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Solar PV Manufacturing Cost Model Group:
Installed Solar PV System Prices

NREL

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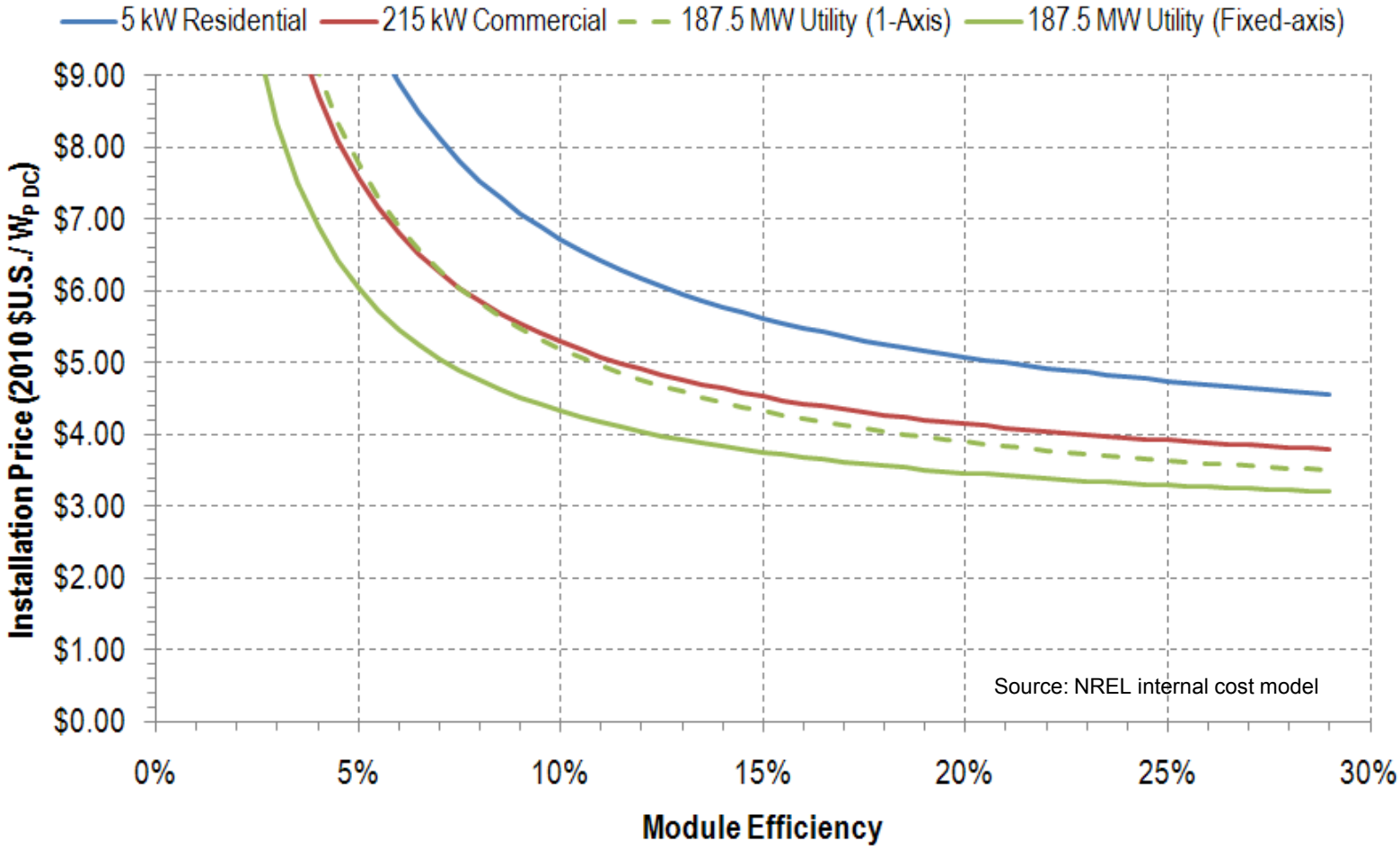
The Value of Module Efficiency



