Meeting Maryland’s RPS

A Study of Renewable Portfolio Standard Resources

Prepared for the Maryland Climate Coalition

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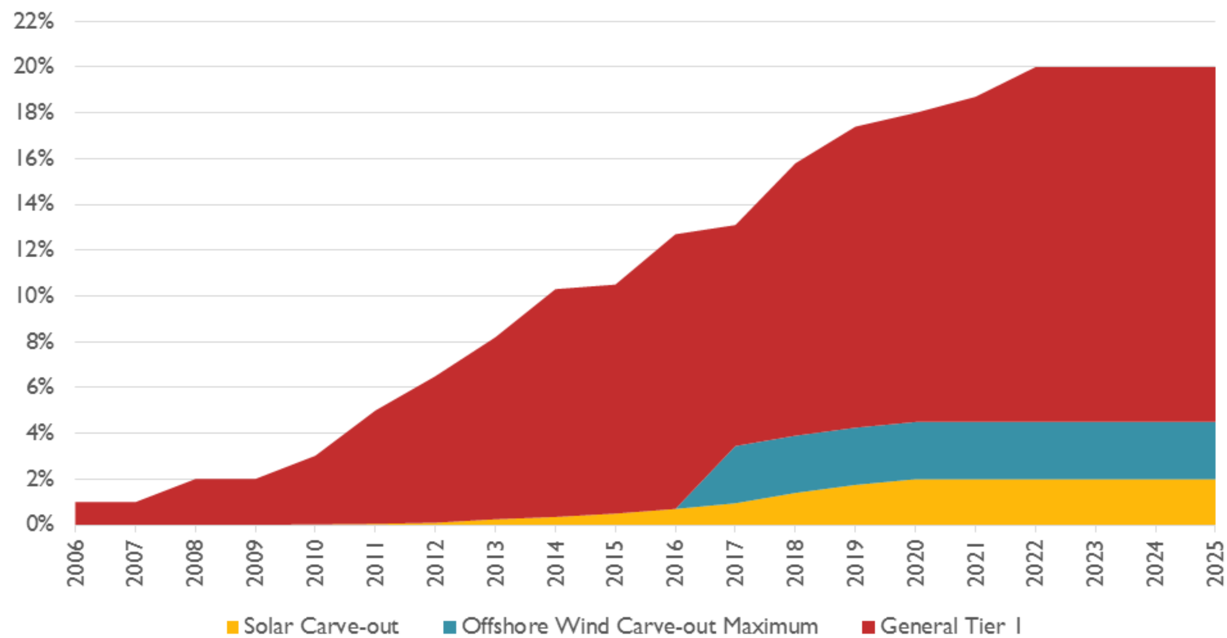
EXECUTIVE SUMMARY

Maryland's legislation to require minimum thresholds for renewable energy resources in the state's energy mix, called the Maryland Renewable Portfolio Standard (RPS), allows for a wide variety of renewable resources. And, as one important goal of an RPS is to support the expansion of those resources over time, it is worth noting concerns that not all renewable resources are created equal: A number of the resources listed as eligible under the RPS emit pollutants such as carbon dioxide, sulfur dioxide, nitrogen oxides, and mercury. In the event that Maryland policymakers were to increase the state's RPS requirements, the question of which resources will be used to comply becomes more pertinent. The figure below represents the current Maryland RPS Tier 1 policy, which carves out specific requirements for solar and offshore wind. The red area represents the remaining RPS Tier 1 requirement, which can be met through a wide variety of eligible renewable resources. Which resources will expand in capacity to fill this requirement?

Figure ES- 1. Maryland Tier 1 RPS requirement as a percent of sales



Source: Synapse Energy Economics, based on Md. Public Utility Companies Code § 7-701 et seq.

At the request of the Maryland Climate Coalition, Synapse explored the expected energy mix both in Maryland and in its regional electricity grid, the PJM Interconnect, under different Maryland RPS policies. The state was able to comply with the RPS in all the options Synapse modeled—including a reference case using the current RPS policy and three options with variations in the requirements and eligible resources. The scenarios modeled include:

- A reference case using the current RPS
- Option 1: Increase Tier 1 requirements and solar carve-out
- Option 2: Remove emitting resources from RPS eligibility
- Option 3: Increase Tier 1 and solar carve-out and remove emitting resources from RPS

Synapse's analysis explored which resources would be chosen based on economics, and also on other factors such as resource availability and siting constraints. Results showed that onshore wind and solar PV would be the key resources for compliance. Other resources were either not economically competitive, too constrained in location or fuel availability, or unlikely to be developed for a variety of other reasons. Regarding the emitting resources, the elimination of their eligibility to contribute to the RPS Tier 1 pool of resources had no impact on the ability to meet the existing or expanded RPS.

1. INTRODUCTION

As Maryland's Renewable Energy Portfolio Standard (RPS) evolves, policymakers must make choices about how to best meet the state's goals for supporting renewable energy sources and for reducing polluting emissions from the energy sector. Several decision-makers and advocates in the state are currently proposing an expansion of the RPS to require more renewables, an expansion that would likely intensify any differences in the environmental impacts of the resources defined as eligible Tier 1 renewables. Environmental and health advocates have strong concerns about several of the eligible resources, particularly those renewables that emit carbon dioxide (CO_2) and other pollutants such as sulfur dioxide (SO_2), mercury, and nitrogen oxides (NO_X). This prompts the question: What impact would a stronger RPS have on the renewable energy sources included, and could an RPS be achieved without the use of the emitting sources that are currently permitted?

Comparing the eligible RPS resources can be difficult. Among the factors that complicate the decision-making process are:

- how different resources react to changing incentives;
- expected changes in costs and technologies;
- how different energy technologies fit into the region's electricity dispatch system;
- whether or not energy resources produce emissions of carbon dioxide, sulfur dioxide, nitrogen oxides, mercury, or other pollutants;
- whether or not energy resources are produced within the state; and
- whether or not a resource provides energy as a byproduct rather than as its primary purpose.

To shed some light on the interactions between different RPS options and various energy technologies, Synapse Energy Economics (Synapse) modeled and analyzed three distinct options for a future Maryland RPS policy to compare with the current policy. This report describes the different energy resources eligible as Tier 1 resources under the current RPS, as well as what the modeling suggests about how these resources will fit into the bigger picture under different scenarios.

1.1. Maryland's Current RPS

Maryland's Renewable Energy Portfolio Standard (RPS) was enacted in May 2004 under Maryland Public Utility Companies Code § 7-701 and has been revised a number of times since. Several policymakers have recently suggested an additional revision that would expand the RPS.[1] Rather than recount its history, this report considers what renewable resource development the current RPS will foster. This report also considers how future renewable resource deployment will increase under a variety of more aggressive Maryland RPS policies.

Maryland's RPS, like that of most states, requires utilities to procure a minimum amount of energy from renewable resources each year, as a function of total sales. The accounting mechanism used to track compliance is the renewable energy credit (REC). Under the state's RPS, one REC is awarded for every megawatt-hour (MWh) generated by a renewable generator. The REC includes characteristics of the generator, including the date the MWh was generated, the generating technology, and the geographic and electric topological location. These data are necessary to ensure that the REC in question is eligible to satisfy a utility's RPS requirements, for which the details can be of particular importance. In Maryland, utilities can obtain RECs in a variety of ways: The utility can own the generator, it can buy the RECs along with energy and/or capacity in a short- or long-term contract, it can purchase RECs *without* electrical products in a short-term or long-term contract, and it can purchase RECs on the spot market. Should a Maryland utility fail to obtain sufficient RECs to comply with the RPS, it is obligated to make an alternative compliance payment (ACP) for each and every lacking REC. Generally, the ACP is not viewed as a fine or penalty; rather, it ensures that the cost of compliance is capped – if RECs were to trade at a price above the ACP, the utility would choose the lower-cost option of paying the ACP rather than procuring the more costly RECs.

Resources

In its definition of which energy resources are eligible to earn RECs, the Maryland RPS allows for a wide variety of renewable generation technologies. Some renewable technologies can be located anywhere within the PJM Regional Transmission Organization and contribute to compliance for a Maryland utility, whereas other technologies must be located within the state for their generation to contribute toward Maryland RPS compliance. It is important to note that the RPS includes Tier 1 carve-outs for solar and offshore wind resources, meaning that RECs from those technologies must comprise a certain portion of RPS Tier 1 compliance. The RPS has specific requirements for the location of carve-out resources, and not all REC-eligible resources will meet the carve-out requirement.

PJM-wide options

RPS-eligible technologies that can be interconnected anywhere within the PJM system include hydroelectric, tidal, wave, ocean thermal, landfill gas, biomass, onshore wind, offshore wind, and fuel cells fueled by an RPS-compliant resource.

[1] Hicks, J. 2015. "Md. lawmakers to propose boosting state levels of renewable energy use." *The Washington Post*. December 8. Available at https://www.washingtonpost.com/local/md-politics/md-lawmakers-to-propose-boosting-state-levels-of-renewable-energy-use/2015/12/08/d88594ec-9dbe-11e5-a3c5-c77f2cc5a43c_story.html.

In-state only options

RPS eligible technologies that must be located within the state of Maryland and be interconnected to the grid include solar water heat, geothermal electric, solar thermal electric, solar photovoltaic (PV), geothermal heat pumps, municipal solid waste, and poultry litter.

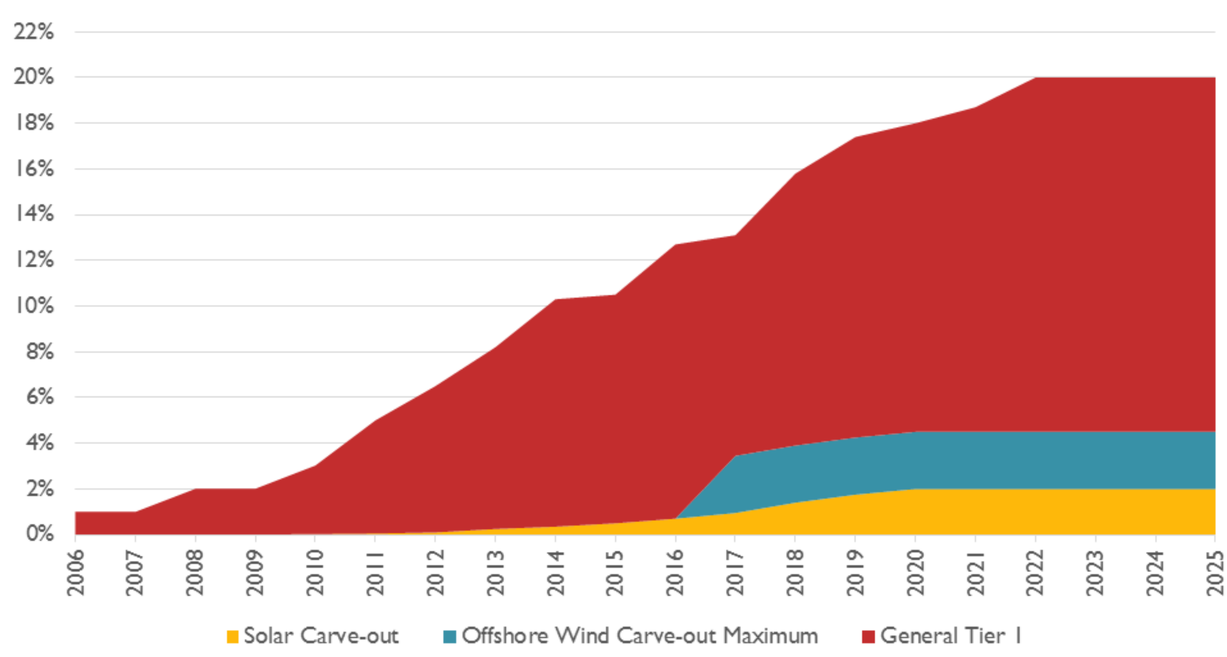
Requirements

The Maryland RPS is divided into two tiers, Tier 1 and Tier 2. The tiers are not interchangeable – the technology types applicable to Tier 1 are not applicable to Tier 2, and vice versa.

