Improving the Completeness and Accuracy of Levelized Cost of Electricity Calculations

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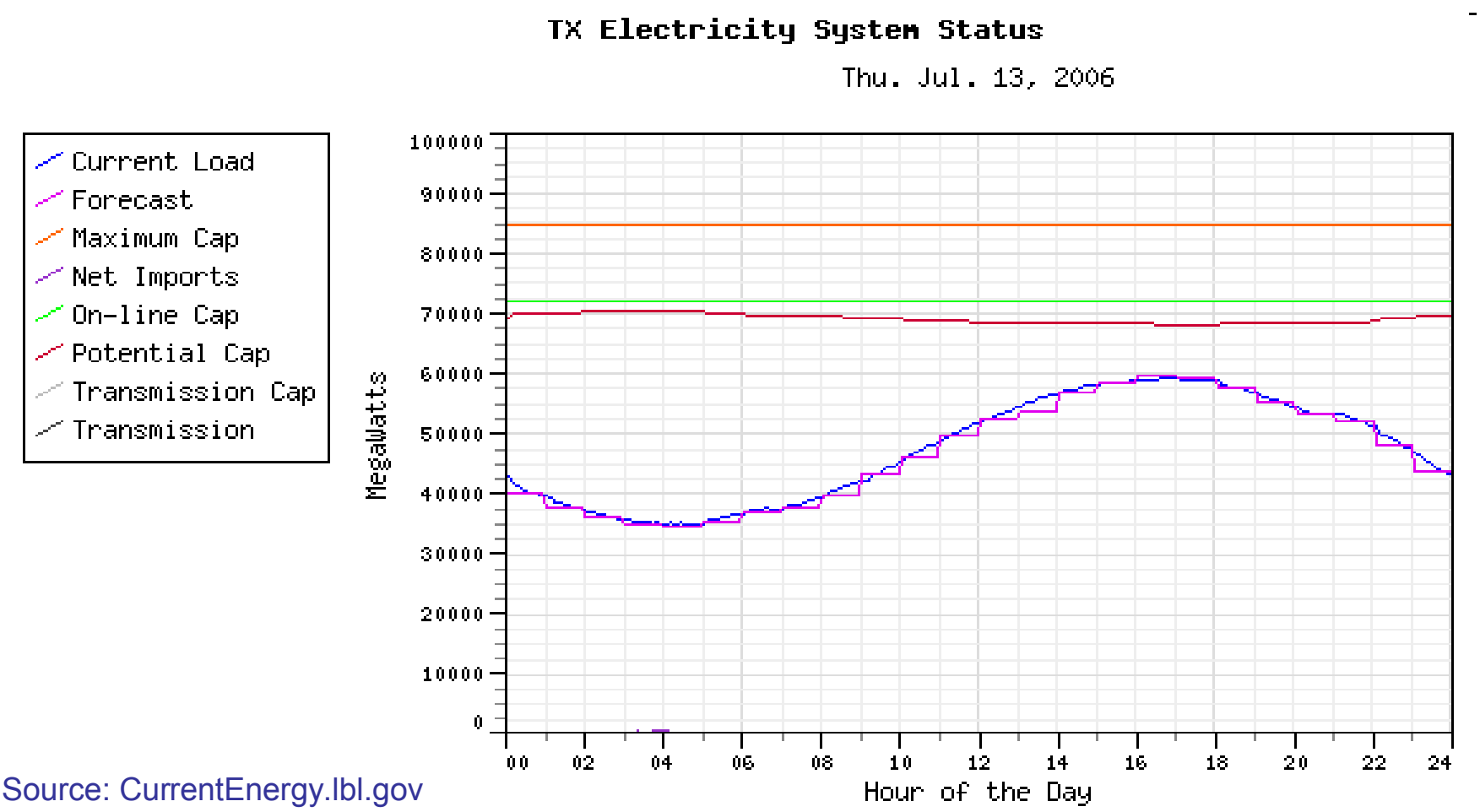
Estimated Levelized Cost of New Generation Sources, 2017