- $0.05–$0.10/W_{DC} /1% (absolute)

Installation Cost Model Methodology

- First-hand data from industry stakeholders
  - Installers
  - System developers
  - Utilities
  - Module and other component manufacturers

…Supplemented with public data sources

  - For example, Photon International module and inverter price surveys; RS Means labor rates and contractor overhead rates

- External review of results with stakeholders and industry analysts
  - Review critical assumptions
  - Compare results to completed and quoted projects, as well as public databases (e.g., CSI)
- Conduct sensitivity analyses (identify key cost drivers)
  - Continuously review and revise

Actual 2009–2010 project costs (under NDA)

- (40+) residential & commercial rooftop
- 8 utility-scale projects (all > 5 MW)

NREL PV System Price Model: Utility Scale




Modules

Inverters

- Prefabricated storage shed

Installation Materials

- Racking and ground mounts (tracker)
- DC wiring, combiner boxes, disconnect, conduit, and connectors
- AC wiring, meter, monitoring, disconnect, conduit, and connectors

Land and Site Preparation

- Land purchase or lease
- Leveling, plant removal, sediment control, roads, fencing, and surface treatment

Installer Markup

- Inventory and contingency costs

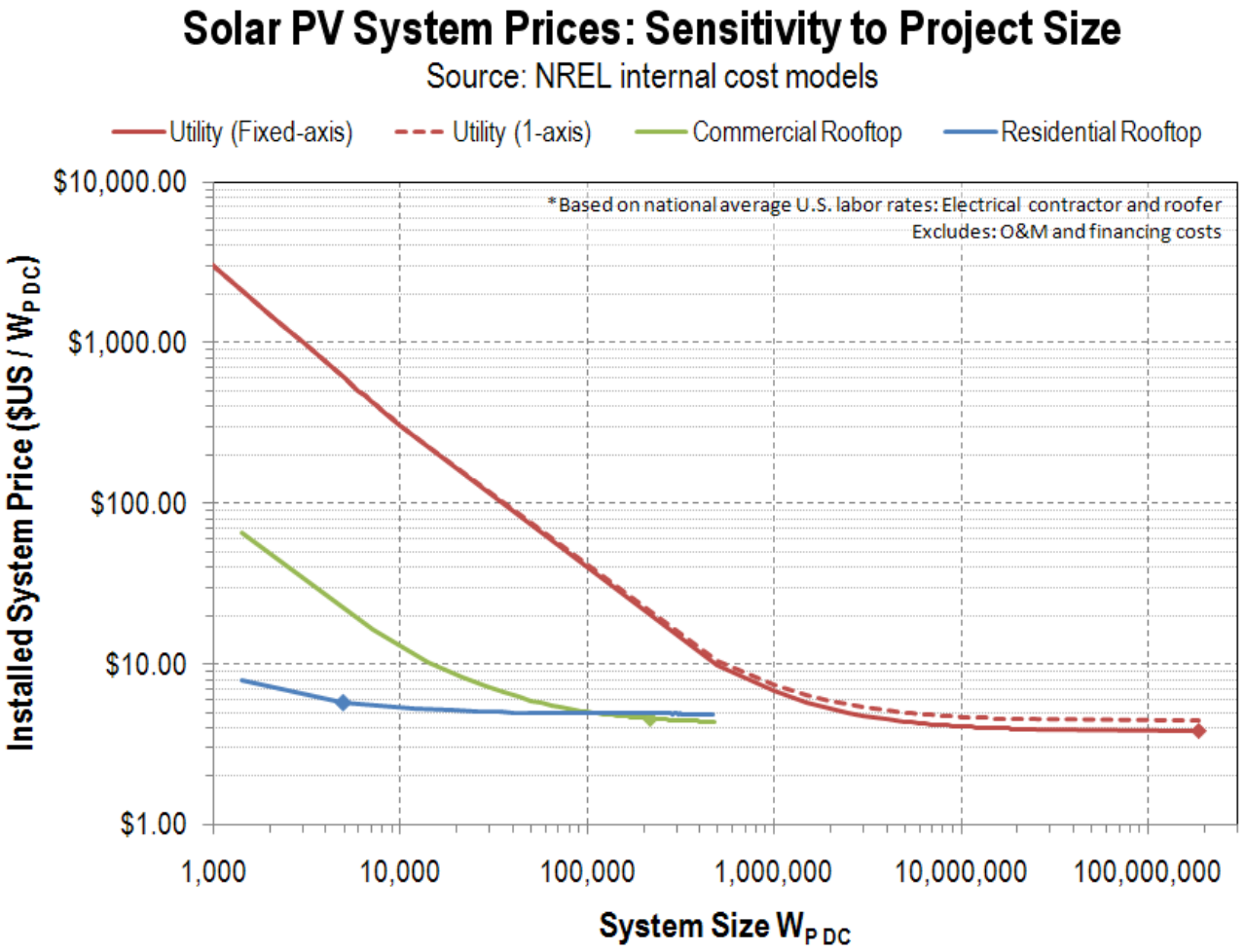
Labor Content and Rates

- Labor type (electrical and hardware)
- Installation time per component
- Overhead
- Installer profit

Indirect Capital Costs

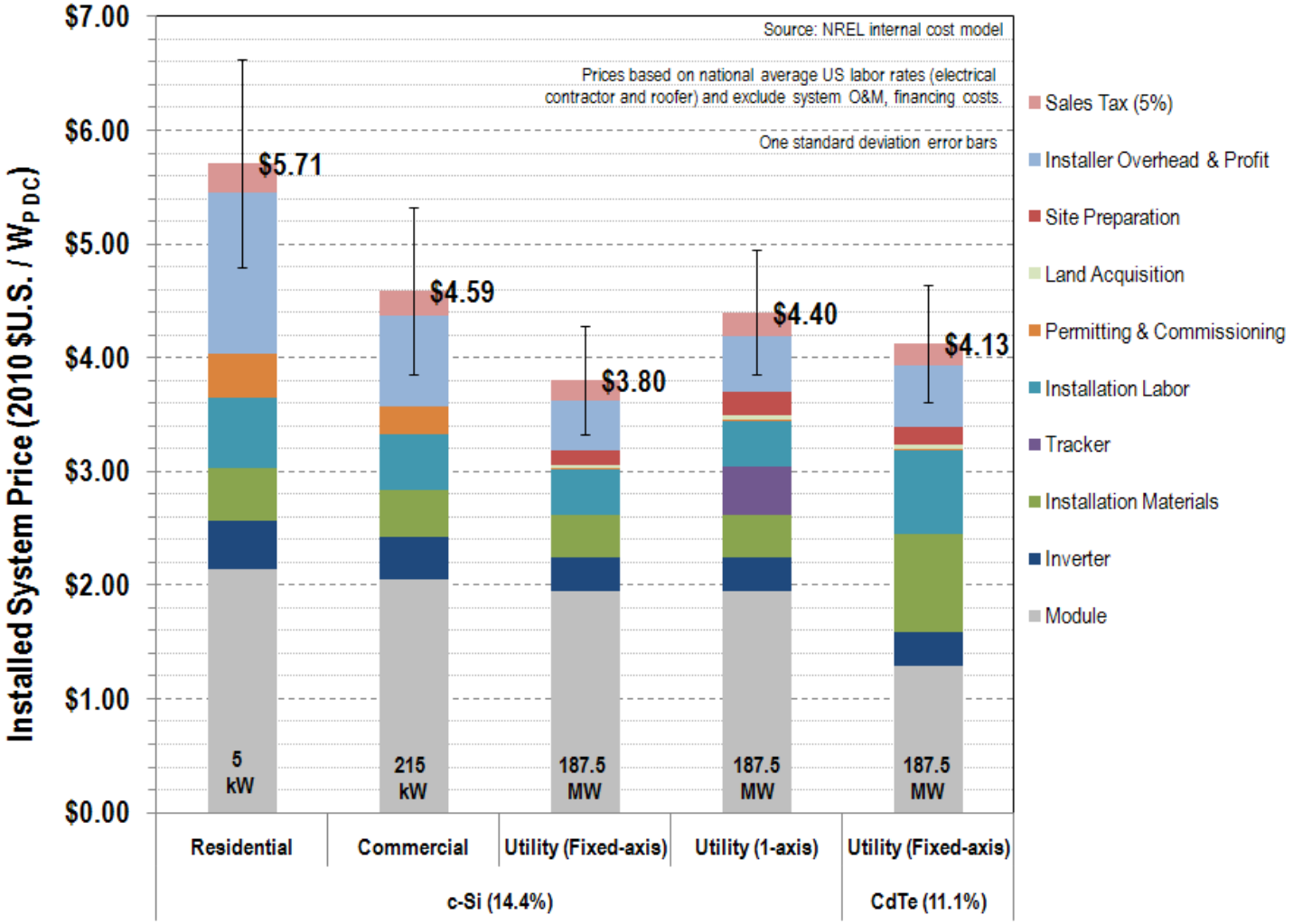
- Environmental permitting
- Grid interconnect (materials and labor)
- Sales tax

