Arizona's Solar Market Analysis and Research Tool

The Market-Determined Cost of Inputs to Utility-Scale Electricity Generation

Version 1.0
November 09

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This paper is part of the Az Smart Research Program. Further details can be found at www.azsmart.org.

Az SMART is sponsored by Arizona Public Service Company, BrightSource Energy, Inc., Create-a-Soft, Salt River Project, Science Foundation Arizona, Tucson Electric Power, and Viasol Energy Solutions under grant number SRG STI 0407-08.

Arizona's Solar Market Analysis and Research Tool (Az SMART)

Arizona's Solar Market Analysis and Research Tool (Az SMART) is a breakthrough analysis environment that will enable stakeholders to examine the complex interaction of economic, security, environmental, and technological issues that impact Arizona's ability to become a global leader in solar power innovation, development and deployment. Multi-disciplinary research efforts and capabilities at Arizona State University and the University of Arizona are being utilized in close collaboration with partners from industry and government in the creation and use of Az SMART.

The goal of the three-year project is to develop a unique analysis tool, tailored to the examination of a successful roll-out of large-scale solar energy infrastructure in Arizona, and the required electric grid technologies to enable that infrastructure.

The principal outputs of the project are Solar Feasibility research, a Solar Scorecard for Arizona, and ultimately, the analytical tool that integrates them into a decision support framework. The end product will be accessible by remote web access (www.azsmart.org), as well as at Decision Theater, a dynamic, immersive visualization environment facility at Arizona State University

Arizona's Solar Scorecard

Researchers at the L. William Seidman Research Institute of the W. P. Carey School of Business at Arizona State University are developing Arizona's Solar Scorecard. The Solar Scorecard comprises metrics drawn from energy usage forecasts, environmental valuation analyses, economic development analyses, and energy security evaluations. It is assembled from a series of whitepapers which provide the research and analysis to translate commercial and public policy choices into measures of economic, environmental, social and energy security impact on Arizona. The 13 whitepapers are as follows:

1. *Energy Sector Technology;*
2. *The Market-Determined Cost of Inputs to Utility-Scale Electricity Generation;*
3. *Incentives and Taxation;*
4. *Individual and Utility Decision Environment;*
5. *AZ Energy Demand Analysis;*
6. *Regulations and Standards;*
7. *Energy Usage/ Supply Forecasts;*
8. *Emissions/Pollution Analysis;*
9. *Solar Export Potential;*
10. *Environmental Valuation Analysis;*
11. *Solar Inter-State Competition;*
12. *Economic Development Analysis;*
13. *Energy Security Issues.*

About This Paper

This white paper is the 2nd paper out of the series of 13 white papers that make up the Solar Scorecard. The primary goal of this paper is to examine the key cost determinants in utility scale electricity generation. Estimates of the market-determined financial costs associated with various utility scale generation technologies are computed. As Az SMART progresses the estimates contained within this paper will be refined to ensure variations in key cost determinants across technologies are accounted for. Distributed forms of generation, and their financial cost characteristics, will be examined in a future paper.

The financial cost estimates contained in this paper serve as a building block for future research that will evaluate how successful various incentive and taxation schemes are at altering the relative cost of electricity generation across technologies. Further these financial cost estimates will be crucial when examining the economic impact of solar generation in future papers that are part of the overall Solar Scorecard. It is important to note that this paper focuses exclusively on the financial costs associated with various forms of generation. Any environmental benefits/costs have been set aside to be examined at a later date.

Executive Summary

- There are a variety of technologies currently available to generate electricity. One of the major factors that determines a state's generation mix is cost. Market forces as well as government intervention will play a crucial role in determining Arizona's future generation mix.

- To calculate levelized cost estimates, where available, data from the Energy Information Administration (EIA) was employed. The advantage of EIA data is that it provides information on a significant number of the factors that ultimately enable us to generate financial cost estimates for a broad range of technologies.[1] Due to the uncertainty surrounding the future cost of building power plants,[2] the EIA forecasts four capital cost cases through 2030 that attempt to encapsulate some of the uncertainty surrounding capital costs. These scenarios also include potential learning-by-doing effects as well as a technology optimism factor.[3]

[1] To make the estimates Arizona centric, some alterations were made where it was felt required. For instance the EIA assumes a wind capacity of over 40 percent whilst in Arizona it appears that the highest capacity factor is approximately 35 percent (Black & Veatch, 2007).
[2] Construction inflation has received some attention in recent years. See (Seidman Research Institute, 2008) for a recent discussion of construction inflation in Arizona.
[3] For more details on these factors see (EIA, 2009).

Levelized Cost Estimates

Utility Scale Levelized Cost per MWh of Electricity Delivered in 2009 and 2030

	2009	*2030*			
Technology	**Reference[4]**	**Rising[5]**	**Reference[6]**	**Falling[7]**	**% Change (Ref.)**
Scrubbed New Coal	$102	$112	$96	$86	-5.9%
IGCC	$111	$118	$99	$87	-10.8%
IGCC with carbon sequestration	$141	$144	$117	$101	-17.2%
Conv Gas/Oil Comb Cycle	$105	$125	$119	$115	13.5%
Adv Gas/Oil Comb Cycle (CC)	$101	$119	$113	$109	11.8%
Adv CC with carbon sequestration	$133	$149	$138	$131	3.5%
Conv Comb Turbine	$125	$155	$150	$148	20.3%
Adv Comb Turbine	$113	$133	$130	$128	15.1%
Fuel Cells	$228	$239	$212	$196	-7.0%
Adv Nuclear	$132	$144	$111	$93	-16.0%
Bio-mass	$148	$148	$120	$104	-19.1%
MSW - Landfill Gas	$119	$130	$113	$103	-5.4%
Geothermal	$92	$169	$133	$108	43.8%
Conventional Hydropower	$103	$118	$96	$74	-7.4%
Wind	$127	$150	$116	$95	-9.0%
Wind Offshore	$227	$246	$186	$150	-17.8%
Solar Thermal	$301	$283	$210	$165	-30.3%
Photovoltaic	$393	$375	$267	$201	-32.0%

[4] Only the reference case is shown in 2009 as there is little difference between the cases.
[5] The *rising capital costs case* assumes that the cost adjustment factor is 25 percentage points higher than in the reference case between 2013 and 2030. Cost decreases due to learning can and do still occur. These cost reductions can partially or fully offset any cost factor increases, however for most technologies, costs in 2030 are *above* their 2008 levels.
[6] In the EIA *reference case*, initial overnight costs for all technologies are updated to be consistent with costs estimates collected in early 2008. Changes in these overnight capital costs are driven by a cost adjustment factor, which is based on the projected producer price index for metals and metal product
[7] The *falling plant capital costs case* assumes that overnight costs for the various generating technologies decreases at a faster rate than in the reference case, starting in 2013. By 2030, the cost adjustment factor is assumed to be 25 percentage points below its reference case value.

The Competitiveness of Solar

- The initial estimates contained in this paper suggests that even if solar generation enjoys significant *reductions* in capital costs (45-59 percent) whilst traditional generation face *increasing* capital costs (1-23 percent) traditional generation still remains more cost competitive in 2030 absent government intervention.

- For solar thermal to achieve a levelized cost of $155 per MWh (the closest traditional generation levelized costs) in 2030 its overnight capital cost per KW would need to be approximately $2,100 (2009$) whilst PV overnight capital costs per KW would have to be approximately $1,960 (2009$). These capital costs represent reductions of 58 percent and 67 percent relative to the reference capital cost case in 2009.

- Alternatively if gas prices are approximately $11.20 (2009$) per MBTU in 2030 then the levelized cost of gas conventional combustion turbine would be equal to that of solar thermal ($165 per MWh). The gas price of $11.20 represents an increase of 15 percent above the EIA forecast in 2030 ($9.75 (2009$)).

