# A Guide to Differences Among Renewable Energy Cost Estimations

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# Abstract

Solar and wind energy continue to be one of the fastest-growing and most dynamic parts of the electricity generation industry. The costs of building wind and solar projects, as well as the value of the electricity that is produced in the end, have experienced an environment of dramatic cost declines through most of their lifetime as feasible generation technologies. The various organizations that report the costs of solar and wind power capital expenses are rarely, if ever, in agreement. This report explores the differing data collection approaches and model methodologies used by capital expense (CAPEX) estimation organizations. The goal of the report is to allow consumers of this data to better understand why differences exist and how that understanding of the methodology behind the CAPEX figures should be analyzed.

**Keywords**
Balance of systems
Capital expense
Renewable energy
Solar photovoltaic (PV)
Wind

# Executive Summary

- Reported capital expenses for both solar and wind projects vary widely among different estimating organizations, sometimes on the order of 2x. This report explores these differences by asking three key questions:
  - What are the reasons for the differences in CAPEX estimations?
  - How do data collection methods account for the difference in CAPEX estimations?
  - How are model methodologies different amongst estimating organizations?
- Discussion took place with several key estimating organizations to explore data collection approaches, cost segmentation, model methodology, and project logistics. In addition, comparisons were made among the CAPEX breakdowns, where applicable. Insights emerging from this effort include:
  - Bottom-up and top-down methodologies have their own strengths and weaknesses, and results of specific reports should be viewed within the context of the methodology used for data collection and modeling.
  - The time-lag between data collection and report publication appears to be a primary reason for variation in both solar and wind CAPEX estimates. Organizations with shorter time-lags had lower cost data, primarily because pricing data is declining at such a steep rate that a matter of months can impact cost reporting.
  - Each organization uses its own unique segmentation of line item costs. In some cases, these segmentations can be similarly built-up into major line items that can be compared across organizations, but not in all cases. The varying segmentation differences can make it difficult to compare costs by segment across the collection of estimates.
  - Organizations' views of PV module costs and inverters are relatively uniform. CAPEX differentials on a project-wide basis are primarily due to differences in costs for installation and balance-of-system.
  - A consensus exists amongst organizations around turbine/tower pricing. Almost all variation of CAPEX in wind is in non-turbine costs.

# Table of Contents

# Introduction

Understanding the Problem

# The Dilemma

- "Austin Energy signed a new solar PPA for a price between $23 and $27 per MWh…"—Austin Statesman, 9/5/2017
- "NV Energy's solar project for Apply may be the lowest solar price for power in the U.S. at $32.40 per MWh…--Electrek, 11/4/2017
- "The median price for the new solar bids in Colorado was $29.50 per MWh…"—NRDC Bulletin, 1/16/2018
- "…the energy output of the solar plant will be below 70 pounds/MWh…"—PV Magazine on UK solar project with Shell, 1/18/2018
- "Customers will pay $49.50 per MWh for the solar electricity…"—Las Vegas Review Journal on Switch project, 2/8/2018

Dry Lake Switch Solar Project, Nevada

*Courtesy: Las Vegas Review Journal*

# The Dilemma: CAPEX Differentiation in Utility Solar

- Despite being the most stable and easiest to calculate factor in levelized cost of energy (LCOE), capital expenses, or CAPEX, can still be a mystery.
- Different organizations estimate utility solar CAPEX at wide variations.
- Variance can be almost 2x. Why?

| | Utility Solar CAPEX ($/$W_{AC}$) | Date of Publication |
|---|---|---|
| BNEF | $1.20 | Feb-18 |
| EIA | $2.67 | Sep-17 |
| EPRI | $1.72 | Nov-17 |
| GTM | $1.31 | Oct-17 |
| Lazard | $1.30 | Nov-17 |
| LBNL | $1.69 | Sep-17 |
| NREL | $1.74 | Aug-17 |

Notes: Most recent estimate from each organization, based on each organization's classification of utility, fixed-tilt overnight costs for complete Poly-Si PV project. Ratings for all are in AC sizing of project. GTM and BNEF numbers have been normalized for AC rating by multiplying by 1.2 to account for inverter loading.

# The Dilemma: CAPEX Differentiation in Utility Wind

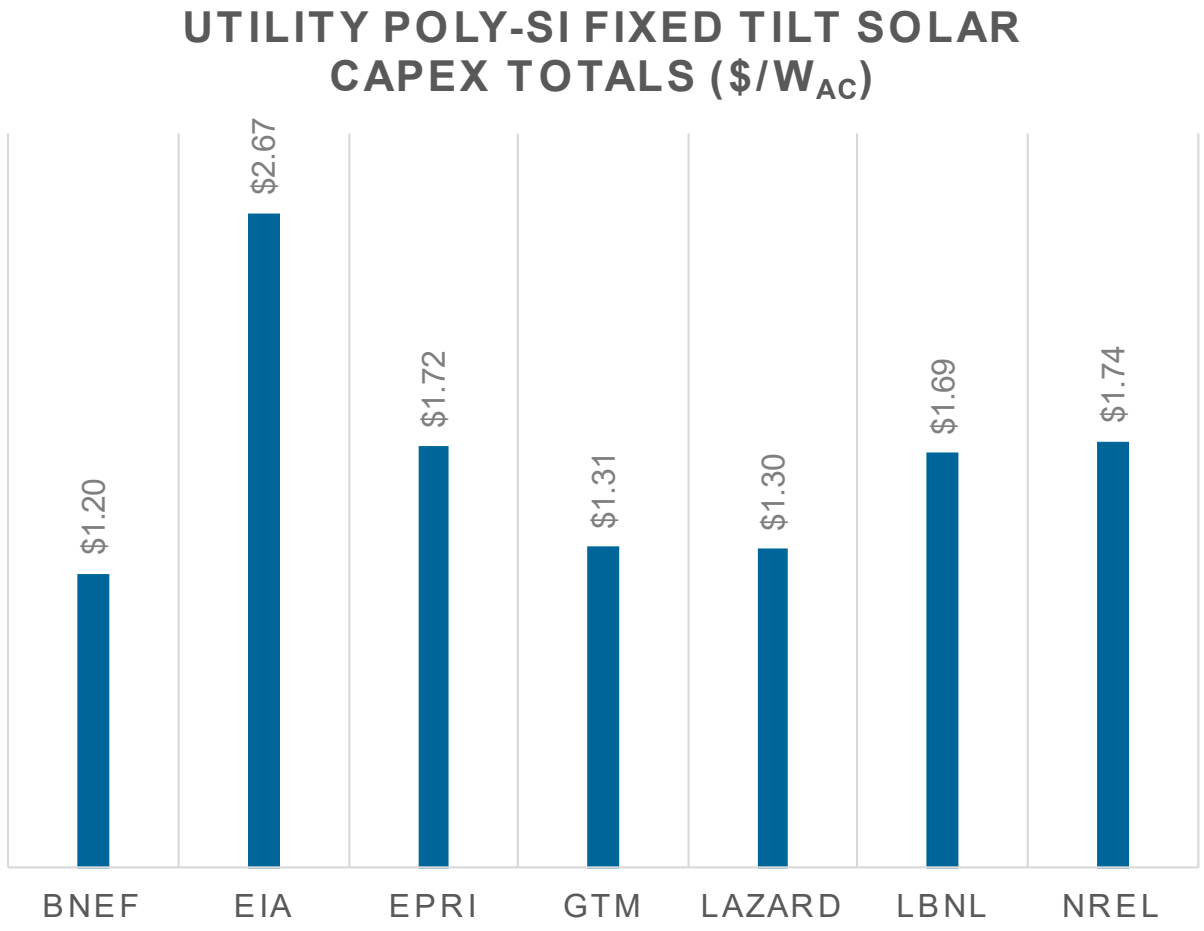
- Wind CAPEX estimations among organizations also show a large differentiation.
- Offshore wind is not covered in this report due to the scarcity of projects and cost numbers.
- Wind also sees variance of more than 2x. Why?

| | Onshore Wind CAPEX ($/kW) | Date of Publication |
|---|---|---|
| BNEF | $1,200 | Feb-18 |
| DOE | $1,590 | Mar-17 |
| EIA | $2,670 | Sep-17 |
| EPRI | $1,720 | Nov-17 |
| Lazard | $1,300 | Nov-17 |

Notes: Most recent estimate from each organization, based on each organization's capacity-weighted onshore wind project estimate. Ratings for all are in AC.

# The Dilemma: CAPEX Differentiation

- Solar CAPEX estimates are represented in the chart on the right; clear differentiation is apparent across all estimation organizations.
- Even in the lowest three CAPEX numbers (BNEF, Lazard, and GTM), variance among the estimates is 9%.



# Benchmarking Research Questions

- What are the reasons for the differences in CAPEX estimations?
- How do data collection methods account for the difference in CAPEX estimations?
- How are model methodologies different amongst estimating organizations?

# Report Methods

- This report was developed through discussions and ongoing dialogue with the following organizations:
  - Bloomberg New Energy Finance (BNEF)[1]
  - Energy Information Administration (EIA)[2]
  - Electric Power Research Institute (EPRI)[3]
  - Greentech Media (GTM)[1]
  - Lazard
  - Lawrence Berkeley National Laboratory (LBNL)
  - National Renewable Energy Laboratory (NREL)
- Other organizations were contacted, but didn't elect to participate.
- Discussion topics include analysis of data collection, cost segmentation, model methodology and project logistics for each estimation organization.
- OPEX is purposely excluded, as it is an LCOE issue, not an up-front cost issue.

