimated LCOE reductions from 2002-2003 to 2012-2013 in comparison to core analysis that only varies capital cost and capacity factor

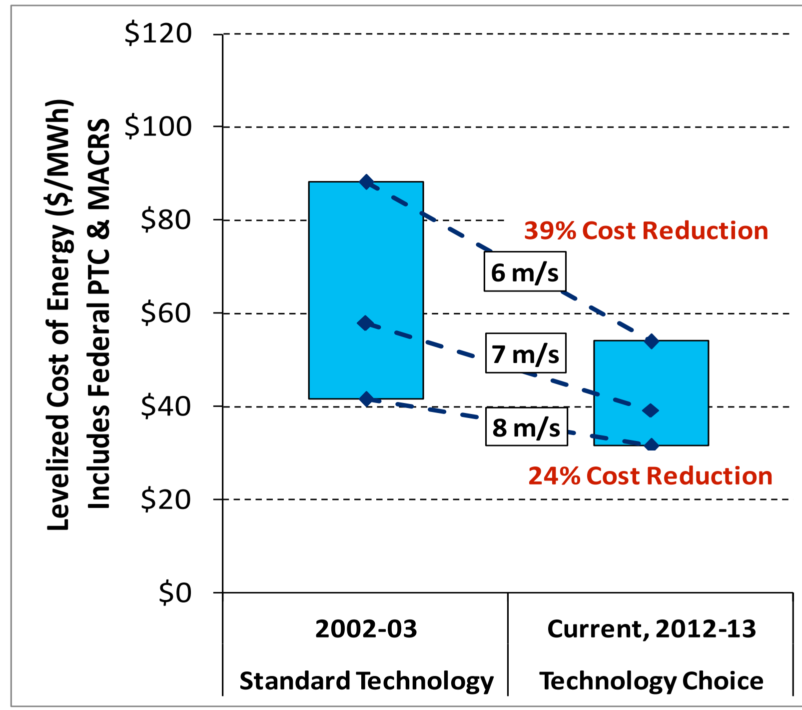
Core Assumptions

only varies capital cost and capacity factor



Side Analysis Assumptions

also varies O&M, availability, and financing



Note: "Technology Choice" assumes that IEC Class III machines are only available for sites up to 7.5 m/s average wind speed at hub height (sea level air density)

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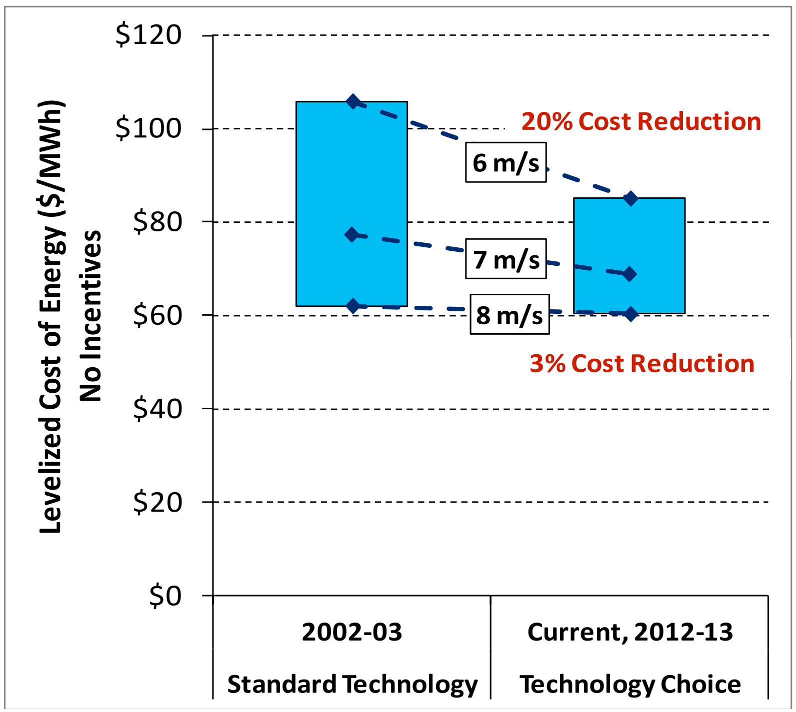
Side Analysis: Impact of Improvements in O&M, Financing, and Availability (*without* PTC/MACRS)