Sensitivity Analysis

- Sensitivity analysis was performed to investigate how the levelized cost of the various generation technologies could vary with changes in some of the input. Even with plausible changes in input values solar generation still remains uncompetitive against traditional generation.

Remark

- In an analysis of solar, we find some stark results. Solar thermal and utility-scale PV systems are not cost-competitive, now or in the foreseeable future, against other traditional generation resources without *significant government intervention* that alters the market determined value of the key inputs that determine costs of generation *or significant deviations* away from the expected future values of the key inputs such as capital and fuel costs.

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List of Acronyms

Abbreviation	*Definition*
Entities	
APS	Arizona Public Service Company
CPUC	California Public Utilities Commission
DSIRE	Database of State Incentives for Renewable Energy
EIA	Energy Information Administration
NREL	National Renewable Energy Laboratory
Other Terms	
Btu	British thermal units
GWh	gigawatt hours
HVAC	heating, ventilating and air conditioning
kW	kilowatt
kWh	kilowatt hour
LCOE	Levelized cost of electricity
MW	megawatt
MWh	megawatt hour
O&M	Operations and maintenance
PV	photovoltaic
RES	Renewable energy standard
RPS	Renewable Portfolio Standard
T&D	Transmission and Distribution
WACC	Weighted-Average Cost of Capital

1. Introduction

There are a variety of technologies currently available to generate electricity. One of the major factors that determines a state's generation mix is cost. Market forces as well as government intervention will assist in determining Arizona's future generation mix.

The purpose of this paper is to identify and estimate the key inputs that ultimately determine the financial costs associated with the various generation technologies that are available now and/or will be in the foreseeable future, with a particular focus on renewable generation. We will construct cost estimates for the installation of new generation plants for various technologies absent government intervention, such as subsidies for renewable technologies or potential carbon taxes.[8] Also, any current financial incentives as well as any preferential tax treatments are excluded.

The unfettered market-determined financial cost of generation provides a more complete (full cost) assessment of the various technologies. This approach serves as a building block to enable us to evaluate how various incentive and taxation schemes attempt to alter the relative cost of electricity generation across technologies.

The key inputs that determine the financial costs associated with each technology vary. For instance, solar generation technologies are relatively more capital-intensive than their natural gas counterparts, which tend to be more fuel-intensive.[9]

Other factors also influence choice of generation technology. For instance, regulated utilities in Arizona are required to meet 15 percent of their electricity sales in 2025 using renewable generation methods.[10] Clearly, for regulated utilities the decision of when to install or purchase renewable generation, or at least the last date by which renewable generation needs to be in place, is potentially determined more by regulation than by financial motives. System integrity,

[8] The effect of government regulations and standards on electricity generation costs will be the focus of further research.
[9] We are using the term "intensive" to denote which component of generation costs tends to be the most significant source of overall cost.
[10] Database of State Incentives for Renewables & Efficiency (DSIRE)

location constraints, proximity to load pockets, potential intermittency issues, water usage, other environmental concerns (carbon emissions etc), access to fuel supplies, are further considerations that ultimately determine generation mixes for utilities.[11] However, even allowing for other issues, cost competitiveness remains a key determinant in electricity generation decision-making.[12] Thus, given its importance, examination of the key factors that determine generation costs warrants further examination.

The structure of the paper is as follows. Section 2 examines Arizona's current generation mix and lists the utility-scale electricity generation technologies examined. Section 3 discusses the levelized cost method that is typically adopted to enable assessment of financial costs of generation across various technologies. Section 4 contains our levelized cost forecasts. Section 5 examines the potential costs associated with energy efficiency. Section 6 provides some conclusions.

2. Electricity Generation Technologies

Arizona does not rely on a single technology for its electricity requirements. Also, renewable generation (non-hydroelectric) is only a small percentage of the overall generation mix. Table 1 illustrates.

[11] All of which (and wider social considerations - economic development for example) will be examined as part of the "Solar Scorecard".

[12] This is especially true when a utility is price regulated.

Table 1: Electric Power Industry Generation by Primary Energy Source 2007[13]

Generation Method	*Percentage (Megawatt Hours)*
Coal	36.4
Petroleum	0.0004
Natural Gas	33.9
Nuclear	23.6
Hydroelectric	5.8
Other Renewables[14]	0.00037
Pumped Storage[15]	0.1

Source: Energy Information Administration (EIA)

Generation in Arizona is currently dominated by coal, natural gas and nuclear technologies. Together, these three technologies account for approximately 94 percent of the state's total electricity generation.[16]

Market forces and government intervention will cause the future generation mix in Arizona to be significantly different from what is reported in table 1.[17] Also, table 1 hides the fact that within each generic generation method reported there are numerous different techniques utilized to produce electricity.

The utility scale technologies examined in this paper are listed in Table 2. These technologies encompass a broad range of different generation technologies that are currently, or will be in the foreseeable future. available for adoption in the United States.

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[13] 2007 is the most recent year of state generation data provided by the EIA.

[14]Other renewables includes biogenic municipal solid waste, wood, black liquor, other wood waste, landfill gas, sludge waste, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind.

[15] Pumped storage is a method of storing and producing electricity to supply (typically) high peak demands by moving water between reservoirs at different elevations.

[16] Due to the interconnectivity and agreements with neighboring states and utilities, the electricity generation and electricity consumption mixes in Arizona vary over time.

[17] For instance the current renewable portfolio standard in Arizona means that the renewable component will increase through time.

Table 2: List of Technologies Examined

Generation Technologies
High Sulfur Pulverized Coal with Wet Flue Gas Desulfurization
Advanced Coal - Integrated Coal Gasification Combined Cycle (IGCC)
Advanced Coal with carbon sequestration
Combined Cycle - Conventional Gas/Oil Combined Cycle Combustion Turbine
Advanced Combined Cycle - Advanced Gas/Oil Combined Cycle Combustion Turbine
Advanced Combined Cycle with carbon sequestration
Combustion Turbine – Conventional Gas Combustion Turbine
Advanced Combustion Turbine - Steam Injected Gas Turbine
Molten Carbonate Fuel Cell
Advanced Nuclear - Advanced Light Water Reactor
Biomass - Integrated Gasification Combined Cycle
Municipal Solid Waste (MSW)
Geothermal
Conventional Hydropower - Hydraulic Turbine
Wind
Wind Offshore
Solar Thermal - Central Receiver
Solar Photovoltaic - Single Axis Flat Plate

Source: EIA

Examining the technologies listed in Table 2 enables us to provide a variety of cost estimates across all of the currently available generic forms of generation technologies.