Solar and Wind Project

*Courtesy: Vox Media*

1: BNEF and GTM are private, for-profit organizations that require a subscription for access to data

2: Data collection and modeling performed by Leidos, a contracting organization

3. Data collection and modeling performed by Sargent & Lundy, a contracting organization

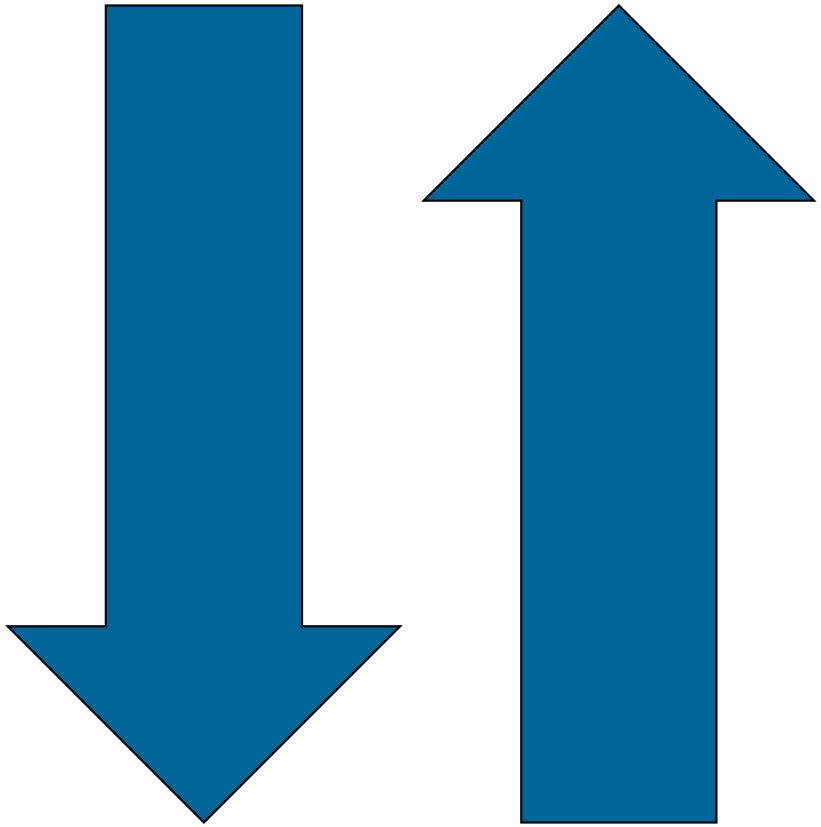
# Methodology Discussion

Differing Approaches to CAPEX Modeling

# Model Differentiation: Top-Down vs. Bottom-Up

## Top-Down

- Data is collected from real installed projects that have been reported either in a public database or an aggregation of privately reported data from real projects.
- Top-Down Estimating Organizations:
  - LBNL



## Bottom-Up

- Data is collected on a component-by-component basis from interviews and questionnaires with industry participants.
- Bottom-Up Estimating Organizations:
  - BNEF
  - GTM
  - NREL

# Model Differentiation: Hybrid Top-Down/Bottom-Up

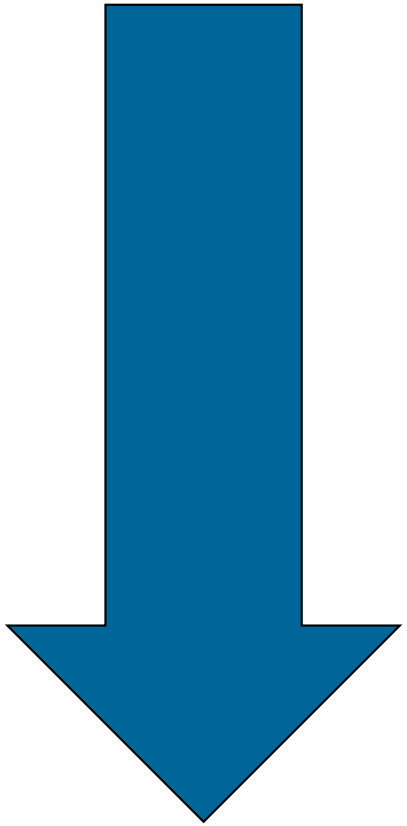
## Top-Down/Bottom-Up Hybrid

- Some combination of reported cost numbers from existing databases, with additional elements that add a bottom-up factor to the analysis.

- Hybrid Estimating Organizations:
  - EIA
  - EPRI
  - Lazard

# Model Differentiation: Top-Down Details

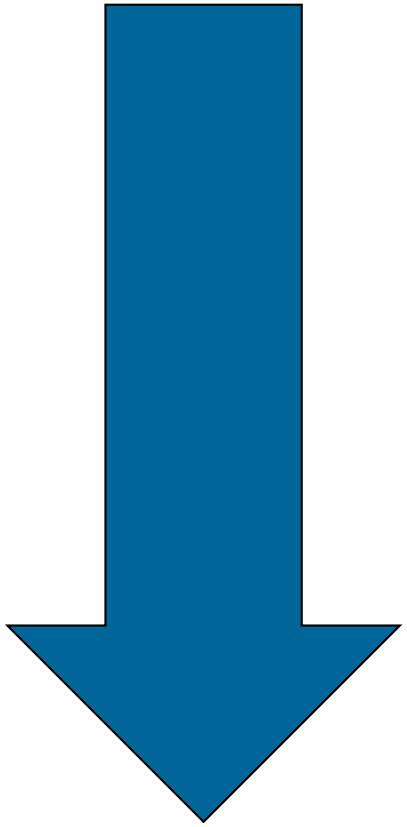
- Top-Down Model
  - Data is collected from public databases or from privately collected real cost data points.
  - In some cases, all data points used in the analysis are final price data of installed projects and there is no segmentation of costs.
  - Data is self-reported into public databases or aggregated from private databases that require such reporting.



# Model Differentiation: Top-Down Strengths and Weaknesses

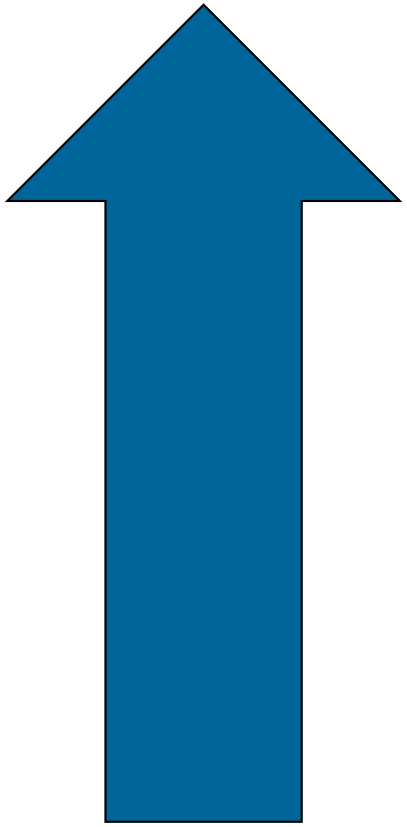
- Strengths:
  - Real reported pricing, not hypothesized
  - Sharing of confidential information isn't a concern because data is obtained from published sources
  - Scraping of databases is an automated, low-cost task
  - In some cases, granularity of detail is enormous

- Weaknesses:
  - Long time lag between project construction and report publication
  - Potential for disinterested data input that is error-prone
  - In some cases, granularity of detail is sparse



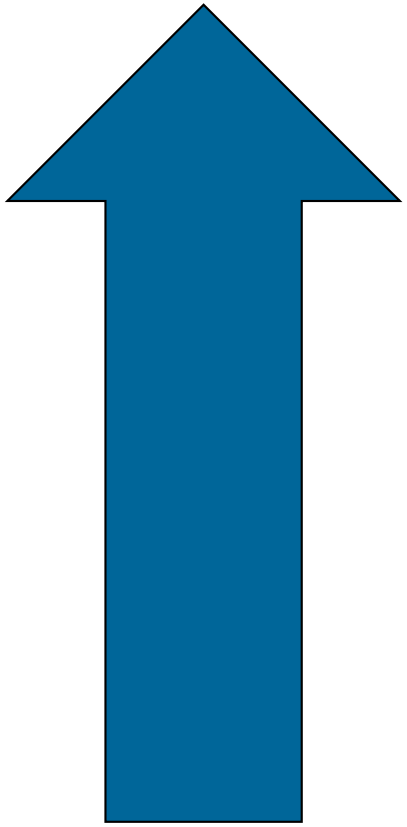
# Model Differentiation: Bottom-Up Details

- Bottom-Up Model
  - Data collected from interviews on a component-by-component basis.
  - Inquiries are performed through in-person interviews or through questionnaires.
  - Interviewees are industry participants throughout the supply chain, from component suppliers through project developers.



# Model Differentiation: Bottom-Up Strengths and Weaknesses

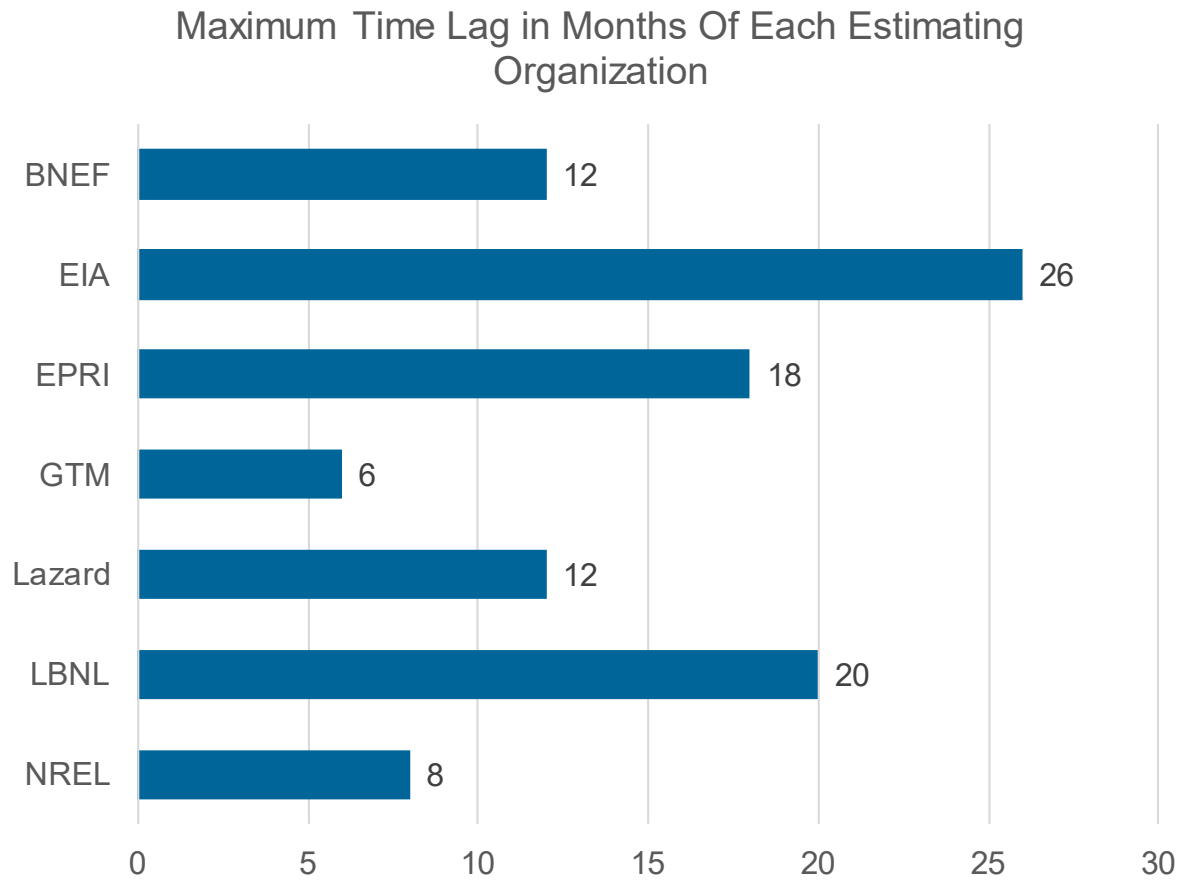
- Strengths:
  - Interview process can lead to shorter lag-time between data collection and report publication
  - Estimating organization is in complete control of level of detail, regional variation, quantity of information, etc.



