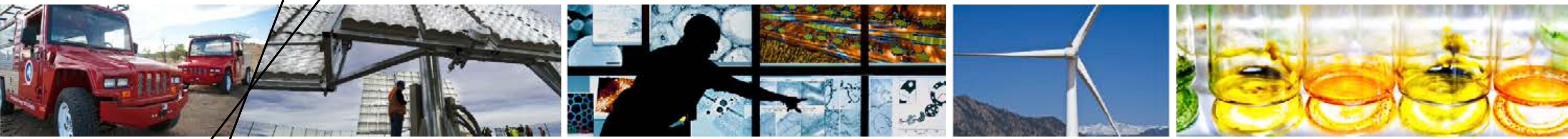
NATIONAL RENEWABLE ENERGY LABORATORY

# U.S. Solar Photovoltaic System Cost Benchmark Q1 2016



**Draft Edition (6/27/2016)**

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energy.gov/sunshot
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- **Introduction & Key Definitions**
- Overall Model Outputs
- Market Study and Model Inputs
- Model Output: Residential PV
- Model Output: Commercial PV
- Model Output: Utility-Scale PV
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# Introduction

(1) **NREL has been modeling U.S. Photovoltaic (PV) system prices and costs since 2009**. This year, our report benchmarks capital costs of U.S. solar PV for residential, commercial, and utility-scale systems built in the first quarter of 2016 (Q1 2016).

(2) **Our methodology includes bottom-up accounting for all system and project-development costs incurred when installing residential, commercial, and utility-scale systems, and it models the capital costs for such systems.** In general, we attempt to model the typical installation techniques and business operations from an installed-cost perspective, and our benchmarks are national averages of installed capacities, weighted by state. The residential benchmark is further averaged across installer and integrator business models, weighted by market share. All benchmarks assume non-union construction labor, although union labor cases are considered for utility-scale systems.

# Introduction

## (3) This report is produced in conjunction with several related research activities at NREL and Lawrence Berkeley National Laboratory (LBNL).


- Chung, Donald, Carolyn Davidson, Ran Fu, Kristen Ardani, and Robert Margolis. 2015. *U.S. Photovoltaic Prices and Cost Breakdowns: Q1 2015 Benchmarks for Residential, Commercial, and Utility-Scale Systems*. NREL/TP-6A20-64746. Golden, CO: NREL.

- Fu, Ran, Ted James, Donald Chung, Douglas Gagne, Anthony Lopez, and Aron Dobos. 2015. *Economic Competitiveness of U.S. Utility-scale Photovoltaics Systems in 2015: Regional Cost Modeling of Installed Cost ($/W) and LCOE ($/kWh).* IEEE 42nd Photovoltaic Specialist Conference, New Orleans, LA.

- Feldman, David, Galen Barbose, Robert Margolis, Mark Bolinger, Donald Chung, Ran Fu, Joachim Seel, Carolyn Davidson, Naïm Darghouth, and Ryan Wiser. 2015. *Photovoltaic System Pricing Trends, Historical, Recent, and Near-Term Projections*. NREL/PR-6A20-64898. Golden, CO: NREL.

- Barbose, Galen, and Naïm Darghouth. 2015. *Tracking the Sun VIII: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States.* Berkeley, CA: LBNL.

- Bolinger, Mark, and Joachim Seel. 2015. *Utility-Scale Solar 2014: An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States*. Berkeley, CA: LBNL.

- Ardani, Kristen, and Robert Margolis. 2015. *Decreasing Soft Costs for Solar Photovoltaics by Improving the Interconnection Process: A Case Study of Pacific Gas and Electric*. NREL/TP-7A40-65066. Golden, CO: NREL.

# Key Definitions

| Unit | Description |
|---|---|
| **Value** | 2016 U.S. Dollar (USD) |
| **System Size** | Direct current (DC terms); inverter prices are converted by DC-to-AC ratios |

| Sector Category | Description | Size Range |
|---|---|---|
| **Residential PV** | Residential rooftop systems | 3 kW – 10 kW |
| **Commercial PV** | Commercial rooftop systems, ballasted racking | 10 kW – 2 MW |
| **Utility-scale PV** | Ground-mounted systems, fixed-tilt and one-axis tracker | > 2 MW |

| Benchmarks | Difference and Reason |
|---|---|
| **2009~2015** | Generic net profits for all three sectors are estimated for final transaction price |
| **Q1 2016 (this report)** | Generic net profits for all three sectors are **removed**.<br><br>With our new no net profit assumption, our modeled costs can be interpreted as the minimum price a developer might charge for a system—i.e. the price that would result in a developer net income of zero. We adopted this approach owing to the wide variation in developer profits in all three sectors, where project pricing is highly dependent on region and project specifics such as local retail electricity rate structures, local rebate and incentive structures, competitive environment, and overall project/deal structures. |

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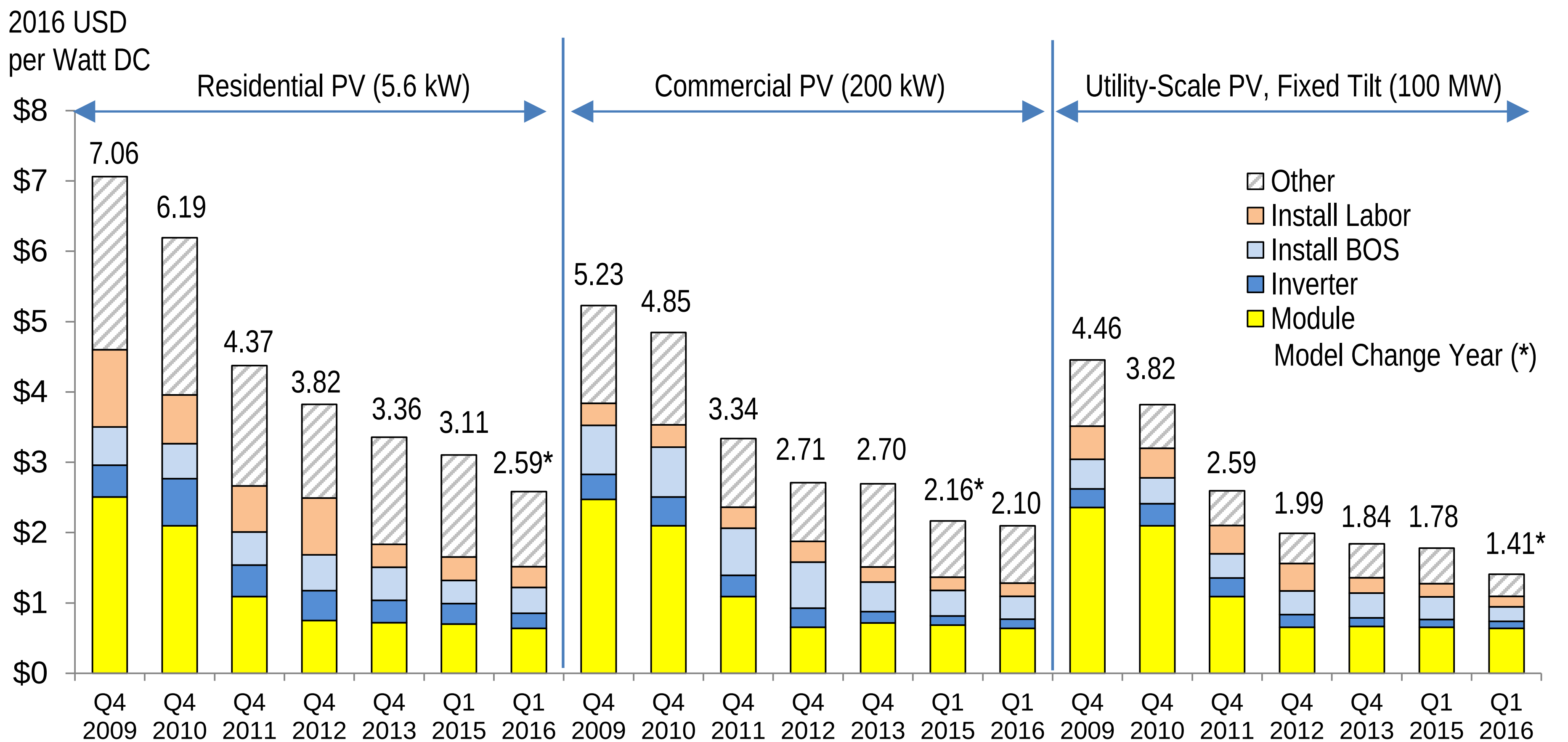
# Overall Model Results




(1) Values are inflation-adjusted using the Consumer Price Index (CPI). Thus, historical values from our models are adjusted and presented as real U.S. Dollars (USD) instead of nominal USD.

(2) Cost categories are aggregated for comparison purpose. For instance, "Install BOS" represents structural and electrical components. The "other" category contains different items for different sectors.

(3) Large differences between Q1 2015 and Q1 2016 in residential and utility-scale sectors and between Q4 2013 and Q1 2015 in commercial sector are caused by model changes, such as the removed generic net profit and the amplification of economies of scale impacts on EPC and developer costs. See details on next slide.

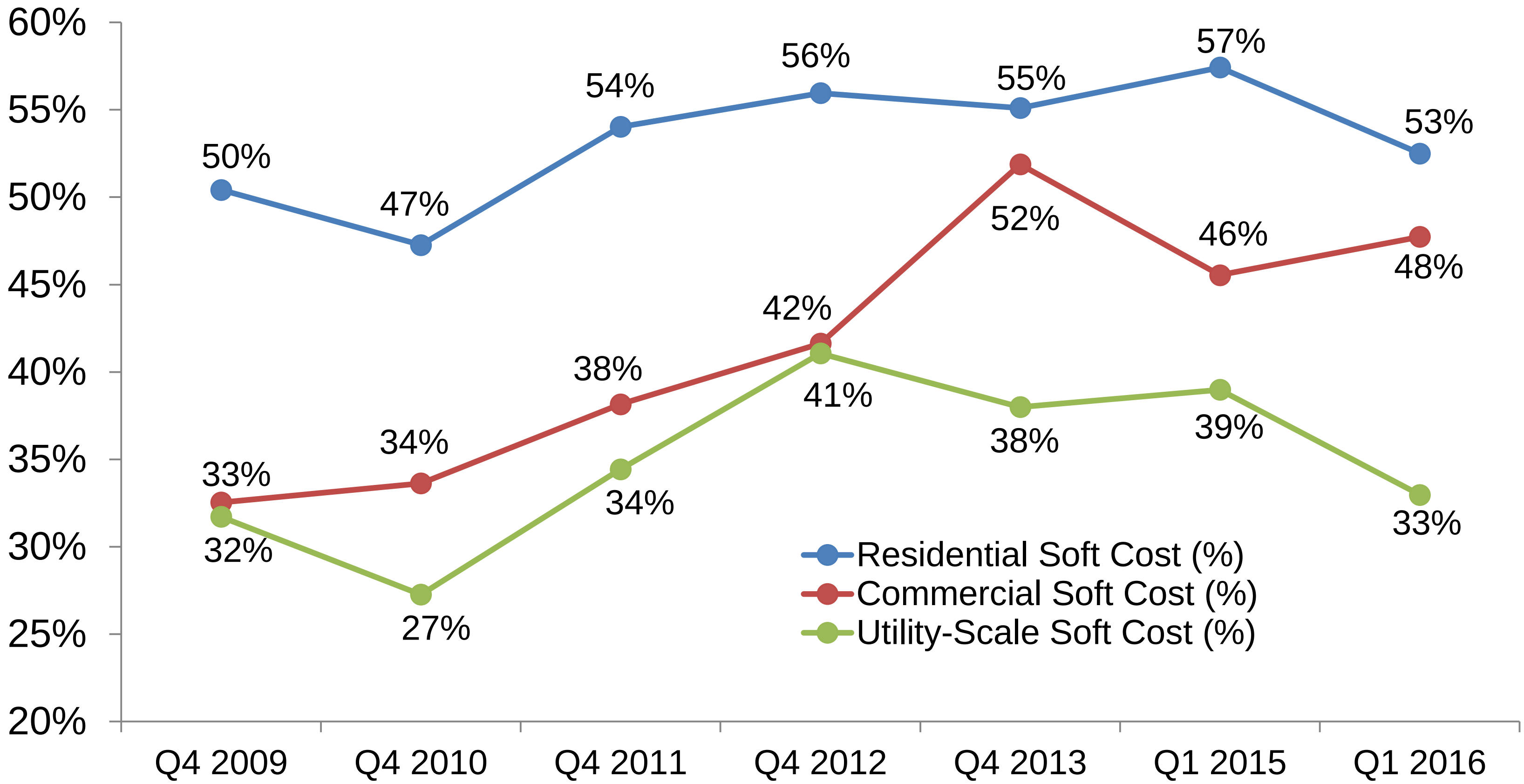
# Overall Model Results

Q1 2015 – Q1 2016 Difference Breakdown

| Sector | (1) Differences Between Q1 2015 and Q1 2016 (2016 USD per Watt DC)<br><br>(1) = (2) + (3) + (4) | (2) Removed Generic Net Profit | (3) Year-to-Year Nominal Cost Decline | (4) Inflation Impact | Major Model Changes for Q1 2016 |
|---|---|---|---|---|---|
| **Residential** | $3.11 – $2.59 = $0.52 | $0.38 | $0.12 | $0.02 | Generic net profit is removed; More inverter options are added |
| **Commercial** | $2.16 – $2.10 = $0.06 | $0.00 | $0.05 | $0.01 | None |
| **Utility-Scale (Fixed-tilt)** | $1.78 – $1.41 = $0.37 | $0.00 | $0.36<br><br>= $0.08 (actual cost decline before model change)<br><br>+ $0.12 (EPC cost decline after model change)<br><br>+ $0.16 (developer cost decline after model change) | $0.01 | More aggressive economies of scale are applied on both EPC and developer costs to reflect labor productivity, construction logistics, bulk price, and discounted developer overhead for larger systems |

Differences between Q1 2015 and Q1 2016 are presented in the breakdown categories, including “removed generic net profit”, “year-to-year nominal cost decline”, and “inflation impact”. Overall, in Q1 2016, the year-to-year nominal cost declines before model changes across residential, commercial, and utility-scale sectors are $0.12, $0.05, and $0.08 per Watt DC. The key contributors to those continued cost declines include lower module and inverter prices, lower install labor costs due to improved labor productivities, and lower installer and developer overheads due to the competitive market condition.

# Overall Model Results (Soft Cost)




(1) "Soft Cost" in this report is defined as non-hardware cost—i.e., "Soft Cost" = Total Cost – Hardware Cost (module, inverter, and structural and electrical BOS).

(2) Based on the historical soft cost estimates from our models, residential and commercial sectors have larger soft cost percentage than utility-scale sector.

(3) "Soft Cost" and "Hardware Cost" can affect each other. For instance, module efficiency improvements in past years have reduced the need for excess modules (thus reducing hardware costs) and this trend has consequently reduced direct labor cost and related installation overhead (both are soft costs)

(4) A higher soft cost percentage (%) does not represent a soft cost increment, but rather, a slower cost decline pace than that of hardware cost.