Tier 1

All renewable generating technologies can be used for Tier 1, with some important caveats. Only hydroelectric facilities smaller than 30 MW can generate RECs suitable for Tier 1 compliance. Furthermore, while Tier 1 compliance can use RECs generated by offshore wind generators located anywhere within PJM, the offshore wind carve-out requirement can only be met with generators located near Maryland's Atlantic waterfront. The RECs necessary for Tier 1 compliance, expressed as a percent of sales, are shown in Figure 1. Note that Tier 1 requirements remain at 2022 levels in years thereafter. The ACP for Tier 1 RECs is $40 per insufficient REC. As discussed above, this number dictates the maximum amount a utility will pay for compliance. The general Tier 1 requirements are represented in Figure 1 as "Other Tier 1," colored red.

Figure 1. Maryland Tier 1 RPS requirement as a percent of sales



Source: Synapse Energy Economics, based on Md. Public Utility Companies Code § 7-701 et seq.

Tier 1 solar carve-out

The Maryland RPS includes a solar carve-out that ramps from a 0.01 percent of sales requirement in 2009 to a 2.00 percent of sales requirement in 2020 and beyond. The ACP for solar is considerably larger than it is for general Tier 1 resources: $350 in 2015 and 2016, $200 in 2017 and 2018, and declining by $50 every two years thereafter until reaching $50 in 2023 and beyond. The Tier 1 solar carve-out requirement is represented in yellow in Figure 1.

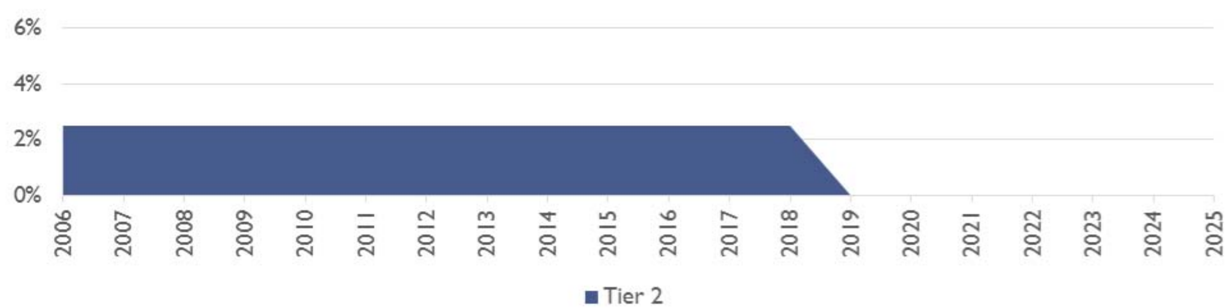
Tier 1 offshore wind carve-out

The Maryland RPS also includes an offshore wind carve-out. Unlike the solar carve-out, the legislation that defines the role of offshore wind in meeting Tier 1 requirements doesn't state an explicit quantity. Instead, it calls for the Maryland Public Service Commission (PSC) to define the actual requirements, subject to a 2.5 percent limitation. Although offshore wind turbines located anywhere in PJM can be used for general Tier 1 compliance, only turbines located on the outer continental shelf between 10 and 30 miles off the coast of Maryland in a U.S. Department of Interior designated leasing zone qualify for the carve-out.[2] The maximum offshore wind carve-out is depicted in blue in Figure 1; should the PSC not require the full 2.5 percent, the remainder is to be allocated as additional general Tier 1 requirement.

Tier 2

The Maryland RPS Tier 2 carve-out has allowed for various technologies in the past, but currently is quite simple: non-pumped storage hydroelectric generation. The requirement is 2.5 percent per year, with the final year of the requirement in 2018 as shown in Figure 2.

Figure 2. Maryland Tier 2 RPS requirement as a percent of sales



Source: Synapse Energy Economics, based on Md. Public Utility Companies Code § 7-701 et seq.

1.2. Maryland's Potential Future RPS

Synapse modeled three potential changes to the Maryland RPS. One of the three options included increasing both the solar carve-out and the overall Tier 1 requirements. Another option included

[2] For the purposes of this report, the region that qualifies for the offshore wind carve-out is referred to as being "in state".

eliminating emitting resources from the list of technologies eligible for RPS compliance. The third option entailed both increasing RPS requirements and excluding the emitting generators from eligible technologies. For purposes of comparison, Synapse also modeled a future based on the existing RPS policy with its current requirements and eligible technologies, resulting in analysis of four different outcomes under four different Maryland RPS policies. Importantly, this report highlights the changes to future generation likely to result from any of the three altered RPS policies, as compared to what is expected under the current policy. Table 1 summarizes the differences between the options modeled.

Table 1. RPS options modeled

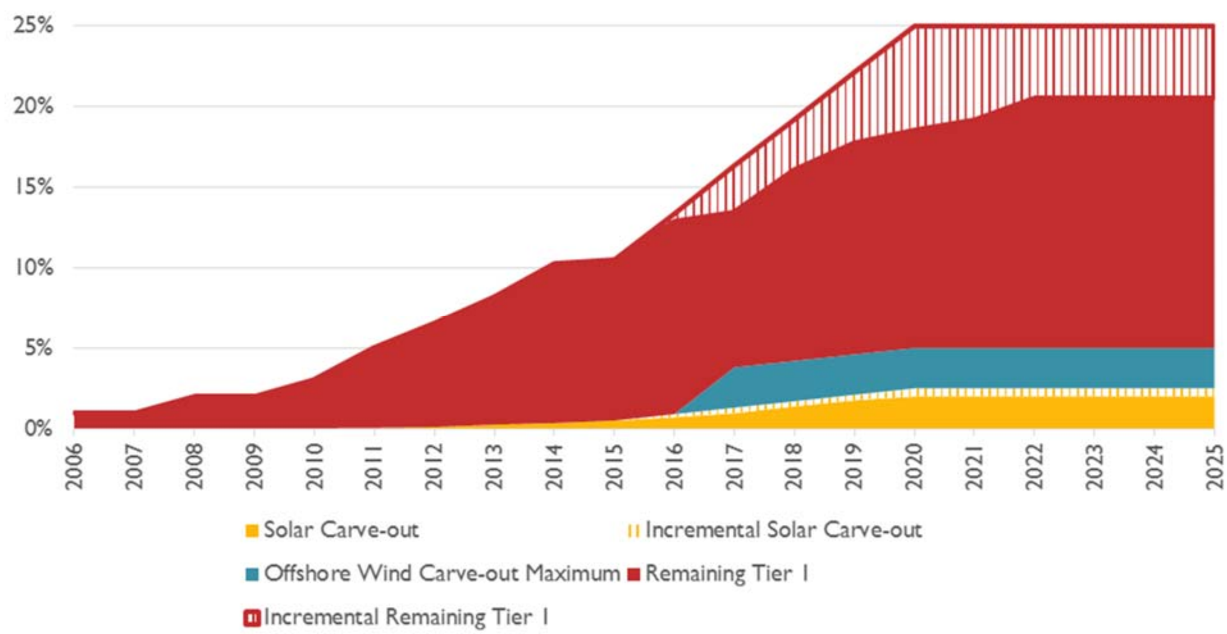
RPS Policy	Increase Tier 1 Requirements	Increase Solar Carve-out	Remove Emitting Resources
Current			
Option 1	✓	✓	
Option 2			✓
Option 3	✓	✓	✓
Note: Emitting resources include biomass, landfill gas, poultry litter, municipal solid waste, and thermal biomass.			

Where RPS requirements are increased in the options modeled, Table 2 and Figure 3 show the variation between the current (reference) case and the case with the increase.

Table 2. Variation in RPS requirements in options modeled

Year	Reference		Increased Requirement (in Option 1 and 3)	
	Solar Carve-out	Other Tier 1	Solar Carve-out	Other Tier 1
2006	0.00%	1.00%	0.00%	1.00%
2007	0.00%	1.00%	0.00%	1.00%
2008	0.01%	2.00%	0.01%	1.99%
2009	0.01%	2.00%	0.01%	1.99%
2010	0.03%	3.00%	0.03%	2.97%
2011	0.05%	4.95%	0.05%	4.90%
2012	0.10%	6.40%	0.10%	6.30%
2013	0.25%	7.95%	0.25%	7.70%
2014	0.35%	9.95%	0.35%	9.60%
2015	0.50%	10.00%	0.50%	10.00%
2016	0.70%	12.00%	0.90%	12.50%
2017	0.95%	12.15%	1.30%	15.00%
2018	1.40%	14.40%	1.70%	17.50%
2019	1.75%	15.65%	2.10%	20.00%
2020	2.00%	16.00%	2.50%	22.50%
2021	2.00%	16.70%	2.50%	22.50%
2022	2.00%	18.00%	2.50%	22.50%

Figure 3. Variation in RPS requirements in options modeled



Option 1: Increase Tier 1 and Solar Carve-out

Under Option 1, the resources eligible for Tier 1 RPS compliance remain unchanged. The percent of Tier 1 compliant generation increases, as does the size of the solar carve-out.

Option 2: Remove Emitting Resources from RPS

Under Option 2, the resources eligible for Tier 1 RPS compliance are changed: RECs from generators with air emissions are no longer eligible for RPS Tier 1 compliance under this option. These include biomass, landfill gas, poultry litter, municipal solid waste, and thermal biomass. The quantity of RECs required is unchanged, as are the carve-out requirements.

Option 3: Increase Tier 1 and Solar Carve-out and Remove Emitting Resources from RPS

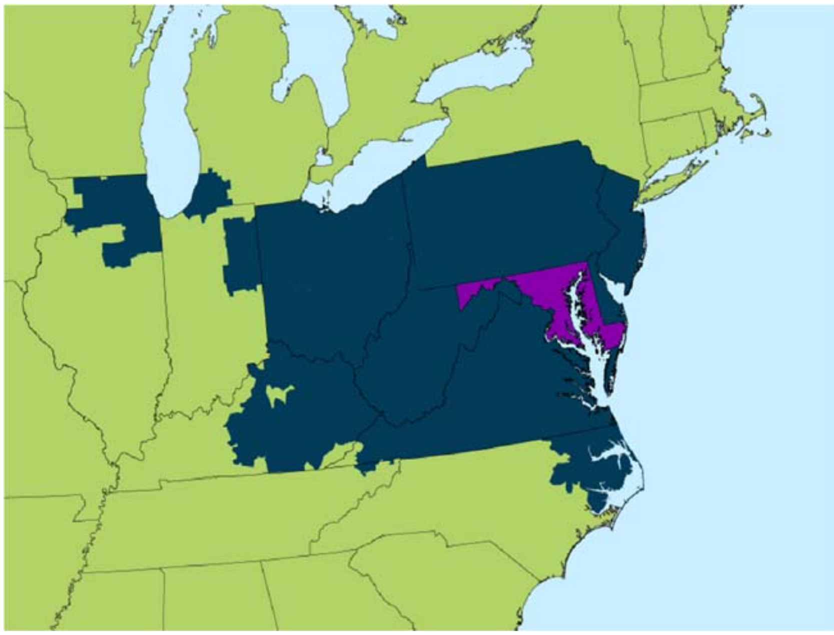
Under Option 3, the resources eligible for Tier 1 RPS compliance are changed: RECs from generators with air emissions are no longer eligible for RPS Tier 1 compliance under this option. These include biomass, landfill gas, poultry litter, municipal solid waste, and thermal biomass. The percent of Tier 1 compliant generation increases, as does the size of the solar carve-out.

2. AVAILABLE RESOURCES

As described above, a variety of resource types are eligible to generate RECs under Maryland's RPS. A description of these resources and their expected behavior given an increase in the RPS follows. While most REC-generating resources may be located anywhere within the PJM region in order to contribute toward Maryland RPS compliance (Figure 4), several resource types must be located within the state of Maryland to qualify.[3] These include solar energy used to generate heat or electricity; geothermal energy used to generate heat or electricity; poultry litter-to-energy; waste-to-energy; and refuse-derived fuel.

[3] Because the PJM region is defined electrically and not geographically, resources located outside of the apparent PJM territory may be eligible, depending on transmission details. Additionally, offshore wind turbines located in a U.S. Department of Interior designated leasing zone located on the outer continental shelf between 10 and 30 miles off the coast of Maryland are considered "in state" within this study.