- Weaknesses:
  - Data collection is very labor-intensive
  - Interviewees can combine real data with forward-looking hypotheses
  - Data quality can vary dramatically based on interviewee's level of investment in the outcome
  - Major players may not participate, leading to incomplete information

# Key Differentiation Factor: Time Lag

- The shorter the time-lag, the better chance that current costs are being evaluated.
- It is impossible to quantitatively identify exactly how much time-lag impacts the final estimation.
- However, industry participants (developers and financiers) stated the time lag issue was identified as the largest impact on final estimations.



# Key Differentiation Factor: Solar AC vs. DC Sizing

- Today, the AC measurement and the DC measurement of most solar projects are different, due to over-installation of DC panels vs. inverter capacity.
- This concept is measured by the term “inverter loading ratio” or “ILR”.
- Most estimating organizations agreed that average ILR should be somewhere between 1.2 and 1.3 (i.e., the DC capacity is 20% or 30% more than the AC capacity).
- Every organization except for GTM present their final CAPEX number in terms of AC capacity. GTM’s ILR is stated as 1.2. Those organizations that present AC capacity costs state that they do so to compare costs across other generation types (fossil fuel power plants are always measured in terms of AC capacity).


Solectria Inverters for Alamosa Project, Colorado

*Courtesy: Business Intelligence*

# Methodology Differentiation

Methodology Influence on Final CAPEX Numbers

# Data Collection

- Top-down data collected from public databases should be populated by relatively clean sources, due to the fact that posting the data is required by law or by financial covenants. However, the potential carelessness of the people doing the data entry must be accounted for and scrubbed out.
- Bottom-up data collected from private databases by an independent engineering firm should be relatively clean due to the motivation to enter the data correctly in order to meet requirements of financial covenants.
- Bottom-up data collected via a questionnaire process requires a quality check to ensure data is collected in an identical manner.

**Data collection varies by model approach, but in each case care must be taken to ensure clean and robust data is collected.**

# Model Project Sizing

- Each estimating organization utilizes its own method for sizing the system in a cost model. In most cases, a hypothetical model of a system is established at an arbitrary size. Some examples for solar include:
  - BNEF: 10 MW
  - EIA: 50 MW
  - EPRI/S&L: Pull together data from multiple projects and size them to the following plant sizes: 100 kW (commercial),11 MW (small utility), 50 MW (large utility)
  - GTM: 10 MW
  - Lazard: 30 MW
  - LBNL: Only uses reported data and range of CAPEX, although report has a section on the impact of economies of scale based on size of project
  - NREL: 10 kW and 2 MW (commercial), >2 MW (utility)

**It's unclear how project sizing impacts the final CAPEX numbers. It would be expected that the smaller the project, the fewer economies of scale and therefore the higher $/W price. However it appears that there are few, if any, economies of scale for solar beyond a 10-MW power block.**

# Labor Rate Modeling

- Labor comprises a large part of project installation costs. Estimation organizations have a number of options in determining estimated labor costs, from a simple multiplication factor to utilizing outside databases of labor costs (most commonly the Bureau of Labor Statistics (BLS)) to further partitioning union labor rates and non-union labor rates. Some examples include:
  - EPRI/S&L: Detailed regional and sometimes state labor rates are applied. Calculated using BLS data and further broken down into job categories (i.e., master electrician rates, apprentice electrician rates, etc.). A union vs. non-union rate is then applied. In states with union requirements, the model adjusts to reflect that.
  - GTM: Only BLS data
  - Lazard: Only labor data collected from actual projects or estimations by developers
  - NREL: Regional labor data, which is then further segmented into union or non-union states

**There doesn't seem to be significant correlation between the method of labor rate calculation and the final, national CAPEX number. Geographic breakdowns for labor rates (such as done by EPRI/S&L and NREL) are significant for regional variation data, however.**

# PV Module Technology Differentiation

- Estimation organizations show some variation in which module technology type(s) they track. Some examples include:
  - EPRI/S&L: By far the most segments covered, including mono Si, poly Si, CdTe thin film, and CIGS thin film as well as two tracking choices: fixed-tilt and single-axis tracking (SAT)
  - GTM: Does not break down by module technology type, but does segment by SAT vs. fixed-tilt
  - Lazard: No differentiation
  - LBNL: Addresses impact of tracking and non-tracking projects on CAPEX, but doesn't address module technology type
  - NREL: Does not break down by module type

**Although most estimation organizations base their numbers on poly Si fixed-tilt projects, some provide more technology and fixture categories.**

# Geographical Variation

- A key component of nationwide CAPEX estimates is regional variation. When data is taken from existing databases or real project cost data, regional variation is inherently limited, which might impact overall cost estimates (e.g., if the majority of wind data comes from Midwestern states, the inherently lower costs of that region compared to costs in New York or California might skew the nationwide aggregate number). Some examples include:
  - BNEF: Nationwide estimate only
  - EIA: Based on available data, then aggregated into nationwide estimate
  - EPRI/S&L: Based on available data, with labor rate adjustments by region
  - GTM: Nationwide estimate only
  - Lazard: Nationwide estimate only; no regional variation factored in
  - LBNL: Based on available data, with further breakdowns on states with available information
  - NREL: 45 locations throughout the U.S. are modeled and then aggregated into a nationwide estimate

**Regional variation of project coverage can lead to noticeable CAPEX differences.**

# Methodology Differentiation

Cost Segmentation

# Segmentation Overview

- Each estimation organization uses its own unique segmentation of line item costs.
- In some cases, these segmentations can be similarly built-up into major line items that can be compared across organizations, but not in all cases.
- The varying segmentation differences can make it difficult to compare costs by segment across the constellation of estimates.
- The only figure that can be universally compared is the final $/W or $/kW estimate of each organization.

**Examples of solar cost segmentation include:**

- Modules
- Inverters
- Balance of System
- Medium-Voltage Power Equipment
- High-Voltage Power Equipment
- Land Preparation Costs
- EPC Costs
- Soft Costs (taxes, supervision, etc.)

# Inclusion/Exclusion of Segments

- Although most estimating organizations approach CAPEX in a comprehensive manner, there are a few small differences in the exclusion of segments. These include:
  - Soft costs: The exact definition of soft costs varies from organization to organization. It can mean all developer costs not included in installation costs, such as analysis of site, insurance, and project contingency. In GTM's case, only costs that are incurred prior to installation are factored in. Others, such as insurance and post-installation certification, are not included.
  - Transmission costs: All estimation organizations exclude long distance transmission as a part of CAPEX due to the extremely variable transmission needs of projects. However some organizations include costs of a transmission line out to five miles (EPRI/S&L, NREL). Others include the cost of the transmission study, but not the physical interconnection (GTM, BNEF). Others include the high-voltage substation required for interconnection, but nothing outside of its fence (EIA, Lazard).

# CAPEX vs. OPEX: Inverter Replacement

- There are a few isolated circumstances where there are differences between whether an item is classified as a capital expense or an operating expense. The most significant of these is inverter replacement.

- Most PV systems are expected to generate power between 20 and 25 years. However, inverters are expected to have relatively high failure rates prior to the end-of-life of the project. Therefore, inverter replacement is usually expected.

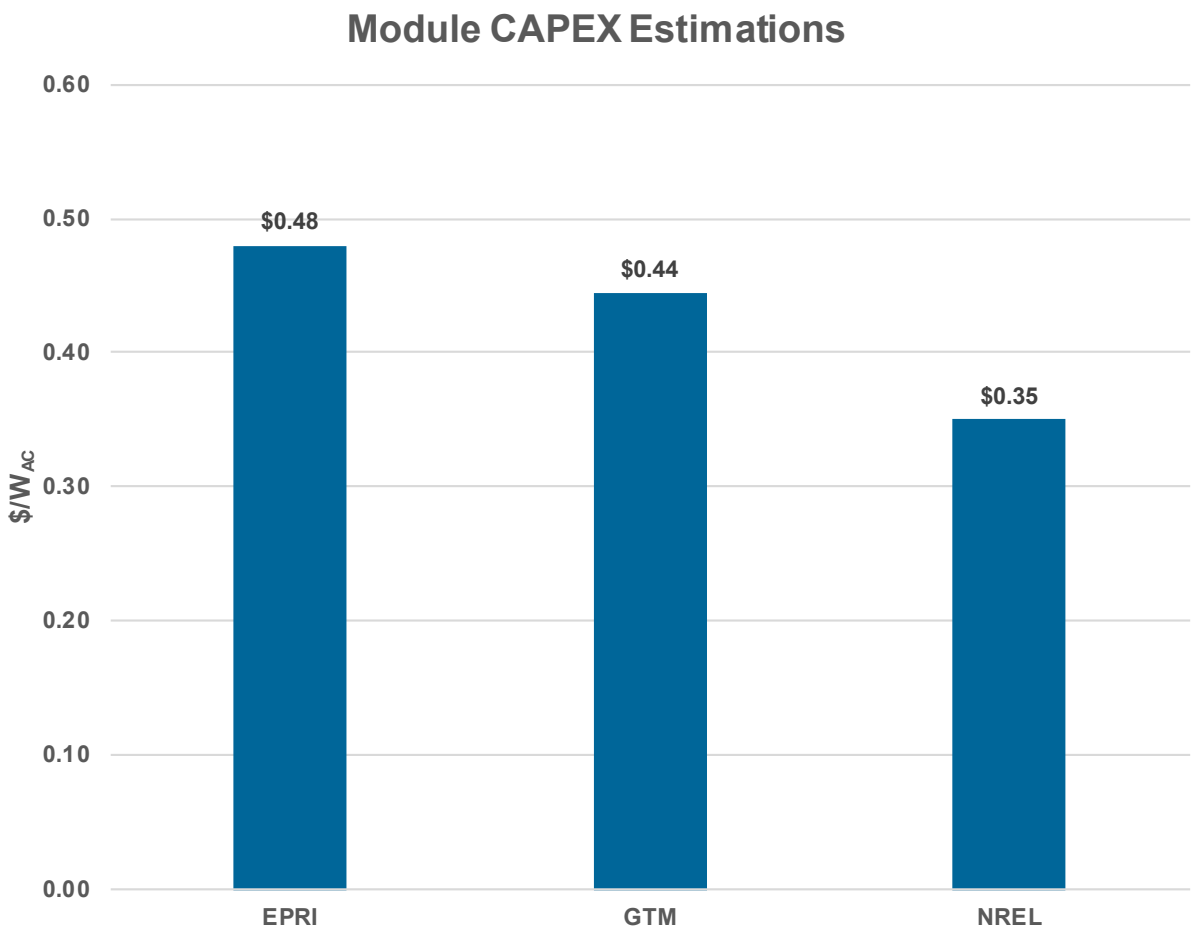
- In most cases, inverter replacement is calculated as an operating expense, as part of the general repair budget. However in some cases (most notably NREL), inverter replacement is calculated as part of a reserve fund that is included in capital expense.

