Distributed Generation Potential Study for Pennsylvania

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ACEEE	American Council for an Energy-Efficient Economy
BC	Benefit-Cost
CBECS	Commercial Buildings Energy Consumption Survey
CHP	Combined heat and power
DG	Distributed generation
DOE	Department of Energy
DSM	Demand-side Management
EDC	Electric Distribution Company
EF	Energy Factor
EIA	Energy Information Administration
EM&V	Evaluation, measurement and verification
EPA	Environmental Protection Agency
EUL	Effective Useful Life
KW	Kilowatt
KWH	Kilowatt hour
MECS	Manufacturing Energy Consumption Survey
MEF	Modified Energy Factor
MET ED	Metropolitan Edison Company
MFG	Manufacturing
MPS	Market Potential Study
MW	Megawatt
MWH	Megawatt hour
NEEP	Northeast Energy Efficiency Partnership
NREL	National Renewable Energy Lab
NTG	Net-to-gross
PA	Pennsylvania
PECO	PECO Energy Company
PENELEC	Pennsylvania Electric Company
PENN POWER	Pennsylvania Power Company

PPL	PPL Electric Utilities Corporation
PUC	Public Utility Commission
PY	Program Year
RECS	Residential Energy Consumption Survey
SEER	Seasonal Energy Efficiency Ratio
Solar PV	Solar Photovoltaic
SWE	Statewide Evaluator
T&D	Transmission and distribution
TRC	Total Resource Cost Test
TRM	Technical Reference Manual
WPP	West Penn Power Company

EXECUTIVE SUMMARY

This study summarizes the distributed generation (DG) market potential analysis performed by the Statewide Evaluator (SWE) team for the State of Pennsylvania through a 10-year period of June 1, 2016 through May 31, 2025. The State of Pennsylvania commissioned the study as a companion report to the "Energy Efficiency Potential Study for Pennsylvania[1]". The SWE conducted this study noting that as part of Act 129[2] "EE&C[3] measures" that count towards a possible Phase III energy reduction target can include commission-approved DG technologies such as solar photovoltaic and combined heat and power.

Approach Summary

The SWE team used a bottom-up approach to estimate the potential of various distributed generation technologies in the residential, commercial and industrial sectors. The DG technologies assessed in this study are categorized as rooftop solar photovoltaic (solar PV) and combined heat and power (CHP) technologies. The SWE utilized a "bottom-up" modeling approach to first estimate technology-level savings and costs to estimate cost-effectiveness, and then applied cost-effective technology generation savings to all applicable shares of each EDC's energy load. While the SWE considered the cost-effectiveness[4] of several measures within each DG category, only those measures that were cost-effective and/or found to be part of electric distribution company (EDC)[5] DSM portfolios were fully analyzed in this report for technical, economic and achievable potential. Some measures such as landfill gas, animal waste gas, digester and small-scale wind (less than 500 kW systems) were not analyzed beyond cost-effectiveness, and therefore are not included in the SWE team's estimate of technical potential. Further details of the market research and modeling techniques utilized in this assessment are provided in **Section 1** of this report.

Cumulative vs. Incremental Annual Savings

It is important to note the distinction between cumulative annual savings and incremental savings. Incremental annual savings are those which occur in a given year due to participation in energy efficiency programs in that given year. Cumulative annual energy savings are those which accumulate in any given year due to participation in distributed generation programs in that given year as well as participation in prior years, to the extent that participation in prior years continues to yield savings. Cumulative annual energy savings account for the fact that technologies installed in prior years may have useful lives which are greater than one year, and therefore produce savings which persist into the future for some time. However, cumulative annual energy savings also reflect savings decay – that is savings that can no longer be counted in a given year once a measure is no longer operational or has "burned-out."

All savings values included in this report reflect cumulative annual savings. However, for the purposes of this study cumulative annual and the sum of the annual incremental are identical since the study horizon is 10 years, and no technologies included in this report have an estimated useful life (EUL) of less than 10 years.

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[1] *Energy Efficiency Potential Study for Pennsylvania*, Statewide Evaluation Team, 2015.

[2] Act 129 EE&C Phase II Implementation Order – Entered Aug. 3, 2012.The Act 129 Phase 2 EE&C Program Implementation Order. From the Public Meeting of August 2, 2012. Docket Nos. M-2012-2289411 and M-2008-2069887

[3] EE&C = energy efficiency and conservation

[4] Per the PA Act 129 TRC Order

[5] EDCs evaluated within this study include Duquesne Light and Power, PPL Energy, PECO Energy, and the four First Energy Companies: Met-Ed, Penelec, PennPower, and West Penn Power.

Study Limitations

As with any assessment of potential, this study necessarily builds on various assumptions and data sources, including the following:

- DG technology lives, technology savings and technology costs
- The discount rate for determining the net present value (NPV) of future savings
- Projected penetration rates for DG technologies
- Projections of electric generation avoided costs for electric capacity and energy as defined in the 2009 and 2011 Pennsylvania PUC TRC Orders
- Projections of transmission and distribution (T&D) avoided costs
- EDC load forecasts and assumptions on their disaggregation by sector, segment, and end-use

While the SWE has sought to use the best and most current available data, there are assumptions where there may be a reasonable alternative that would yield slightly different results. Furthermore, while the lists of DG technologies examined in this study characterize a representative list of commercially available solar PV and CHP technologies, the technology list is not exhaustive. Finally, there was no attempt to place a dollar value on some difficult to quantify non-energy benefits arising from installation of some technologies, such as CO2 emission reductions or the value of energy security in the case of a power grid failure, which may in turn support some personal choices to implement particular DG technology that may otherwise not be cost-effective or only marginally so.

Distributed Generation Savings Potential Findings

Table ES-1 and Figure ES-1 summarize the cumulative annual potential of all DG technologies in Pennsylvania. All energy (MWh) and demand (MW) potential in this report is summarized at the 3, 5 and 10 year time horizon. Of note is that while technical potential includes energy and demand savings from both CHP and solar PV technologies, cost-effective potential was found only for CHP technologies under PA's TRC test, and therefore is the only technology contributing to economic and achievable potential. The SWE estimates that 413,508 MWh of potential (47.2 MW of demand savings) can be realized with DG technologies by 2020 under the base achievable scenario, representing 0.3% of total energy sales. The SWE also estimates an emissions reduction potential of approximately 150,481 metric tons of carbon dioxide (CO2) associated with the base achievable scenario by 2020.

Table ES-1: Statewide Cumulative Energy & Demand Savings Potential by Scenario by Year

Scenario	2018	2020	2025	Average Annual
Cumulative Savings Potential - MWh				
Technical	13,117,733	21,924,076	44,145,324	4,414,532
Economic	617,949	1,033,036	2,079,790	207,979
Maximum Achievable	494,476	826,624	1,664,225	166,422
Base Achievable	247,355	413,508	832,506	83,251
Cumulative Energy Savings Potential - % of 2010 Total Load				
Technical	8.9%	14.9%	30.1%	3.0%
Economic	0.4%	0.7%	1.4%	0.1%
Maximum Achievable	0.3%	0.6%	1.1%	0.1%
Base Achievable	0.2%	0.3%	0.6%	0.1%
Demand Savings Potential – Peak MW				
Technical	2,384.9	3,985.8	7,997.4	799.7

Scenario	2018	2020	2025	Average Annual
Economic	70.5	117.9	237.4	23.7
Maximum Achievable	56.4	94.4	190.0	19.0
Base Achievable	28.2	47.2	95.0	9.5
Cumulative Demand Savings Potential - % of 2014 Total Load				
Technical	13.0%	21.7%	43.5%	4.4%
Economic	0.4%	0.6%	1.3%	0.1%
Maximum Achievable	0.3%	0.5%	1.0%	0.1%
Base Achievable	0.2%	0.3%	0.5%	0.1%
Avoided CO_2 Savings Potential – Metric Tons[6]				
Technical	8,623,668	14,412,268	29,019,853	2,901,985
Economic	224,880	375,935	756,862	75,686
Maximum Achievable	179,946	300,819	605,633	60,563
Base Achievable	90,016	150,481	302,959	30,296

Figure ES-1: Statewide Cumulative DG Energy (MWh) Savings by Scenario by Year

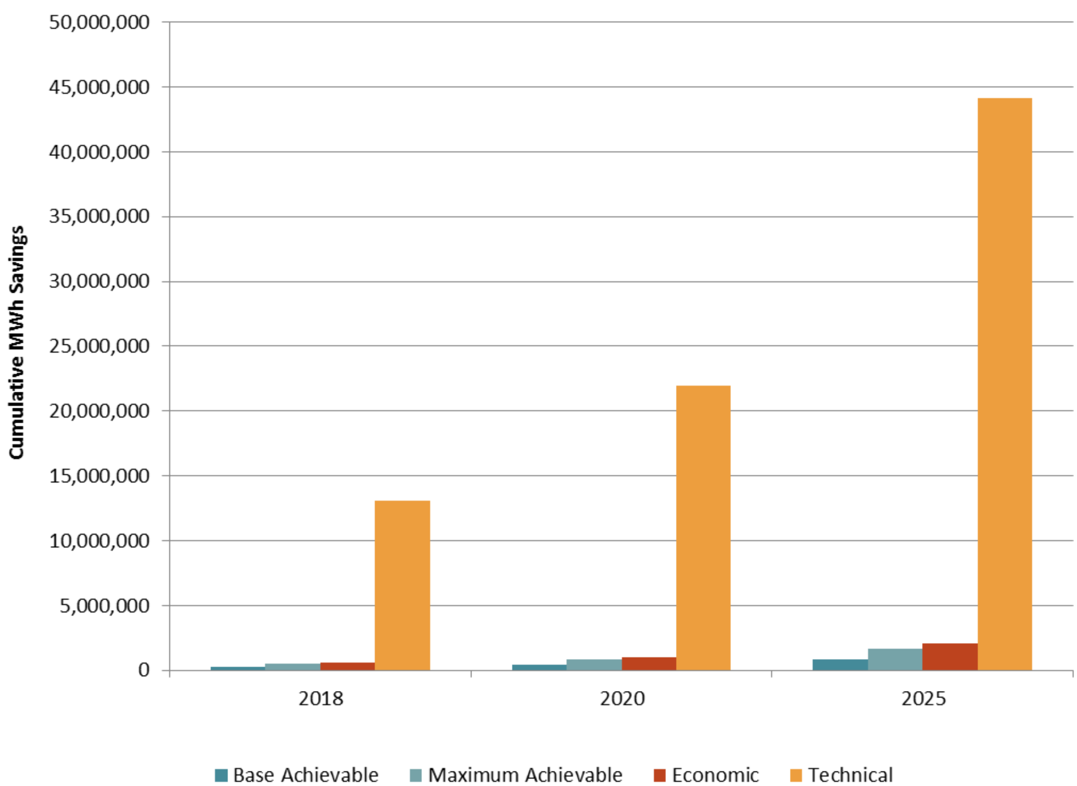


Figure ES-2 shows the cumulative annual energy (MWh) savings impacts for each potential scenario relative to the combined EDC statewide load forecast for 2016-2025.

[6] The SWE used a CO2 emission rate multiplier of 1,707 lbs of CO2 per MWh-saved derived from a 2014 PJM Emission Report, then converted it to metric tons

Figure ES-2: 2016-2025 Statewide Energy Forecast and DG Potential Savings Projections by Scenario

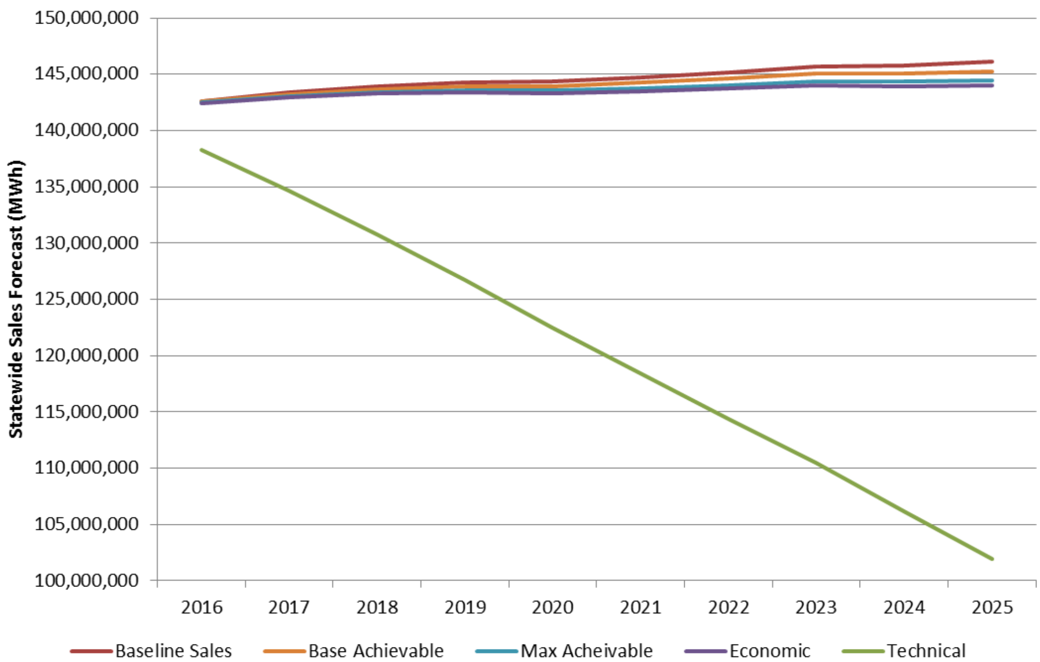


Table ES-2 summarizes the cumulative potential by DG technology, by scenario, by year. As mentioned earlier, CHP technologies were the only technologies that passed TRC cost-effectiveness. On an average annual basis, the technical scenario shows potential for 1,257,670 MWh of CHP savings and 3,156,863 MWh of Solar PV savings.