3. Levelized Cost Analysis

The levelized cost of generation is the constant (minimum) real price, in 2009 dollars for this report, per megawatt hour (MWh) that producers would need to receive in order to recover all costs incurred for installation (including finance costs), operation and maintenance of the plant over its lifetime. Simply stated, the levelized cost of generation is the price per MWh at which the present value of future revenues from the electricity generated by the plant would equal the present value of all financial costs.[18]

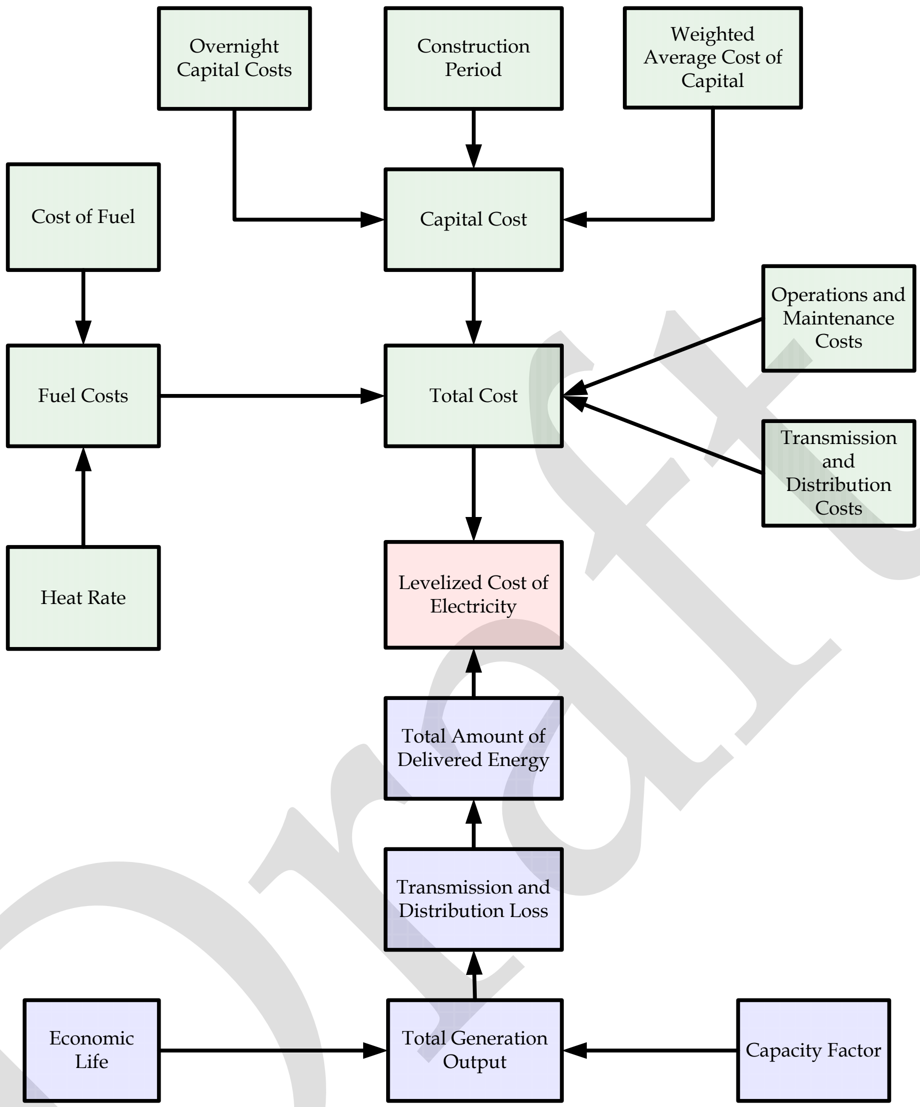
Calculating the levelized cost of generation enables financial comparisons to be made across technologies where variations may be significant. For example, some technologies might be capital intensive whilst others are fuel intensive. Alternatively, some technologies might have superior output capabilities to others but also have higher capital or installation costs.

3.1. Key Determinants in Generation Levelized Cost Analysis

Figure 1 depicts how the key inputs interface with each other to determine the levelized costs for each technology.

[18] It is important to note that this calculation does not imply that *each year* (discounted) revenues will equal (discounted) costs. In fact, in the earlier years of a plant's lifetime, discounted costs are likely to be greater than discounted revenues.

Figure 1: Key Determinants in Levelized Cost Analysis



Below is a brief discussion of each of the key components of levelized costs and the reasons these may vary across technologies.

3.1.1. Capacity Factor

Typically, the "size" of a generation plant refers to its nameplate capacity. If a plant has a nameplate capacity of 200 megawatts (MW), it can theoretically produce 200 MW of electricity every hour. Thus, the maximum amount of MWh it could produce in a given year, in theory, is 1,752,000 MWh.[19]

However, no generation plant can run for 100 percent of the time, certainly not over its entire lifetime. The *capacity factor* of a plant is the ratio of the electricity that is feasibly expected to be produced by the generation plant over its lifetime to the electricity that could theoretically be produced if the plant were to run continually at full power over its lifetime.

Table 2 shows the amount of electricity generated by a plant with a nameplate capacity of one MW in a year for various capacity factors.

Table 3: Annual Electricity Generated for a 1 MW Plant with Various Capacity Factors

Capacity Factor	*Annual Electricity Generated (MWhs)*
10%	876
20%	1,752
30%	2,628
40%	3,504
50%	4,380
60%	5,256
70%	6,132
80%	7,008
90%	7,884
100%	8,760

Source: Authors' Calculations

A higher capacity factor corresponds to a greater amount of electricity that a plant can produce in a given year. Thus, for a given technology and plant life, a higher capacity factor also corresponds to lower levelized cost. This is because the fixed costs, capital costs (including finance charges), and some fixed operations and maintenance costs will be distributed over more output MWhs.

[19] 8,760 hours per year x 200 MW capacity.

Given the various generation technologies and their differences in overall cost composition, a given percentage increase in capacity factor is going to have a varying effect on levelized costs. Those technologies that tend to be more capital intensive (more of the overall costs of generation are capital/fixed costs) will benefit more, reducing levelized costs, from an increase in capacity factors than technologies that tend to more variable cost (for example, fuel costs) dominant.

3.1.2. Life of Plant

The life of a plant is another important factor that determines the overall levelized cost of electricity. The longer the lifetime of a generation plant, for a given capacity factor, the greater the overall level of output generated. This increased level of output will cause the fixed costs per unit of output to fall. This will ultimately lower the levelized cost of producing electricity.[20] Again, more capital or fixed cost intensive technologies will benefit more, in terms of reductions in levelized costs, than those technologies that tend to be overall more variable/fuel cost orientated.

3.1.3. "Overnight" Capital Cost

The so-called "overnight" capital cost of a new generation plant is the summation of costs associated with the construction and purchase of equipment that enables the plant to be commercially operational.[21] These costs represent the expenditures that would be required as if the generation plant were constructed overnight. Overnight capital costs are usually expressed in terms of costs per kilowatt (kW) of installed nameplate capacity.[22] Importantly, these overnight capital costs do not include any finance costs associated with constructing a facility.

[20] Assuming that the increased lifetime of the generation plant does not cause fixed costs and/or operations and maintenance costs to increase significantly.

[21] This is sometimes referred to as the EPC (engineering, procurement, construction) cost

[22] Note nameplate capacity and effective capacity (the output that will actually produce) will vary due to the generating plants capacity factor.

If overnight capital costs increase, and there are no changes in other levelized cost determinants,[23] then the levelized cost of generation will increase. The change in levelized costs across technologies will vary due to differences in plant lifetimes and/or capacity factors. The smaller the plant lifetime and/or the lower the capacity factor, the larger the absolute increase in levelized costs caused by increased overnight costs.

3.1.4. Cost of Capital

Construction of a generation plant is typically funded through a mixture of debt and equity. In order to secure sufficient levels of funding, competitive rates of return must be offered. The cost of capital is referred to as the weighted-average cost of capital (WACC), where the weights are determined by the particular mixture of debt and equity

An increase in the WACC will cause an increase in the overall cost of building and operating a generation plant thus this will ultimately increase levelized costs. The generation facilities that are more capital intensive (and therefore require higher levels of finance) will face larger increases in levelized costs if the WACC increases.

3.1.5. Construction Period

The levelized cost of generation increases as more time is required to build a plant. This increase in levelized cost is due to an increase in finance costs. The longer it takes to build a generation facility, the longer funds are tied up in the project and these funds require a rate of return. The construction period across technologies will vary. Some technologies such as nuclear have a longer construction time period than say natural gas due to the scale and complexity surrounding building nuclear rather than gas plants.