Assumed improvements in O&M costs, financing rates, and availability lead to substantial additional estimated LCOE reductions from 2002-2003 to 2012-2013 in comparison to core analysis that only varies capital cost and capacity factor

Core Assumptions

only varies capital cost and capacity factor



Side Analysis Assumptions

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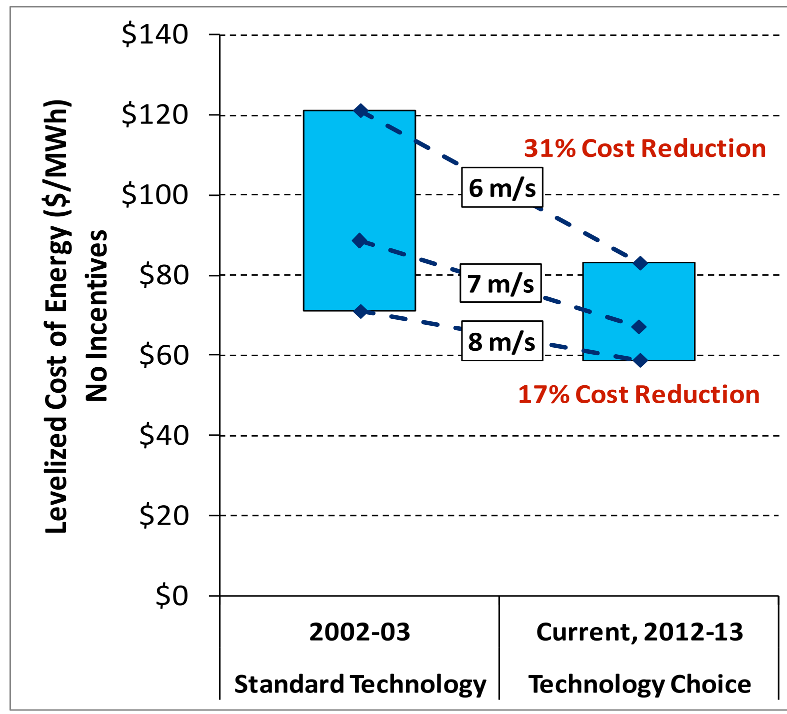