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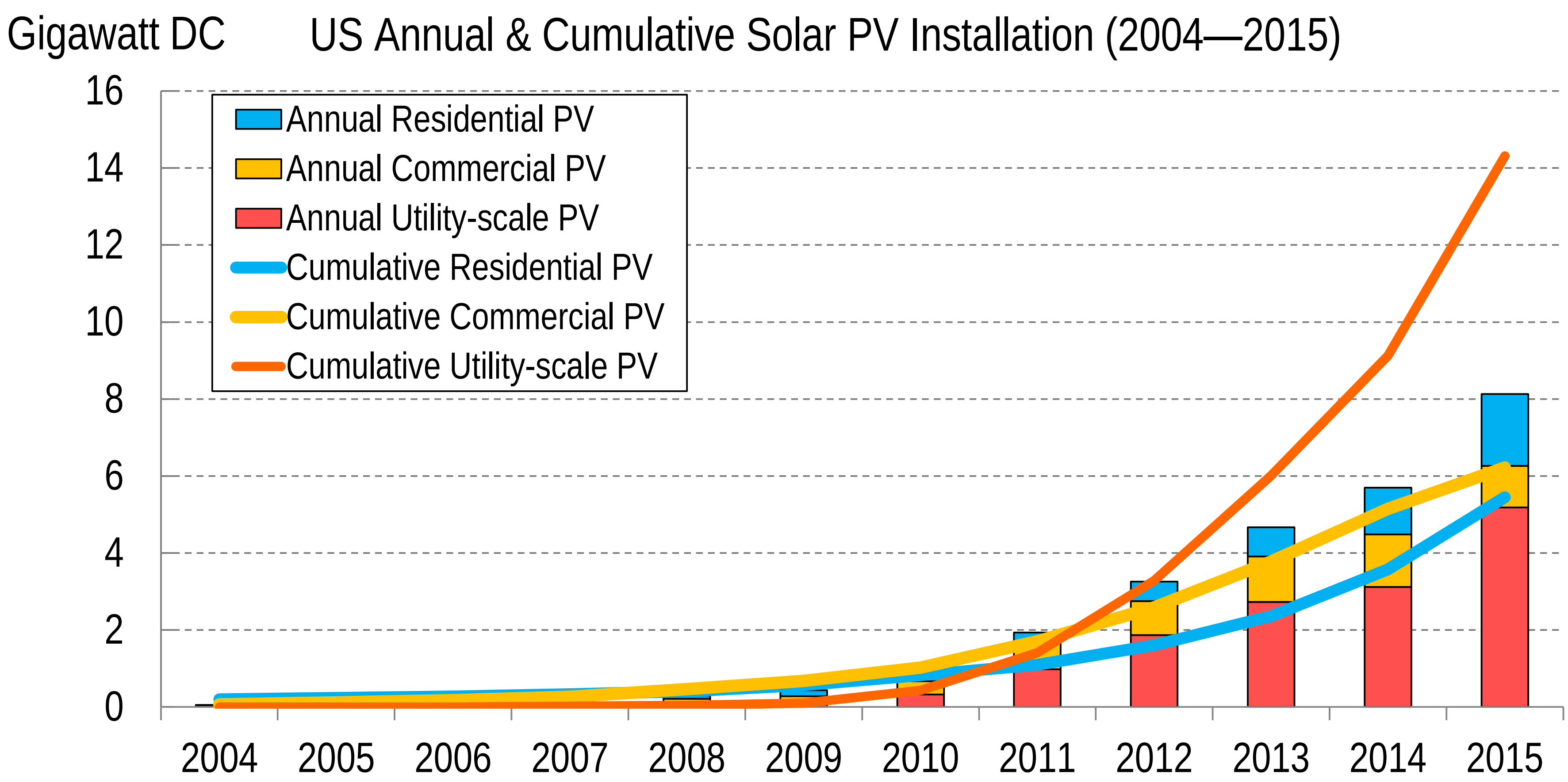
# US Solar PV Market Growth




Source: NREL, Bloomberg

The compound annual growth rates (CAGR) for the residential, commercial, and utility-scale PV sectors in the United States from 2010 – 2015 are 46%, 43% and 101% respectively. Utility-scale PV has been the solar industry's largest segment consistently since 2012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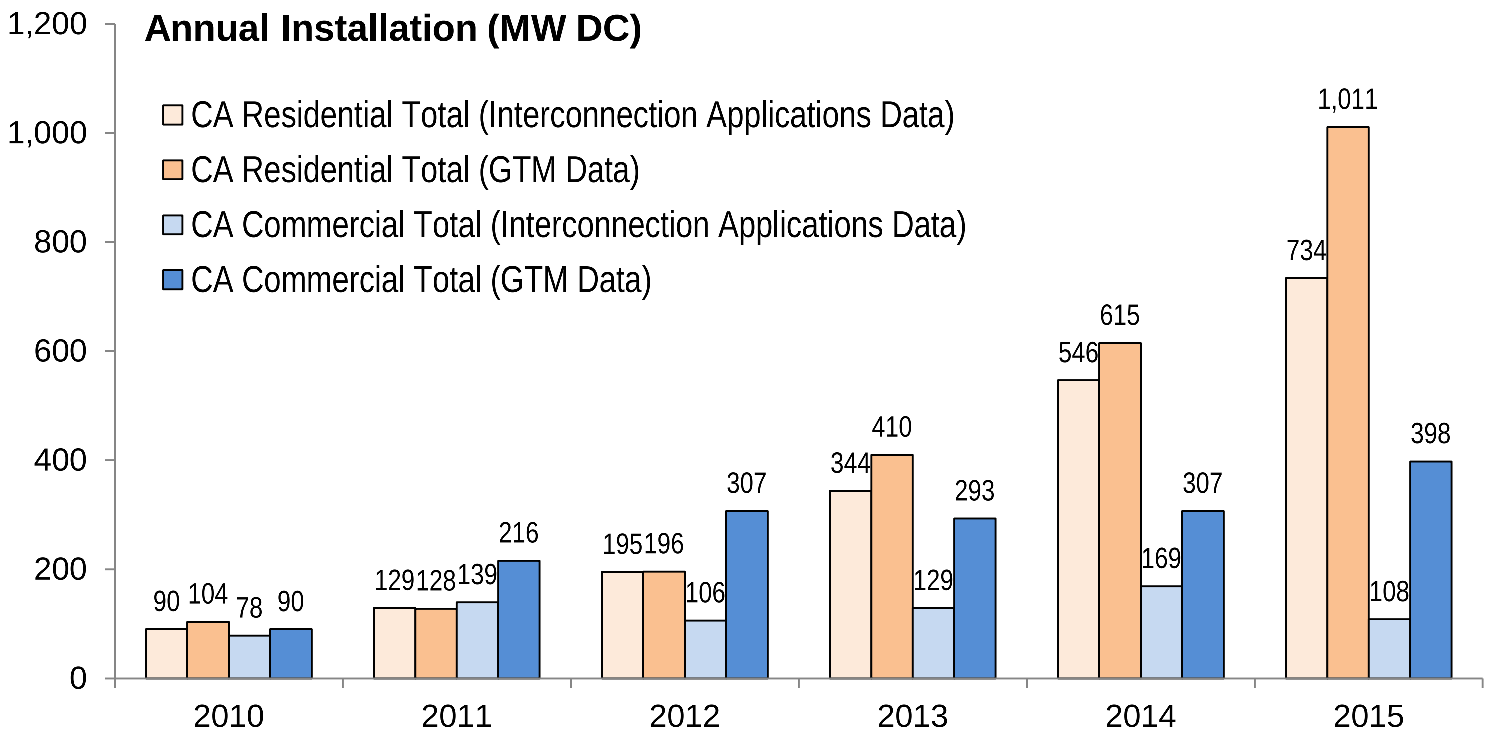
# Database for Residential & Commercial Sectors



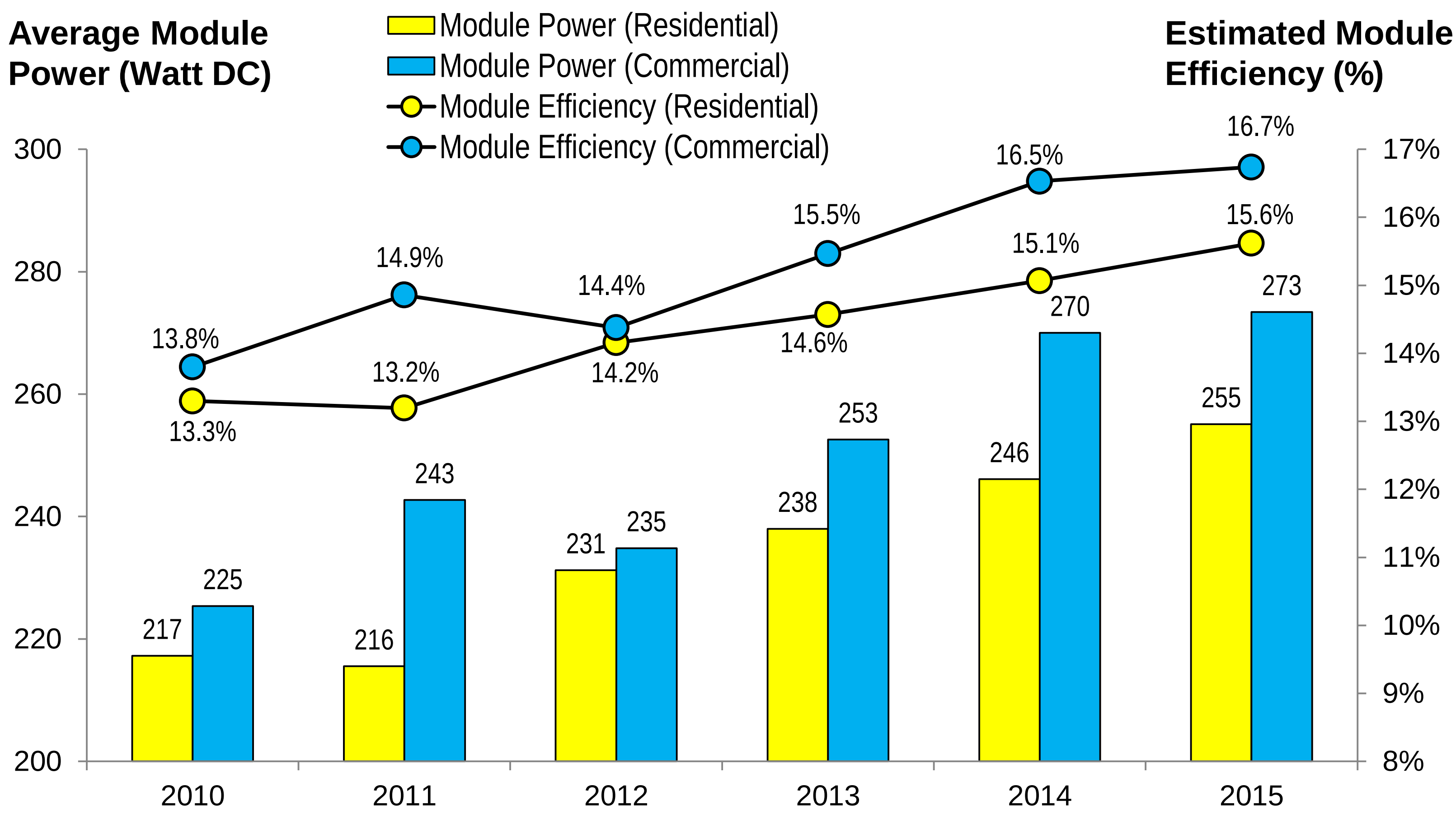

**Net Energy Metering (NEM) Interconnection Applications Data Set:**

(1) The California Solar Initiative (CSI) Data Set has been used in previous NREL analyses, but as the program winds down, the number of new applications (and consequently data collection) has decreased substantially. However, while CSI may no longer represent the most comprehensive source of data on the California residential and commercial solar market, California's Net Energy Metering (NEM) Interconnection Applications Data Set provides a robust substitute. The database is updated monthly and contains all interconnection applications in the service territories for the state's three investor-owned utilities (PG&E, SCE, and SDG&E). We utilized this database to benchmark the typical module power and efficiency figures, as well as the market penetration data on module-level power electronics.

(2) Only roof-top systems in the database are analyzed for residential and commercial sectors. Ground-mounted systems are excluded. Also, systems with only AC power records and systems that are still in the validation phase were excluded.

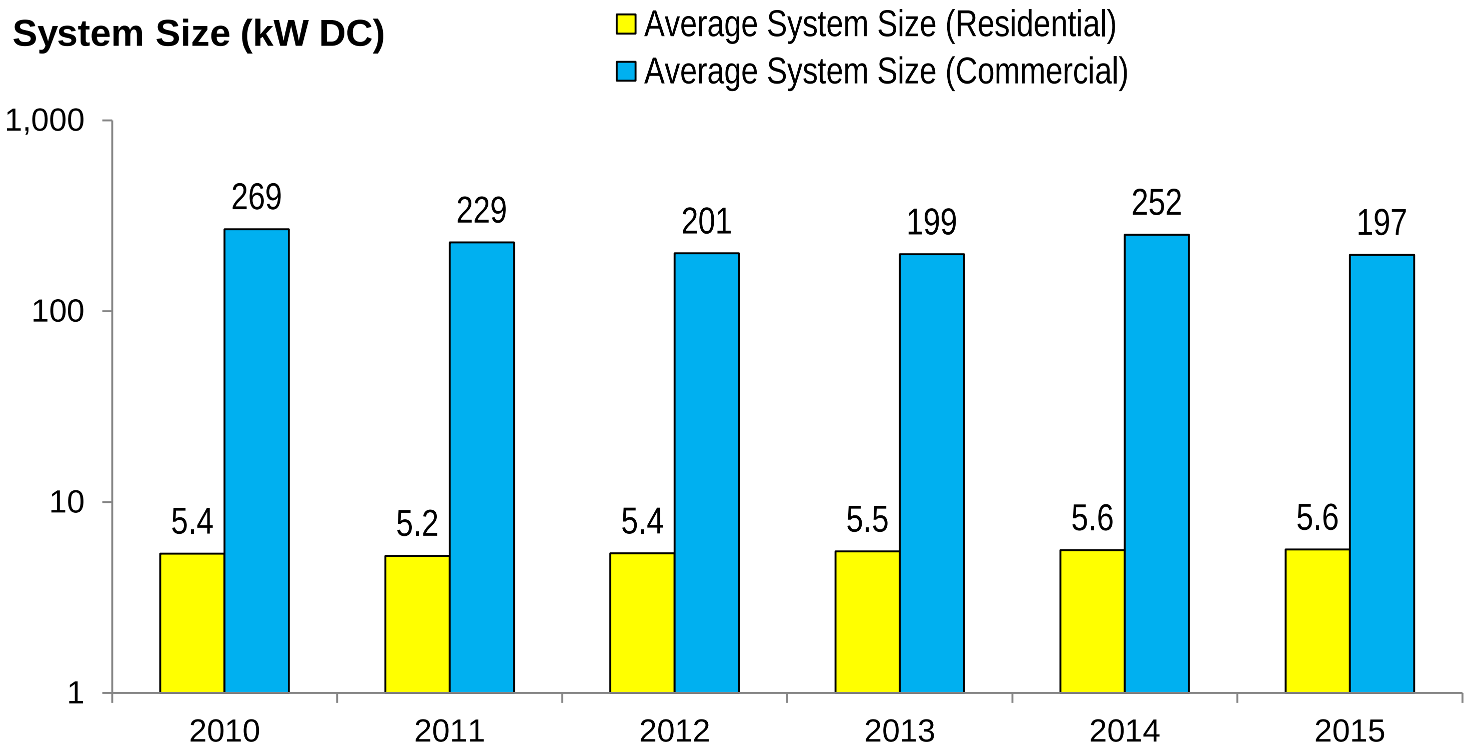
(3) NEM represents the majority of residential systems in CA (89% in 2014 and 73% in 2015) and a sizable portion of commercial systems in CA (55% in 2014 and 27% in 2015).

# Module Power and Efficiency Trend (California)




Since 2010, the commercial sector has had a consistently higher module power and efficiency than the residential sector, though both residential and commercial sectors have been steadily improving. In this benchmark report, we use 15.6% and 16.7% module efficiencies for residential and commercial sectors, respectively.

# PV System Size Trend (California)




System size change for residential sector over the last five years in California was not significant. We use 5.6 kW as the baseline case in our cost model this year.