# Major Categories of Cost

Solar CAPEX

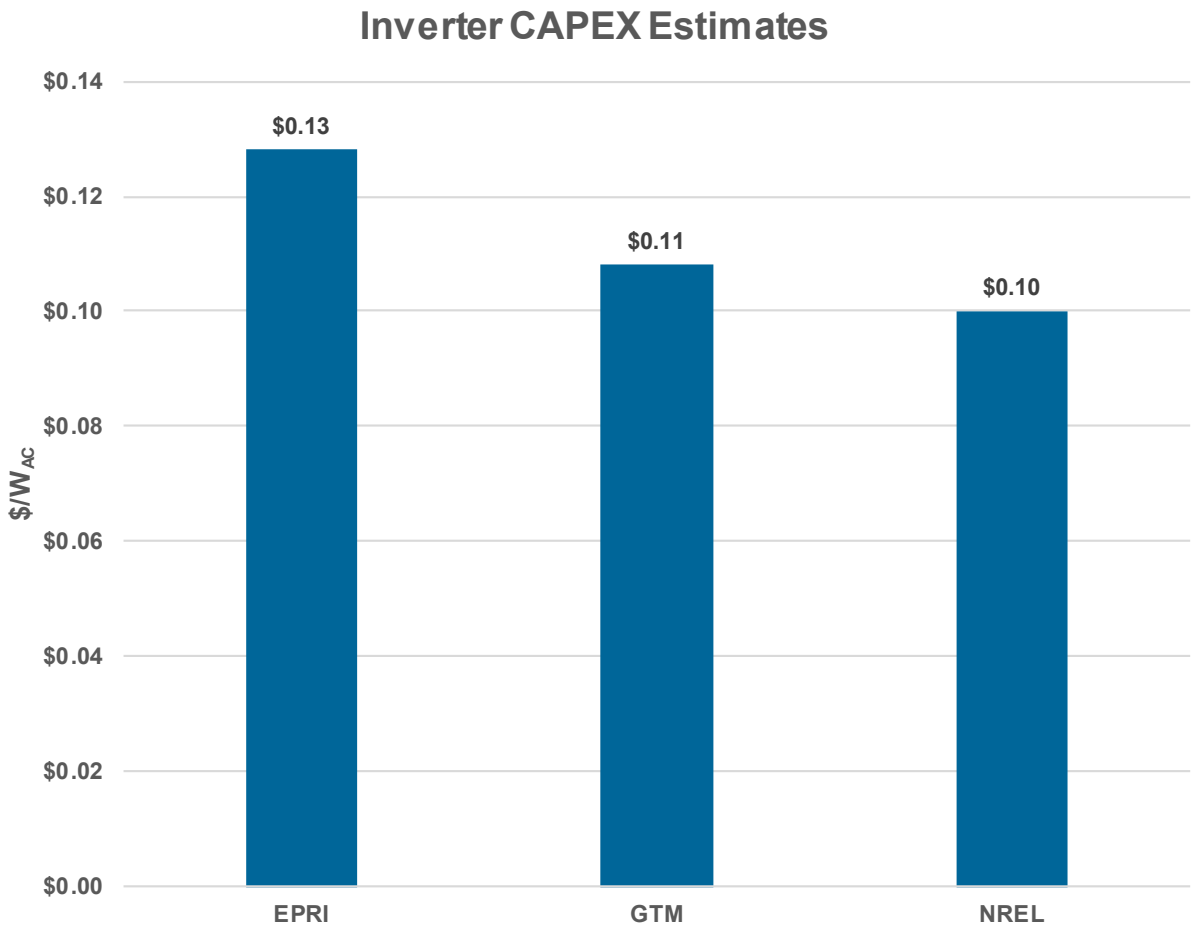
# Modules

- Only three estimating organizations break out module costs:
  - EPRI/S&L: Module costs include the cost of installing the modules. S&L does not break out the installation cost segment into a separate labor category.
  - GTM: Costs are adjusted from DC to AC with an ILR of 1.2. Module costs are based on a separate cost tracker for module pricing within the GTM organization.
  - NREL: Module costs represent polysilicon crystalline modules.



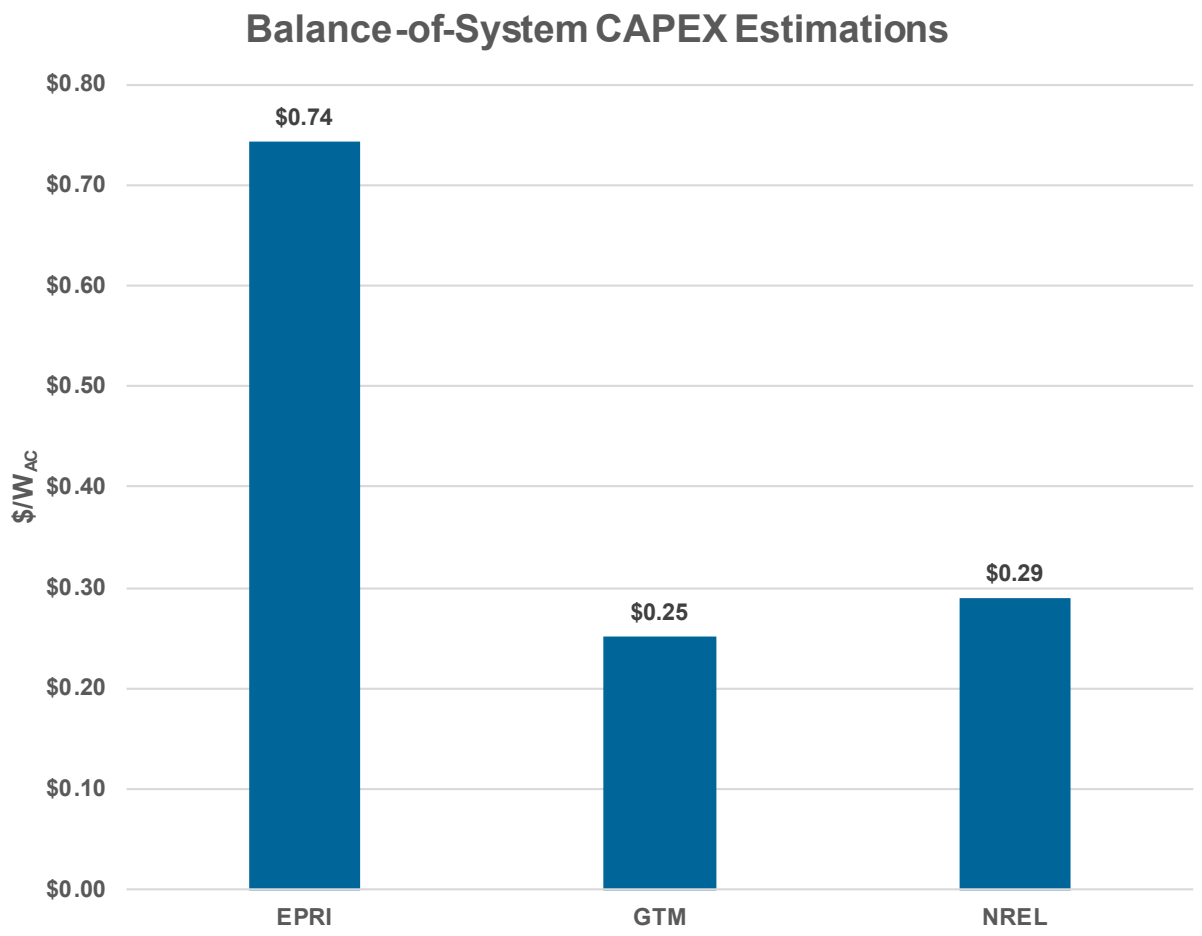
# Inverters

- Inverter costs track closely among all three organizations:
  - EPRI/S&L: As in the case with modules, inverter costs include the installation cost of the inverter, which covers concrete pad pouring, medium-voltage connectors, and control systems. With inclusion of labor costs, the $0.13/W for utility systems is comparable to the other estimates.
  - GTM: Costs are adjusted from DC to AC with an ILR of 1.2.
- Across the board, inverter pricing seems to be in agreement across organizations.



# Balance-of-System

- Balance-of-system (BOS) costs include all electrical work (cabling, runways, DC optimizers, low-voltage transformers and pads, etc.) and all structural components (racking, ground-mounts, fencing, etc.).
- NREL's and GTM's BOS costs are in relative alignment after adjusted GTM's estimate from DC to AC with an ILR of 1.2.
- EPRI/S&L estimates include all installation labor in addition to BOS equipment and materials.

