

LAZARD'S LEVELIZED COST OF ENERGY ANALYSIS—VERSION 8.0

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LAZARD

# Introduction

Lazard's Levelized Cost of Energy Analysis ("LCOE") addresses the following topics:

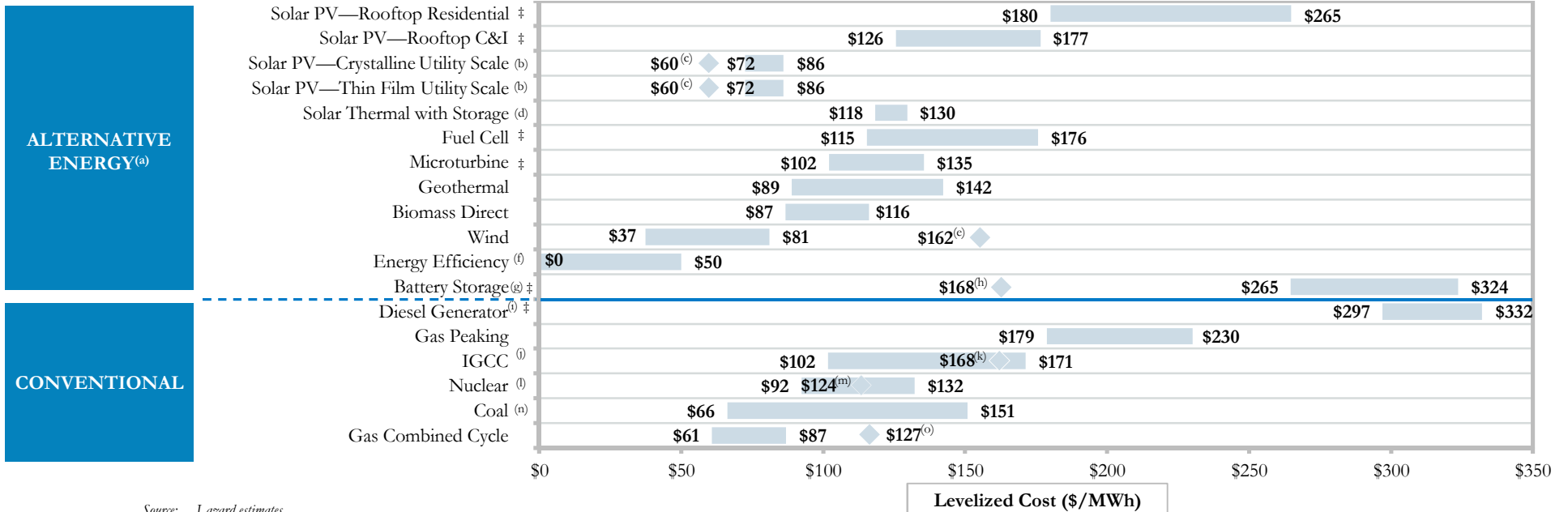
- Comparative "levelized cost of energy" for various technologies on a \$/MWh basis, including sensitivities, as relevant, for U.S. federal tax subsidies, fuel costs, geography and cost of capital, among other factors
- Comparison of the implied cost of carbon abatement given resource planning decisions for various generation technologies
- Illustration of how the cost of utility-scale and rooftop solar-produced energy compares against generation rates in large metropolitan areas of the United States
- Illustration of utility-scale and rooftop solar versus peaking generation technologies globally
- Illustration of how the costs of utility-scale and rooftop solar and wind vary across the United States, based on average available resources
- Forecast of rooftop solar levelized cost of energy through 2017
- Comparison of assumed capital costs on a \$/kW basis for various generation technologies
- Decomposition of the levelized cost of energy for various generation technologies by capital cost, fixed operations and maintenance expense, variable operations and maintenance expense, and fuel cost, as relevant
- Considerations regarding the usage characteristics and applicability of various generation technologies, taking into account factors such as location requirements/constraints, dispatch capability, land and water requirements and other contingencies
- Summary assumptions for the various generation technologies examined
- Summary of Lazard's approach to comparing the levelized cost of energy for various conventional and Alternative Energy generation technologies

Other factors would also have a potentially significant effect on the results contained herein, but have not been examined in the scope of this current analysis. These additional factors, among others, could include: capacity value vs. energy value; stranded costs related to distributed generation or otherwise; network upgrade, transmission or congestion costs; integration costs; and costs of complying with various environmental regulations (e.g., carbon emissions offsets, emissions control systems). The analysis also does not address potential social and environmental externalities, including, for example, the social costs and rate consequences for those who cannot afford distribution generation solutions, as well as the long-term residual and societal consequences of various conventional generation technologies that are difficult to measure (e.g., nuclear waste disposal, environmental impacts, etc.)

While prior versions of this study have presented the LCOE inclusive of the U.S. Federal Investment Tax Credit and Production Tax Credit, Versions 6.0 – 8.0 present the LCOE on an unsubsidized basis, except as noted on the page titled "Levelized Cost of Energy—Sensitivity to U.S. Federal Tax Subsidies"

# Unsubsidized Levelized Cost of Energy Comparison

Certain Alternative Energy generation technologies are cost-competitive with conventional generation technologies under some scenarios; such observation does not take into account potential social and environmental externalities (e.g., social costs of distributed generation, environmental consequences of certain conventional generation technologies, etc.) or reliability-related considerations (e.g., transmission and back-up generation costs associated with certain Alternative Energy generation technologies)



Source: Lazard estimates.

Note: Here and throughout this presentation, unless otherwise indicated, analysis assumes 60% debt at 8% interest rate and 40% equity at 12% cost for conventional and Alternative Energy generation technologies. Assumes Powder River Basin coal price of \$1.99 per MMBtu and natural gas price of \$4.50 per MMBtu. Analysis does not reflect potential impact of recent draft rule to regulate carbon emissions under Section 111(d).

‡ Denotes distributed generation technology.

(a) Analysis excludes integration costs for intermittent technologies. A variety of studies suggest integration costs ranging from \$2.00 to \$10.00 per MWh.

(b) Low end represents single-axis tracking. High end represents fixed-tilt installation. Assumes 10 MW system in high insolation jurisdiction (e.g., Southwest U.S.). Not directly comparable for baseload. Does not account for differences in heat coefficients, balance-of-system costs or other potential factors which may differ across solar technologies.

(c) Diamonds represents estimated implied levelized cost of energy in 2017, assuming \$1.25 per watt for a single-axis tracking system.

(d) Low end represents concentrating solar tower with 18-hour storage capability. High end represents concentrating solar tower with 10-hour storage capability.

(e) Represents estimated implied midpoint of levelized cost of energy for offshore wind, assuming a capital cost range of \$3.10 – \$5.50 per watt.

(f) Estimates per National Action Plan for Energy Efficiency; actual cost for various initiatives varies widely. Estimates involving demand response may fail to account for opportunity cost of foregone consumption.

(g) Indicative range based on current stationary storage technologies; assumes capital costs of \$500 – \$750/KWh for 6 hours of storage capacity, \$60/MWh cost to charge, one full cycle per day (full charge and discharge), efficiency of 75% – 85% and fixed O&M costs of \$22.00 to \$27.50 per KWh installed per year.

(h) Diamond represents estimated implied levelized cost for “next generation” storage in 2017; assumes capital costs of \$300/KWh for 6 hours of storage capacity, \$60/MWh cost to charge, one full cycle per day (full charge and discharge), efficiency of 75% and fixed O&M costs of \$5.00 per KWh installed per year.

(i) Low end represents continuous operation. High end represents intermittent operation. Assumes diesel price of \$4.00 per gallon.

(j) High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

(k) Represents estimate of current U.S. new IGCC construction with carbon capture and compression. Does not include cost of transportation and storage.

(l) Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies.

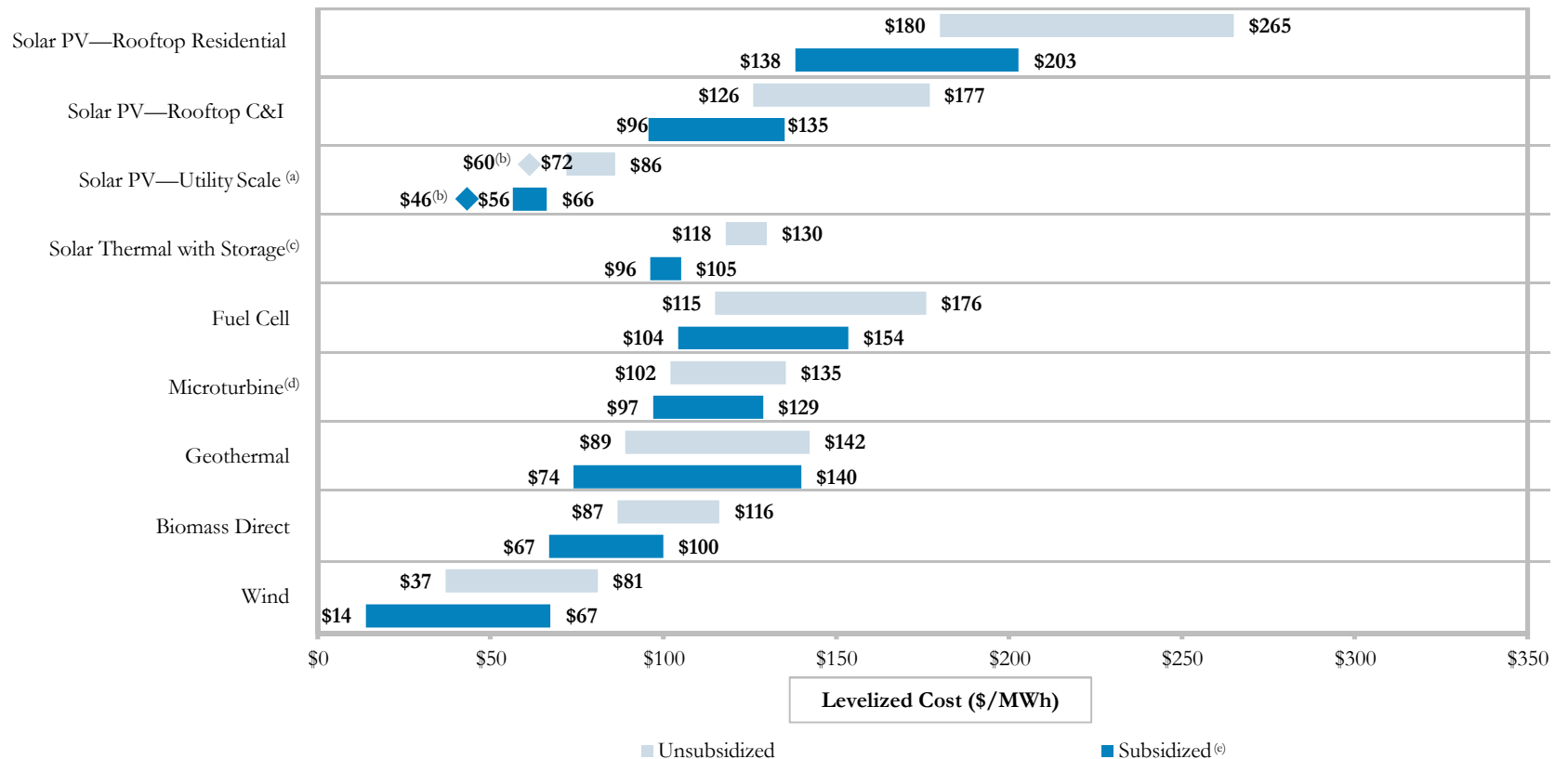
(m) Represents estimate of current U.S. new nuclear construction.

