Understanding Trends in Wind Turbine Prices Over the Past Decade

Mark Bolinger and Ryan Wiser
Lawrence Berkeley National Laboratory

October, 2011

The work described in this presentation was funded by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (Wind & Water Power Program) under Contract No. DE-AC02-05CH11231

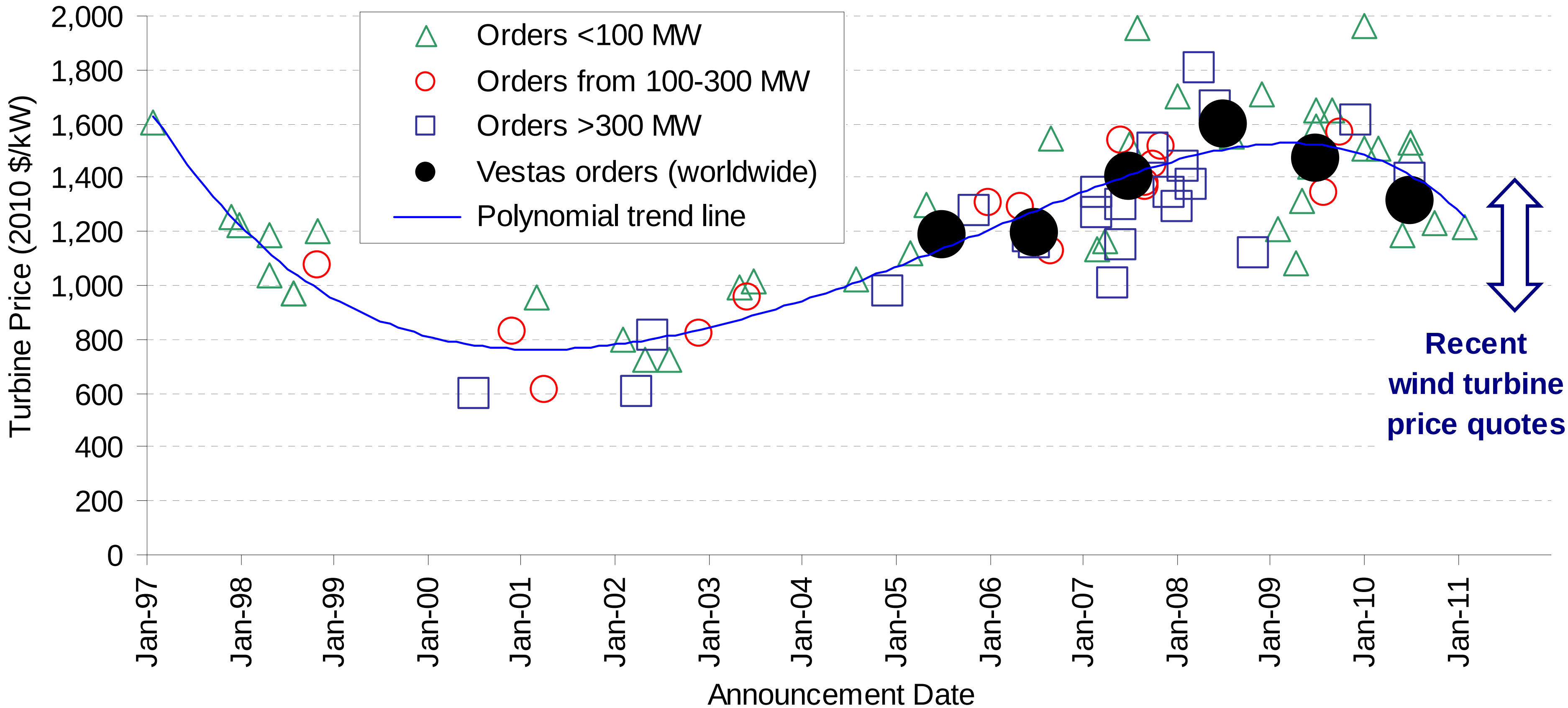
Motivation

1) Turbine prices in the U.S. have fallen ~20%-30% in recent years, but from elevated levels – prices had previously *doubled* from 2002-2008
2) This doubling in price contradicts standard "learning curve" theory, and requires an alternate explanation
   - Traditional learning curves suggest that wind project costs should fall by 10-15% for each doubling in installed capacity
   - Global installed wind capacity doubled *twice* from 2002-2008, suggesting a 20%-30% cost *decrease* should have occurred
3) This divergence between theory and reality has important implications for the wind industry, policymakers, R&D program managers, and energy analysts
4) Although LCOE is the true metric of concern, turbine prices account for roughly 50%-60% of LCOE (60%-70% of project costs), so this is a first step to understanding changes in LCOE

Presentation Outline

1) Documentation of Turbine Price Trends
2) Analysis of Seven Turbine Price Drivers
    - 4 endogenous: labor costs, warranty provisions, profitability, turbine design (i.e., scaling)
    - 3 exogenous: raw materials prices, energy prices, foreign exchange rates
3) Magnitude of Impact from 2002-2010
    - By individual driver over two periods: 2002-08 and 2009-2010
    - All 7 drivers in aggregate on a yearly basis from 2002-2010
4) Conclusions

Documentation of Turbine Price Trends



- LBNL sample is 81 transactions totaling ~24 GW
- Vestas global orders total >30 GW from 2005-2010

Analysis of Seven Turbine Price Drivers

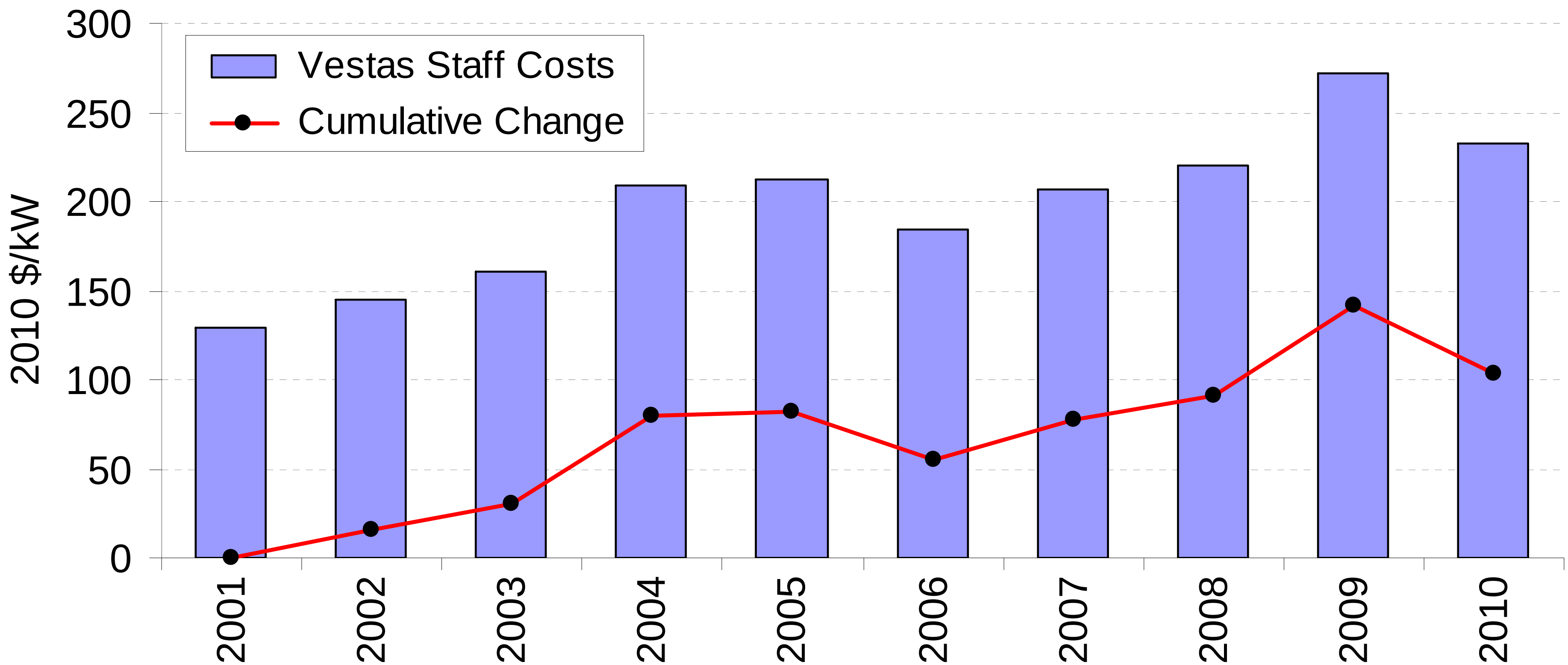
1) Endogenous
   - Labor Costs
   - Warranty Provisions
   - Turbine Manufacturer Profitability
   - Turbine Design (scaling)
2) Exogenous
   - Raw Materials Prices
   - Energy Prices
   - Foreign Exchange Rates