[23] For instance an increase in overnight costs might cause the plant capacity and/or lifetime of plant to increase or lower annual operations and maintenance costs.

3.1.6. Operations & Maintenance Costs

Operations and maintenance (O&M) costs are the costs associated with running a generation plant on a day-to-day basis. O&M costs might include the labor costs associated with workers at a plant or routine maintenance to ensure the plant is in good working order. It is common to express O&M costs as a dollar amount per kW of *installed* capacity per year.[24] It is also common in the literature to separate any fuel costs or payments.

The higher the O&M costs *per kilowatt of installed capacity* - which could differ across technologies due to varying labor requirements[25] - the higher the O&M costs *per MWh* of electricity.[26]

3.1.7. Fuel Costs

Some generation technologies, such as coal, natural gas and nuclear, require fuel as inputs to production. It is common to express fuel prices in terms of dollars per million British Thermal Units (Btu).[27]

For a given heat rate, higher fuel prices correspond to higher levelized costs. Fuel prices can and do vary significantly through time.[28] Thus for technologies that use fuels the *predicted* levelized cost may vary significantly from the *actual* levelized cost realized. When providing levelized cost estimates for these types of technologies, it is may be prudent to provide a range of values based on various assumed fuel prices.

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[24] There is usually a distinction made between fixed O&M costs and variable (non-fuel) O&M costs, which tend to be expressed in terms of dollars per kwh. However the variable O&M costs usually represent a small component of overall O&M costs so the focus is on fixed O&M costs.

[25] For example, in terms of number of workers and required skill sets.

[26] Even if the O&M costs per installed kilowatt of capacity are the same across technologies, if the capacity factors are different, O&M costs per MW will vary.

[27] A Btu is the quantity of heat required to raise the temperature of 1 pound of liquid water by 1 degree Fahrenheit at the temperature at which water has its greatest density - approx 39 degrees Fahrenheit. MBtu (and sometimes MMBtu) represent a million British thermal units.

[28] A utility's ability to hedge against future price increases (by agreeing a fixed price contract) is directly linked to its overall financial "health".

3.1.8. Heat Rates

Heat rates measure the amount of Btus each generation technology uses to generation one unit of electricity. It is common to report heat rates as the number of Btus needed to generate one kilowatt hour of electricity. An improvement in fuel efficiency would be reflected in the lowering of heat rates.

It is a combination of fuel prices and heat rates that ultimately determines the fuel cost component in levelized costs. If fuel prices increase and at the same time heat rates fall, the net effect on levelized costs is dependent on which factor changes by the greater proportion.[29]

3.1.9. Inflation Rate

Generation costs are distributed over the lifetime of a plant. To calculate levelized costs in real terms, all future cost payments that are in nominal terms have to be converted into real dollars.

It is important to note that when real levelized costs are calculated, to ensure that sufficient revenue is generated over the plant's lifetime to recoup all costs, the electricity provider must be able to *maintain* the real price of electricity that it charges. For this to occur, the electricity provider must be able to increase electricity prices at the assumed inflation rate.

3.2. Other Costs of Electricity Provision

The discussion thus far has been on the levelized cost of *generation*. However, there are other significant costs that are incurred as part of ensuring electricity *provision*. There are costs incurred in ensuring that the correct amount of electricity is delivered to the final customer in a timely fashion.

[29]If fuel prices increase there is a greater incentive (increased cost savings) to attempt to improve heat rates.

3.2.1. Transmission and Distribution (T&D) Costs

Electricity provision requires a transportation system that enables electricity to be moved from an electricity generation plant's location (supply) to the final customer's location (demand), which is often referred to as a load pocket.

Transmission lines move electricity at high voltage (typically 69,000 volts or higher) from power plants to transformers via a network of power lines. Transformers, which are typically found in fenced enclosures close to the load pocket/communities, connect high-voltage transmission lines to the low-voltage distribution network. The distribution network ultimately delivers electricity to homes and businesses.

Transmission and distribution costs associated with electricity provision by a specific plant are a function of the location of the plant relative to the load pocket. The further the generation source is from the load pocket and/or existing transmission lines that have available capacity, the higher the final cost of delivering electricity to the final customer. Also, if the load pocket is relatively dispersed, the required distribution costs will be higher, resulting in an increase to the delivered cost of electricity.

Given that transmission and distribution costs are specific to location, the levelized costs of various technologies will ultimately depend on the delivery location. For example, the levelized cost estimates of electricity provision for the southern part of Arizona may differ from estimates in the northern part of Arizona.[30] Similarly, delivery costs might differ between rural and urban areas because of population density.

In order to simplify the analysis,[31] we adopt aggregate transmission and distribution cost estimates taken from the EIA.[32]

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[30]This difference could be caused by any of a number of factors. For example, the various technologies site locations available to serve the southern area/load pockets might be significantly further away than in the northern areas. Northern Arizona has greater wind capacity than southern Arizona. See Black and Veatch, 2007. Thus, to serve the southern area using wind resources might imply a significantly higher amount of transmission investment than what is required to serve the northern area.

[31] This will be re-examined in a future version of this report (Stage 2 of AzSMART).

3.2.1.1. Loss Factor

When electricity is transported from source (generation plant) to its destination (final customer), some of the electricity that is generated is lost. Because some electricity output is lost and therefore is not sold, the levelized cost of *delivered* electricity, even ignoring any transmission and distribution costs, will differ from the levelized cost of *generation*.

This loss factor can be important when comparing central generation plants[33] versus distributed generation systems[34] such as residential photovoltaic (PV) systems. This is because distributed systems potentially have lower loss factors[35] assuming that either the customer uses the electricity generated and/or excess generated power is sent short distances.

3.2.1.2. Intermittency and Reduction in Control Costs

The electrical grid requires supply and demand to match continually in real-time. One significant issue that surrounds some renewable generation sources, especially wind and solar, is the problem of intermittency. For the majority of technologies available the electricity provider has significant (sometimes complete) control over when and how much generation output will occur.

Technologies, such as wind and solar, are truly at the mercy of the elements. If on a particular day the solar insolation or wind speeds are low, the output from solar or wind is significantly negatively affected. Further, throughout a given day, the output from these sources can vary significantly. The provider has limited or no control over the generation timing profile.

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[32] The EIA has price forecasts broken down into components: generation, transmission and distribution.
[33] Utility scale generation plants
[34] Generation facilities that are customer located
[35] Potentially zero.

From a planning point of view, the timing of when electricity will be dispatched, relative to when it is required is an important concern. The time of dispatch is especially important when the planner is calculating which technologies are generation substitutes.

Improvements in storage capabilities have caused a reduction in some of the issues surrounding variability or timing, especially for solar. Additionally, to counter these issues there are three options available to the electricity provider:

1. do not install these types of generation facilities;
2. choose locations to install these facilities that have the smallest amount of potential variability – e.g. consistently windy/sunny areas;
3. install additional traditional generation sources to act as back-up facilities.

The first option is limited in Arizona. Given that regulated utilities are required to meet renewable portfolio standards, their ability to avoid building intermittent renewable technologies is directly linked to their ability to meet the RPS requirement through out-of-state renewable electricity purchases. The second option has some potential tradeoffs. The most desirable locations might be a significant distance away from load pockets. Any cost reductions created by increased annual output or reduced variability in output levels might be offset by increased transmission and distribution costs. The third option solves the intermittency issue by having sufficient back up generation facilities that can be utilized when needed because of a reduction or variability in output from renewable sources. Typically, the back-up generation would be natural gas plants, as they are the most time-flexible form of generation. Having back-up generation in place increases the overall cost of implementing renewable generation technologies.

The intermittency/integration costs are important when evaluating traditional versus renewable generation sources. Understanding the costs associated with having a significant deployment of renewable resources is an on-going resource agenda.[36]

[36] See Northern Arizona University, 2007 for an example.