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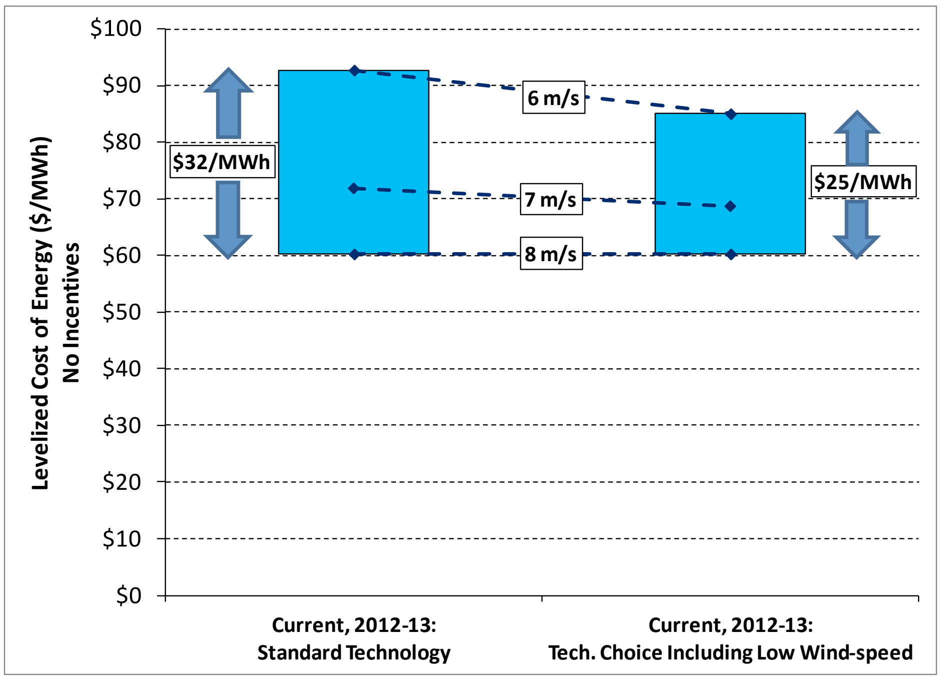
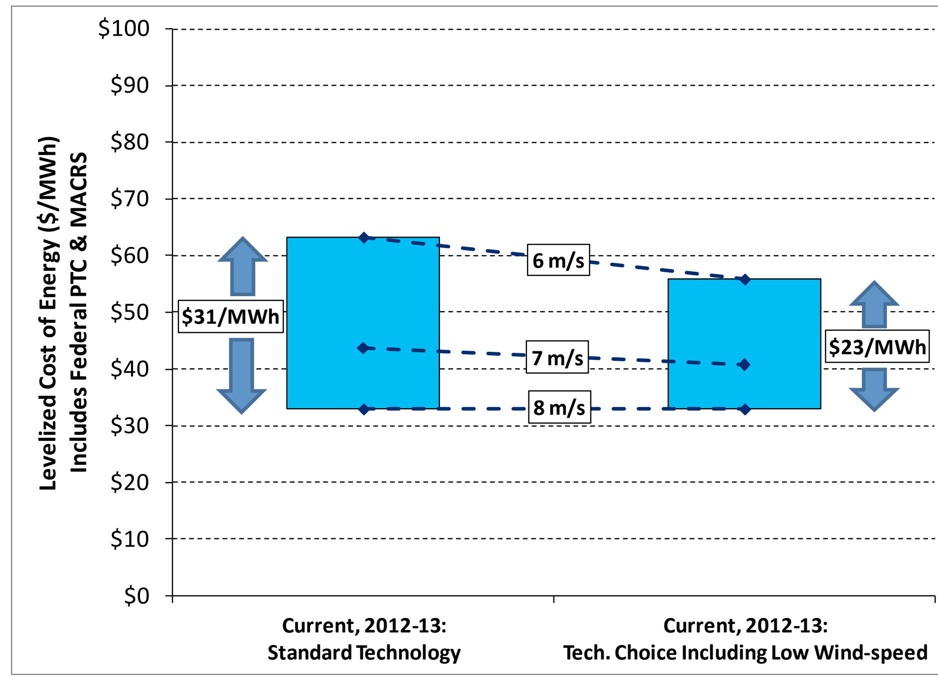
Designing Turbines for Low Wind-Speed Sites: Narrowing the Gap in LCOE

The proliferation of turbines designed for lower wind speeds has narrowed the gap between the LCOE of high- and low- wind speed sites, increasing the economic attractiveness of developing wind projects in lower wind speed areas

Without Federal Incentives



With Federal PTC/MACRS



Notes: Does not consider Treasury Grant program / 30% ITC (see later results); "Tech. Choice" assumes that IEC Class III machines are only available for sites up to 7.5 m/s average wind speed at hub height (sea level air density)