Table ES-2: Statewide Potential by DG Technology by Scenario by Year

		2018	2020	2025	Average Annual
DG Technology	Scenario	Cumulative Energy Savings Potential - MWh			
Combined Heat & Power (CHP)	Technical	3,736,051	6,245,974	12,576,696	1,257,670
	Economic	617,949	1,033,036	2,079,790	207,979
	Max. Achievable	494,476	826,624	1,664,225	166,422
	Base Achievable	247,355	413,508	832,506	83,251
Solar PV	Technical	9,381,682	15,678,102	31,568,628	3,156,863
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Total	**Technical**	**13,117,733**	**21,924,076**	**44,145,324**	**4,414,532**
	Economic	**617,949**	**1,033,036**	**2,079,790**	**207,979**
	Max. Achievable	**494,476**	**826,624**	**1,664,225**	**166,422**
	Base Achievable	**247,355**	**413,508**	**832,506**	**83,251**

Figure ES-3 shows that 71.5% of the cumulative technical potential in 2020 comes from Solar PV technology, followed by CHP technologies with 28.5% of overall potential. Cost-effective achievable potential was only found with CHP technologies.

Figure ES-3: Statewide 2020 Savings Distribution by DG Technology, Technical Scenario

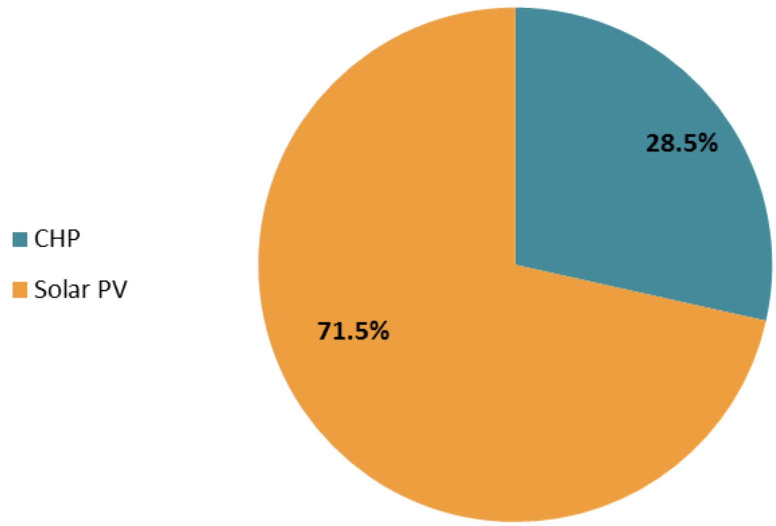


Table ES-3 and Table ES-4 show the statewide TRC benefits and costs for the base achievable scenario, as well as the acquisition costs for all cost-effective DG technologies. Since no solar PV technologies passed cost-effectiveness, CHP technologies are the only technologies in the maximum and base achievable scenarios. Passing CHP technologies have a TRC ratio of 1.16, with an acquisition cost of $60.5/MWh under the base achievable scenario.

Table ES-3: Statewide TRC Cost-Effectiveness Results by Scenario for 2016-2020

	NPV Costs (Millions)	NPV Benefits (Millions)	NPV Net Benefits (Millions)	TRC Ratio
Maximum Achievable	$460.46	$532.35	$71.89	1.16
Base Achievable	$230.34	$266.30	$35.96	1.16

Table ES-4: Statewide Acquisition Costs by Scenario for 2016-2020

	2016-2020 Costs (Millions)	2016-2020 Savings (MWh)	Acquisition Cost ($/1st-YR MWh Saved)
Maximum Achievable	$58.14	494,476	$117.6
Base Achievable	$14.97	247,355	$60.5

This study concludes that while there are still substantial amounts of technical potential for distributed generation technologies, there are limited opportunities for cost-effective potential when individual distributed generation technologies are screened using the total resource cost (TRC) test rules in Pennsylvania. Furthermore, those technologies that did pass cost-effectiveness did so with a modest average TRC ratio of 1.16. This finding is a consequence of several factors, including high distributed generation equipment costs (especially for solar photovoltaic systems), moderate to low avoided costs in Pennsylvania (resulting in minimum benefits for distributed generation technologies), and a limitation of 15 years of benefits (due to statutory definitions within Act 129 that limit consideration to a maximum 15 year life for all equipment and measures) for distributed generation technologies that typically have a 20 to 30 year lifetime.

However, the SWE notes that distributed generation technologies such as solar photovoltaic and combined heat and power can still play a role in EDC demand side management programs given the significant amount of technical potential found in this study. Furthermore, distributed generation resources can provide non-energy benefits to customers such as carbon dioxide emission reductions and added energy security that businesses can benefit from in the case of a power grid failure; these benefits among others were not quantified in this report. With relative low acquisition costs, these resources can still provide value to Pennsylvania rate-payers and allow the EDCs to reduce energy demand, while still keeping their portfolio of DSM programs cost-effective.

Organization of the Report

The remainder of this report is organized in the following seven sections as follows:

Section 1: Analysis Approach details the methodology used to develop the estimates of technical, economic, and achievable potential for distributed generation savings.

Section 2: Characterization of Pennsylvania Service Area provides a summary of the electric sales distribution by sector for the forecast horizon of this study (2016 to 2025).

Section 3: Summary of Distributed Generation Savings Potential Findings (2016-2025) provides a breakdown of the technical, economic, and achievable potential of all DG technologies combined (solar PV and CHP) for the portfolio, by sector, and by EDC.

Section 4: Solar Photovoltaic Savings Potential Findings (2016-2025) provides a breakdown of the technical, economic, and achievable potential of the solar PV technologies for all sectors.

Section 5: Combined Heat & Power Savings Potential Findings (2016-2025) provides a breakdown of the technical, economic, and achievable potential of the CHP technologies in the commercial and industrial sectors.

Section 6: Conclusions presents the final discussion regarding potential for distributed generation savings in Pennsylvania from 2016 to 2025.

1 ANALYSIS APPROACH

This section describes the overall methodology the SWE Team utilized to conduct the Pennsylvania statewide electric distributed generation potential study. The main objective of this study is to estimate the technical, economic, achievable energy (MWh) and demand (MW) savings potential for distributed generation resources statewide for the periods of 3, 5 and 10 years beginning June 1, 2016.

This electric distributed generation potential study provides results that are both statewide and specific to each of the seven Pennsylvania EDCs. To accomplish this objective, the SWE Team created a series of unique distributed generation potential models for each of the seven EDCs and for each primary market sector (residential, commercial, and industrial).

1.1 Overview of Approach

The SWE Team used a bottom-up approach to estimate distributed generation potential by first estimating generation equipment potential, installed technology costs, as well as cost-effectiveness, and then applied cost-effective generation opportunity to all applicable shares of energy consumption within each market sector. Many methodological activities and steps are similar to those performed in the companion 2015 potential study for energy efficiency[7] conducted by the SWE team. However, due to the lower prevalence of cost-effective distributed generation resources as compared to energy efficiency resource, there is more limited Pennsylvania and national market research. This limitation results in study assumptions, which this report attempts to make transparent. For distributed generation resources, the SWE considered potential achievements over a twenty year period. Results presented in a three, five and ten year period are scaled as a percentage over the twenty year period assuming a flat ramp rate of achievements. Further details of the market research and modeling techniques utilized in this assessment are provided in the following sections.

1.2 Forecast Disaggregation

This analysis of the potential for distributed generation savings begins with utilizing the most recent and available electricity sales forecasts from Pennsylvania EDCs for a period of 10 years beginning June 1, 2016, which reflects annual energy reductions from Act 129 Phases I and II.

Disaggregated forecast data provides the foundation for the development of energy efficiency potential estimates for the commercial and industrial sectors. The SWE Team applied the technology-level savings factors discussed in the Technical Potential section below to the corresponding share of the EDC's energy load by sector (residential, commercial and industrial), and by segment (building type).

For each sector, the SWE Team disaggregated each EDC's baseline 2016-2025 load forecast using a top-down analysis. The SWE Team conducted this top-down forecast disaggregation by applying EDC-specific sector and segment (building type) consumption shares derived from the 2014 Pennsylvania Residential and Non-Residential Baseline reports to each EDC's load forecast. In this exercise, the SWE Team:

- Determined energy consumption per customer sector in baseline year (2016)
- Determined the energy consumption share per segment within each sector in the baseline year (2016)
- Forecasted the 10-year end-use energy consumption by sector and segment through 2025

[7] *Energy Efficiency Potential Study for Pennsylvania*, Statewide Evaluation Team, 2015.

The commercial sector, as defined in this analysis, was comprised of the following business segments:

- Institutional
  - Education
  - Healthcare
  - Government/Public Service
  - Other Institutional
- Grocery
- Lodging
- Office
- Restaurant
- Retail
- Warehouse
- Miscellaneous

The industrial sector, as defined in this analysis, was comprised of the following industrial segments:

- Manufacturing
  - Chemicals
  - Computers and Electronics
  - Food
  - Metals
  - Paper
  - Plastics
  - Other
- Mining
- Other Non-Manufacturing

The residential sector, as defined in this analysis, was comprised of the following residential segments:

- Single Family Detached
- Single Family Attached
- Multifamily

1.2.1 Premise Eligibility Considerations for CHP

For the combined heat and power (CHP) technologies potential estimate, only a portion of the non-residential population was included. That is, only those customer segments whose electric and thermal load profiles allow for the application of CHP were considered. Using the known business type customer data for the largest customers and customer demand profiles from other jurisdictions, the customer energy sales data was utilized to estimate customers with a peak load of 150 kW or more. Customers with less than 150 kW of peak demand are not expected to have the consistent electric and thermal loads necessary to support CHP.

A thermal factor was applied to potential candidate customer loads to reflect thermal load considerations in CHP sizing. In most cases, on-site thermal energy demand is smaller than electrical demand. Thus, CHP size is usually dictated by the thermal load in order to achieve proper efficiencies and adequate returns on investment. Using electric and thermal intensity data from prior studies, the SWE used power to heat ratios for the prime mover CHP technology for different market segments to calculate the thermal factor as shown in Equation 1-1.

Equation 1-1: Thermal Factor Equation

$$\boldsymbol{Thermal\ Factor} = \frac{\boldsymbol{P/H\ (CHP\ System)}}{\boldsymbol{P/H\ (Customer\ Segment)}}$$

A thermal factor of one (1.0) would result in the CHP system capacity being equal to the electric demand of the facility. A thermal factor of less than one would indicate that the application is thermally limited and the resulting CHP system size would be below the electric demand of the facility. A thermal factor greater than one indicates that a CHP system sized to the thermal load would produce more electricity than can be used on-site, resulting in excess power that could be exported to the grid. Table 1-1 and Table 1-2 summarize the thermal factors and corresponding kWh building consumption threshold the SWE used for CHP sizing. Any customer premises with an annual kWh consumption below the listed thresholds were removed from the analysis. To develop the kWh thresholds, the SWE team utilized the energy generation of the smallest CHP technology assessed in this study (150 kW micro turbine) and divided that energy generation by the thermal factor for each commercial and industrial segment. The thermal factors and thresholds are intended to be reasonable values representative of the average building in each commercial segment that would be eligible to have a CHP technology installed onsite.

