MEASURING THE COST AND VALUE OF WIND AND SOLAR

(General Observations and Comments on Gowrisankaran, Reynolds and Samano --- GRS)

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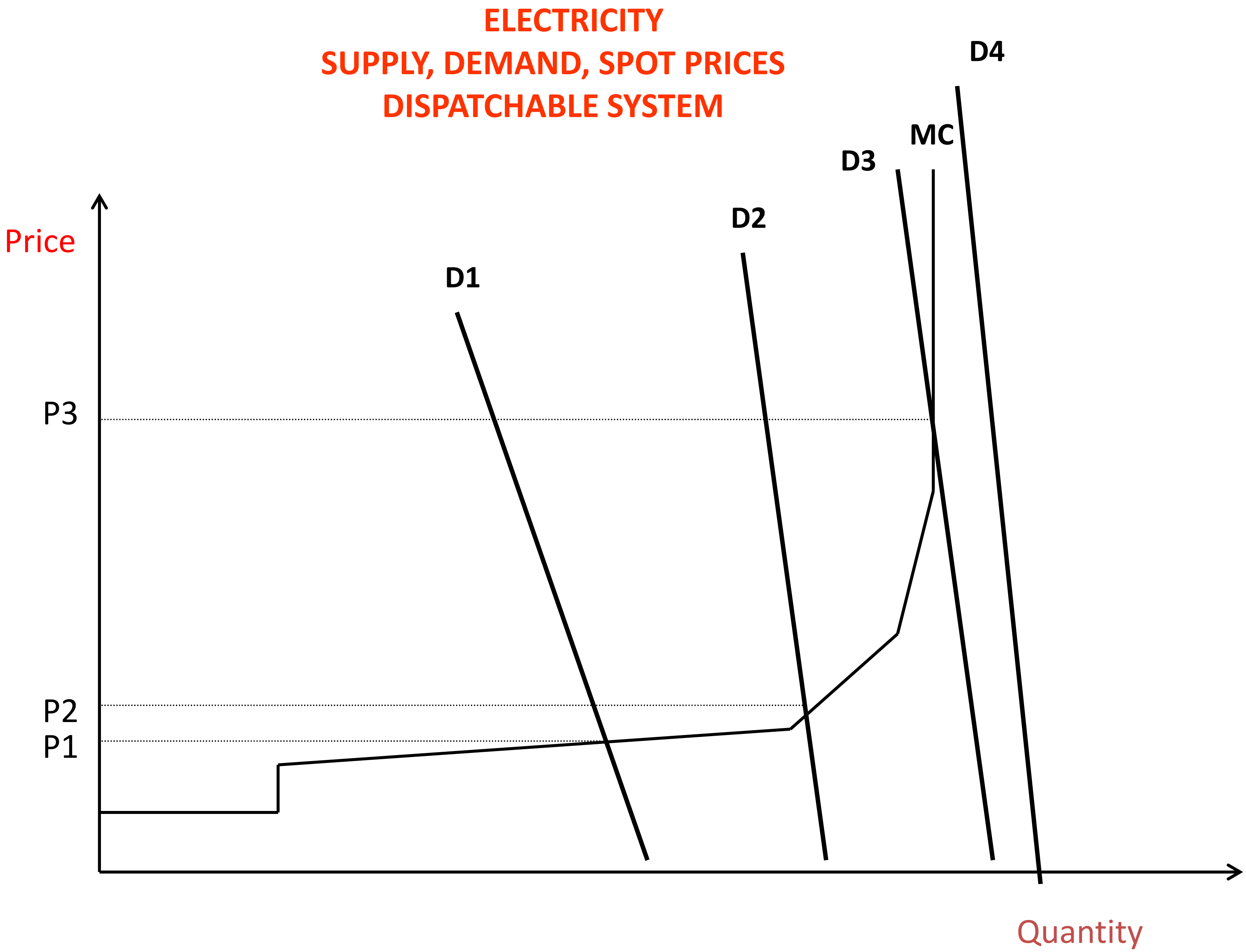
The views expressed here are my own and do not reflect the views of the Sloan Foundation, MIT or any other organization with which I am affiliated

Solar and Wind Technologies

- Wind and Solar (absent storage) supply electricity intermittently based on the attributes of the wind and insolation at any point in time
- Unlike dispatchable generating technologies, intermittent generating technologies cannot be managed through traditional economic scheduling and dispatch protocols to reflect MC =0 and in this sense are quite different from dispatchable technologies
- So, wind and solar generation varies by time and location based on the vagaries of solar and wind resources <u>not</u> based on prevailing <u>system</u> supply, demand, marginal cost and wholesale price conditions
- The quantity and location of production from intermittent generators can vary widely and quickly on the network and dispatchable generators supported by adequate transmission capacity must be able to respond quickly to keep supply, demand, and reliability criteria in balance
- Government policies (direct and tax subsidies, feed-in tariffs loan guarantees, RPS mandates, contract duration requirements, RECs, etc.) effectively " force" intermittent renewable generation into the system when it may (and usually is today) otherwise be uneconomical