Figure 4. Map of the PJM region (blue), with Maryland highlighted in violet



Source: PJM

2.1. In-State Resources

Solar PV

Solar PV devices, which generate electricity directly upon absorption of sunlight, are eligible for in-state Tier 1 RECs under Maryland's RPS. Solar PV projects may be utility-scale or distributed (i.e., located on rooftops). The maximum potential of solar PV installations (Table 3) was defined as the total potential of utility-scale PV in Maryland as cited in a 2015 report from the National Renewable Energy Laboratory (NREL).[4]

Significant reductions in the installed cost of PV projects over the study period were assumed. The Synapse cost forecast is based on ongoing review of data and forecasts for module costs, balance of system costs and installed costs, and on costs reported in other countries with rapidly growing PV sectors. The forecast incorporates project costs reported by developers to state and federal agencies and is informed by discussions with developers and other industry experts. Data consulted also includes costs reported directly from government agencies and from the annual *Tracking the Sun* report from Lawrence Berkeley National Labs (LBNL).[5]

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[4] Brown, A., Beiter, P., Heimiller, D., Davidson, C., Denholm, P., Melius, J., Lopez, A., Hettinger, D., Mulcahy, D., and G. Porro. 2015. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." National Renewable Energy Laboratory. p83. Available at: www.nrel.gov/docs/fy15osti/64503.pdf.

[5] Barbose, G., Weaver, S., and N. Darghouth. 2014. "Tracking the Sun VII: An Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2013." Lawrence Berkeley National Laboratory.

Table 3. Solar PV potential and costs (2014$)

2020 Potential	
In-State Capacity (MW)	466,000
In-State Generation (GWh/yr)	796,000

2020 Costs	
Capital ($/kW)	1,629
Fuel ($/mmBtu)	0
FOM ($/MW-yr)	7,524
VOM ($/MWh)	0

Sources: Brown et al., 2015; Barbose et al., 2014.

Solar Thermal

Solar thermal generation refers to the use of sunlight to capture heat, typically for the purposes of heating water. This reduces or avoids the need to heat water with electricity or direct combustion of fossil fuels. Solar thermal water heaters are awarded RECs as a function of the amount of heat captured by the system. Solar thermal resources have been eligible to receive Tier 1 in-state RECs since 2012[6] but have only been listed as a separate resource in Maryland's compliance reports since 2012. The RECs generated by solar thermal systems more than tripled from 2012 to 2013.[7,8] However, the technology remains a marginal part of Maryland's renewable portfolio, representing less than a half percent of the total Tier 1 RECs generated in state. Solar thermal water heaters in Maryland are used primarily as a supplement to conventional water heaters, rather than as a replacement. Such systems are capital-intensive and have payback periods that vary based on many factors, of which possible REC revenue is only one. A system's cost-effectiveness benefits from economies of scale, and depends on the amount of hot water used on site and the comparative price of fully heating that water with electricity or natural gas. As a result, many installations of solar thermal water heaters are located at institutional sites such as hotels and universities, which tend to have large roof areas and use considerable amounts of hot water. [9,10] Moreover, institutional consumers can more easily secure financing for these capital-intensive improvements. Because the economics of installing solar thermal water heaters are complex, the installation rate is not expected to be particularly dependent on changes to the RPS. Therefore, solar thermal installations are modeled to maintain their linear growth rate throughout the study period under all scenarios. The potential assumed in 2020 can be found in Table 4.

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6 Maryland General Assembly. 2011. "An Act Concerning Renewable Energy Portfolio Standard - Renewable Energy Credits - Solar Water Heating Systems." Senate Bill 717. Available at: mgaleg.maryland.gov/2011rs/bills/sb/sb0717e.pdf.

7 Public Service Commission of Maryland. 2014. "Renewable Energy Portfolio Standard Report with Data for Calendar Year 2012." p14. Available at: www.psc.state.md.us/wp-content/uploads/2014-Renewable-Energy-Portfolio-Report.pdf.

8 Ibid., p17.

9 University of Maryland. 2010. "Solar Hot Water at the Diner." Available at: www.sustainability.umd.edu/content/campus/energy.php#Solar Diner.

10 Hasek, Glenn. 2009. "Future Looks Brighter for Solar Hot Water Heating Systems at Hotels." *GreenBiz*. March 18. Available at www.greenbiz.com/news/2009/03/18/future-looks-brighter-solar-hot-water-heating-systems-hotels.

Table 4. Solar thermal resource modeled

2020 Resource Modeled	
In-State Generation (GWh/yr)	13.2

Source: Synapse extrapolation from Maryland Public Service Commission data, 2011 – 2015.

Geothermal

Maryland's geothermal systems operate by using underground soils or water reservoirs as heat sources or sinks in order to exchange thermal energy. They are used typically for heating or cooling purposes rather than for electricity generation. Water or glycol is pumped through an underground loop where it exchanges heat with soils that maintain a constant and moderate temperature throughout the year, thereby providing warmth in winter and coolant in summer. The 50 to 60°F fluid can then be used for space heating or cooling. Geothermal systems have been eligible to receive Tier 1 in-state RECs since 2013.[11] Only 44 RECs were awarded to this resource in 2013, which represents less than a hundredth of a percent of the total number of Tier 1 RECs awarded to in-state resources.[12] No RECS were awarded to geothermal resources in previous years as this resource was not eligible to receive RECs before 2013. Geothermal systems are awarded RECs using a methodology similar to solar thermal resources. Geothermal systems can be extremely efficient and low-cost to operate but have prohibitively high up-front costs that may depend greatly on site-specific characteristics. Similar to solar thermal water heaters, the cost-effectiveness of geothermal systems varies depending on the comparative price of performing the same heating or cooling function with electricity or natural gas. Because the economics of installing geothermal systems are complex and the practice rare, the installation rate is not expected to depend on changes to the RPS. Geothermal installations are therefore assumed to maintain their 2012 to 2013 growth rate throughout the study period under all scenarios. The potential assumed in 2020 can be found in Table 5.

Table 5. Geothermal resource modeled

2020 Resource Modeled	
In-State Generation (GWh/yr)	0.4

Source: Synapse extrapolation from Maryland Public Service Commission data, 2011 – 2015.

Municipal Solid Waste

Incineration has been the preferred means of municipal solid waste disposal at many different periods of time and in many different locations. Recently, there has been a resurgence of interest in municipal solid waste incineration as a means of generating electricity. Municipal solid waste incineration has been

[11] Maryland General Assembly. 2011. "An Act Concerning Renewable Energy Portfolio Standard - Renewable Energy Credits - Geothermal Heating and Cooling." Senate Bill 652. Available at: mgaleg.maryland.gov/2012rs/bills/sb/sb0652e.pdf.

[12] Public Service Commission of Maryland. 2015. p17.

included in Maryland's RPS since its inception. The RPS statute was revised to make generation from municipal solid waste incineration eligible for Tier 1 rather than Tier 2 RECs in 2011.[13]

Municipal solid waste incineration is seen by many as a "win-win" because it allows the disposal of what would otherwise be a cumbersome waste product while serving as a useful and potentially lucrative energy source. However, energy generation from municipal solid waste is complex, as the composition of the fuel is not necessarily constant over time or optimal for energy generation purposes. The municipal solid waste most appropriate for energy generation has high proportions food and other organic waste as well as paper or cardboard products.[14] Even in the most optimal cases, municipal solid waste tends to have higher ash and moisture contents than preferred fuel materials, further complicating the energy generation process.[15] As a result, energy generation from municipal solid waste is often one of the most expensive methods for the disposal of solid waste.[16] Moreover, in order for a plant to operate economically, it must have a sufficient solid waste stream throughout the year. This often requires aggregation of waste from many communities, which adds to transport costs and may introduce vulnerabilities into the fuel supply chain.

Municipal solid waste incinerators may also present serious environmental concerns. Municipal solid waste often contains trace amounts of heavy metals and other contaminants. It is difficult to remove these contaminants from municipal solid waste before incineration and therefore many municipal solid waste projects (including those in Maryland) are required to install costly advanced emissions controls.[17] Even given these controls, the emissions from municipal solid waste may contain relatively high concentrations of hazardous compounds. For these reasons, proposed projects often elicit strong opposition from those who live or work in the immediate vicinity of a project site.

Due to these complexities, municipal solid waste plants are often developed on a case-by-case basis. In Maryland, there are three major municipal solid waste plants currently operating. The smallest, in Harford County, does not contribute to Maryland RPS compliance as it is not connected to the PJM grid and is therefore ineligible.[18] In addition, this plant is scheduled to retire in 2016.[19] The other two plants are the 61.3 MW Wheelabrator Baltimore project and the 54 MW Montgomery County Resource

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[13] Maryland General Assembly. 2011. "An Act Concerning Renewable Energy Portfolio - Waste-to-Energy and Refuse-Derived Fuel." Senate Bill 690. Available at: mgaleg.maryland.gov/2011rs/bills/sb/sb0690e.pdf.

[14] The World Bank. 1999. "Municipal Solid Waste Incineration." p11. Available at: www.worldbank.org/urban/solid_wm/erm/CWG%20folder/Waste%20Incineration.pdf.

[15] Ibid.

[16] The World Bank. 1999. "Decision Makers' Guide to Municipal Solid Waste Incineration." p1. Available at: web.mit.edu/urbanupgrading/urbanenvironment/resources/references/pdfs/DecisionMakers.pdf.

[17] Ibid., p13.

[18] Power Plant Research Program. "Maryland Power Plants and the Environment." Available at: pprp.info/ceir17/HTML/Chapter2-1-5.html.

[19] Harford County. "Waste-to-Energy." Available at: www.harfordcountymd.gov/306/Waste-To-Energy.

Recovery Facility incinerator.[20] Together, these plants have been awarded approximately 660,000 RECs each year since 2009, with REC production from municipal solid waste incineration remaining relatively constant between 2009 and 2013.[21] It is expected that these plants will continue to operate at their historical level, generating approximately the same quantity of RECs irrespective of the prospective changes to the RPS analyzed in this study.

There is one major new municipal solid waste incinerator that has been proposed in Maryland, to be located in South Baltimore. This project has been under development since before 2010.[22] The project's status is currently in question as its environmental permits may have expired, and no substantial construction has occurred on the project since 2013.[23] Moreover, the project has had persistent difficulties securing financing. This difficulty remained even after RECs from municipal solid waste were made eligible for Tier 1 status.[24]

Although the project plans call for major construction to begin in the near future, many of the major organizations that had agreed to purchase power from the plant have reneged on their commitments due to environmental concerns,[25] and no information pertaining to newly signed power purchase agreements have been publicly released.[26] As a result, it is expected that any further change to the RPS will not make a material difference to the likelihood of the project's completion; such RPS changes are likely to be general rather than specifically targeted to benefit municipal solid waste incineration. It was assumed that the project would not reach completion within the study period due to the lack of power purchasing agreements already in place. As such, the potential for municipal solid waste incineration assumed in 2020 (Table 6) represents only the two currently operational REC-generating plants.

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[20] Power Plant Research Program. 2013. "Power plant locations in and around Maryland." Available at: pprp.info/powerplants/powerplantinformation.htm.

[21] Public Service Commission of Maryland. 2011-2015. "Renewable Energy Portfolio Standard Reports with Data for Calendar Years 2009-2013." Available at: www.psc.state.md.us/wp-content/uploads/.

[22] Wheeler, T. 2015. "Trash-burning power project hits new snag." *The Baltimore Sun.* February 16. Available at: www.baltimoresun.com/features/green/blog/bs-md-incinerator-20150216-story.html.

[23] Shen, F. 2015. "State sets deadline for Energy Answers to prove incinerator permit is valid." *The Baltimore Brew. Available* at: www.baltimorebrew.com/2015/11/25/state-sets-deadline-for-energy-answers-to-prove-incinerator-permit-is-valid/.

[24] Vail, B. 2014. "Baltimore teens take out the trash: Youth battle a waste incinerator." *In These Times.* Available at: inthesetimes.com/article/17351/teens_take_out_the_trash.

[25] Wheeler, T. 2015. "Trash-burning power project hits new snag."