First 3 Drivers Rely on Vestas' Financials

- Estimates of labor costs, warranty provisions, and profitability all depend on turbine OEM financial filings
- Among the top 6 turbine OEMs that installed 92% of all capacity in the US from 2002-2010, only Vestas files financial reports that contain directly applicable and complete historical data on these three drivers
- Vestas can serve as a proxy for the US market over this period: ranked 2nd in US (1st globally); homogenous technology among OEMs; competitive US market; focus is on changes over time rather than on absolute numbers

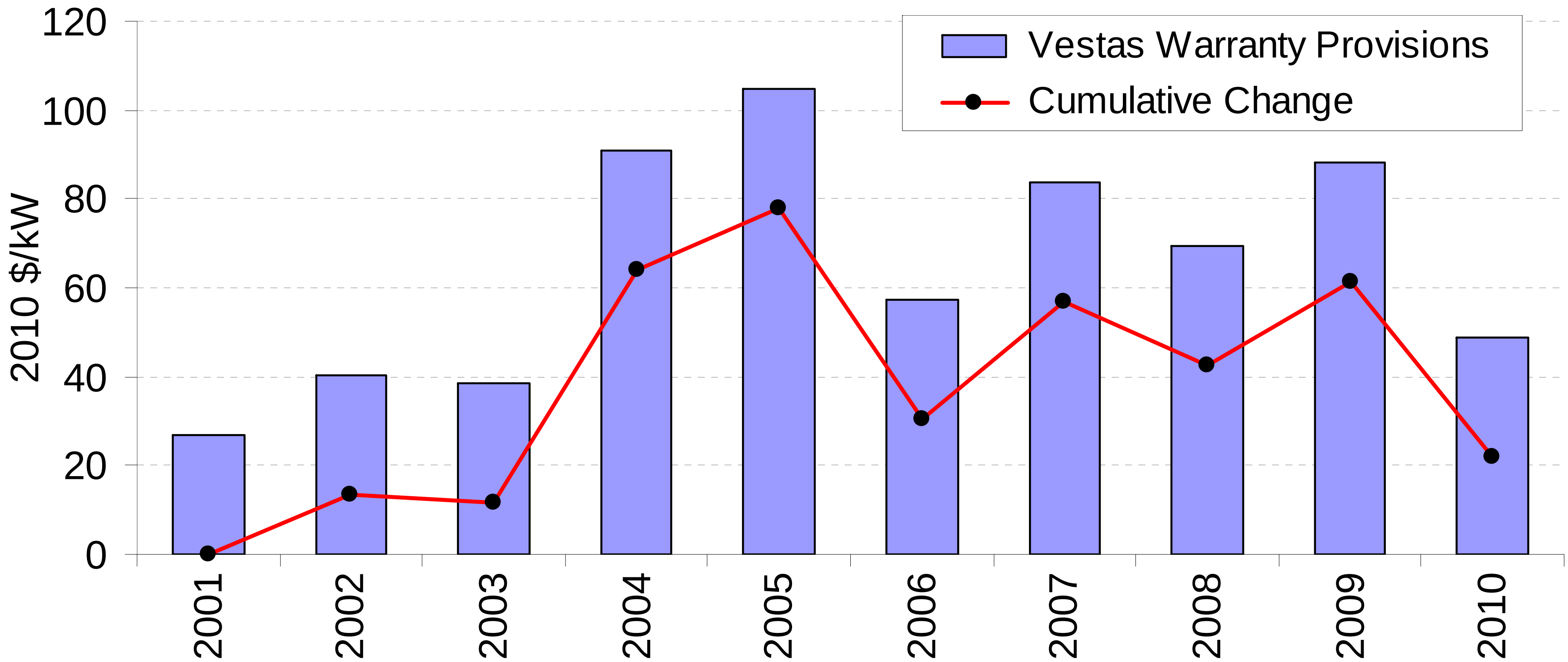
		MW Installed 2002-10	% Market Share	
1	GE Wind	16,174	45%	Conglomerate – does not break out wind numbers
2	Vestas	5,523	15%	Only "pure-play" wind OEM with full history
3	Siemens	4,216	12%	Conglomerate – does not break out wind numbers
4	Mitsubishi	2,737	8%	Conglomerate – does not break out wind numbers
5	Gamesa	2,454	7%	Subsidiary issues (aeronautics, solar); limited history
6	Suzlon	2,080	6%	Subsidiary issues (REpower, Hansen); limited history
	Top 6 Total:	**33,184**	**92%**	

Vestas Labor Costs



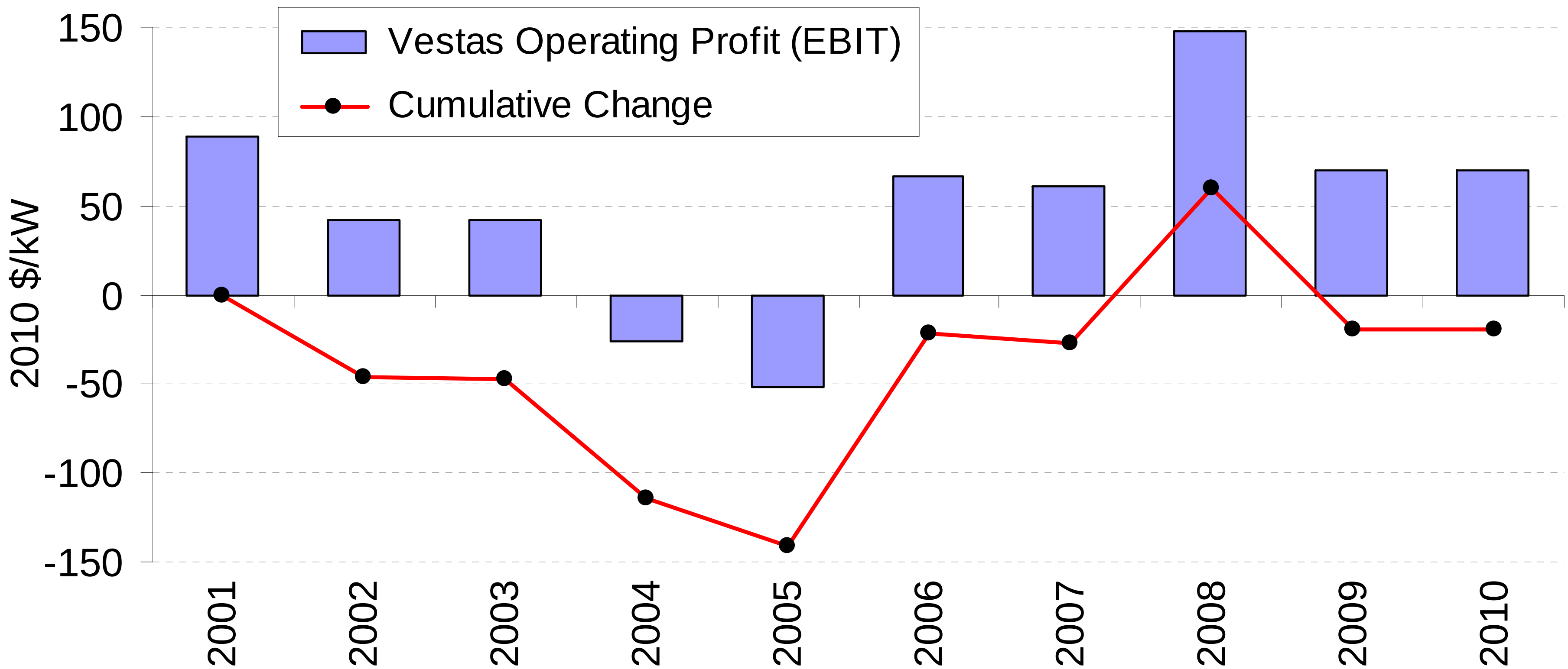
Cumulative $142/kW increase through 2009, with a subsequent $39/kW drop in 2010 ($103/kW increase over entire 2002-2010 period)