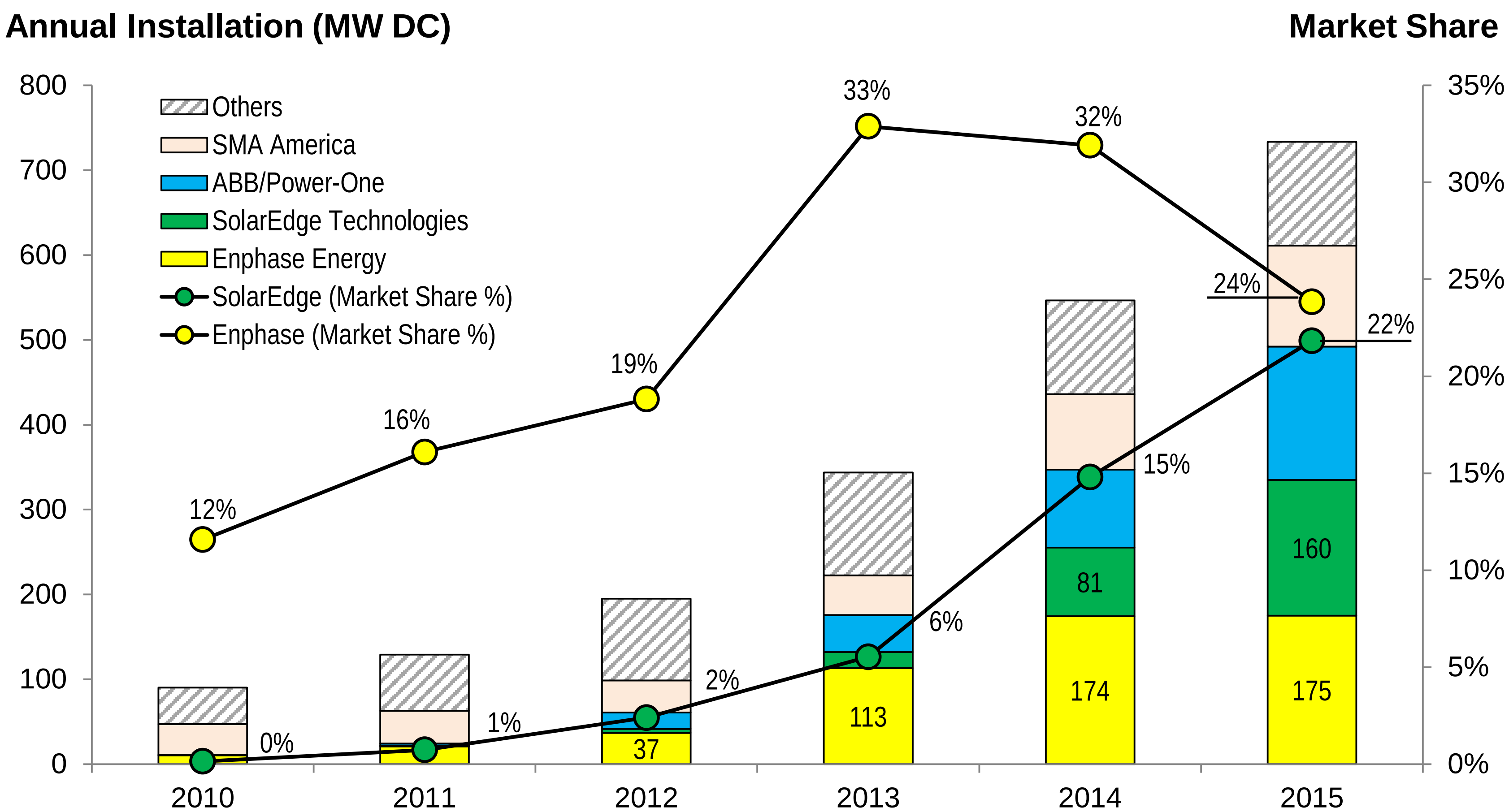
Conversely, the commercial sector had a more volatile system size change during the same period. This volatility likely reflects the wide scope for "commercial customers", which includes schools, office buildings, malls, retail stores, and government projects. For this report, we use 200 kW as the baseline case in our model.

# Inverter Solutions – Microinverter & DC Power Optimizer

Microinverters and DC power optimizers are collectively referred to as "Module-Level Power Electronics" (MLPE). By allowing designs with different roof configurations (orientations and tilts) and constantly tracking the maximum power point (MPPT) for each module, MLPEs provide an optimized design solution at the module level. Today, Enphase (microinverters) and SolarEdge (DC power optimizers) are the leading companies offering MLPE solutions.

| | String Inverter | DC Power Optimizer | Microinverter |
|---|---|---|---|
| Function | PV panels are connected in parallel by one or multiple strings and then directly connected to the string inverter for DC-to-AC conversion. If one panel is shaded, the whole string will be impacted. | Each PV panel has one power optimizer for DC-to-DC conversion so that the traditional junction box is replaced and then all of panels are connected by string inverter for DC-to-AC conversion. Shading only impacts individual module. | Each PV panel has one microinverter for DC-to-AC conversion and thus there is no string inverter in the end. Shading only impacts individual module. |
| Relative product price | Low | Medium | High |
| Performance in shading | Bad | More efficient | More efficient |
| Performance in various direction or irregular roof | Low | Medium | High |
| Module-level monitoring and troubleshooting | No | Yes (i.e., SolarEdge Cellular Kit) | Yes (i.e., Enphase "Envoy + Enlighten") |
| Improved energy yield from module mismatch reduction | No | Yes | Yes |
| Number of electronic components | Normal | Greater (thus may have some component risks) | Greater (thus may have some component risks) |
| Safety for installation | Normal | Normal | Safer. Use only AC cable with no high-voltage DC power |

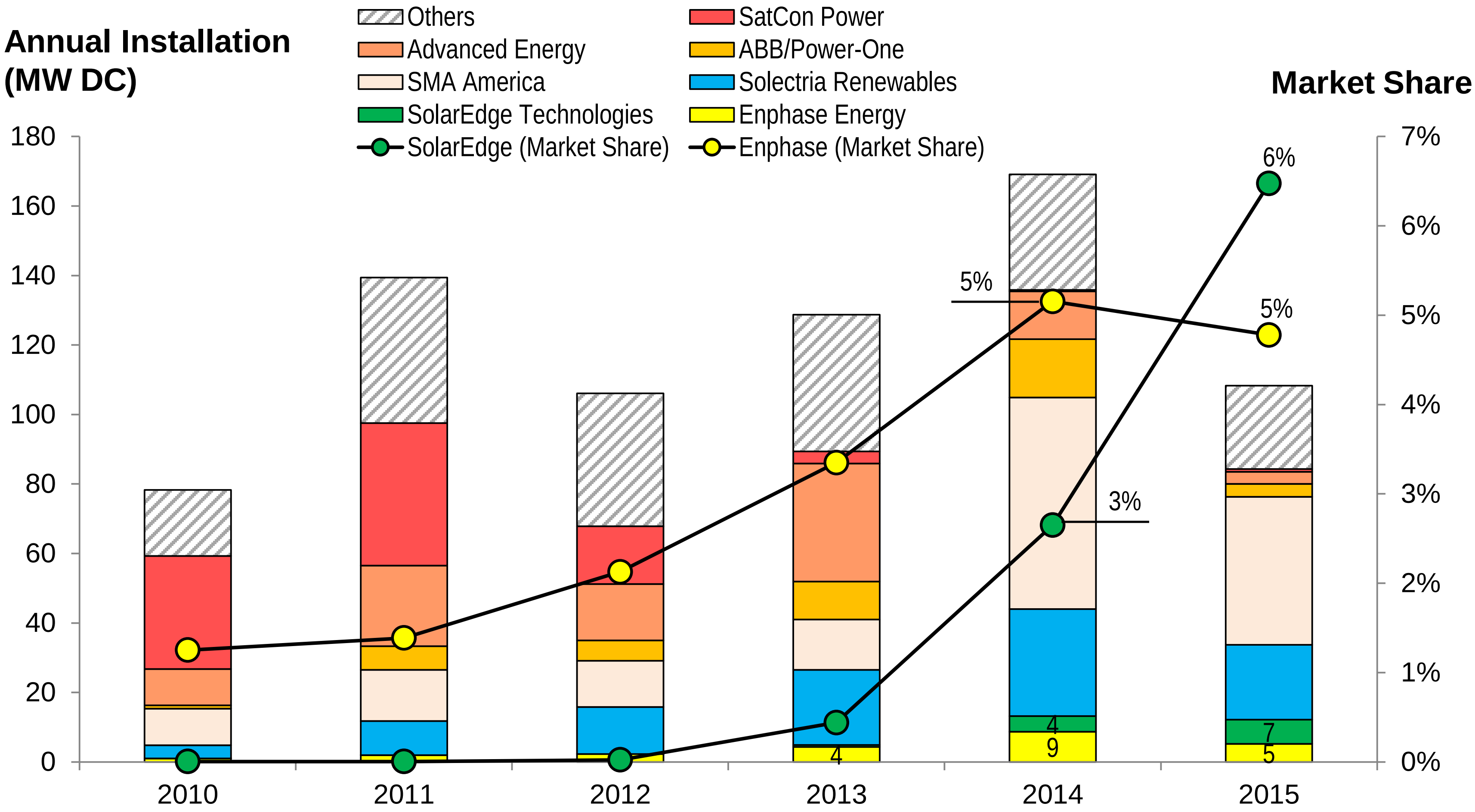
# Inverter Market – Residential PV Sector (California)




According to NEM Interconnection Applications Data Sets, market uptake of MLPEs has been growing rapidly since 2010 in the California residential solar sector. This increasing market growth may be driven by the decreasing MLPE costs and by the "rapid shutdown" on buildings required by Article 690.12 of the National Electric Code (NEC) since 2014 – MLPEs inherently meet rapid shutdown requirements without the need to install any additional electrical equipment.

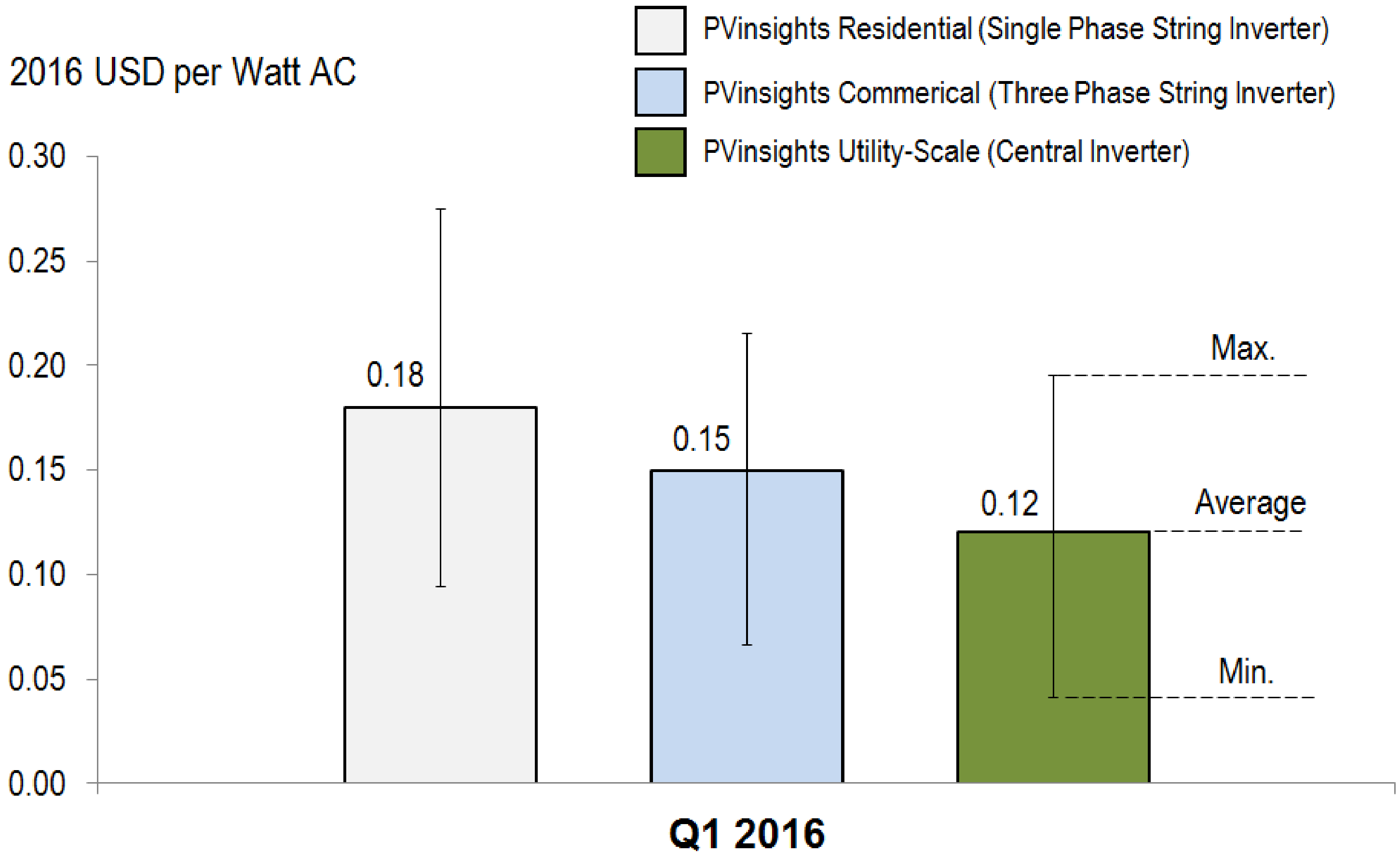
In 2015, the combined Enphase and SolarEdge inverter solutions reached 46% of the total California residential market share. Therefore, our residential system cost model has been updated with new functions to estimate the costs of these MLPE inverter solutions.

# Inverter Market – Commercial PV Sector (California)




Conversely, MLPEs have been growing slowly in the California commercial PV sector, with market share only 11% (the commercial inverter market is more fragmented than that for residential). Thus, MLPE inverter solutions are not built into our commercial cost model this year.

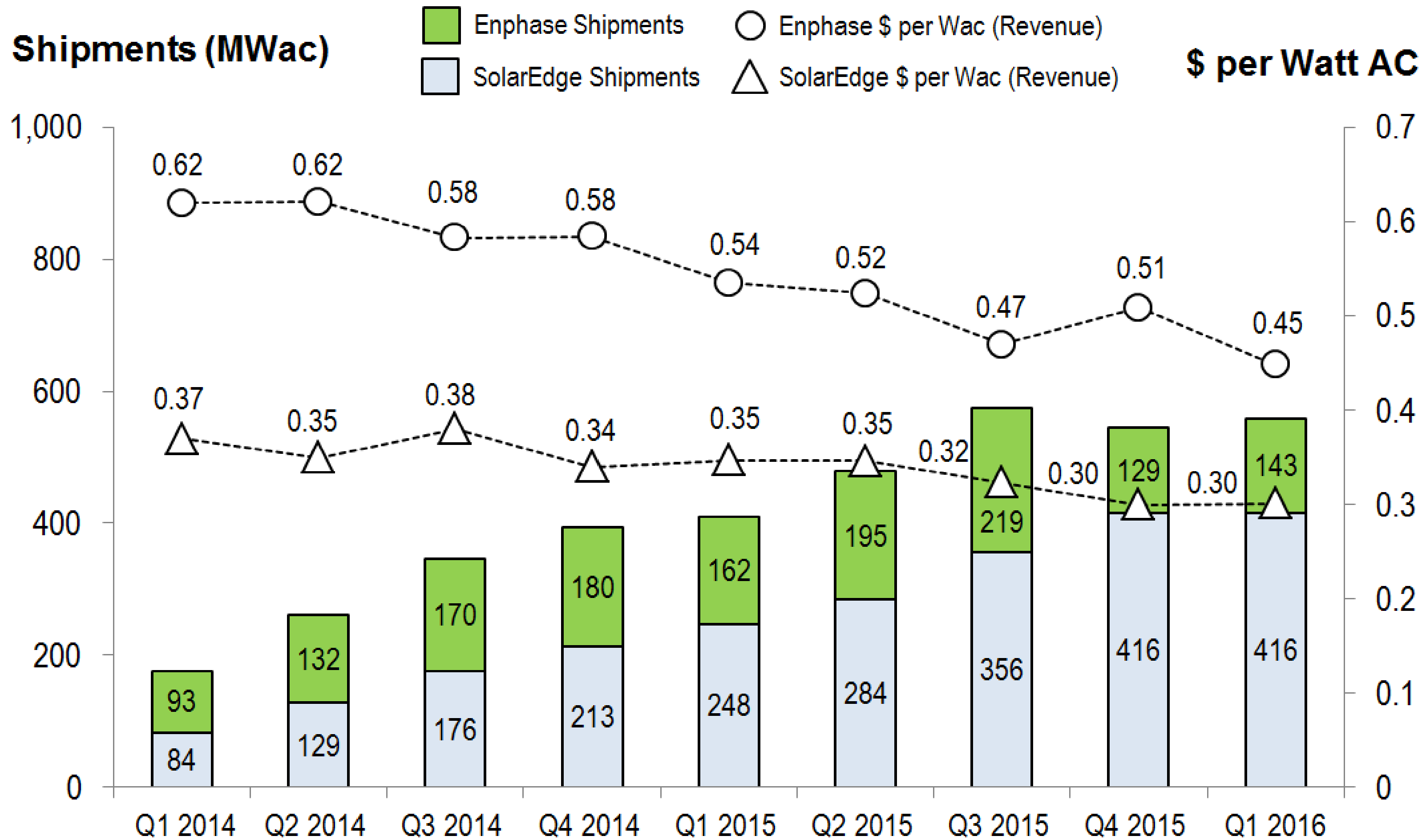
# Inverter Price for non-MLPEs




Source: NREL, PVinsights Database

**PVinsights Database**:
We sourced inverter prices for non-MLPEs ($ per Watt AC) from the PVinsights Database, which contains typical prices between Tier 1 suppliers and developers in the market.