(n) Based on advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

(o) Incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

# Levelized Cost of Energy—Sensitivity to U.S. Federal Tax Subsidies

U.S. federal tax subsidies remain an important component of the economics of Alternative Energy generation technologies (and government incentives are, generally, currently important in all regions); while some Alternative Energy generation technologies have achieved notional “grid parity” under certain conditions (e.g., best-in-class wind/solar resource), such observation does not take into account potential social and environmental externalities (e.g., social costs of distributed generation, environmental consequences of certain conventional generation technologies, etc.) or reliability-related considerations (e.g., transmission and back-up generation costs associated with certain Alternative Energy generation technologies)

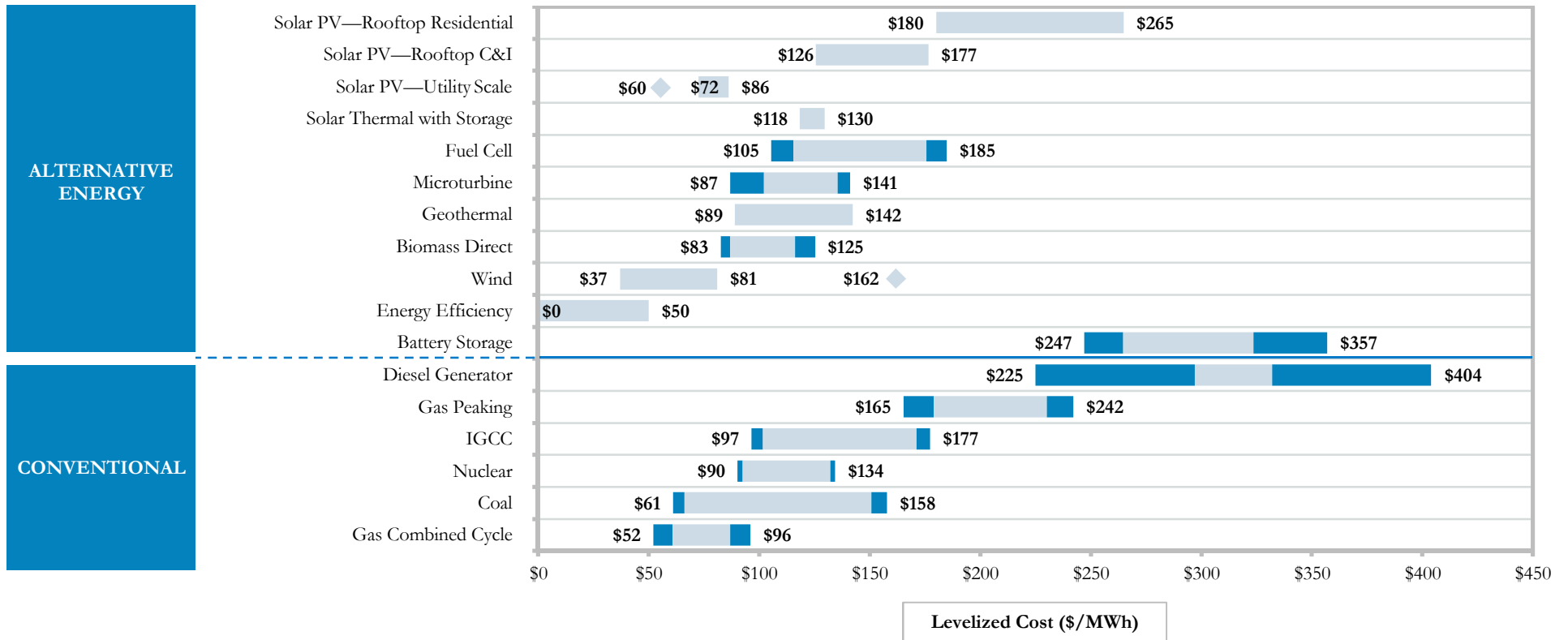


Source: Lazard estimates.

- (a) Low end represents single-axis tracking. High end represents fixed-tilt installation. Assumes 10 MW fixed-tilt installation in high insolation jurisdiction (e.g., Southwest U.S.).
- (b) Diamonds represent estimated implied levelized cost of energy in 2017, assuming \$1.25 per watt for a single-axis tracking system.
- (c) Low end represents concentrating solar tower with 18-hour storage. High end represents concentrating solar tower with 10-hour storage capability.
- (d) Reflects 10% Investment Tax Credit. Capital structure adjusted for lower Investment Tax Credit; assumes 50% debt at 8.0% interest rate, 20% tax equity at 12.0% cost and 30% common equity at 12.0% cost.
- (e) Except where noted, reflects 30% Investment Tax Credit. Assumes 30% debt at 8.0% interest rate, 50% tax equity at 12.0% cost and 20% common equity at 12.0% cost.

# Levelized Cost of Energy Comparison—Sensitivity to Fuel Prices

Variations in fuel prices can materially affect the levelized cost of energy for conventional generation technologies, but direct comparisons against “competing” Alternative Energy generation technologies must take into account issues such as dispatch characteristics (e.g., baseload and/or dispatchable intermediate load vs. peaking or intermittent technologies)



Source: Lazard estimates.

Note: Darkened areas in horizontal bars represent low end and high end levelized cost of energy corresponding with ±25% fuel price fluctuations.

# Cost of Carbon Abatement Comparison

As policymakers consider the best and most cost-effective ways to limit carbon emissions (including in the U.S., in respect of Section 111(d) regulations), they should consider the implicit costs of carbon abatement of various Alternative Energy generation technologies; an analysis of such implicit costs suggests that policies designed to promote wind and utility-scale solar development could be a particularly cost effective way of limiting carbon emissions; rooftop solar and solar thermal remain expensive, by comparison

- Such observation does not take into account potential social and environmental externalities or reliability-related considerations

	Units	CONVENTIONAL GENERATION			ALTERNATIVE ENERGY RESOURCES			
		Coal <sup>(b)</sup>	Gas Combined Cycle	Nuclear	Wind	Solar PV Rooftop	Solar PV Utility Scale <sup>(c)</sup>	Solar Thermal <sup>(d)</sup> with Storage
Capital Investment/KW of Capacity <sup>(a)</sup>	\$/kW	\$3,000	\$1,006	\$5,385	\$1,400	\$3,500	\$1,750	\$9,800
<b>Total Capital Investment</b>	<b>\$mm</b>	<b>\$1,800</b>	<b>\$805</b>	<b>\$3,339</b>	<b>\$1,498</b>	<b>\$8,505</b>	<b>\$3,255</b>	<b>\$6,860</b>
<i>Memo: Total ITC/PTC Tax Subsidization</i>	\$mm	—	—	—	\$449	\$2,552	\$977	\$2,058
<b>Facility Output</b>	<b>MW</b>	<b>600</b>	<b>800</b>	<b>620</b>	<b>1,070</b>	<b>2,430</b>	<b>1,860</b>	<b>700</b>
Capacity Factor	%	93%	70%	90%	52%	23%	30%	80%
<b>Effective Facility Output</b>	<b>MW</b>	<b>558</b>	<b>558</b>	<b>558</b>	<b>558</b>	<b>558</b>	<b>558</b>	<b>558</b>
MWh/Year Produced <sup>(e)</sup>	GWh/yr	4,888	4,888	4,888	4,888	4,888	4,888	4,888
Levelized Cost of Energy	\$/MWh	\$66	\$61	\$92	\$37	\$180	\$72	\$118
<b>Total Cost of Energy Produced</b>	<b>\$mm/yr</b>	<b>\$324</b> <sup>2</sup>	<b>\$298</b>	<b>\$452</b>	<b>\$183</b>	<b>\$880</b>	<b>\$354</b> <sup>1</sup>	<b>\$579</b>
Carbon Emitted	mm Tons/yr	4.54	1.92	—	—	—	—	—
<b>Difference in Carbon Emissions</b>	mm Tons/yr							
vs. Coal		—	2.62	4.54	4.54	4.54	4.54	4.54
vs. Gas		—	—	1.92	1.92	1.92	1.92	1.92
<b>Difference in Total Energy Cost</b>	<b>\$mm/yr</b>							
vs. Coal		—	(\$26)	\$128	(\$141)	\$557	\$31	\$255
vs. Gas		—	—	\$154	(\$115)	\$582	\$57	\$281
<b>Implied Abatement Cost/(Saving)</b>	<b>\$/Ton</b>							
vs. Coal		—	(\$10)	\$28	(\$31)	\$123	\$7	\$56
vs. Gas		—	—	\$80	(\$60)	\$304	\$30	\$147

Source: Lazard estimates.