Vestas Warranty Provisions



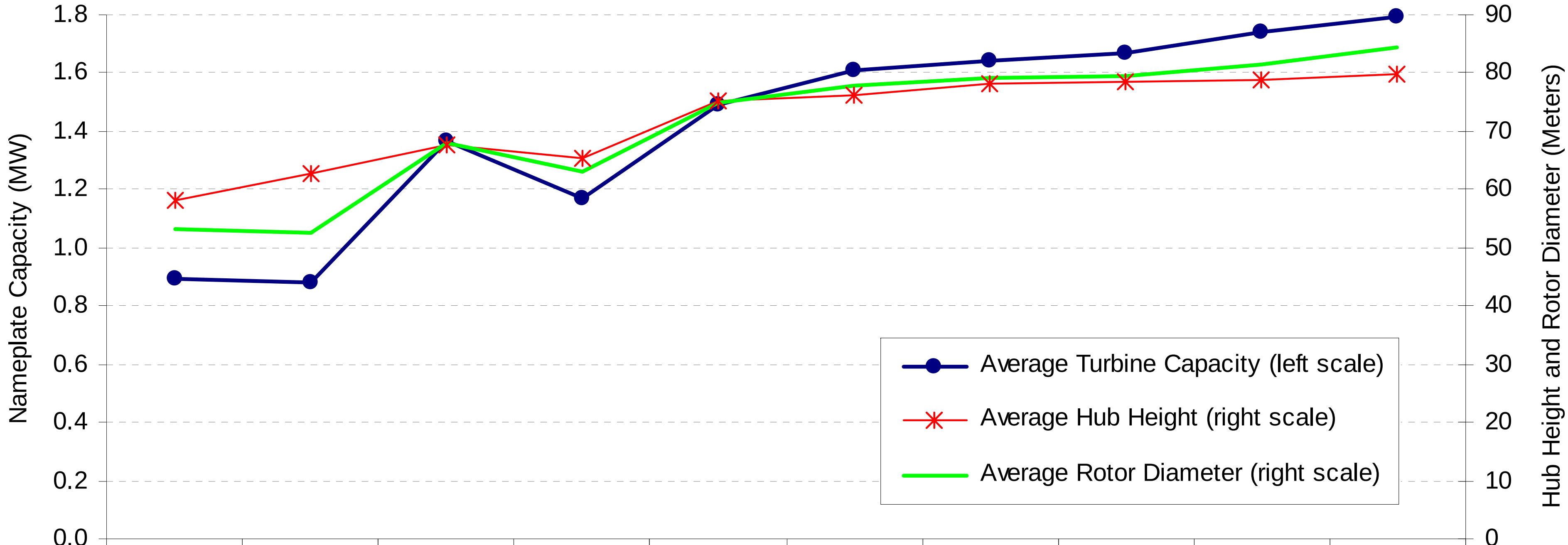
Cumulative $61/kW increase through 2009, with a subsequent $39/kW drop in 2010 (a $22/kW increase over entire 2002-2010 period)

Vestas Profitability



Cumulative $59/kW increase through 2008, with a subsequent $78/kW drop in 2009 and no change in 2010 (a $19/kW decrease over 2002-2010)

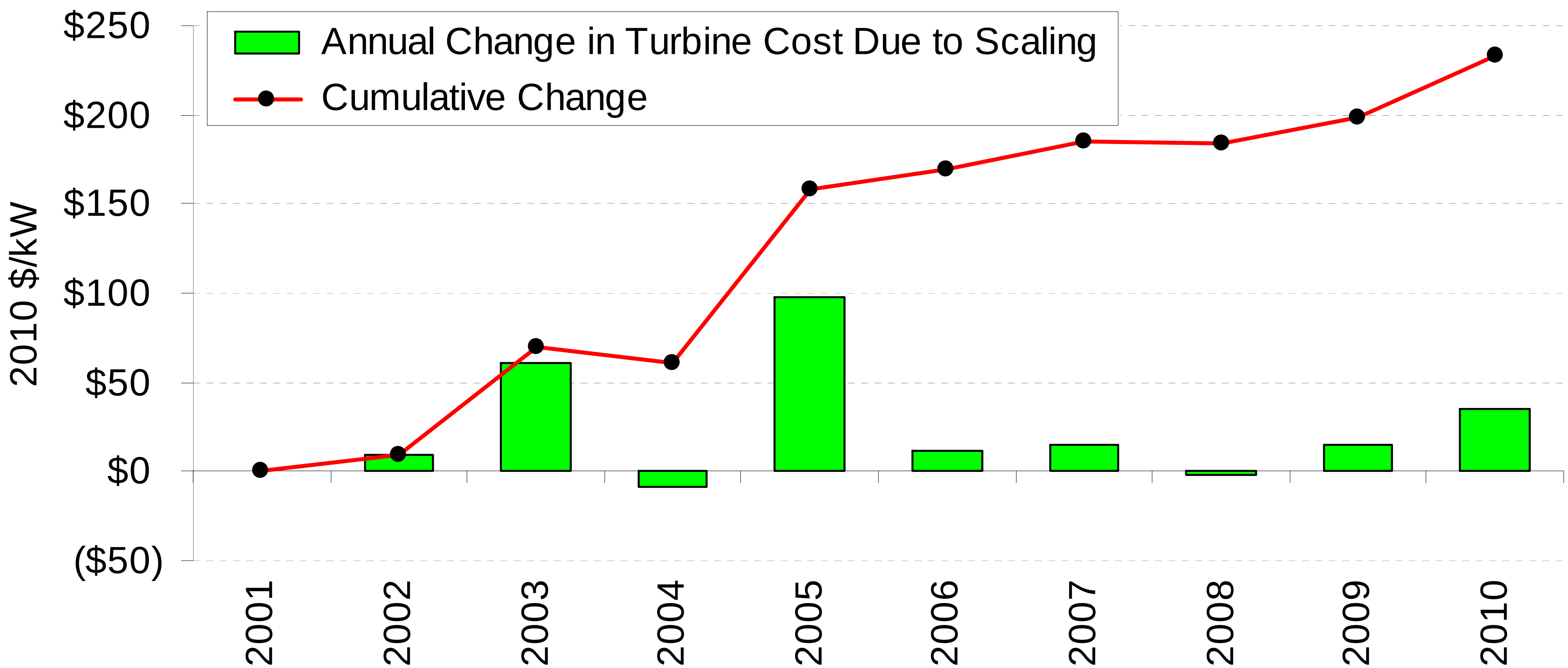
Turbine Design (Scaling)