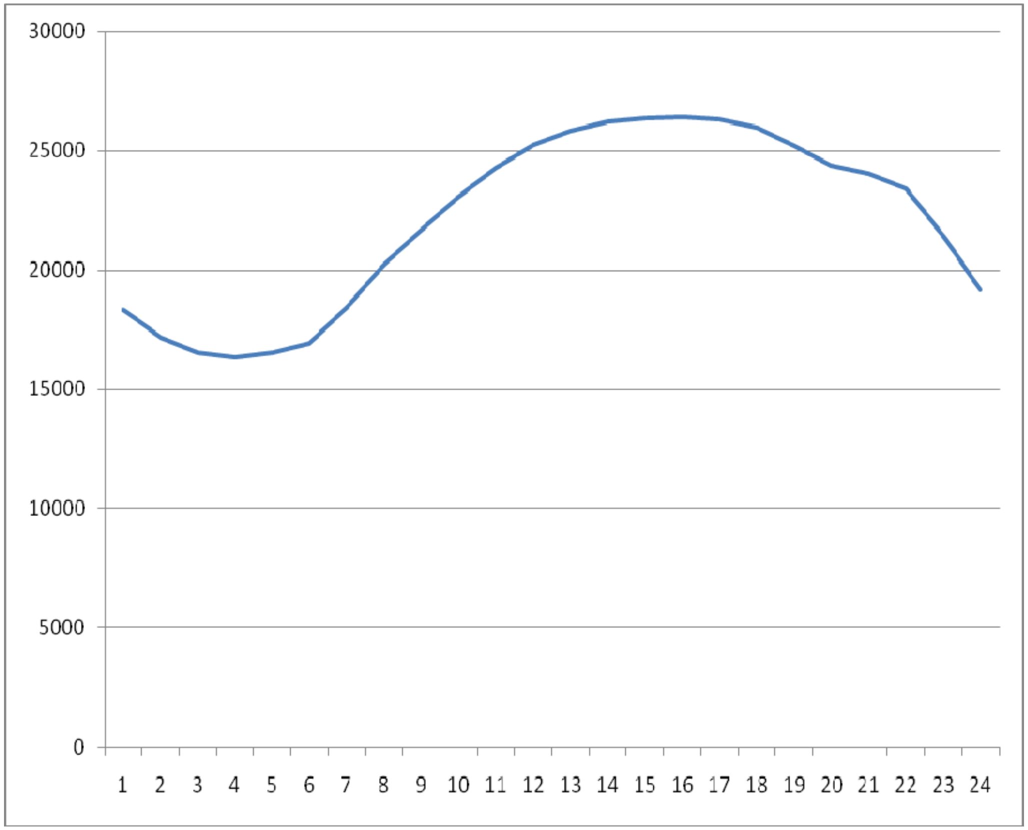
HOW MUCH DO THESE INTERMITTENT TECHNOLOGIES REALLY COST?

- Reasonable question to ask given “forcing” by public policy and interest in finding ways to reduce CO2 emissions <u>efficiently</u> in the absence of an appropriate price being place on CO2 emissions
  - Cost/KWh: Compared to what?
  - PDV using costs <u>and</u> market value of output
  - Cost per ton of CO2 avoided by forcing intermittent technologies into the system
    - Compared to alternative CO2 mitigation opportunities in all sectors
    - Compared to “optimal” CO2 emission price trajectory ($12/ton per in 2011 according to latest Nordhaus estimate)
  - GRS paper focuses on PV solar installations at a particularly attractive location for solar in Arizona but I will make more general observations about both wind and solar


ELECTRICITY
SUPPLY, DEMAND, SPOT PRICES
DISPATCHABLE SYSTEM
D4
MC
D3
D2
D1
Price
P3
P2
P1
Quantity

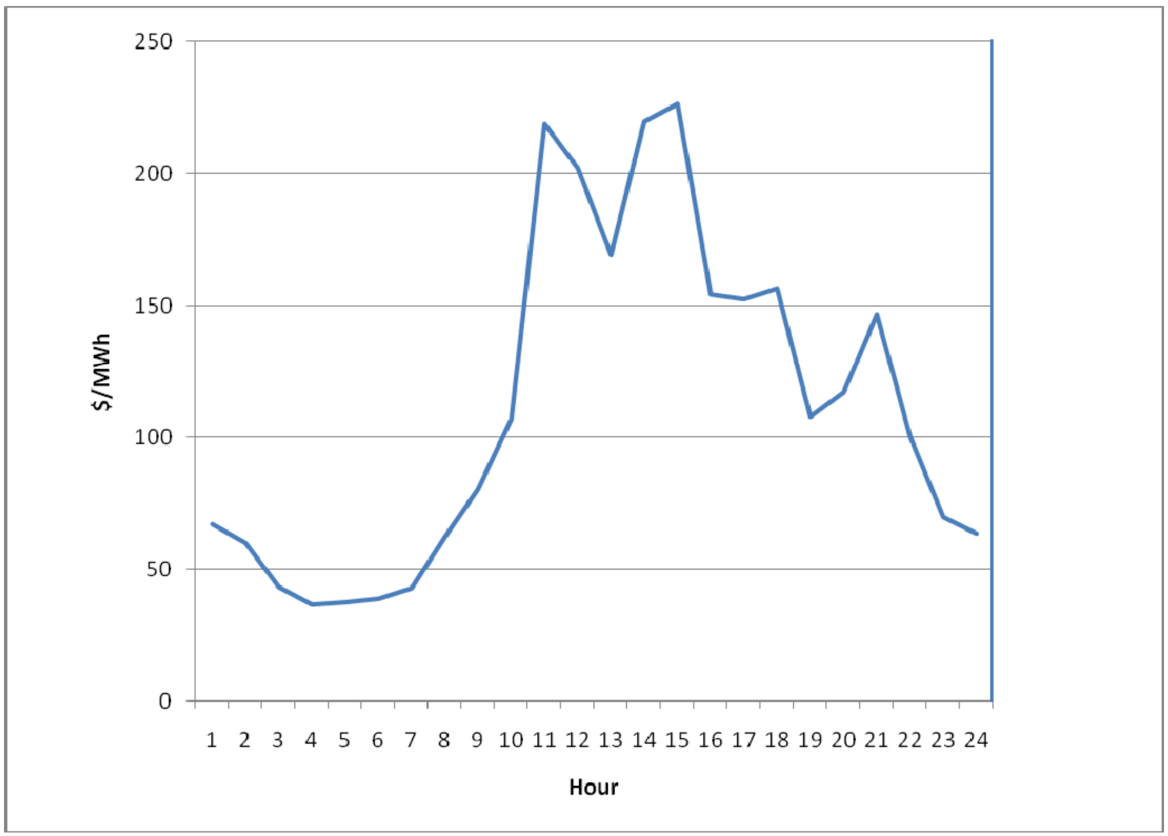
Real Time Demand New England, July 7, 2010