Note: Does not reflect production tax credit or investment tax credit. Assumes 2014 dollars, 20 – 40 year economic life, 40% tax rate and 5 – 40 year tax life. Assumes 2.5% annual escalation for O&M costs and fuel prices. Inputs for each of the various technologies are those associated with the low end levelized cost of energy.

- (a) Includes capitalized financing costs during construction for generation types with over 24 months construction time.
- (b) Based on advanced supercritical pulverized coal. Does not incorporate carbon capture and compression.
- (c) Represents single-axis tracking.
- (d) Low end represents concentrating solar tower with 18-hour storage capability.
- (e) All facilities sized to produce 4,888 GWh/yr.

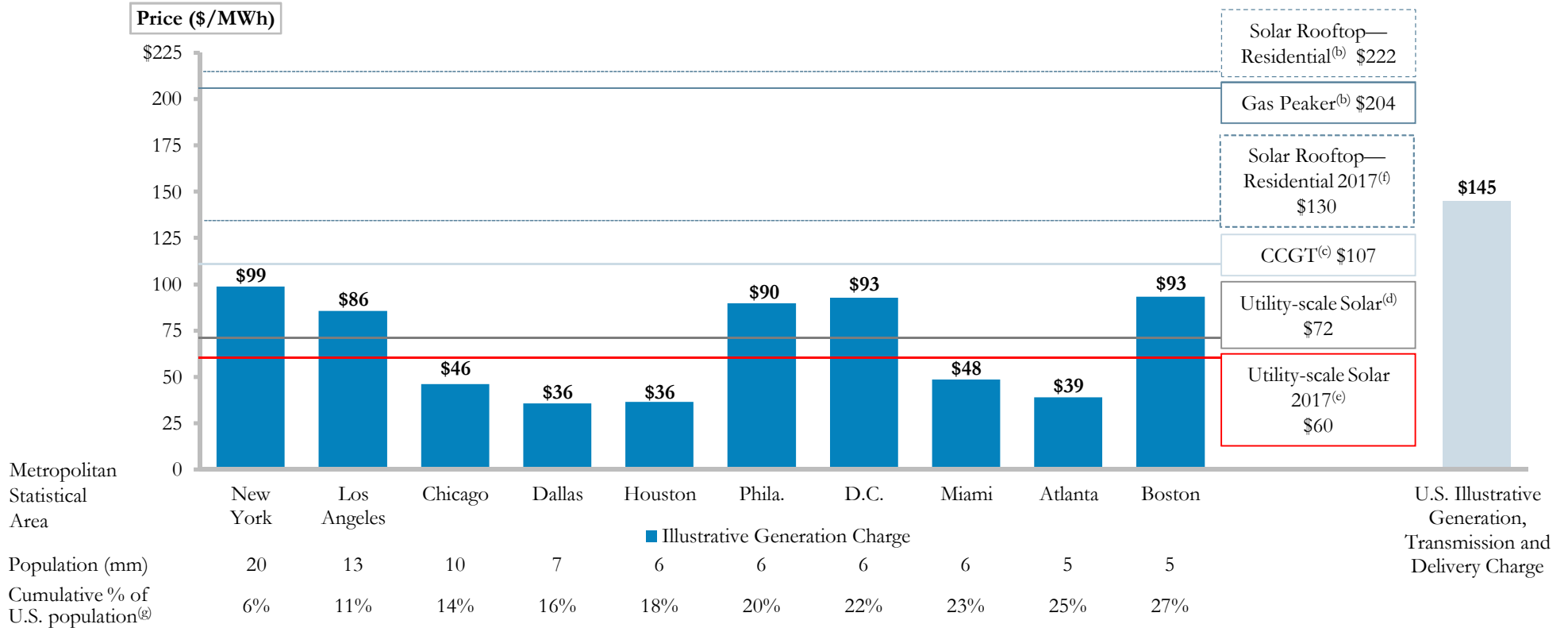
### Illustrative Implied Carbon Abatement Cost Calculation:

$$\begin{aligned}
 \text{④ Difference in Total Energy Cost vs. Coal} &= \text{①} - \text{②} \\
 &= \$354 \text{ mm/yr (solar)} - \$324 \text{ mm/yr (coal)} = \$31 \text{ mm/yr} \\
 \text{⑤ Implied Abatement Cost vs. Coal} &= \text{④} \div \text{③} \\
 &= \$31 \text{ mm/yr} \div 4.54 \text{ mm Tons/yr} = \$7/\text{Ton}
 \end{aligned}$$

## Generation Rates for the 10 Largest U.S. Metropolitan Areas<sup>(a)</sup>

Setting aside the legislatively-mandated demand for solar and other Alternative Energy resources, utility-scale solar is becoming a more economically viable peaking energy product in many areas of the U.S. and, as pricing declines, could become economically competitive across a broader array of geographies

- Such observation does not take into account potential social and environmental externalities or reliability-related considerations



Source: EEI, Ventyx.

Note: Actual delivered generation prices may be higher, reflecting historical composition of resource portfolio.

(a) Defined as 10 largest Metropolitan Statistical Areas per the U.S. Census Bureau for a total population of 83 million.

(b) Represents an average of the high and low levelized cost of energy.

(c) Assumes 25% capacity factor.

(d) Represents low end of utility-scale solar. Excludes investment tax credit.

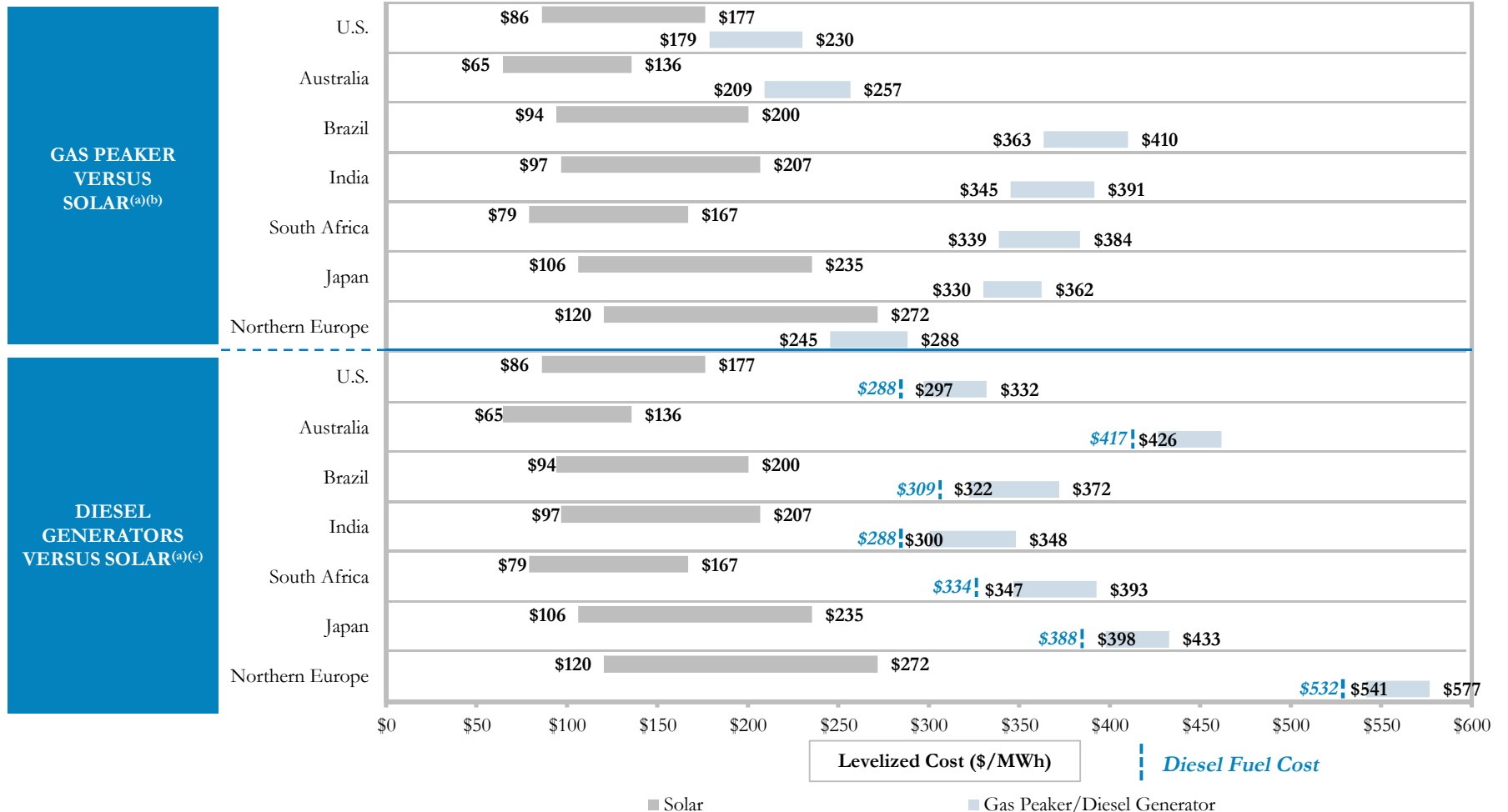
(e) Represents estimated implied levelized cost of energy in 2017, assuming \$1.25 per watt for a single-axis tracking system. Excludes investment tax credit.

