DECEMBER 2016

# LAZARD'S LEVELIZED COST OF ENERGY ANALYSIS—VERSION 10.0

LAZARD

# Introduction

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

- Comparative "levelized cost of energy" analysis 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 for various generation technologies
- Illustration of how the cost of various generation technologies compares against illustrative generation rates in a subset of the largest metropolitan areas of the U.S.
- 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 U.S., based on illustrative regional resources
- Illustration of the declines in the levelized cost of energy for various generation technologies over the past several years
- Comparison of assumed capital costs on a $/kW basis for various generation technologies
- Illustration of the impact of cost of capital on the levelized cost of energy for selected 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

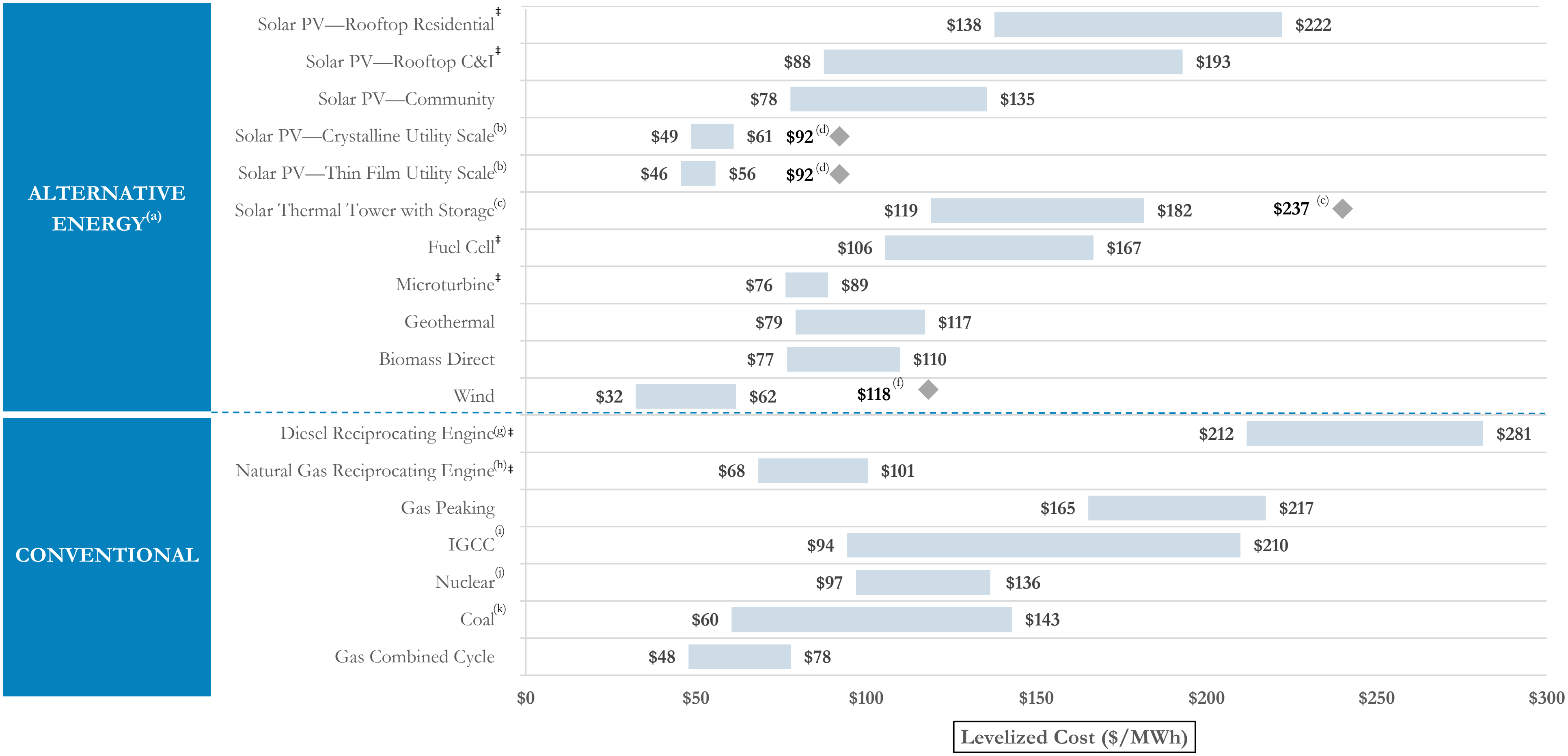
Other factors would also have a potentially significant effect on the results contained herein, but have not been examined in the scope of this current analysis. These additional factors, among others, could include: capacity value vs. energy value; stranded costs related to distributed generation or otherwise; network upgrade, transmission or congestion costs or other integration-related costs; significant permitting or other development costs, unless otherwise noted; 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 – 10.0 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"

Note: This study has been prepared by Lazard for general informational purposes only, and it is not intended to be, and should not be construed as, financial or other advice.

# 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.), reliability or intermittency-related considerations (e.g., transmission and back-up generation costs associated with certain Alternative Energy 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. Reflects global, illustrative costs of capital, which may be significantly higher than OECD country costs of capital. See page 15 for additional details on cost of capital. Analysis does not reflect potential impact of recent draft rule to regulate carbon emissions under Section 111(d). See pages 18–20 for fuel costs for each technology. See following page for footnotes.

‡ Denotes distributed generation technology.

# Unsubsidized Levelized Cost of Energy Comparison (cont'd)

(a) Analysis excludes integration (e.g., grid and conventional generation investment to overcome system intermittency) costs for intermittent technologies.

(b) Low end represents single-axis tracking system. High end represents fixed-tilt design. Assumes 30 MW system in a high insolation jurisdiction (e.g., Southwest U.S.). Does not account for differences in heat coefficients within technologies, balance-of-system costs or other potential factors which may differ across select solar technologies or more specific geographies.

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

(d) Illustrative "PV Plus Storage" unit. PV and battery system (and related mono-directional inverter, power control electronics, etc.) sized to compare with solar thermal with 10 hour storage on capacity factor basis (52%). Assumes storage nameplate "usable energy" capacity of ~400 $MWh_{dc}$, storage power rating of 110 $MW_{ac}$ and ~200 $MW_{ac}$ PV system. Implied output degradation of ~0.40%/year (assumes PV degradation of 0.5%/year and battery energy degradation of 1.5%/year, which includes calendar and cycling degradation). Battery round trip DC efficiency of 90% (including auxiliary losses). Storage opex of ~$10/kWh-year and PV O&M expense of ~$9.2/kW DC-year, with 20% discount applied to total opex as a result of synergies (e.g., fewer truck rolls, single team, etc.). Total capital costs of ~$3,900/kW include PV plus battery energy storage system and selected other development costs. Assumes 20 year useful life, although in practice the unit may perform longer. Illustrative system located in U.S. Southwest.

(e) Diamond represents an illustrative solar thermal facility without storage capability.

(f) Represents estimated implied midpoint of levelized cost of energy for offshore wind, assuming a capital cost range of $2.75 – $4.50 per watt.

(g) Represents distributed diesel generator with reciprocating engine. Low end represents 95% capacity factor (i.e., baseload generation in poor grid quality geographies or remote locations). High end represents 10% capacity factor (i.e., to overcome periodic blackouts). Assumes replacement capital cost of 65% of initial total capital cost every 25,000 operating hours.

(h) Represents distributed natural gas generator with reciprocating engine. Low end represents 95% capacity factor (i.e., baseload generation in poor grid quality geographies or remote locations). High end represents 30% capacity factor (i.e., to overcome periodic blackouts). Assumes replacement capital cost of 65% of initial total capital cost every 60,000 operating hours.

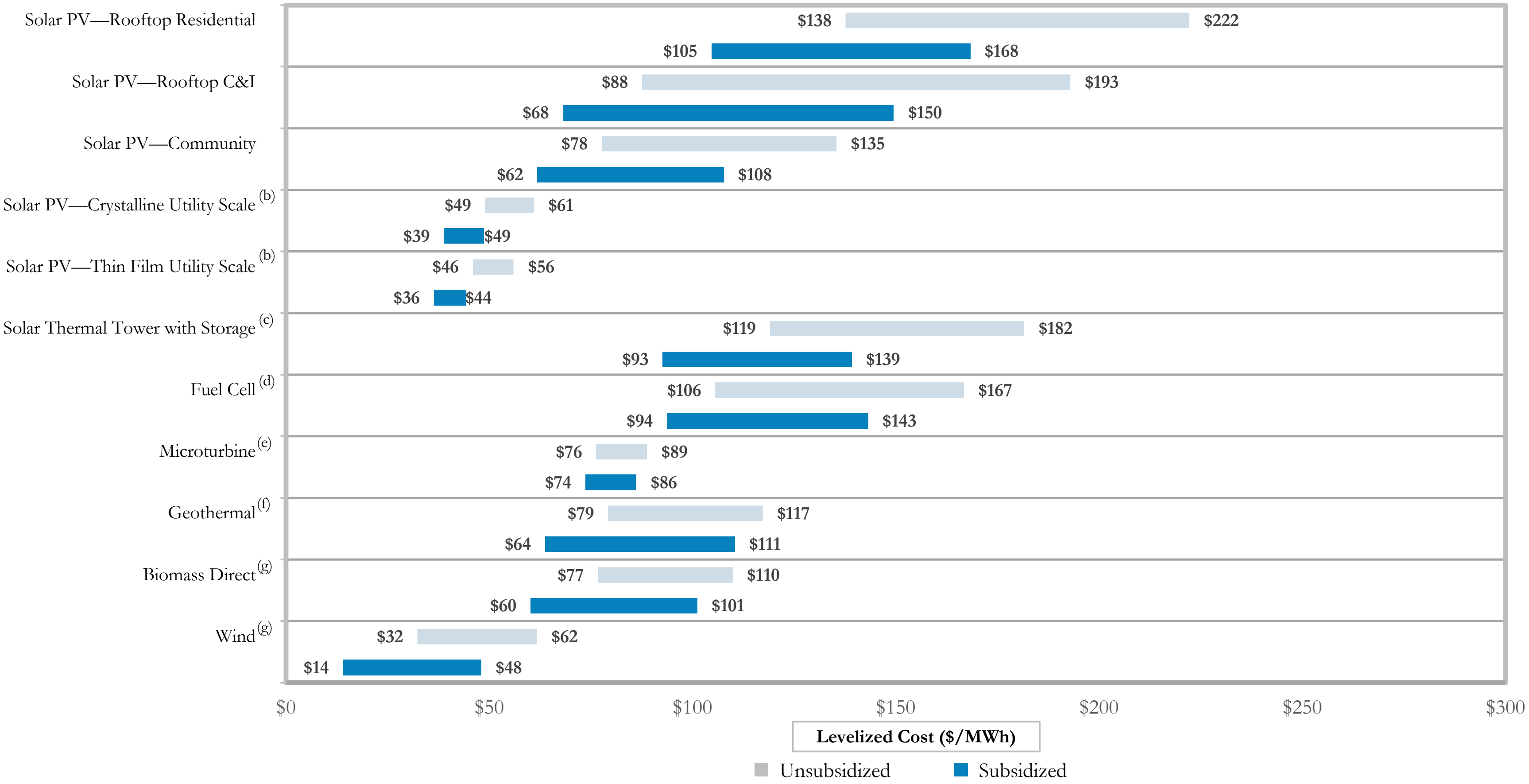
(i) Does not include cost of transportation and storage.