[26] Jedra, C. 2015. "Despite protests and delays, full-time construction of power plant set for 2016." *Capital Gazette.* October 30. Available at: www.capitalgazette.com/maryland_gazette/news/ph-ac-gn-energy-answers-power-plant-1028-20151030-story.html.

Table 6. Municipal solid waste resource modeled

2020 Resource Modeled	
In-State Capacity (MW)	115
In-State Generation (GWh/yr)	662.7

Source: Synapse extrapolation from Maryland Public Service Commission data, 2011 – 2015.

Poultry Litter

Poultry litter is a carbonaceous waste material that can be incinerated for energy purposes or subjected to anaerobic decomposition to produce methane, which can then be burned to produce heat or electricity. When incinerated, poultry litter can be treated similarly to other forms of biomass, with the exception that it is generally used in a wet form rather than pre-dried. Mass-based parameters for this study were therefore calculated on a wet basis. Besides its high moisture content, poultry litter is high in nitrogen, phosphorus, and ash content and has a rather low heat content. This makes it less attractive as a source of fuel than conventional forms of biomass. Poultry litter projects are often proposed both as a means to generate electricity and as a means of waste disposal, with similar motivations to municipal solid waste incineration.

Approximately 460,000 tons of poultry litter is produced in Maryland annually. Presently, the majority is applied to agricultural lands as a low-cost fertilizer. This practice presents environmental hazards, however, as runoff of excess nutrients has contributed to the eutrophication of the Chesapeake Bay.[27] In addition, more chicken litter is produced in Maryland than can be economically used as fertilizer.[28] As a result, there has been strong interest in poultry litter-to-energy conversion. In-state energy generation from poultry litter is eligible for Tier 1 RECs under Maryland's RPS. To date no RECs have been generated by this resource, because no proposed projects have proceeded to an operational phase. Despite recurrent interest in the technology, proposed poultry litter incinerators have faced stiff opposition due to the damages caused by plant emissions.[29] In other locations, biomass facilities have been opposed on the basis of noise, smell, and increased traffic; whether those challenges factor into opposition of poultry litter incinerators in Maryland remains to be seen.[30]

In order to determine the full technical potential of poultry litter-to-energy conversion in Maryland, Synapse assumed that as much as the entire supply of poultry litter may be used as feedstock material for a single plant or for multiple plants. Virtually all of the poultry litter produced in Maryland is located

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[27] Boesch, D., Brinsfield, R., and R. Magnien. 2001. "Chesapeake Bay Eutrophication: Scientific Understanding, Ecosystem Restoration, and Challenges for Agriculture." *J. Environ. Qual*. 30:303–320.

[28] Wheeler, T. 2015. "Legislation coming on farm pollution?" *The Baltimore Sun*. January 28. Available at: www.baltimoresun.com/news/maryland/politics/blog/bal-legislation-coming-on-farm-pollution-20150128-story.html.

[29] Anderson. D. 2015. "Harford environmental advocates push to remove chicken waste as alternative energy source." *The Baltimore Sun*. November 24. Available at: www.baltimoresun.com/news/maryland/harford/aberdeen-havre-de-grace/ph-ag-chicken-manure-energy-protest-1127-20151124-story.html.

[30] Jose, S., Bhaskar, T. 2015. *Biomass and Biofuels.* CRC Press. Page 19.

in one of eight counties clustered on the Delmarva Peninsula.[31] Therefore, it was assumed that one or more centrally located plants (for example, in Dorchester County) would be able to obtain the totality of the poultry litter produced in those eight counties. The costs for a standard fluidized-bed incinerator[32] were assumed for the poultry litter plant, as this technology is often used for poultry litter incineration and has been proposed in Maryland (Table 7).[33] A range of fuel costs were tested, ranging from the cost of collecting the litter and transporting it to a central plant on the low end, to the cost of transporting the litter and replacing the value of the litter as fertilizer on the high end. These costs are specifically applicable to Maryland, as cited in Lichtenberg et al.[34] These assumed fuel costs are comparable to costs assumed in a report prepared for the Northeast Regional Biomass Program, which examines the costs of poultry litter incineration in Maryland in particular.[35]

The capacity of the proposed plant was based on the same Northeast Regional Biomass Program report, which describes several different plant sizes and their yearly tonnage requirements. The tonnage requirement for a 35 MW plant was only slightly below the total poultry litter production and therefore this plant size was assumed to be the total potential (Table 7).

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[31] United States Department of Agriculture. 2012. "Census of Agriculture." National Agricultural Statistics Service. Available at: quickstats.nass.usda.gov/results/176B3310-B113-3906-BFFC-BA0A3BEFA5A1.

[32] Energy Information Administration. 2015. "Updated Capital Cost Estimates for Electricity Generation Plants." p105. Available at: www.eia.gov/forecasts/aeo/assumptions/pdf/electricity.pdf.

[33] Maryland Department of Agriculture. 2014. "MDA Awards $970,000 for New Manure Management Technology Project; Farm Partners with Irish Co. with Support from Mountaire." Available at: news.maryland.gov/mda/press-release/2014/10/29/mda-awards-970000-for-new-manure-management-technology-project-farm-partners-with-irish-co-with-support-from-mountaire/.

[34] Lichtenberg, E., Parker, D., and L. Lynch. 2002. "Economic Value of Poultry Litter Supplies In Alternative Uses." University of Maryland Center for Agricultural and Natural Resource Policy. Available at: www.arec.umd.edu/sites/default/files/_docs/CANRP%20Poultry%20Litter%20Report.pdf.

[35] Bock, B. 2000. "Poultry Litter to Energy: Technical and Economic Feasibility". Prepared for the Northeastern Regional Biomass Program. Available at: www.brbock.com/RefFiles/PoultryLitter_Energy.doc.

Table 7. Poultry litter potential and costs (2014$)

2020 Potential	
In-State Capacity (MW)	35
In-State Generation (GWh/yr)	261

2020 Costs	
Capital ($/kW)	3,617
Fuel ($/mmBtu)	1.66
FOM ($/MW-yr)	107,269
VOM ($/MWh)	5.34

Sources: Lichtenberg et al., 2002; Bock, 2000; EIA, 2015.

2.2. PJM-Wide Resources

Hydropower

Hydroelectric generation is eligible for both Tier 1 and Tier 2 RECs under Maryland's RPS. Hydropower may be generated anywhere within PJM to be eligible. Projects under 30 MW are eligible for Tier 1 RECs while larger projects are considered to be Tier 2 resources. Due to weather fluctuations, the number of RECs generated from hydropower in both tiers has varied from year to year between 2009 and 2013, but has generally been between 500,000 and 800,000 for Tier 1 resources and 1,100,000 and 1,400,000 for Tier 2 resources.[36] While the amount of hydropower resources yet to be developed in Maryland or the entire PJM region may be small, it was assumed that generation from hydropower may increase during the study period and that the extent of the increase may vary based on changes to the RPS. No specific capacity increase was assumed. Capital costs (Table 8) were taken from data from NREL, while fixed and variable operation and management (O&M) costs were those reported by the EIA. [37,38]

Table 8. Hydropower potential and costs (2014$)

2020 Potentials	
In-State Capacity (MW)	200
In-State Generation (GWh/yr)	1,100
PJM-Wide Capacity (MW)	4,900 – 9,700
PJM-Wide Generation (GWh/yr)	26,000 – 52,500

2020 Costs	
Capital ($/kW)	6,270
Fuel ($/mmBtu)	0
FOM ($/MW-yr)	15,392
VOM ($/MWh)	5.86

Sources: Brown et al., 2015; Short et al., 2011; EIA, 2015.

Ocean

Several technologies for capturing energy from the ocean are explicitly included in Maryland's RPS as qualifying PJM-wide resources. These include wave, tidal, current, and ocean thermal-based

[36] Public Service Commission of Maryland. 2011-2015. Renewable Energy Portfolio Standard Reports with Data for Calendar Years 2009-2013.

[37] Short, W., Sullivan, P., Mai, T., Mowers, M., Uriarte, C., Blair, N., Heimiller, D., and A. Martinez. 2011. Regional Energy Deployment System (ReEDS). National Renewable Energy Laboratory. Available at: www.nrel.gov/analysis/reeds/pdfs/reeds_documentation.pdf.

[38] Energy Information Administration. 2015. "Updated Capital Cost Estimates for Electricity Generation Plants." p105.

technologies. Wave, tidal, and current energy generation systems convert the motion of ocean waters into usable energy while ocean thermal systems function similarly to the geothermal systems described above. Although the amount of energy that can potentially be gleaned from the ocean is vast, present-day technologies for the conversion of ocean energy tend to be inefficient, expensive, and difficult to site. As a result, no RECs have yet been generated from ocean sources. For the purposes of this study, it was assumed that this trend would continue and ocean energy technologies would not be deployed before 2025.

Fuel Cells

Similar to batteries, fuel cells operate by capturing electrical energy that is a byproduct of a chemical reaction. Generally, fuel cells use hydrogen or methane gas as a fuel, which is then combined with oxygen to produce water (in the case of hydrogen fueling) or water and CO_2 (in the case of methane fueling). In Maryland's RPS, energy generated from fuel cells can qualify for Tier 1 if the fuel source is methane from a qualifying form of biomass or anaerobic digestion. As a result, this energy can be considered to be ultimately sourced from a qualifying biomass or digestion project rather than the fuel cell itself. For the purposes of this study, therefore, fuel cells were not considered as an independent generation source.

Landfill Gas

Most landfills contain some amount of organic matter. This matter decomposes over time, releasing gaseous byproducts. When refuse is first added to a landfill, it decomposes under aerobic conditions (i.e., in the presence of oxygen), resulting primarily in the production of CO_2 gas. However, as further refuse is added, oxygen is consumed but cannot be replaced. This leads to the development of anaerobic conditions, under which decomposition of organic matter produces methane gas. At many landfills, this methane can be captured and burned to produce energy. However, the installation of the necessary apparatus is very site-specific.

Energy production from landfill gas is eligible for both in-state and PJM-wide Tier 1 RECs under Maryland's RPS. In Maryland, generation of RECs from landfill gas resources was relatively steady from 2009 to 2012 and approximately doubled from 2012 to 2013.[39] Because the development schedule of landfill gas projects is rarely based on purely economic considerations, RECs from landfill gas in Maryland were assumed to be steady at the 2013 level for the entire study period. The assumed generation for Maryland is shown in Table 9. No specific production level was assumed for landfill gas resources outside of Maryland.

[39] Public Service Commission of Maryland. 2011-2015. Renewable Energy Portfolio Standard Reports with Data for Calendar Years 2009-2013.

Table 9. Landfill Gas resource modeled

2020 Resource Modeled	
In-State Generation (GWh/yr)	102.6

Source: Synapse extrapolation from Public Service Commission of Maryland data, 2011 – 2015.

Biomass

Use of qualifying biomass to generate heat or power is eligible for Tier 1 RECs when performed anywhere within PJM. Biomass can be processed using heat (for example, through incineration or pyrolysis) or by undergoing anaerobic digestion. Qualifying forms of biomass include certain forestry residues, food or animal wastes, and "energy crops" that are grown specifically for energy generation purposes. Biomass may be co-fired with other fuels and remain eligible for RECs under Maryland's RPS. For the purposes of this study, it was assumed that all energy generated from biomass resulted from biomass incineration in a fluidized bed reactor or similar facility.

The majority of the RECs generated from biomass and used for compliance in Maryland have been awarded for incineration of forestry wastes elsewhere in PJM.[40] At present, it is difficult to site woody biomass incinerators in Maryland due to a prohibition on the use of solid fuel in small furnaces.[41] It was assumed that the legal status of woody biomass incineration within Maryland would not change during the study period. Outside of Maryland, it was assumed that generation from biomass may respond to changes in the RPS. The potential of biomass within Maryland and in PJM as a whole (Table 10) was taken from NREL.[42] Capital and O&M costs were assumed to be those reported by the EIA,[43] while a region-specific supply curve was used to determine fuel costs.[44]

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[40] Ibid.