In order to compare *all* generation technologies on an equal basis we have chosen to set aside any intermittency and/or reduction in control costs at this juncture.

4. Cost Estimations

To calculate levelized cost estimates, where available, data from the EIA was adopted. The advantage of the EIA data is that it provides information on a significant number of the factors discussed in Section 3 for a broad range of technologies.[37]

Due to the uncertainty surrounding the future cost of building power plants,[38] the EIA forecasts four capital cost cases through 2030 that attempt to encapsulate some of the uncertainty surrounding capital costs. These scenarios also include potential learning-by-doing effects as well as a technology optimism factor.[39]

In the EIA *reference case*, initial overnight costs for all technologies are updated to be consistent with costs estimates collected in early 2008. Changes in these overnight capital costs are driven by a cost adjustment factor, which is based on the projected producer price index for metals and metal product.[40]

The *frozen plant capital costs case* assumes that base overnight costs for all new electric generating technologies are frozen at 2013 levels. However, cost decreases due to learning can and do still occur.[41] For the majority of technologies examined, the capital costs are higher than the reference case in 2030, but lower than 2008 levels.

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[37] To make the estimates Arizona centric, some alterations were made where it was felt required. For instance the EIA assumes a wind capacity of over 40 percent whilst in Arizona it appears that the highest capacity factor is approximately 35 percent (Black & Veatch, 2007).
[38] Construction inflation has received some attention in recent years. See (Seidman Research Institute, 2008) for a recent discussion of construction inflation in Arizona.
[39] For more details on these factors see (EIA, 2009).
[40] The EIA reports that there is significant correlation between commodity prices and power plant costs, however there may be other factors that influence future costs that raise the uncertainties surrounding the future costs of building new power plants – thus the need for various alternative capital cost cases.
[41] Especially for some renewable technologies.

The *rising capital costs case* assumes that the cost adjustment factor is 25 percentage points higher than in the reference case between 2013 and 2030. Cost decreases due to learning can and do still occur. These cost reductions can partially or fully offset any cost factor increases, however for most technologies, costs in 2030 are *above* their 2008 levels.

The *falling plant capital costs case* assumes that overnight costs for the various generating technologies decreases at a faster rate than in the reference case, starting in 2013. By 2030, the cost adjustment factor is assumed to be 25 percentage points below its reference case value.

These additional capital cost cases enable some sensitivity analysis to be performed to see how the levelized costs of the different technologies may change under various different capital cost assumptions.[42]

Below is a snapshot of the overnight capital cost assumed throughout the analysis Capital costs here do not include any federal or state tax credits or incentives.

[42] See Section 4.2.

Table 4: Capital Cost For Various Generation Technologies (per Kilowatt 2007$)

	Reference		*Frozen*		*Rising*		*Falling*	
Technology	**2009**	**2030**	**2009**	**2030**	**2009**	**2030**	**2009**	**2030**
Scrubbed New Coal	$2,054	$1,654	$2,058	$1,964	$2,066	$2,456	$2,044	$1,170
IGCC	$2,370	$1,804	$2,374	$2,141	$2,384	$2,668	$2,358	$1,276
IGCC with carbon sequestration	$3,477	$2,533	$3,484	$3,006	$3,498	$3,746	$3,459	$1,791
Conv Gas/Oil Comb Cycle	$960	$773	$962	$918	$966	$1,144	$955	$547
Adv Gas/Oil Comb Cycle (CC)	$945	$717	$947	$851	$951	$1,060	$940	$507
Adv CC with carbon sequestration	$1,879	$1,340	$1,883	$1,590	$1,891	$1,981	$1,869	$947
Conv Comb Turbine	$669	$539	$670	$640	$673	$797	$665	$381
Adv Comb Turbine	$632	$460	$633	$545	$636	$680	$628	$325
Fuel Cells	$5,307	$3,456	$5,317	$4,104	$5,339	$5,113	$5,280	$2,445
Adv Nuclear	$3,303	$2,372	$3,309	$2,951	$3,323	$3,676	$3,286	$1,653
Biomass	$3,747	$2,488	$3,754	$3,012	$3,769	$3,834	$3,728	$1,735
MSW - Landfill Gas	$2,538	$2,043	$2,543	$2,426	$2,553	$3,023	$2,525	$1,446
Geothermal	$1,958	$3,942	$1,962	$4,661	$1,970	$5,825	$1,948	$2,678
Conventional Hydropower	$2,253	$1,920	$2,257	$2,157	$2,266	$2,690	$2,235	$1,179
Wind	$1,921	$1,615	$1,925	$1,918	$1,933	$2,389	$1,912	$1,143
Wind Offshore	$3,830	$2,859	$3,838	$3,395	$3,854	$4,230	$3,811	$2,023
Solar Thermal	$4,959	$3,082	$4,969	$3,660	$4,989	$4,560	$4,934	$2,181
Photovoltaic	$5,978	$3,823	$5,990	$4,539	$6,014	$5,655	$5,948	$2,705

Source: EIA

The EIA also provides data on O&M costs, construction time, and heat rates for various technologies. Capacity factor information was taken from the EIA, (2009), Lazard, (2008) and Black & Veatch, (2007). Table 5 provides details.

Table 5: O&M Costs, Construction Period, Heat Rates and Capacity Factors for Various Generation Technologies

Technology	*Capacity Factor*[43]	*Fixed O&M ($2007/kW-yr)*	*Variable O&M ($2007/kWh)*	*Construction Period (yrs)*	*Heat Rate (Btu/kWh)*[44]	
					2008	**2030**[45]
Scrubbed New Coal	0.85	$27.53	$0.0046	4	9,200	8,740
IGCC	0.80	$38.67	$0.0029	4	8,765	7,450
IGCC with carbon sequestration	0.80	$46.12	$0.0044	4	10,781	7,307
Conv Gas/Oil Comb Cycle	0.85	$12.48	$0.0021	3	7,196	6,800
Adv Gas/Oil Comb Cycle (CC)	0.85	$11.70	$0.0020	3	6,752	6,333
Adv CC with carbon sequestration	0.85	$19.90	$0.0029	3	8,613	7,493
Conv Comb Turbine	0.85	$12.11	$0.0036	2	10,810	10,450
Adv Comb Turbine	0.85	$10.53	$0.0032	2	9,289	8,550
Fuel Cells	0.95	$5.65	$0.0499	3	7,930	6,960
Adv Nuclear	0.90	$90.02	$0.0005	6	10,434	10,434
Biomass	0.83	$64.45	$0.0067	4	9,646	7,765
MSW - Landfill Gas	0.90	$114.25	$0.0000	3	13,648	13,648
Geothermal	0.90	$164.64	$0.0000	4		
Conventional Hydropower	0.60	$13.63	$0.0024	4		
Wind	0.35	$30.30	$0.0000	3		
Wind Offshore	0.40	$89.48	$0.0000	4		
Solar Thermal	0.31	$56.78	$0.0000	3		
Photovoltaic	0.23	$11.68	$0.0000	2		

Source: EIA, Lazard and Black & Veatch

[43] The EIA, (2009) capacity factor is presented unless the EIA does not provide an estimate, then the upper bound estimate from Lazard is taken. If the EIA capacity factor is higher (lower) than the upper (lower) bound provided by Black & Veatch, (2007) the Black and Veatch estimate is adopted.
[44] Only heat rates for technologies that require a fuel are presented.
[45] The EIA assumed that heat rates for fossil fuel technologies decrease linearly until 2025. Thus it was assumed that after 2025 the heat rate remains at its 2025 level.