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

(k) Reflects average of Northern Appalachian Upper Ohio River Barge and Pittsburgh Seam Rail coal. High end 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(a)

**Given the extension of the Investment Tax Credit ("ITC") and Production Tax Credit ("PTC") in December 2015 and resulting subsidy visibility, 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)**



*Source: Lazard estimates.*

(a) Unless otherwise noted, the subsidized analysis assumes projects placed into service in time to qualify for full PTC/ITC. Assumes 30% debt at 8.0% interest rate, 50% tax equity at 10.0% cost and 20% common equity at 12.0% cost, unless otherwise noted.

(b) Low end represents a single-axis tracking system. High end represents a fixed-tilt design. Assumes 30 MW installation in high insolation jurisdiction (e.g., Southwest U.S.).

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

(d) The ITC for fuel cell technologies is capped at $1,500/0.5 kW of capacity.

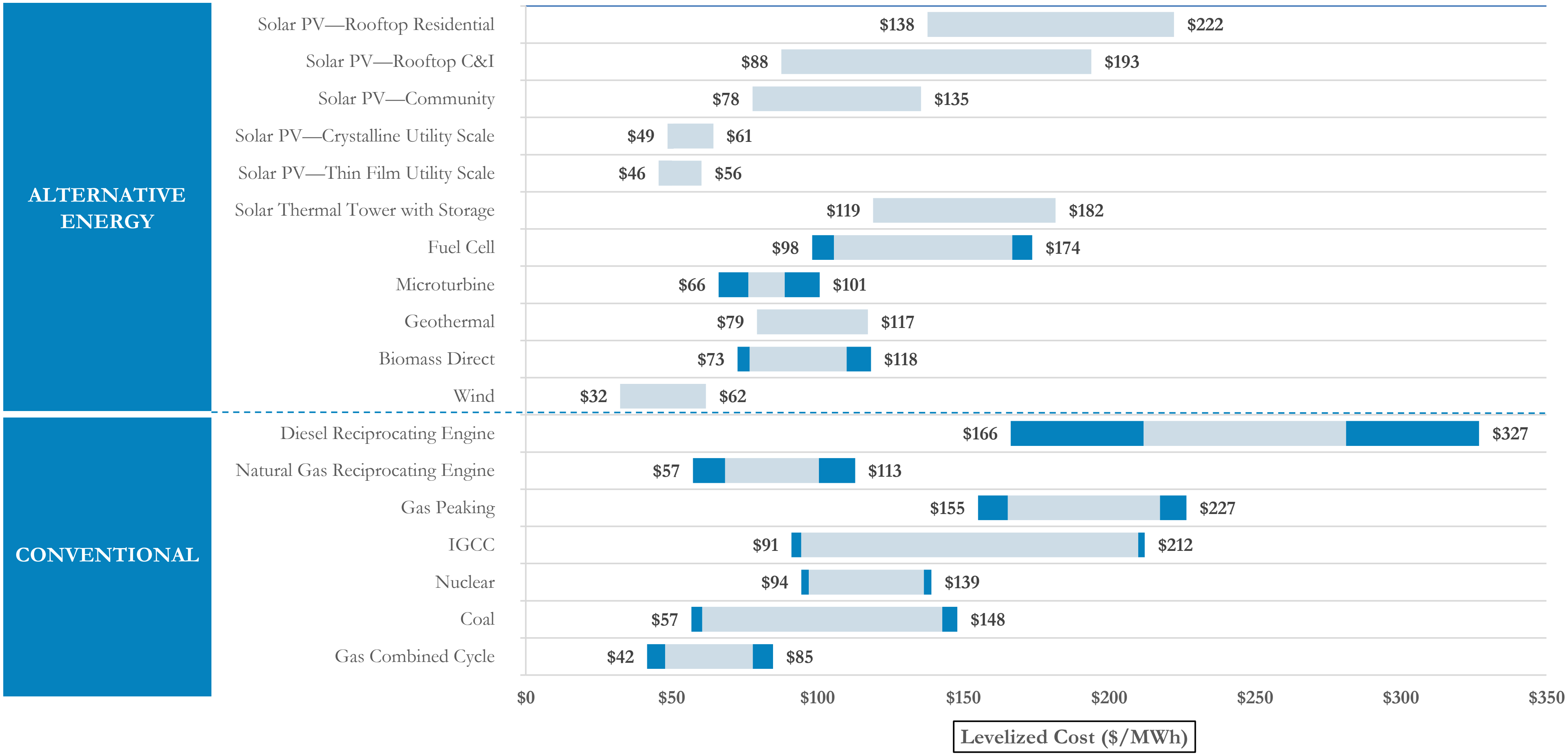
(e) Reflects 10% ITC only. Reflects no PTC. Capital structure adjusted for lower ITC; assumes 50% debt at 8.0% interest rate, 30% tax equity at 10.0% cost and 20% common equity at 12.0% cost.

(f) Reflects no ITC. Reflects $23/MWh PTC, escalated at ~1.5% annually for a term of 10 years.

(g) Reflects no ITC. Reflects $23/MWh PTC, escalated at ~1.5% annually for a term of 10 years. Due to high capacity factor and, relatedly, high PTC investor appetite, assumes 15% debt at 8.0% interest rate, 70% tax equity at 10.0% cost and 15% 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 the Clean Power Plan and related 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 or grid-related considerations**

| | | CONVENTIONAL GENERATION | | | ALTERNATIVE ENERGY RESOURCES | | | |
|---|---|---|---|---|---|---|---|---|
| | **Units** | **Coal**[b] | **Gas Combined Cycle** | **Nuclear** | **Wind** | **Solar PV Rooftop Residential** | **Solar PV Utility Scale**[c] | **Solar Thermal with Storage**[d] |
| Capital Investment/KW of Capacity[a] | $/kW | $3,000 | $1,006 | $5,385 | $1,250 | $2,000 | $1,450 | $10,296 |
| **Total Capital Investment** | **$mm** | **$1,800** | **$704** | **$3,339** | **$1,263** | **$6,380** | **$2,697** | **$6,795** |
| Facility Output | MW | 600 | 700 | 620 | 1010 | 3190 | 1860 | 660 |
| Capacity Factor | % | 93% | 80% | 90% | 55% | 18% | 30% | 85% |
| **Effective Facility Output** | **MW** | **558** | **558** | **558** | **558** | **558** | **558** | **558** |
| MWh/Year Produced[e] | GWh/yr | 4,888 | 4,888 | 4,888 | 4,888 | 4,888 | 4,888 | 4,888 |
| Levelized Cost of Energy | $/MWh | $60 | $48 | $97 | $32 | $138 | $49 | $119 |
| **Total Cost of Energy Produced** | **$mm/yr** | **$296** ② | **$234** | **$474** | **$158** | **$673** | **$237** ① | **$582** |
| **CO$_2$ Equivalent Emissions** | Tons/MWh | 0.92 | 0.51 | — | — | — | — | — |
| Carbon Emitted | mm Tons/yr | 4.51 | 2.50 | — | — | — | — | — |
| **Difference in Carbon Emissions** | mm Tons/yr | | | | | | | |
| vs. Coal | | — | 2.01 | 4.51 | 4.51 | 4.51 | 4.51 ③ | 4.51 |
| vs. Gas | | — | — | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| **Difference in Total Energy Cost** | $mm/yr | | | | | | | |
| vs. Coal | | — | ($62) | $179 | ($138) | $377 | ($58) ④ | $286 |
| vs. Gas | | — | — | $241 | ($76) | $439 | $4 | $348 |
| **Implied Abatement Cost/(Saving)** | $/Ton | | | | | | | |
| vs. Coal | | — | ($31) | $40 | ($31) | $84 | ($13) ⑤ | $63 |
| vs. Gas | | — | — | $96 | ($30) | $176 | $1 | $139 |

*Source: Lazard estimates.*

Note: Unsubsidized figures. Assumes 2016 dollars, 20 – 40 year economic life, 40% tax rate and five – 40 year tax life. Assumes 2.25% 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. LCOE figures calculated on a 20-year basis.