Table 1-1: Commercial Thermal Factors for CHP Size[8]

Commercial Segment	Thermal Factor	kWh Threshold
Education	0.75	700,800
Health	0.94	559,149
Public service	0.62	847,742
Institutional	0.62	847,742
Grocery	0.20	2,628,000
Lodging	0.84	625,714
Office	0.62	847,742
Restaurant	0.48	1,095,000
Retail	0.37	1,420,541
Warehouse	0.68	770,110
Misc.	0.68	770,110

Table 1-2: Industrial Thermal Factors for CHP Size

Industrial Segment	Factor	kWh Threshold
Mfg: Chemicals and Allied Products	1.29	407,442
Mfg: Electronic Equipment	0.26	2,021,538
Mfg: Food	1.10	477,818
Mfg: Primary Metals	0.33	1,592,727
Mfg: Paper and Allied Products	2.37	221,772
Mfg: Rubber and Mixed Plastics	0.31	1,695,484
Mfg: Misc Mfg	1.34	392,239
Mining & Extraction	0.25	2,102,400
Other Non-Manufacturing	1.34	392,239

[8] ICF International's 2010 Combined Heat and Power Market Assessment for the California Energy Commission. This study included compiled energy consumption data for different building types and end-uses from the DOE EIA Commercial Buildings Energy Consumption Survey (CBECS), the DOE Manufacturing Energy Consumption Survey (MECS), the Major Industrial Plant Database (MIPD), and the Commercial Energy Profile Database (CEPD).

1.3 Technology Characterization

The following section details the main assumptions used for each DG technology analyzed in this report.

1.3.1 Solar Photovoltaic Systems (PV)

Photovoltaic systems utilize solar panels, a packaged collection of photovoltaic cells, to convert sunlight into electricity. A system is constructed with multiple solar panels, a DC/AC inverter, a racking system to hold the panels, and electrical system interconnections. These systems are often roof-mounted systems that face south-west, south, and/or, south-east. This study only analyzed the potential associated with roof-mounted systems installed on residential, commercial and industrial buildings. This study did not explore the technical potential associated with ground-mounted or utility-scale solar PV installations, because these technologies were determined to often not be connected to customer premise metering and were also found to be non-cost-effective within the study horizon. One of the largest considerations in solar photovoltaic systems is the installed cost of equipment. The values utilized in this study are summarized in Table 1-3 below and reflect the cost to install rooftop solar systems in Pennsylvania as of 2014. The SWE conducted additional research on the declining cost of rooftop solar PV in the U.S. and its impact on cost-effectiveness – this analysis is summarized in Section 4.3.

Table 1-3: Solar Photovoltaic Installed Costs

Sector	Size (kW)	Type	System Cost ($/ DC Watt)	DC to AC Derate Factor
Residential	3.2	Rooftop	$4.09	85%
Commercial/Industrial	50.0	Rooftop	$3.65	95%

Photovoltaic cost data was summarized from the following sources[9]:

- PA Department of Environmental Protection. 2013. Reported costs from PA Sunshine Residential/Small Business Solar PV Program.
- National Renewable Energy Lab (NREL). 2012a. *Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections.* Technical Report DOE/GO-102012-3829
- NREL. 2012b. SunShot Vision Study. Chapter 4: *Photovoltaics: Technologies, Cost, and Performance.* DOE/GO-102012-3037
- Lawrence Berkeley National Lab (LBNL). 2011. *Tracking the Sun VI: An Historical Summary of the Installed Cost of Photovoltaics in the United States from 1998 to 2012.* LBNL-6350EE
- E3 (Energy and Environmental Economics, Inc.) 2012. *Technical Potential for Local Distributed Photovoltaics in California.* http://www.cpuc.ca.gov/NR/rdonlyres/8A822C08-A56C-4674-A5D2-099E48B41160/0/LDPVPotentialReportMarch2012.pdf

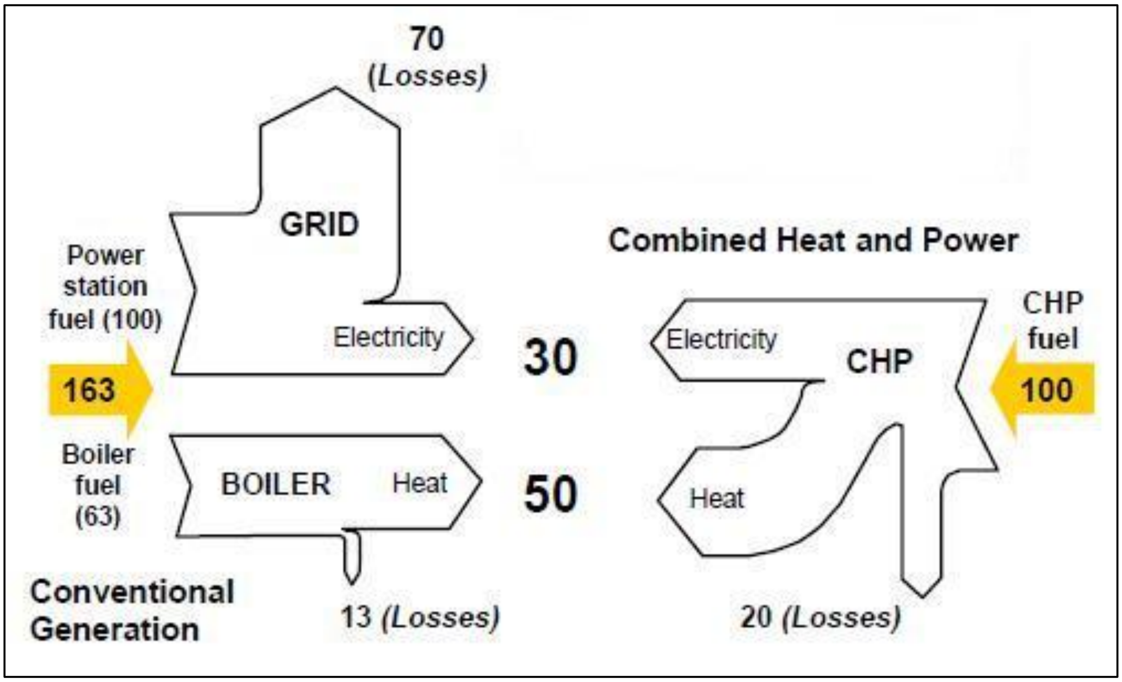
1.3.2 Combined Heat and Power (CHP)

In most CHP applications, a heat engine creates shaft power that drives an electrical generator (fuel cells can produce electrical power directly from electrochemical reactions). The waste heat from the engine is then recovered to provide steam or hot water to meet on-site needs. By combining the thermal and electrical energy generation in one process, the total efficiency of a CHP application far exceeds that of a separate plant and boiler system. Overall, the efficiency of CHP technologies can reach 80% or more, while simple-cycle electricity generation reaches only 30% and combined cycle generation typically achieves 50%. When considering both thermal and electric energy generation, CHP requires 40% less

[9] Solar costs presented in this report are inclusive of the solar investment tax credit (ITC), but do not include solar production tax credits (PTC) or solar renewable energy credits (RECS).

energy input to achieve the same energy output as a separate plant and boiler system. Figure 1-1 illustrates this point.

Figure 1-1: Energy Efficiency: CHP vs. Separate Power Plant and Boiler[10]



Common technologies used in CHP applications and explored in this study include:

- Steam turbines
- Gas turbines
- Micro turbines
- Fuel Cells
- Internal combustion engines

Selecting a specific CHP technology depends on a number of factors, which include but are not limited to power requirements, the duty cycle, space constraints, thermal energy needs, emission regulations, fuel availability, utility prices, and interconnection issues. In general, internal combustion engines are the prime mover for systems under 500kW with gas turbines becoming progressively more popular as system size increases above that. Table 1-4 summarizes the CHP technologies evaluated in this study and their assumed operating parameters.

[10] *Combined Heat and Power Potential for New York State*. Onsite Energy Corporation for NYSERDA, October 2002.

Table 1-4: CHP Technology Comparison[11]

Parameter	Internal Combustion Engine	Gas Turbine	Steam Turbine	Micro-Turbine	Fuel Cell
Size (kW)	50-5,000	500-50,000	10-100,000	30-250	200-2,000
Electric Efficiency	28-39%	25-40% (simple) 40-60% (combined)	5-15%	25-28%	36-42%
Overall Efficiency	73-79%	64-72%	~80%	67-72%	62%-67%
Fuels	Natural gas, biogas, propane, liquid fuels	Natural gas, biogas, propane, distillate oil	All	Natural gas, biogas, propane, distillate oil	Hydrogen, natural gas, propane
NO_x Emissions (lb/MWh)	0.15-2.17	0.55-0.68	Function of boiler emissions	0.14-0.17	0.01-0.04
Uses for Heat Recovery	Hot water, low pressure steam, district heating	Direct heat, hot water, low or high pressure steam, district heating	Low or high pressure steam, district heating	Direct heat, hot water, low pressure steam	Hot water, low or high pressure steam
Thermal Output (Btu/kWh)	3,000-6,100	3,200-5,000	n/a	4,800-6,300	1,500-3,000
Useable Temp (°F)	200-500	500-1,100	n/a	400-650	140-700

Table 1-5 summarizes detailed CHP cost considerations and assumptions utilized in this analysis.

Table 1-5: Detailed CHP Cost Consideration Summary[12]

Technology Type	Fuel Type	Size (kW)	Installed System Cost ($/W)	Waste Heat Utilization (kBtu/kWh)	Capacity Factor	System Lifetime (years)	O&M Costs ($/kWh)
Fuel Cell	Natural Gas	175	$6.31	4.17	0.71	10	$0.04
	Natural Gas	500	$5.58	6.02			$0.04
	Biogas	800	$5.71	8.71			$0.03
	Natural Gas	1125	$5.25	6.04			$0.03
Gas Turbine	Natural Gas	2500	$3.32	7.01	0.81	20	$0.01
	Biogas	3000	$2.32	12.40			

[11] *Combined Heat and Power Potential for New York State*. Onsite Energy Corporation for NYSERDA, October 2002. And *Combined Heat and Power Market Assessment*. ICF International for the California Energy Commission, April 2010.

[12] Natural gas fuel costs were assumed to be $6.53/dekatherm; 2013 EIA Energy Outlook Assessment average industrial sector retail costs for years 2015 through 2025 in nominal dollars. The SWE ran additional CHP savings potential scenarios considering a conservative forecasted price for natural gas at $5.75/dekatherm and a scenario based on the historically low price of natural gas ($4.61/dekatherm) of the past five years. Findings are presented in Section 5.3.

Technology Type	Fuel Type	Size (kW)	Installed System Cost ($/W)	Waste Heat Utilization (kBtu/kWh)	Capacity Factor	System Lifetime (years)	O&M Costs ($/kWh)
	Natural Gas	3500	$1.31	5.84			
Micro Turbine	Natural Gas	25	$2.97	7.31	0.49	10	$0.02
	Biogas	100	$2.63	12.70			$0.01
	Natural Gas	100	$2.49	5.80			$0.02
	Natural Gas	200	$2.44	6.88			$0.02
Reciprocating Engine	Natural Gas	150	$2.21	4.38	0.40	20	$0.02
	Natural Gas	350	$1.94	4.47			$0.02
	Biogas	1250	$1.61	10.36			$0.02
	Natural Gas	1250	$1.64	4.39			$0.01
	Natural Gas	3000	$1.13	5.11			$0.01
	Natural Gas	4500	$1.13	4.95			$0.01
Steam Turbine	Biogas	1500	$1.12	4.52	0.90	25	$0.004
		3500	$0.48	4.57			$0.004
		5500	$0.43	4.39			$0.004

1.3.3 Other Technologies Considered

The SWE team considered other DG technologies such as simple cycle landfill gas, animal waste gas, digester as well as small-scale wind (less than 500 kW systems). However, because these measures were found to not be cost-effective under PA's TRC rules and because these measures are not typically part of the DSM programs under Act 129 they were not further analyzed for technical potential.

1.4 Potential Savings Overview

Potential studies often distinguish between several types of energy efficiency potential: technical, economic, achievable, and program. However, because there are often important definitional issues between studies, it is important to understand the definition and scope of each potential estimate as it applies to this analysis.

The first two types of potential, technical and economic, provide a theoretical upper bound for energy generation from distributed technology equipment. Still, even the best-designed portfolio of programs is unlikely to capture 100% of the technical or economic potential. Therefore, achievable potential attempts to estimate what savings may realistically be achieved through market interventions, when it can be captured, and how much it would cost to do so. Figure 1-2 illustrates the four most common types of energy efficiency potential.