Economies of Scale



- Trend towards larger system sizes and building block system designs
- Utility-scale benefits nearly fully realized at 20 MW_{DC}

NREL System Price Model: Q4 2010 Results



- Markup on all materials (module, inverter, and BoS) included in "Installer Overhead & Profit"
  Residential \$0.89/W_{DC}, commercial \$0.55/W_{DC}, and utility (fixed-axis) \$0.31/W_{DC}
- Reflects inventory costs (interest during construction) and contingency

Installation Materials

	Residential Rooftop	Commercial Rooftop	Ground Mount Utility*
System size (kWp dc)	5.0	216	317,000
			*Fixed axis
Bill of Materials	$/Wp dc	$/Wp dc	$/Wp dc
Module	$2.15	$2.05	$1.95
Mounting (racking) hardware	$0.30	$0.30	$0.00
Storage	$0.00	$0.00	$0.00
Inverter	$0.42	$0.37	$0.29
Tracker	$0.00	$0.00	$0.62
Combiner boxes	$0.02	$0.02	$0.01
Meter	$0.02	$0.04	$0.00
System Monitor	$0.09	$0.03	$0.00
DC, AC-Disconnects	$0.01	$0.01	$0.00
Fuses and Holders	$0.01	$0.01	$0.00
Wiring (including connectors, conduit)	$0.02	$0.02	$0.16
	$3.03	$2.83	$3.04
Markup on materials[1]	$0.89	$0.55	$0.31
	$3.91	$3.38	$3.35
[1] *Markup on materials assumptions:*	*30%*	*20%*	*10%*

Source: NREL internal cost model

Utility-scale Hardware Costs

Mounting hardware

- Fixed-axis: $0.20/$W_{DC}$
- 1-axis: $0.45/$W_{DC}$

1.2 MW inverter-assembly

- (2) Inverters, preassembled
- Single 34.5 kV MV transformer (~ 6,700 kg)
- Storage shed (pre-fabricated)
- Roads not needed for installation (80 hrs)