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

(b) Reflects average of Northern Appalachian Upper Ohio River Barge and Pittsburgh Seam Rail coal. Does not incorporate carbon capture and compression.

(c) Represents crystalline utility-scale solar with single-axis tracking.

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

(e) All facilities illustratively sized to produce 4,888 GWh/yr.

**Illustrative Implied Carbon Abatement Cost Calculation:**

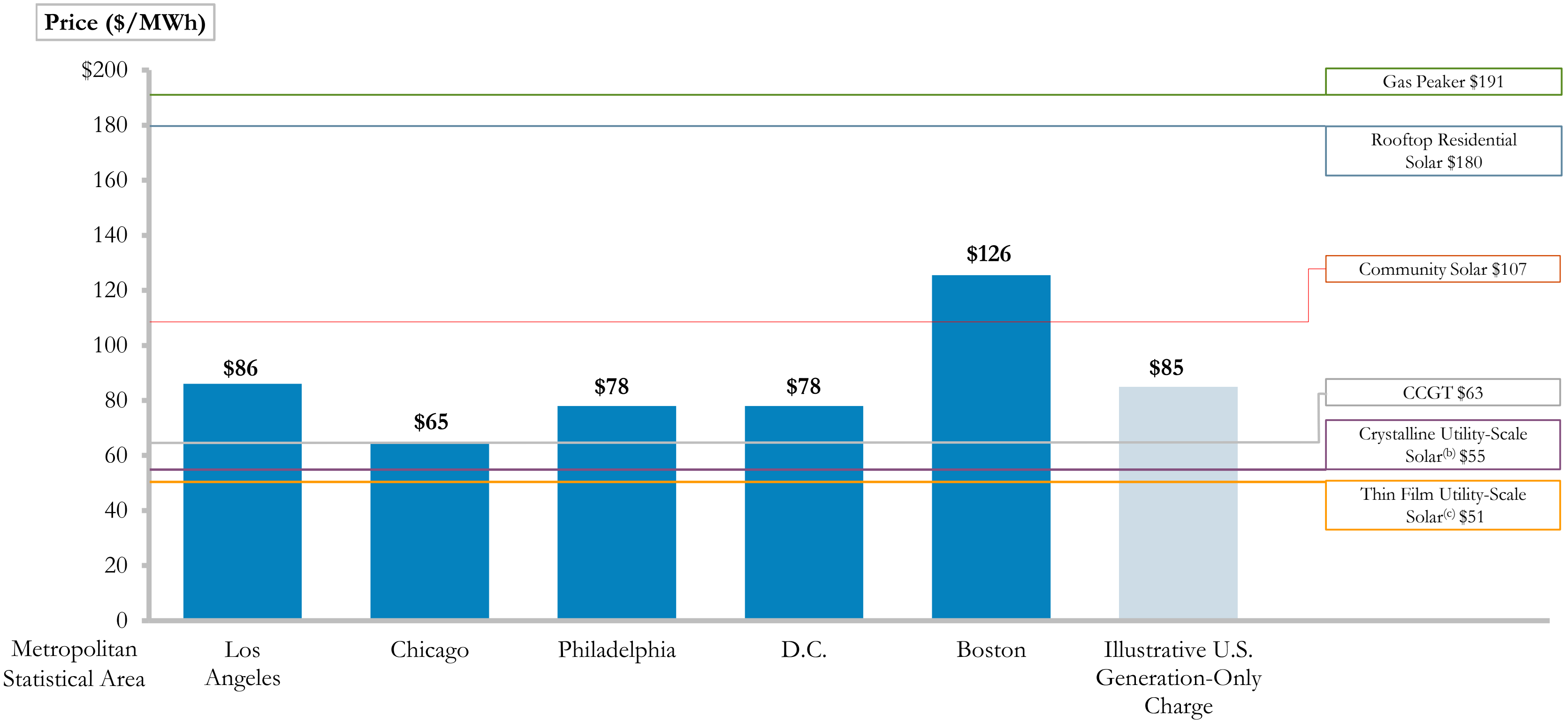
④ Difference in Total Energy Cost vs. Coal = ① – ②
= $237 mm/yr (solar) – $296 mm/yr (coal) = ($58) mm/yr

⑤ Implied Abatement Cost vs. Coal = ④ ÷ ③
= ($58) mm/yr ÷ 4.51 mm Tons/yr = ($13)/Ton

# Generation Rates for Selected Large U.S. Metropolitan Areas(a)

## 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 key, high population 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, Lazard estimates.*

Note: Actual delivered generation prices may be higher, reflecting historical composition of resource portfolio. All technologies represent an average of the high and low levelized cost of energy values unless otherwise noted. Represents average retail rate for generation-only utility charges per EEI for 12 months ended December 31, 2015.

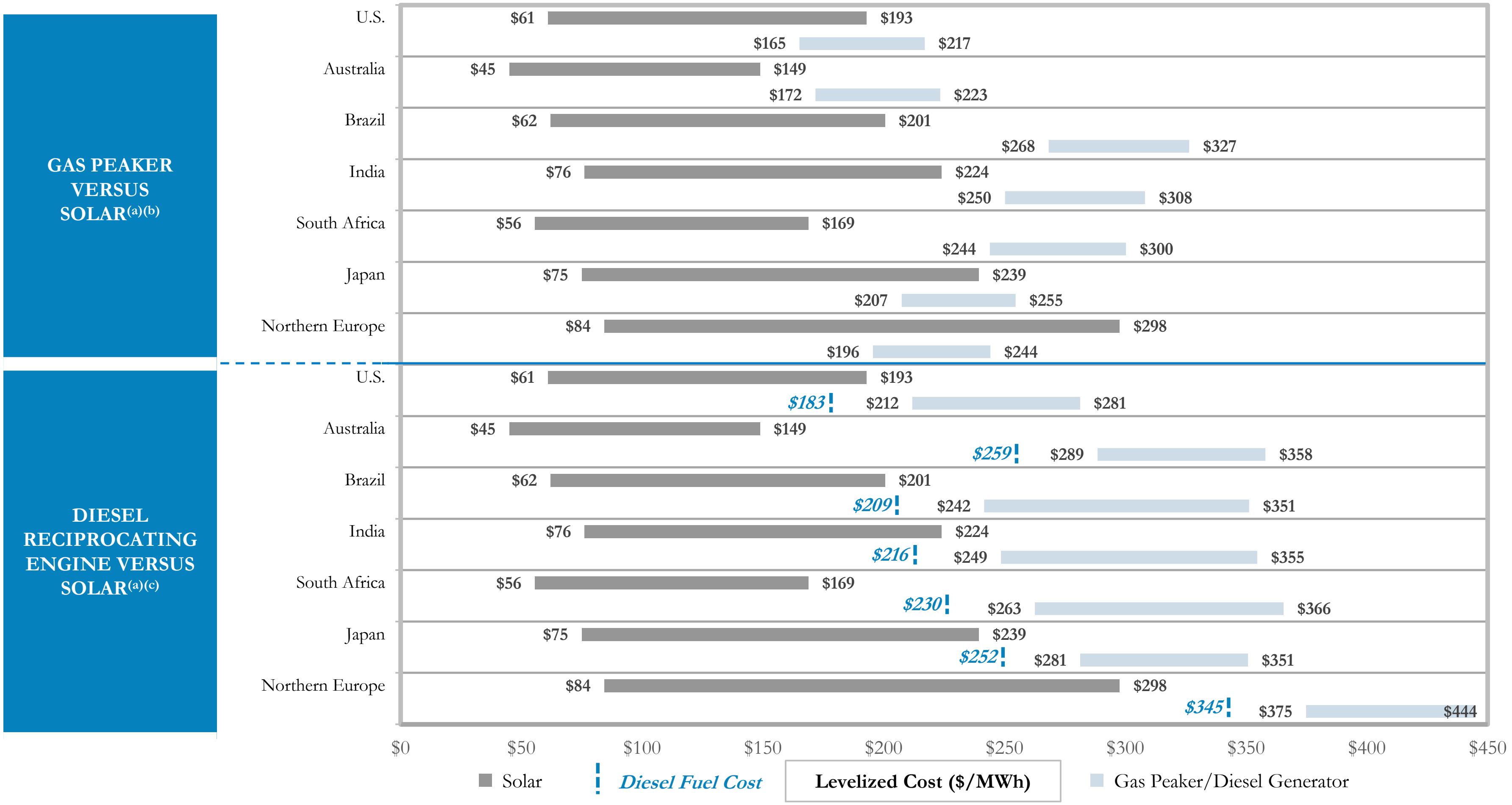
(a) Includes only those cities among top ten in population (per U.S. census) for which generation-only average $/kWh figures are available.

(b) Represents crystalline utility-scale solar with single-axis tracking design. Excludes Investment Tax Credit.

(c) Represents thin film utility-scale solar with single-axis tracking design. Excludes Investment Tax Credit.