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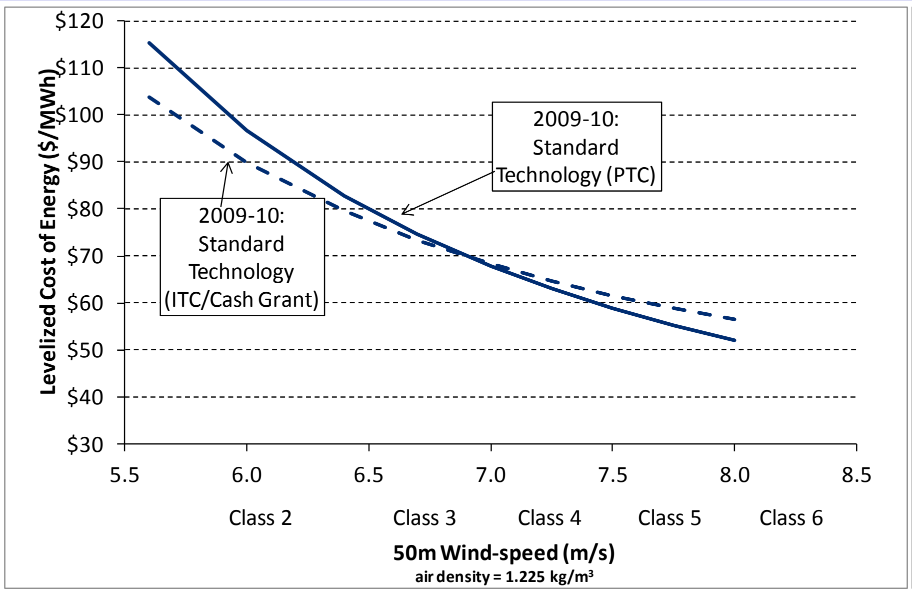
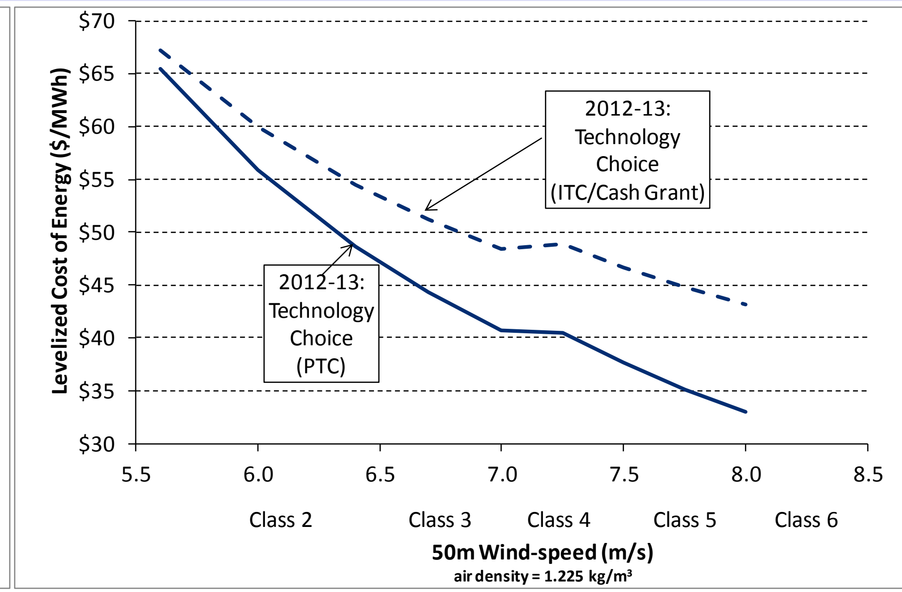
Side Analysis: Incentive Choice Has Also Impacted the Economics of Low Wind Speed Sites

- 30% ITC/Grant applied to capital cost is relatively more lucrative than PTC on "face-value" basis when a project has a low capacity factor and high costs → see results for 2009-2010 'Standard Technology' in chart on left
- Current turbines / pricing have higher assumed capacity factors and lower costs, making PTC the better choice in virtually all developable wind regimes on "face value" basis → see results for 2012-2013 turbines in chart on right





Note: Results ignore benefits of ITC/Treasury grant beyond direct face value;

"Technology Choice" assumes that IEC Class III machines are only available for sites up to 7.5 m/s average wind speed at hub height (sea level air density)