[41] Code of Maryland Regulations. 1988. "Chapter 9.04: Control of Fuel Burning Equipment, Stationary Internal Combustion Engines, and Certain Fuel-Burning Installations: Prohibition of Certain New Fuel-Burning Equipment" Title 26, Subtitle 11: Air Quality. Available online at: yosemite.epa.gov/r3/r3sips.nsf/9eeb842c677f8f5d85256cfd004c3498/21a38b098ec77a9785256d1f0048e959/$FILE/md_fuel_burning_equip_26_11_09_04.pdf.

[42] Brown et al. 2015. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." National Renewable Energy Laboratory. p88.

[43] Energy Information Administration. 2015. "Updated Capital Cost Estimates for Electricity Generation Plants." p105.

[44] Short et al. 2011. Regional Energy Deployment System (ReEDS). National Renewable Energy Laboratory.

Table 10. Biomass potential and costs (2014$)

2020 Potentials	
In-State Capacity (MW)	200
In-State Generation (GWh/yr)	1,700
PJM-Wide Capacity (MW)	4,800 – 12,000
PJM-Wide Generation (GWh/yr)	37,000 – 94,500

2020 Costs	
Capital ($/kW)	3,617
Fuel ($/mmBtu)	2.82 – 4.77
FOM ($/MW-yr)	107,269
VOM ($/MWh)	5.34

Sources: Brown et al., 2015; EIA, 2015; Short et al., 2011.

Black Liquor

Black liquor is a byproduct of wood pulp manufacturing when using the kraft process. It contains a sufficient amount of organic matter to serve as a low-quality fuel and is often incinerated on site at paper mills to provide process heat, steam, or electricity. Energy production from black liquor is included in Maryland's RPS as a qualifying form of biomass and is eligible to receive Tier 1 RECs both in state and PJM-wide. Black liquor incineration is not, however, a stand-alone process; it exists only at paper mills. Energy generation from black liquor increases or decreases based on the output of paper mills rather than based on traditional economic concerns. As such, an increase in REC prices is not expected to impact REC production from black liquor. Indeed, the RECs awarded to black liquor resources within Maryland go to a single facility and their number was essentially constant between 2009 and 2012, with a slight decrease from 2012 to 2013.[45] It was assumed that the number of RECs generated from black liquor in Maryland would stay constant at the average of 2009 – 2013 levels for the entire study period under all conditions (Table 11). Outside of Maryland, black liquor was not isolated from the general biomass category.

Table 11. Black Liquor resource modeled

2020 Resource Modeled	
In-State Generation (GWh/yr)	123.7

Source: Synapse extrapolation from Public Service Commission of Maryland data, 2011 – 2015.

Onshore Wind

Generation from onshore wind turbines represents a large portion of the renewable energy produced both in Maryland and in PJM as a whole. Onshore wind resources are eligible for Tier 1 RECs both in state and PJM-wide. In terms of in-state generation of RECs, onshore wind was second only to municipal solid waste in the number of RECs awarded in 2013 (the most recent year for which data was available).[46] Onshore wind from anywhere within PJM represents the largest share of RECs used for compliance within Maryland in 2013, at 38.5 percent of the total Tier 1 RECs retired for compliance. The majority of the onshore wind RECs used for compliance in Maryland were generated elsewhere in PJM,

[45] Public Service Commission of Maryland. 2011-2015. Renewable Energy Portfolio Standard Reports with Data for Calendar Years 2009-2013.

[46] Public Service Commission of Maryland. 2015. p17.

predominantly in Illinois, Indiana, and Pennsylvania.[47] The number of RECs generated from onshore wind resources has increased by a hundredfold in four years, from just over 20,000 in 2009 to almost 2,000,000 in 2013.[48] It is expected that generation from onshore wind in PJM will increase during the study period to an extent that may vary based on changes to the RPS. The potentials for onshore wind within Maryland and in PJM as a whole (Table 12) were taken from NREL.[49] Wind costs for land-based wind were based on research done for the U.S. Department of Energy's (DOE) recent *Wind Vision Report*.[50]

Table 12. Onshore wind potential and costs (2014$)

2020 Potentials	
In-State Capacity (MW)	900
In-State Generation (GWh/yr)	3,000
PJM-Wide Capacity (MW)	78,100 – 361,100
PJM-Wide Generation (GWh/yr)	227,000 – 1,135,000

2020 Costs	
Capital ($/kW)	1,700
Fuel ($/mmBtu)	0
FOM ($/MW-yr)	50,161
VOM ($/MWh)	0

Sources: Brown et al., 2015; U.S. DOE. 2015.

Offshore Wind

Offshore wind generated in PJM is eligible for Tier 1 RECs, however no projects have yet been developed. This is partially because offshore wind remains expensive compared to onshore wind and other resources. The Maryland Offshore Wind Energy Act of 2013 created an offshore wind carve-out in the state's RPS of up to 2.5 percent of the state's total retail electricity sales.[51] Although offshore wind located anywhere within PJM is eligible for Tier 1 compliance, only offshore wind located off of the Maryland coast is eligible for compliance with the RPS offshore wind carve-out. It was assumed, therefore, that this carve-out would be satisfied within the study period regardless of changes to the RPS. Due to the lengthy development schedules of offshore wind projects, it was assumed that the carve-out would be satisfied by 2025 but not by 2020. Offshore wind costs (Table 13) were taken from the *Wind Vision* assumptions.[52]

[47] Ibid., p23.

[48] Public Service Commission of Maryland. 2011-2015. Renewable Energy Portfolio Standard Reports with Data for Calendar Years 2009-2013.

[49] Brown et al. 2015. "Estimating Renewable Energy Economic Potential in the United States: Methodology and Initial Results." National Renewable Energy Laboratory. p82.

[50] United States Department of Energy (U.S. DOE). 2015. *Wind Vision: A New Era for Wind Power in the United States*. Available at: www.energy.gov/sites/prod/files/WindVision_Report_final.pdf.

[51] Maryland General Assembly. 2013. *Maryland Offshore Wind Energy Act of 2013.* House Bill 226. Available at: mgaleg.maryland.gov/2013RS/bills/hb/hb0226E.pdf.

[52] U.S. DOE, 2015.

Table 13. Offshore wind potential and costs (2014$)

2020 Potentials	
In-State Capacity (MW)	0
In-State Generation (GWh/yr)	0
PJM-Wide Capacity (MW)	0
PJM-Wide Generation (GWh/yr)	0

2020 Costs	
Capital ($/kW)	4,601
Fuel ($/mmBtu)	0
FOM ($/MW-yr)	116,624
VOM ($/MWh)	0

Source: U.S. DOE, 2015.

3. Electricity Modeling Approach

The ReEDS Model

The Regional Energy Development System (ReEDS) model—a long-term capacity expansion and dispatch model of the electric power system in the lower 48 states, developed by the National Renewable Energy Laboratory (NREL)—is used as the modeling platform for the electricity sector impacts analysis.[53] ReEDS has a high degree of renewable resource detail, with many wind and solar resource regions, each with availability by resource class and unique grid connection costs. Model outputs include generation, capacity, transmission expansion, capital and operating costs, and emissions of CO_2, SO_2, NO_x, and mercury. The model operates in two-year steps, with each two-year period divided into 17 time slices representing morning, afternoon, evening, and night in each of the four seasons, plus an additional summer peak time slice. ReEDS includes data on the existing fossil fuel facilities in each of the model's 134 Power Control Areas (PCAs) based on data reported in EIA's Form 860 Annual Electric Generator Report.

ReEDS has been used by NREL to analyze a number of future climate and energy policy scenarios, renewable energy development scenarios, renewable portfolio standards, and cap-and-trade policies. NREL also makes available detailed data sets from its SunShot modeling[54] (rooftop PV) and *Renewable Energy Futures*[55] study (electric vehicle penetration), with resources divided into ReEDS's 134 control areas. These capabilities and data make ReEDS very useful for examining high renewable energy scenarios and policies that impact renewable energy.

ReEDS does not co-optimize load-side resources such as energy efficiency and rooftop solar; input assumptions for these resources have been developed and are discussed below. In addition, ReEDS represents coal and gas fleets with blocks of capacity types, not with specific units. Therefore, the

[53] Short et al. 2010.

[54] U.S. Department of Energy. 2015. "The Sunshot Vision Study." Last Accessed December 2015. Available at: http://energy.gov/downloads/sunshot-vision-study.

[55] National Renewable Energy Laboratory. 2012. *Renewable Electricity Futures Study*. Hand, M.M.; Baldwin, S.; DeMeo, E.; Reilly, J.M.; Mai, T.; Arent, D.; Porro, G.; Meshek, M.; and D. Sandor. eds. 4 vols. NREL/TP-6A20-52409. Golden, CO: National Renewable Energy Laboratory. Available at: http://www.nrel.gov/analysis/re_futures/.

model's retirement of coal and gas capacity is driven primarily by the capacity factors of plant types within a control area, and it does not take into account drivers such as recent regulations relating to cooling water and coal ash. However, ReEDS does distinguish between coal capacity with and without SO_2 controls, and it applies SO_2 costs and complies with the national SO_2 cap.

ReEDS is a recursive-dynamic linear program, solving for each two-year time period as it moves successively from the present day forward in time. The objective function is a minimization of power sector capital and operating costs in each two-year period.

In addition to meeting loads in each time slice, there are a number of reserve margin constraints the model must also meet. Planning reserves—the level of firm generating capacity above the forecasted system peak—are modeled based on levels required by the North American Reliability Corporation (NERC) in 13 regions, and range from 12.5 to 17.2 percent. ReEDS endogenously determines the capacity value for wind and utility-scale solar resources, and this value can change as resources are built. The model also represents system-level operating reserve requirements, including contingency reserves (6 percent of demand in each time slice), frequency regulation reserves (1.5 percent of demand), and forecast error reserves (endogenously determined, increases with wind and PV penetration).

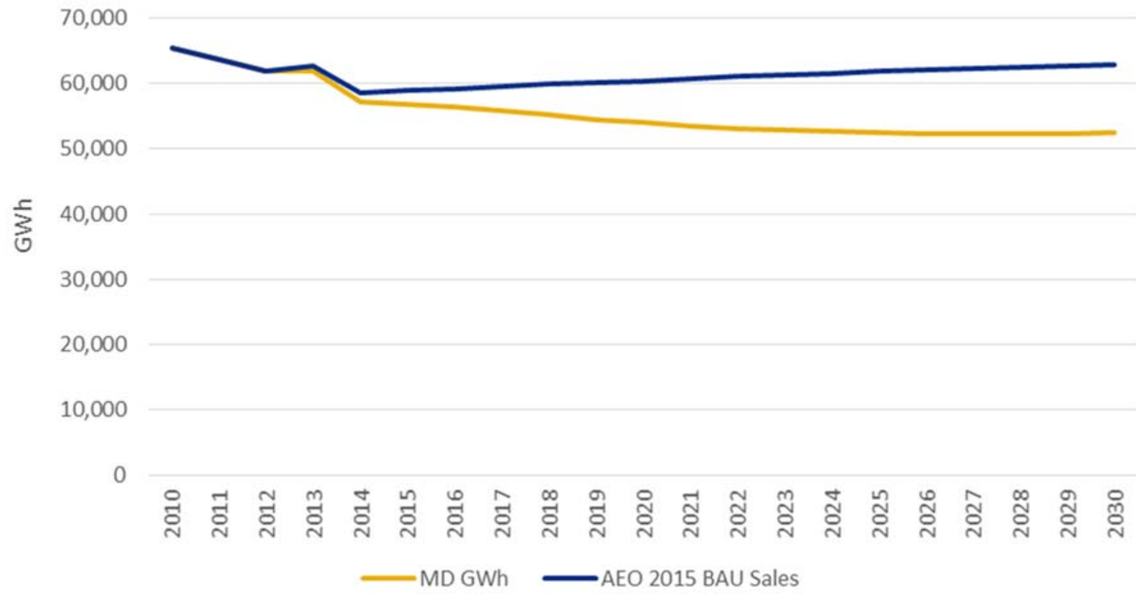
ReEDS benefits from NREL's detailed data sets on renewable resource potentials and constraints across the country. Wind resources are modeled in 356 regions of the United States, based on high-resolution wind speed modeling and taking into account environmental and land-use exclusions (described in more detail below). Biomass, geothermal, PV, and hydropower plants are built at the resolution of the model's 134 power control areas.