# 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 and Lazard estimates.*

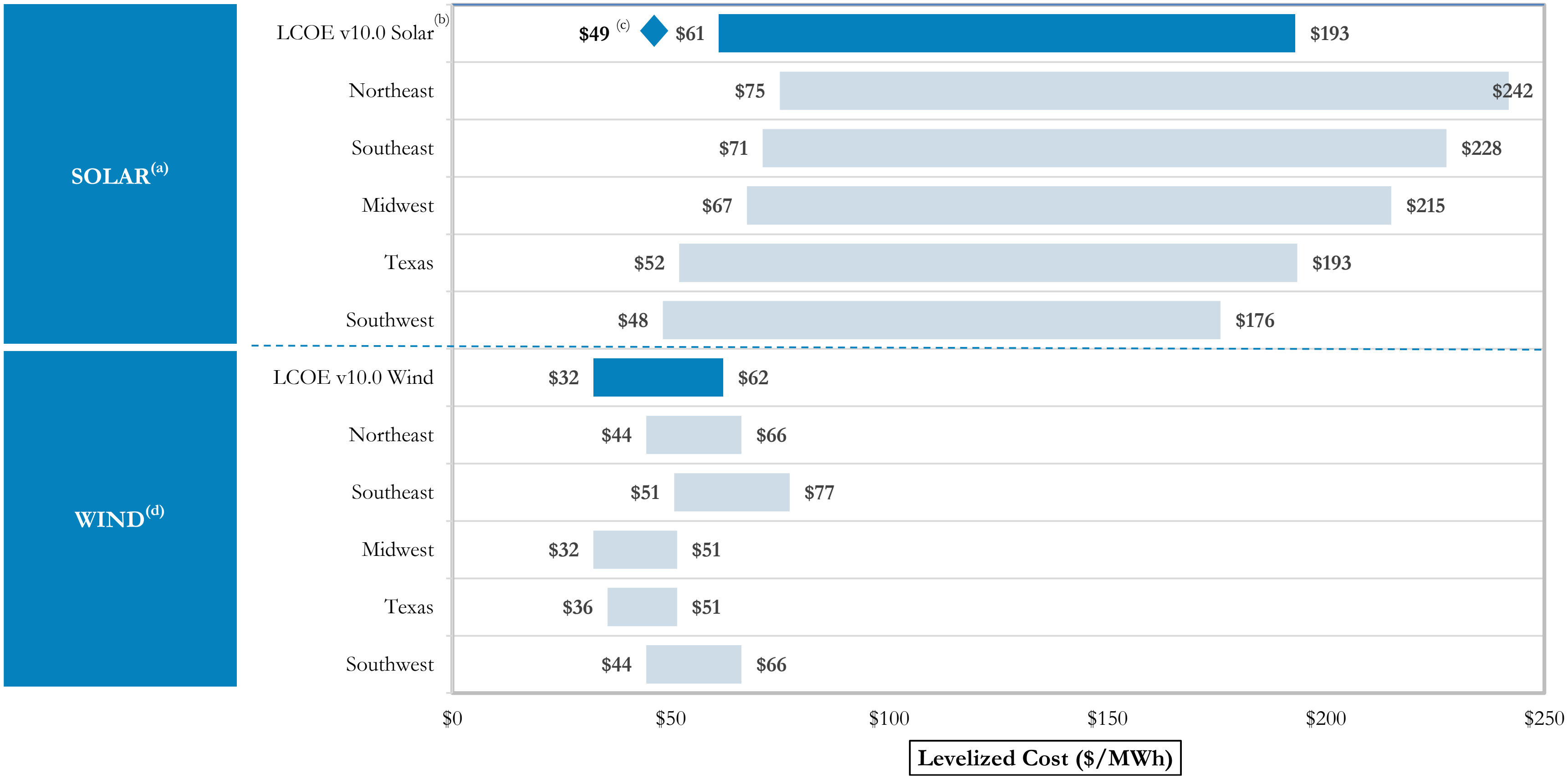
(a) Low end assumes crystalline utility-scale solar with a fixed-tilt design. High end assumes rooftop C&I solar. Solar projects assume illustrative capacity factors of 26% – 30% for Australia, 26% – 30% for Brazil, 22% – 23% for India, 27% – 29% for South Africa, 16% – 18% for Japan and 13% – 16% for 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 $4.00 for Australia, $8.00 for Brazil, $7.00 for India, $7.00 for South Africa, $7.00 for Japan and $6.00 for Northern Europe (all in U.S.$ per MMBtu). Assumes a capacity factor of 10%.

(c) Diesel assumes high end capacity factor of 10% representing intermittent utilization and low end capacity factor of 95% representing baseload utilization, O&M cost of $30 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 $3.60 for Australia, $2.90 for Brazil, $3.00 for India, $3.20 for South Africa, $3.50 for Japan and $4.80 for Northern Europe (all in U.S.$ 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 U.S. 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, 20% – 26% for Texas and 22% – 28% for the Southwest. Assumes wind capacity factors of 35% – 40% for the Northeast, 30% – 35% for the Southeast, 45% – 55% for the Midwest, 45% – 50% for Texas and 35% – 40% for the Southwest.

(a) Low end assumes a crystalline utility-scale solar fixed-tilt design, as tracking technologies may not be available in all geographies. High end assumes a rooftop C&I solar system.

(b) Low end assumes a crystalline utility-scale solar fixed-tilt design with a capacity factor of 21%.

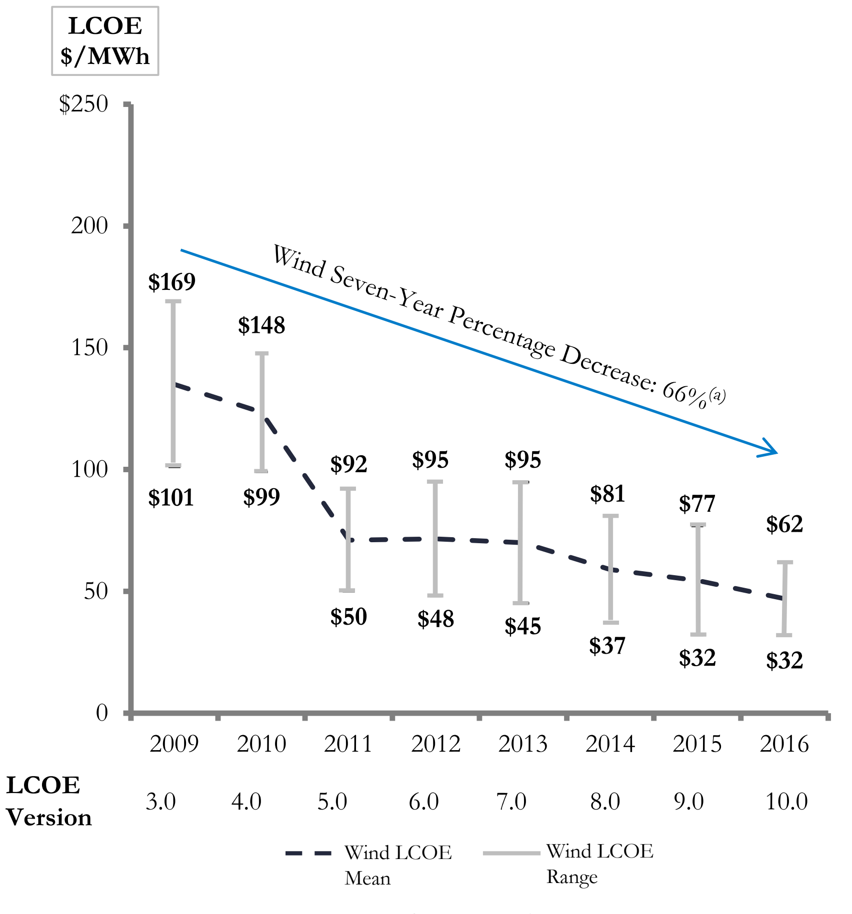
(c) Diamond represents a crystalline utility-scale solar single-axis tracking system with a capacity factor of 30%.

(d) Assumes an onshore wind generation plant with capital costs of $1.25 – $1.70 per watt.

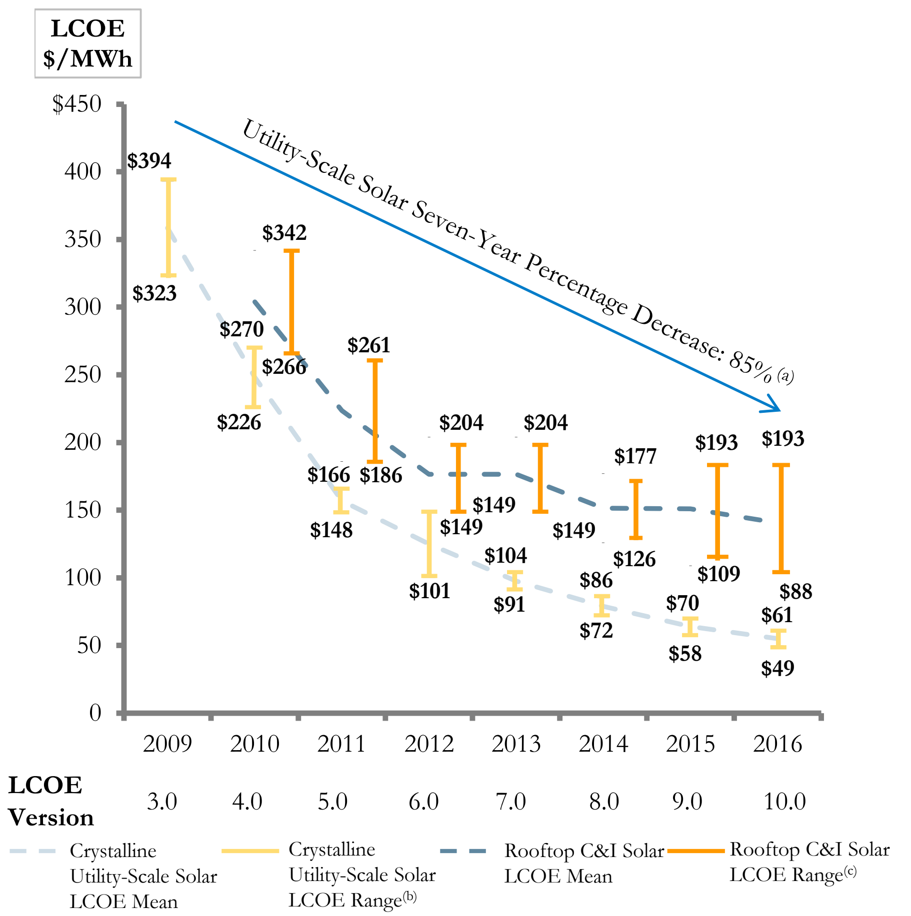
# Unsubsidized Levelized Cost of Energy—Wind/Solar PV (Historical)