(f) Represents estimated implied levelized cost of energy in 2017, assuming \$2.20 per watt (average of high and low).

(g) Represents 2013 census data.

# Solar versus Peaking Capacity—Global Markets

Solar PV can be an attractive resource relative to gas and diesel-fired peaking in many parts of the world due to high fuel costs; without storage, however, solar lacks the dispatch characteristics of conventional peaking technologies



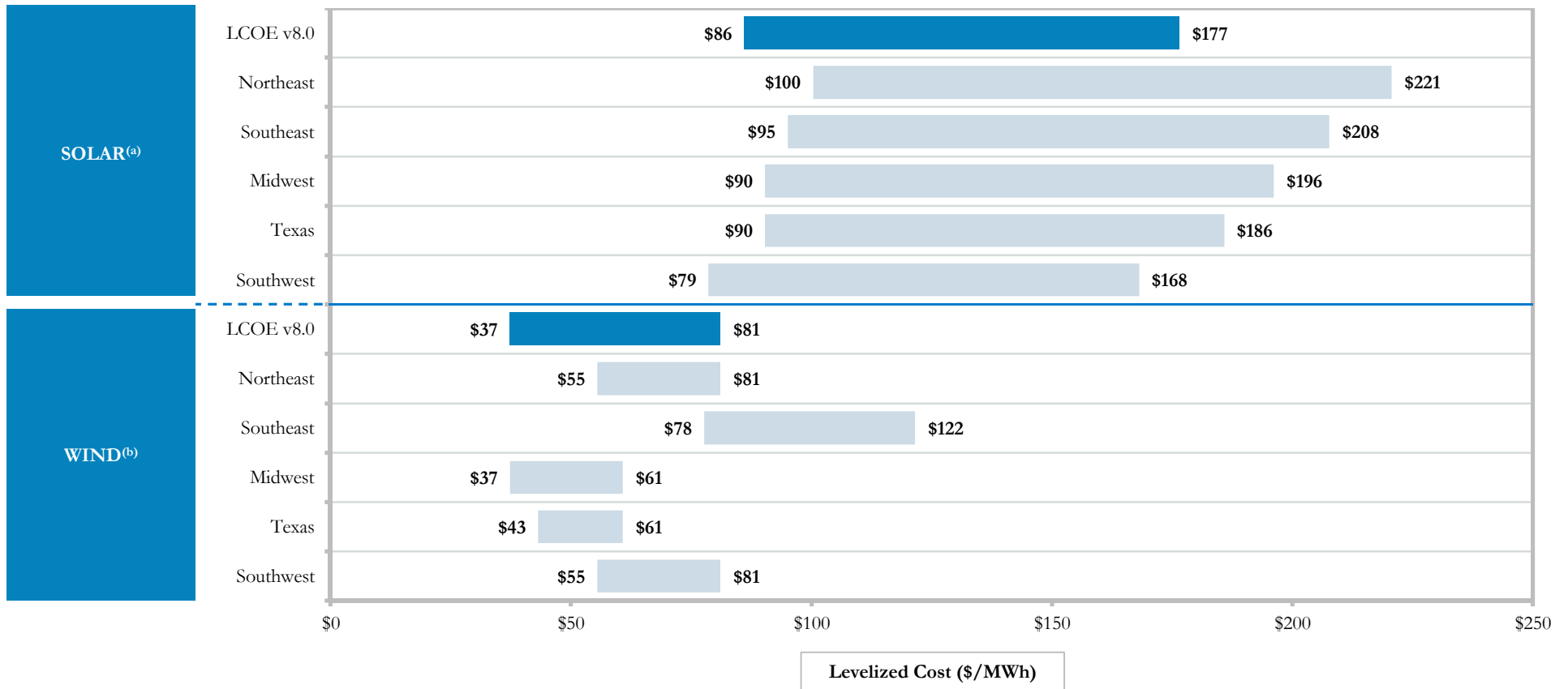
Source: World Bank, IHS Waterborne LNG, Department of Energy of South Africa, Sydney and Brisbane Hub Trading Prices and Lazard estimates.

- (a) Low end assumes a solar fixed-tilt utility-scale system with per watt capital costs of \$1.50. High end assumes a solar rooftop C&I system with per watt capital costs of \$3.00. Solar projects assume capacity factors of 26% – 28% for Australia, 25% – 27% for Brazil, 23% – 25% for India, 27% – 29% for South Africa, 15% – 17% for Japan and 13% – 15% for Northern Europe. Equity IRRs of 12% are assumed for Australia, Japan and Northern Europe and 18% for Brazil, India and South Africa; assumes cost of debt of 8% for Australia, Japan and Northern Europe, 14.5% for Brazil, 13% for India and 11.5% for South Africa.
- (b) Assumes natural gas prices of \$7 for Australia, \$16 for Brazil, \$15 for India, \$15 for South Africa, \$17 for Japan and \$10 for Northern Europe (all in U.S.\$ per MMBtu). Assumes a capacity factor of 10%.
- (c) Diesel assumes high end capacity factor of 30% representing intermittent utilization and low end capacity factor of 95% representing baseload utilization, O&M cost of \$15 per KW/year, heat rate of 10,000 Btu/KWh and total capital costs of \$500 to \$800 per KW of capacity. Assumes diesel prices of \$5.80 for Australia, \$4.30 for Brazil, \$4.00 for India, \$4.65 for South Africa, \$5.40 for Japan and \$7.40 for Northern Europe (all in U.S.\$ per gallon).



## Wind and Solar Resource—U.S. Regional Sensitivity (Unsubsidized)

The availability of wind and solar resource has a meaningful impact on the levelized cost of energy for various regions of the United States. This regional analysis varies capacity factors as a proxy for resource availability, while holding other variables constant. There are a variety of other factors (e.g., transmission, back-up generation/system reliability costs, labor rates, permitting and other costs) that would also impact regional costs



Source: Lazard estimates.

Note: Assumes solar capacity factors of 16% – 18% for the Northeast, 17% – 19% for the Southeast, 18% – 20% for the Midwest, 19% – 20% for Texas and 21% – 23% for the Southwest. Assumes wind capacity factors of 30% – 35% for the Northeast, 20% – 25% for the Southeast, 40% – 52% for the Midwest, 40% – 45% for Texas and 30% – 35% for the Southwest.

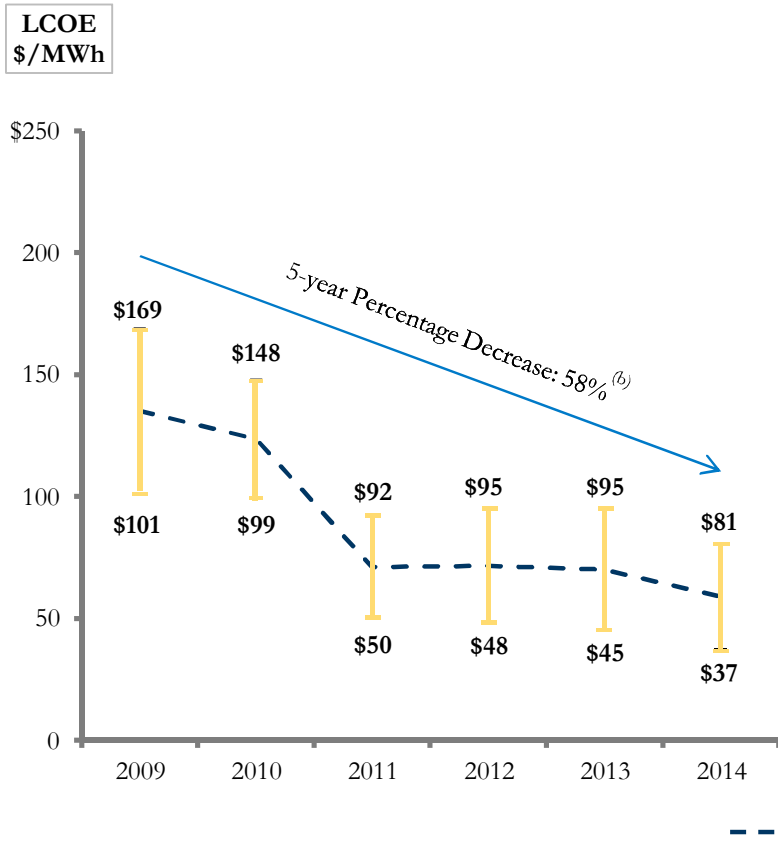
(a) Low end assumes a solar fixed-tilt utility-scale system with per watt capital costs of \$1.50. High end assumes a solar rooftop C&I system with per watt capital costs of \$3.00.

(b) Assumes an onshore wind generation plant with capital costs of \$1.40 – \$1.80 per watt.