Source: Constructed from Data from the New England ISO (http://www.iso-ne.com



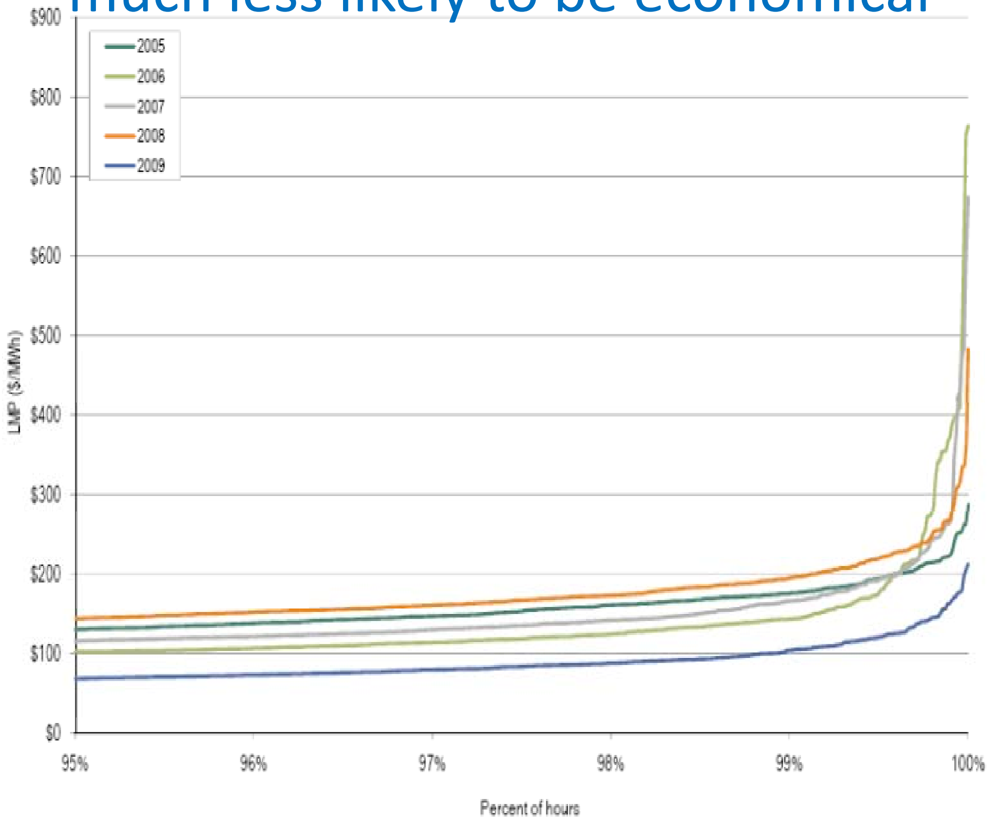
Real-Time Day-Ahead Spot Energy Prices (July 7, 2010)

Source: Constructed from New England ISO (http://www.ne-iso.com)