**Over the last seven 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



*Source: Lazard estimates.*

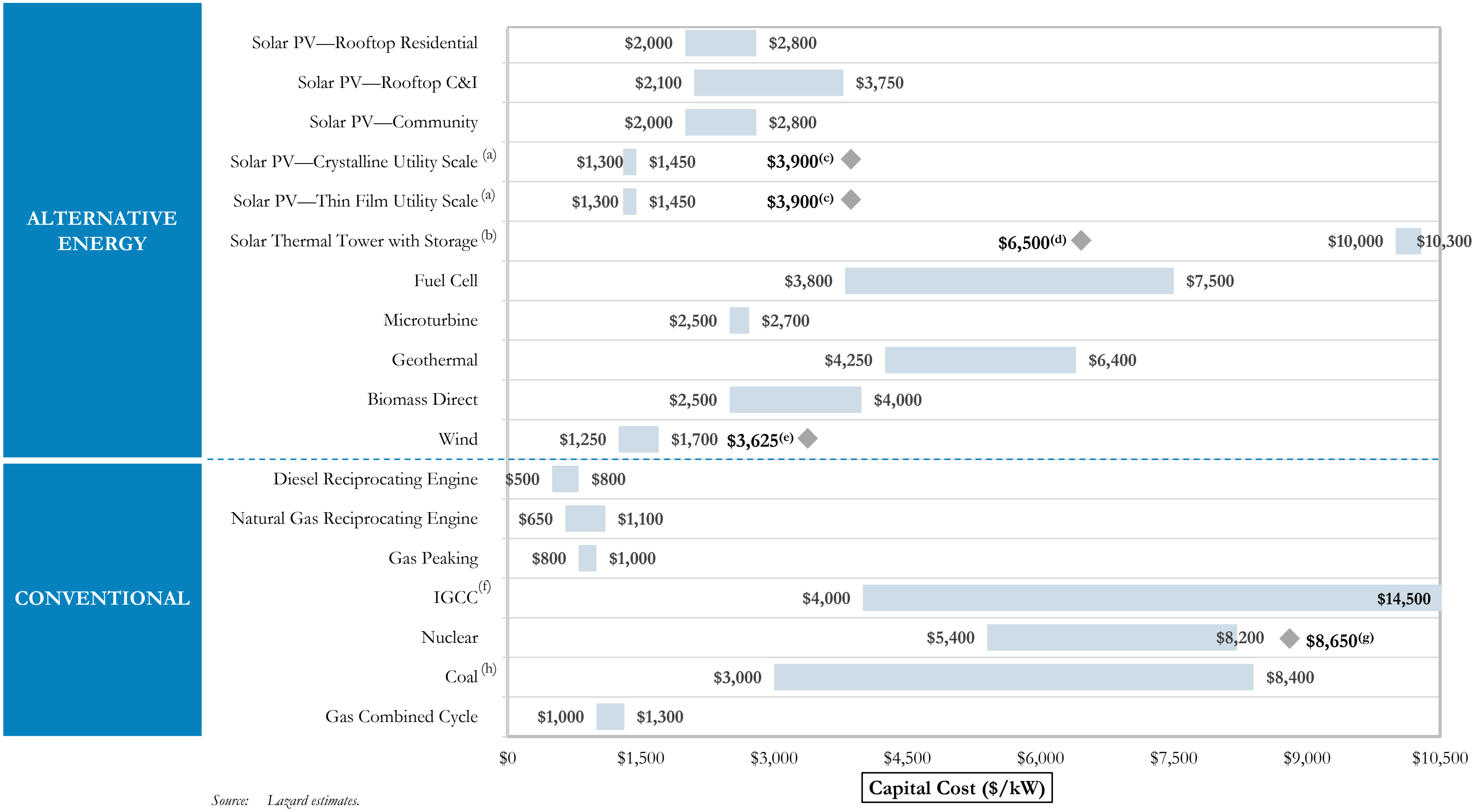
(a) Represents average percentage decrease of high end and low end of LCOE range.

(b) Low end represents crystalline utility-scale solar with single-axis tracking in high insolation jurisdictions (e.g., Southwest U.S.), while high end represents crystalline utility-scale solar with fixed-tilt design.

(c) Lazard's LCOE initiated reporting of rooftop C&I solar in 2010.

# 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 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**

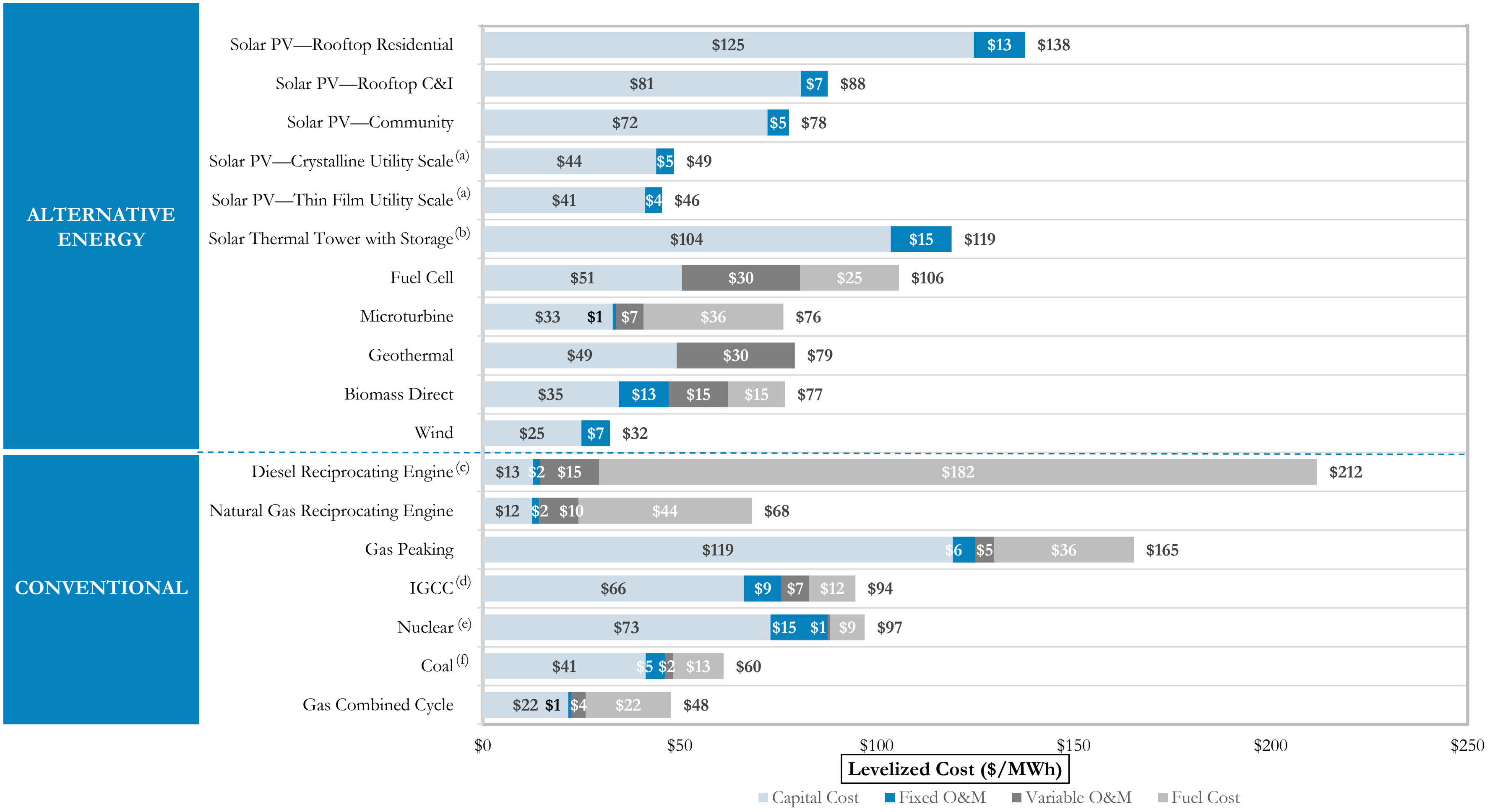


*Source:* *Lazard estimates.*

(a) High end capital cost represents the capital cost associated with the low end LCOE of utility-scale solar. Low end capital cost represents the capital cost associated with the high end LCOE of utility-scale solar.
(b) Low end represents concentrating solar tower with 10-hour storage capability. High end represents concentrating solar tower with 18-hour storage capability.
(c) Diamond represents PV plus storage.
(d) Diamond represents solar thermal tower capital costs without storage.
(e) Represents estimated midpoint of capital costs for offshore wind, assuming a capital cost range of $2.75 – $4.50 per watt.
(f) High end represents Kemper and it incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.
(g) Represents estimate of current U.S. new nuclear construction.
(h) Reflects average of Northern Appalachian Upper Ohio River Barge and Pittsburgh Seam Rail coal. Does not incorporate carbon capture and compression.