# Inverter Price for MLPEs




Source: NREL, Corporate filings

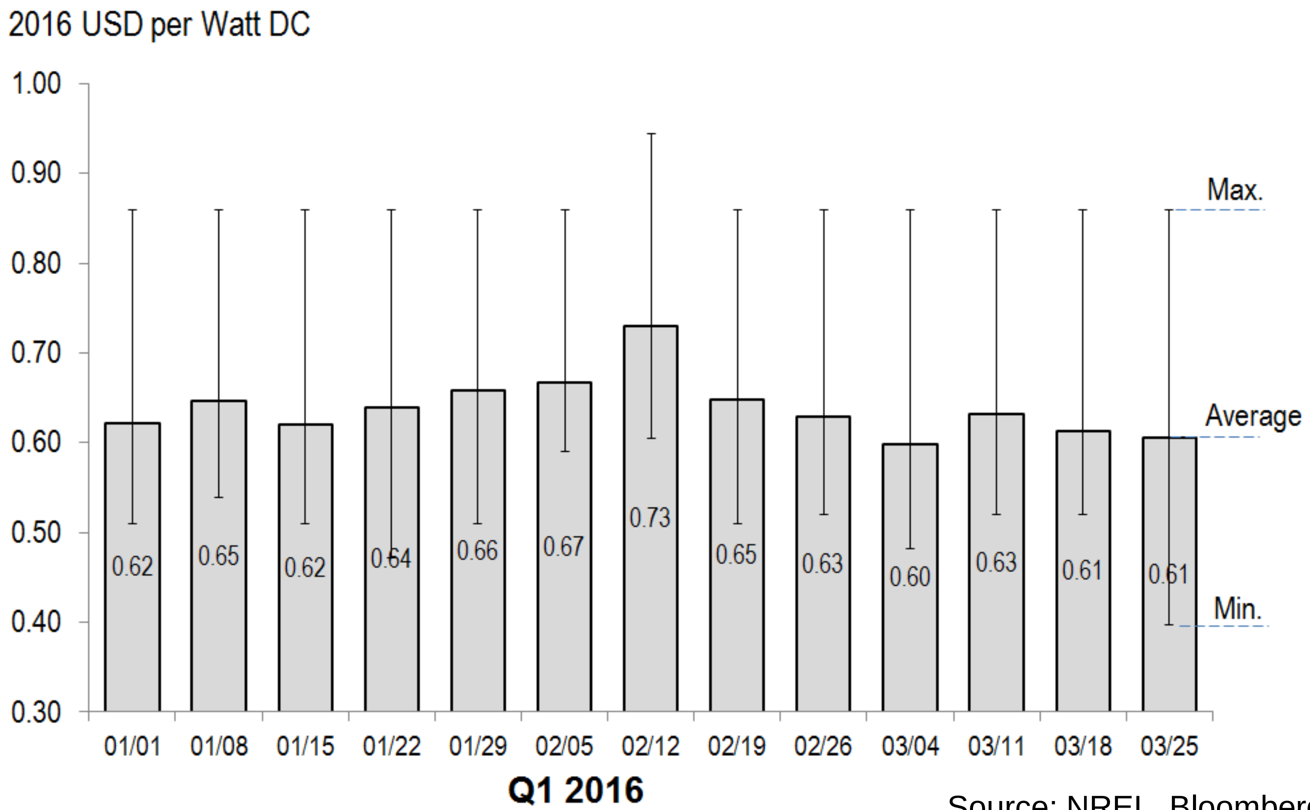
For inverter prices of MLPEs, we used data from public corporate filings. Q1 2016 Enphase revenue was $0.45/Wac, which can represent the typical microinverter price. Q1 2016 SolarEdge revenue was $0.30/Wac including $0.10/Wac DC power optimizer (GTM). Thus, SolarEdge string inverter price was estimated as $0.20/Wac, which can represent the DC optimizer string inverter price.

# Inverter Price and DC-to-AC ratios

$ per Watt AC from previous two slides are converted to be $ per Watt DC in this table by using the different DC-to-AC ratios. In our benchmark, $ per Watt DC are used for inverter prices.

| Inverter Type | Used for Which Sector | $ per Watt AC | DC-to-AC Ratio | $ per Watt DC |
|---|---|---|---|---|
| Single Phase String Inverter | Residential PV (non-MLPE) | 0.176 | 1.15 | 0.15 |
| Microinverter | Residential PV (MLPE) | 0.45 | 1.15 | 0.39 |
| DC Power Optimizer String Inverter | Residential PV (MLPE) | 0.20 | 1.15 | 0.17 |
| Three Phase String Inverter | Commercial PV (non-MLPE) | 0.15 | 1.15 | 0.13 |
| Central Inverter | Utility-scale PV (fixed-tilt) | 0.12 | 1.40 (Oversized) | 0.09 |
| Central Inverter | Utility-scale PV (1-axis tracker) | 0.12 | 1.20 | 0.10 |

# Module Price



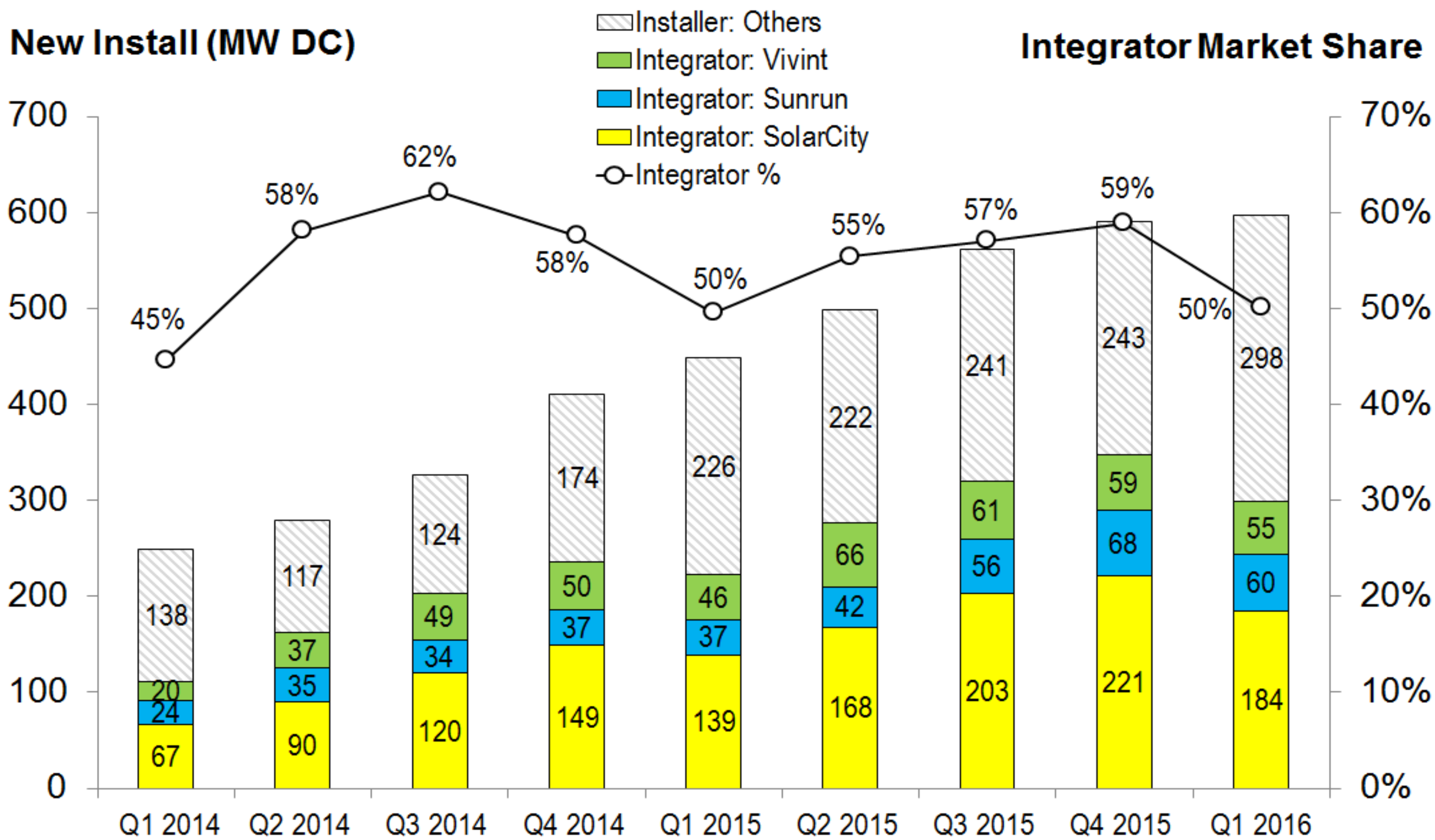

Source: NREL, Bloomberg, SPV Research

(1) We used Bloomberg data to represent the typical average selling price (ASP) between Tier 1 module suppliers and **first buyers** in the global market. Also, Solar PV Market Research (SPV) survey indicates that the U.S. ASP has about a 6% discount compared to the global market because of the country's large demand and competitive market condition. Using this regional discount, we adjusted Bloomberg global module price data in this figure and benchmarked the Q1 2016 average U.S. crystalline silicon (C-Si) module ASP at $0.64/W for all three sectors.

(2) Interviews conducted for this analysis suggested even lower prices ($0.58 – 0.60/W) due to the recent liquidity issues of some large developers. However, since this benchmark report only covers Q1 2016, the impact from company bankruptcy in April 2016 is not covered in this report.

(3) Module prices in 2016 have also been influenced by changes in currency exchange rates—i.e. the USD has appreciated against the Chinese Yuan by 5% between Q1 2015 and Q1 2016.

# Residential PV: Integrator vs. Installer




Source: NREL, Corporate filings, GTM

Our residential PV sector is benchmarked based on two different business structures: “installer” and “integrator”. For the purposes of this analysis, we define installers as businesses that engage in lead generation, sales, and installation, but do not provide financing solutions. The integrator performs all of the installer’s functions, but does provide financing and system monitoring for third-party-owned systems. In our models, the difference between installers and integrators manifests in the overhead cost category, where the integrator is modeled with higher expenses for customer acquisition, financial structuring, and asset management.

This benchmarking analysis uses the 50% (integrator) and 50% (installer) market shares evident in Q1 2016 to compute the national weighted average case in the residential PV model.

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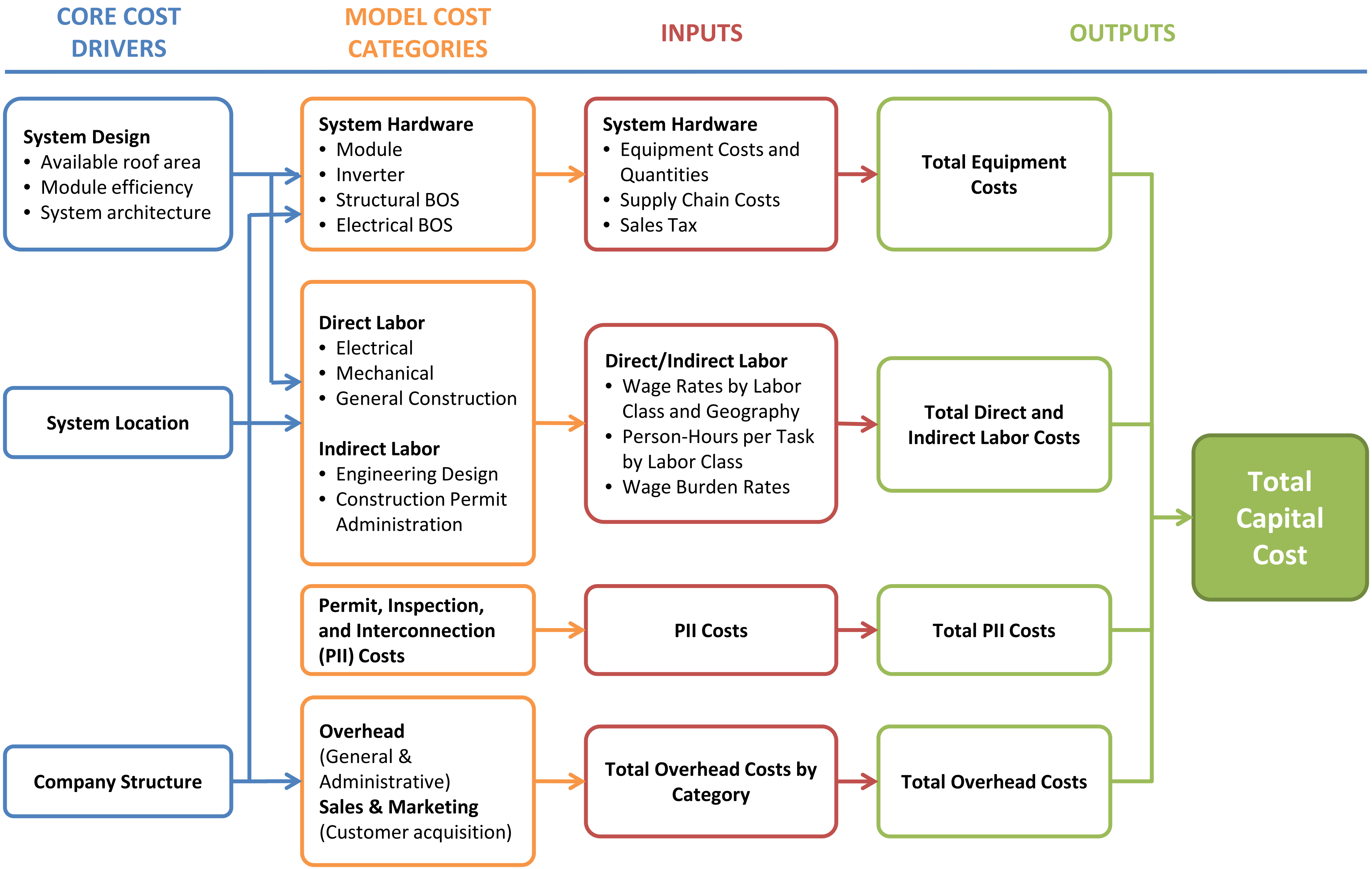
# Residential PV: Model Structure