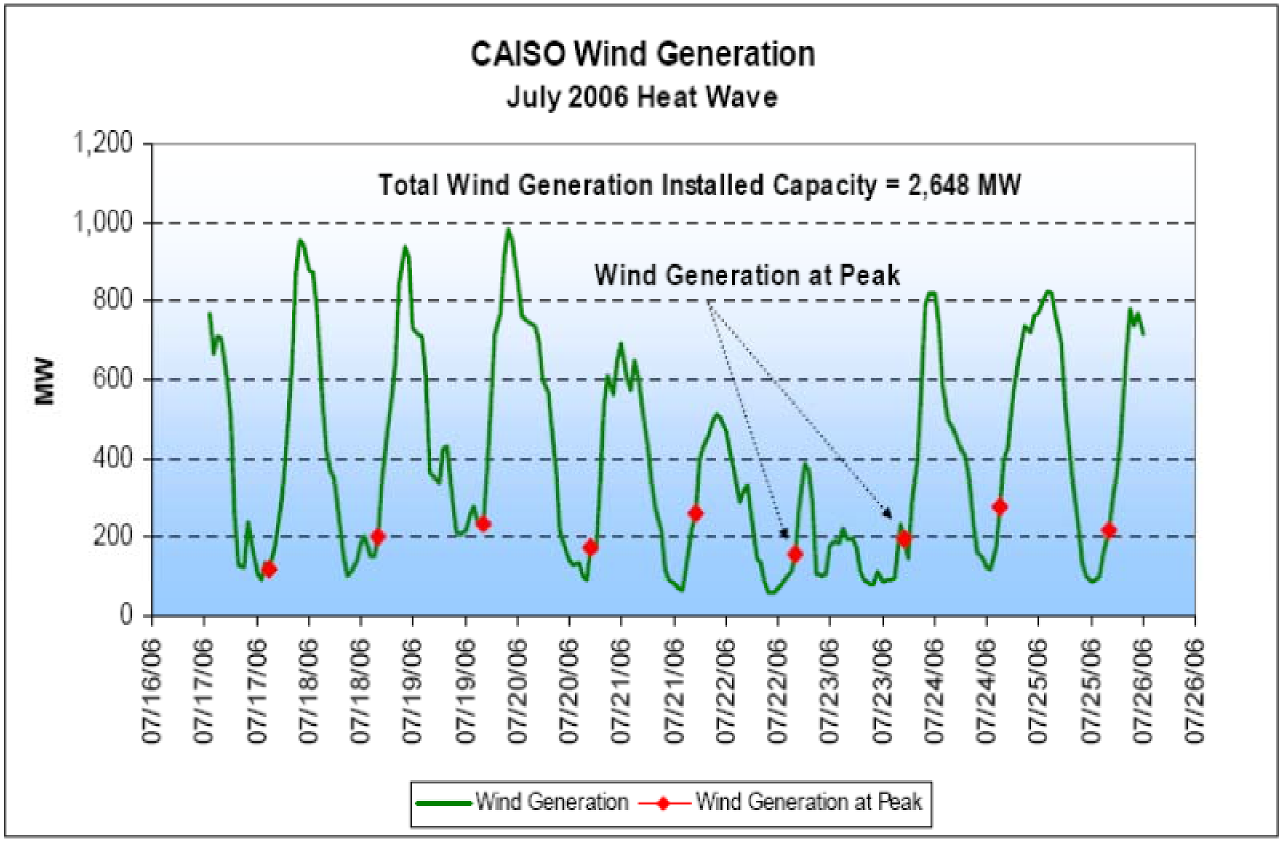
A Tiny Fraction of the Hours in the Year Have High Market Values

- A generator that does not generate during these hours is much less likely to be economical