COD:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Turbines:	1,895	467	1,219	351	1,591	1,515	3,190	5,004	5,733	2,855
Capacity:	1,690 MW	412 MW	1,668 MW	409 MW	2,370 MW	2,440 MW	5,249 MW	8,348 MW	9,993 MW	5,113 MW

- From 2001-2010, average capacity increased by 101%, hub height by 37%, and rotor diameter by 59%
- NREL's "turbine cost and scaling model" enables us to isolate the cost impact of this scaling

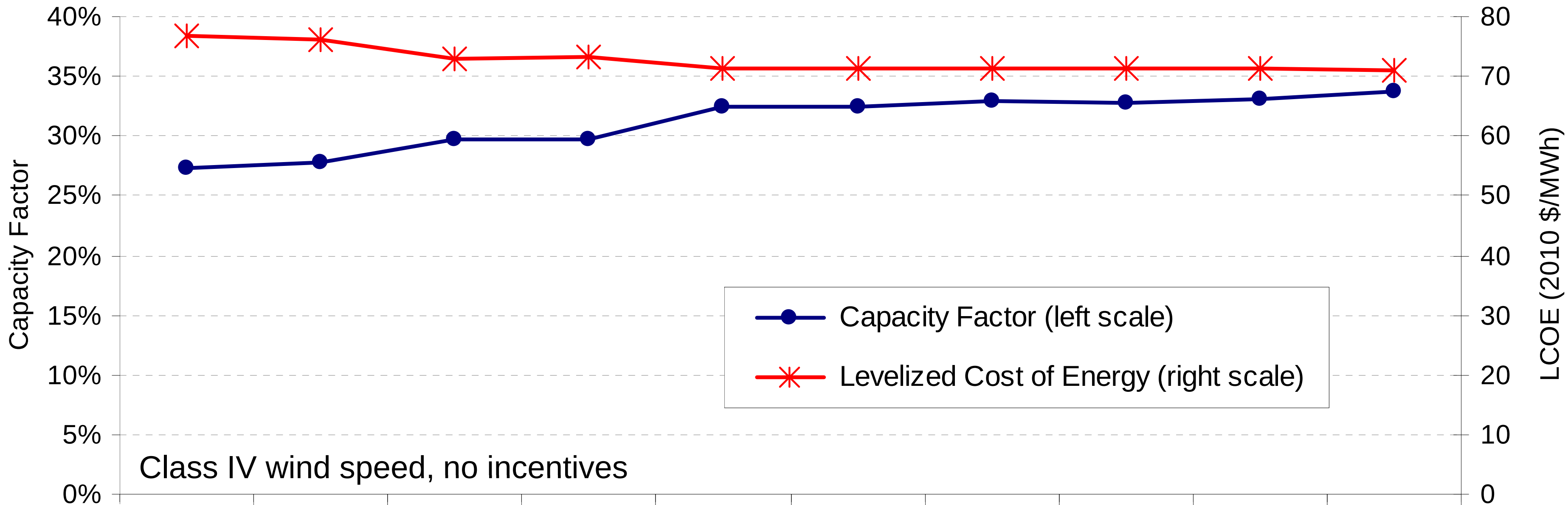
Scaling Impact



Cumulative $233/kW increase over entire 2002-2010 period

2 caveats: (1) NREL's model focuses only on scaling, not other design or efficiency improvements; (2) NREL's model relies on standard relationships between size, weight, and other parameters, and will not capture design innovation outside the bounds of these relationships

*BUT…*Scaling Also Enables Higher Capacity Factor & Lower LCOE



COD:	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Capacity:	0.89 MW	0.88 MW	1.37 MW	1.17 MW	1.49 MW	1.61 MW	1.65 MW	1.67 MW	1.74 MW	1.79 MW
HH:	58.2 m	62.7 m	67.6 m	65.3 m	75.3 m	76.1 m	78.2 m	78.5 m	78.9 m	79.8 m
RD:	53.1 m	52.7 m	68.2 m	63.2 m	74.8 m	77.8 m	79.0 m	79.3 m	81.6 m	84.3 m

Unlike the other drivers analyzed, the higher $/kW cost of scaling results in a benefit (lower LCOE) that outweighs the incremental cost

Analysis of Seven Turbine Price Drivers

1) Endogenous
   - Labor Costs
   - Warranty Provisions
   - Turbine Manufacturer Profitability
   - Turbine Design (scaling)
2) Exogenous
   - Raw Materials Prices
   - Energy Prices
   - Foreign Exchange Rates

"Bill of Materials" is Fairly Consistent Across Different Turbines

Turbine make/model:	Vestas V82	Gamesa G8X	Vestas V80	Vestas V112
Nameplate capacity:	1.65 MW	2.0 MW	2.0 MW	3.0 MW
Tower height:	78 meters	67 meters	78 meters	84 meters
Rotor diameter:	82 meters	80 meters	80 meters	112 meters
Mass (kg per kW)				
Steel	96.3	82.3	104.7	81.7
Fiberglass/Resin/Plastic	18.2	11.1	12.3	16.3
Iron/Cast Iron	17.8	16.3	10.3	21.9
Copper	1.8	1.8	1.4	1.6
Aluminum	1.9	0.0	0.8	1.1
Total	**135.9**	**111.4**	**129.6**	**122.7**
% of Total Turbine Mass				
Steel	70%	74%	81%	66%
Fiberglass/Resin/Plastic	13%	10%	9%	13%
Iron/Cast Iron	13%	15%	8%	18%
Copper	1%	2%	1%	1%
Aluminum	1%	0%	1%	1%
Total	**98.3%**	**100.0%**	**99.9%**	**99.0%**

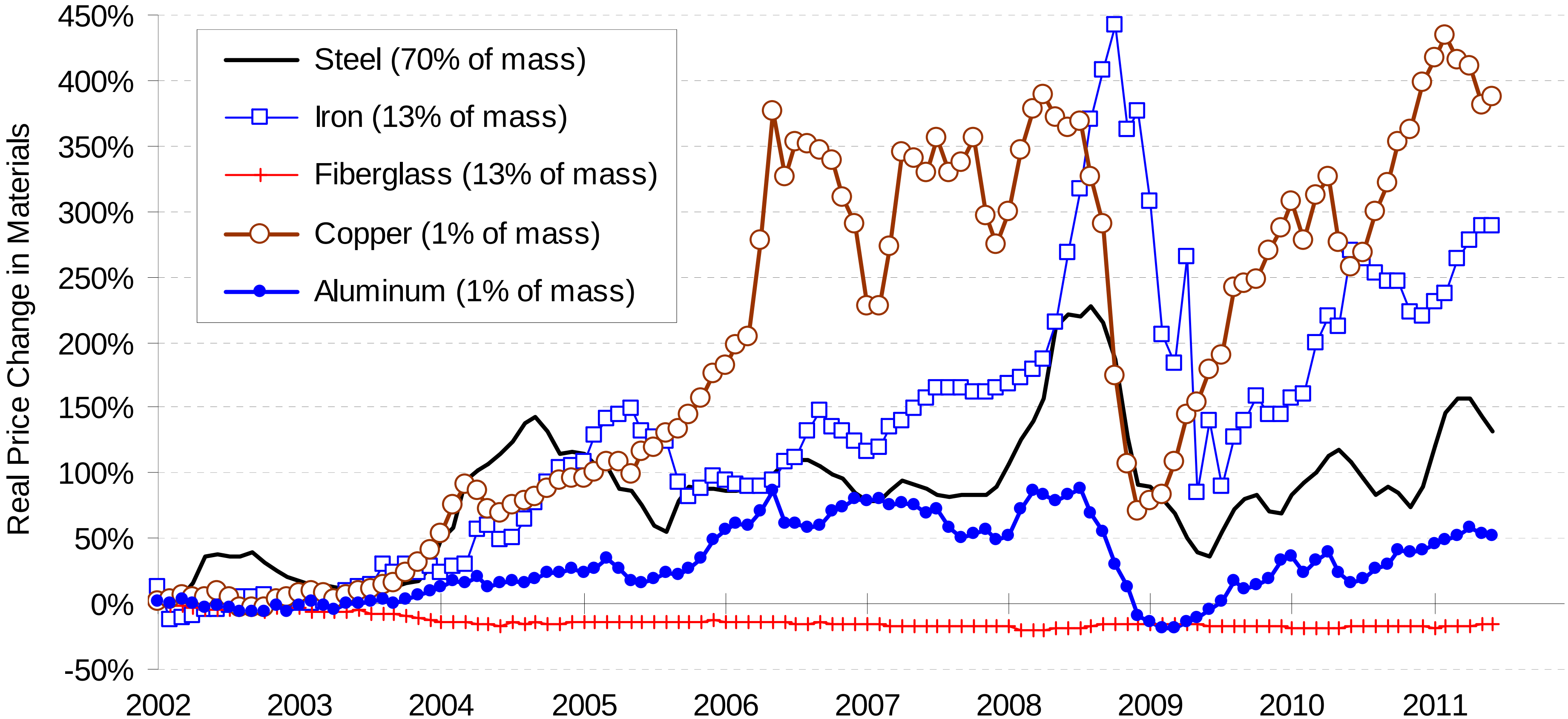
Source: Vestas 2006b, Martínez et al. 2009, Elsam 2004, D'Souza et al. 2011