Table 6 details the fuel cost assumptions made. Again, information was drawn from a variety of sources including EIA, Lazard and Black & Veatch. For instance, the EIA provides a forecast for natural gas and fuel prices however they do not provide a forecast for nuclear fuel or biomass fuel etc. Fuel prices were taken from the remaining sources in these instances.

Table 6: Fuel Cost Assumptions

	Cents per Million BTU (2009$)		
Fuel Type	**2009**	**2015**	**2030**
Natural Gas	7.09	7.53	9.75
Coal	2.03	2.06	2.16
Nuclear Fuel	0.52	0.52	0.52
Biomass Fuel[46]	2.19	2.19	2.19
Landfill Gas Fuel[47]	2.06	2.06	2.06

Source: EIA, Lazard and Black & Veatch

Finally, some inputs were assumed constant across technologies. These assumptions are simplifying assumptions due to a lack of detailed data existing that suggests that these inputs may vary significantly across technologies. Table 7 provides details.

Table 7: Common Assumptions

Variable	*Value*
Weighted Average Cost of Capital	13.2%
Economic Life	30
Transmission Loss Factor	8%
Inflation Rate	3%
Transmission and Distribution Costs per MWh[48]	$31.87 - 34.55

Source: Beck, EIA and Authors' Calculations

[46] The midpoint of the estimate was taken from Black & Veatch, (2007) and assumed constant in real terms over the forecast period.
[47] The midpoint of the estimate was taken from Black & Veatch, (2007) and assumed constant in real terms over the forecast period.
[48] The EIA forecasts some variability in T&D costs

4.1. Utility Scale Generation Levelized Cost Results

Using the data presented in the previous section point estimates of the levelized cost for each generation technology, under the various capital cost assumptions, are presented for the years 2009 and 2030 in table 8.

Table 8: Utility Scale Levelized Cost per MWh of Electricity Delivered in 2009 and 2030

	2009		*2030*		
Technology	**Reference[49]**	**Rising**	**Reference**	**Falling**	**% Change (Ref.)**
Scrubbed New Coal	$102	$112	$96	$86	-5.9%
IGCC	$111	$118	$99	$87	-10.8%
IGCC with carbon sequestration	$141	$144	$117	$101	-17.2%
Conv Gas/Oil Comb Cycle	$105	$125	$119	$115	13.5%
Adv Gas/Oil Comb Cycle (CC)	$101	$119	$113	$109	11.8%
Adv CC with carbon sequestration	$133	$149	$138	$131	3.5%
Conv Comb Turbine	$125	$155	$150	$148	20.3%
Adv Comb Turbine	$113	$133	$130	$128	15.1%
Fuel Cells	$228	$239	$212	$196	-7.0%
Adv Nuclear	$132	$144	$111	$93	-16.0%
Bio-mass	$148	$148	$120	$104	-19.1%
MSW - Landfill Gas	$119	$130	$113	$103	-5.4%
Geothermal	$92	$169	$133	$108	43.8%
Conventional Hydropower	$103	$118	$96	$74	-7.4%
Wind	$127	$150	$116	$95	-9.0%
Wind Offshore	$227	$246	$186	$150	-17.8%
Solar Thermal	$301	$283	$210	$165	-30.3%
Photovoltaic	$393	$375	$267	$201	-32.0%

Source: Authors' Calculations

[49] Only the reference case is shown in 2009 as there is little difference between the cases.

Figure 2: Levelized Cost of Delivered Electricity 2009: Reference Case

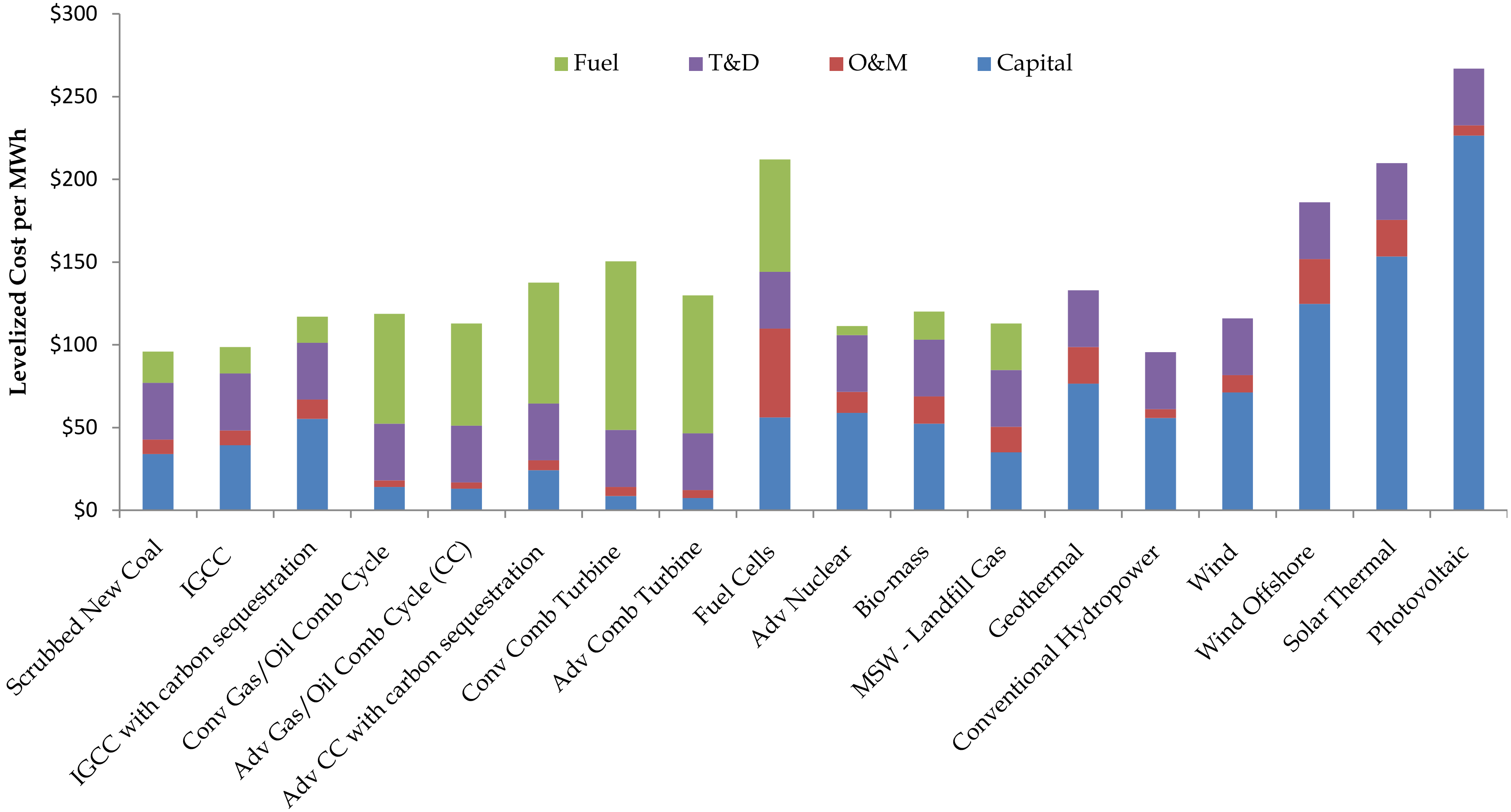
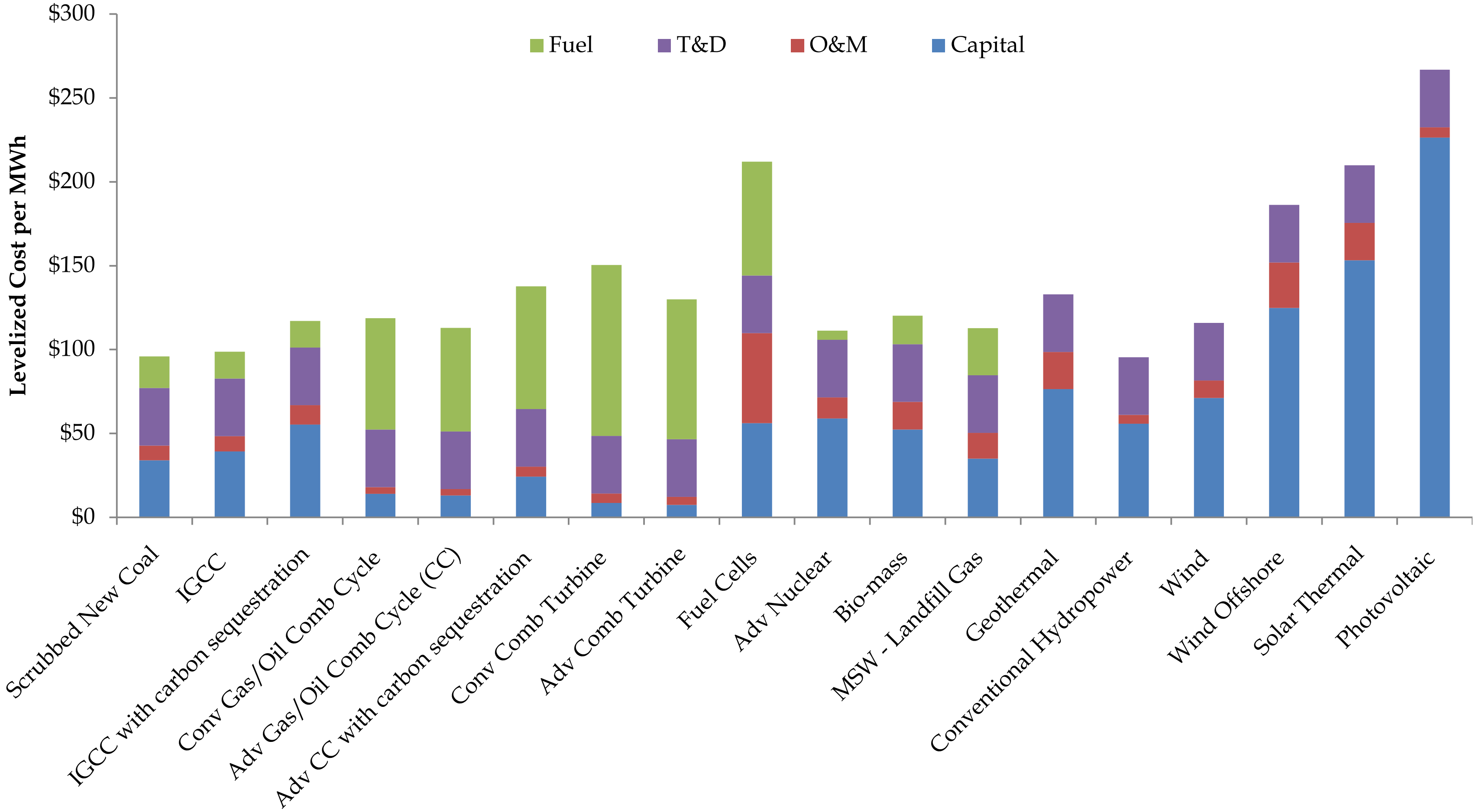