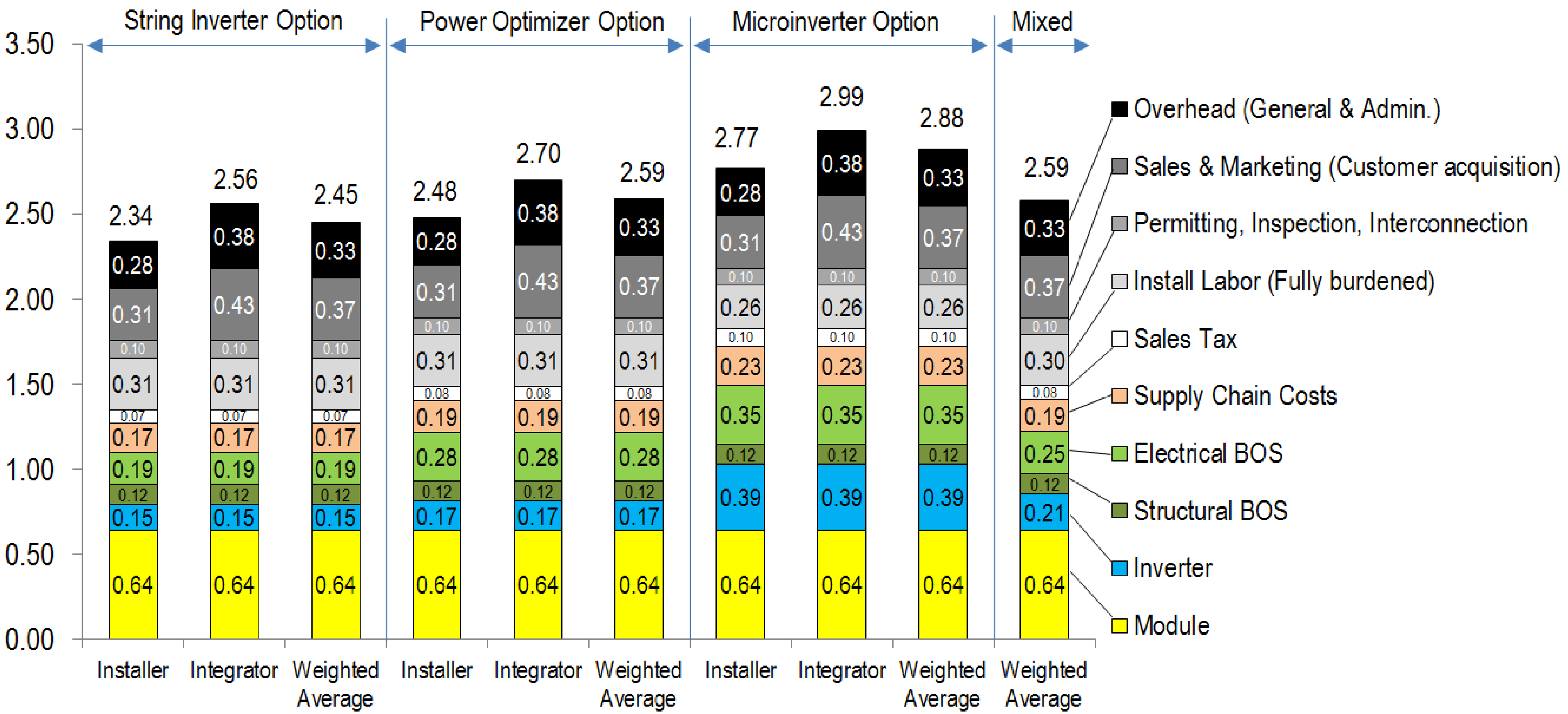


# Residential PV: Modeling Inputs and Assumptions

| Category | Modeled Value | Description | Sources |
|---|---|---|---|
| System size | 5.6 kW | Average installed size per system | Interconnection applications data |
| Module efficiency | 15.6% | Average module efficiency used in the model | Interconnection applications data |
| Module price | $0.64 per Wdc | Ex-factory gate (first buyer) average selling price; Tier 1 modules | Bloomberg database, SPV survey, industry interviews |
| Inverter price | Vary by inverter option | Ex-factory gate prices (first buyer) average selling price; Tier 1 inverters | Interconnection applications data, PVinsights database, corporate filings, industry interviews |
| Structural BOS (Racking) | $0.12 per Wdc | Ex-factory gate prices; includes flashing for roof penetrations | Model assumptions, industry interviews |
| Electrical BOS | Vary by inverter option | Wholesale prices for conductors, switches, combiners and/or transition boxes, conduit, grounding equipment, monitoring system/production meter, fuses, and breakers | Model assumptions, industry interviews, RSMeans |
| Supply chain costs (% of equipment costs) | 12 – 15%<br>Vary by equipment | Costs associated with warehousing, shipping and logistics | Industry interviews |
| Sales tax | Vary by location | National benchmark applies an average (by state) weighted by 2015 installed capacities | Database of State Incentives for Renewables & Efficiency (DSIRE), RSMeans |
| Direct installation labor | Electrician: $19.01 – $37.52 per hour;<br>Laborer: $12.41 – $24.63 per hour;<br>Vary by location and inverter option | Modeled labor rate depends on state; national benchmark uses weighted average of state rates; | U.S. Bureau of Labor Statistics (BLS), industry interviews |
| Burden rates (% of direct labor) | Total nationwide average: 31.8% | Workers compensation (state-weighted average), federal and state unemployment insurance, FICA, builders risk, public liability | RSMeans |
| Permitting, inspection and interconnection | $0.10 per Wdc | Includes assumed building permitting fee of $400 and eight labor hours: three hours for building permit preparation, two hours for interconnection application preparation, one hour for building permit and interconnection application submission, and two hours for final building inspection | Vote Solar, Vote Solar and Interstate Renewable Energy Council (IREC), industry interviews |
| Sales & marketing (customer acquisition) | $0.31 (installer)<br>$0.43 (integrator) | Total cost of sales and marketing activities over the last year—including marketing and advertising, sales calls, site visits, bid preparation, and contract negotiation; adjusted based on state “cost of doing business” index | Feldman et al., corporate filings, industry interviews |
| Overhead (general & administrative) | $0.28 (installer)<br>$0.38 (integrator) | General and administrative (G&A) expenses—including fixed overhead expenses covering payroll (excluding permitting payroll), facilities, administrative, finance, legal, information technology, and other corporate functions as well as office expenses; adjusted based on state “cost of doing business” index | Feldman et al., corporate filings, industry interviews |

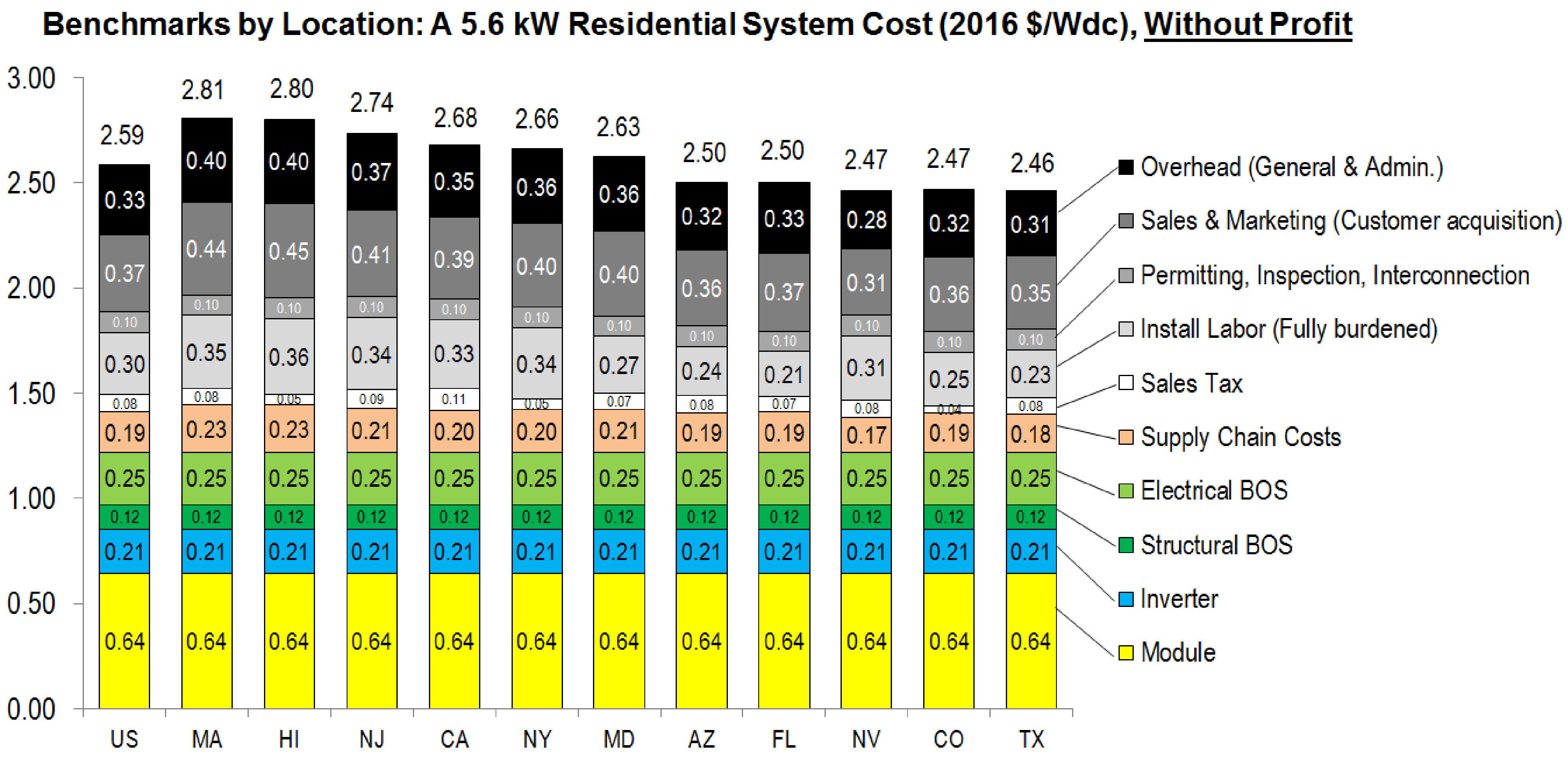
# Residential PV: Model Outputs

## US National Benchmark: A 5.6 kW Residential System Cost (2016 $/Wdc), <u>Without Profit</u>



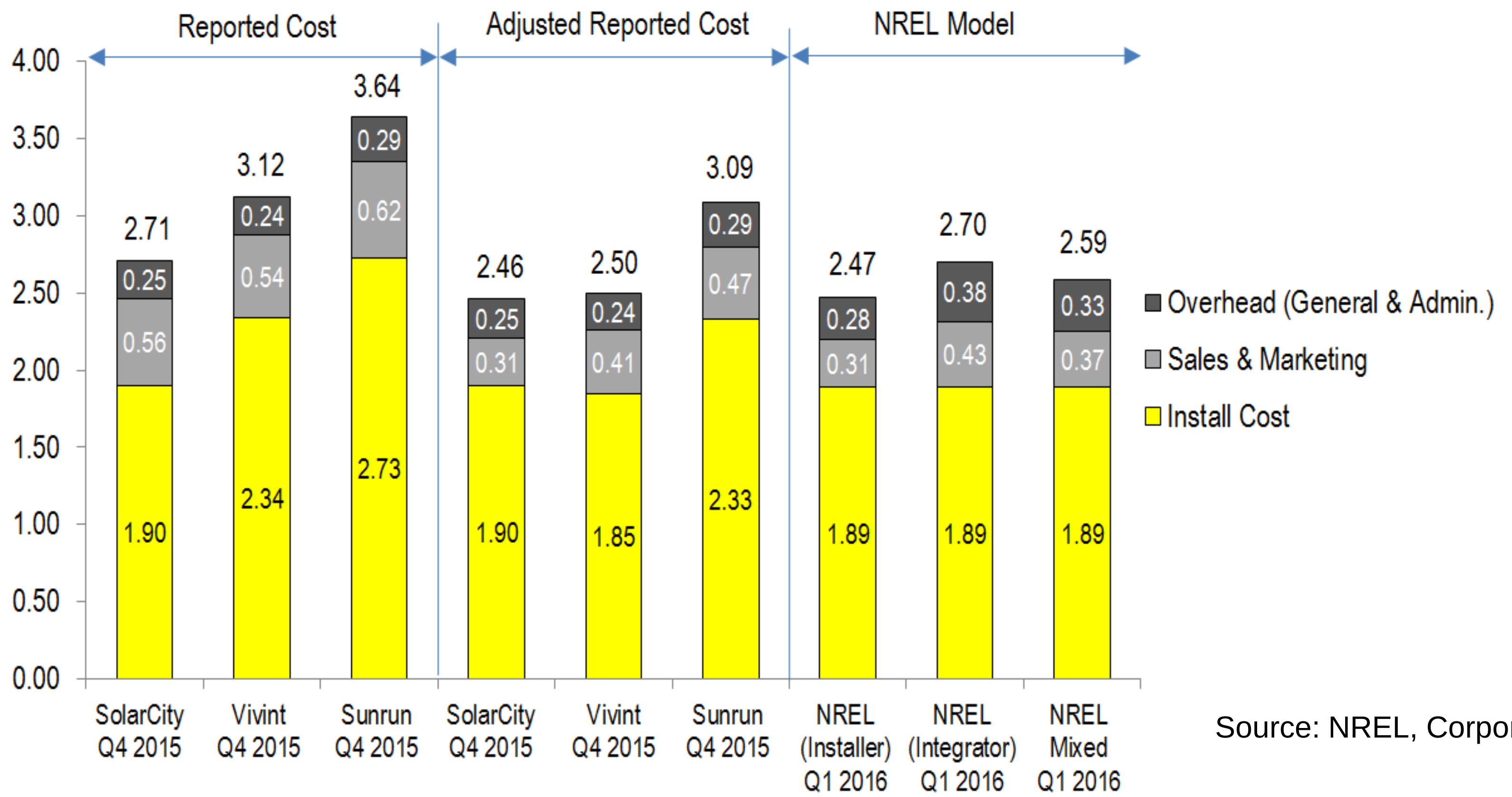

(1) The national benchmark applies an average weighted by 2015 installed capacities.
(2) Market shares 50% and 50% (for installers and integrators respectively) are used to compute the national weighted average.
(3) String inverter/power optimizer/microinverter options are modeled. The “Mix” case uses their market shares (54%, 22%, and 24%).
(4) Generic net profit is excluded from our cost model—the numbers in this chart represent “cost” instead of “price”.

# Residential PV: Model Outputs




(1) The top U.S. residential solar markets (by 2015 installation) are modeled.
(2) The main cost drivers for different regions are labor rates, sales tax, and selling, general, and administrative (SG&A) expenses—i.e. the cost of doing business

# Residential PV: Model Outputs




Source: NREL, Corporate filings

Our bottom-up modeling approach yields a different cost structure than those reported by public solar integrators in their corporate filings. The principal differences is that integrators will typically capitalize their cost of revenue on their income statements—i.e. they will not book the costs as expenses in the period in which they occur, but will recognize them over time as depreciation or amortization expenses. In capitalizing the cost of revenue, solar companies will often add it under the “Install” or “Sales & Marketing” categories, which are primarily comprised of cost depreciation, maintenance, and amortization of initial direct cost of leased solar systems.

Capitalized costs are not accounted for in the NREL bottom-up models. Thus, to yield a more equitable comparison, we have adjusted the reported figures by removing the capitalized costs. However, it is also worth noting that the reported costs include both residential and commercial systems.