The mass data come from life-cycle analyses (LCAs) of these four turbines, and are fairly consistent across turbines.

We focus on the Vestas V82 (1.65 MW) data, for two reasons:

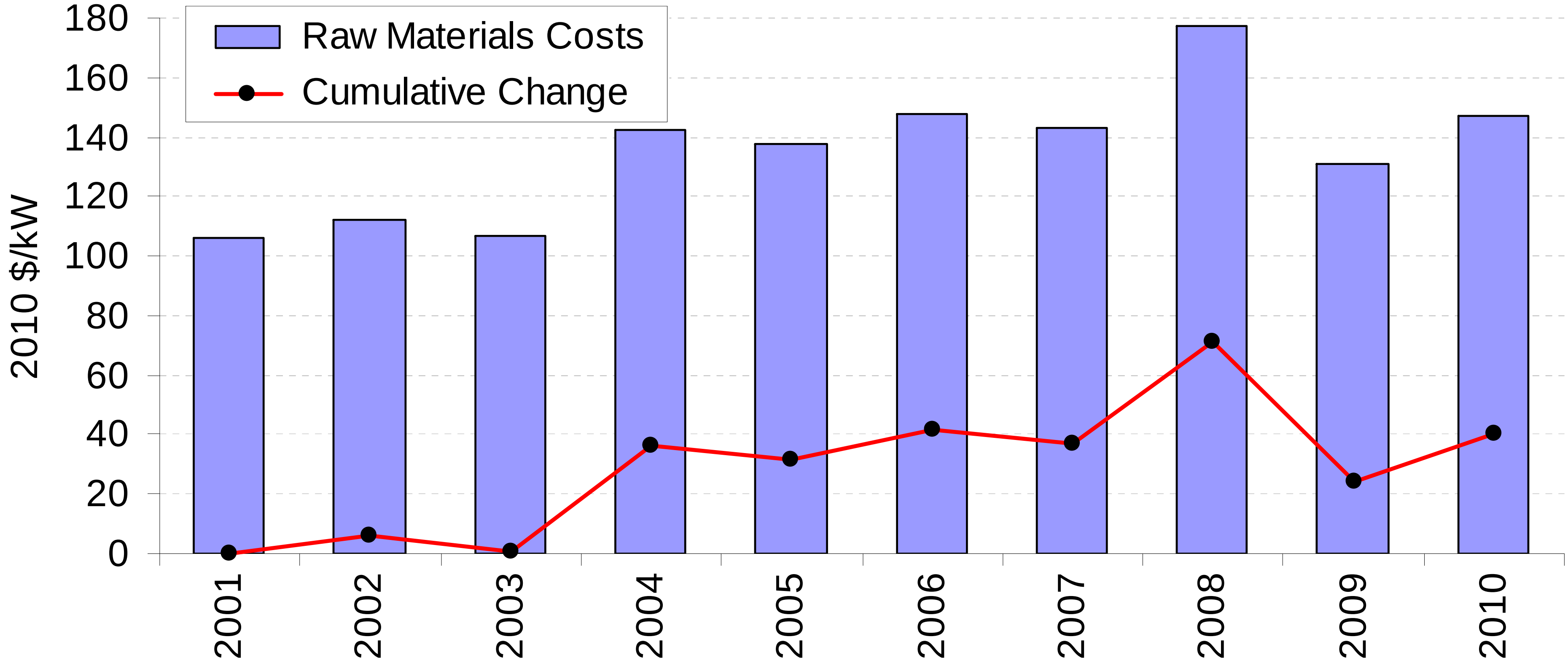
1) 1.65 MW is most representative of the avg turbine size installed 2002-2010
2) The V82 LCA also provides a useful breakdown on energy consumption

Raw Materials Prices



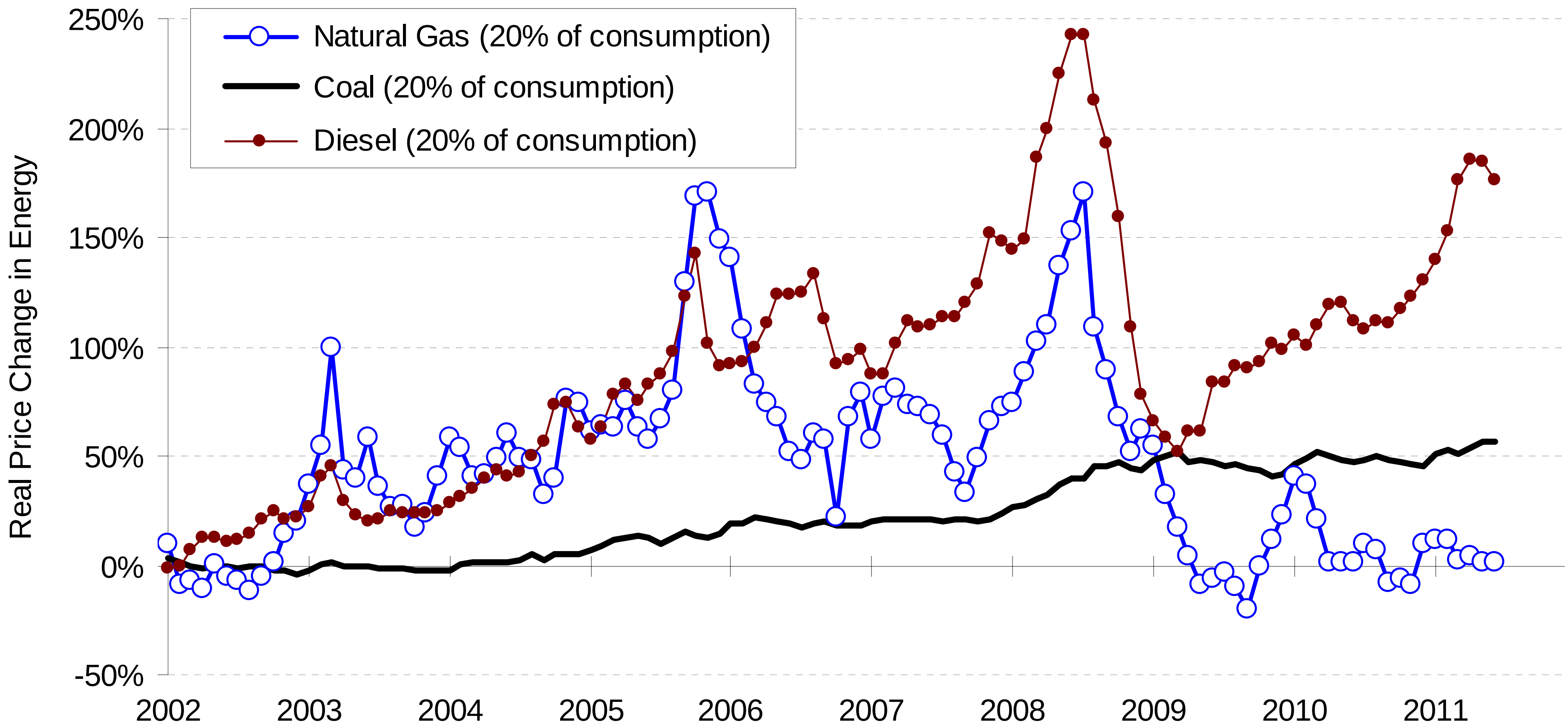
Ferrous metals (steel and iron) account for the bulk of the mass, and have the largest price impact.