Figure 1-2: Types of Potential[13]

Not Technically Feasible	Technical Potential			
Not Technically Feasible	Not Cost-Effective	Economic Potential		
Not Technically Feasible	Not Cost-Effective	Market & Adoption Barriers	Achievable Potential	
Not Technically Feasible	Not Cost-Effective	Market & Adoption Barriers	Program Design, Budget, Staffing, & Time Constraints	Program Potential

1.5 Technical Potential

Technical potential is the theoretical maximum amount of energy use that could be generated by distributed generation resources, disregarding all non-engineering constraints such as cost-effectiveness and the willingness of end users to adopt the generation technologies. Technical potential is only constrained by factors such as technical feasibility and applicability of equipment.

1.5.1 Solar Photovoltaic Systems

Because the potential of solar photovoltaic is not limited by customer consumption or premise equipment consumption, the estimate of technical potential for solar photovoltaic systems in this report is based in part on the available roof area and consisted of the following steps:

- Step 1: Outcomes from the forecast disaggregation analysis were used to characterize the existing and new residential, commercial and industrial building stocks. Relevant characterized parameters included number of facilities, average number of floors, and average premise square footage.
- Step 2: The total available roof area feasible for installing solar PV systems was calculated. Relevant characterized parameters included share of pitched and flat roofs and unusable area due to other rooftop equipment.
- Step 3: Estimated the expected power density (kW per square foot of roof area).
- Step 4: Using PVWatts[14] and measurement & verification (M&V) evaluations of solar PV systems, the SWE used its technical potential solar calculator to calculate energy generation/savings using researched system capacity factors from PVWatts and M&V reports.

Table 1-6 summarizes the main inputs used to estimate the available roof area for solar PV installations for the residential, commercial and industrial sectors.

[13] Reproduced from "Guide to Resource Planning with Energy Efficiency." November 2007. US Environmental Protection Agency (EPA). Figure 2-1.

[14] PVWatts estimates solar PV energy production and costs. Developed by the National Renewable Energy Laborator. http://pvwatts.nrel.gov/

Table 1-6: Premise Characterization and Solar Photovoltaic System Assumptions

Variable	Unit	Residential	Commercial	Industrial
Sloped Roof Share	percentage	92%	10%	5%
Flat Roof Share	percentage	8%	90%	95%
Usable Sloped Roof	percentage	18%	18%	18%
Usable Flat Roof	percentage	70%	65%	65%
PV Density	W(DC)/sf	14.3	14.3	14.3

1.5.2 Combined Heat and Power and Biogas Systems

To estimate technical potential for CHP and biogas, the SWE team first calculated the average building consumption for each commercial and industrial segment. This was used to then estimate a savings share for each CHP technology based on its generation capacity. Those savings shares were then applied to the applicable share of the sector load to estimate technical potential. The core equation utilized in the technical potential analysis for each individual distributed generation technology is shown in Equation 1-2 below.

Equation 1-2: Core Equation for Combined Heat and Power Technical Potential

Technical Potential of C&I Distributed Generation = Total End Use MWh Sales by Building/Industry Type × Applicability Factor × Remaining Factor × Generation Share

Where:

- **Total End Use MWh Sales by Building/Industry Type** = the electricity used by each premise type in each market segment. The SWE Team obtained this premise consumption data from the Pennsylvania EDC customer data and the Pennsylvania Statewide Act 129 2014 Non-Residential End Use & Saturation Study[15]. This characterization was considered for two sizes of premises: premises with demand consumption ranging from 150kW to 1,250kW and premises with demand consumption larger than 1,250kW.
- **Applicability Factor** = the fraction of premises where combined heat and power and distributed generation that is technically feasible. For example, a lack of consistent premise thermal loads or a lack of centralized thermal heating systems often result in a premise that is not technically feasible for a cost-effective combined heat and power installation.
- **Remaining Factor** = the fraction of the premises remaining without distributed generation resources. The SWE reviewed and considered existing distributed generation resources for each EDC since 2000 from EIA form 861, Commonwealth of Pennsylvania datasets and, and EDC databases and reported savings.
- **Generation Share** = the percentage reduction in existing or forecasted new electricity consumption resulting from new generation. In many cases, this share was limited by 100% of the premise consumption.

[15] *Pennsylvania Statewide Commercial and Industrial End Use & Saturation Study*, Statewide Evaluation Team, April 18, 2012.

1.6 Economic Potential

Economic potential refers to the subset of the technical potential that is economically cost-effective (based on screening with the TRC) as compared to conventional supply-side energy resources. The SWE Team calculated the TRC benefit-cost ratios for this study according to the Pennsylvania PUC's TRC Orders. All technologies that were not found to be cost-effective based on the results of the TRC were excluded from further analysis. For instance, the SWE found that none of the solar PV technologies passed the TRC test, and were therefore not evaluated further. The SWE Team then readjusted and applied allocation factors to the remaining technologies that were cost-effective.

1.6.1 Total Resource Cost Test

The SWE Team utilized the 2009 and 2011 Pennsylvania PUC TRC Orders to determine the cost-effectiveness for distributed generation resources in this potential study. The TRC measures the net costs of a DSM program as a resource option based on the total costs of the technology/program, including both the participants' and the utility's costs.

In general, the benefits calculated in the TRC usually include the avoided electric supply costs for the periods when there is a premise electric load reduction due to generation; savings of other resources such as fossil fuels and water; economic benefits of alternative energy credits; and applicable federal and state energy efficiency tax credits. However, consistent with Act 129 and the 2013 PA TRC Order, only the electricity savings and avoided operation and maintenance costs were used to calculate the benefits for the PA TRC.[16]

Costs in the TRC are the program costs paid by the utility (or program administrator) and the participants. Thus, all equipment costs, installation, operation and maintenance, and program administration costs are included in this test regardless of who pays for them. Net fuel costs are also included by estimating the expected operating fuel costs for CHP technologies and removing the fuel costs to operate a traditional steam boiler serving the premise requirements of building and process heat loads. These non-incentive costs were also included in the development of program acquisitions costs and estimates of the program costs related to achievable potential savings.

The PA TRC Order limits measure lives to a maximum of 15 years when calculating the TRC. Although many distributed generation resources may have longer effective useful lives (EUL), the measure lives and the associated benefits are capped at a maximum of 15 years for purposes of cost-effectiveness calculations.

1.6.2 Avoided Costs

The SWE Team based the avoided cost forecasts utilized for measure cost-effective screening and for reporting potential benefits on the Pennsylvania PUC's 2013 TRC Order and each EDC's avoided cost structure, including energy, transmission, distribution, and generation capacity avoided costs. Each EDC provided the latest available electric generation avoided cost projections, while the SWE Team developed the transmission and distribution (T&D) avoided cost projections used in this study. According to the latest PUC TRC Order, the discount rate used in the calculation of the Pennsylvania TRC is the utility's after-tax weighted average cost of capital. Avoided energy costs were differentiated by time and season where possible. Details on each EDC's avoided costs can be found in Appendix B.

[16] Tax credits, while traditionally a benefit in the TRC are treated as a reduction to costs in the PA TRC, according to the TRC Order.

1.7 Achievable Potential

Achievable potential is the amount of energy that can realistically be saved given various market barriers. Achievable potential takes into account real-world barriers to encouraging end users to implement distributed generation technologies; the non-equipment costs of delivering programs (for administration, marketing, analysis, and EM&V); and the capability of programs and administrators to boost program activity over time. Barriers include financial, customer awareness and willingness to participate in programs, technical constraints, and other barriers the "program intervention" is modeled to overcome. Additional considerations include political and/or regulatory constraints. While many different incentive scenarios could be modeled, the number of achievable potential scenarios for this study was limited to the two described below due to the available budget for this potential study.

- **Maximum Achievable** estimates achievable potential on paying incentives equal to 50% of technology incremental costs[17].
- **Base Achievable** estimates achievable potential on EDCs paying incentive levels at an average of $0.05/Kwh-saved, which is based on current Act 129 EDC distributed generation programs for the non-residential sector (on average equal to 16 percent of incremental equipment costs).

The SWE Team analyzed the two selected achievable potential scenarios with different anticipated penetration curves or market acceptance models for each incentive level. In the maximum achievable scenario, the penetration curve is based on a penetration assuming 50% funding of the technology incremental costs, while the base achievable scenario penetration curve is based on a business-as-usual funding of approximately 16% of technology incremental costs.

2 CHARACTERIZATION OF PENNSYLVANIA SERVICE AREAS & PHASE I/II PROGRAM OFFERINGS

The following section provides a brief overview of the seven EDC service areas included under Act 129 and their forecasted load.

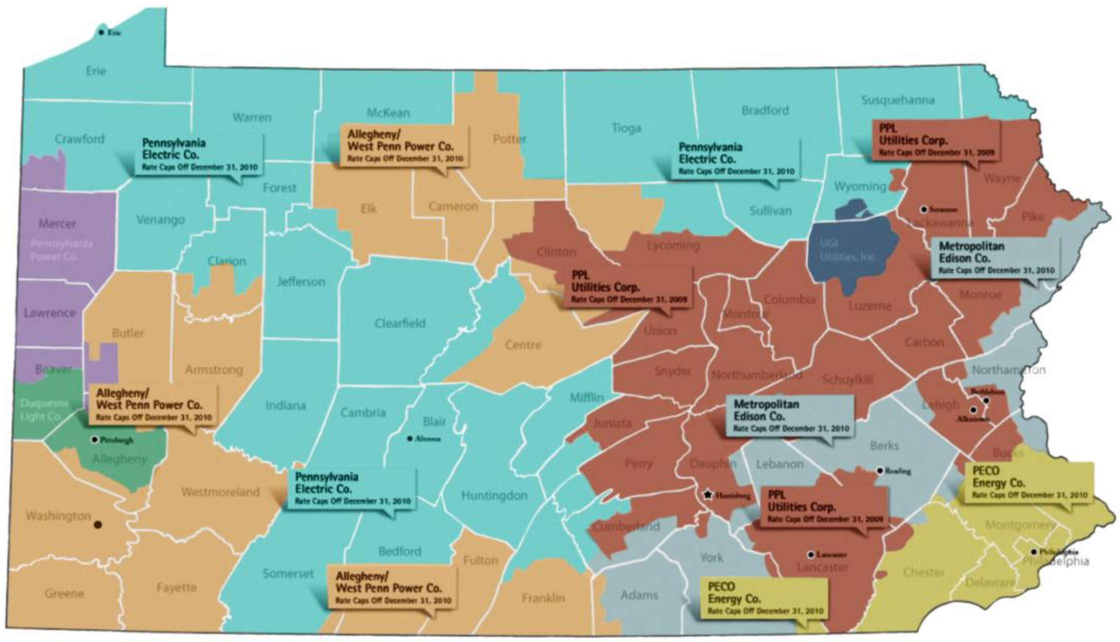
2.1 EDC Areas

There are currently eleven EDCs that provide electric energy to Pennsylvania customers. The focus of this analysis is on the seven largest EDCs including: Duquesne Light Company (Duquesne), Metropolitan Edison Company (Met-Ed), Pennsylvania Electric Company (Penelec), Pennsylvania Power Company (Penn Power), West Penn Power Company (West Penn), PECO Energy Company (PECO), and PPL Electric Utilities Corporation (PPL).

Figure 2-1 shows the service area for each of the seven Pennsylvania EDCs included in this study. Each EDC's territory varies in size and demographics.

[17] The SWE team considered incentives equal to 100% of incremental costs for distributed generation technologies to be well outside of industry norms and would result in prohibitively high acquisition costs; consequently a 50% incentive value was utilized for the maximum achievable scenario.

Figure 2-1: Pennsylvania EDC Service Territory Map



2.2 2010 Historical Load & Statewide Load Forecast

2.2.1 2010 Historical Load

Table 2-1 presents the forecasted energy (MWh) sales by EDC and Customer Class for the period beginning June 2009 and ending May 2010. The SWE has selected the load of this year to be consistent with Act 129 of 2008, which required the PA EDCs to reduce electric consumption at least one percent (1%) by May 31, 2011 and three percent by May 31, 2013, relative to their forecast load for the period June 1, 2009 through May 31, 2010. Savings targets for Phase II of Act 129 were also established based on the 2009/2010 forecast load. Consequently, the DG potential estimates in this report have also been compared to the 2009/2010 forecast load for each EDC.