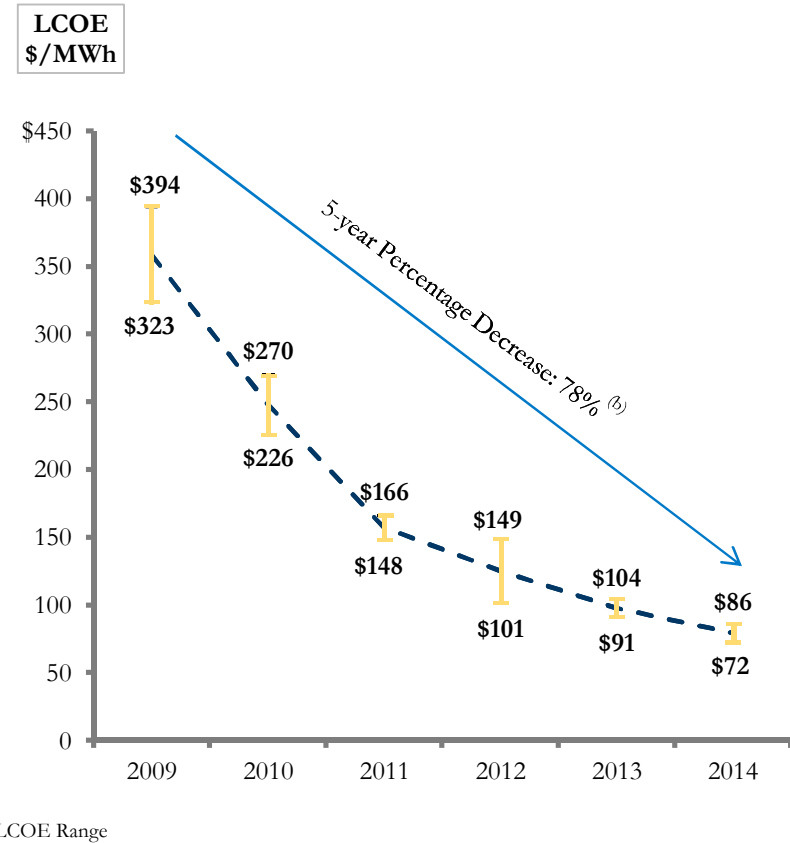
## Levelized Cost of Energy—Wind/Solar PV (Historical)

Over the last five years, wind and solar PV have become increasingly cost-competitive with conventional generation technologies, on an unsubsidized basis, in light of material declines in the pricing of system components (e.g., panels, inverters, racking, turbines, etc.), and dramatic improvements in efficiency, among other factors

WIND LCOE



SOLAR PV LCOE<sup>(a)</sup>



Source: Lazard estimates.

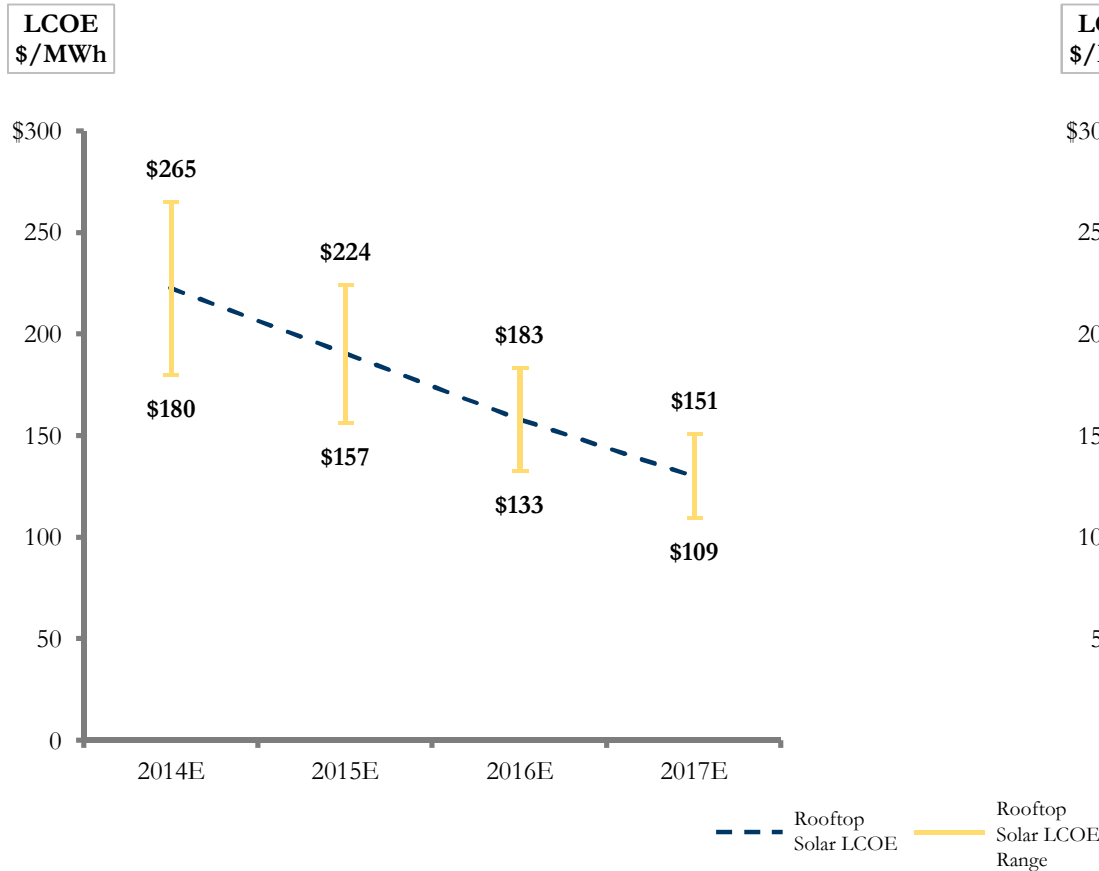
(a) Represents LCOE range of utility-scale crystalline solar PV. High end represents fixed installation, while low end represents single-axis tracking in high insolation jurisdictions (e.g., Southwest U.S.).

(b) Represents average percentage decrease of high and low of LCOE range.

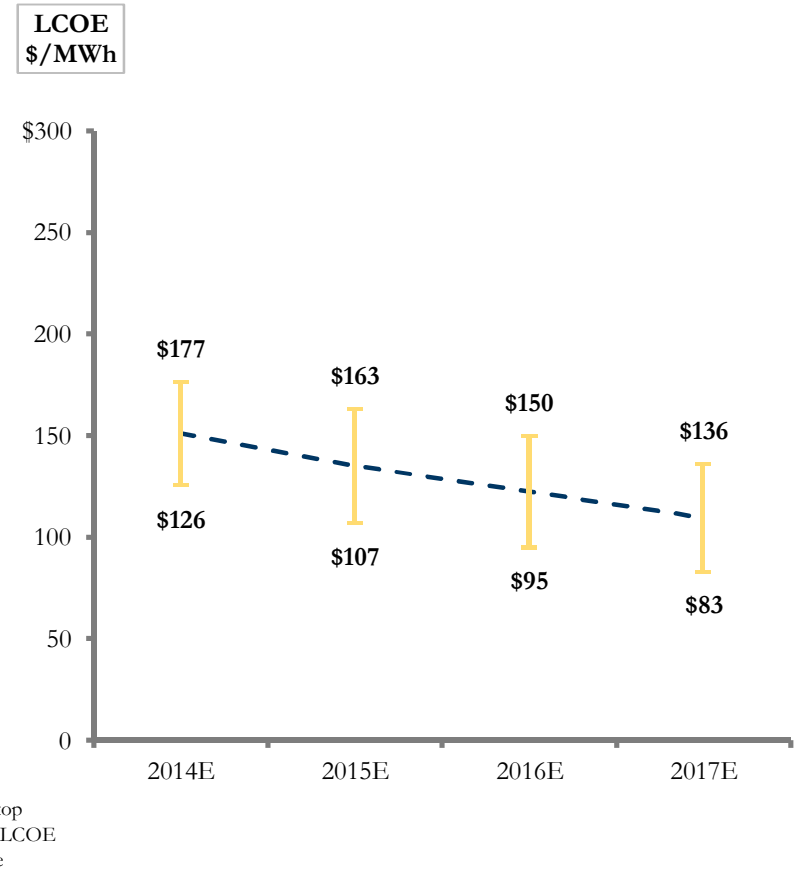
## Levelized Cost of Energy—Rooftop Solar (Forecasted)

Rooftop solar has benefited from the rapid decline in price of both panels and key balance-of-system components (e.g., inverters, racking, etc.); while the small-scale nature and added complexity of rooftop installation limit cost reduction levels (vs. levels observed in utility-scale applications), more efficient installation techniques, lower costs of capital and improved supply chains will contribute to a lower rooftop solar LCOE over time

ROOFTOP RESIDENTIAL LCOE<sup>(a)</sup>



ROOFTOP C&I LCOE<sup>(b)</sup>



Source: Lazard estimates, BNEF and Wall Street research.