Figure 3: Levelized Cost of Delivered Electricity 2030: Reference Case



Examining Table 8, if significant capital cost reductions (falling capital cost) occur for solar generation then the levelized cost per MWh in 2030 for solar thermal is $165 and for PV it is $201. If we assume rising capital costs for traditional generation all traditional resources have a levelized cost ranging from $112 (scrubbed coal) to $155 (gas conventional combustion turbine).[50]

Even if solar generation enjoys significant *reductions* in capital costs (45-59 percent) whilst traditional generation face *increasing* capital costs (1-23 percent) traditional generation still remains more competitive in 2030 if there is no government intervention.

For solar thermal to achieve a levelized cost of $155 per MWh in 2030 its overnight capital cost per KW would need to be approximately $2,100 (2009$) whilst PV overnight capital costs per KW would have to be approximately $1,960 (2009$). These capital costs represent reductions of 58 percent and 67 percent relative to the reference capital cost case in 2009.

Alternatively if gas prices are approximately $11.20 (2009$) per MBTU in 2030 then the levelized cost of gas conventional combustion turbine would be equal to that of solar thermal ($165 per MWh). The gas price of $11.20 represents an increase of 15 percent above the EIA forecast in 2030 ($9.75 (2009$)).

High capacity factor wind generation[51] initially appears to be competitive against some traditional resources (mainly gas and nuclear). However, some caution must be exercised, as the analysis has not yet incorporated the additional costs of integration and transmission.[52] Also, the amount of high capacity factor wind in Arizona is limited.[53]

[50] Assuming a natural gas fuel cost of 9.75 cents (2009$) per million BTU.
[51] In Arizona the "high capacity factor wind" is approximately 35 percent.
[52] For instance, in Beck, (2009) their integration costs may vary from approximately $1-$4 per MWh depending upon the amount of wind penetration.
[53] See Black and Veatch, (2007).

4.2. Levelized Cost Sensitivity Analysis

To investigate how the levelized cost of the various generation technologies may vary with changes in the input variables, Monte Carlo simulations were run using @RISK.[54] Assigning distributions to the key inputs, Monte Carlo simulations provide a probability distribution associated with the levelized costs of each generation technology and a 90 percent confidence interval can be derived.

To run Monte Carlo simulations using @RISK requires upper and lower bounds on the variability for the various inputs be defined Also the type of distribution assumed must also be defined – in all cases to simplify the analysis triangular distributions were assumed. Table 9 and 10 describes the upper and lower bounds assumed.

Table 9: Variability in Common Assumptions and Fuel Prices

Variable	*Low*	*Mean*	*High*
WACC	11.88%	13.20%	14.52%
Economic Life	25	30	40
Transmission Loss Factor	7.20%	8%	8.80%
Inflation Rate	2%	3%	6.80%
Natural Gas Fuel (Cents per MBtu $2009)	7.09	7.53	9.75
Coal Fuel (Cents per MBtu $2009)	2.03	2.06	2.16
Nuclear Fuel (Cents per MBtu $2009)	0.468	0.52	0.572
Biomass Fuel (Cents per MBtu $2009)	1.971	2.19	2.409
Landfill Gas Fuel(Cents per MBtu $2009)	1.854	2.06	2.266

[54] A Monte Carlo simulation draws values from a distribution for each key input and uses these "draws" to calculate the levelized cost.

Table 10: Variability in Capacity Factor

Capacity Factor	*Low*	*Mean*	*High*
Scrubbed New Coal	0.80	0.85	0.90
IGCC	0.75	0.80	0.85
IGCC with carbon sequestration	0.75	0.80	0.85
Conv Gas/Oil Comb Cycle	0.80	0.85	0.90
Adv Gas/Oil Comb Cycle (CC)	0.80	0.85	0.90
Adv CC with carbon sequestration	0.80	0.85	0.90
Conv Comb Turbine	0.80	0.85	0.90
Adv Comb Turbine	0.80	0.85	0.90
Fuel Cells	0.90	0.95	0.99
Adv Nuclear	0.85	0.90	0.95
Biomass	0.75	0.83	0.90
MSW - Landfill Gas	0.85	0.90	0.95
Geothermal	0.85	0.90	0.95
Conventional Hydropower	0.55	0.60	0.65
Wind	0.25	0.30	0.35
Wind Offshore	0.35	0.40	0.45
Solar Thermal	0.25	0.31	0.40
Photovoltaic	0.20	0.23	0.30

The 90 percent levelized cost confidence intervals for the various technologies for the reference capital cost case in 2030 are presented in table 11.[55]

[55] 100,000 iterations were completed.