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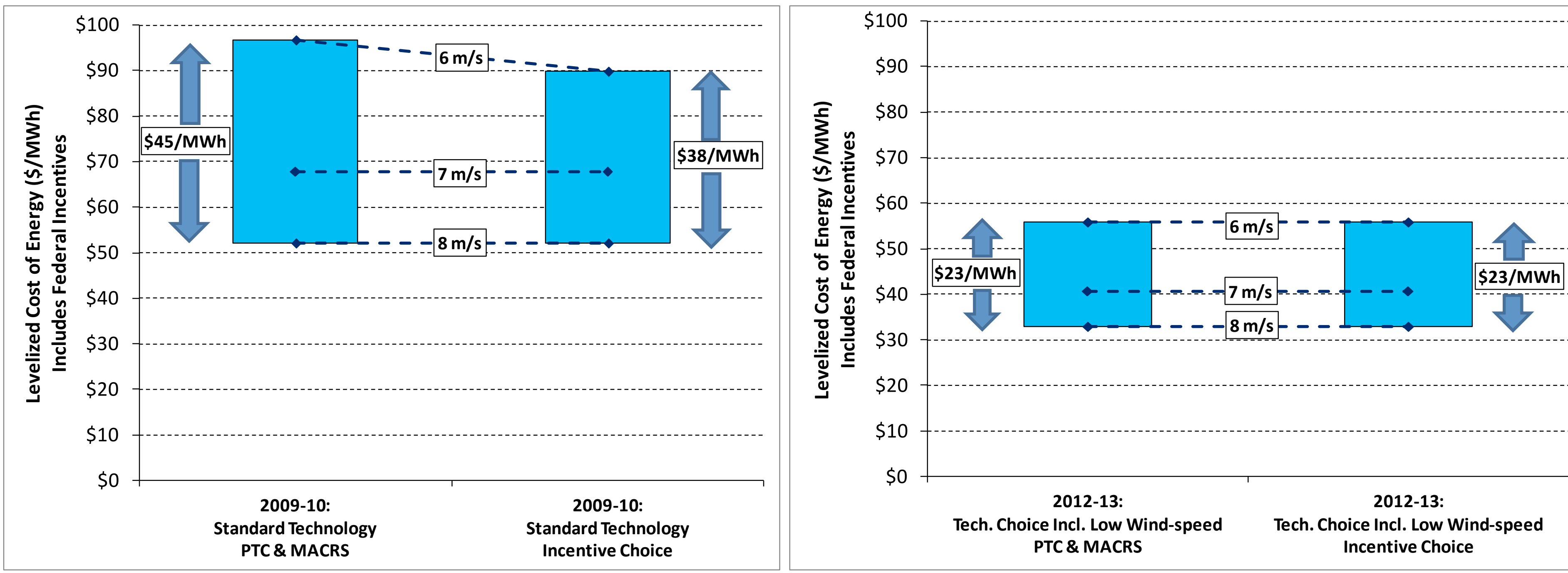
Result Was Narrowing in LCOE Between High & Low Wind Sites in 2009-2010, Not in 2012-2013

ITC/Grant improved the economics of low wind speed sites in 2009-2010; estimated lower capital costs and improved capacity factors result in face value of PTC > ITC/Grant in 2012-2013 even in low wind speed sites *(ancillary benefits of ITC/Grant may still outweigh loss in face value in such sites)*



Note: "Tech. Choice" assumes that IEC Class III machines are only available for sites up to 7.5 m/s average wind speed at hub height (sea level air density)