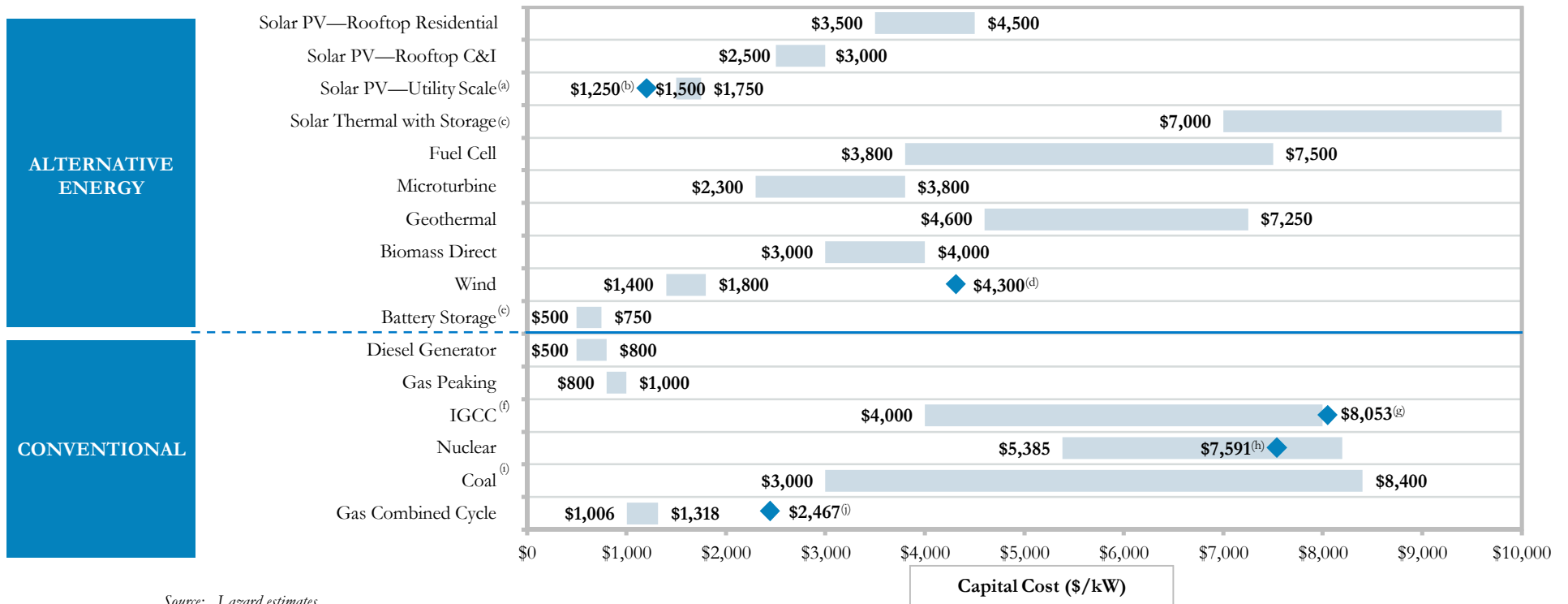
Note: Assumes capacity factors of 20% – 23%.

(a) Represents total high-end capital costs per watt of \$4.50, \$3.75, \$3.00 and \$2.40 and total low-end capital costs per watt of \$3.50, \$3.00, \$2.50 and \$2.00 over 2014 – 2017, respectively. Assumes fixed O&M of \$25 – \$30 per kW/year for 2014 – 2017.

(b) Represents total high-end capital costs per watt of \$3.00, \$2.75, \$2.50 and \$2.25 and total low-end capital costs per watt of \$2.50, \$2.10, \$1.85 and \$1.60 over 2014 – 2017, respectively. Assumes fixed O&M of \$13 – \$20 per kW/year for 2014 – 2017.

# Capital Cost Comparison

While capital costs for a number of Alternative Energy generation technologies (e.g., solar PV, solar thermal) are currently in excess of some conventional generation technologies (e.g., gas), declining costs for many Alternative Energy generation technologies, coupled with rising long-term construction and uncertain long-term fuel costs for conventional generation technologies, are working to close formerly wide gaps in electricity costs. This assessment, however, does not take into account issues such as dispatch characteristics, capacity factors, fuel and other costs needed to compare generation technologies

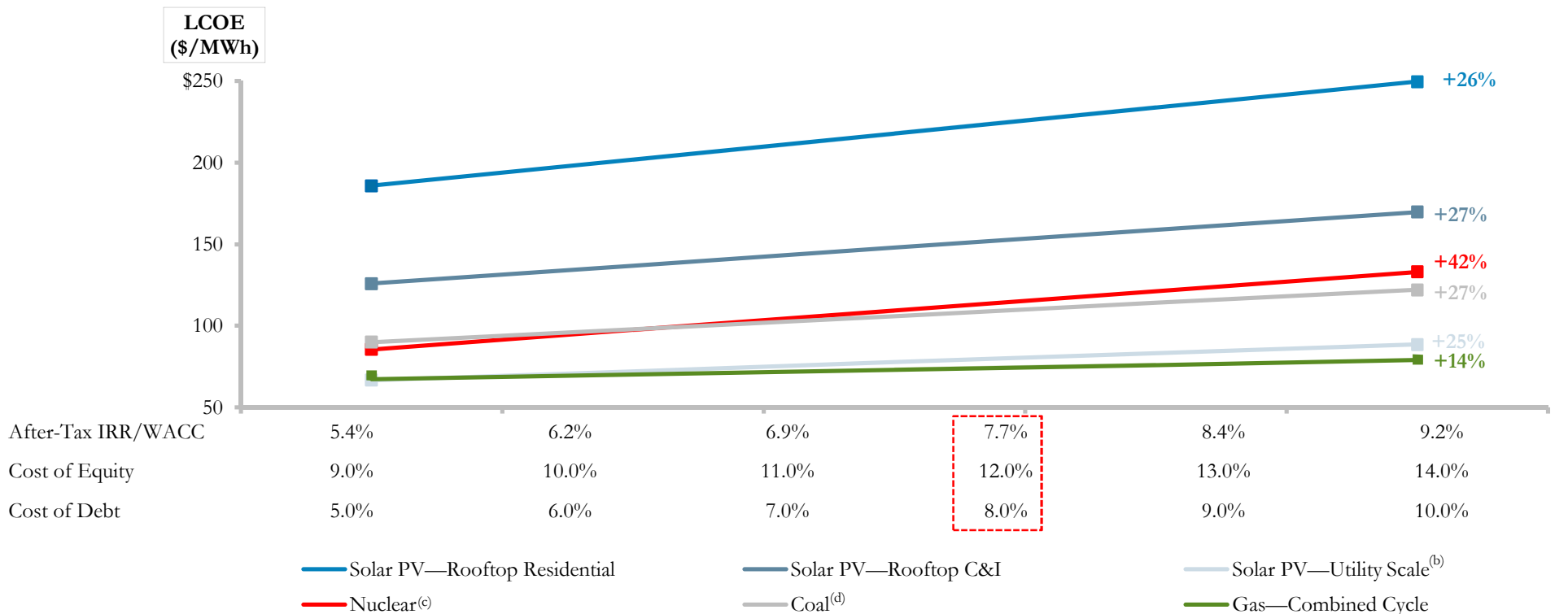


Source: Lazard estimates.

- (a) High end represents single-axis tracking. Low end represents fixed-tilt installation.
- (b) Diamond represents estimated capital costs in 2017, assuming \$1.25 per watt for a single-axis tracking system.
- (c) Low end represents concentrating solar tower with 10-hour storage capability. High end represents concentrating solar tower with 18-hour storage capability.
- (d) Represents estimated midpoint of capital costs for offshore wind, assuming a capital cost range of \$3.10 – \$5.50 per watt.
- (e) Indicative range based on current stationary storage technologies.
- (f) High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.
- (g) Represents estimate of current U.S. new IGCC construction with carbon capture and compression. Does not include cost of transportation and storage.
- (h) Represents estimate of current U.S. new nuclear construction.
- (i) Based on advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.
- (j) Incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

# Levelized Cost of Energy—Sensitivity to Cost of Capital

A key issue facing Alternative Energy generation technologies resulting from the potential for intermittently disrupted capital markets (and the relatively immature state of some aspects of financing Alternative Energy technologies) is the impact of the availability and cost of capital<sup>(a)</sup> on their LCOEs; availability and cost of capital have a particularly significant impact on Alternative Energy generation technologies, whose costs reflect essentially the return on, and of, the capital investment required to build them



Source: Lazard estimates.

(a) Cost of capital associated with the particular Alternative Energy generation technology (not the cost of capital of the investor/developer).

(b) Assumes a fixed-tilt Solar PV utility-scale system with capital costs of \$1.50 per watt.

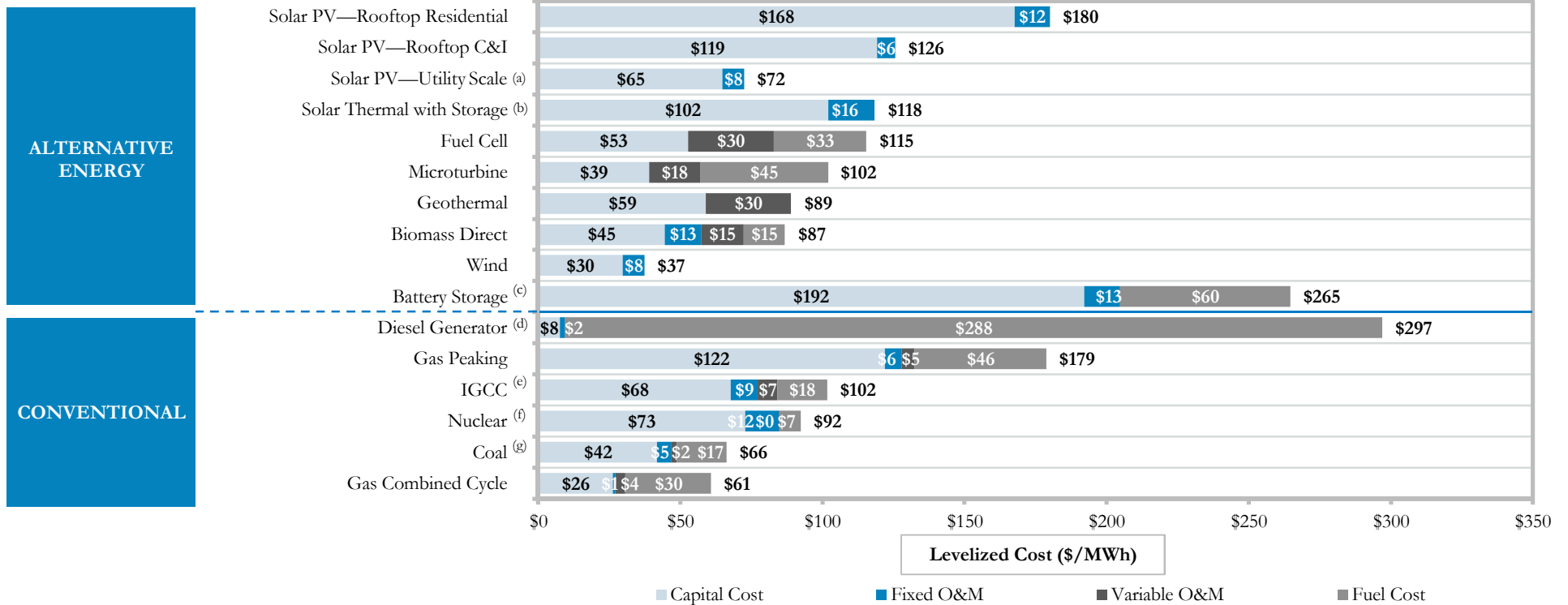
(c) Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies.