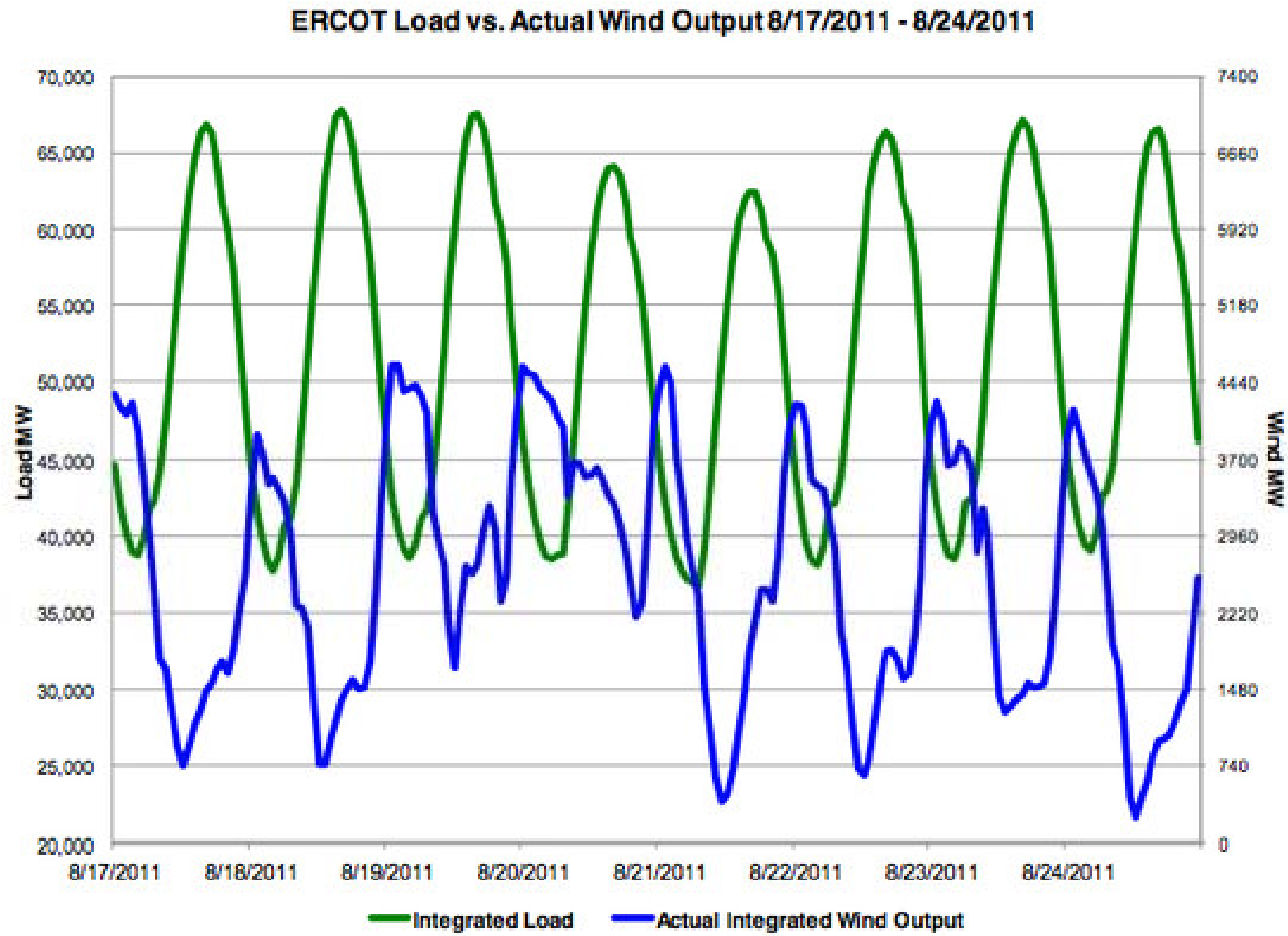


Top 5% of annual hours in PJM

State of the Market Report for PJM 2009, Monitoring Analytics, LLC (Independent Market Monitor for PJM), Volume 2, page 64, March 11, 2016

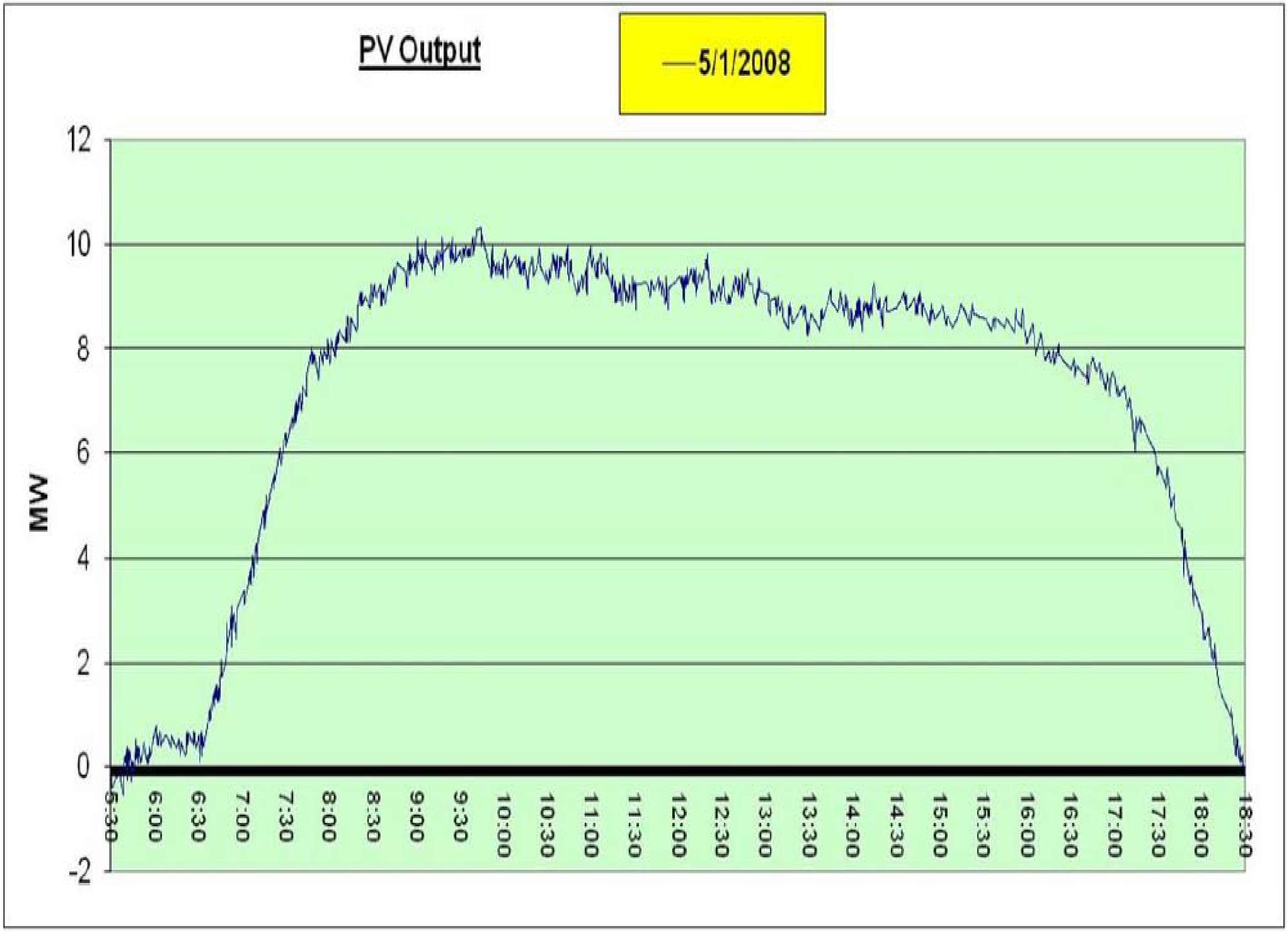


Source: NERC (2009), page 37.