Raw Materials Impact



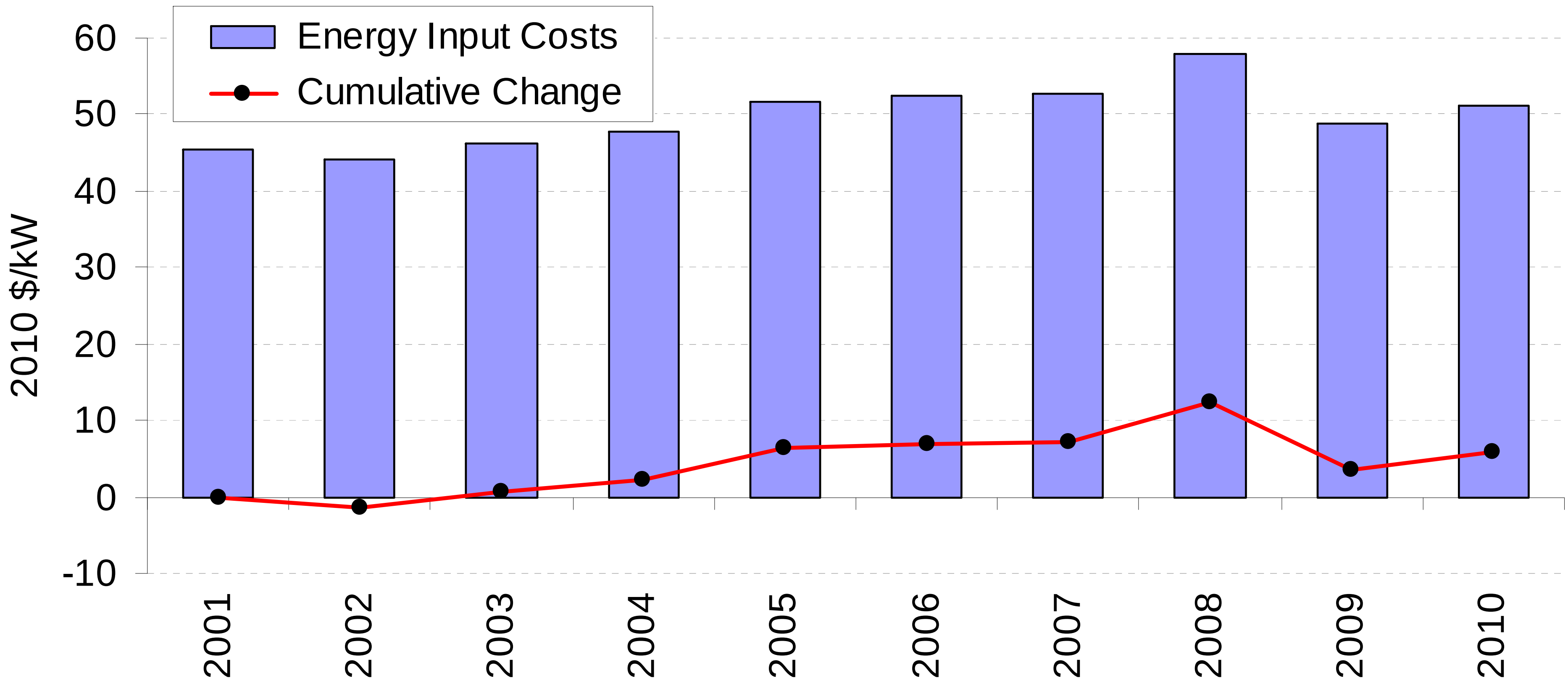
Cumulative $71/kW increase through 2008, with a subsequent $31/kW drop in 2009-10 (a $41/kW increase over entire 2002-2010 period)

Energy Prices



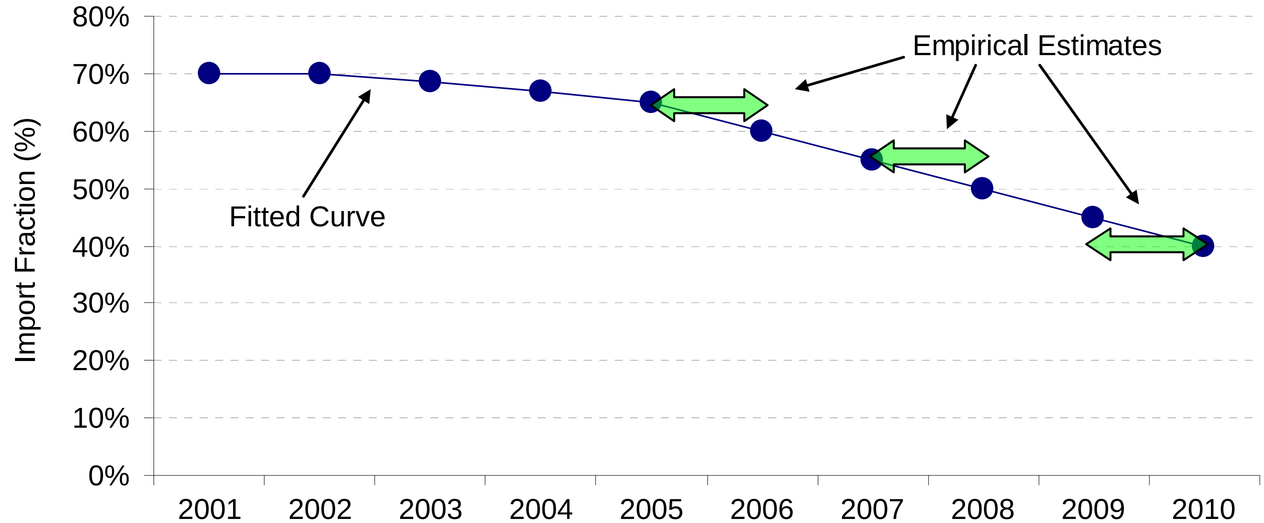
Assume that these fossil fuels equally account for 60% of 3 GJ/kW of primary energy consumption during the manufacturing and transport phases, with the rest coming from stable-priced resources (e.g., nuclear and renewables)

Energy Impact



Cumulative $12/kW increase through 2008, with a subsequent $7/kW drop in 2009-10 (a $6/kW increase over entire 2002-2010 period)

Foreign Exchange Rate Risk: Several Moving Pieces



Analysis must account for a declining import fraction (increasing domestic content) over time…