(d) Based on advanced supercritical pulverized coal.

Reflects cost of capital assumption utilized in Lazard's Levelized Cost of Energy Analysis

## Levelized Cost of Energy Components—Low End

Certain Alternative Energy generation technologies are already cost-competitive with conventional generation technologies; a key factor regarding the long-term competitiveness of currently more expensive Alternative Energy technologies is the ability of technological development and increased production volumes to materially lower the capital costs of certain Alternative Energy technologies, and their levelized cost of energy, over time (e.g., as has been the case with solar PV and wind technologies)

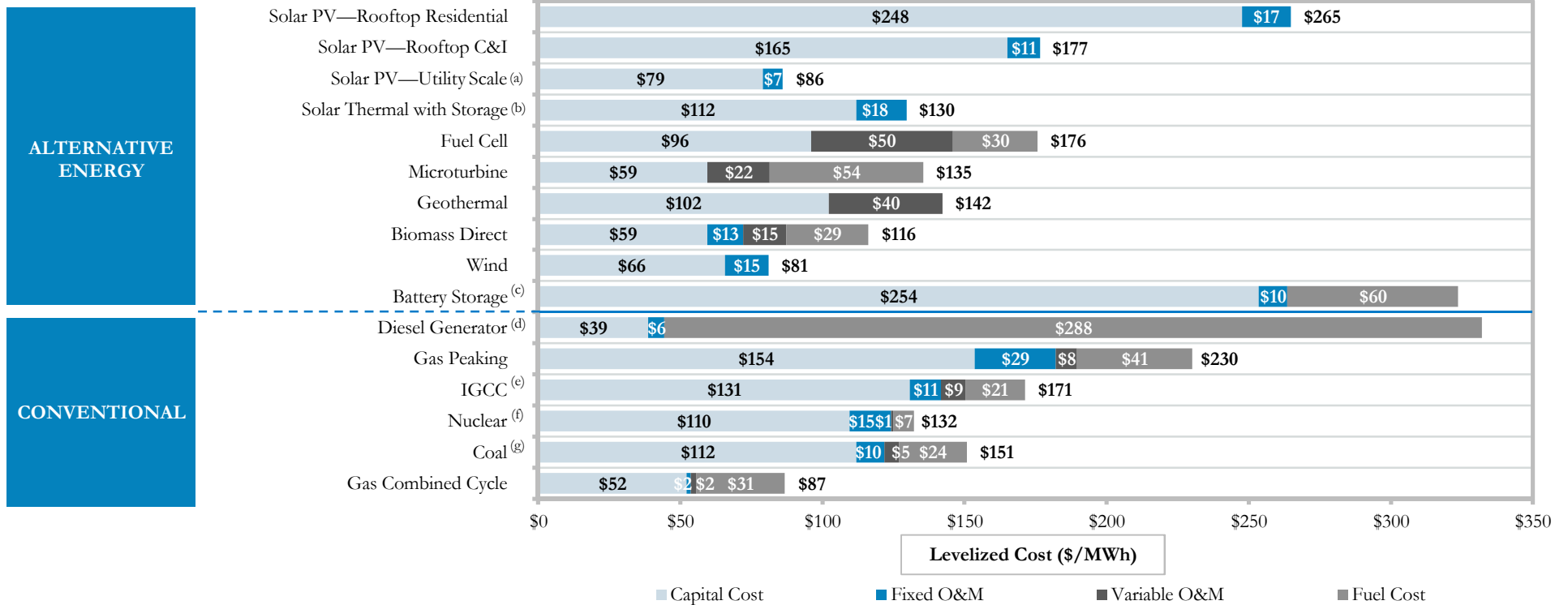


Source: Lazard estimates.

- (a) Low end represents single-axis tracking.
- (b) Low end represents concentrating solar tower with 18-hour storage capability.
- (c) Low end represents lead acid battery.
- (d) Low end represents continuous operation.
- (e) Does not incorporate carbon capture and compression.
- (f) Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies.
- (g) Based on advanced supercritical pulverized coal. Does not incorporate carbon capture and compression.

# Levelized Cost of Energy Components—High End

Certain Alternative Energy generation technologies are already cost-competitive with conventional generation technologies; a key factor regarding the long-term competitiveness of currently more expensive Alternative Energy technologies is the ability of technological development and increased production volumes to materially lower the capital costs of certain Alternative Energy technologies, and their levelized cost of energy, over time (e.g., as has been the case with solar PV and wind technologies)



Source: Lazard estimates.

- (a) High end represents fixed-tilt installation.
- (b) High end represents concentrating solar tower with 10-hour storage capability.
- (c) High end represents NaS technology.
- (d) High end represents intermittent operation.
- (e) High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.
- (f) Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies.
- (g) Based on advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

## Energy Resources: Matrix of Applications

While the levelized cost of energy for Alternative Energy generation technologies is becoming increasingly competitive with conventional generation technologies, direct comparisons must take into account issues such as location (e.g., central station vs. customer-located) and dispatch characteristics (e.g., baseload and/or dispatchable intermediate load vs. peaking or intermittent technologies)

- This analysis does not take into account potential social and environmental externalities or reliability-related considerations

		LEVELIZED COST OF ENERGY	CARBON NEUTRAL/ REC POTENTIAL	STATE OF TECHNOLOGY	LOCATION			DISPATCH			
					CUSTOMER LOCATED	CENTRAL STATION	GEOGRAPHY	INTERMITTENT	PEAKING	LOAD- FOLLOWING	BASE- LOAD
ALTERNATIVE ENERGY	SOLAR PV	\$72 – 265 <sup>(a)</sup>	✓	Commercial	✓	✓	Universal <sup>(b)</sup>	✓	✓		
	SOLAR THERMAL	\$118 – 130 <sup>(a)</sup>	✓	Commercial		✓	Southwest	✓	✓	✓	
	FUEL CELL	\$115 – 176	?	Emerging/ Commercial	✓		Universal				✓
	MICROTURBINE	\$102 – 135	?	Emerging/ Commercial	✓		Universal				✓
	GEOTHERMAL	\$89 – 142	✓	Mature		✓	Varies				✓
	BIOMASS DIRECT	\$87 – 116	✓	Mature		✓	Universal			✓	✓
	ONSHORE WIND	\$37 – 81	✓	Mature		✓	Varies	✓			
BATTERY STORAGE	\$265 – 324	✓	Emerging	✓	✓	Varies		✓	✓		
CONVENTIONAL	DIESEL GENERATOR	\$297 – 332	✗	Mature	✓		Universal	✓	✓	✓	✓
	GAS PEAKING	\$179 – 230	✗	Mature	✓	✓	Universal		✓	✓	
	IGCC	\$102 – 171	✗ <sup>(c)</sup>	Emerging <sup>(d)</sup>		✓	Co-located or rural				✓
	NUCLEAR	\$92 – 132	✓	Mature/ Emerging		✓	Co-located or rural				✓
	COAL	\$66 – 151	✗ <sup>(c)</sup>	Mature <sup>(d)</sup>		✓	Co-located or rural				✓
	GAS COMBINED CYCLE	\$61 – 87	✗	Mature	✓	✓	Universal			✓	✓

Source: Lazard estimates.

(a) LCOE study capacity factor assumes Southwest location.

(b) Qualification for RPS requirements varies by location.

(c) Could be considered carbon neutral technology, assuming carbon capture and compression.

(d) Carbon capture and compression technologies are in emerging stage.



## Levelized Cost of Energy—Key Assumptions

	Units	Solar PV				Solar Thermal Tower with Storage <sup>(d)</sup>	Fuel Cell
		Rooftop—Residential	Rooftop—C&I	Utility Scale— Crystalline <sup>(c)</sup>	Utility Scale— Thin Film <sup>(c)</sup>		
Net Facility Output	MW	0.005	1	10	10	75 – 110	2.4
EPC Cost	\$/kW	\$3,500 – \$4,500	\$2,500 – \$3,000	\$1,750 – \$1,500	\$1,750 – \$1,500	\$8,750 – \$6,250	\$3,000 – \$7,500
Capital Cost During Construction	\$/kW	included	included	included	included	\$1,050 – \$750	included
Other Owner's Costs	\$/kW	included	included	included	included	included	\$800 – included
Total Capital Cost <sup>(a)</sup>	\$/kW	\$3,500 – \$4,500	\$2,500 – \$3,000	\$1,750 – \$1,500	\$1,750 – \$1,500	\$9,800 – \$7,000	\$3,800 – \$7,500
Fixed O&M	\$/kW-yr	\$25.00 – \$30.00	\$13.00 – \$20.00	\$20.00 – \$13.00	\$20.00 – \$13.00	\$115.00 – \$80.00	—
Variable O&M	\$/MWh	—	—	—	—	—	\$30 – \$50
Heat Rate	Btu/kWh	—	—	—	—	—	7,260 – 6,600
Capacity Factor	%	23% – 20%	23% – 20%	30% – 21%	30% – 21%	80% – 52%	95%
Fuel Price	\$/MMBtu	—	—	—	—	—	\$4.50
Construction Time	Months	3	3	12	12	30	3
Facility Life	Years	20	20	20	20	40	20
CO <sub>2</sub> Emissions	lb/MMBtu	—	—	—	—	—	0 – 117
Investment Tax Credit <sup>(b)</sup>	%	—	—	—	—	—	—
Production Tax Credit <sup>(b)</sup>	\$/MWh	—	—	—	—	—	—
Levelized Cost of Energy <sup>(b)</sup>	\$/MWh	\$180 – \$265	\$126 – \$177	\$72 – \$86	\$72 – \$86	\$118 – \$130	\$115 – \$176

Source: Lazard estimates.