Table 11: 90 Percent Confidence Interval for Reference Capital Case in 2030

	2030		
Technology	**Lower Bound**	**Mean**	**Upper Bound**
Scrubbed New Coal	$89	$93	$98
IGCC	$90	$96	$101
IGCC with carbon sequestration	$105	$112	$120
Conv Gas/Oil Comb Cycle	$102	$108	$116
Adv Gas/Oil Comb Cycle (CC)	$97	$103	$110
Adv CC with carbon sequestration	$118	$125	$134
Conv Comb Turbine	$126	$135	$147
Adv Comb Turbine	$110	$117	$127
Fuel Cells	$189	$198	$208
Adv Nuclear	$98	$107	$116
Biomass	$109	$117	$125
MSW - Landfill Gas	$106	$111	$116
Geothermal	$116	$127	$138
Conventional Hydropower	$83	$91	$100
Wind	$106	$123	$143
Wind Offshore	$155	$176	$198
Solar Thermal	$161	$192	$227
Photovoltaic	$195	$236	$279

Source: Authors' Calculations

Examining the confidence intervals, the sensitivity analysis suggests that solar generation will still remain uncompetitive against traditional resources in 2030 for the reference capital cost case. There is no overlap between the solar thermal and photovoltaic 90 percent confidence intervals and traditional generation confidence intervals.

5. Negative Generation: Energy Efficiency Options

So far the focus has been on the costs of generating and delivering *additional* electricity. Instead, an alternative approach is to examine negative generation options. Consumers could adopt energy-efficient options which enables them to lower their overall electricity requirements.

The method used to calculate the levelized cost of energy-efficient options (negative generation) differs from the method used to calculate levelized costs for different types of generation technologies.

The *additional* capital costs associated with adopting an energy-efficient option versus an alternative "standard option" is compared against the total amount of electricity savings obtained by adopting the more energy-efficient option over its lifetime.

Given that it is the *additional* capital costs that is used to determine the levelized costs associated with an energy-efficient options, implicitly the levelized cost analysis is assuming either that the adopter is replacing a option that is at the end of its useful life or the adopter currently does not have the standard option in place.

If the adopter already has a functioning standard option in place then the correct cost of installing the energy-efficient option is the *full* capital cost associated with purchasing and installing the energy-efficient option. This would significantly increase the levelized cost of each energy-efficient option.

A recent paper (ICF International, 2007) examined the market potential for energy-efficient options in Arizona Public Service Company's (APS) service area. It identified one hundred suitable energy-efficient options.[56] The most significant area for energy efficiency savings were identified as central air conditioning in the residential sector. In the non-residential sector heating, ventilating and air conditioning (HVAC) systems and interior lighting would play the largest roles in securing energy efficiencies.

[56] Out of an estimated 223 potential energy efficient measures. See ICF (2007) for more details.

The options examined in the paper (ICF International, 2007) are recent, comprehensive and Arizona specific and thus represent the best source of information on the levelized cost of energy-efficient options in Arizona. Because of this, the levelized cost calculations from the paper were adopted and extrapolated out to estimate the total potential amount of energy savings available in all of Arizona.

It is important to note that energy-efficient options' levelized costs do not act in the same way as generation levelized costs. The levelized costs associated with energy-efficient options are usually ranked from lowest to highest. As the lowest cost energy-efficient options are assumed to be adopted first, the implication is that to generate additional energy efficiencies the levelized cost would increase. With generation levelized costs it is usually assumed that replication of plants is possible at a constant levelized cost especially when examining traditional sources of generation.[57]

Energy-efficient options have an advantage over generation options because they typically do not incur any transmission and distribution costs or have any loss factors (lost savings) associated with them. In fact, energy-efficient options can potentially *lower* the overall level of required transmission and distribution investment by reducing overall electricity demand.[58]

Using the results from (ICF International, 2007), there are significant energy efficiencies to be made in the APS service area alone over the next twenty years at a levelized cost less than those reported for generation.

[57] Sensitivity analysis can be performed to show how levelized costs may vary as and when the more ideal "locations" for generation are used up first. This may be particularly important when examining renewable generation such as solar and wind that tend to have more location specific levelized costs than other traditional forms of generation.
[58] Any transmission and distribution savings have been ignored.

It is estimated that if all cost effective energy-efficient options[59] were adopted, APS' annual energy requirements would decrease by approximately 8,000 gigawatt hours (GWhs). If all identified energy efficiency measures were adopted then the reduction would be 9,000 GWhs.[60]

The majority of energy efficiency measures examined have a levelized cost of between $0 and $50 per MWh but increase significantly once approximately 8,000 GWh hours (1,600 MW of capacity) has been "installed".[61]

Given that APS' market share is approximately 38 percent[62] and assuming that non-APS service areas are similar to APS',[63] scaling up these efficiencies suggests that the state could obtain approximately 21,000 GWh hours of cost-effective energy efficiency savings.[64]

6. Conclusions

There are numerous technologies that can be employed to enable utilities to continue to meet electricity requirements in Arizona, now and in the foreseeable future. Examination of unfettered market-determined levelized costs for new utility scale generation yields important insights. High capacity factor wind and energy efficiency programs are likely competitive with traditional sources of generation.[65] Unfortunately both high capacity factor wind and cost effective energy efficiencies are capacity constrained in Arizona.

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[59] They determine cost effective (economic potential) occurring when the levelized cost of the efficiency measure is less than or equal to the avoided generation costs (which is approximately 5-8 cents.).
[60] The levelized costs associated with the difference between the cost effective and technical potential energy efficiency savings (approximately 1,000 GWhs) increases significantly from approximately 5-8 cents to 25 cents. These saving may become cost effective if energy efficiency can be used as a substitute for renewable generation (thus the "avoided costs" used to determine cost effective could potentially be higher) which is being considered at the moment at the federal level.
[61] It is important to again note that the analysis uses incremental capital costs.
[62]EIA estimate for 2006.
[63]This is a strong but simplifying assumption.
[64]However, just because there are cost effective energy efficiency measures from a utility's perspective this does not mean that customers will immediately adopt the measure. The savings may occur over a longer time period than the customer will living in the house or the customer may have a higher discount rate than the utility or the customer may be credit-constrained.
[65] Although other non-financial factors such as intermittency and timing of output might hinder wind's competitiveness versus traditional generation.

In an analysis of solar, the renewable resource that Arizona has in plentiful supply, we find some stark results. Solar thermal and utility-scale PV systems are not cost-competitive, now or in the foreseeable future, against other traditional generation resources without significant government intervention that alters the market determined value of the key inputs that determine costs of generation or significant deviations away from the expected future values of the key inputs such as capital and fuel costs.

Glossary

British Thermal Unit (Btu): A Btu is the quantity of heat required to raise the temperature of 1 pound of liquid water by 1 degree Fahrenheit at the temperature at which water has its greatest density - approx 39 degrees Fahrenheit.

Capacity factor: The ratio of the electricity that is feasibly expected to be produced by a generation plant over its life time considered to the electricity that could have been produced if the plant runs continually at full power over its lifetime.

Levelized Cost: The levelized cost of generation is the constant real price for this report that producers would need to receive if all the incurred costs of installing (including finance costs), operating and maintaining the plant are recovered over the life of the plant.

Nameplate capacity: The maximum amount of electricity (typically measured in megawatts) that an electricity generating plant can produce each hour. For example, if a plant has a nameplate capacity of 200 megawatts then theoretically the plant can produce 200 megawatts of electricity every hour.

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