U.S. Average Levelized Costs ($2010 per MWh) for plants entering service in 2017

Plant Type	Capacity Factor (%)	Levelized Capital Cost	Fixed O&M	Variable O&M (incl fuel)	Trans-mission	Total Levelized Cost
Dispatchable Technologies						
Conventional Coal	85	64.9	4.0	27.5	1.2	**97.7**
Advanced Coal	85	74.1	6.6	29.1	1.2	**110.9**
Advanced Coal w/ CCS	85	91.8	9.3	36.4	1.2	**138.8**
National Gas						
Combined Cycle	87	17.2	1.9	45.8	1.2	**66.1**
Adv CC	87	17.5	1.9	42.4	1.2	**63.1**
Adv CC w/ CCS	87	34.3	4.0	50.6	1.2	**90.1**
Combustion Turbine	30	45.3	2.7	76.4	3.6	**127.9**
Adv CT	30	31.0	2.6	64.7	3.6	**101.8**
Advanced Nuclear	90	87.5	11.3	11.6	1.1	**111.4**
Geothermal	91	75.1	11.9	9.6	1.5	**98.2**
Biomass	83	56.0	13.8	44.3	1.3	**115.4**
Non-Dispatchable Technologies						
Wind	33	82.5	9.8		3.8	**96.0**
Solar PV	25	140.7	7.7		4.3	**152.7**
Solar Thermal	20	195.6	40.1		6.3	**242.0**
Hydro	53	76.9	4.0	6.0	2.1	**88.9**

Typical Daily Demand Curve



Source: CurrentEnergy.lbl.gov

Background

- In December 2012, ATI published a report on “The Hidden Costs of Wind Electricity”, available at
  www.atinstitute.org/wp-content/uploads/2012/12/Hidden-Cost.pdf

- We believe its conclusions apply to all non-dispatchable sources,
- … LCOE calculations can play a valuable role for policymakers, and
- … they could be more accurate without introducing undue complexity

- LCOE tables can serve different purposes – the one we were trying to address was the full cost to society of each generation technology which meets a particular segment of demand, rather than the economic calculation which would confront the developer of any given facility

Background

- We contended that LCOE tables would more closely match reality, be easier to understand and more valuable for policymakers and the public if:
  - All costs were included and all subsidies were excluded,
  - All entries were dispatchable, and
  - The LCOE for any generation mix could be found by taking a weighted average of the LCOE's of the components
  - None of which are true in today's LCOE tables

In Short, We Argued That …

- The entries for non-dispatchable sources should not be "wind" or "solar" by themselves, but entries such as
  - "wind, added to combined-cycle gas"
  - "wind, added to combustion-turbine gas"
  - "wind, added to coal"
  - "wind plus storage (plus backup)"

- The calculations for non-dispatchable sources should
  1. Exclude special accelerated depreciation rules
  2. Use appropriate cost recovery periods (rather than 30 years for all technologies)
  3. Count the costs of transmission infrastructure and transmission losses
  4. Count all costs that these sources impose on dispatchable ones (or on the system)
     - Capital
     - O&M
     - Fuel

Why Do These Corrections Matter?

- Because we concluded that even with conservative assumptions "wind added to combined-cycle gas" costs almost twice what has been reported, and "wind added to coal" costs more than twice what has been reported

	Table 1. Levelized Cost of Wind Electricity, (starting from the assumptions in the Energy Information Administration's 2012 Annual Energy Outlook)	Onshore Wind Added to Natural Gas (c / kWh)	Onshore Wind Added to Coal (c / kWh)
	As reported by EIA, but using lower wind turbine cost from DOE's Office of Energy Efficiency and Renewable Energy [5]	**8.2**	**8.2**
1 2	Backing out an implicit subsidy, and assuming a 20-year lifetime	10.1	10.1
3	Plus the capital and O&M costs imposed on primary fossil plants	11.8	15.6
4	Plus the fuel costs imposed on primary fossil plants	12.4	16.5
5 6	Plus low-end estimates for the cost of transmission (from EWITS) and transmission losses, for a large-scale wind buildout	**15.1**	**19.2**

How Did LCOE Calculations Go Off Track?

- When all sources were dispatchable, comparisons made sense and weighted averages worked
- When non-dispatchable sources were added, comparisons broke down and weighted averages no longer worked
  - Which was reflected in EIA's decision to divide the 2012 LCOE table into dispatchable and non-dispatchable parts
  - … and to state that "caution should be used when comparing them"
- The fundamental issue is that (in the absence of storage)
  - There is no such thing as a non-dispatchable source operating by itself
  - There is only a fossil source plus a non-dispatchable source or a hydro source plus a non-dispatchable source

Why Should All Entries Be Dispatchable?

- Because that's how the electric system works
  - Without storage, a non-dispatchable source cannot be used in its standalone form to meet any portion of real-time demand
  - If a non-dispatchable source is in the mix, someone has to combine it with a dispatchable source before anyone can use it

How Could We Make Them Dispatchable?