(a) Includes capitalized financing costs during construction for generation types with over 24 months construction time.

(b) While prior versions of this study have presented LCOE inclusive of the U.S. Federal Investment Tax Credit and Production Tax Credit, Versions 6.0 – 8.0 present LCOE on an unsubsidized basis, except as noted on the page titled “Levelized Cost of Energy—Sensitivity to U.S. Federal Tax Subsidies.”

(c) Low end represents single-axis tracking. High end represents fixed-tilt installation. Assumes 10 MW system in high insolation jurisdiction (e.g., Southwest U.S.). Not directly comparable for baseload. Does not account for differences in heat coefficients, balance-of-system costs or other potential factors which may differ across solar technologies.

(d) Low end represents concentrating solar tower with 18-hour storage capability. High end represents concentrating solar tower with 10-hour storage capability.

## Levelized Cost of Energy—Key Assumptions (cont'd)

	Units	Microturbine	Geothermal	Biomass Direct	Wind	Off-Shore Wind	Battery Storage <sup>(c)</sup>
Net Facility Output	MW	1	30	35	100	210	6
EPC Cost	\$/kW	\$2,300 – \$3,800	\$4,021 – \$6,337	\$2,622 – \$3,497	\$1,100 – \$1,400	\$2,500 – \$4,620	\$500 – \$750
Capital Cost During Construction	\$/kW	included	\$579 – \$913	\$378 – \$503	included	included	included
Other Owner's Costs	\$/kW	included	included	included	\$300 – \$400	\$600 – \$880	included
Total Capital Cost <sup>(a)</sup>	\$/kW	\$2,300 – \$3,800	\$4,600 – \$7,250	\$3,000 – \$4,000	\$1,400 – \$1,800	\$3,100 – \$5,500	\$500 – \$750
Fixed O&M	\$/kW-yr	—	—	\$95.00	\$35.00 – \$40.00	\$60.00 – \$100.00	\$27.50 – \$22.00
Variable O&M	\$/MWh	\$18.00 – \$22.00	\$30.00 – \$40.00	\$15.00	—	\$13.00 – \$18.00	—
Heat Rate	Btu/kWh	10,000 – 12,000	—	14,500	—	—	—
Capacity Factor	%	95%	90% – 80%	85%	52% – 30%	43% – 37%	25% – 25%
Fuel Price	\$/MMBtu	\$4.50	—	\$1.00 – \$2.00	—	—	\$60 <sup>(c)</sup>
Construction Time	Months	3	36	36	12	12	3
Facility Life	Years	20	20	20	20	20	20
CO <sub>2</sub> Emissions	lb/MMBtu	—	—	—	—	—	—
Investment Tax Credit <sup>(b)</sup>	%	—	—	—	—	—	—
Production Tax Credit <sup>(b)</sup>	\$/MWh	—	—	—	—	—	—
Levelized Cost of Energy <sup>(b)</sup>	\$/MWh	\$102 – \$135	\$89 – \$142	\$87 – \$116	\$37 – \$81	\$110 – \$214	\$265 – \$324

Source: Lazard estimates.

(a) Includes capitalized financing costs during construction for generation types with over 24 months construction time.

(b) While prior versions of this study have presented LCOE inclusive of the U.S. Federal Investment Tax Credit and Production Tax Credit, Versions 6.0 – 8.0 present LCOE on an unsubsidized basis, except as noted on the page titled “Levelized Cost of Energy—Sensitivity to U.S. Federal Tax Subsidies.”

(c) Assumes capital costs of \$500 – \$750/KWh for 6 hours of storage capacity, \$60/MWh cost to charge, one full cycle per day (full charge and discharge), efficiency of 75% – 85% and fixed O&M costs of \$22.00 to \$27.50 per KWh installed per year.

## Levelized Cost of Energy—Key Assumptions (cont'd)

	Units	Diesel Generator <sup>(e)</sup>	Gas Peaking	IGCC <sup>(d)</sup>	Nuclear <sup>(e)</sup>	Coal <sup>(f)</sup>	Gas Combined Cycle
Net Facility Output	MW	2	216 – 103	580	1,100	600	550
EPC Cost	\$/kW	\$500 – \$800	\$580 – \$700	\$3,257 – \$6,390	\$3,750 – \$5,250	\$2,027 – \$6,067	\$743 – \$1,004
Capital Cost During Construction	\$/kW	included	included	\$743 – \$1,610	\$1,035 – \$1,449	\$487 – \$1,602	\$107 – \$145
Other Owner's Costs	\$/kW	included	\$220 – \$300	included	\$600 – \$1,500	\$486 – \$731	\$156 – \$170
Total Capital Cost <sup>(a)</sup>	\$/kW	\$500 – \$800	\$800 – \$1,000	\$4,000 – \$8,000	\$5,385 – \$8,199	\$3,000 – \$8,400	\$1,006 – \$1,318
Fixed O&M	\$/kW-yr	\$15.00	\$5.00 – \$25.00	\$62.25 – \$73.00	\$95.00 – \$115.00	\$40.00 – \$80.00	\$6.20 – \$5.50
Variable O&M	\$/MWh	—	\$4.70 – \$7.50	\$7.00 – \$8.50	\$0.25 – \$0.75	\$2.00 – \$5.00	\$3.50 – \$2.00
Heat Rate	Btu/kWh	10,000	10,300 – 9,000	8,800 – 10,520	10,450	8,750 – 12,000	6,700 – 6,900
Capacity Factor	%	95% – 30%	10%	75%	90%	93%	70% – 40%
Fuel Price	\$/MMBtu	\$28.76	\$4.50	\$1.99	\$0.70	\$1.99	\$4.50
Construction Time	Months	3	25	57 – 63	69	60 – 66	36
Facility Life	Years	20	20	40	40	40	20
CO <sub>2</sub> Emissions	lb/MMBtu	0 – 117	117	169	—	211	117
Investment Tax Credit <sup>(b)</sup>	%	—	—	—	—	—	—
Production Tax Credit <sup>(b)</sup>	\$/MWh	—	—	—	—	—	—
Levelized Cost of Energy <sup>(b)</sup>	\$/MWh	\$297 – \$332	\$179 – \$230	\$102 – \$171	\$92 – \$132	\$66 – \$151	\$61 – \$87

Source: Lazard estimates.

(a) Includes capitalized financing costs during construction for generation types with over 24 months construction time.

(b) While prior versions of this study have presented LCOE inclusive of the U.S. Federal Investment Tax Credit and Production Tax Credit, Versions 6.0 – 8.0 present LCOE on an unsubsidized basis, except as noted on the page titled “Levelized Cost of Energy—Sensitivity to U.S. Federal Tax Subsidies.”

(c) Low end represents continuous operation. High end represents intermittent operation. Assumes diesel price of \$4.00 per gallon.

(d) High end incorporates 90% carbon capture and compression. Does not include cost of storage and transportation.

(e) Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies.

(f) Based on advanced supercritical pulverized coal. High end incorporates 90% carbon capture and compression. Does not include cost of storage and transportation.

## Summary Considerations

*Lazard has conducted this study comparing the levelized cost of energy for various conventional and Alternative Energy generation technologies in order to understand which Alternative Energy generation technologies may be cost-competitive with conventional generation technologies, either now or in the future, and under various operating assumptions, as well as to understand which technologies are best suited for various applications based on locational requirements, dispatch characteristics and other factors. We find that Alternative Energy technologies are complementary to conventional generation technologies, and believe that their use will be increasingly prevalent for a variety of reasons, including RPS requirements, carbon regulations, continually improving economics as underlying technologies improve and production volumes increase, and government subsidies in certain regions.*

*In this study, Lazard's approach was to determine the levelized cost of energy, on a \$/MWh basis, that would provide an after-tax IRR to equity holders equal to an assumed cost of equity capital. Certain assumptions (e.g., required debt and equity returns, capital structure, and economic life) were identical for all technologies, in order to isolate the effects of key differentiated inputs such as investment costs, capacity factors, operating costs, fuel costs (where relevant) and U.S. federal tax incentives on the levelized cost of energy. These inputs were developed with a leading consulting and engineering firm to the Power & Energy Industry, augmented with Lazard's commercial knowledge where relevant. This study (as well as previous versions) has benefitted from additional input from a wide variety of industry participants.*

*Lazard has not manipulated capital costs or capital structure for various technologies, as the goal of the study was to compare the current state of various generation technologies, rather than the benefits of financial engineering. The results contained in this study would be altered by different assumptions regarding capital structure (e.g., increased use of leverage) or capital costs (e.g., a willingness to accept lower returns than those assumed herein).*

*Key sensitivities examined included fuel costs and tax subsidies. Other factors would also have a potentially significant effect on the results contained herein, but have not been examined in the scope of this current analysis. These additional factors, among others, could include: capacity value vs. energy value; stranded costs related to distributed generation or otherwise; network upgrade, transmission or congestion costs; integration costs; and costs of complying with various environmental regulations (e.g., carbon emissions offsets, emissions control systems). The analysis also does not address potential social and environmental externalities, including, for example, the social costs and rate consequences for those who cannot afford distribution generation solutions, as well as the long-term residual and societal consequences of various conventional generation technologies that are difficult to measure (e.g., nuclear waste disposal, environmental impacts, etc.).*