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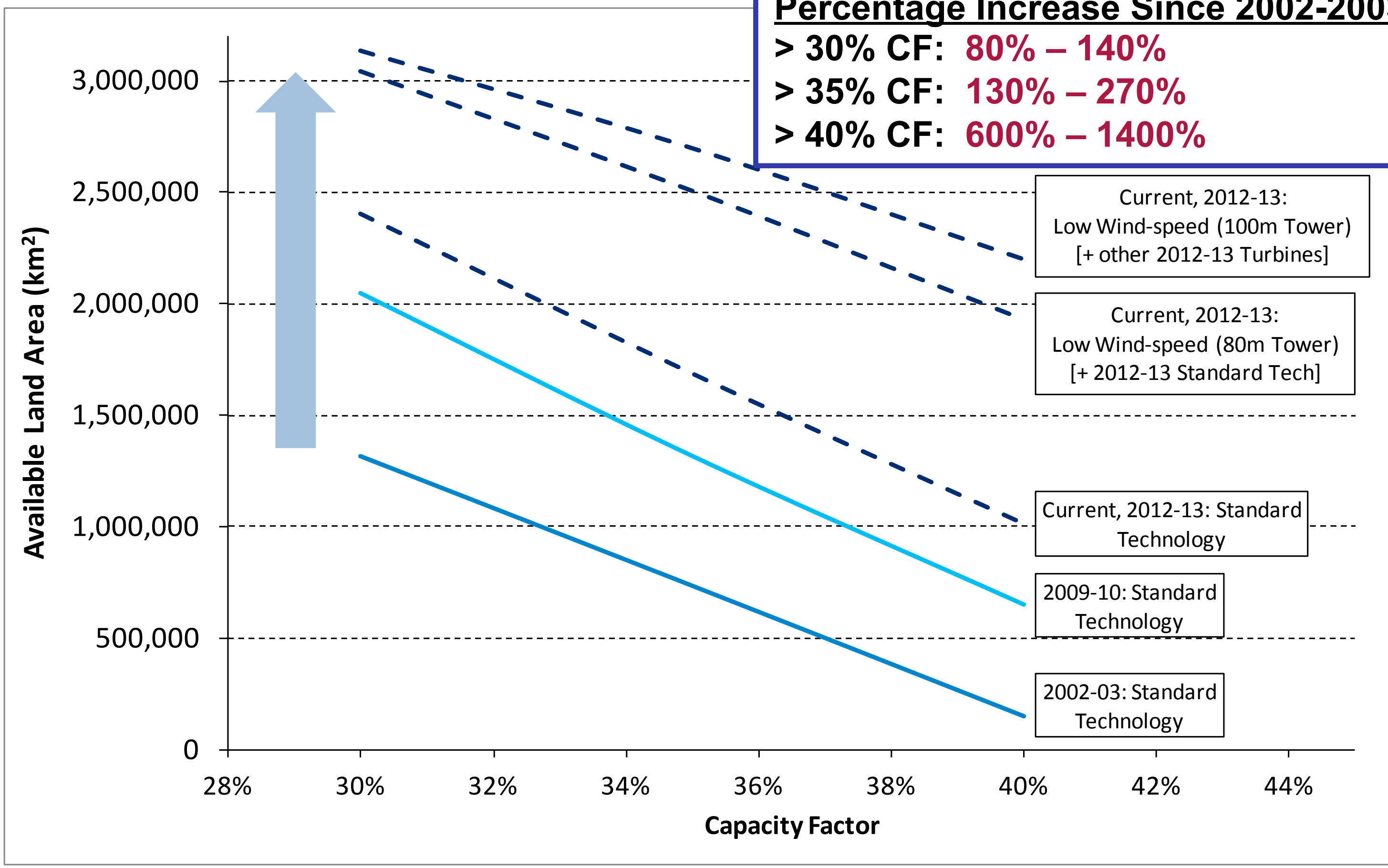
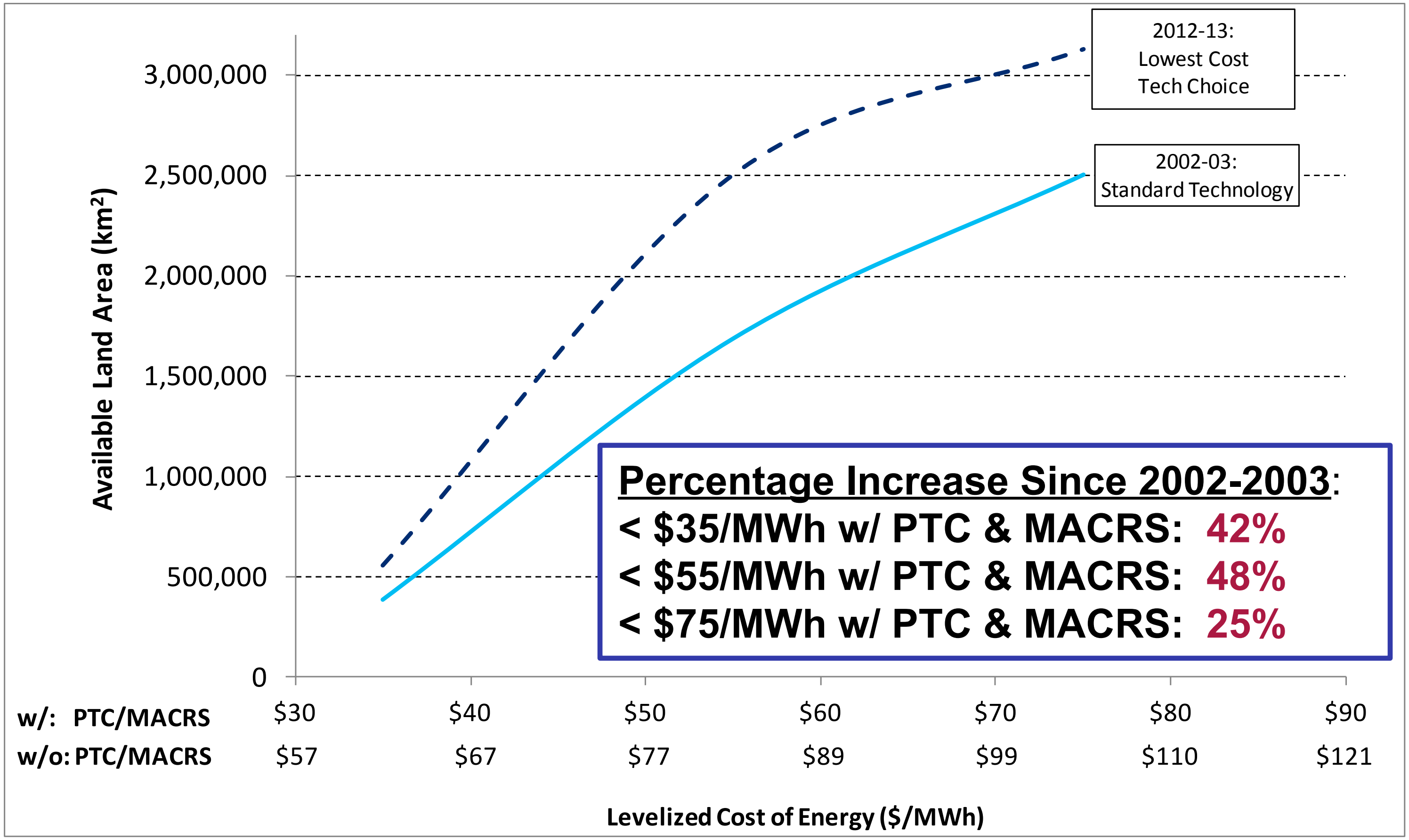
Land Area Exceeding Capacity Factor Thresholds Has Increased Dramatically