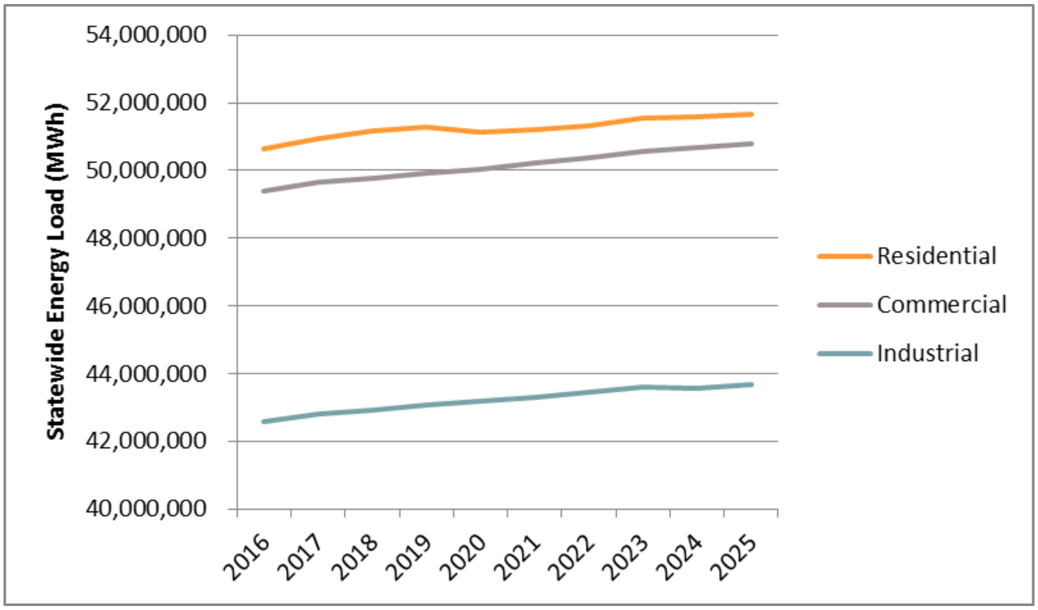
Table 2-1: 2009/2010 Energy (MWh) Forecast Sales by EDC and Customer Sector

EDC	Residential	Commercial	Industrial	Total
Duquesne	4,188,344	7,081,429	2,815,727	14,085,500
FE: Met-Ed	6,199,448	4,126,943	4,538,643	14,865,033
FE: Penelec	4,882,328	4,261,919	5,255,052	14,399,300
FE: Penn Power	1,845,141	1,162,174	1,765,619	4,772,933
FE: West Penn	7,931,627	5,533,913	7,473,127	20,938,667
PECO	14,009,363	20,961,102	4,415,535	39,386,000
PPL	15,136,306	12,829,784	10,248,276	38,214,367
Statewide	**54,192,558**	**55,957,264**	**36,511,978**	**146,661,800**

2.2.2 Statewide Load Forecast

As discussed earlier, a critical first step in the modeling process is to disaggregate each EDC's load by sector. As shown in Figure 2-2, the energy (MWh) sales forecast grows at a compounded annual growth rate of 0.24% per year across all sectors over the 10-year forecast horizon.

Figure 2-2: Statewide Energy (MWh) Sales Forecast by Sector from June 2016 – May 2025



3 SUMMARY OF DG SAVINGS POTENTIAL FINDINGS

This section of the report presents the estimates of DG technical, economic, and achievable potential of all DG technologies (solar PV and CHP) for the Commonwealth of Pennsylvania as well as for each EDC service area. Electric DG savings, cost estimates, and benefit-cost estimates are presented in this section.

3.1 Summary

Table 3-1 summarizes electric DG savings potential for all sectors for all seven EDCs combined across the state. The five-year (2020) potential under the base achievable scenario amounts to 413,508 MWh (47.2 MW) by 2020, representing a possible 0.3% reduction of total 2010 energy sales.[18]

Table 3-1: Statewide Cumulative Energy & Demand DG Savings Potential by Scenario by Year

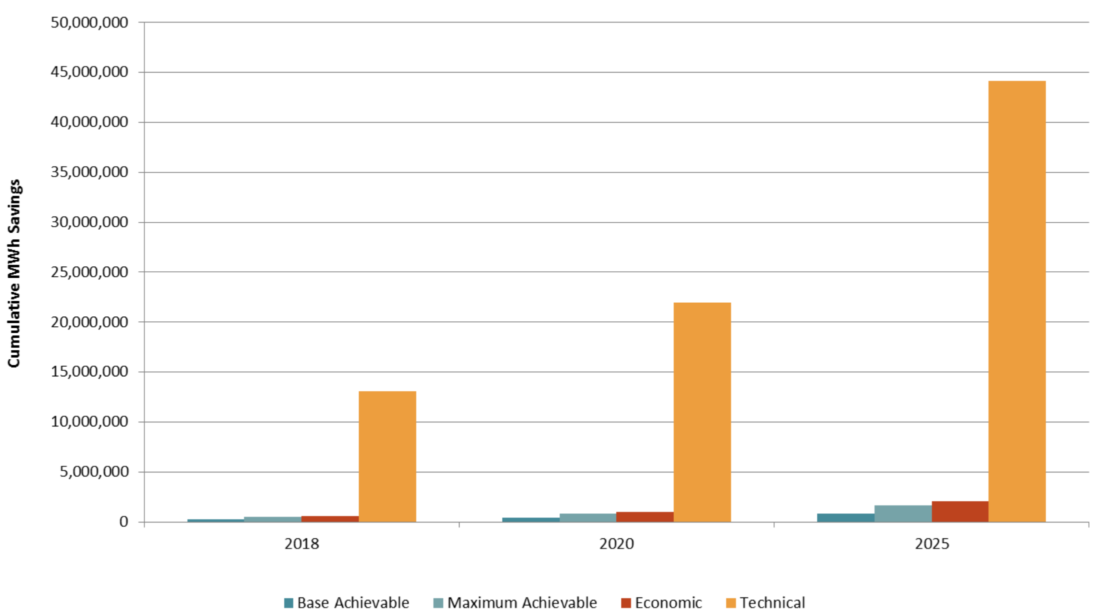
	2018	2020	2025	Average Annual
Cumulative Savings Potential - MWh				
Technical	13,117,733	21,924,076	44,145,324	4,414,532
Economic	617,949	1,033,036	2,079,790	207,979
Maximum Achievable	494,476	826,624	1,664,225	166,422

[18] While the SWE only assessed DG savings potential for eligible buildings (based on 2012 annual kWh consumption), the % of sales metric is calculated based on the 2010 kWh sales of all buildings (eligible and non-eligible buildings).

	2018	2020	2025	Average Annual
Base Achievable	247,355	413,508	832,506	83,251
Cumulative Energy Savings Potential - % of 2010 Total Load				
Technical	8.9%	14.9%	30.1%	3.0%
Economic	0.4%	0.7%	1.4%	0.1%
Maximum Achievable	0.3%	0.6%	1.1%	0.1%
Base Achievable	0.2%	0.3%	0.6%	0.1%
Demand Savings Potential – Summer Peak MW				
Technical	2,384.9	3,985.8	7,997.4	799.7
Economic	70.5	117.9	237.4	23.7
Maximum Achievable	56.4	94.4	190.0	19.0
Base Achievable	28.2	47.2	95.0	9.5
Cumulative Demand Savings Potential - % of 2014 Total Load				
Technical	13.0%	21.7%	43.5%	4.4%
Economic	0.4%	0.6%	1.3%	0.1%
Maximum Achievable	0.3%	0.5%	1.0%	0.1%
Base Achievable	0.2%	0.3%	0.5%	0.1%
Avoided CO_2 Savings Potential – Metric Tons				
Technical	8,583,252	14,344,723	28,883,849	2,888,385
Economic	223,826	374,173	753,315	75,331
Maximum Achievable	179,103	299,409	602,794	60,279
Base Achievable	89,594	149,775	301,540	30,154

Figure 3-1 summarizes the same potential by scenario by year.

Figure 3-1: Statewide Cumulative DG Energy (MWh) Potential by Scenario by Year



3.2 DG Potential by Sector

Table 3-2 presents the cumulative potential by customer class for all DG technologies. Five-year cumulative technical potential in the residential sector is estimated at just over 3.5 million MWh, representing a 2.4% reduction in 2010 sector load. Five-year cumulative technical potential in the commercial and industrial sector is estimated to achieve a 7.8% and 4.7% reduction in sector load respectively.

Table 3-2: 2020 Statewide Cumulative DG Potential by Sector by Scenario by Year

	Residential	Commercial	Industrial
2020 Cumulative Energy Savings Potential - MWh			
Technical	3,520,779	11,458,086	6,945,211
Economic	0	280,685	752,351
Max Achievable	0	224,585	602,039
Base Achievable	0	112,330	301,178
2020 Cumulative Energy Savings Potential - % of 2010 Total Sector Load			
Technical	2.4%	7.8%	4.7%
Economic	0.0%	0.2%	0.5%
Max Achievable	0.0%	0.2%	0.4%
Base Achievable	0.0%	0.1%	0.2%
2020 Cumulative Demand Savings Potential - MW			
Technical	735.0	2,171.7	1,079.1
Economic	0.0	32.0	85.9
Max Achievable	0.0	25.6	68.7
Base Achievable	0.0	12.8	34.4

Figure 3-2 and shows the cumulative technical potential distribution by sector in 2020, while Figure 3-3 shows the same potential by sector under the base achievable scenario. Since there are no Solar PV technologies that pass cost-effectiveness, there are no residential savings in the base achievable scenario. The industrial sector accounts for 72.8% of base achievable savings in 2020, and the commercial sector accounts for 27.2% of 2020 savings.

Figure 3-2: Statewide 2020 DG Savings Distribution by Customer Sector, Technical Scenario

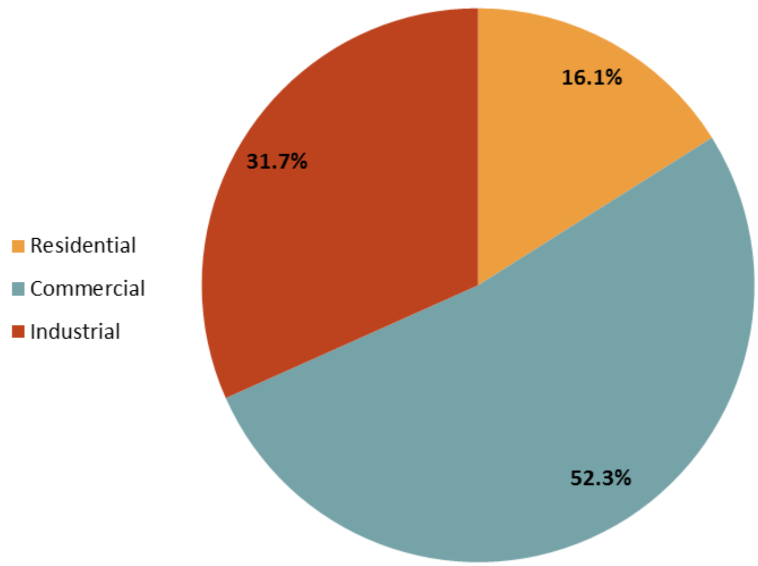
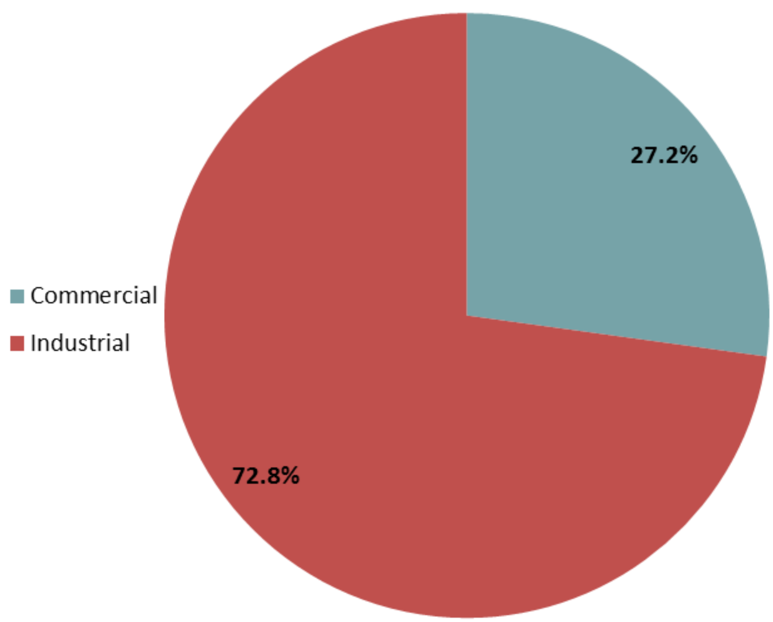


Figure 3-3: Statewide 2020 DG Savings Distribution by Customer Sector, Base Achievable Scenario



3.3 DG Potential by Technology Type

Figure 3-4 shows the DG potential by technology type for the technical scenario in 2020. Solar PV technologies account for more than 71% of technical potential in 2020 with CHP accounting for 28.5%. Cost-effective achievable potential was only found with CHP technologies.