Key Electric Power System Modeling Assumptions

Electricity Loads

Electricity loads from the U.S. Energy Information Administration's 2015 Annual Energy Outlook (AEO) Reference Case form the basis of the loads in the reference case and all alternative RPS scenarios. To this, expiring embedded energy efficiency in the AEO and state-level energy efficiency requirements (EERS) for all states are included. Additionally, for Maryland, the modeled electricity load includes impacts of Maryland PSC Order 87082, which directs Maryland utilities to, after 2015, increase energy efficiency savings by 0.2% per year until levels of 2% are achieved in accordance with the EmPOWER Maryland Energy Efficiency Act of 2008 ("EmPOWER"). Figure 5 shows the original AEO 2015 Reference Case load for Maryland ("AEO 2015 BAU sales"), and the final Maryland loads applied in the ReEDS modeling (MD GWh).

Figure 5. Maryland electricity loads



Source: Synapse Energy Economics, based on AEO 2015 data.

Fuel Prices

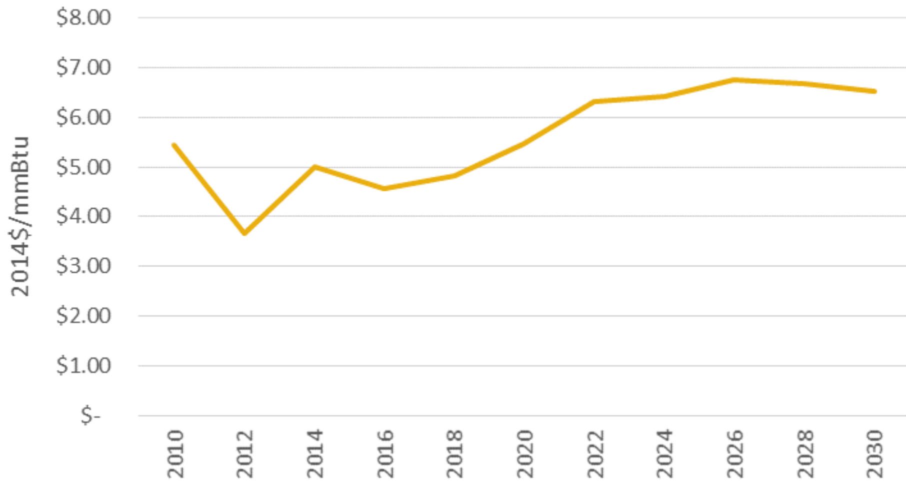
Coal, oil, and uranium prices are taken from the AEO 2015 Reference case. Natural gas prices in ReEDS are dynamic, changing based on power sector gas use. ReEDS also develops regional natural gas prices for each run year using a national and multiple regional supply curves. NREL describes this process as follows:

> In each year, each census region is characterized by a price-demand set point taken from the AEO Reference scenario, and two elasticity coefficients that model the rate of regional price change with respect to change in the regional gas demand from its set point and the overall change in the national gas demand from the national price-demand set point. These elasticity coefficients are developed through a regression analysis across an ensemble of AEO scenarios (as described in Logan et al. [11], though the numbers have since been updated using more recent AEO scenarios). The supply curves reflect natural gas resource, infrastructure, and non-electric sector demand assumptions embedded within the AEO modeling.[56]

Gas prices in the modeled Reference Case are shown in Figure 6.

[56] U.S. DOE 2015, Appendix G, p. 57.

Figure 6. Natural Gas Prices in MD RPS Reference Case



Source: Synapse Energy Economics, using NREL ReEDS Model.

Variable Renewable Energy Technology Costs and Potentials

Wind

Onshore wind resources are developed by ReEDS. The wind supply curves in ReEDS are defined in 356 regions, each with a specified capacity potential in five wind classes 3 through 7. The potential for new wind is based on modeling by AWS Truepower using the Mesomap® process. The country was modeled at a 200-m horizontal spatial resolution, and the results were processed to exclude areas such as urban areas, federally protected lands and onshore water features. Wind costs for land-based wind are based on research done for DOE's recent *Wind Vision Report*.[57] Base wind costs in 2015 range from $1,794 per kW for projects in Class 3 areas to $1,674 per kW for projects in Class 7. Interest during construction, regional cost adders, and interconnection costs are added to these base values. ReEDS also adds a location-specific cost adder for a spur line connecting the project to the nearest transmission. Fixed O&M for all land-based wind is $52 per kW-yr throughout the study period.

The *Wind Vision Report* assumes cost reductions and capacity factor increases over time for land-based wind. For land-based wind in this study, base costs are held constant over the study period at the levels cited above, but increased capacity factors from the *Wind Vision* are applied. Possible land-based capacity factors in 2020 range from 35% to 49%, and in 2050 they range from 40% to 60%.[58]

Offshore wind resources are modeled as prescribed builds in the ReEDS model. NREL continues to refine and improve its offshore wind resource representation within the model, and the preliminary nature of

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[57] U.S. DOE. 2015.

[58] See U.S. DOE 2015, Appendix H.

its operational representation would create too much uncertainty in the results. Instead, in response to the Maryland Offshore Wind Energy Act of 2013—legislation that created an offshore wind carve-out in the state's RPS of up to 2.5 percent of the state's total retail electricity sale—a prescribed capacity trajectory of 200 MW in 2024, followed by another 200 MW coming online in 2026, for a total offshore wind installation of 400 MW, is modeled in the Reference Case and all alternative RPS scenarios. The ReEDS model includes additional offshore wind capacity to the extent that it is economic.

Offshore wind costs are also taken from the *Wind Vision* assumptions, but in the case of offshore wind, that study's forecast of falling costs over time are used. Base overnight costs in 2020 are $5,966 per kW in Class 3 areas and $64,620 for projects in all other areas. These costs fall by roughly 30% over the study period. Fixed O&M for all offshore wind is $117 per kW-yr in 2020 falling to $104 in 2050. Possible offshore capacity factors in 2020 range from 35% to 51%, and in 2050 they range from 38% to 55%.

Photovoltaics

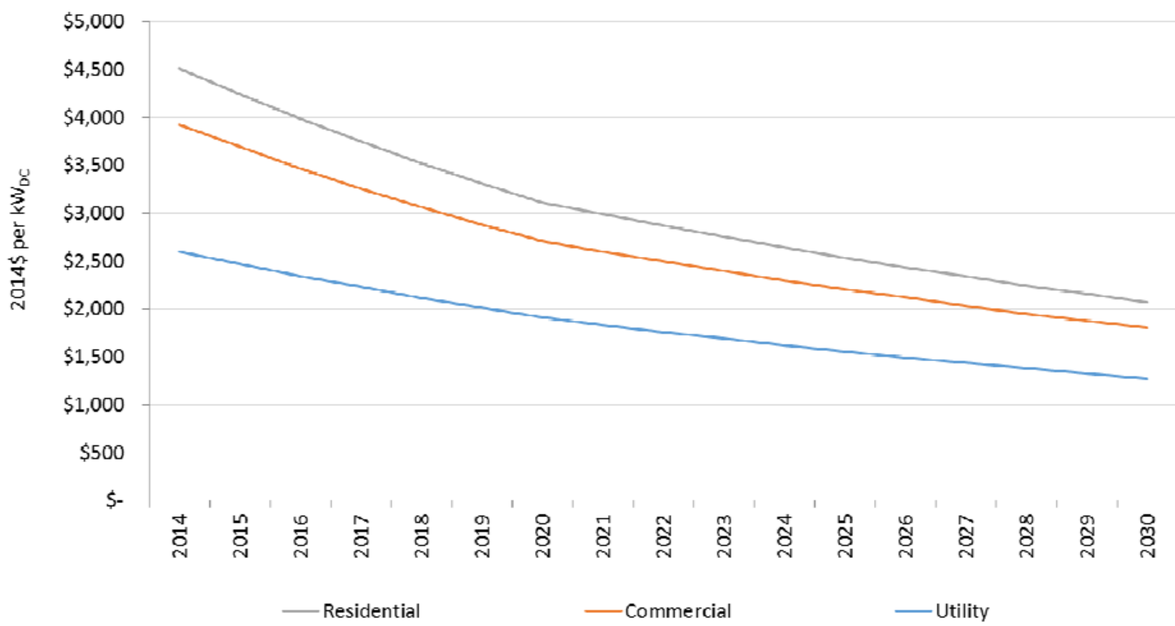
Utility-scale PV capacity is also developed by ReEDS. Rooftop PV capacity additions are an input to the model. Rooftop PV resources are derived from data from the Department of Energy's SunShot analyses, which also used ReEDS. NREL has made available the rooftop PV penetration data from three of the SunShot scenarios: the 50%, 62.5% and 75% scenarios. These percentages refer to the reduction assumed in PV costs between 2010 and 2020. Rooftop PV capacity additions for these scenarios were developed using NREL's SolarDS model and then entered into ReEDS for the SunShot analyses. Capacity additions for this analysis follow the levels associated with the SunShot 50% scenario; the cost trajectory follows approximately 80% of the levels in the SunShot 50% cost reduction scenario.

Significant reductions in the installed cost of PV projects over the study period are assumed. As seen in Figure 7, 2015 costs range from $2,471 per kW_{DC} for ground-mounted projects 1 MW and above ("utility scale") to $4,243 for residential scale projects (10 kW and under). These costs are based on project costs reported by developers to state and federal agencies, informed by discussions with developers and other industry experts. We access reported costs directly from government agencies and from the annual *Tracking the Sun* report from Lawrence Berkeley National Labs.[59]

The Synapse cost forecast is based on ongoing review of data and forecasts for module costs, balance of system costs and installed costs and on costs reported in other countries with fast-growing PV sectors. We assume that large ground mounted projects reach $1.00 per W_{DC} in 2040 (stated in 2013$). For comparison, the DOE's SunShot goal is $1.00 per W_{DC} in 2020 in 2010$.

[59] Barbose et al., 2014.

Figure 7. Capital Costs for New PV Capacity



Source: Synapse Energy Economics, 2015.

Table 14 compares Synapse's assumed cost reduction rates to recent actual rates, as shown in in the LBNL report.[60]

Table 14. Annual Average PV Cost Reductions Historical and Assumed

	2008 – 2013	2014-2020 for this study	2021-2030 for this study
Utility scale	10%	5.0%	4.0%
Commercial	13%	6.0%	4.0%
Residential	12%	6.0%	4.0%

Source: Barbose et al., 2014; Synapse Analysis

The modeling assumed 2015 fixed O&M costs of $15.30 per kW-yr for utility-scale projects, $20.40 for commercial projects, and $25.50 for residential projects.

Concentrating Solar Power

Concentrating solar plants (CSP) are developed by ReEDS. Cost assumptions, shown in Table 15, are from a 2012 Black & Veatch report. Fixed O&M is $545 per kW-year throughout the study period, and there is

[60] Barbose et al., 2014.

no variable O&M. Capacity factors were developed by NREL for five classes of insolation level and for each of the 17 annual time slices in ReEDS.

Table 15. Assumptions for new CSP plants (2014$ per kW)

	2020	2030
CSP without storage	$5,032	$4,622
CSP with storage	$7,237	$5,885

Source: Black & Veatch, 2012.

Other Resources

The generation levels for a number of resources were provided to ReEDS as proscribed builds under all RPS conditions. These resources include solar thermal, geothermal, municipal solid waste, and in-state landfill gas and black liquor. The assumptions used for these resources are described in Section 2.

Other Policies Represented

In addition to modeling the existing Maryland RPS and alternative RPS scenarios for the state, there are several other policies represented by ReEDS.

First, all other existing state RPS trajectories are included, along with their specified solar carve-outs, if applicable. Qualified generation (by source and technology) produce RECs, which are tracked for compliance. There is some limited trading of "bundled" RECs between states for which power trade also exists. Alternative Compliance Payments (ACP) are modeled as well, to account for RPS shortfalls.