Utility DC and AC wiring costs

- Wiring: $0.15–$0.19/W_{DC}
- Conduit and connectors: $0.05–$0.07/W_{DC}

Markup on materials

- Inventory costs, project delays, and contingency

Installation Labor

	Residential Rooftop	Commercial Rooftop	Ground Mount Utility*
System size (kWp dc)	5.0	216	317,000
			*Fixed axis
Labor Costs			
Electrical hours	24.9	656.3	1,784,482.5
Hardware hours	39.8	1,651.2	554,735.2
	64.7	2,307.5	2,339,217.6
	$/Wp dc	$/Wp dc	$/Wp dc
Electrical	$0.30	$0.18	$0.34
Hardware	$0.33	$0.31	$0.07
Overhead[2]	$0.34	$0.16	$0.06
Profit[2]	$0.19	$0.10	$0.13
	$1.16	$0.75	$0.59
[2] *Labor overhead and profit margin assumptions:*			
Worker's Compensation Insurance	*6.4%*	*6.4%*	*6.4%*
Federal and State Unemployment Insurance	*6.2%*	*6.2%*	*6.2%*
Social Security Taxes (FICA)	*7.7%*	*7.7%*	*7.7%*
Builder's Risk Insurance	*0.4%*	*0.4%*	*0.4%*
Public Liability	*2.0%*	*2.0%*	*2.0%*
Operating Overhead	*54.0%*	*32.0%*	*22.4%*
Profit	*30.0%*	*20.0%*	*10.0%*

Source: NREL internal cost model

Installation Labor Costs

Skilled electrical labor

- Role in utility-scale installations?
- Opportunities to integrate electrical assembly at factory?

Overhead rates > 3x national average for electrical contractors

- Reflects cost of permitting process?
- Design efforts?
- Customer acquisition costs?
- NREL data from inexperienced installers?

Indirect Installation Costs

	Residential Rooftop	Commercial Rooftop	Ground Mount Utility*
System size (kWp dc)	5.0	216	317,000
			*Fixed axis
Indirect Project Costs	$/Wp dc	$/Wp dc	$/Wp dc
Permitting	$0.08	$0.23	$0.00
Grid interconnect	$0.30	$0.01	$0.01
Land	$0.00	$0.00	$0.04
Site Prep	$0.00	$0.00	$0.20
Sales Tax[3]	$0.26	$0.21	$0.21
	$0.64	$0.45	$0.46
	$/Wp dc	$/Wp dc	$/Wp dc
Total System Price:	$5.71	$4.58	$4.40

[3] *Sales tax assumption: 5%*

Indirect Project Costs

Environmental permitting

- $1 MM (CA SEQA)

Grid interconnect

- Utility scale: Substation materials and labor ($1.5–$3.0 MM, 69–230 kV)
- Rooftop "commissioning" costs?

Land acquisition

- $500–$10,000/acre
  - As high as $105K/acre (2008)
- 5–8 acres/MW

Site preparation

- $5K–$25K/acre
- Leveling, hydrology, plant removal, roads, and sediment control

Source: NREL internal cost model

Summary and Discussion

Hardware and labor costs account for > ⅓ of system price

- Integrate electrical components and wiring at factories?
  Save on-site labor and hardware costs?
- Limited benefits associated with lightweight inverters?
  Roads and concrete pad still necessary: Heavy MV transformers
- Cost benefits of higher DC voltages?
  1,000 V_{DC} to 1,500 V_{DC} → 1.2 MW_{DC} to 2.4 MW_{DC} inverter blocks

Indirect project costs: 5%–11% of system prices

- Site preparation ~ 5x land acquisition cost
  System and component designs to reduce preparation requirements?
- Commissioning costs?
- Permitting delays, opportunity to *fast track* standard system designs?

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APPENDIX

Utility-scale PV: Uncertainty Analysis (1)

Regional cost differences

- Labor rates
- Installer productivity
- Permitting and delays
- Land costs

Technology selection

- Module efficiency
- Configuration

Economies of scale

- Project size (indirect costs)
- Installer purchasing power

Utility-scale PV: Uncertainty Analysis (2)