- By combining non-dispatchable sources with dispatchable sources or with storage
  - Wind + storage + backup
  - CT Gas + wind
  - CC Gas + wind
  - Coal + wind
  - Hydro + wind

But That's Impractical Because The Number of Combinations of Dispatchable Capacity and Non-Dispatchable Capacity Is Too Large

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To Make It Practical, Create Entries Such As

- Wind, added to Combined-cycle Gas
- Wind, added to Combustion-turbine Gas
- Wind, added to Coal
- Wind, added to Hydro

- Then combine these entries with dispatchable entries by taking weighted averages
  - 95% CC Gas + 5% Wind added to CC gas
  - 90% CC Gas + 10% Wind added to CC gas
  - 85% CC Gas + 15% Wind added to CC gas

- (Up to the point of curtailment of the wind generation, at which point new entries would be required)

With Regard to Imposed Costs

- The most important ones are costs of additional capital, O&M and fuel consumption imposed by non-dispatchable sources onto dispatchable sources

- Unless wind can replace 100% of equivalent fossil capacity or a primary fossil plant's lifetime production and lifetime O&M remain unchanged (when it runs in conjunction with wind), then wind's levelized cost of capital (LCOC) and its O&M must be increased by an appropriate percentage of the fossil plant's LCOC and O&M

- Likewise, if adding wind to fossil saves less than 100% of the fuel that the fossil plant would otherwise have consumed, then the cost of fuel not saved must be added to wind's LCOE

Logical Sources for Measuring or Calculating Imposed Costs and Transmission Costs (because they have the data and/or the software)

- Utilities and utility consortiums such as EIPC
- Regional system operators with experience with wind and solar:
  - Midwest ISO, Ercot, PJM West, CA ISO, BPA
- NREL and other national laboratories
- Researchers who have access to sufficient databases, simulation software and real-world dispatch protocols, margin requirements and plant operating constraints

Remarks

- Some cost curves may be non-linear for increasing levels of wind penetration
  - Use piecewise linear approximations

- Wind may displace different sources at different hours
  - Take weighted averages

We Think There is a Close Relationship Between Imposed Costs and Avoided Costs (next slide)

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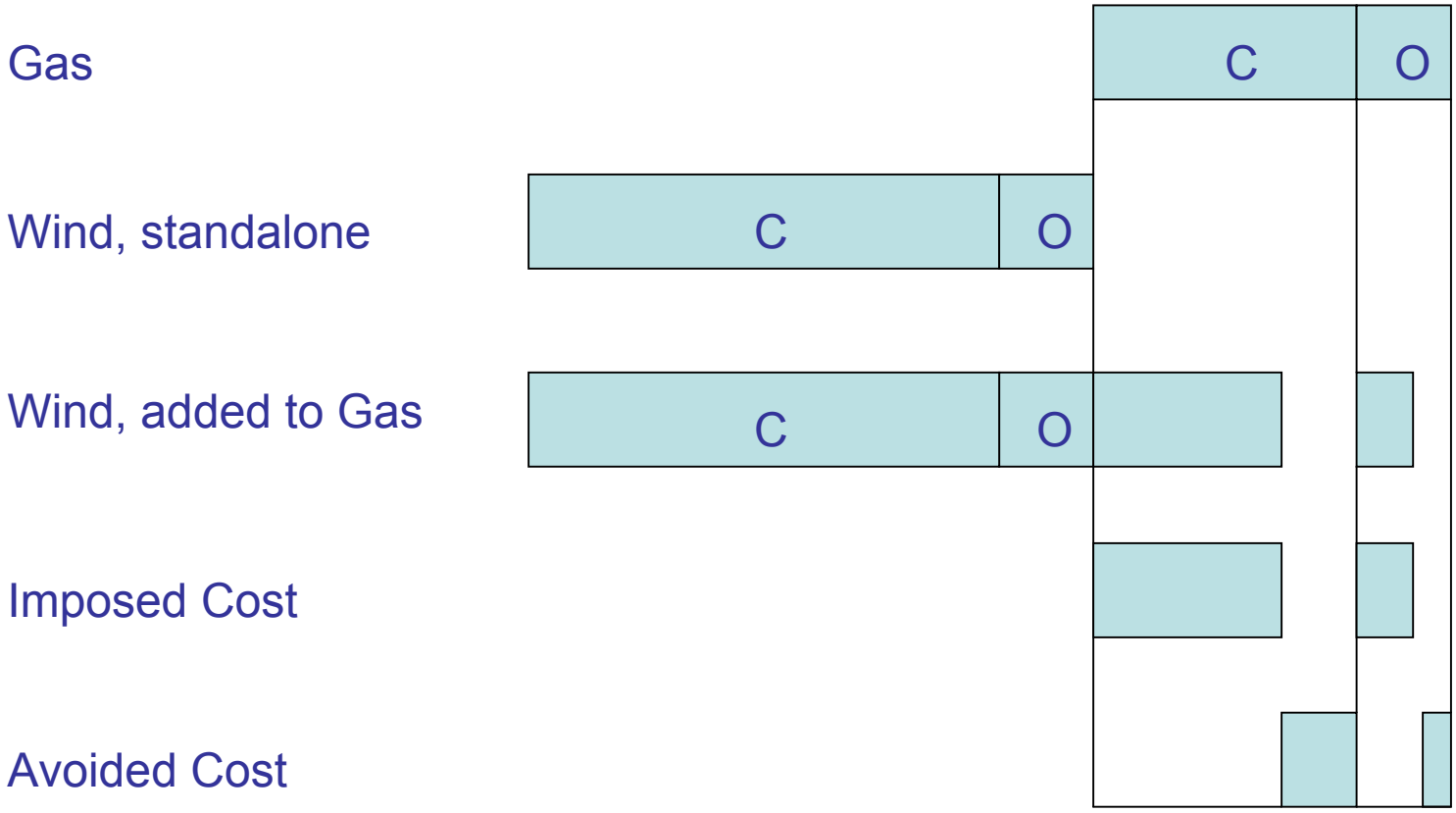
LCOE of Gas == Imposed Cost + Avoided Cost