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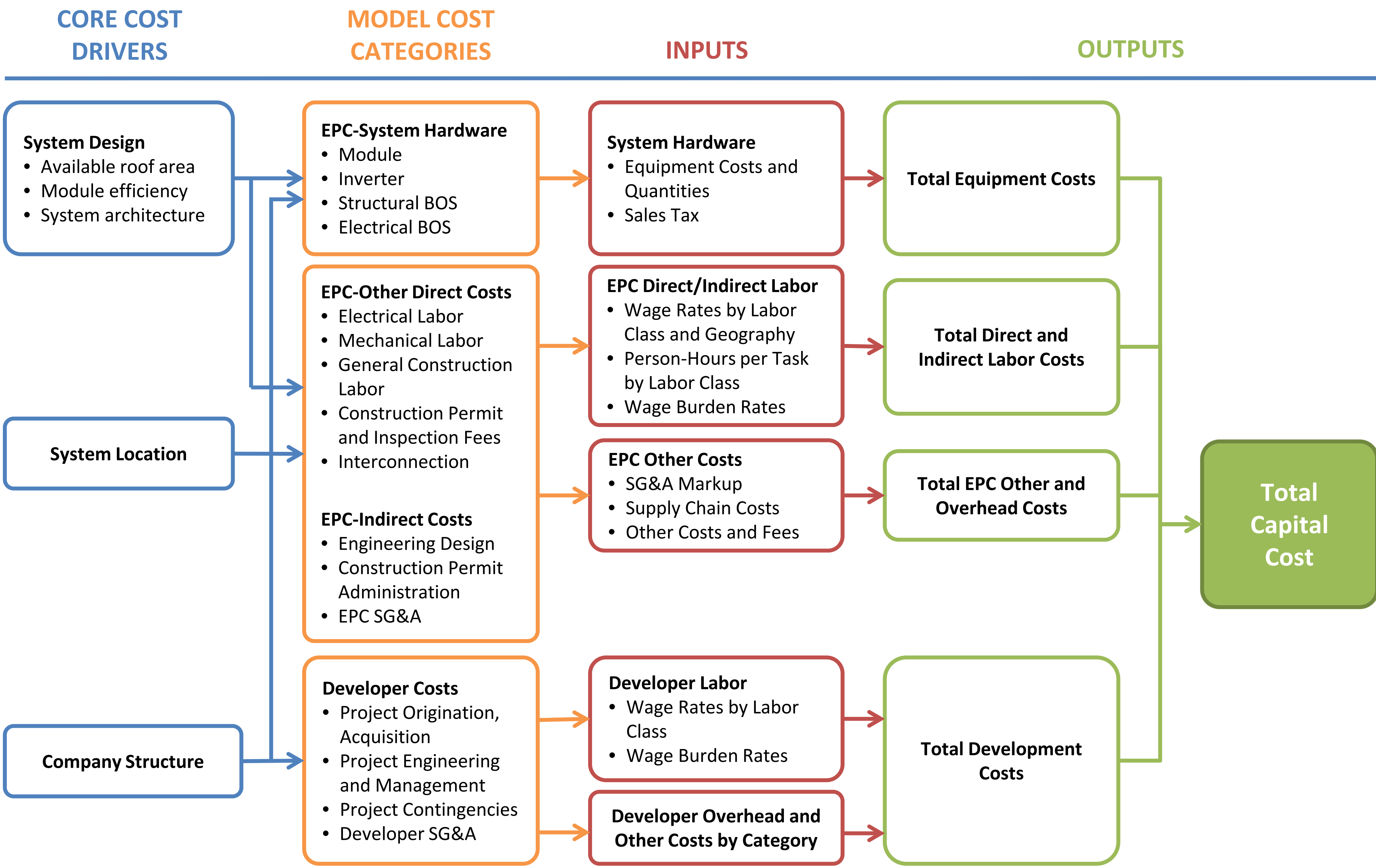
# Commercial PV: Model Structure





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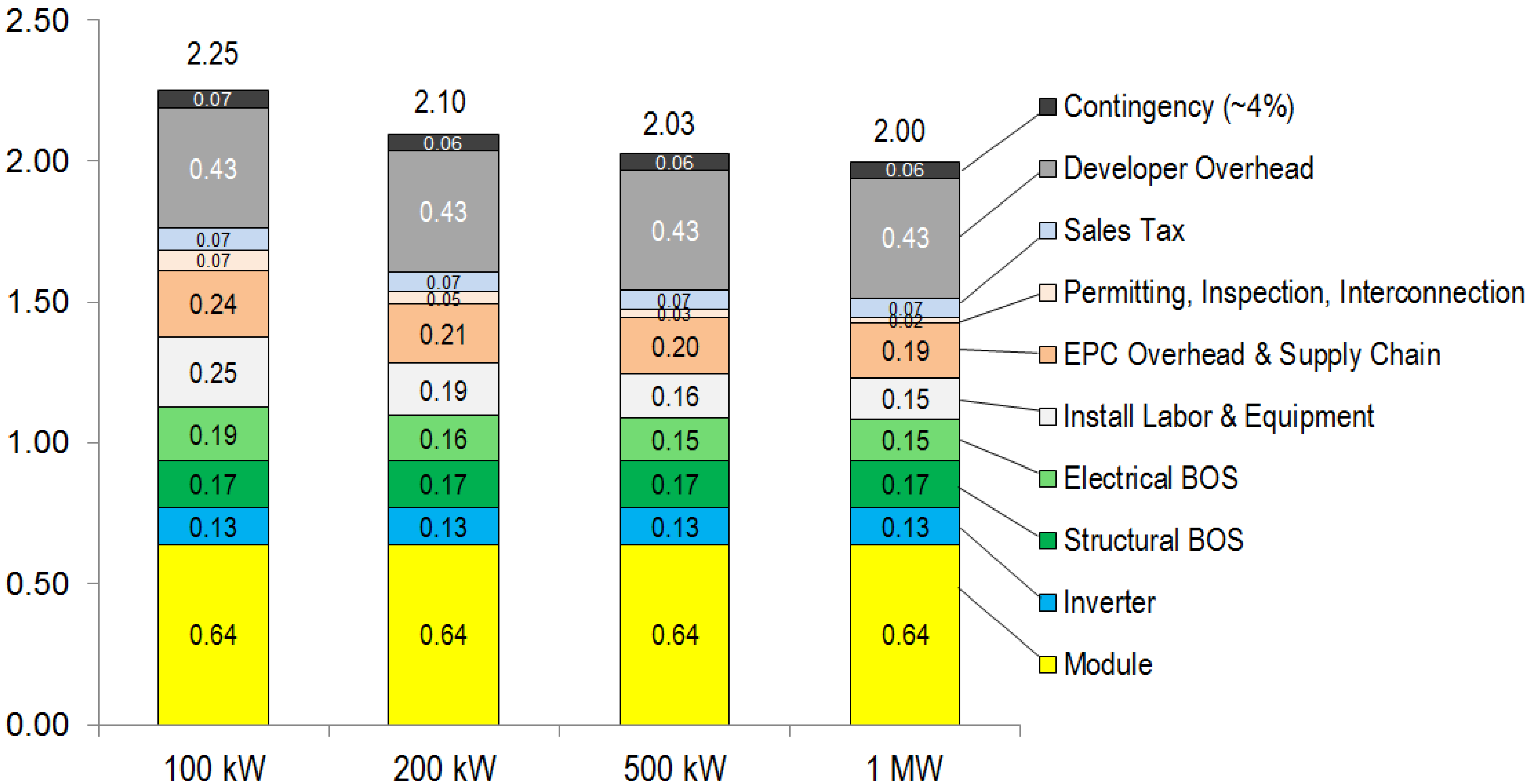
# Commercial PV: Modeling Inputs and Assumptions

| Category | Modeled Value | Description | Sources |
|---|---|---|---|
| System size | 200 kW | Average installed size per system | Interconnection applications data |
| Module efficiency | 16.7% | Average module efficiency used in the model | Interconnection applications data |
| Module price | $0.64 per Wdc | Ex-factory gate (first buyer) average selling price; Tier 1 modules | Bloomberg database, SPV survey, industry interviews |
| Inverter price | $0.13 per Wac | Ex-factory gate prices (first buyer) average selling price; Tier 1 inverters | PVinsights database, industry interviews |
| Structural components (racking) | $0.14 – 0.30 per Wdc; Vary by location and system size | Ex-factory gate prices; flat-roof ballasted racking system | Model assumptions, ASCE design code, Industry interviews |
| Electrical components | Vary by location and system size | Conductors, conduit and fittings, transition boxes, switchgear, panel boards, etc. | Model assumptions, industry interviews, RSMeans |
| EPC overhead and supply chain costs (% of equipment costs) | 15% | Costs associated with EPC SG&A, warehousing, shipping and logistics | Industry interviews |
| Sales tax | Vary by location | National benchmark applies an average (by state) weighted by 2015 installed capacities | Database of State Incentives for Renewables & Efficiency (DSIRE), RSMeans |
| Direct installation labor | Electrician: $19.01 – $37.52 per hour; Laborer: $12.41 – $24.63 per hour; Vary by location and inverter option | Modeled labor rate assumes non-union labor and depends on state; national benchmark uses weighted average of state rates; | U.S. Bureau of Labor Statistics (BLS), industry interviews |
| Burden rates (% of direct labor) | Total nationwide average: 31.8% | Workers compensation (state-weighted average), federal and state unemployment insurance, FICA, builders risk, public liability | RSMeans |
| Permitting, inspection and interconnection | $0.04 – 0.05 per Wdc | For construction permits fee, interconnection, testing, and commissioning | Industry interviews |
| Developer overhead | Assume 10 MW system development and installation per year for a typical developer | Includes fixed overhead expenses such as payroll, facilities, travel, insurance, administrative, business development, finance, and other corporate functions; assumes 10 MW/year of system sales | Model assumptions, industry interviews |
| Contingency | 4% | Estimated as markup on EPC price | Industry interviews |

# Commercial PV: Model Outputs

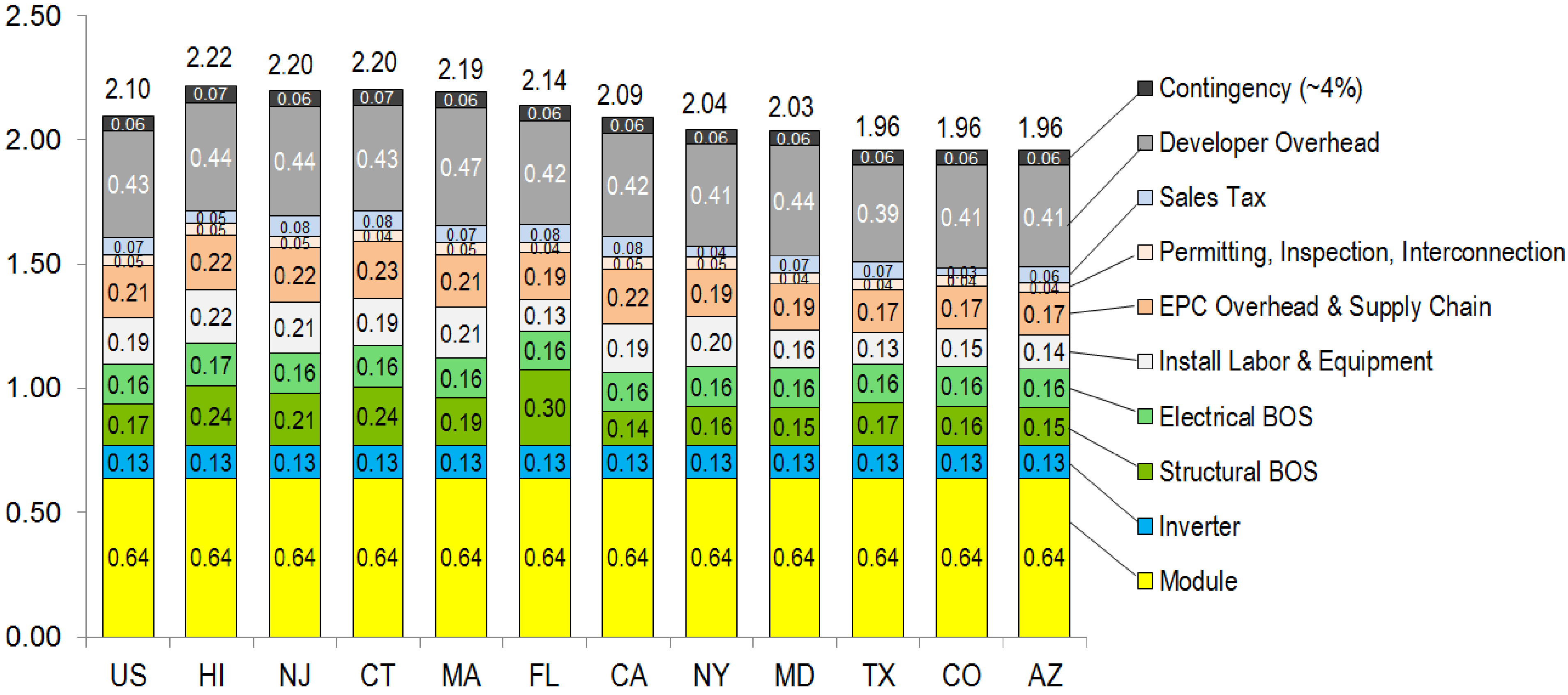
**US National Benchmark: Commercial System Cost (2016 $/Wdc), Without Profit**




(1) The national benchmark applies an average weighted by 2015 installed capacities.
(2) Different system sizes were modeled because of the wide scope for “commercial”, which comprises a diverse customer base occupying a variety of building sizes.
(3) Economies of scale, driven by hardware, labor, and related markups, are demonstrated in this chart.
(4) Since we assumed that a typical developer has 10 MW system development and installation per year, the developer overheads do not vary for different sizes per system. When developer has more annual installation, this developer overhead will decline.

# Commercial PV: Model Outputs

**Benchmark by Location: A 200 kW Commercial System Cost (2016 $/Wdc), Without Profit**




(1) The top U.S. commercial solar markets (by 2015 installation) are modeled.

(2) The main cost drivers for different regions in the commercial PV market are the same as in the residential model (i.e. labor rates, sales tax, and cost of doing business index) but also include costs associated with wind/snow loading.