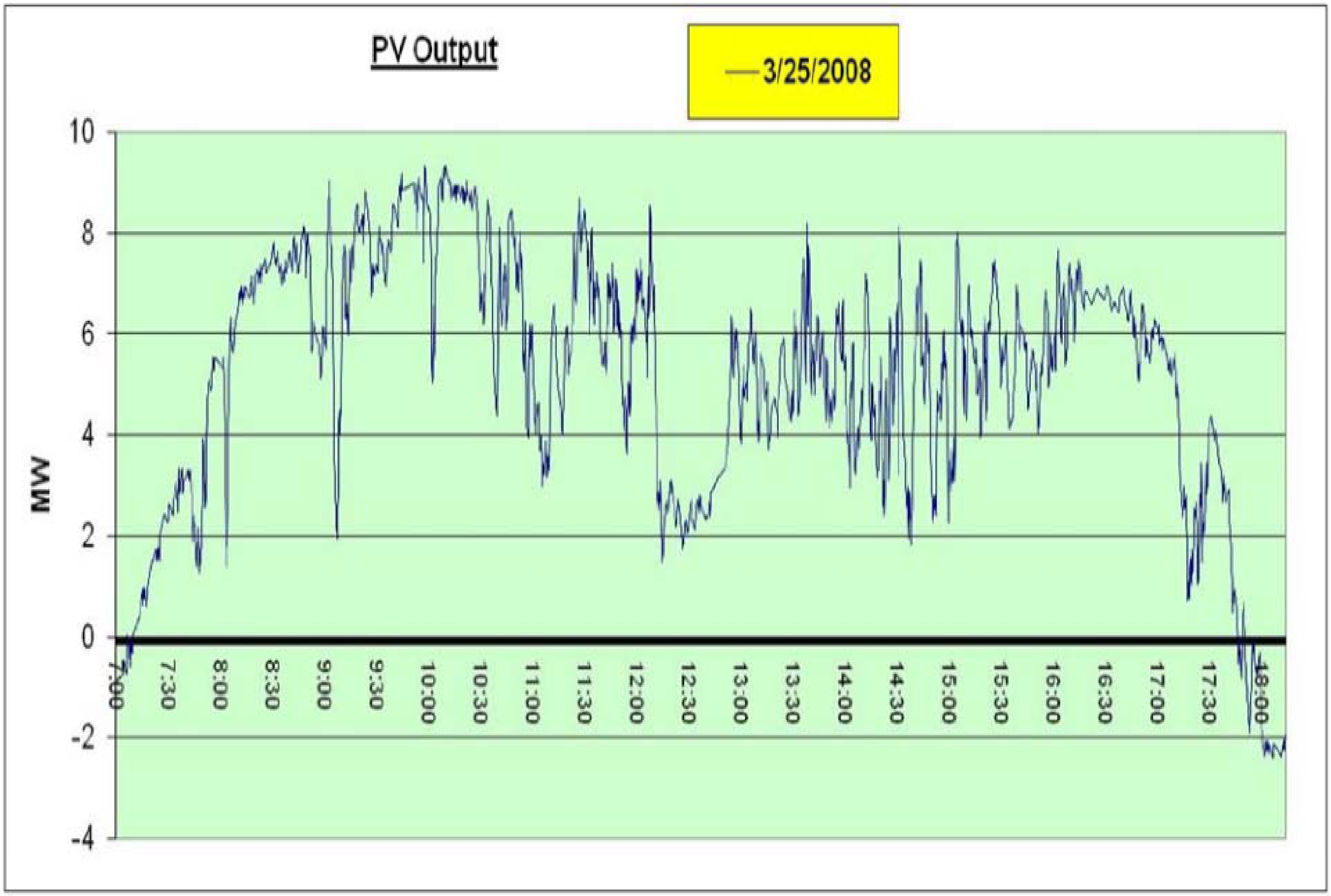
Source: ERCOT (2011)