# Levelized Cost of Energy Components—Low End

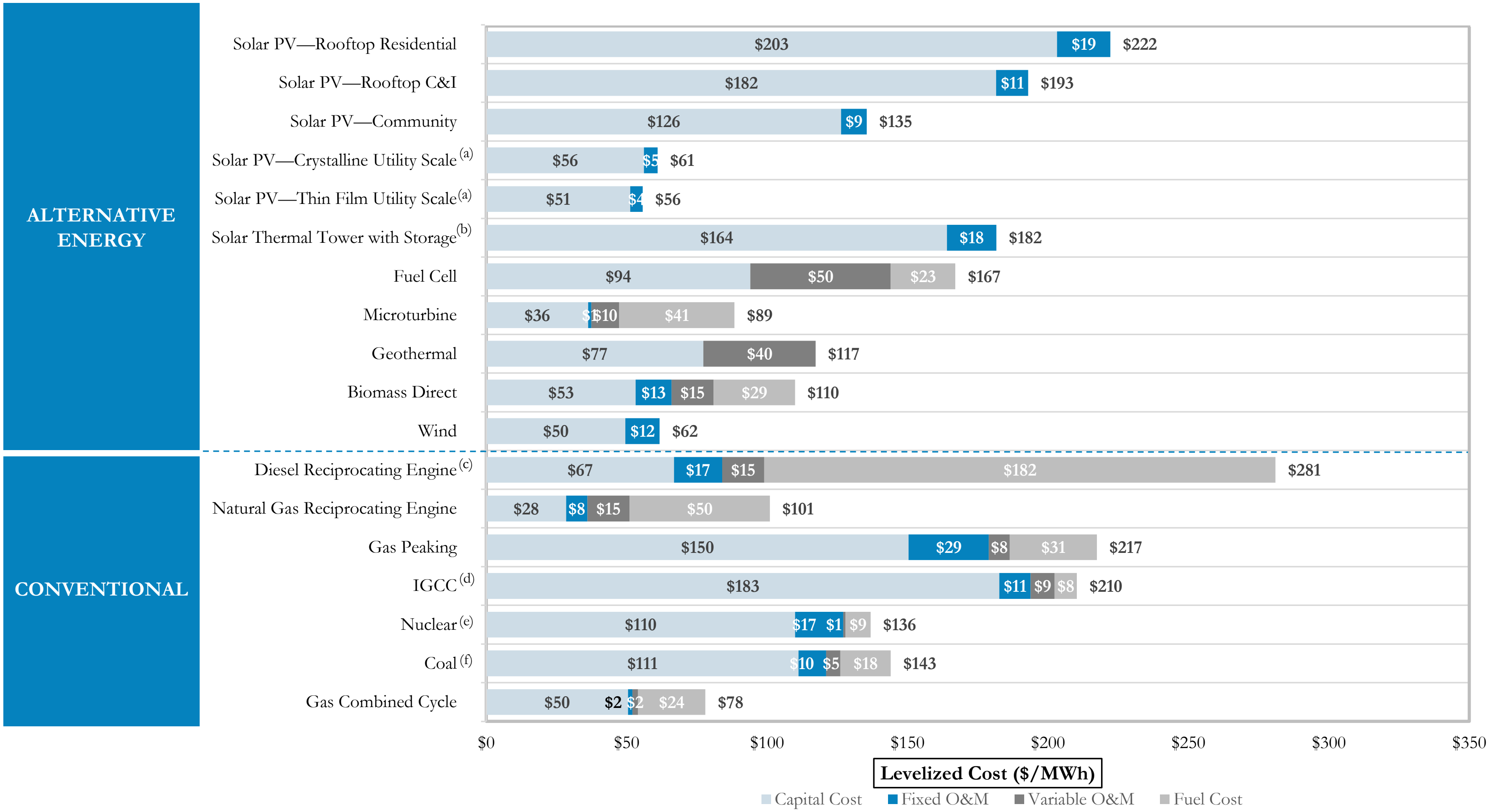
**Certain Alternative Energy generation technologies are already cost-competitive with conventional generation technologies; a key factor regarding the long-term competitiveness of currently more expensive Alternative Energy technologies is the ability of technological development and increased production 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) | Represents the low end of a utility-scale solar single-axis tracking system. |
| (b) | Represents concentrating solar tower with 18-hour storage capability. |
| (c) | Represents continuous operation. |
| (d) | Does not incorporate carbon capture and compression. |
| (e) | Does not reflect decommissioning costs or potential economic impact of federal loan guarantees or other subsidies. |
| (f) | Reflects average of Northern Appalachian Upper Ohio River Barge and Pittsburgh Seam Rail 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) Represents the high end of utility-scale solar fixed-tilt design.

(b) Represents concentrating solar tower with 10-hour storage capability.

(c) Represents intermittent operation.

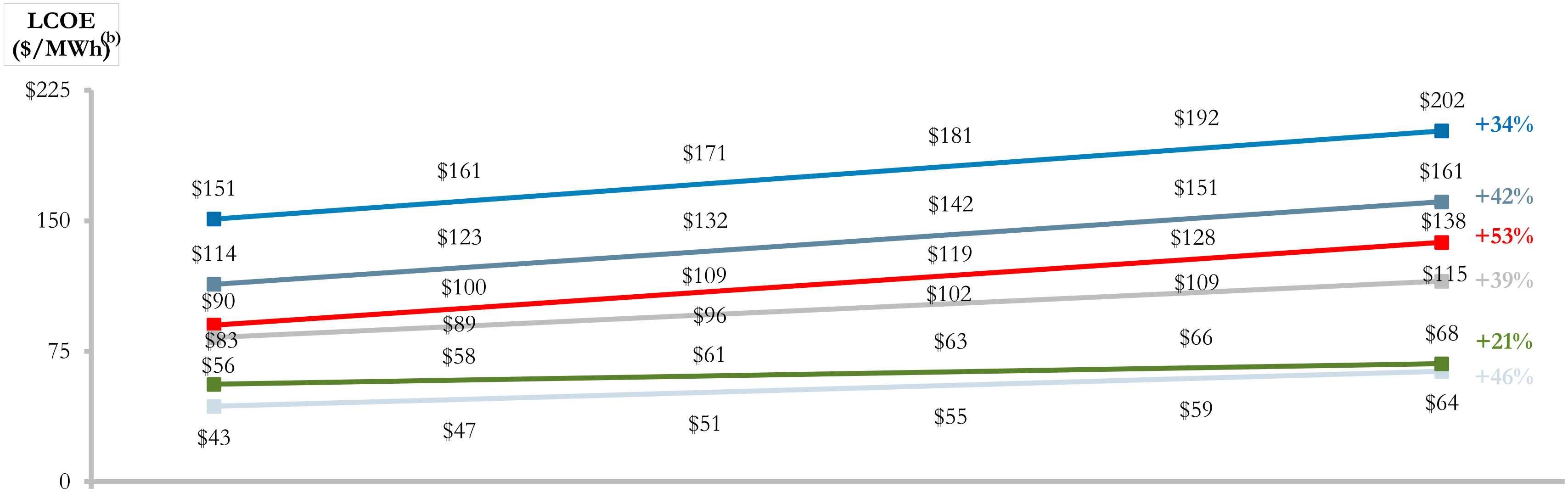
(d) Incorporates 90% carbon capture and compression. Does not include cost of transportation and storage.

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

(f) Based on of Northern Appalachian Upper Ohio River Barge and Pittsburgh Seam Rail coal. High end 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 is the impact of the availability and cost of capital[(a)] on LCOEs (as a result of capital markets dislocation, technological maturity, etc.); 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**



| | | | | | | |
|---|---|---|---|---|---|---|
| After-Tax IRR/WACC | 5.4% | 6.2% | 6.9% | 7.7% | 8.4% | 9.2% |
| Cost of Equity | 9.0% | 10.0% | 11.0% | 12.0% | 13.0% | 14.0% |
| Cost of Debt | 5.0% | 6.0% | 7.0% | 8.0% | 9.0% | 10.0% |

■ Solar PV—Rooftop Residential ■ Solar PV—Rooftop C&I ■ Solar PV—Utility Scale

■ Nuclear (c) ■ Coal (d) ■ Gas—Combined Cycle

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

☐ Reflects potentially more prevalent North American cost of capital—see next page for additional details

*Source: Lazard estimates.*

(a) Cost of capital as used herein indicates the cost of capital for the asset/plant vs. the cost of capital of a particular investor/owner.