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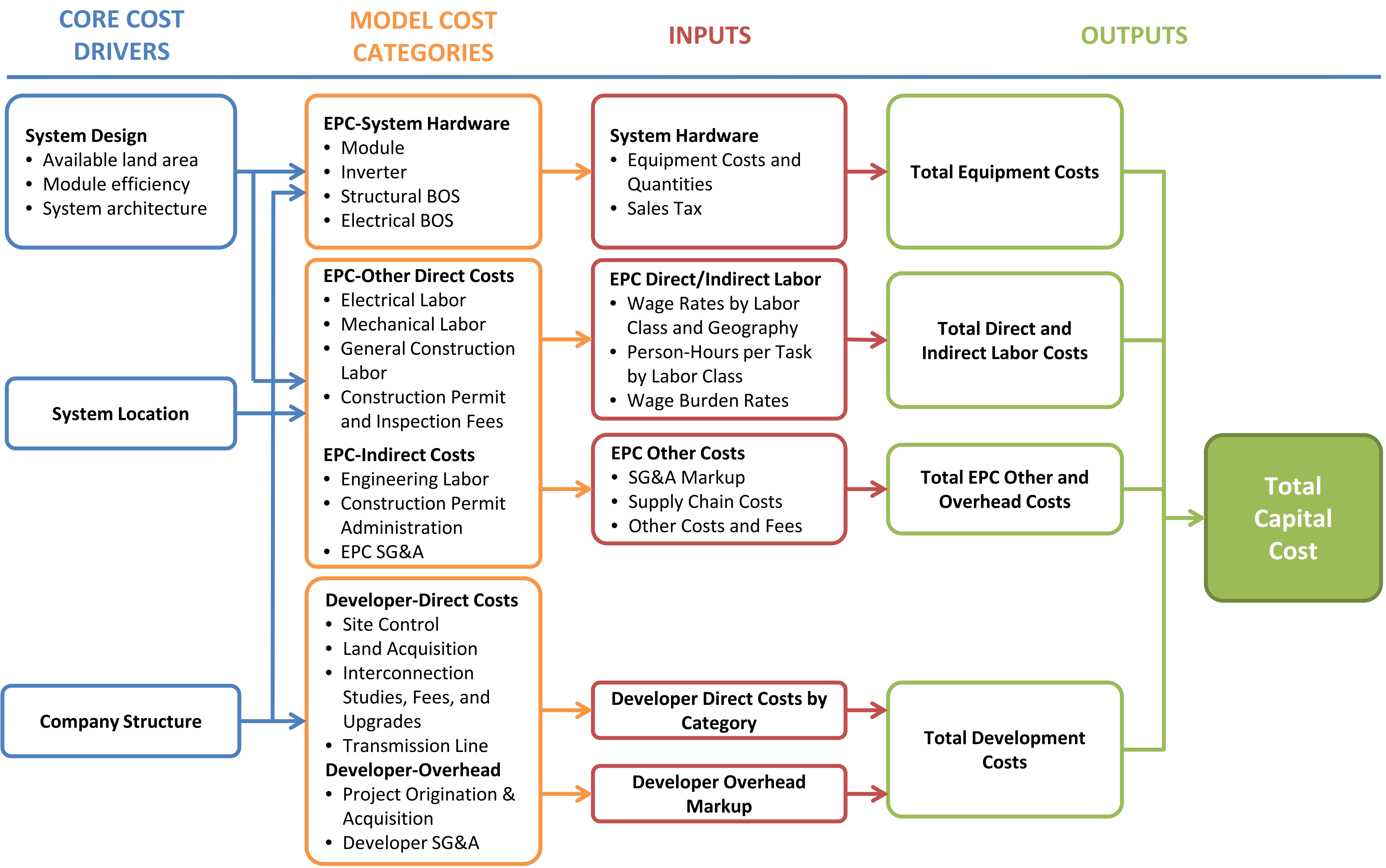
# Utility-Scale PV: Model Structure



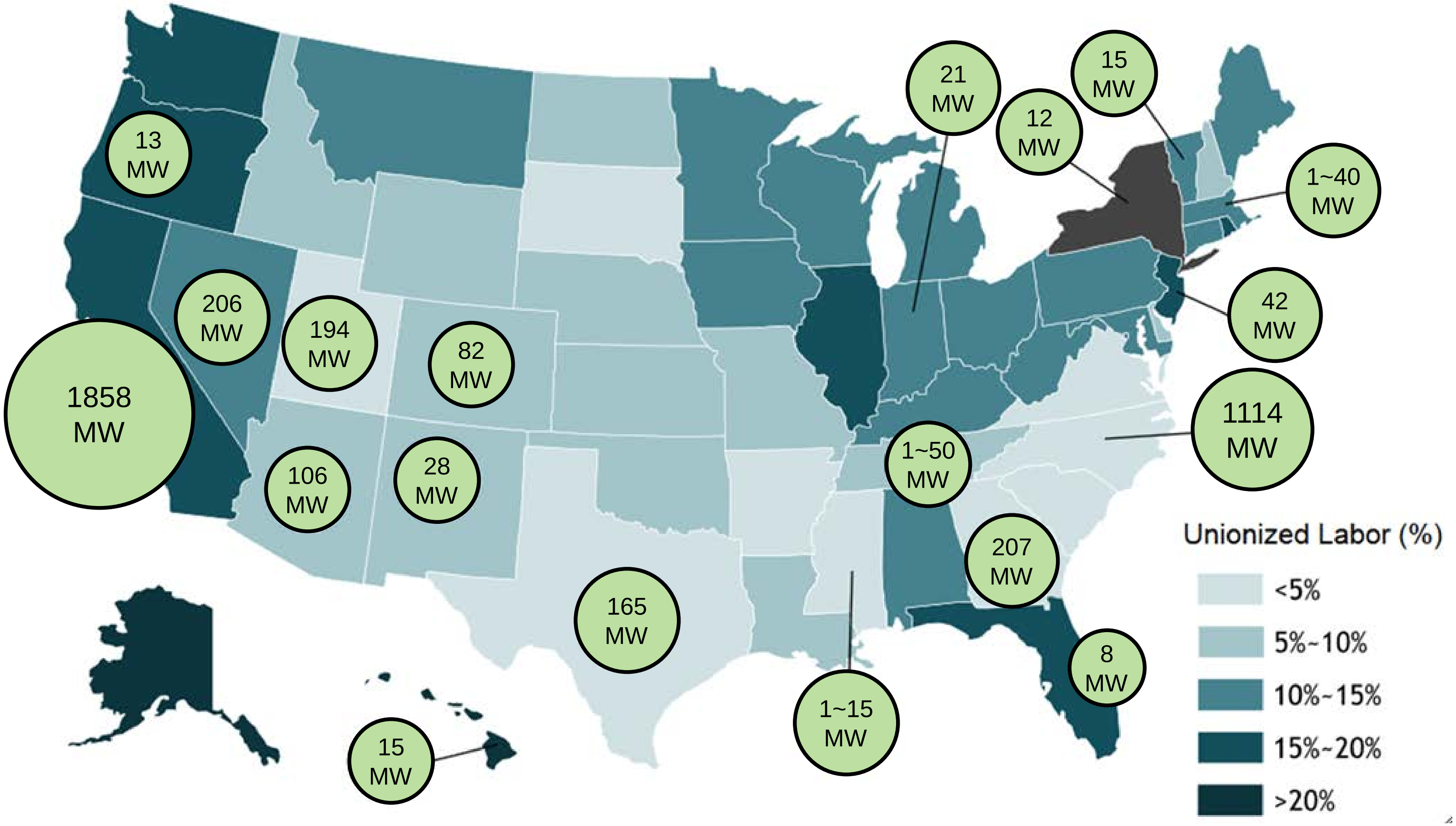


Unpublished Results. Do not cite or distribute.

# Utility-Scale PV: Modeling Inputs and Assumptions

| Category | Modeled Value | Description | Sources |
|---|---|---|---|
| System size | 100 MW | A large utility-scale system capacity | Model assumption |
| Module efficiency | 16.7% | Average module efficiency used in the model | Industry interviews |
| Module price | $0.64 per Wdc | Ex-factory gate (first buyer) average selling price; Tier 1 modules | Bloomberg database, SPV survey, industry interviews |
| Inverter price | $0.09 per Wdc (fixed-tilt)<br>$0.10 per Wdc (one-axis tracker) | Ex-factory gate prices (first buyer) average selling price; Tier 1 inverters.<br>DC-to-AC ratio = 120% for one-axis tracker<br>DC-to-AC ratio = 140% for fixed-tilt | PVinsights database,<br>industry interviews |
| Structural components (racking) | $0.14 – 0.30 per Wdc;<br>Vary by location and system size | Ex-factory gate prices; fixed-tilt racking or one-axis tracking system | Model assumptions,<br>ASCE design code, industry interviews |
| Electrical components | Vary by location and system size | Conductors, conduit and fittings, transition boxes, switchgear, panel boards, on-site transmission, etc. | Model assumptions, industry interviews,<br>RSMeans |
| EPC overhead and supply chain costs (% of equipment costs) | 10 – 15%<br>Vary by system size | Costs associated with EPC SG&A, warehousing, shipping and logistics | Industry interviews |
| Sales tax | Vary by location | National benchmark applies an average (by state) weighted by 2015 installed capacities | Database of State Incentives for Renewables & Efficiency (DSIRE), RSMeans |
| Direct installation labor | Electrician: $19.01 – $37.52 per hour;<br>Laborer: $12.41 – $24.63 per hour;<br>Vary by location and inverter option | Modeled labor rate assumes non-union and union labor and depends on state; national benchmark uses weighted average of state rates; | U.S. Bureau of Labor Statistics (BLS),<br>industry interviews |
| Burden rates (% of direct labor) | Total nationwide average: 31.8% | Workers compensation (state-weighted average), federal and state unemployment insurance, FICA, builders risk, public liability | RSMeans |
| Permitting, inspection and interconnection | $0.03 – 0.09 per Wdc<br>Vary by system size and location | For construction permits fee, interconnection, testing, and commissioning | Industry interviews |
| Transmission line (gen-tie line) | $0.00 – 0.02 per Wdc<br>Vary by system size | System size < 10 MW, use 0 mile;<br>System size > 200 MW, use 5 miles<br>10 – 200 MW, use linear interpolation | Model assumptions, industry interviews |
| Developer overhead | 3 – 12%<br>Vary by system size | Includes overhead expenses such as payroll, facilities, travel, legal fees, administrative, business development, finance, and other corporate functions | Model assumptions, industry interviews |
| Contingency | 3% | Estimated as markup on EPC cost | Industry interviews |

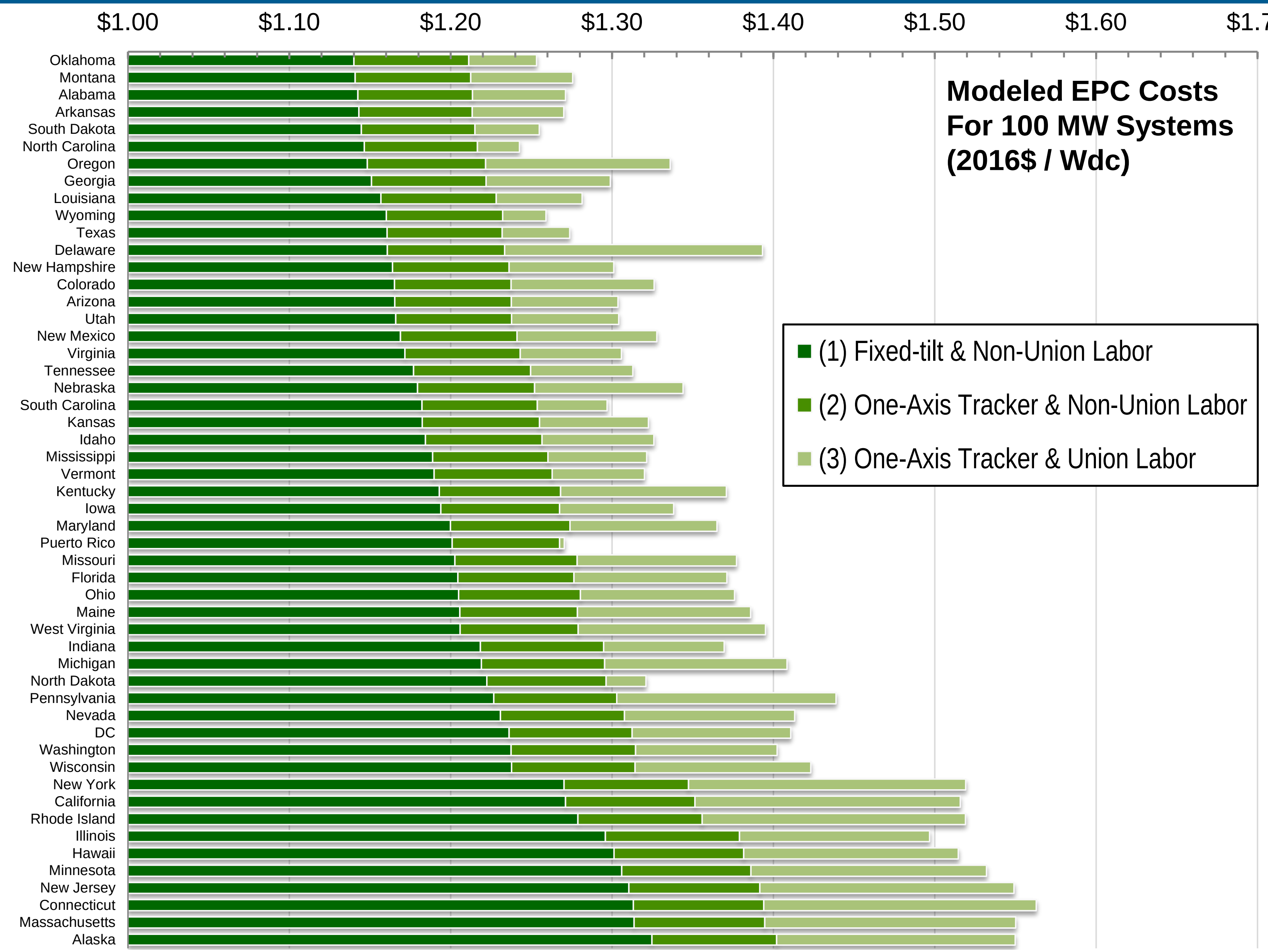
# Utility-Scale PV: Union Labor




Source: NREL, BLS, GTM

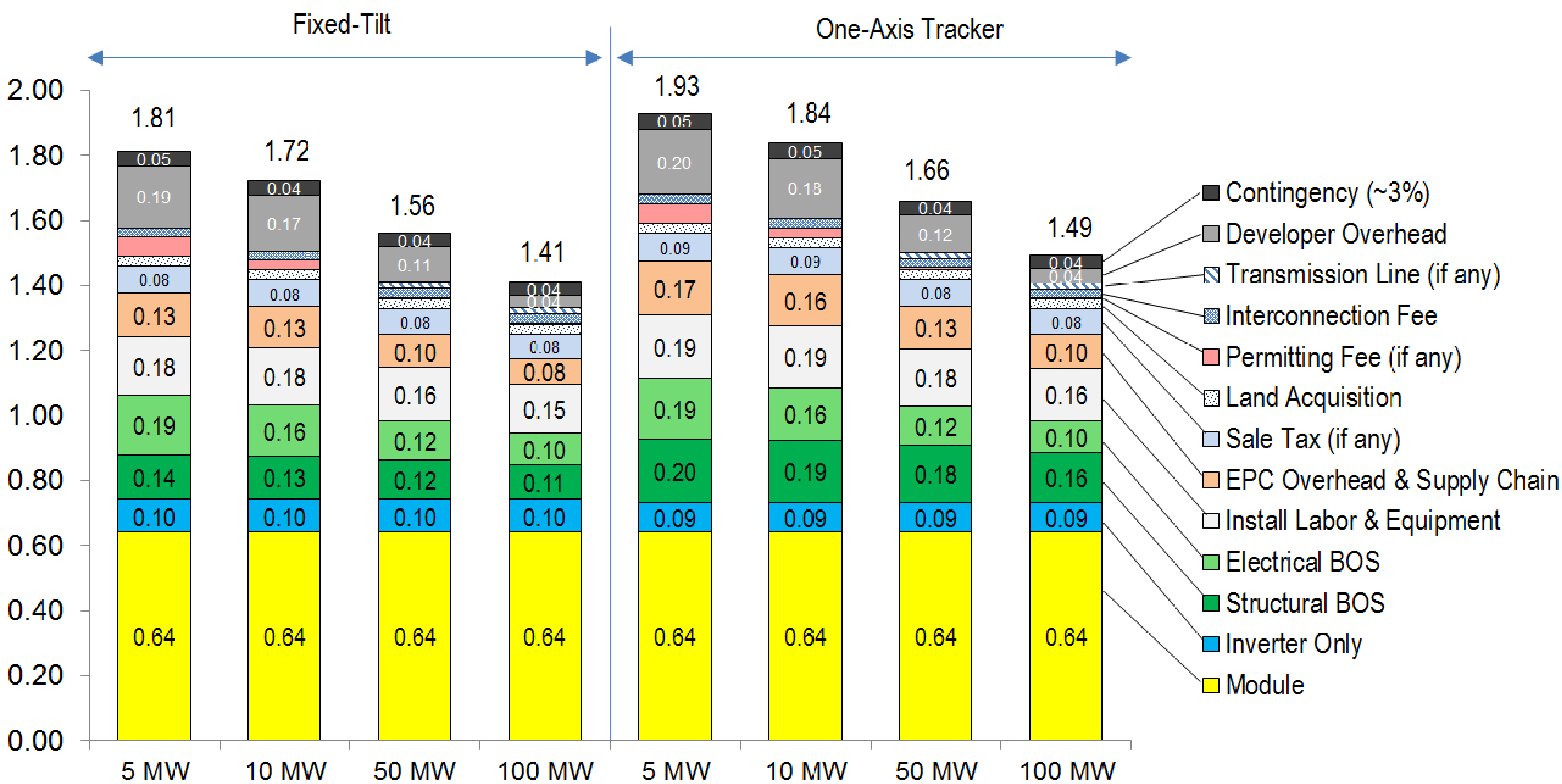
Although EPCs and developers tend to employ low-cost, non-union labor (presented by a BLS survey in this model) for PV system construction when possible, union labor is sometimes mandated. Construction trade unions may negotiate with local jurisdiction and EPC/developer during the public review period of the permitting process. This figure shows 2015 utility-scale PV installation capacity (MW) and unionized labor percent in each state. The unionized labor number represents the percent of employed workers in the overall construction who are union members.