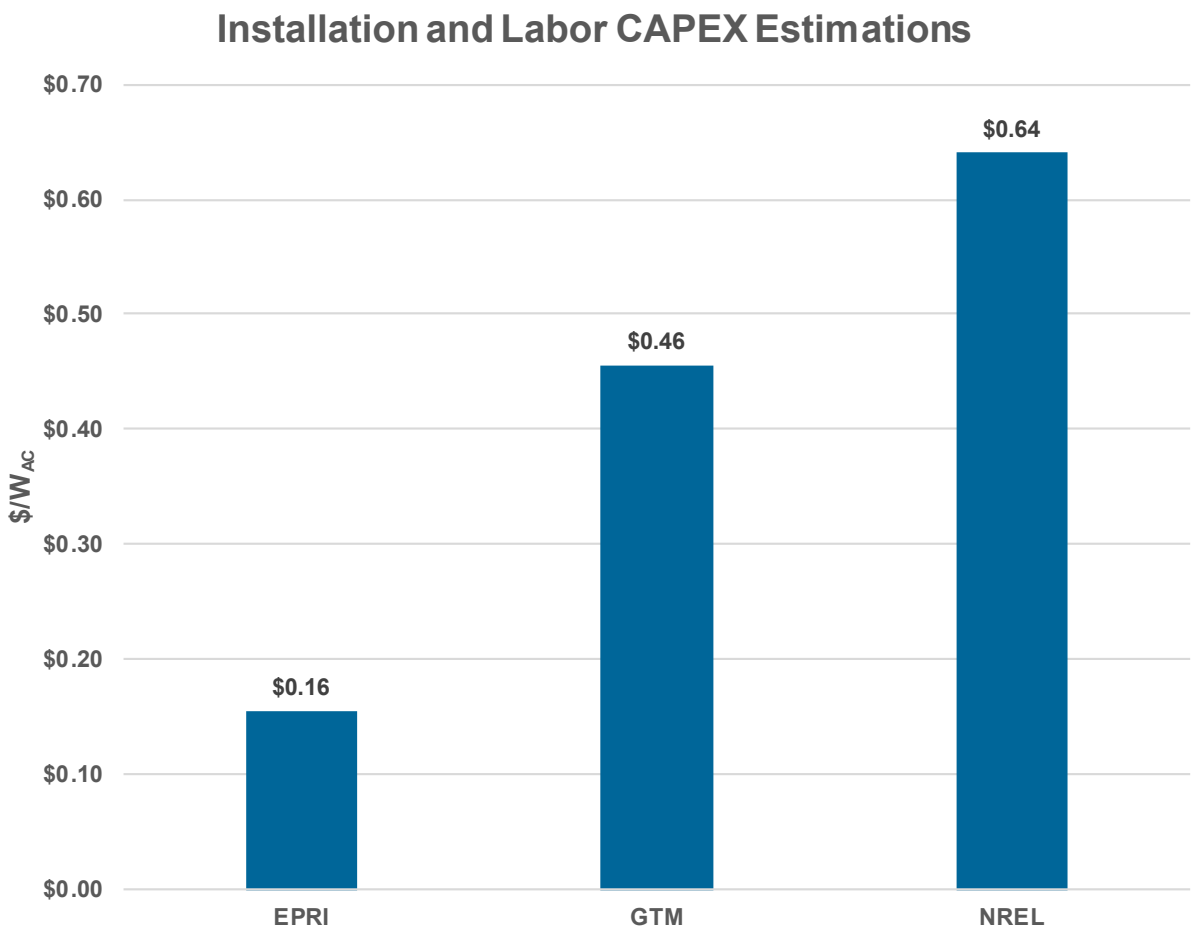


# Installation and Labor Costs

- Installation and labor costs are skewed among bottom-up organizations because EPRI/S&L combines labor and materials in each cost segment already discussed, while other organizations break out these categories separately.

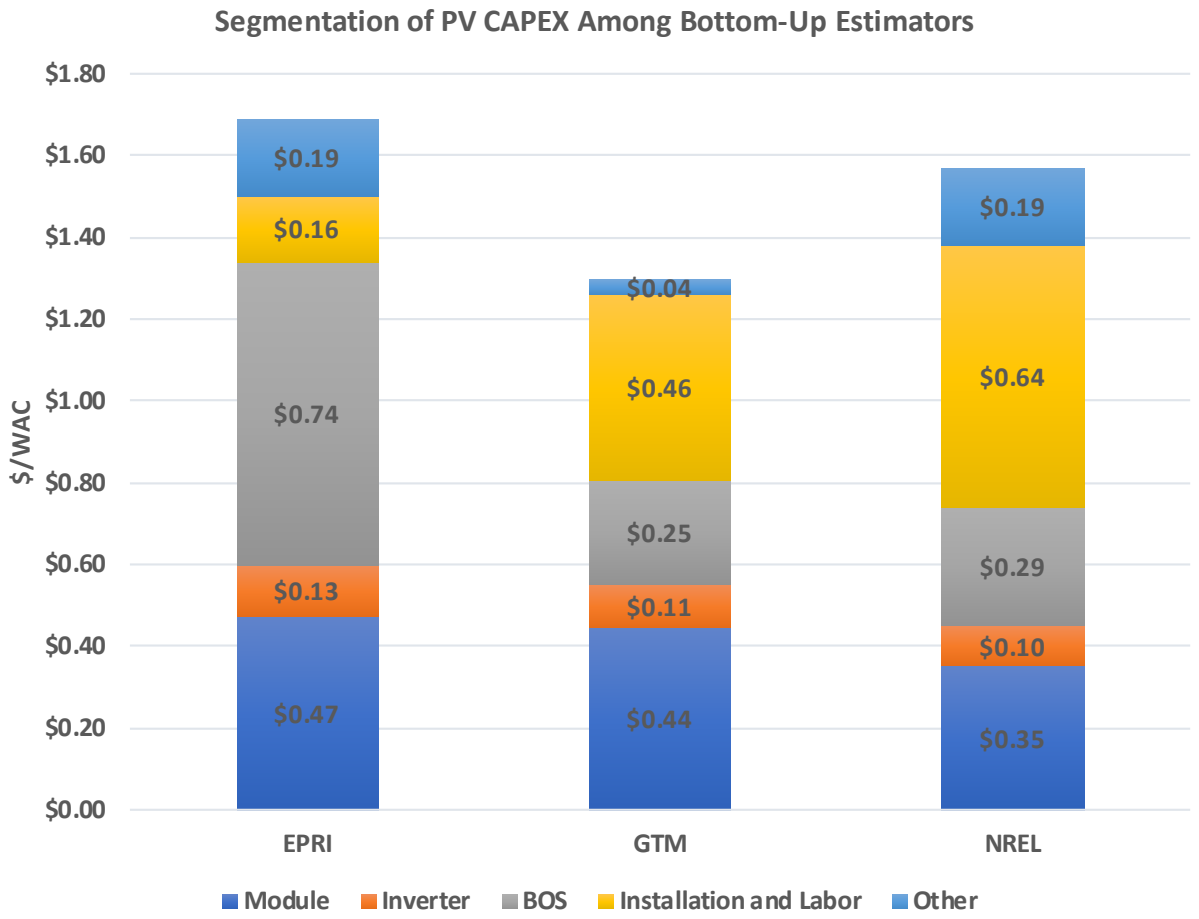
- EPRI costs here include only Engineering, Procurement, and Contracting (EPC) costs, while GTM and NREL include both EPC and installation labor. This segmentation difference is a primary reason for differences in installation and equipment/materials costs.

- Installation costs are one of the starkest differences between GTM and NREL. This is mostly due to the EPC category, for which GTM includes basic costs incurred by the developer for installation, but not equipment rental or depreciation, labor, and profit.



# Bottom-Up Segmentation Comparison

- Segmentation analysis is extremely difficult because:
  - Top-down estimators don't report segmentation
  - Among organizations that do report it, segmentation buckets are different
  - EPRI, for instance, reports equipment segmentation with labor and installation costs built-in
  - The chart on the right is an illustrative analysis, not a definitive quantitative analysis. Among the key points:
    - Module and inverter prices are relatively similarly priced across organizations
    - Balance-of-system and installation and labor costs have the widest variations
    - Other (or "soft costs") have variations that are influenced more by the way costs are grouped than by actual cost differentials in the line items that are being compared



# CAPEX Estimator Profiles

Solar Estimation Organizations

# Segmentation Tables Description

- In the following slides, each organization's segmentation and approach are described in tables. These tables show the following:
  - Equipment Segments: The types of equipment that are modeled and reported in the estimating organization's publication
  - Installation Segments Modeled: The categories of installation costs that are modeled as part of the overall estimation, but aren't necessarily published in the final publication
  - Installation Segments Reported: The installation cost segmentation that are published in the final CAPEX publication
  - System Segmentation by Size: The taxonomies of system size used in the final publication
  - Other System Segmentations: Technology and system structure segments (i.e. technology type of module, fixed tilt or tracked, etc.) that are reported in the publication

| Estimating Organization |
|---|
| Core Methodology: |
| Most Recent Published Figures: |
| Lag-time From Data Collection: |
| System Sizing Format: |
| **Segmentation** |
| **Equipment Segments** |
| |
| **Installation Segments Modeled** |
| |
| **Installation Segments Reported** |
| |
| **System Segmentations by Size** |
| |
| **Other System Segmentations** |
| |

# Bloomberg New Energy Finance

- Bloomberg New Energy Finance (BNEF) is the energy consulting arm of Bloomberg LLC, a private media corporation based in New York, NY.
- BNEF analyzes solar and wind data through bottom-up methodology that is based on interviews with dozens of industry participants.
- BNEF provides reports on solar and wind cost estimates for clients who subscribe to its services.
- In addition to overall CAPEX reports, BNEF also has teams that provide reports specifically on PV module and wind turbine prices and LCOE estimates.

# Bloomberg New Energy Finance Segmentation

- BNEF uses a detailed bottom-up methodology that involves dozens of interviews with industry participants.
- BNEF publishes its CAPEX, OPEX and LCOE data each year.
- BNEF models five segments and publishes all five.
- BNEF did not provide underlying data for the purposes of this study, so only publicly available BNEF data is used in this report.

| BNEF |
|---|
| Core Methodology: Bottom-Up |
| Most Recent Published Figures: June 2017 |
| Lag-time From Data Collection: 12 |
| System Sizing Format: DC |
| **Segmentation** |
| **Equipment Segments** |
| Module |
| Balance of System |
| **Installation Segments Modeled** |
| EPC Margin |
| EPC Costs |
| Overhead Costs |

| BNEF (Cont.) |
|---|
| **Installation Segments Reported** |
| Module |
| Inverter |
| Balance of System |
| EPC |
| Other Costs |
| **System Segmentations by Size** |
| 5 kW |
| 100 kW |
| 10 MW |
| **Other System Segmentations** |
| Crystalline-Si |
| Thin Film |
| Tracked |
| Fixed Mount |

# Energy Information Administration

- The Energy Information Administration (EIA), the statistics arm of the Department of Energy, publishes a triennial report on cost comparisons of different generation reports.