The Clean Air Interstate Rule/Cross State Air Pollution Rule (CAIR/CSAPR) NO_x and SO_2 regulations are modeled as regional programs, with two SO_2 groups (16 and 7 states) and one NO_X group (28 states) comprising the entire country. CSAPR phase-1 begins in 2016 and phase-2 begins in the 2018 model year. Implicit trading of emission allowances is assumed by allowance states to go up to 118 percent of their allowance budgets (ReEDS "frictionless" trading). Mercury and Air Toxics Standards (MATS) pollution control regulations are also modeled in ReEDS. MATS is implemented through emission control upgrades (unit retrofits) and associated capital costs, and updated emission control factors.

Finally, the Clean Power Plan, as finalized by the U.S. Environmental Protection Agency on August 3, 2015, is modeled. Specifically, it is modeled as a requirement that each affected state comply with its annual "new-source complement adjusted" mass-based emission limit (tons CO_2) beginning in 2022. The new source complement requirement adjusts mass-caps upwards in order to account for the inclusion of emissions from new fossil resource, as well as existing fossil resources. States are permitted to participate in a national CO_2 allowance trading program in order to meet their compliance requirements.

4. MODELING RESULTS

In recent years, due to the economics of power generation in the Mid-Atlantic region, Maryland has become a substantial importer, generating substantially less than its total demand. The reference case demonstrates a resurgence in local generation, led by a growth in gas generation.

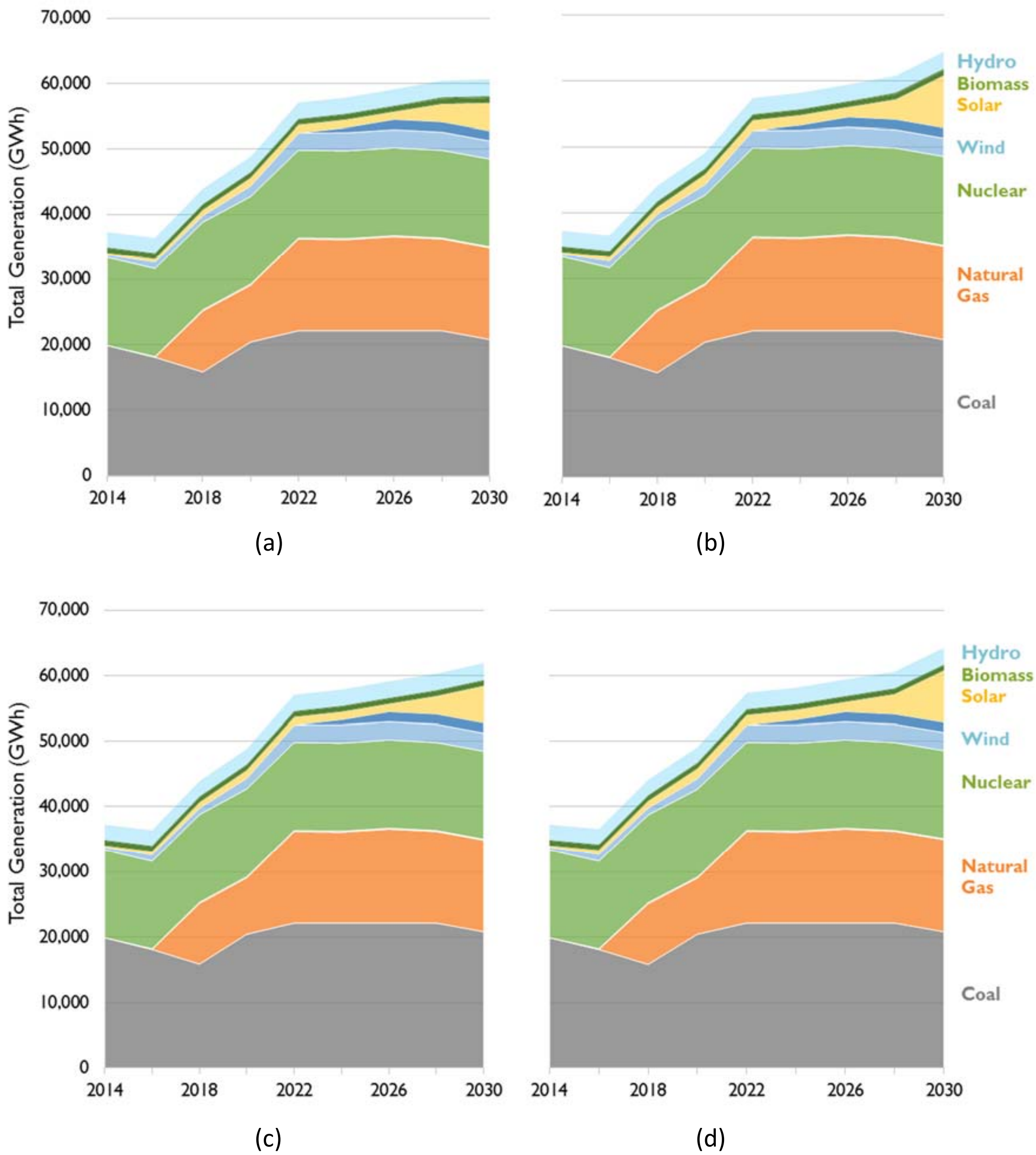


Figure 8: In-state generation under four cases: (a) Reference case (b) Increased Tier 1 requirements (c) Non-emitting resources able to be used for RPS compliance and (d) increased Tier 1, no emitting resources allowed.

In-state generation results are quite similar among the four cases, with a few distinctions near the end of the study period, as shown in Tables 16 through 18. Wind generation is consistent amongst the four cases in state; solar production varies much more widely by case. In the two increased Tier 1 cases, solar energy was used in conjunction with out-of-state REC purchases to meet the increased standard. Solar generation is 25 percent higher with the increased RPS by 2020.

As the PJM-wide REC market becomes more constrained nearer 2030, in-state solar becomes more competitive. By 2030 both of the Tier 1 cases have 86 percent more solar energy production than the Reference case. Whether or not emitting resources are allowed to contribute to the RPS has little bearing on solar production, but this policy choice does impact whether poultry litter is utilized. In the two scenarios that exclude emitting resources, no poultry litter is built, while in the Reference and Increased Tier 1 cases an identical 130 GWh of electricity fueled by poultry litter are generated annually in 2028 and 2030.

Table 16: Wind generation in Maryland by case, offshore and onshore (GWh)

	2014	2016	2018	2020	2022	2024	2026	2028	2030
Reference	409	1,005	1,007	1,643	2,629	3,532	4,297	4,303	4,302
Increased Tier 1	409	1,076	1,078	1,639	2,612	3,528	4,294	4,300	4,299
Non-emitting RPS	409	1,005	1,007	1,643	2,629	3,532	4,297	4,303	4,302
Tier 1 + Non-emitting	409	1,076	1,078	1,639	2,612	3,528	4,294	4,300	4,299

Source: Synapse Energy Economics, ReEDS analysis, 2015.

Table 17: Solar generation in Maryland by case, offshore and onshore (GWh)

	2014	2016	2018	2020	2022	2024	2026	2028	2030
Reference	226	443	859	1,198	1,185	1,174	1,161	2,694	4,211
Increased Tier 1	226	567	1,042	1,497	1,481	1,467	1,450	2,987	7,858
Non-emitting RPS	226	443	859	1,198	1,185	1,174	1,161	2,694	5,590
Tier 1 + Non-emitting	226	567	1,042	1,497	1,481	1,467	1,450	2,987	7,858

Source: Synapse Energy Economics, ReEDS analysis, 2015.

Table 18: Poultry litter generation in Maryland by case, offshore and onshore (GWh)

	2014	2016	2018	2020	2022	2024	2026	2028	2030
Reference	0	0	0	0	0	0	0	130	130
Increased Tier 1	0	0	0	0	0	0	0	130	130
Non-emitting RPS	0	0	0	0	0	0	0	0	0
Tier 1 + Non-emitting	0	0	0	0	0	0	0	0	0

Source: Synapse Energy Economics, ReEDS analysis, 2015.

Capacity of electric generating resources follows similar patterns as generation. Coal capacity falls off as existing units retire due to age and environmental regulations (including the Clean Power Plan). This capacity is replaced by a combination of gas combustion turbine (CT) and combined-cycle (CC) capacity, supplemented by renewables to meet the RPS standards.

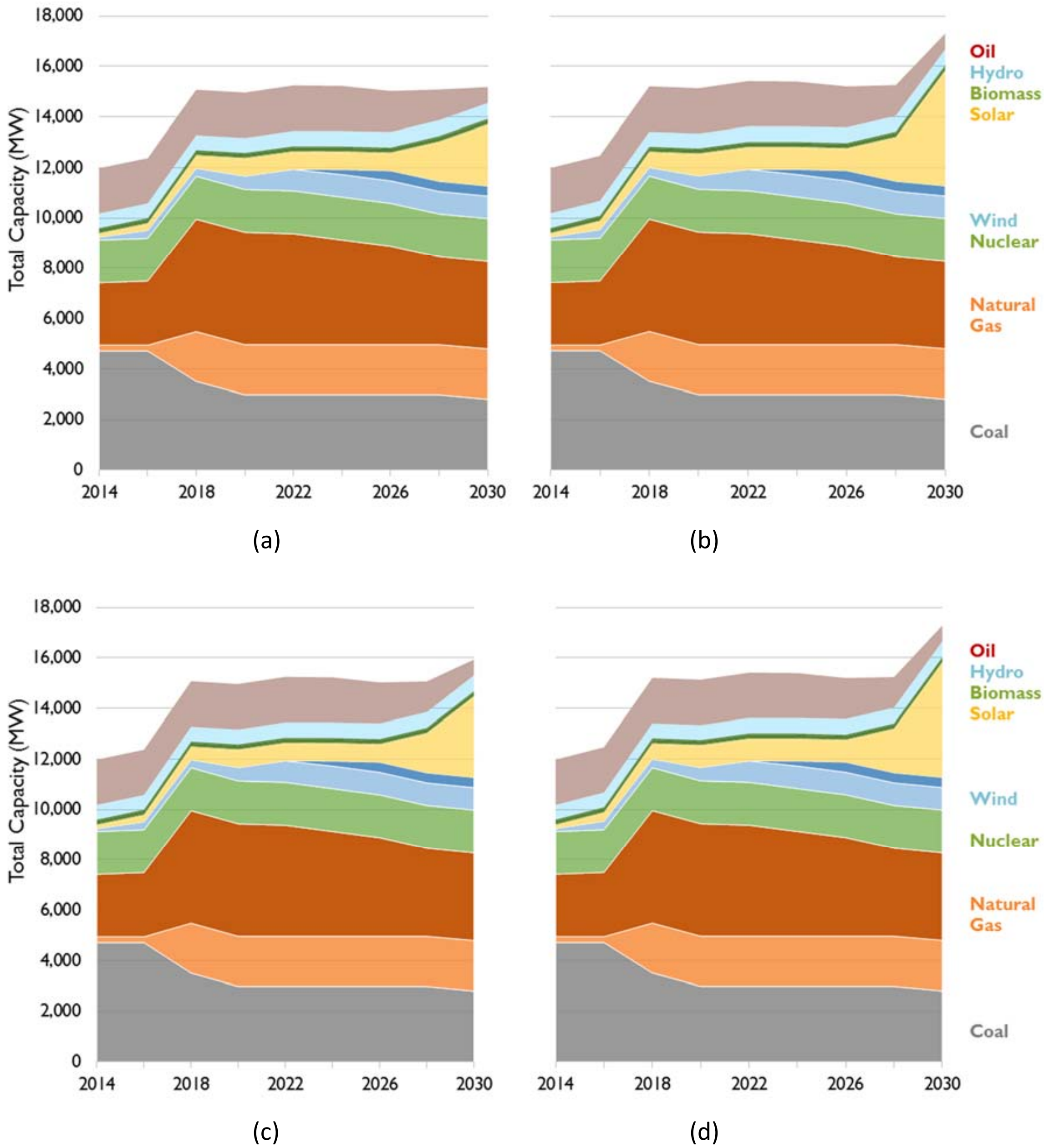


Figure 9: In-state capacity (MW) under 4 cases: (a) Reference case (b) Increased Tier 1 requirements (c) Non-emitting resources able to be used for RPS compliance and (d) increased Tier 1, no emitting resources allowed.