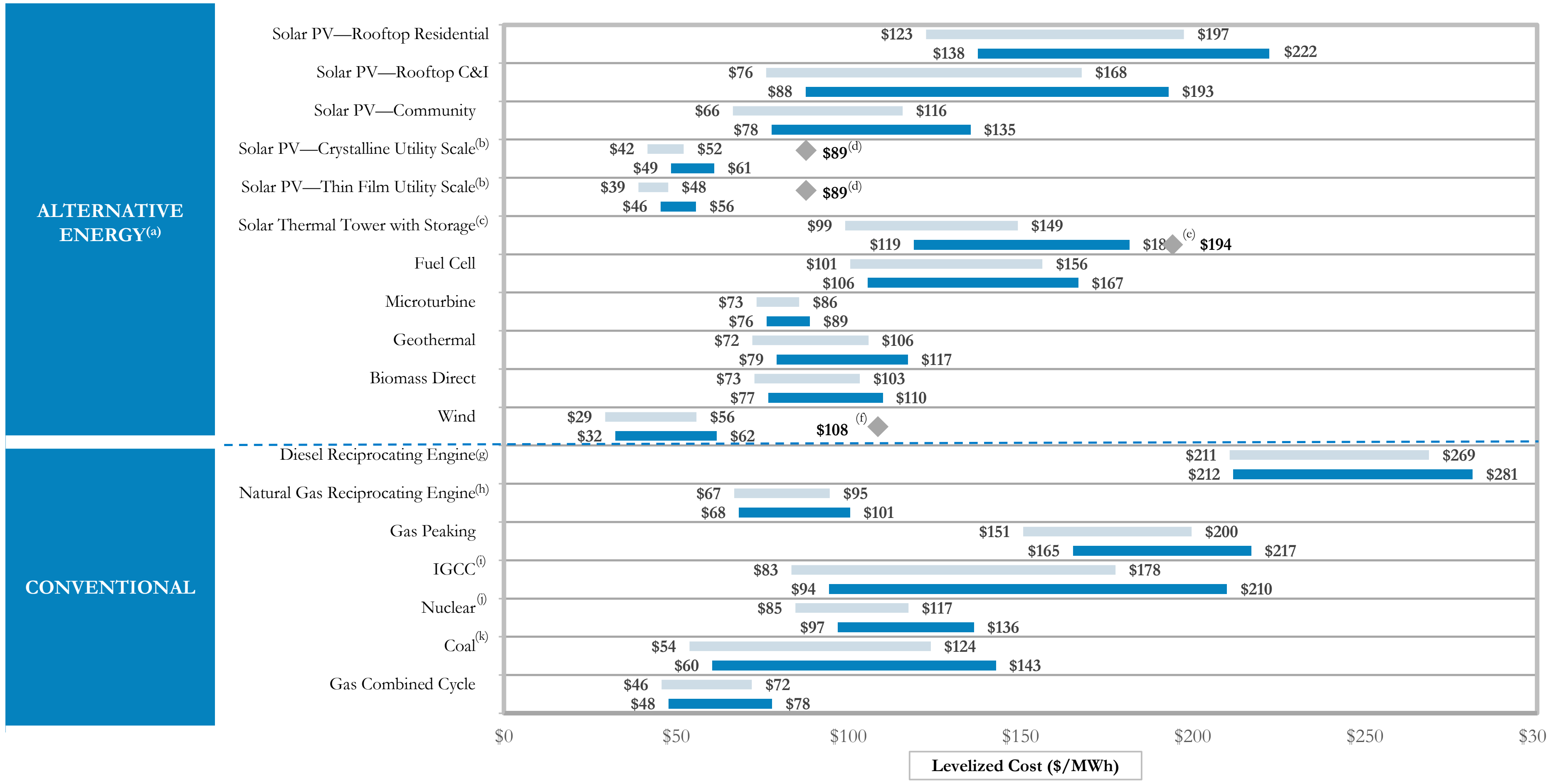
(b) Reflects average of high and low LCOE for given cost of capital assumption.

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

(d) Based on average of Northern Appalachian Upper Ohio River Barge and Pittsburgh Seam Rail coal. Does not incorporate carbon capture and compression.

# Unsubsidized Levelized Cost of Energy—Cost of Capital Comparison

**While Lazard's analysis primarily reflects an illustrative global cost of capital (i.e., 8% cost of debt and 12% cost of equity), such assumptions may be somewhat elevated vs. OECD/U.S. figures currently prevailing in the market for utility-scale renewables assets/investment—in general, Lazard aims to update its major levelized assumptions (e.g., cost of capital, capital structure, etc.) only in extraordinary circumstances, so that results track year-over-year cost declines and technological improvements vs. capital markets**



*Source:* *Lazard estimates.*

Note: Reflects equivalent cost and operational assumptions as pages 2 – 3. Analysis assumes 60% debt at 6% interest rate and 40% equity at 10% cost for conventional and Alternative Energy generation technologies. Assumes an average coal price of \$1.47 per MMBtu based on Northern Appalachian Upper Ohio River Barge and Pittsburgh Seam Rail coal. Assumes a range of \$0.65 – \$1.33 per MMBtu based on Illinois Based Rail for IGCC. Assumes a natural gas price of \$3.45 per MMBtu for Fuel Cell, Microturbine, Gas Peaking and Gas Combined Cycle. Analysis does not reflect potential impact of recent draft rule to regulate carbon emissions under Section 111(d).

‡ Denotes distributed generation technology.

# Energy Resources: Matrix of Applications

## While the levelized cost of energy for Alternative Energy generation technologies is in some cases competitive with conventional generation technologies, direct comparisons must take into account issues such as location (e.g., centralized vs. distributed) 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**

| | | | | | LOCATION | | | DISPATCH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **LEVELIZED COST OF ENERGY** | **CARBON NEUTRAL/ REC POTENTIAL** | **STATE OF TECHNOLOGY** | **DISTRIBUTED** | **CENTRALIZED** | **GEOGRAPHY** | **INTERMITTENT** | **PEAKING** | **LOAD-FOLLOWING** | **BASE-LOAD** |
| **ALTERNATIVE ENERGY** | **SOLAR PV** | \$46 – 222[a] | ✓ | Commercial | ✓ | ✓ | Universal[b] | ✓ | ✓ | | |
| | **SOLAR THERMAL** | \$119 – 182 | ✓ | Commercial | | ✓ | Varies | ✓ | ✓ | ✓ | |
| | **FUEL CELL** | \$106 – 167 | ? | Emerging/ Commercial | ✓ | | Universal | | | | ✓ |
| | **MICROTURBINE** | \$76 – 89 | ? | Emerging/ Commercial | ✓ | | Universal | | | | ✓ |
| | **GEOTHERMAL** | \$79 – 117 | ✓ | Mature | | ✓ | Varies | | | | ✓ |
| | **BIOMASS DIRECT** | \$77 – 110 | ✓ | Mature | | ✓ | Universal | | | ✓ | ✓ |
| | **ONSHORE WIND** | \$32 – 62 | ✓ | Mature | | ✓ | Varies | ✓ | | | |
| **CONVENTIONAL** | **DIESEL RECIPROCATING ENGINE** | \$212 –281 | × | Mature | ✓ | | Universal | ✓ | ✓ | ✓ | ✓ |
| | **NATURAL GAS RECIPROCATING ENGINE** | \$68 – 101 | × | Mature | ✓ | | Universal | ✓ | ✓ | ✓ | ✓ |
| | **GAS PEAKING** | \$165 – 217 | × | Mature | ✓ | ✓ | Universal | | ✓ | ✓ | |
| | **IGCC** | \$94 – 210 | ×[c] | Emerging[d] | | ✓ | Co-located or rural | | | | ✓ |
| | **NUCLEAR** | \$97 – 136 | ✓ | Mature/ Emerging | | ✓ | Co-located or rural | | | | ✓ |
| | **COAL** | \$60 – 143 | ×[c] | Mature[d] | | ✓ | Co-located or rural | | | | ✓ |
| | **GAS COMBINED CYCLE** | \$48 – 78 | × | Mature | ✓ | ✓ | Universal | | | ✓ | ✓ |

*Source: Lazard estimates.*

(a) Represents the full range of solar PV technologies; low end represents thin film utility-scale solar single-axis tracking, high end represents the high end of rooftop residential solar.

(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—Methodology

**Lazard's Levelized Cost of Energy analysis consists of creating a power plant model representing an illustrative project for each relevant technology and solving for the $/MWh figure that results in a levered IRR equal to the assumed cost of equity (see pages 18 – 20 for detailed assumptions by technology)**

## WIND — HIGH CASE SAMPLE CALCULATIONS

| *Year*(a) | *0* | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|---|
| Capacity (MW) – (A) | | 100 | 100 | 100 | 100 | 100 |
| Capacity Factor (%) – (B) | | 38% | 38% | 38% | 38% | 38% |
| Total Generation ('000 MWh) – (A) x (B) = (C)* | | 329 | 329 | 329 | 329 | 329 |
| ***Levelized Energy Cost ($/MWh) – (D)*** | | ***$61.75*** | ***$61.75*** | ***$61.75*** | ***$61.75*** | ***$61.75*** |
| **Total Revenues – (C) x (D) = (E)*** | | **$20.3** | **$20.3** | **$20.3** | **$20.3** | **$20.3** |
| Total Fuel Cost – (F) | | $0.0 | $0.0 | $0.0 | $0.0 | $0.0 |
| Total O&M – (G)* | | 4.0 | 4.1 | 4.2 | 4.3 | 4.4 |
| **Total Operating Costs – (F) + (G) = (H)** | | $4.0 | $4.1 | $4.2 | $4.3 | $4.4 |
| **EBITDA – (E) - (H) = (I)** | | **$16.3** | **$16.2** | **$16.1** | **$16.0** | **$15.9** |
| Debt Outstanding - Beginning of Period – (J) | | $102.0 | $100.0 | $97.8 | $95.4 | $92.9 |
| Debt - Interest Expense – (K) | | (8.2) | (8.0) | (7.8) | (7.6) | (7.4) |
| Debt - Principal Payment – (L) | | (2.0) | (2.2) | (2.4) | (2.5) | (2.8) |
| Levelized Debt Service – (K) + (L) = (M) | | ($10.2) | ($10.2) | ($10.2) | ($10.2) | ($10.2) |
| **EBITDA – (I)** | | $16.3 | $16.2 | $16.1 | $16.0 | $15.9 |
| Depreciation (MACRS) – (N) | | (34.0) | (54.4) | (32.6) | (19.6) | (19.6) |
| Interest Expense – (K) | | (8.2) | (8.0) | (7.8) | (7.6) | (7.4) |
| **Taxable Income – (I) + (N) + (K) = (O)** | | **($25.9)** | **($46.2)** | **($24.4)** | **($11.2)** | **($11.1)** |
| **Tax Benefit (Liability) – (O) x (tax rate) = (P)**(b) | | **$10.4** | **$18.5** | **$9.7** | **$4.5** | **$4.4** |
| **After-Tax Net Equity Cash Flow – (I) + (M) + (P) = (Q)** | **($68.0)** | **$16.5** | **$24.5** | **$15.7** | **$10.3** | **$10.2** |
| **IRR For Equity Investors** | 12.0% | | | | | |

| **Key Assumptions**(c) | |
|---|---|
| Capacity (MW) | 100 |
| Capacity Factor | 38% |
| Fuel Cost ($/MMBtu)(d) | $0.00 |
| Heat Rate (Btu/kWh) | 0 |
| Fixed O&M ($/kW-year) | $40.0 |
| Variable O&M ($/MWh) | $0.0 |
| O&M Escalation Rate | 2.25% |
| **Capital Structure** | |
| Debt | 60.0% |
| Cost of Debt | 8.0% |
| Equity | 40.0% |
| Cost of Equity | 12.0% |
| **Taxes and Tax Incentives:** | |
| Combined Tax Rate | 40% |
| Economic Life (years)(e) | 20 |
| MACRS Depreciation (Year Schedule) | 5 |
| **Capex** | |
| EPC Costs ($/kW) | $1,100 |
| Additional Owner's Costs ($/kW) | $600 |
| Transmission Costs ($/kW) | $0 |
| Total Capital Costs ($/kW) | $1,700 |
| **Total Capex ($mm)** | $170 |

🟦 Technology-dependent

🟥 Levelized

*Source: Lazard estimates.*

Note: Wind—High LCOE case presented for illustrative purposes only.