- The report only provides total CAPEX costs. However it is based on a robust analysis of detailed costs from completed projects. The analysis is done by Leidos, an independent engineering firm with access to costs from its own database of projects for which it has provided lending scores.

- Main point of contact for EIA's CAPEX reports: Christopher Namovicz at chris.namovicz@eia.gov

# Energy Information Administration Segmentation

- For solar costs, EIA provides CAPEX for two project sizes (20 MW and 150 MW) and for both fixed and tracked.
- The EIA report, because it is only published every three years and because of the nature of data collection by Leidos, has the longest potential lag time between completion of project and report publication.

| EIA Solar |
|---|
| Core Methodology: Bottom-Up/Top-Down Hybrid |
| Most Recent Published Figures: Sep-2017 |
| Lag-time From Data Collection: 18-26 months |
| System Sizing Format: AC |
| **Segmentation** |
| **Equipment Segments** |
| Modules |
| Balance of System |
| **Installation Segments modeled** |
| EPC |
| **Installation Segments Reported** |
| Total Costs |
| **System Segmentations by Size** |
| 20 MW |
| 150 MW |
| **Other System Segmentations** |
| Polycrystalline Si |
| Fixed Mount |
| Single-Axis Tracking |

# EPRI/Sargent & Lundy

- The Electric Power Research Institute (EPRI) utilizes data for its solar and wind CAPEX estimations from Sargent & Lundy (S&L).
- S&L is a private independent engineering contractor based in Chicago, IL with more than 1,000 employees. Its primary business is to provide credit ratings to lending bodies for energy projects through analysis of detailed cost and performance data of those projects.
- For the purposes of providing its CAPEX data to EPRI, S&L aggregates and anonymizes known project costs from its database of projects. In some cases, modeling factors are added to the estimation, such as regional labor rates and cost-of-doing-business factors.
- Main point of contact for EPRI/S&L's CAPEX reports: Robin Bedilion at rbedilion@epri.com


# EPRI/S&L Segmentation

- 11 installation categories, the most detailed for any estimation organization.
- Four segmentation sizes vary between residential, commercial, small utility, and large utility.
- Underlying data is collected in model that has more than 500 line items.
- Data segments by four module types and three tracker types.
- EPRI is the only organization that builds installation and labor costs into equipment segments, making comparisons with other detailed estimating organizations difficult.
- Overall, EPRI's reported data is the most granular and detailed of any estimating organization.

| EPRI/Sargent & Lundy Solar |
|---|
| Core Methodology: Bottom-Up/Top Down-Hybrid |
| Most Recent Published Figures: Oct-17 |
| Lag-time From Data Collection: 12-18 |
| System Sizing Format: DC and AC |
| **Segmentation** |
| **Equipment Segments** |
| Modules |
| Inverter, Pad Mount Transformer and installation |
| **Installation Segments Modeled** |
| Site preparation |
| Raceways, Wiring, Conduits & Combiner Boxes |
| Substation and medium-voltage system |
| Backup power + supervisory control and data acquisition |
| Mounting System (including module installation) |
| Engineering and management |
| Contingency and profit |
| Modules |
| Interest During Construction |
| Owner's Cost |

| EPRI/Sargent & Lundy Solar (Cont.) |
|---|
| **Installation Segments Reported** |
| Site preparation |
| Inverter, Pad Mount Transformer and installation |
| Raceways, Wiring, Conduits & Combiner Boxes |
| Substation and medium-voltage system |
| Backup power + supervisory control and data acquisition |
| Mounting System (including module installation) |
| Engineering and management |
| Contingency and profit |
| Modules |
| Owner's Cost |
| **System Segmentations by Size** |
| 5 kW |
| 100 kW |
| 11 MW |
| 50 MW |
| **Other System Segmentations** |
| Mono Si |
| Poly Si |
| CdTe |
| CIGS |
| Single-Axis Tracker |
| Fixed Mount |

# Greentech Media Research

- Greentech Media Research (GTM) is a cleantech consulting and analysis firm based in Boston, MA. In addition to its consulting business, it also operates a cleantech news website, also called Greentech Media. In 2016, GTM was purchased by Wood Mackenzie, the U.K.-based energy data and consulting firm.

- GTM provides solar and wind CAPEX, OPEX, and LCOE data to subscription clients. It also performs customized research projects for consulting clients.

- Main contact for more information about GTM's solar and wind reports: Ben Gallagher at gallagher@gtmresearch.com

gtm.
A Wood Mackenzie Business

# Greentech Media Segmentation

- GTM provides some of the most detailed segmentation of solar cost data available. GTM breaks down installation and equipment into a total of nine segments, providing cost data on each segment.
- GTM's CAPEX numbers are derived from a thorough interview process with more than 60 industry participants. Results are updated every six months in a bi-annual report. All data is modeled using a bottom-up methodology, so cost information is gathered for each segment that is published. The lag time between data collection and report publication (six months maximum) is the shortest of all estimating organizations.
- GTM's solar project data is reported in DC sizing. Therefore all GTM CAPEX numbers discussed in this report have been adjusted to AC sizing for the purposes of comparison.

| Greentech Media |
|---|
| Core Methodology: Bottom-Up |
| Most Recent Published Figures: Nov-17 |
| Lag-time From Data Collection: 6 |
| System Sizing Format: DC |
| **Segmentation** |
| **Equipment Segments** |
| Module |
| Inverter |
| **Installation Segments Modeled** |
| Electrical Balance of System |
| Structural Balance of System |
| Labor |
| EPC Contractor |
| Civil Engineering |
| Permitting and Interconnection |
| Miscellaneous |

| Greentech Media (Cont.) |
|---|
| **Installation Segments Reported** |
| Module |
| Inverter |
| Electrical Balance of System |
| Structural Balance of System |
| Labor |
| EPC Contractor |
| Civil Engineering |
| Permitting and Interconnection |
| Miscellaneous |
| **System Segmentations by Size** |
| <100 KW |
| 100-1000 KW |
| 1-5 MW |
| >5 MW |
| **Other System Segmentations** |
| Fixed Tilt |
| Tracking |

# Lawrence Berkeley National Laboratory

- Lawrence Berkeley National Laboratory (LBNL) is a Department of Energy National Laboratory, founded in 1931. It is based in Berkeley, CA and managed by the University of California, Berkeley.

- LBNL covers solar costs through two publications:
  - Tracking the Sun is an annual review of residential and small commercial solar installations. It has provided cost data each year since 2009.
  - Utility Scale Solar Report is an annual publication done by LBNL on behalf of the Department of Energy's SunShot Program.

- LBNL is the only pure top-down estimating organization.

- Main contact for more questions about LBNL's Utility Scale Solar report: Mark Bolinger at mabolinger@lbl.gov

# LBNL Segmentation

- LBNL only covers one segment: total project cost. There is no further breakdown of cost categories.
- Three technology segments are covered:
  - Fixed-tilt silicon modules
  - Tracking silicon modules
  - Fixed-tilt thin film modules
- LBNL data is based on public databases of solar cost figures, which means its publication has an inherently long time lag between system installation and report publication.

| LBNL Solar |
|---|
| Core Methodology: Top-Down |
| Most Recent Published Figures Aug-17 |
| Lag-time From Data Collection: 20 |
| System Sizing Format: AC |
| **Segmentation** |
| **Equipment Segments** |
| Total Costs |
| **Installation Segments Modeled** |
| Total Costs |
| **Installation Segments Reported** |
| Total Costs |
| **System Segmentations by Size** |
| 5-20 MW |
| 20-50 MW |
| 50-100 MW |
| >100 MW |
| **Other System Segmentations** |
| Fixed Tilt Silicon |
| **Other System Segmentations** |
| Fixed Tilt |
| Tracker |
| Poly Si |
| Mono Si |

# LBNL Sourcing

- LBNL collects data from the following databases and data sources:
  - Technology Trends: Form EIA-860, FERC Form 556, state regulatory filings, the National Renewable Energy Laboratory (NREL), the Solar Energy Industries Association (SEIA), interviews with project developers and owners, trade press articles
  - Installed Prices: Form EIA-860, Section 1603 grant data from the U.S. Treasury, FERC Form 1, data from applicable state rebate and incentive programs, state regulatory filings, company financial filings, interviews with developers and owners, trade press articles, and data previously gathered by NREL
  - O&M Costs: FERC Form 1 and state regulatory filings (empirical data)
  - Capacity Factors: FERC Electric Quarterly Reports, FERC Form 1, Form EIA-923, state regulatory filings PPA Prices: FERC Electric Quarterly Reports, FERC Form 1, Form EIA-923, state regulatory filings, company financial filings, trade press articles

# Lazard Inc.

- Lazard Inc. is a New York, NY-based investment and merchant bank.
- Lazard publishes an annual report on U.S. CAPEX, OPEX and LCOE data on all generation types. It utilizes a bottom-up methodology.
- Lazard only publishes the total CAPEX number, and does not break it down by the segmentations that are used to model the final number.
- Main contact for more information about Lazard's energy reports: Garrett Haddad at garrett.haddad@lazard.com.