Differences between the four cases in terms of capacity are limited, focused on the end of the study period. Capacity values are presented in Tables 19 through 21. Wind capacity additions are nearly identical amongst the four cases, with 25 MW of incremental capacity in 2016 associated with the increased Tier 1 RPS requirement. The RPS level impacts solar substantially more – an additional 171 MW by 2020 in both cases. The incremental later in the study period depends on the eligibility of thermal biomass resources – with such resources eligible for the RPS, and additional 2,121 MW of PV is built by 2030. Without eligible biomass resources, the increment is only 1,353 MW – resulting from higher baseline PV builds to meet the RPS in the absence of biomass.

Table 19: Wind capacity in Maryland by case, offshore and onshore (MW)

	2014	2016	2018	2020	2022	2024	2026	2028	2030
Reference	120	321	321	531	853	1,095	1,295	1,295	1,295
Increased Tier 1	120	346	346	531	848	1,095	1,295	1,295	1,295
Non-emitting RPS	120	321	321	531	853	1,095	1,295	1,295	1,295
Tier 1 + Non-emitting	120	346	346	531	848	1,095	1,295	1,295	1,295

Source: Synapse Energy Economics, ReEDS analysis, 2015.

Table 20: Solar capacity in Maryland by case (MW)

	2014	2016	2018	2020	2022	2024	2026	2028	2030
Reference	159	281	519	716	716	716	716	1,580	2,438
Increased Tier 1	159	352	624	887	887	887	887	1,751	4,559
Non-emitting RPS	159	281	519	716	716	716	716	1,580	3,206
Tier 1 + Non-emitting	159	352	624	887	887	887	887	1,751	4,559

Source: Synapse Energy Economics, ReEDS analysis, 2015.

Table 21: Poultry litter capacity in Maryland by case, offshore and onshore (MW)

	2014	2016	2018	2020	2022	2024	2026	2028	2030
Reference	0	0	0	0	0	0	0	18	18
Increased Tier 1	0	0	0	0	0	0	0	18	18
Non-emitting RPS	0	0	0	0	0	0	0	0	0
Tier 1 + Non-emitting	0	0	0	0	0	0	0	0	0

Source: Synapse Energy Economics, ReEDS analysis, 2015.

These results should be taken in the context of the broader PJM RTO in which Maryland operates. Figure 10, below, shows total PJM generation and capacity across the study period under reference case assumptions.

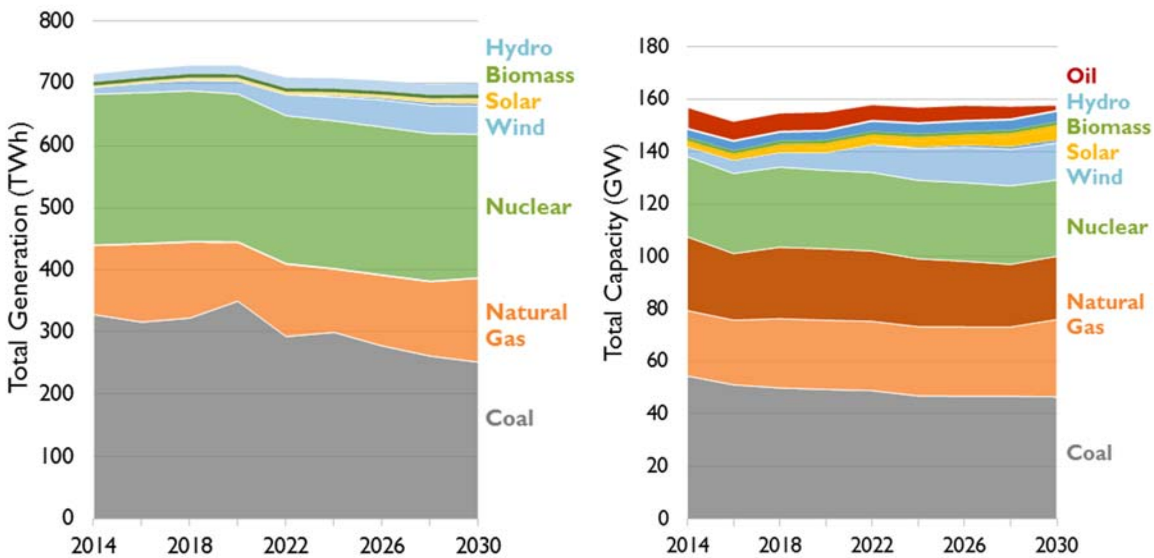


Figure 10: PJM wide reference case model outputs: (a) Generation (TWh) and (b) Capacity (GW)

5. Analysis

5.1. RPS Compliance

Both Maryland and the PJM region comply with the RPS policies across the member states throughout the study period. Although RPS resource eligibility differs slightly in the PJM states, all RPS policies allow wind and solar PV—the resources that make up the bulk of the compliance. Other renewable resources are allowed in enough PJM states that, in aggregate, RPS compliance can be concluded.

The reference case model results indicate that RPS policies across PJM will be satisfied with RECs rather than alternative compliance payments, because sufficient renewable energy is generated to comply with the RPS policies across the region. Furthermore, a lack of substantial over-compliance with the region's RPS policies suggests not only that the utilities will adhere to the RPS policy, but that without the RPS policy there would be less renewable energy generated across the region during some or all of the study period.

Synapse modeled an alternative future case in which the Maryland RPS was both increased and accelerated. The model results demonstrate that this increase in RPS requirement was met with additional renewable energy generation. Considering the reference case results, this isn't surprising—relative to all of PJM's RPS requirements, the additional Maryland requirements amount to a relatively small addition. Given that PJM is able to meet the reference case RPS, complying with a slightly more aggressive region-wide RPS policy would not be onerous.

An additional alternative future case modeled a Maryland RPS that no longer allowed emitting resources such as woody biomass, poultry litter, or municipal solid waste to be used for RPS compliance. Similar to the increased Maryland RPS scenario, the PJM region proved large enough that the change modeled in the Maryland RPS didn't prove challenging region-wide. The model results show that Maryland would have no trouble complying with its RPS policy if emitting resources were not permitted for compliance.

When both alternatives were modeled together—an increased requirement for renewables and the elimination of emitting resources as compliance options—the results show that Maryland will continue to achieve compliance through RECs.

5.2. Model Limitations

The capacity and energy generated by a number of renewable resources were exogenous to the model. Synapse hard-coded the capacity and generation for the following resources: solar thermal, geothermal, municipal solid waste, in-state landfill gas, and black liquor. There are a number of reasons to not allow a capacity expansion model like ReEDS to select these resources, including the following:

1. Development of the resource isn't driven by economics. Rather, it is determined by motivation to process waste or convert a waste stream to a value stream, or because individuals or organizations are embracing a low-carbon future due to a non-economic motivator.
2. Development experience is so limited that costs are neither well understood nor predictable on a larger scale.
3. There are extraordinary non-financial development challenges, such as obtaining siting approval.
4. The resource represents such a small percentage of RPS compliance in Maryland and PJM—and thus an insignificant percentage of the PJM electric system—that any differences in forecasted quantities are unlikely to have tangible impacts on the results.

Synapse's hard-coding of these resources is a pragmatic, transparent, and reasonable approach to modeling given the questions this report seeks to answer. The values chosen by Synapse do not reflect a detailed study of those resources' economics, politics, relevant regulations, or other inputs necessary for a detailed analysis. The values chosen do not represent a forecast in its own right.

5.3. The RPS Compliance Build Margin

The results clearly demonstrate that onshore wind is the economically preferred resource for RPS compliance for the next decade. It is certainly true that other renewable resources are built across the study period, perhaps opportunistically or to comply with specific RPS carve-out requirements. However, the dramatic increase in installed wind powered generators coupled with the determination that RPS policies are both necessary and sufficient to drive renewable energy installation in PJM demonstrates that onshore wind is the resource on the RPS compliance build margin. (Being economically preferred, resources on the compliance build margin are built before other resources to meet compliance requirements.) Incremental changes to general Tier 1 requirements in Maryland's RPS will generally result in similar changes in total wind generation across PJM.

The model output shows a significant change in 2028 and 2030. In those years, solar PV installations are substantial. ReEDS is a linear programming optimization model, which means that it will appear to play favorites with a single resource for any given period studied. In this case, the rapid change from wind to solar PV suggests that the cost curves for the two technologies cross in 2027. That is, for the forecasted cost curves for onshore wind and solar PV, and for the resource availability in PJM, solar PV eventually becomes the least-cost renewable resource.

These results indicate that the renewable build margin is currently dominated by onshore wind, and that it will likely eventually shift to solar PV. These results should not be interpreted to suggest that 2028 is the precise year in which this will happen, or that actual builds of wind will fall off suddenly and dramatically in a given year when (if) solar PV does become the least-cost renewable resource in the region.

5.4. Poultry Litter Is a Renewable Resource with Marginal Economics

Synapse modeled the cost curve for poultry litter fuel as two-staged. Half of the poultry litter was modeled at a low price, with the remainder at a higher price. The low price reflects just the cost of transportation, because approximately half of the poultry litter in Maryland doesn't have another economic use and as a result would come at little to no cost. The other half of the litter is being used for fertilizer; a generator would need to both absorb the shipping costs and the cost of a fertilizer alternative for the farmers in order to use that litter for generation.

The model results show a poultry litter facility being built in 2028, and it is only large enough to process the less expensive of the two-tier priced fuel. This result occurs both in the reference case and the expanded Tier 1 requirements case. This result suggests that the use of poultry litter to generate electricity is economically challenging but possible at the prices modeled – poultry litter as an RPS-compliant resource is neither obviously favorable nor clearly unfavorable. The year in which the model built the resource is illustrative rather than valuable as a forecast. Should a generator fueled by Maryland poultry litter be built, it will be a function of much more specific details than were available for this analysis. Furthermore, whether or not a poultry litter-fired generator gets built in Maryland is likely also a function of politics, an appetite for risk, an ability to sign long-term fuel supply contracts, project siting considerations, and a variety of other non-electric planning factors. Absent any significant additional subsidies, it does appear that the value of RECs will be an important factor for a profitable poultry-litter fueled generator. Finally, the modeling results suggest that increasing Maryland's RPS will not result in an increase in the quantity of electricity generated by poultry litter resources in Maryland.

6. CONCLUSION

For Maryland, as well as for the PJM region, RPS compliance is likely to be dominated first by onshore wind and later by solar PV due to their economic advantages over other resources. Modeling showed that Maryland's RPS, combined with the policies of other PJM states, will have the intended effect of boosting wind and solar resources in the region. While the deployment of any eligible Tier 1 resource might expand somewhat in response to a more aggressive RPS, the modeling done for this report demonstrates that the lion's share of new generation will come initially from onshore wind and, if costs evolve as forecasted, eventually from solar PV. Indeed for many of the emitting resources, developing new capacity would have little to do with RPS requirements and more to do with the decision to use waste by-products as an energy source irrespective of electric sector economics. As discussed above, these types of products are characterized by a complicated mix of siting, fuel availability, economic, political, and environmental issues. Still other resources, such as ocean, tidal, and offshore wind, are not expected to factor significantly into the energy mix until later years when their U.S. industries begin to mature.

The purpose of this study was to analyze if Tier 1 RPS compliance would occur and with what changes in generating resources under an expanded RPS policy. If the RPS requirements were increased, what changes should be expected in the future generating mix? Additionally, would Maryland be able to meet an expanded RPS policy—or even its current policy—if generating resources that emit sulfur dioxide, nitrogen oxides, mercury, or carbon dioxide were removed from the list of Maryland RPS-compliant generators? Yes, Maryland can meet an expanded RPS. Yes, Maryland can comply with its current RPS levels without the use of emitting resources. And finally, yes, Maryland can comply with an increased RPS requirement without the use of emitting resources. The impacts of changes to the Maryland RPS considered in this report are tiny when compared to fluctuations of the overall regional grid in which it operates, and Synapse's analysis shows that PJM is capable of meeting RPS requirements under all options modeled.