Figure 3-4: Statewide 2020 DG Savings Distribution by Technology, Technical Scenario

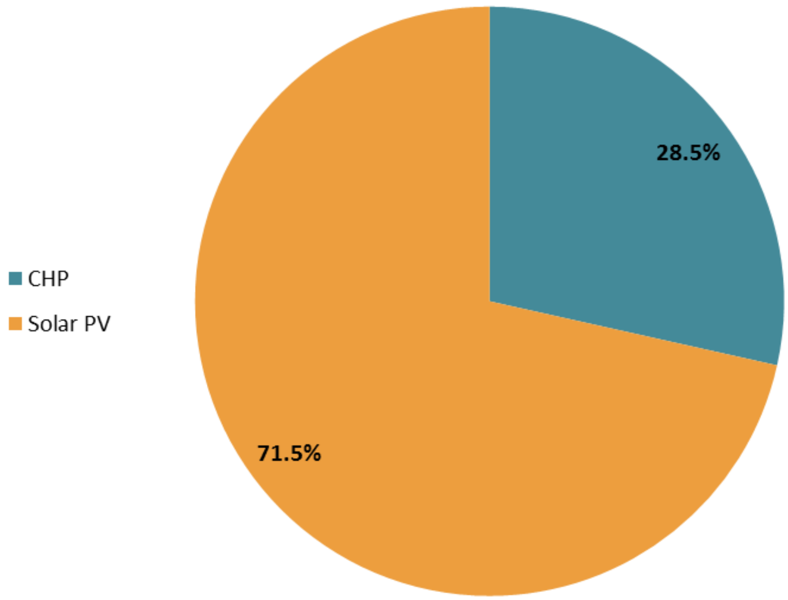


Table 3-3 provides the DG potential by technology type for 2018, 2020, and 2025. CHP technologies were found to be the only cost effective technologies and thus are the only technology with economic and achievable potential.

Table 3-3: Statewide Cumulative DG Potential by Technology Type by Scenario

		2018	2020	2025	Average Annual
DG Technology	Scenario	Cumulative Savings Potential - MWh			
Combined Heat & Power (CHP)	Technical	3,736,051	6,245,974	12,576,696	1,257,670
	Economic	617,949	1,033,036	2,079,790	207,979
	Max. Achievable	494,476	826,624	1,664,225	166,422
	Base Achievable	247,355	413,508	832,506	83,251
Solar PV	Technical	9,381,682	15,678,102	31,568,628	3,156,863
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Total	**Technical**	**13,117,733**	**21,924,076**	**44,145,324**	**4,414,532**
	Economic	**617,949**	**1,033,036**	**2,079,790**	**207,979**
	Max. Achievable	**494,476**	**826,624**	**1,664,225**	**166,422**
	Base Achievable	**247,355**	**413,508**	**832,506**	**83,251**

3.4 DG Potential by EDC

Table 3-4 summarizes the DG potential by EDC by scenario by year. In the base achievable scenario, the SWE found that PECO and Duquesne show the largest potential for DG potential at 1.1% and 1.0% of 2010 energy sales respectively. This occurred because technologies that did pass the TRC test had benefits that only moderately out-weighed the costs; and with PECO and Duquesne having the highest avoided cost rates a greater number of CHP technologies passed the TRC test for PECO and Duquesne as compared to the other EDCs.

Table 3-4: Cumulative DG Potential (MWh) by EDC by Scenario by Year

	2018	2020	2025	Average Annual
Duquesne				
Technical	1,414,971	2,363,139	4,750,199	475,020
Economic	72,902	121,836	245,106	24,511
Maximum Achievable	58,338	97,496	196,140	19,614
Base Achievable	29,185	48,776	98,125	9,813
Base Achievable % of 2010 Load	0.3%	0.5%	1.0%	0.1%
First Energy: Met Ed				
Technical	1,180,526	1,968,854	3,943,500	394,350
Economic	49,309	82,265	164,786	16,479
Maximum Achievable	39,453	65,822	131,849	13,185
Base Achievable	19,733	32,921	65,945	6,594
Base Achievable % of 2010 Load	0.1%	0.2%	0.4%	0.0%
First Energy: Penelec				
Technical	1,364,352	2,276,020	4,561,240	456,124
Economic	51,251	85,507	171,288	17,129
Maximum Achievable	41,010	68,421	137,062	13,706
Base Achievable	20,515	34,227	68,563	6,856
Base Achievable % of 2010 Load	0.1%	0.2%	0.5%	0.0%
First Energy: Penn Power				
Technical	365,306	611,740	1,237,836	123,784
Economic	13,205	22,037	44,172	4,417
Maximum Achievable	10,567	17,634	35,346	3,535
Base Achievable	5,286	8,822	17,682	1,768
Base Achievable % of 2010 Load	0.1%	0.2%	0.4%	0.0%
First Energy: WPP				
Technical	1,514,357	2,532,275	5,105,020	510,502
Economic	81,360	136,079	274,301	27,430
Maximum Achievable	65,104	108,890	219,493	21,949
Base Achievable	32,568	54,471	109,800	10,980
Base Achievable % of 2010 Load	0.2%	0.3%	0.5%	0.1%
PECO				
Technical	3,957,446	6,614,815	13,321,825	1,332,183
Economic	210,205	350,953	704,290	70,429
Maximum Achievable	168,207	280,834	563,577	56,358
Base Achievable	84,147	140,489	281,933	28,193
Base Achievable % of 2010 Load	0.3%	0.6%	1.1%	0.1%
PPL				
Technical	3,320,775	5,557,233	11,225,704	1,122,570
Economic	139,718	234,359	475,849	47,585
Maximum Achievable	111,797	187,526	380,758	38,076
Base Achievable	55,922	93,802	190,458	19,046

	2018	2020	2025	Average Annual
Base Achievable % of 2010 Load	0.2%	0.4%	0.8%	0.1%
Statewide Total				
Technical	**13,117,733**	**21,924,076**	**44,145,324**	**4,414,532**
Economic	**617,949**	**1,033,036**	**2,079,790**	**207,979**
Maximum Achievable	**494,476**	**826,624**	**1,664,225**	**166,422**
Base Achievable	**247,355**	**413,508**	**832,506**	**83,251**
Base Achievable % of 2010 Load	**0.2%**	**0.3%**	**0.6%**	**0.1%**

3.5 DG Benefits and Costs

Table 3-5 provides the economic impacts by EDC for the DG achievable scenarios. Overall, capturing the estimated potential would result in a net present value of more than $266 million in lifetime benefits for an investment of $230 million (net present value) in the base achievable potential scenario. The Commonwealth of Pennsylvania would capture approximately $36 million in net benefits and a TRC ratio of 1.2 by securing the volume of base achievable CHP. Greater benefits would be realized if Act 129 legislation did not limit technology measure benefits to a maximum of 15 years.

Table 3-5: Five-Year DG TRC Benefit-Cost Ratios by Achievable Scenario, by EDC

	NPV Costs (Million $)	NPV Benefits (Million $)	NPV Net Benefits (Million $)	TRC B/C Ratio
Maximum Achievable Potential				
Duquesne	$57.7	$69.7	$12.0	1.2
First Energy: Met Ed	$37.6	$41.7	$4.1	1.1
First Energy: Penelec	$38.9	$41.5	$2.5	1.1
First Energy: Penn Power	$7.3	$8.6	$1.3	1.2
First Energy: WPP	$54.8	$62.1	$7.3	1.1
PECO	$158.8	$194.1	$35.3	1.2
PPL	$105.3	$114.7	$9.4	1.1
Statewide	**$460.5**	**$532.4**	**$71.9**	**1.2**
Base Achievable Potential				
Duquesne	$28.9	$34.8	$6.0	1.2
First Energy: Met Ed	$18.8	$20.9	$2.1	1.1
First Energy: Penelec	$19.5	$20.7	$1.3	1.1
First Energy: Penn Power	$3.7	$4.3	$0.6	1.2
First Energy: WPP	$27.4	$31.1	$3.7	1.1
PECO	$79.4	$97.1	$17.7	1.2
PPL	$52.7	$57.4	$4.7	1.1
Statewide	**$230.3**	**$266.3**	**$36.0**	**1.2**

Table 3-6 represents the total program expenses paid by the EDCs to realize 5-year (2020) achievable savings estimates under the maximum and base achievable scenarios. The first-year MWh acquisition cost is between $117/MWh in the maximum achievable scenario assuming 50% incentives for all technologies, and $60/MWh in the base achievable scenario assuming a 16% incentive. The estimated EDC acquisition costs include incentive costs as well as non-incentive costs such as marketing, administrative costs, and EM&V.

Table 3-6: Five-Year (2016 -2020) DG Acquisition Costs (TRC) by Achievable Scenario by EDC

EDC	Program Costs ($Million)	Program Savings (MWh)	Acquisition Costs ($/MWh)	Program Costs ($Million)	Program Savings (MWh)	Acquisition Costs ($/MWh)
	Maximum Achievable			Base Achievable Scenario		
Duquesne	$6.8	58,338	$116.74	$1.8	29,185	$60.26
First Energy: Met Ed	$4.7	39,453	$118.20	$1.2	19,733	$60.7
First Energy: Penelec	$5.3	41,010	$130.12	$1.3	20,515	$64.4
First Energy: Penn Power	$0.9	10,567	$83.56	$0.3	5,286	$49.9
First Energy: WPP	$7.2	65,104	$110.67	$1.9	32,568	$58.4
PECO	$18.7	168,207	$111.02	$4.9	84,147	$58.5
PPL	$14.6	111,797	$130.31	$3.6	55,922	$64.6
Statewide	**$58.1**	**494,476**	**$117.58**	**$15.0**	**247,355**	**$60.53**

4 SOLAR PHOTOVOLTAIC SAVINGS POTENTIAL

This section of the report presents the estimates of solar photovoltaic (solar PV) technical potential for the Commonwealth of Pennsylvania.

4.1 Summary

The five-year cumulative potential under the technical scenario amount to 15,678,102 MWh (3,273 MW) representing a possible 10.7% reduction of 2010 energy sales. The SWE found solar PV to be not cost-effective under the guidelines used by the TRC Order in PA; therefore no savings potential is shown for the economic scenario or either achievable scenario. Table 4-1 summarizes the SWE's findings.

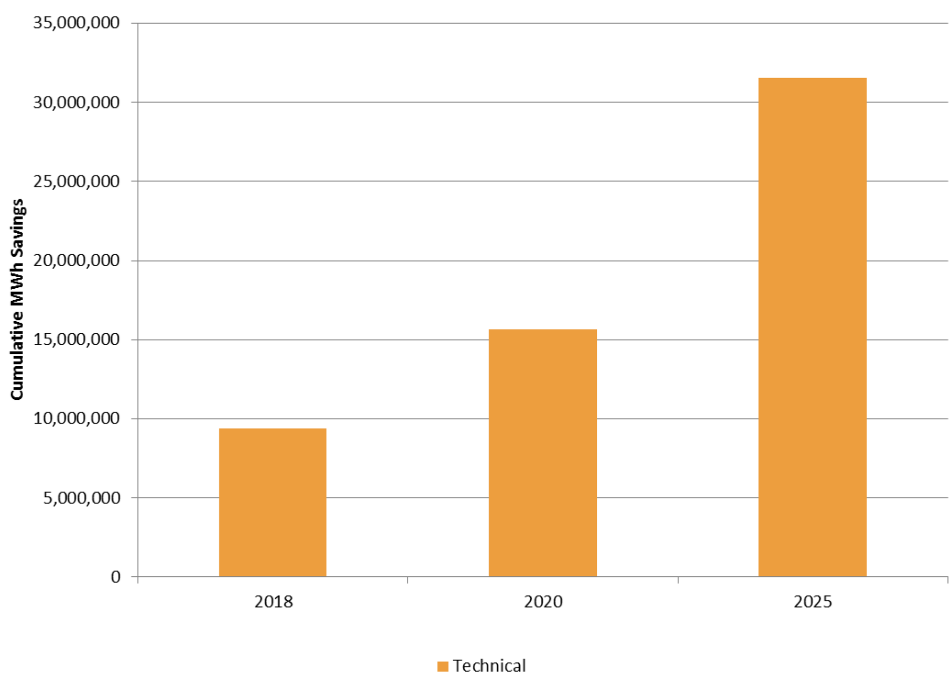
Table 4-1: Statewide Cumulative Energy & Demand Solar PV Savings Potential by Scenario, by Year

	2018	2020	2025	Average Annual
Cumulative Savings Potential - MWh				
Technical	9,381,682	15,678,102	31,568,628	3,156,863
Economic	0	0	0	0
Maximum Achievable	0	0	0	0
Base Achievable	0	0	0	0
Cumulative Energy Savings Potential - % of 2010 Total Load				
Technical	6.4%	10.7%	21.5%	2.2%
Economic	0.0%	0.0%	0.0%	0.0%
Maximum Achievable	0.0%	0.0%	0.0%	0.0%

Base Achievable	0.0%	0.0%	0.0%	0.0%
Demand Savings Potential – Summer Peak MW				
Technical	1,958	3,273	6,562	656
Economic	0	0	0	0
Maximum Achievable	0	0	0	0
Base Achievable	0	0	0	0
Cumulative Demand Savings Potential - % of 2014 Total Load				
Technical	10.7%	17.8%	35.7%	3.6%
Economic	0.0%	0.0%	0.0%	0.0%
Maximum Achievable	0.0%	0.0%	0.0%	0.0%
Base Achievable	0.0%	0.0%	0.0%	0.0%
Avoided CO_2 Savings Potential – Metric Tons				
Technical	7,264,071	12,139,278	24,443,033	2,444,303
Economic	0	0	0	0
Maximum Achievable	0	0	0	0
Base Achievable	0	0	0	0

Figure 4-1 summarizes the same technical solar PV potential across all sectors for all seven EDCs for the 2018, 2020 and 2025 time horizon.