# Lazard Segmentation

- Lazard publishes only a single CAPEX number for overall costs. It assumes a project size of 30 MW or larger with polycrystalline panels.
- Internally, Lazard models its final CAPEX number on three installation cost segments (EPC installation, balance of system, and labor) and two equipment cost segments (module and inverter).
- Lazard's model is based on hundreds of interviews done with energy industry participants across all generation technologies, including fossil, nuclear, and alternative generation. Its annual report is published shortly after the completion of all interviews, hence the lower lag time than others.

| Lazard Solar |
|---|
| Core Methodology: Bottom-Up |
| Most Recent Published Figures: Nov-17 |
| Lag-time From Data Collection: 12 |
| System Sizing Format: AC |
| **Segmentation** |
| **Equipment Segments** |
| Module |
| Inverter |
| **Installation Segments Modeled** |
| EPC |
| Balance of System |
| Labor Costs |
| **Installation Segments Reported** |
| Total Costs |
| **System Segmentations by Size** |
| 30 MW |

# National Renewable Energy Laboratory

- The National Renewable Energy Laboratory (NREL) is one of sixteen National Laboratories overseen by the Department of Energy. It is based in Golden, CO and is currently managed by Battelle.
- NREL publishes an annual report on CAPEX, OPEX, and LCOE costs for solar energy.
- The NREL report utilizes a bottom-up methodology based on interviews with industry participants on component costs. Those component costs are then aggregated into an overall CAPEX number.
- Main contact for more information about NREL's solar reports: Ran Fu at ran.fu@nrel.gov

# NREL Segmentation

- NREL's solar CAPEX report is published every year and is based on interviews with dozens of industry participants.
- NREL's segmentation is wider and more thorough than any other public organization's methodology. Beneath the five published segments are more than ten line items of data that are collected but not published.
- Due to the long publication process at NREL, installation data can take as long as 16 months before it is published.

| NREL |
|---|
| Core Methodology: Bottom-Up |
| Most Recent Published Figures: Sep-17 |
| Lag-time From Data Collection: 16 |
| System Sizing Format: DC |
| **Segmentation** |
| **Equipment Segments** |
| Module |
| Inverter |
| Electrical BoS |
| **Installation Segments Modeled** |
| PII |
| Land Acquisition |
| Tax |
| Overhead EPC |
| Net Profit EPC |
| Install Labor |
| Contingency |
| Structural BoS |
| Overhead Developer |

| NREL (Cont.) |
|---|
| **Installation Segments Reported** |
| Module |
| Inverter |
| BoS |
| Soft Costs Labor |
| Soft Costs Other |
| **System Segmentations by Size** |
| 3-10 kW |
| 10-2000 kW |
| >2 MW |
| **Other System Segmentations** |
| Fixed Tilt |
| Tracker |

# Solar CAPEX Conclusions and Recommendations

- The time-lag between data collection and report publication is the primary reason for variation in solar CAPEX estimates. Organizations with shorter time-lags had lower cost data, primarily because pricing data is declining at such a steep rate that a matter of months can impact cost reporting.

- Bottom-up and top-down methodologies have their own strengths and weaknesses, and results of specific reports should be viewed within the context of the methodology used for data collection and modeling.

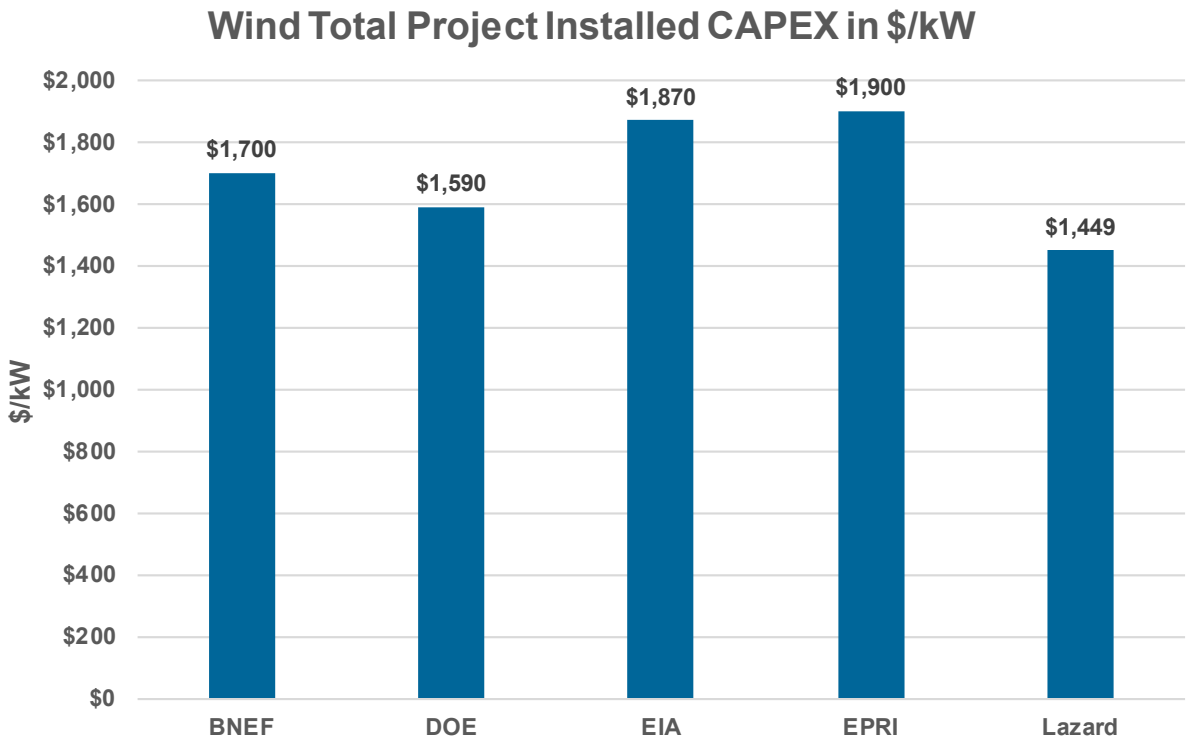
- Organizations' views of PV module costs and inverters are relatively uniform. CAPEX differentials on a project-wide basis are primarily due to differences in costs for installation and balance-of-system.

# Major Categories of Cost

Wind CAPEX

# Wind Project Overall CAPEX Estimates

- Onshore wind overall CAPEX estimates range from a low of $1,450/kW (Lazard) to a high of $1,900/kW (EPRI/S&L).
- Unlike solar differentiation, there are no big-picture segmentation reasons for wind price differentials. All CAPEX figures are stated in AC.
- The two organizations that required the longest time lag, EPRI/S&L and EIA, both had the highest estimates.
- When provided, segmented turbine costs appeared to be uniform across the industry, with variation primarily residing in the balance of system costs.



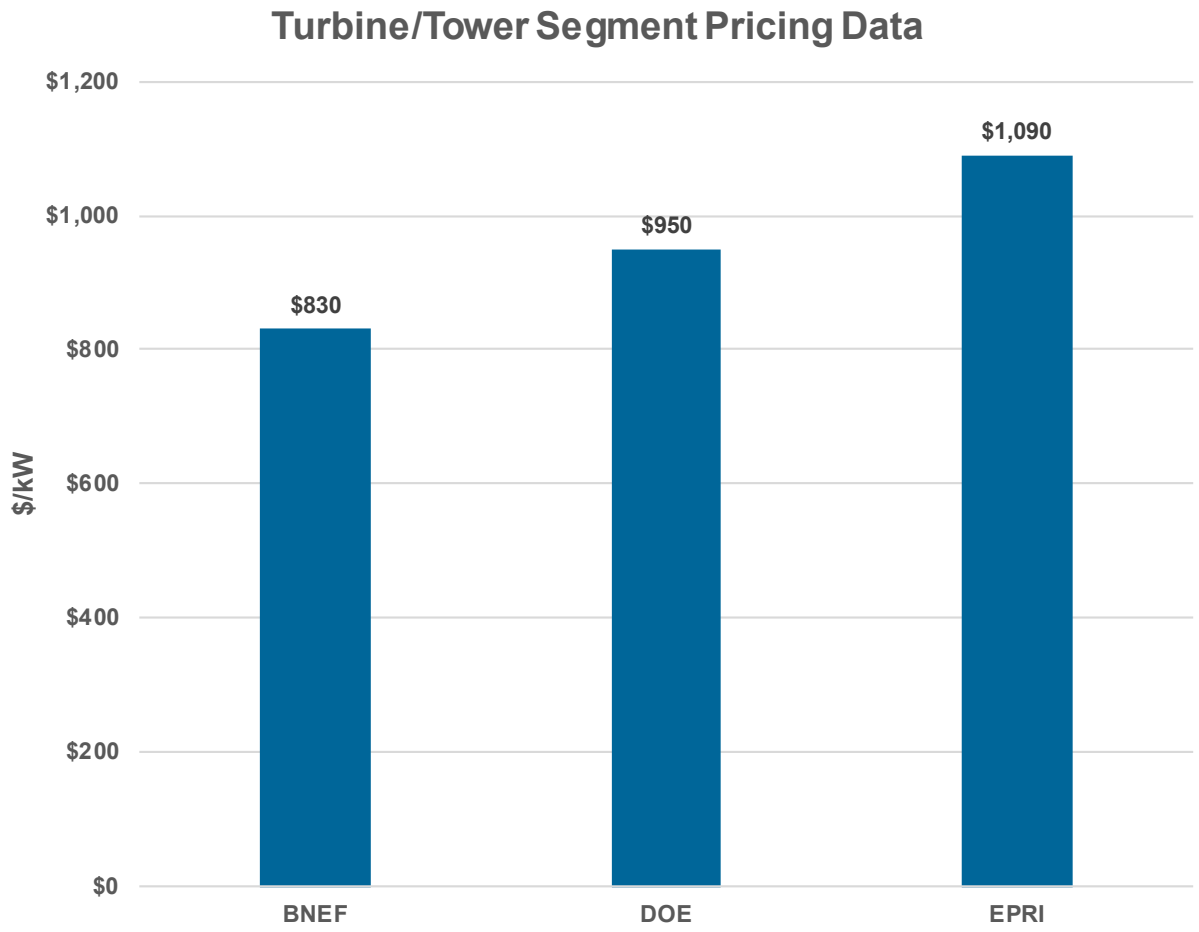
# Wind CAPEX Overview

- Assessing wind project CAPEX is a simpler process than solar, thanks to significantly fewer project cost segments:
  - Turbine/Tower
  - Balance-of-System Costs
  - Installation Costs
- Only three organizations (BNEF, DOE, and EPRI) break out costs beyond total project costs.
- Offshore wind projects and their cost information are so limited in North America that only onshore wind projects are examined in this study.

# Wind Turbine and Tower CAPEX Estimates

- Turbine and tower costs are the most understood and most publicly available information in the wind sector. There is little disagreement around turbine/tower costs.

- Nevertheless, turbine costs still varied significantly. This can again be explained by time lag – the higher prices for turbines came from organizations with longer time lag. BNEF, with the shortest time lag of twelve months, had the lowest turbine costs.