	2002	2003	2004	2005	2006	2007	2008	2009	2010
Denmark	72.8%	54.9%	36.6%	62.1%	49.0%	37.1%	22.0%	28.1%	42.0%
Euro zone	0.0%	10.2%	0.7%	8.5%	18.6%	24.3%	30.5%	19.1%	8.7%
The U.K.	0.0%	0.0%	2.9%	4.0%	2.8%	4.6%	4.1%	4.3%	0.1%
Japan	6.0%	21.6%	23.5%	10.8%	6.7%	10.5%	11.1%	20.3%	0.7%
India	0.9%	4.0%	0.0%	2.2%	15.2%	9.4%	5.9%	9.8%	16.3%
China	0.0%	0.1%	0.2%	0.3%	1.2%	5.0%	5.8%	5.9%	5.9%
Mexico	17.3%	3.6%	4.6%	2.0%	1.2%	1.4%	1.7%	1.5%	5.6%
South Korea	0.1%	4.6%	9.5%	1.7%	1.2%	2.6%	6.0%	5.3%	2.1%
Canada	1.8%	0.8%	21.7%	3.3%	0.8%	2.0%	4.3%	1.1%	8.4%
Other	*1.1%*	*0.2%*	*0.3%*	*5.1%*	*3.3%*	*3.1%*	*8.5%*	*4.6%*	*10.1%*
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Source: LBNL analysis of U.S. Department of Commerce data, via US ITC DataWeb

…as well as a shift over time in the countries from which turbine imports originate.

Exchange Rate Pass-Through

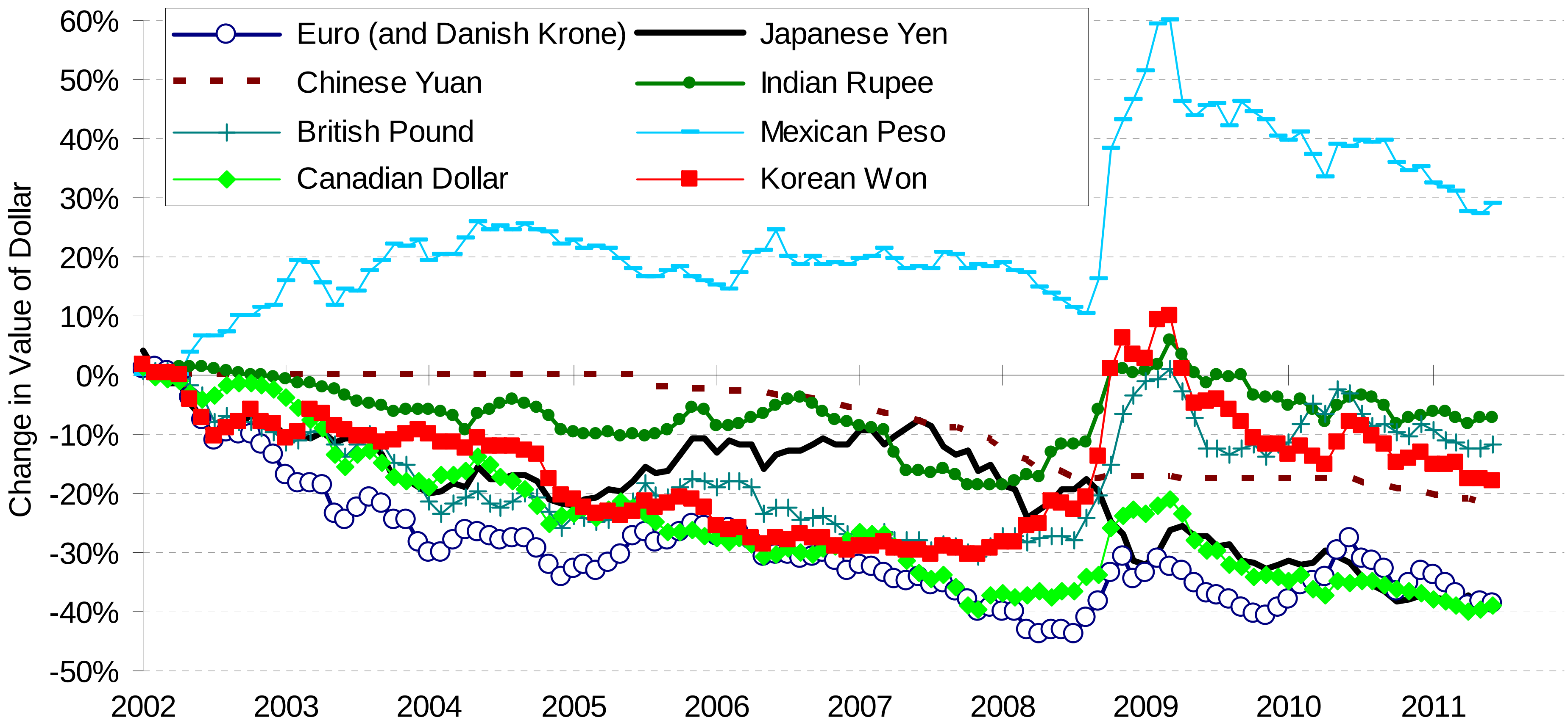
Exporters may not pass along (or even experience) the full extent of exchange rate impacts, for several reasons:

- Cross-border production: importing components from certain countries, while exporting finished goods to others (net impact might be <1:1)
- Pricing to market: absorbing FX-related cost increases (i.e., sacrificing profit margin) in order to increase or maintain market share
- Local currency pricing: most commodities are already priced in USD, and exporters may choose to price their goods in USD for other reasons

Though not specific to wind turbines, the literature on this topic argues for relatively low exchange rate pass-through to the US.

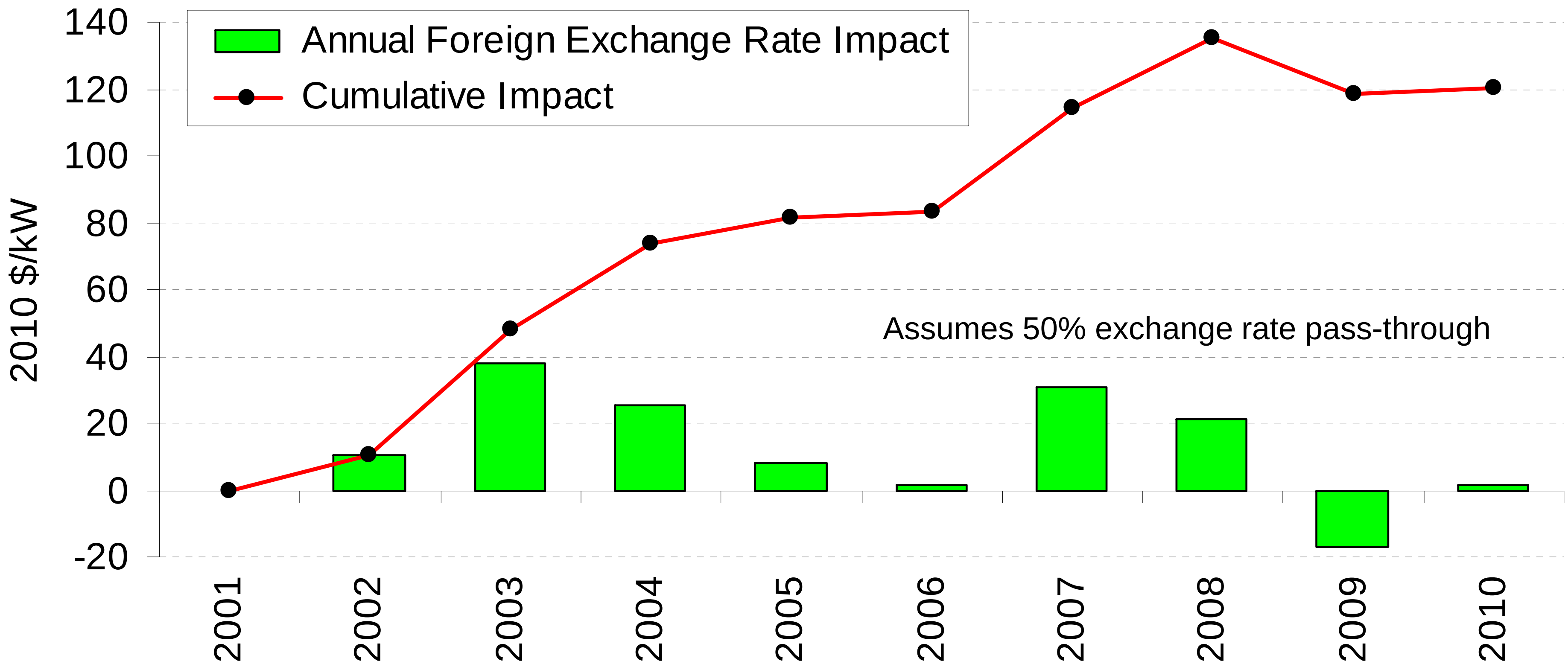
We assume 50% pass-through, but our FX impacts can be easily scaled up or down to reflect different assumptions (e.g., halved for 25% pass-through, doubled for 100% pass-through).