Percentage Increase Since 2002-2003:
> 30% CF: 80% – 140%
> 35% CF: 130% – 270%
> 40% CF: 600% – 1400%



Notes: Wind speed data come from the 50 m long-term assessments produced by AWS Truepower, MN Dept of Commerce, Iowa State Energy Center, Alternative Energy Institute (Texas), and NREL. Alabama, Louisiana, Mississippi, and Florida were not covered by any of these datasets. Standard wind resource exclusions were applied, as documented on the Wind Powering America website. Low wind-speed turbines are assumed to be utilized in sites up to 7.5 m/s sea level equivalent average annual wind-speed, per IEC standards. Site specific conditions may allow these machines to be placed in higher average annual wind-speed sites, which would further increase the percentage increase in available land area beyond what is estimated here.

Land Area Exceeding LCOE Thresholds Has Also Increased Substantially



Notes: Increase in land area meeting a LCOE threshold is lower than the increase from a CF threshold because increased capital cost trends impact LCOE estimates, but not CF; "Tech. Choice" assumes that IEC Class III machines are only available for sites up to 7.5 m/s average wind speed at hub height (sea level air density)

Conclusions

- Economic attractiveness of wind projects in recent past was reduced due to increased capital cost, move toward lower wind speed sites, and lower electricity prices
- Examination of historical trends in capital costs and capacity factors, individually, gives an incomplete picture of technology advancement as well as historical & current developments
- Recent declines in turbine prices & improved technology have reduced the estimated LCOE of wind; LCOE for projects being planned today in fixed resource areas is estimated to be at an all-time low
- Considering plausible assumptions for not only capital cost and capacity factor, but also O&M, financing & availability, the **LCOE for 2012-2013 projects is estimated to be as much as ~24% and ~39% lower than the previous low in 2002-2003** in 8 m/s and 6 m/s (at 50 m) resource areas, respectively (with the PTC/MACRS); **when only considering capital cost and capacity factor, the reduction is ~5% and ~26%**

Conclusions

- Technology advancement for lower wind speeds has narrowed the gap in LCOE between lower and higher wind speed sites; choice of 30% ITC/ Treasury Grant may have further encouraged development in lower wind speed sites, especially in 2009-2010
- The amount of land area meeting or exceeding certain capacity factor and LCOE thresholds has substantially increased as a result of these technology improvements → helps alleviate to a degree transmission and siting barriers
- Technology advancement & learning still applies to onshore wind, despite its relative maturity, but all modes of technical advancement must be considered rather than emphasizing individual parameters
- Despite these recent and impressive technological advancements, three counter-veiling factors may intervene to raise LCOE:
  - potential for increased pricing if demand for wind turbines begins to catch up with supply, or if other exogenous influences are triggered (e.g., higher commodities and/or labor costs)
  - potential continued move towards lower wind speed sites as a result of severe transmission/siting limitations
  - potential near-term loss of federal PTC/ITC/Treasury Grant