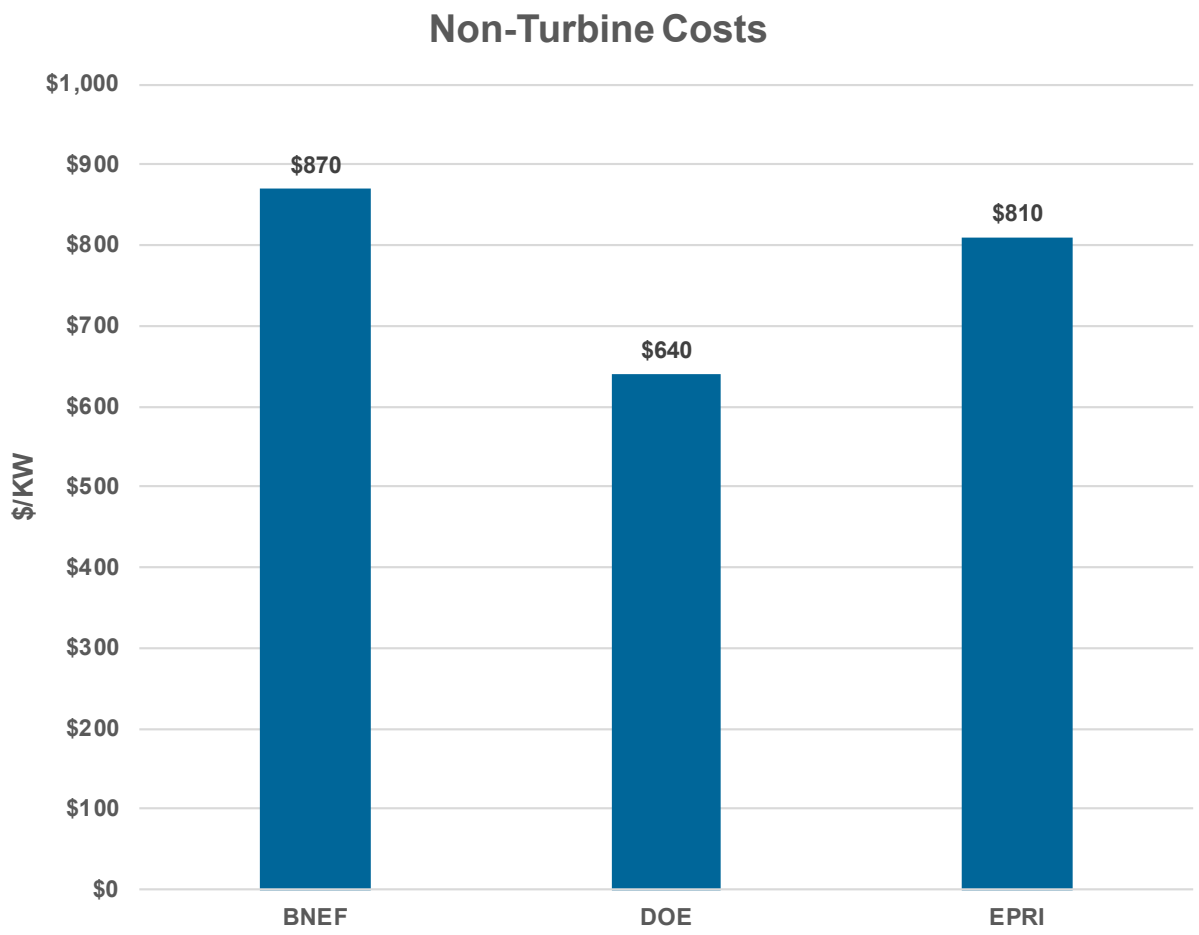


# Non-Turbine Balance-of-Systems and Installation CAPEX Estimates

- Segmentation of the non-turbine balance-of-system costs for developing an onshore wind farm have different line item segmentation.

- When grouped together as one segment, non-turbine costs are significantly different, especially the difference between DOE and BNEF. This might be due to the lack of detail in DOE's approach, which only asks developers for one line item, whereas BNEF and EPRI both have granular bottom-up approaches to data collection.

- BNEF, which has the shortest data collection to publication route, has the highest $/kW figure of BOS costs, at $870/kW. This number is nearly 30% higher than the DOE number of $640/kW.



# CAPEX Estimator Profiles

Wind Estimation Organizations

# Bloomberg New Energy Finance Wind Segmentation

- BNEF collects data on turbines/towers, balance-of-systems costs, and installation costs separately and then aggregates to overall costs.
- BNEF bases its turbine/tower costs on its own research service, which covers pricing of wind turbines.
- BNEF publishes an annual report on all renewable energy CAPEX, OPEX, and LCOE numbers.

| BNEF |
|---|
| Core Methodology: Bottom-Up |
| Most Recent Published Figures: Jun-17 |
| Lag-time From Data Collection: 12 |
| **Segmentation** |
| **Equipment Segments** |
| Turbine/Tower |
| Balance of System |
| **Installation Segments Modeled** |
| Installation |
| **Installation Segments Reported** |
| Turbine/Tower |
| Balance of System |
| Installation |
| **System Segmentations by Size** |
| 100 MW |

# Department of Energy Wind Segmentation

- The Department of Energy publishes an annual report on wind costs that is based on data collected by LBNL and NREL. This report tracks pricing of wind components and overall project costs.
- Collected data includes detailed information on components of the turbine, but only turbine/tower and total project costs are published.
- The DOE report has the most thorough segmentation of project sizes (and the resulting impact on economies of scale).

| DOE Wind |
|---|
| Core Methodology: Bottom-Up |
| Most Recent Published Figures: Aug-17 |
| Lag-time From Data Collection: 16 |
| **Segmentation** |
| **Equipment Segments** |
| Turbine |
| Blades |
| Tower |
| Pitch Mechanism |
| Hub |
| Nacelle Bed Plate |
| Nacelle Cover |
| **Installation Segments Modeled** |
| Installation |
| **Installation Segments Reported** |
| Turbine/Tower |
| Total Project Costs |
| **System Segmentations by Size** |
| Project costs are averaged across all system sizes |

# Energy Information Administration Wind Segmentation

- The Energy Information Administration contracts data collection for its CAPEX estimates to engineering firm Leidos. Leidos collects cost data from its internal database of projects.
- Leidos' collection and analysis of data and EIA's publication of data can take up to 26 months. That is primarily due to EIA's three year cycle of report publication.
- EIA only reports on total costs, although more detailed information is collected by Leidos.

| EIA Wind |
|---|
| Core Methodology: Top-Down/Bottom-Up Hybrid |
| Most Recent Published Figures: Sep-2017 |
| Lag-time From Data Collection: 18-26 |
| **Segmentation** |
| **Equipment Segments** |
| Turbine/Tower |
| Balance of System |
| **Installation Segments modeled** |
| Installation |
| **Installation Segments Reported** |
| Total Costs |
| **System Segmentations by Size** |
| 100 MW |

# EPRI/Sargent & Lundy Wind Segmentation

- Like its solar data, S&L collects wind cost information from an aggregated and anonymized database of wind projects through its role as a credit rating independent engineering firm.
- S&L's reported cost segmentation is the most granular of all estimating organizations and includes such line items as concrete foundations, land grubbing, etc.
- As with its solar estimates, S&L merges labor with overall installation costs.
- S&L also provides cost data on U.S. regions in addition to its national estimate. This regional data varies by turbine types (where appropriate), labor costs, union-mandated states and a few other factors.

| EPRI Wind |
|---|
| Core Methodology: Bottom-Up/Top-Down Hybrid |
| Most Recent Published Figures: Oct-17 |
| Lag-time From Data Collection: 12-18 |
| **Segmentation** |
| **Equipment Segments** |
| Turbine/Tower |
| Turbine Options |
| Delivery |
| Installation Support and Commissioning |
| **Installation Segments Modeled** |
| Clearing, Grubbing, Excavation |
| Foundation |
| O&M Building |
| Roads and Fencework |
| Electrical System |
| Substation |
| Crane Rental |
| Owner's Cost |

| EPRI Wind Cont. |
|---|
| **Installation Segments Reported** |
| Turbine/Tower |
| Turbine Options |
| Delivery |
| Installation Support and Commissioning |
| Clearing, Grubbing, Excavation |
| Foundation Concrete |
| O&M Building |
| Roads and Fencework |
| Electrical System |
| Substation |
| Crane Rental |
| Owner's Cost |
| **System Segmentations by Size** |
| 200 MW |

# Lazard Wind Segmentation

- Lazard publishes only a single CAPEX figure for wind. It does not break out turbine vs. balance-of-system costs.
- Lazard does collect information on turbine and balance-of-system costs during its interview process, but those segments are not published.
- Lazard, along with BNEF, has the shortest time frame of approximately one year from data collection to published data. This is probably the primary reason why those two organizations have lower total CAPEX estimates.

| Lazard Wind |
|---|
| Core Methodology: Bottom-Up |
| Most Recent Published Figures: Nov-17 |
| Lag-time From Data Collection: 12 |
| **Segmentation** |
| **Equipment Segments** |
| Turbine/Tower |
| **Installation Segments modeled** |
| Installation |
| **Installation Segments Reported** |
| Total Costs |
| **System Segmentations by Size** |
| 100 MW |

# Wind CAPEX Conclusions and Recommendations

- A consensus exists amongst organizations around turbine/tower pricing. Almost all variation of CAPEX in wind is in non-turbine costs.

- The time-lag between data collection and report publication is again the largest contributor to variation in final CAPEX estimates. The organizations with shorter time-lags showed lower pricing overall.

- There still isn't enough data on offshore wind projects in North America to draw reasonable conclusions about costs.

# Acronyms

- $/kW: Dollar per Kilowatt
- $/MW: Dollar per Megawatt
- $/W: Dollar per Watt
- AC: Alternating Current
- BLS: Bureau of Labor Statistics
- BNEF: Bloomberg New Energy Finance
- BOS: Balance of System
- CAPEX: Capital Expense
- CdTe: Cadmium Telluride
- CIGS: Cadmium Indium Gallium Selenide
- DC: Direct Current
- DOE: Department of Energy
- EIA: Energy Information Administration
- EPC: Engineering, Procurement and Contracting
- EPRI: Electric Power Research Institute
- FERC: Federal Energy Regulatory Commission
- GTM: Greentech Media Research
- ILR: Inverter Loading Ratio
- kW: Kilowatt
- kWh: Kilowatt-Hour
- LBNL: Lawrence Berkeley National Laboratory
- LCOE: Levelized Cost of Energy
- MW: Megawatt
- NREL: National Renewable Energy Laboratory
- OPEX: Operating Expense
- PII: Permitting, Inspection and Interconnection
- PV: Photovoltaic
- S&L: Sargent & Lundy
- SAT: Single-Axis Tracker
- Si: Silicon
- UK: United Kingdom

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