* Denotes unit conversion.

(a) Assumes half-year convention for discounting purposes.

(b) Assumes full monetization of tax benefits of losses immediately.

(c) Reflects a "key" subset of all assumptions for methodology illustration purposes only. Does not reflect all assumptions.

(d) Fuel costs converted from relevant source to $/MMBtu for conversion purposes.

(e) Economic life sets debt amortization schedule. For comparison purposes, all technologies calculate LCOE on 20-year IRR basis.

# Levelized Cost of Energy—Key Assumptions

| | | Solar PV | | | | | |
|---|---|---|---|---|---|---|---|
| | **Units** | **Rooftop—Residential** | **Rooftop—C&I** | **Community** | **Utility Scale—Crystalline(c)** | **Utility Scale—Thin Film(c)** | **Solar Thermal Tower with Storage(d)** |
| **Net Facility Output** | MW | 0.005 0.002 | 1 | 1.5 | 30 | 30 | 110 |
| **EPC Cost** | $/kW | $2,000 – $2,800 | $2,100 – $3,750 | $2,000 – $2,800 | $1,450 – $1,300 | $1,450 – $1,300 | $9,000 – $8,750 |
| **Capital Cost During Construction** | $/kW | — | — | — | — | — | $1,300 – $1,250 |
| **Other Owner's Costs** | $/kW | included | included | included | included | included | included |
| **Total Capital Cost(a)** | $/kW | $2,000 – $2,800 | $2,100 – $3,750 | $2,000 – $2,800 | $1,450 – $1,300 | $1,450 – $1,300 | $10,300 – $10,000 |
| **Fixed O&M** | $/kW-yr | $20.00 – $25.00 | $15.00 – $20.00 | $12.00 – $16.00 | $12.00 – $9.00 | $12.00 – $9.00 | $115.00 – $80.00 |
| **Variable O&M** | $/MWh | — | — | — | — | — | — |
| **Heat Rate** | Btu/kWh | — | — | — | — | — | — |
| **Capacity Factor** | % | 18% – 15% | 25% – 20% | 25% – 20% | 30% – 21% | 32% – 23% | 85% – 52% |
| **Fuel Price** | $/MMBtu | 0 | 0 | 0 | 0 | 0 | 0 |
| **Construction Time** | Months | 3 | 3 | 6 | 9 | 9 | 36 |
| **Facility Life** | Years | 20 | 25 | 30 | 30 | 30 | 35 |
| **$CO_2$ Emissions** | lb/MMBtu | — | — | — | — | — | — |
| **Levelized Cost of Energy(b)** | $/MWh | $138 – $222 | $88 – $193 | $78 – $135 | $49 – $61 | $46 – $56 | $119 – $182 |

*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 – 10.0 present LCOE on an unsubsidized basis.

(c) Left column represents the assumptions used to calculate the low end LCOE for single-axis tracking. Right column represents the assumptions used to calculate the high end LCOE for fixed-tilt design. Assumes 30 MW system in high insolation jurisdiction (e.g., Southwest U.S.). Does not account for differences in heat coefficients, balance-of-system costs or other potential factors which may differ across solar technologies.

(d) Left column represents concentrating solar tower with 18-hour storage capability. Right column represents concentrating solar tower with 10-hour storage capability.

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

| | Units | Fuel Cell | Microturbine | Geothermal | Biomass Direct | Wind—On Shore | Wind—Off Shore |
|---|---|---|---|---|---|---|---|
| **Net Facility Output** | MW | 2.4 | 1 0.25 | 20 | 35 | 100 | 210 385 |
| **EPC Cost** | $/kW | $3,000 – $7,500 | $2,500 – $2,700 | $3,700 – $5,600 | $2,200 – $3,500 | $950 – $1,100 | $2,750 – $4,500 |
| **Capital Cost During Construction** | $/kW | — | — | $550 – $800 | $300 – $500 | — | — |
| **Other Owner's Costs** | $/kW | $800 – $0 | included | included | included | $300 – $600 | included |
| **Total Capital Cost**[(a)] | $/kW | $3,800 – $7,500 | $2,500 – $2,700 | $4,250 – $6,400 | $2,500 – $4,000 | $1,250 – $1,700 | $2,750 – $4,500 |
| **Fixed O&M** | $/kW-yr | — | $6.85 – $9.12 | — | $95.00 | $35.00 – $40.00 | $80.00 – $110.00 |
| **Variable O&M** | $/MWh | $30.00 – $50.00 | $7.00 – $10.00 | $30.00 – $40.00 | $15.00 | — | — |
| **Heat Rate** | Btu/kWh | 7,260 – 6,600 | 10,300 – 12,000 | — | 14,500 | — | — |
| **Capacity Factor** | % | 95% | 95% | 90% – 85% | 85% | 55% – 38% | 48% – 40% |
| **Fuel Price** | $/MMBtu | 3.45 | $3.45 | — | $1.00 – $2.00 | — | — |
| **Construction Time** | Months | 3 | 3 | 36 | 36 | 12 | 12 |
| **Facility Life** | Years | 20 | 20 | 25 | 25 | 20 | 20 |
| **$CO_2$ Emissions** | lb/MMBtu | 0 – 117 | — | — | — | — | — |
| **Levelized Cost of Energy**[(b)] | $/MWh | $106 – $167 | $76 – $89 | $79 – $117 | $77 – $110 | $32 – $62 | $82 – $155 |

*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 – 10.0 present LCOE on an unsubsidized basis.

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

| | Units | Diesel Reciprocating Engine(c) | Natural Gas Reciprocating Engine | Gas Peaking | IGCC(d) | Nuclear(e) | Coal(f) | Gas Combined Cycle |
|---|---|---|---|---|---|---|---|---|
| **Net Facility Output** | MW | 0.25 | 0.25 | 216 – 103 | 580 | 1,100 | 600 | 550 |
| **EPC Cost** | $/kW | $500 – $800 | $650 – $1,100 | $580 – $700 | $3,300 – $11,600 | $3,800 – $5,300 | $2,000 – $6,100 | $750 – $1,000 |
| **Capital Cost During Construction** | $/kW | — | — | — | $700 – $2,900 | $1,000 – $1,400 | $500 – $1,600 | $100 – $100 |
| **Other Owner's Costs** | $/kW | included | included | $220 – $300 | $0 – $0 | $600 – $1,500 | $500 – $700 | $200 – $200 |
| **Total Capital Cost(a)** | $/kW | $500 – $800 | $650 – $1,100 | $800 – $1,000 | $4,000 – $14,500 | $5,400 – $8,200 | $3,000 – $8,400 | $1,000 – $1,300 |
| **Fixed O&M** | $/kW-yr | $15.00 | $15.00 – $20.00 | $5.00 – $25.00 | $62.25 – $73.00 | $135.00 | $40.00 – $80.00 | $6.20 – $5.50 |
| **Variable O&M** | $/MWh | $15.00 | $10.00 – $15.00 | $4.70 – $7.50 | $7.00 – $8.50 | $0.50 – $0.75 | $2.00 – $5.00 | $3.50 – $2.00 |
| **Heat Rate** | Btu/kWh | 10,000 | 8,000 – 9,000 | 10,300 – 9,000 | 8,800 – 11,700 | 10,450 | 8,750 – 12,000 | 6,300 – 6,900 |
| **Capacity Factor** | % | 95% – 10% | 95% – 30% | 10% | 75% | 90% | 93% | 80% – 40% |
| **Fuel Price** | $/MMBtu | $18.23 | $5.50 | $3.45 | $1.33 – $0.65 | $0.85 | $1.47 | $3.45 |
| **Construction Time** | Months | 3 | 3 | 25 | 57 – 63 | 69 | 60 – 66 | 36 |
| **Facility Life** | Years | 20 | 20 | 20 | 40 | 40 | 40 | 20 |
| **CO$_2$ Emissions** | lb/MMBtu | 0 – 117 | 117 | 117 | 169 | — | 211 | 117 |
| **Levelized Cost of Energy(b)** | $/MWh | $212 – $281 | $68 – $101 | $165 – $217 | $94 – $210 | $97 – $136 | $60 – $143 | $48 – $78 |

*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 – 10.0 present LCOE on an unsubsidized basis.

(c) Low end represents continuous operation. High end represents intermittent operation. Assumes diesel price of ~$2.50 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) Reflects average of Northern Appalachian Upper Ohio River Barge and Pittsburgh Seam Rail 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, etc.) 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 other important metrics on the levelized cost of energy. These inputs were originally 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 benefited 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.).*