Relevant Foreign Exchange Rates



Since 2001, the dollar has fallen 40% against the Euro, yen, and Canadian dollar (less against other Asian currencies)

Exchange Rate Impacts



Cumulative $136/kW increase through 2008, with a subsequent $15/kW drop in 2009-10 (a $120/kW increase over entire 2002-2010 period)

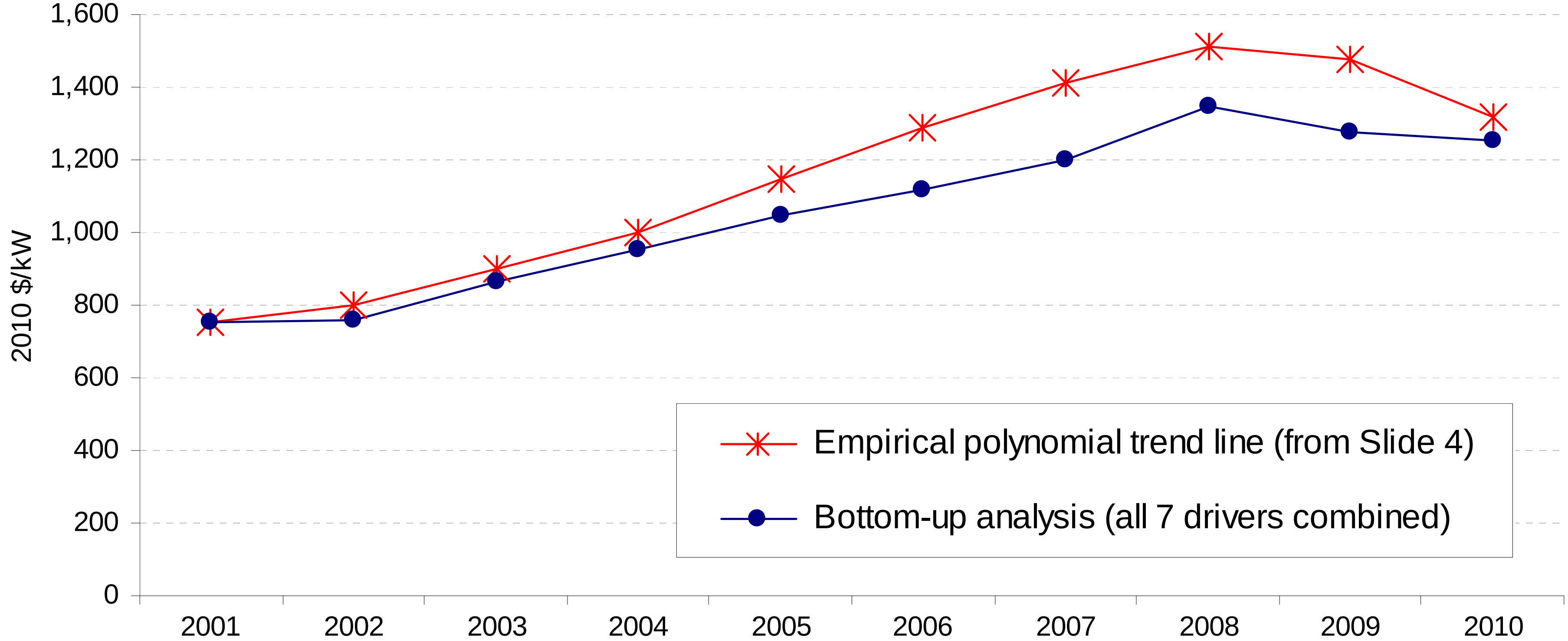
Aggregate Impact: 2002-08 and 2009-10

	2002-2008	2009-2010
Endogenous Drivers	**+$376/kW**	**-$37/kW**
Labor Costs	+91	+12
Warranty Provisions	+42	-20
Profit Margins	+59	-78
Turbine Scaling	+184	+50
Exogenous Drivers	**+$219/kW**	**-$53/kW**
Materials Prices	+71	-31
Steel	*+65*	*-29*
Iron	*+7*	*-2*
Copper	*+9*	*+1*
Aluminum	*+2*	*-1*
Fiberglass	*-11*	*0*
Energy Prices	+12	-7
Diesel	*+10*	*-4*
Coal	*0*	*0*
Natural Gas	*+2*	*-3*
Currency Movements	+136	-15
Total Impact	**+$595/kW**	**-$89/kW**

This bottom-up analysis explains nearly 80% of the increase in turbine prices through 2008 (but less of the decline since then).

Endogenous drivers outweigh exogenous…BUT the largest single impact – from scaling – brings LCOE benefits

Aggregate Impact: All 7 Drivers, Yearly



- In aggregate, these 7 drivers explain 68%-89% of cumulative turbine price movements over this period (depending on the year)
- The notable “wedge” between the two lines (starting in 2005) may be explained by a number of factors, discussed on the next slide

Explaining the Gap

1) We have not captured changes in labor costs or profit margins among component suppliers
   - Most suppliers are not publicly traded (limits data disclosure)
   - Those that are public often serve multiple industries (not wind-specific)
   - Even with a representative sample, it's not clear how to derive $/kW impacts (how to gauge kW for a blade or bearing manufacturer?)
2) FX pass-through could be higher than 50%, though not likely much higher than 80% (as commodities account for ~20%)
3) Beyond scaling, turbines have become more sophisticated and efficient over time, which can add costs (though again, with LCOE and/or grid integration benefits)
4) We rely on Vestas data when the market was served by numerous OEMs, most notably GE Wind

Conclusions

1) No single dominant factor drove turbine prices higher through 2008 or lower since then
2) Scaling had the largest impact through 2008, and could cap any future cost declines, though not without benefit (lower LCOE). Given this tradeoff between capital cost and performance, LCOE is likely a better indicator of "technology learning" than is capital cost.
3) Dollar weakness was another large driver through 2008, but greater localization of the supply chain since then has mitigated the risk of further weakness (and also reduced transport costs)
4) Turbine prices continued to fall through the first half of 2011 (on lower labor costs, warranty provisions, and profit margins), but have recently stabilized as demand picks up ahead of the expiration of the Section 1603 cash grant program
5) Potential impact of impending 1603 grant expiration on turbine prices highlights an *indirect* turbine price driver not otherwise covered in this report – policy risk