LCOE of Gas + LCOE Standalone Wind == LCOE of Wind Added to Gas + Avoided Cost



C – capital
O – O&M

Measuring Fossil Fuel Savings

- It's unlikely that wind saves 100% of the fossil fuel that would otherwise have consumed, because of:
  - Partial load operation
  - Cycling between load levels
  - Shut-down / restart
  - Forced substitution of less-efficient CT gas mode for (typically 50%) more-efficient CC gas mode

- The most credible method to determine fuel savings would be multiple runs of chronological dispatch, either compared with each other or compared with historical results
  - Example: compare 2012 fossil fuel consumption (in some common unit, such as Btu's) for a region which had X% wind penetration against the estimated fuel consumption for that same region with wind generation set to zero

Why Wind's Levelized Cost of Capital (LCOC) must include the LCOC of the source that it's paired with

- Assume a gas plant costs $1000/kW, a wind plant costs $2000/kW, the gas plant's capacity factor (CF) = 100%, the wind plant's CF = 33.3%, both plants last one year, a year consists of 1000 hours, and we build equal nameplate capacity of both plants (which can work without curtailment)

- Then, in a gas-only system, the gas plant's LCOC would equal $1/kWh
- and you might think that wind's LCOC = $6/kWh ($2000 / (0.333 * 1000))

- But in a "gas + wind" system, the gas plant would run only 667 hours and recover $667, while the wind plant would run 333 hours and recover $2000. $333 of capital recovery would be missing.

- That $333 has to be added into the calculation for wind's LCOC.
- Thus, the LCOC of "wind added to gas" would be $7/kWh, not $6/kWh.

Remarks

- Of course, that result depends on the gas plant's operating lifetime remaining unchanged, even though its average level of output is reduced by one-third.
- If a plant running at 67% average output had 50% longer calendar life, then this argument wouldn't hold (net present value considerations aside.)