Figure 4-1: Statewide Cumulative Solar PV Potential by Scenario, by Year



4.2 Solar PV Potential by Sector

Figure 4-2 summarizes the distribution of five-year savings potential by sector under the technical scenario while Table 4-2 details the estimated savings potential by sector, by scenario, by year.

Figure 4-2: Statewide 2020 Solar PV Savings Distribution by Sector, Technical Scenario

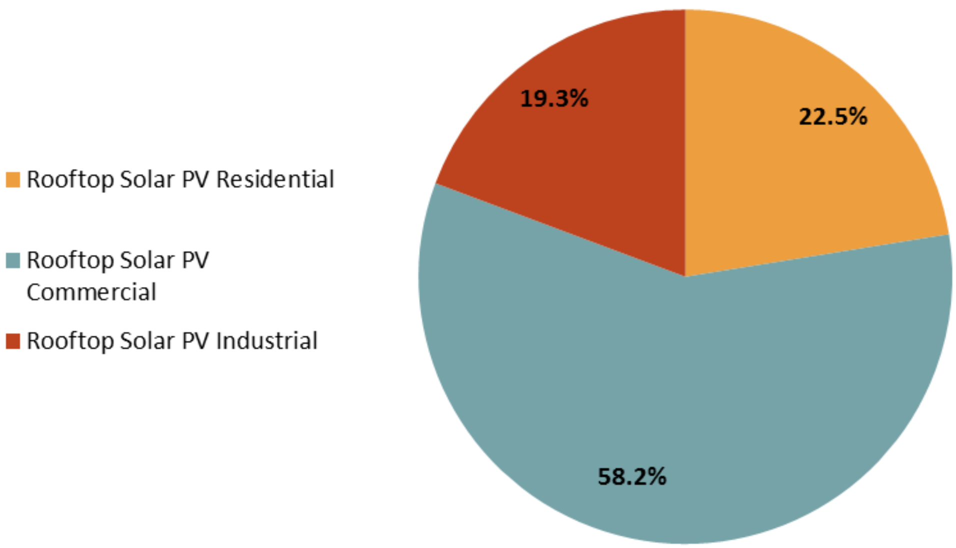


Table 4-2: Statewide Solar PV Potential by Sector by Scenario by Year

		2018	2020	2025	Average Annual
End Use	Scenario	Cumulative Savings Potential - MWh			
Rooftop Solar PV (Residential)	Technical	2,102,328	3,520,779	7,126,937	712,694
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Rooftop Solar PV (Commercial)	Technical	5,464,902	9,130,686	18,374,559	1,837,456
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Rooftop Solar PV (Industrial)	Technical	1,814,452	3,026,637	6,067,132	606,713
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Total	**Technical**	**9,381,682**	**15,678,102**	**31,568,628**	**3,156,863**
	Economic	**0**	**0**	**0**	**0**
	Max. Achievable	**0**	**0**	**0**	**0**
	Base Achievable	**0**	**0**	**0**	**0**

4.3 Solar PV Benefits and Costs

The SWE found there to be no cost-effective potential attainable in Pennsylvania for solar PV under the TRC rules. Table 4-3 summarizes the average first-year (2016) TRC ratios by sector by EDC for solar installations. The average statewide TRC ratio for residential and nonresidential rooftop solar installations was estimated at 0.29 and 0.31 respectively. Because the SWE did not find any cost-effective solar under the PA TRC Order, the acquisition costs associated with solar PV were not analyzed.

Table 4-3: 2016 Solar PV TRC Benefit-Cost Ratios by Sector, by EDC

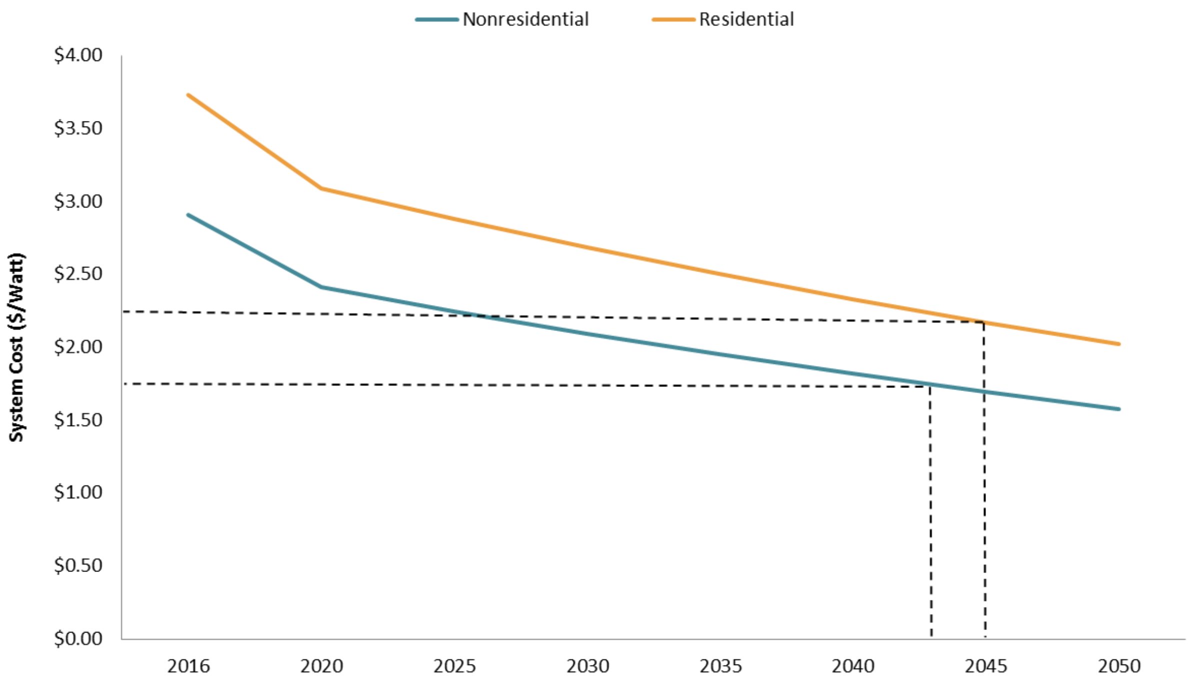
	Residential	Nonresidential
	TRC Ratio	
Duquesne	0.33	0.36
First Energy: Met Ed	0.30	0.32
First Energy: Penelec	0.31	0.34
First Energy: Penn Power	0.29	0.31
First Energy: WPP	0.23	0.25
PECO	0.29	0.31
PPL	0.27	0.29
Statewide Average	**0.29**	**0.31**

To provide further insight on when solar PV might become cost effective in Pennsylvania under the TRC rules, the SWE conducted market research on the declining cost of rooftop solar PV over the next 35 years. Based on findings from a 2012 report by the National Renewable Energy Lab (NREL) [19], solar PV module costs are estimated to decline at a rate of 4.6% until 2020 and then continue to decline at 1.4% after 2020. The Balance of System (BoS) costs were estimated to decline 55% by 2030. The SWE then ran various cost-effectiveness scenarios by adjusting rooftop solar PV costs over various time horizons to see at what cost and in what year rooftop solar PV would become cost effective (holding energy production constant). The SWE's analysis estimates that by the year 2043 nonresidential rooftop solar could become cost effective at an average total system installed cost of $1.74/watt, while residential rooftop solar could become cost effective in 2045 at an average total system cost of $2.17/watt.

below illustrates the SWE's projections of total system cost reductions for rooftop solar, and the point (dotted lines) at which these systems become cost-effective in PA with a TRC value greater than 1.0.

[19] National Renewable Energy Lab (NREL). 2012a. Photovoltaic (PV) Pricing Trends: Historical, Recent, and Near-Term Projections. Technical Report DOE/GO-102012-3829

Figure 4-3: Solar PV System Cost Declination & Cost- Effectiveness Thresholds



5 COMBINED HEAT & POWER

This section of the report presents the estimates of CHP technical, economic, and achievable potential for the Commonwealth of Pennsylvania. CHP potential, cost estimates, and benefit-cost estimates are presented in this section.

5.1 Summary

The five-year cumulative potential for CHP technologies under the base achievable scenario amount to 413,508 MWh (58.7 MW) representing a possible 0.4% reduction of 2010 energy sales in the commercial and industrial sectors. Table 5-1 summarizes the SWE's findings.

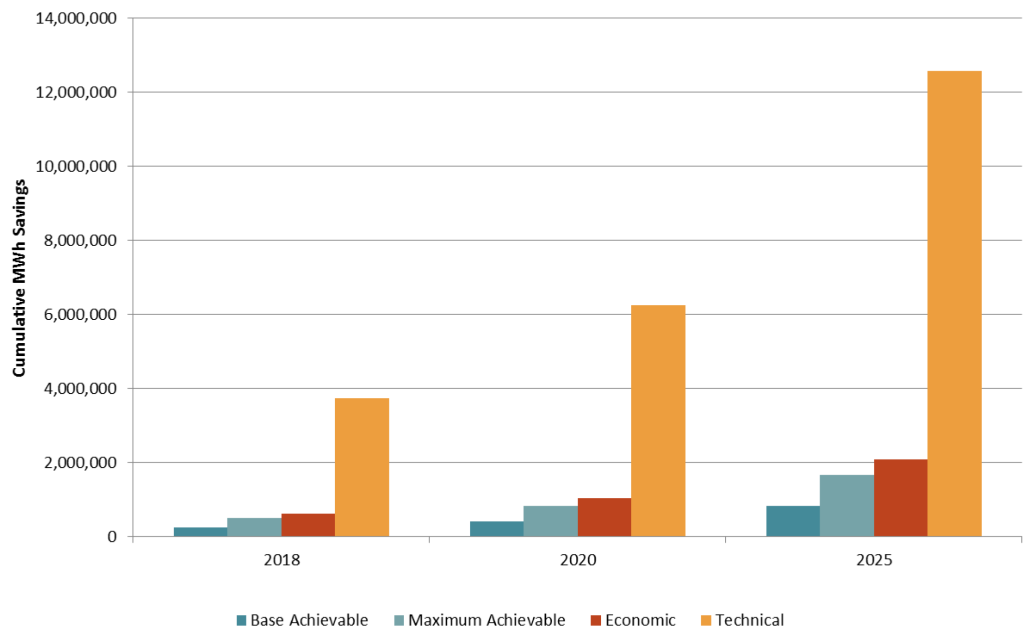
Table 5-1: Statewide Cumulative Energy & Demand CHP Potential by Scenario, by Year

	2018	2020	2025	Average Annual
Cumulative Savings Potential - MWh				
Technical	3,736,051	6,245,974	12,576,696	1,257,670
Economic	617,949	1,033,036	2,079,790	207,979
Maximum Achievable	494,476	826,624	1,664,225	166,422
Base Achievable	247,355	413,508	832,506	83,251
Cumulative Energy Savings Potential - % of 2010 Commercial & Industrial Load				
Technical	4.0%	6.8%	13.6%	1.4%
Economic	0.7%	1.1%	2.2%	0.2%
Maximum Achievable	0.5%	0.9%	1.8%	0.2%
Base Achievable	0.3%	0.4%	0.9%	0.1%
Demand Savings Potential – Summer Peak MW				

	2018	2020	2025	Average Annual
Technical	426.5	713.0	1,435.7	143.6
Economic	70.5	117.9	237.4	23.7
Maximum Achievable	56.4	94.4	190.0	19.0
Base Achievable	28.2	47.2	95.0	9.5
Cumulative Demand Savings Potential - % of 2010 Load				
Technical	2.3%	3.9%	7.8%	0.8%
Economic	0.4%	0.6%	1.3%	0.1%
Maximum Achievable	0.3%	0.5%	1.0%	0.1%
Base Achievable	0.2%	0.3%	0.5%	0.1%
Avoided CO_2 Savings Potential – Metric Tons				
Technical	1,359,597	2,272,990	4,576,820	457,682
Economic	224,880	375,935	756,862	75,686
Maximum Achievable	179,946	300,819	605,633	60,563
Base Achievable	90,016	150,481	302,959	30,296

Figure 5-1 summarizes the same CHP savings potential across all sectors for all seven EDCs combined across the state in the 2018, 2020 and 2025 time horizons.