SUNNY DAY



Source: NERC (2009), page 28

Partly Cloudy Day

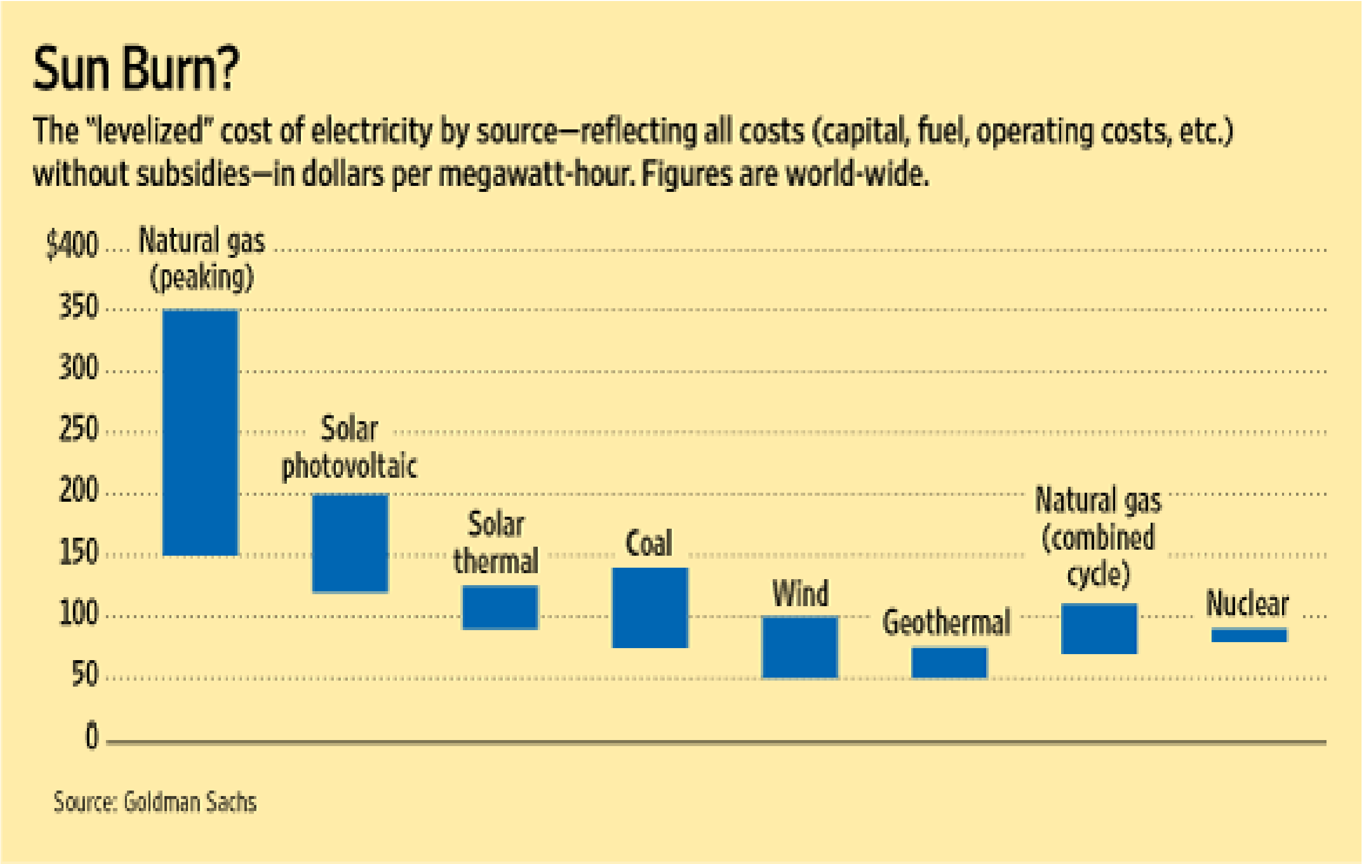


Source: NERC (2009), page 28

DECOMPOSITION OF COST AND VALUE CALCULATIONS

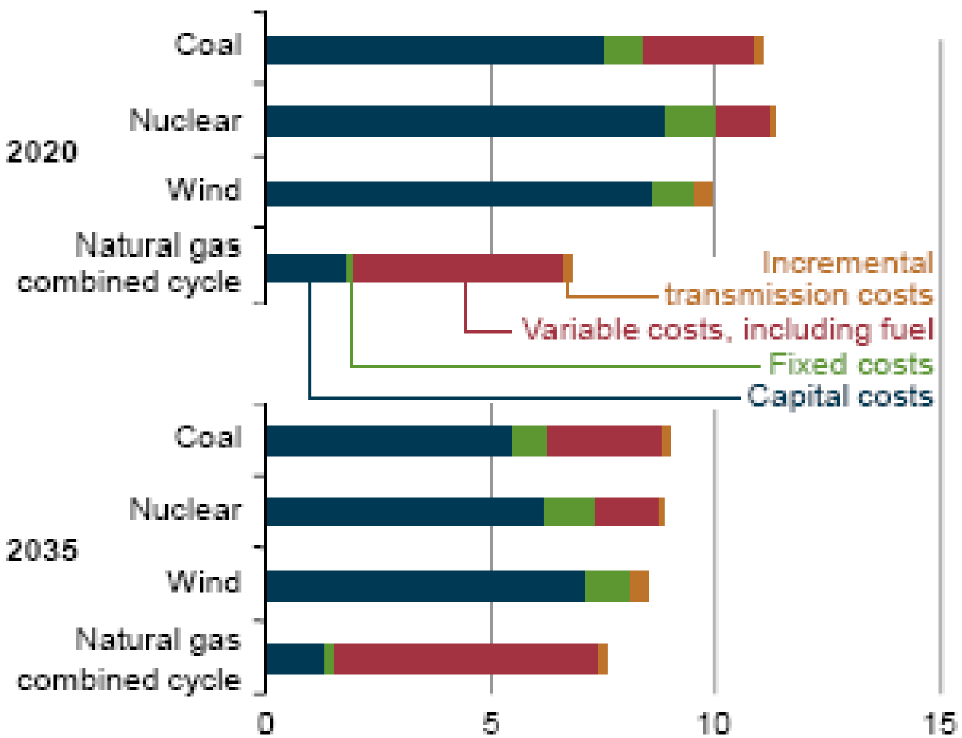
- "Raw" cost of building and operating intermittent generation taking account of market prices at the time the electricity is produced
  - Levelized cost comparisons are meaningless because they ignore variations in the price of electricity at the actual time when supplies are forthcoming from intermittent technologies
    - 6 cents/kWh levelized cost is not cheap if it is produced at night when the market value is 2 cents/KWh
    - 9 cents/kWh levelized cost is not expensive if it is produced during peak periods when the price is 10 cents/kWh
  - Comparing PDV of expected net revenues for incremental additions of intermittent generation to the supply program makes more sense as a quick comparative metric
  - A complete "with and without" system analysis of costs, prices and revenues that takes reliability constraints into account is the gold standard but this requires more complex system models
- Reliability considerations
  - Additional Cost of meeting peak demand reliably
  - Additional Cost of responding to rapid changes in intermittent generation on the network (operating reliability)