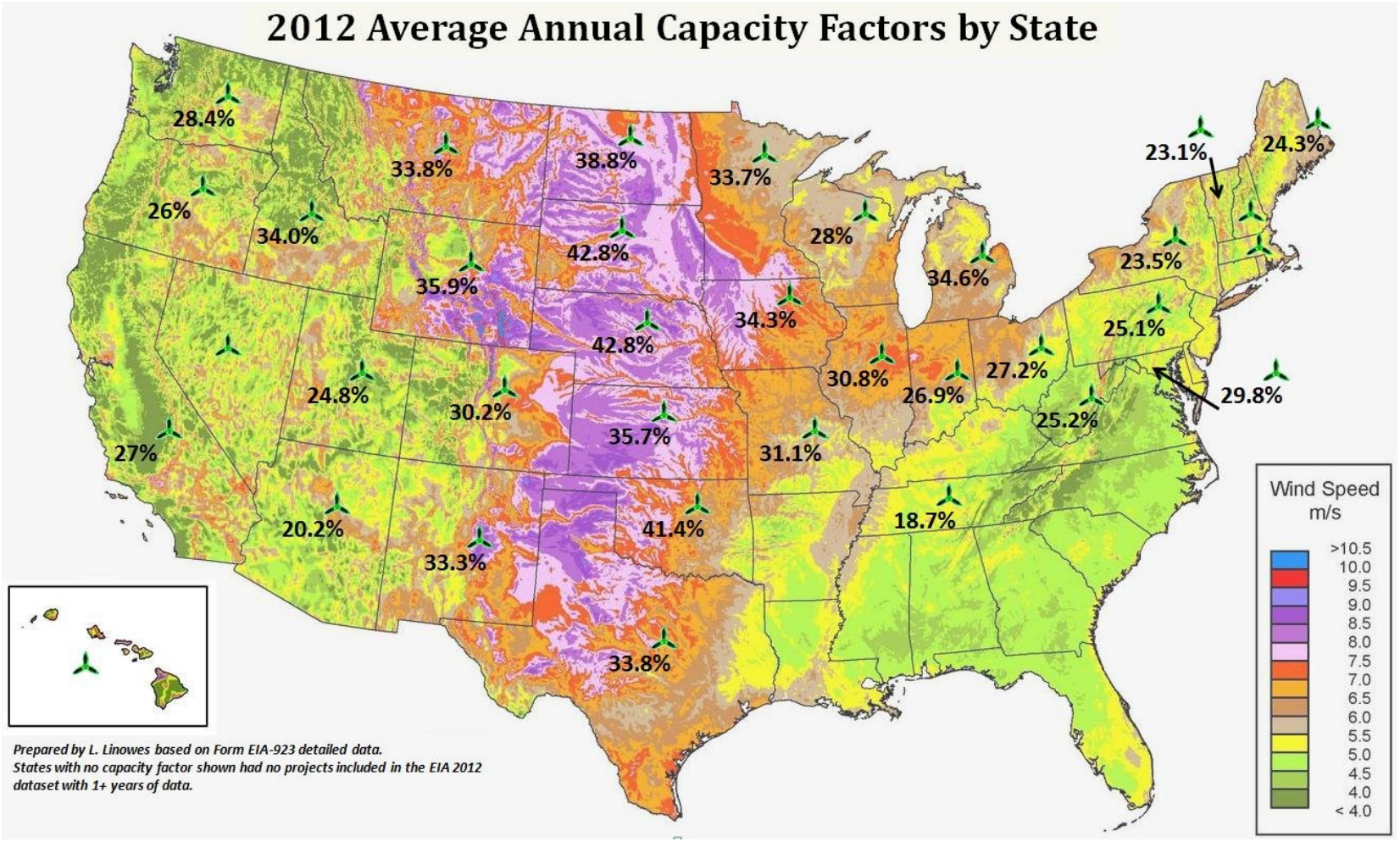
- However, the O&M for a gas plant running with larger and more frequent changes in load must be far higher than the O&M for running steady-state
- Thus even if a gas plant's total lifetime output were unchanged despite being paired with wind, its lifetime O&M would be higher
- Either one of those would be an imposed cost

- Aside: wind must be paired primarily with combined-cycle gas (which suffers O&M impacts due to higher cycling) rather than with combustion-turbine gas (which suffers less), because CT gas + wind would consume more fuel than CC gas running standalone without wind

Why Transmission Costs Are Likely To Be High As Onshore Wind Penetration Increases

- Regions with wind capacity factors greater than 30% are remote from major cities (see next slide)
- 90% of all installations to date have been west of Chicago
- Even short distances within Texas will cost $400/kW (20% of wind turbine cost) if CREZ incorporates 18 GW of wind capacity, as projected, and holds to its latest $7B budget
- The proposed TransWest Express 600kV DC line from Wyoming to southern Nevada would cost $1000/kW (50% of wind turbine cost)
- Most connections from the Great Plains to major cities would be longer than those two, and much longer than the average distance between conventional plants and their load centers

Measured state-level wind capacity factors based on EIA-923 data (courtesy of Lisa Linowes)



Remarks

- Obviously, forecasts about infrastructure which has not been built are more uncertain than measuring facts on the ground
- But that can’t be a reason for ignoring these costs
- It should be a reason for learning them

Summary

- Existing LCOE tables are incomplete and incorrect for non-dispatchable sources, but the costs they impose on dispatchable sources (or the system) could be measured or calculated with enough accuracy for the purpose of high-level policy decisions
- The simplest way to compare generation options is to make them all dispatchable (for some given portion of demand)
- The entries in LCOE tables should be the components of dispatch-able combinations, and each non-dispatchable entry should be specific to the dispatchable source that it will be combined with
- Regional system operators, utilities and national laboratories have the data and software to calculate the missing numbers