# Utility-Scale PV: Model Outputs, EPC Only



# Utility-Scale PV: Model Outputs, EPC + Developer

**US National Benchmark: Utility-Scale System Cost (2016 $/Wdc), <u>Without Profit</u>**




(1) The national benchmark applies an average weighted by 2015 installed capacities.
(2) Non-union labor is used in this chart.
(3) Economies of scale, driven by BOS, labor, related markups, and development cost, are demonstrated in this chart.
(4) “Developer Profit” is excluded from our cost model. Thus, the total costs represent “cost” instead of “price”.

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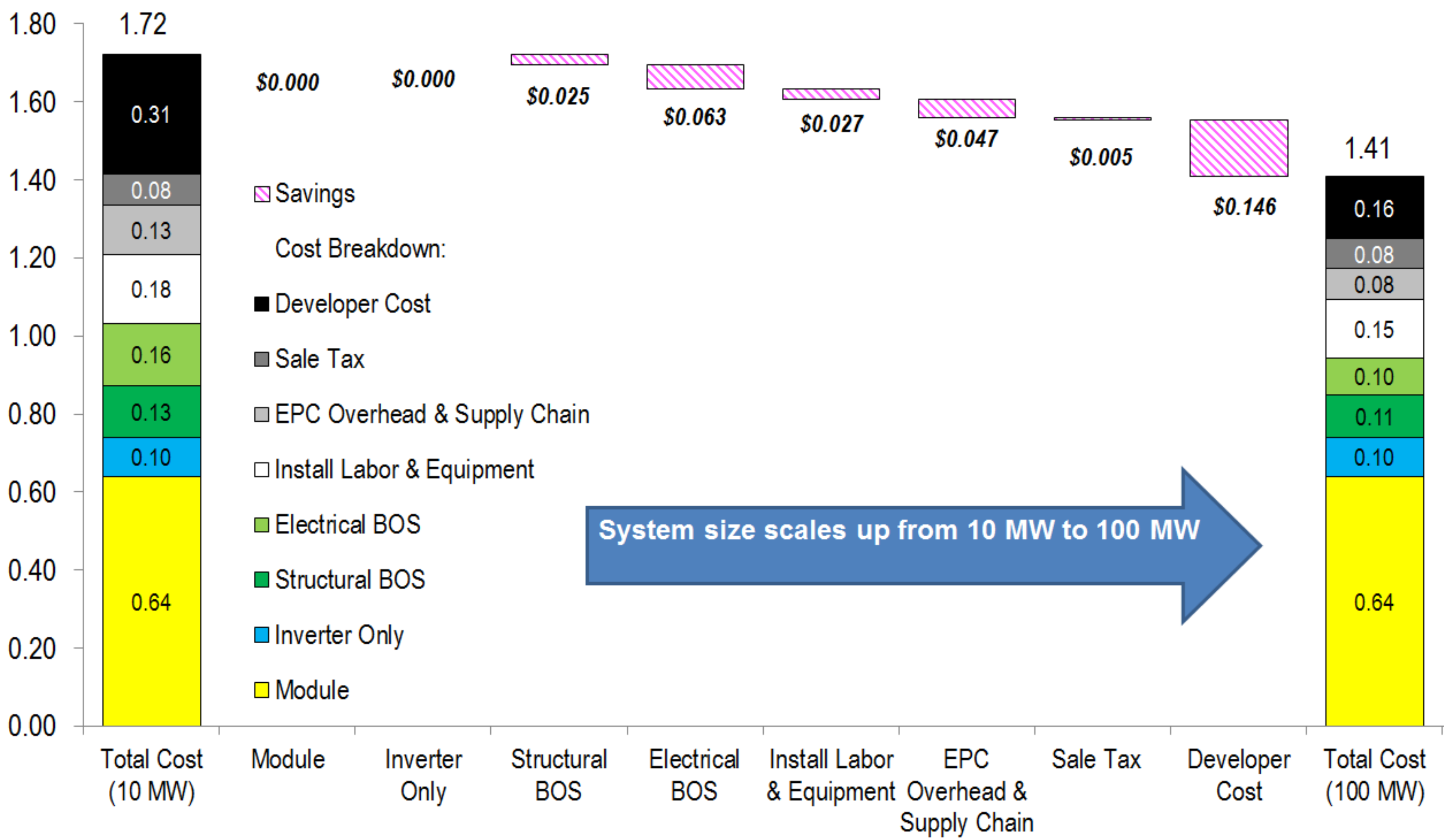
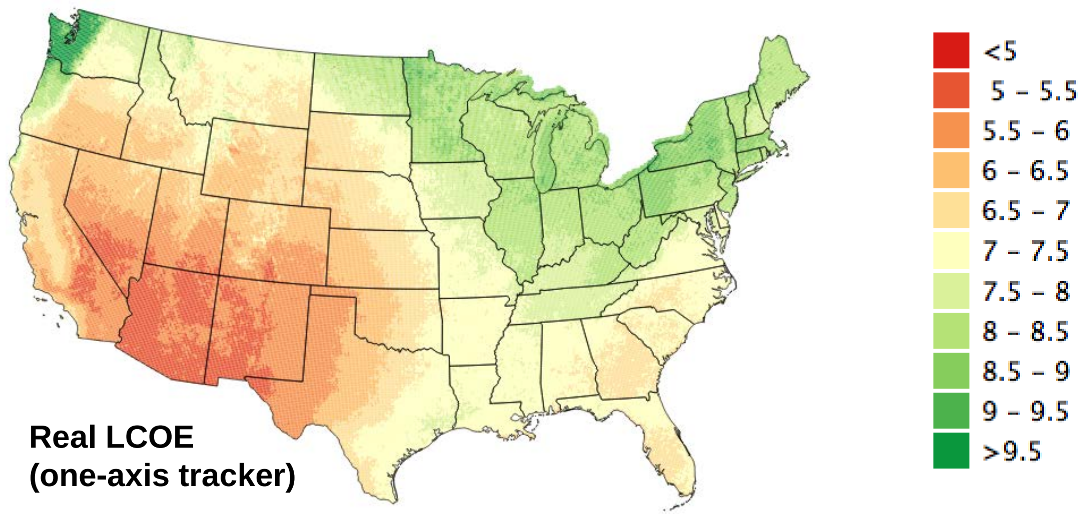
# Model Application – Economies of Scale




Our bottom-up system cost model can demonstrate cost breakdowns for different system configurations. For instance, scaling up system size from 10 MW to 100 MW can gain savings from BOS bulk price, labor learning curve, and lower developer overhead. Note that non-union labor is used in this chart.

# Model Application – Regional LCOE



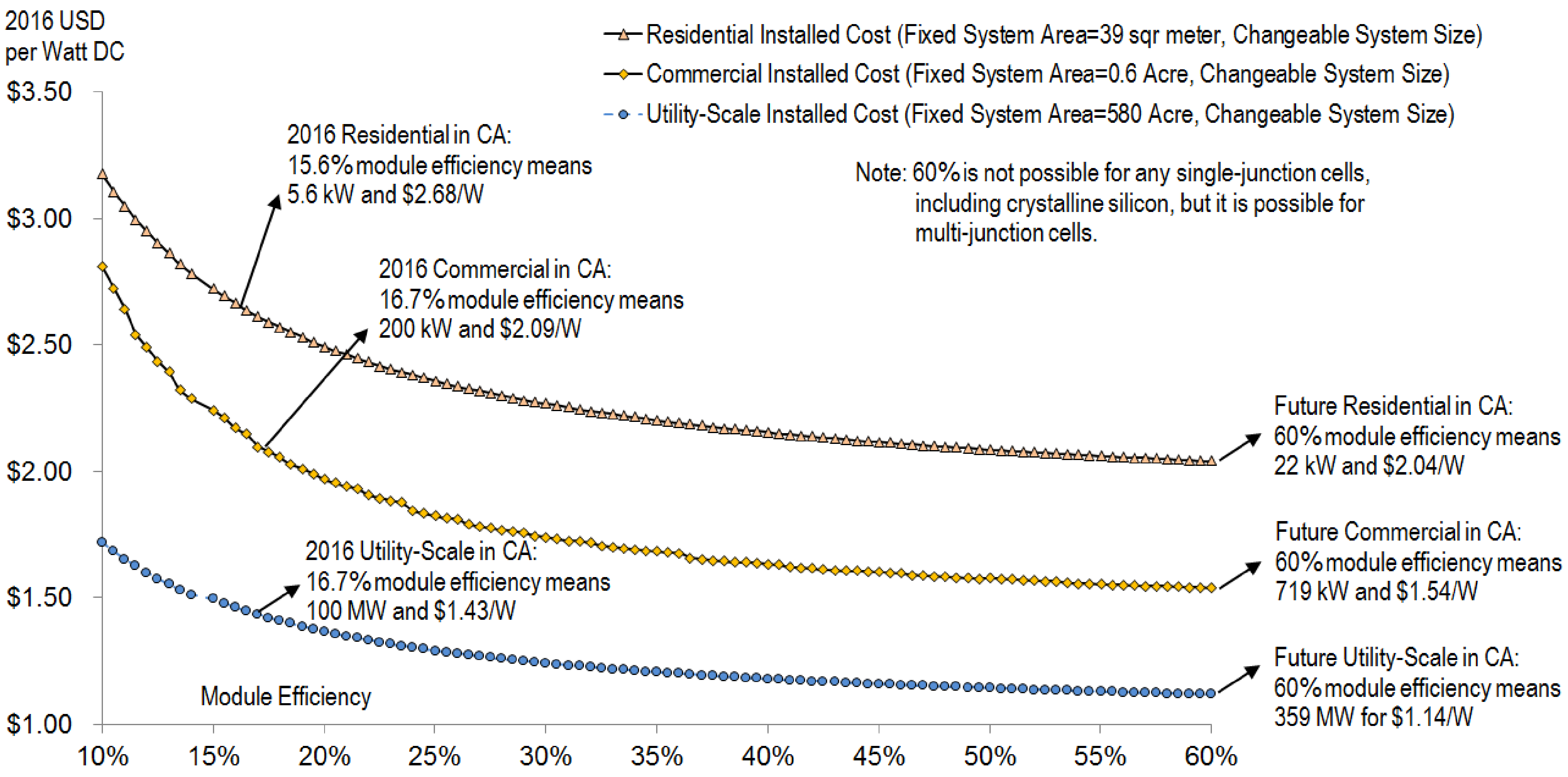

**Real LCOE (one-axis tracker)**

Our bottom-up system cost model can demonstrate regional LCOE by using modeled regional installed costs and localized solar irradiance and weather data (NREL System Advisor Model, SAM)

| | | Fixed-Tilt | | | One-Axis Tracker | | | One-Axis Tracker vs. Fixed-Tilt | | |
|---|---|---|---|---|---|---|---|---|---|---|
| State | Location | Total Installed Costs ($/W) | Nominal LCOE (cent per kWh) | Real LCOE (cent per kWh) | Total Installed Costs ($/W) | Nominal LCOE (cent per kWh) | Real LCOE (cent per kWh) | Installed Costs Premium (%) | Nominal LCOE Change (%) | Real LCOE Change (%) |
| CA | Bakersfield | $ 1.43 | $ 7.94 | $ 6.02 | $ 1.52 | $ 6.50 | $ 4.93 | 5.93% | -18.14% | -18.11% |
| CA | Imperial | $ 1.43 | $ 7.19 | $ 5.45 | $ 1.52 | $ 5.80 | $ 4.40 | 5.93% | -19.33% | -19.27% |
| AZ | Prescott | $ 1.32 | $ 7.03 | $ 5.33 | $ 1.39 | $ 5.55 | $ 4.21 | 5.81% | -21.05% | -21.01% |
| AZ | Tucson | $ 1.32 | $ 6.78 | $ 5.14 | $ 1.39 | $ 5.38 | $ 4.08 | 5.81% | -20.65% | -20.62% |
| NV | Las Vegas | $ 1.39 | $ 7.03 | $ 5.33 | $ 1.47 | $ 5.59 | $ 4.24 | 5.86% | -20.48% | -20.45% |
| NM | Albuquerque | $ 1.32 | $ 6.84 | $ 5.19 | $ 1.40 | $ 5.52 | $ 4.19 | 5.79% | -19.30% | -19.27% |
| CO | Alamosa | $ 1.32 | $ 6.85 | $ 5.19 | $ 1.40 | $ 5.43 | $ 4.11 | 5.80% | -20.73% | -20.81% |
| NC | Jacksonville | $ 1.29 | $ 8.10 | $ 6.14 | $ 1.37 | $ 7.21 | $ 5.47 | 5.73% | -10.99% | -10.91% |
| TX | San Antonio | $ 1.31 | $ 8.02 | $ 6.08 | $ 1.39 | $ 6.82 | $ 5.17 | 5.77% | -14.96% | -14.97% |
| NJ | Newark | $ 1.47 | $ 9.98 | $ 7.57 | $ 1.56 | $ 8.67 | $ 6.57 | 5.85% | -13.13% | -13.21% |
| FL | Orlando | $ 1.36 | $ 9.01 | $ 6.83 | $ 1.43 | $ 7.68 | $ 5.82 | 5.61% | -14.76% | -14.79% |
| HI | Kona | $ 1.47 | $ 8.63 | $ 6.54 | $ 1.56 | $ 7.41 | $ 5.61 | 5.79% | -14.14% | -14.22% |

- ITC = 30%, Discount Rate = Target IRR = 7%, Inflation = Escalator = 2.5%, Analysis period = 30-Yr. Thus, PPA = LCOE for both real and nominal cases. Degradation rate = 0.5%.
- Fixed-tilt: DC-to-AC ratio = 1.40 and Fixed O&M cost = $15/kW per year.
- One-axis tracker: DC-to-AC ratio = 1.20 and Fixed O&M cost = $18/kW per year.

# Model Application – Module Efficiency Impacts




In addition to the installed cost and LCOE estimates, the system cost model is also used to assess the economic benefits of high module efficiency on the installed cost savings. Because higher module efficiency will reduce the number of modules required to reach a certain system size, the related racking/mounting hardware, foundation, BOS, EPC/developer overhead, and labor hours to install a certain amount of materials will be reduced accordingly. This analysis holds module prices equal for any given efficiency, and demonstrates that higher efficiencies can help reduce total system installed costs. Please note that this is a case study based on California system cost.

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# Conclusions

(1) Our Q1 2016 PV cost benchmark modeling results in $2.59/W for residential systems, 2.10/W for commercial systems, $1.41/W for utility-scale fixed-tilt and $1.49/W for utility-scale one-axis tracker systems. Overall, modeled PV installed costs continued to decline in Q1 2016 for all three sectors.

(2) Hardware cost reductions (module and inverter prices, in particular) have been an important driver of reductions in overall system cost in past years, but they may not contribute as much to overall system cost declines going forward. Increased competition, improved labor productivity, and optimized system configuration designs also contribute to cost reductions, particularly for EPC firms building commercial and utility-scale projects.

(3) Regional cost difference, system configuration cost difference (such as MLPE vs. non-MLPE, fixed-tilt vs. one-axis tracker, and small system size vs. large system size), and business structure cost difference (such as installer vs. integrator, and EPC vs. developer) should be considered. Different scenarios will result in different costs. Thus, apple-to-apple comparison can only be applied when we use the same cost scenarios.

# For More Information

(1) Download the full technical report along with this presentation and data file:

- http://www.nrel.gov/analysis/staff/ran_fu.html

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