Despite It's Being a Meaningless Metric for Comparing Dispatchable and Intermittent Technologies Levelized Costs Continue to be Widely Quoted



As printed in *The Wall Street Journal*, September 13, 2010, page R4.
http://online.wsj.com/article/SB10001424052748703846604575447762301637550.html#

Figure 81. Levelized electricity costs for new power plants, 2020 and 2035 (2009 cents per kilowatthour)



Source: EIA Annual Energy Outlook 2011

COST OF CO_2 DISPLACEMENT

- The impact on CO_2 displacement from forcing investment in wind and solar also varies with the time that the carbon-free generation is produced and what it displaces
- Emissions displacement varies by fuel and heat rates of marginal generators "in the stack" at each point in time
- Startup, ramping and spinning reserve costs may be adversely affected by the need to respond to rapid changes in intermittent generation and overgeneration in order to maintain reliability
- Integrating a proper cost/value analysis of intermittent generation with associated CO_2 mitigation leads to an estimate of the cost per ton of CO_2 displaced
- This number can be compared to the cost of other opportunities to reduce CO_2 emissions

HOW DO WE ANSWER THE COST AND VALUE QUESTIONS ?

- Simulate an "optimal" generation configuration meeting reliability constraints and calculate the associated costs and emissions
- Simulate a "constrained optimal" generation configuration given different exogenous (e.g. RPS) quantities of wind and solar capacity and applying NERC reliability criteria and calculate the associate costs and emissions
- The difference gives you the cost of "forcing" intermittent generation on to the system and the associated cost per ton of CO2 displaced from these policies
- A full system analysis like this that integrates varying demand, dispatchable generation, intermittent generation, reliability constraints, market values, and emissions changes is not easy to perform in practice
- But basically that's what the GRS paper does for difference levels of penetration of solar PV in Arizona (using Joskow-Tirole 2007 as a starting point)

NOTES ON THE GRS PAPER

- GRS apply the right basic analytical framework for doing this kind of analysis though it has a number of limitations
  - Focuses only on solar PV so the electricity is produced by the intermittent technology during the day when market prices are relatively high and marginal emissions are relatively low
  - Very attractive location for solar (sun and south --- 23% capacity factor with relatively little variance)
  - Results for far Northern locals would be much less attractive (e.g. \$600/ton CO2 displaced rather than "only" \$250/ton)
  - Deals with peak demand reliability but not network operating reliability (would need a real network model for this)
  - Introducing wind as well might change the analysis in interesting ways

NOTES ON THE GRS PAPER

- At current prices solar is <u>uneconomical</u> compared to traditional dispatchable generation by a long shot and would be welfare neutral only with very high prices for CO_2 (~ $250/ton)
  - Using the current range of estimates of the marginal cot of CO_2 emissions (optimal emissions prices), the optimal quantity of solar PV appears to be <u>zero</u> even at this favorable location
  - Solar costs (including transportation, breakage and installation) would have to fall a lot to bring the cost/ton of CO_2 displaced within the range that reflects reasonable estimates of the optimal trajectory of the marginal cost (price) of CO_2 emissions
  - The peak demand reliability component is relatively small compared to the high "raw cost" of solar
  - My guess is that the incremental operating reliability cost is relatively low as well
  - The big issue is that solar and wind are just very costly ways to generate electricity in many locations and, as a result, costly ways to reduce CO_2 emissions compared to alternatives (e.g. energy efficiency, replacing coal with gas generation, etc.)

QUESTIONS?

- Do we think that “experience effects” will be large enough to drive down the total costs of solar and wind to levels that yield a more reasonable cost/ton of CO_2 displaced?
- How do we design procurement systems that provide incentives to locate and design wind and solar generators with wind and solar resources that are better matched to the varying wholesale price of electricity and attributes at different locations (Arizona vs. Massachusetts, South vs. SW orientation)
- How do we provide better incentives to add storage to intermittent generators to move more output to times when prices are relatively high?
- Why is it good policy to subsidize technologies that reduce CO_2 emissions at costs between \$100/ton and \$500 ton when much cheaper opportunities are available in this and other sectors?