Figure 5-1: Statewide Cumulative CHP Potential by Scenario by Year



5.2 CHP Potential by Technology Type

Figure 5-2 summarizes the distribution of five-year savings potential by technology under the technical scenario. Natural gas reciprocating engines were found to have the largest share of energy savings at 28.4% of all CHP 2020 cumulative technical potential followed by gas turbines at 21.2% of technical potential. Table 5-2 details the estimated 2020 cumulative CHP savings potential by technology type, by scenario by year. Of note is that steam turbine was the only technology to be found cost-effective under the PA TRC calculation, and thus show economic or achievable potential. The SWE team found there to be 413,508 MWh of cumulative energy savings by 2020 under the base achievable scenario for steam turbines.

Figure 5-2: Statewide 2020 Savings Distribution by CHP Technology, Technical Scenario

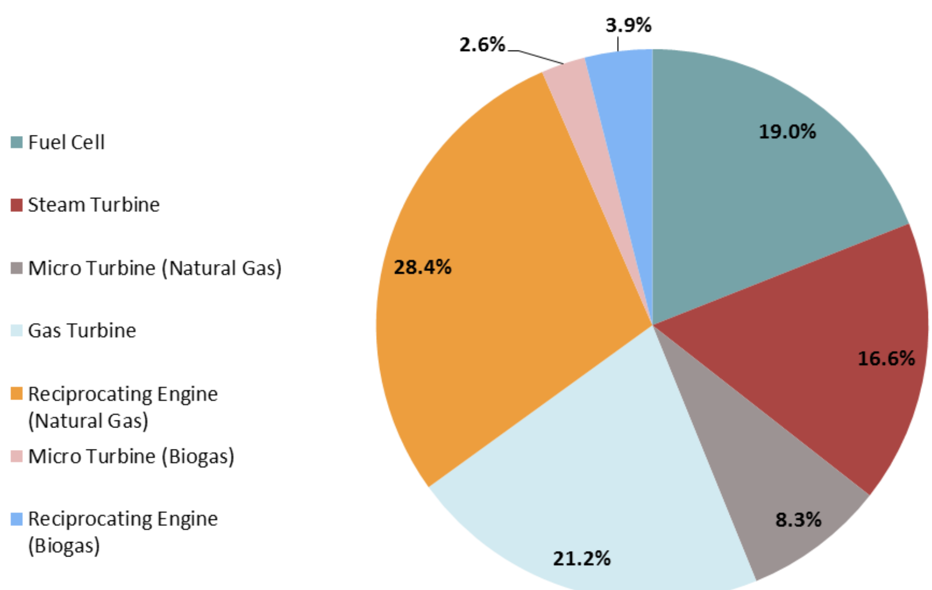


Table 5-2: Statewide Potential by CHP Technology Type by Scenario by Year

		2018	2020	2025	Average Annual
Technology Type	Scenario	Cumulative Savings Potential - MWh			
Fuel Cell	Technical	709,718	1,186,681	2,390,303	239,030
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Steam Turbine	Technical	619,319	1,035,315	2,084,316	208,432
	Economic	617,949	1,033,036	2,079,790	207,979
	Max. Achievable	494,476	826,624	1,664,225	166,422
	Base Achievable	247,355	413,508	832,506	83,251
Micro Turbine (Natural Gas)	Technical	309,260	517,067	1,041,369	104,137
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Gas Turbine	Technical	791,323	1,322,454	2,660,368	266,037
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Reciprocating Engine (Natural Gas)	Technical	1,062,497	1,776,601	3,578,864	357,886
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Micro Turbine (Biogas)	Technical	96,426	161,221	324,706	32,471
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Reciprocating Engine (Biogas)	Technical	147,508	246,635	496,770	49,677
	Economic	0	0	0	0
	Max. Achievable	0	0	0	0
	Base Achievable	0	0	0	0
Total	**Technical**	**3,736,051**	**6,245,974**	**12,576,696**	**1,257,670**
	Economic	**617,949**	**1,033,036**	**2,079,790**	**207,979**
	Max. Achievable	**494,476**	**826,624**	**1,664,225**	**166,422**
	Base Achievable	**247,355**	**413,508**	**832,506**	**83,251**

5.3 Natural Gas Cost Scenario Analysis

The cost effectiveness of some CHP technologies is dependent, in part, on the cost of natural gas needed to fuel and operate them. Given the volatility in the natural gas market, the SWE ran two additional scenarios to help frame the available achievable potential given variations in the price of natural gas. As mentioned earlier, the SWE utilized the 2013 EIA Energy Outlook Assessment's average industrial sector retail costs for years 2015 through 2025 to provide the most likely cost of natural gas during this study horizon ($6.53/dekatherm). It is at this natural gas price that the savings summarized in Section 5.1 and

Section 5.2 is associated with. Natural gas prices, however, have been at historically low levels the past several years; and while nearly all industry projections have the price of natural gas increasing going forward, the SWE ran a potential scenario with the assumption that natural gas prices would stay similar to their past five-year average cost of $4.61/dekatherm. Finally, the SWE estimated the associated potential if the cost of natural gas increased at a more conservative rate to an average of $5.75/dekatherm for C&I customers. Table 5-3 below summarizes the SWE's findings for each potential scenario at the five-year (2020) time horizon under varying natural gas prices. The SWE's findings show that if the historically low natural gas prices were to persist through 2020, base achievable potential would increase 72.5% to 713,483 MWh by 2020 as more CHP technologies become cost effective (namely reciprocating natural gas engines) for more EDCs.

Table 5-3: 2020 Statewide CHP Potential by Natural Gas Cost Scenario

		Most Likely ($6.53/dekatherm)	Conservative ($5.75/dekatherm)	Historical ($4.61/dekatherm)
	Scenario	2020 Cumulative Savings Potential - MWh		
Statewide	***Technical***	**6,245,974**	**6,245,974**	**6,245,974**
	Economic	**1,033,036**	**1,284,073**	**1,779,516**
	Max. Achievable	**826,624**	**1,027,710**	**1,424,729**
	Base Achievable	**413,508**	**514,306**	**713,483**

5.4 CHP Benefits and Costs

Table 5-4 provides the economic impacts by EDC for the CHP base achievable and max achievable scenarios. Overall, the SWE found there to be cost-effective potential attainable in Pennsylvania for one CHP technology – steam turbines. The SWE estimates that the net present value of the cost to attain the savings associated with these cost-effective CHP technologies to be approximately $230 million from 2016 to 2020 under the base achievable scenario, while the benefits amount to over $266 million during the same time horizon resulting in more than $36 million in net benefits and a TRC ratio of 1.2.

Table 5-4: Five-Year CHP TRC Benefit-Cost Ratios by Achievable Scenario, by EDC

	NPV Costs (Million $)	NPV Benefits (Million $)	NPV Net Benefits (Million $)	TRC BC Ratio
Maximum Achievable Potential				
Duquesne	$57.7	$69.7	$12.0	1.2
First Energy: Met Ed	$37.6	$41.7	$4.1	1.1
First Energy: Penelec	$38.9	$41.5	$2.5	1.1
First Energy: Penn Power	$7.3	$8.6	$1.3	1.2
First Energy: WPP	$54.8	$62.1	$7.3	1.1
PECO	$158.8	$194.1	$35.3	1.2
PPL	$105.3	$114.7	$9.4	1.1
Statewide	**$460.5**	**$532.4**	**$71.9**	**1.2**
Base Achievable Potential				
Duquesne	$28.9	$34.8	$6.0	1.2
First Energy: Met Ed	$18.8	$20.9	$2.1	1.1
First Energy: Penelec	$19.5	$20.7	$1.3	1.1

	NPV Costs (Million $)	NPV Benefits (Million $)	NPV Net Benefits (Million $)	TRC BC Ratio
First Energy: Penn Power	$3.7	$4.3	$0.6	1.2
First Energy: WPP	$27.4	$31.1	$3.7	1.1
PECO	$79.4	$97.1	$17.7	1.2
PPL	$52.7	$57.4	$4.7	1.1
Statewide	**$230.3**	**$266.3**	**$36.0**	**1.2**

Table 5-5 summarizes the total estimated program expenses that would be paid by the EDCs to realize the five-year potential estimates under the base achievable and max achievable scenarios. SWE estimates the total five-year programmatic costs for all seven EDCs at $15 million to achieve 247,355 MWh of savings under the base achievable scenario resulting in an acquisition cost of $60.53/MWh-saved.

Table 5-5: Five-Year CHP Acquisition Costs (TRC) by Achievable Scenario by EDC

EDC	2016-2020 Program Costs ($Million)	2016-2020 Program Savings (MWh)	Acquisition Costs ($/MWh)	2016-2020 Program Costs ($Million)	2016-2020 Program Savings (MWh)	Acquisition Costs ($/MWh)
	Maximum Achievable Scenario			Base Achievable Scenario		
Duquesne	$6.8	58,338	$116.74	$1.8	29,185	$60.3
First Energy: Met Ed	$4.7	39,453	$118.20	$1.2	19,733	$60.7
First Energy: Penelec	$5.3	41,010	$130.12	$1.3	20,515	$64.4
First Energy: Penn Power	$0.9	10,567	$83.56	$0.3	5,286	$49.9
First Energy: WPP	$7.2	65,104	$110.67	$1.9	32,568	$58.4
PECO	$18.7	168,207	$111.02	$4.9	84,147	$58.5
PPL	$14.6	111,797	$130.31	$3.6	55,922	$64.6
Statewide	**$58.1**	**494,476**	**$117.58**	**$15.0**	**247,355**	**$60.53**

6 CONCLUSIONS

The final section of this report provides a brief summary of the overall potential findings and general conclusions stemming from the SWE analysis.

6.1 Summary

In summary, while there are still substantial amounts of technical potential for distributed generation technologies (almost 22 million MWh over the five-year time horizon from 2016 to 2020), there are limited opportunities for cost-effective potential in the service areas of the seven Pennsylvania electric distribution companies bound under Act 129 (included in this study). The statewide estimated base achievable potential for the five year time horizon (2016 – 2020) amounts to 413,508 MWh (a 0.3% reduction in the projected 2010 baseline MWh sales). The net present value costs to acquire the savings over the five-year horizon are equal to $230 million, yet yield net present value benefits during the same time horizon in excess of $266 million resulting in net benefits of $36 million and a TRC ratio of 1.16.

As mentioned before, a contributing factor to the limited cost-effective opportunity for DG technologies is due to the statutory definitions within Act 129 that limit DG technology benefits for a period of 15 years, even though these technologies typically have a measure of 20 to 30 years. In light of this constraint, the SWE team assessed the economic potential of DG technologies without the 15 year avoided cost benefit limitation. The SWE found that the statewide economic and base achievable potential of all cost-effective DG technologies increased 54% without the measure life limitation in the Act 129 Statute.

6.2 Concluding Thoughts

The distributed generation potential estimates provided in this report are based upon the latest load forecasts and avoided cost forecasts provided by the seven electric distribution companies. Over time, costs for some distributed generation technologies – especially solar photovoltaic – may decline substantially and serve to increase the potential for cost-effective distributed generation and warrant additional attention. Currently, however, the SWE found limited cost effective potential for distributed generation technologies. This finding is a consequence of several factors, including high distributed generation equipment costs (especially for solar photovoltaic), moderate to low avoided costs in Pennsylvania (resulting in minimum benefits for distributed generation technologies), and a limitation of 15 years of benefits (due to statutory definitions within Act 129 that limit consideration to a maximum 15 year life for all equipment and measures) for distributed generation technologies that typically have a 20 to 30 lifetime.

However, the SWE notes that distributed generation technologies such as solar photovoltaic and combined heat and power can still play a role in EDC demand side management programs given the significant amount of technical potential found in this study. Furthermore, distributed generation resources can provide non-energy benefits to customers such as CO2 emission reductions or energy security in the case of a power grid failure that were not quantified as benefits in this report. With relative low acquisition costs, these resources can still provide value to Pennsylvania rate-payers and allow the EDCs to reduce energy demand, while still keeping their portfolio of DSM program cost-effective.