New York State Energy Research and Development Authority

Energy Efficiency and Renewable Energy Potential Study of New York State

Volume 3: Renewable Energy Methodology and Detailed Results

Final Report

April 2014

Report Number 14-19

The New NY WORKS for Energy

nyserda Energy. Innovation. Solutions.

NYSERDA's Promise to New Yorkers:

NYSERDA provides resources, expertise, and objective information so New Yorkers can make confident, informed energy decisions.

Mission Statement:

Advance innovative energy solutions in ways that improve New York's economy and environment.

Vision Statement:

Serve as a catalyst—advancing energy innovation and technology, transforming New York's economy, empowering people to choose clean and efficient energy as part of their everyday lives.

Core Values:

Objectivity, integrity, public service, partnership, and innovation.

Portfolios

NYSERDA programs are organized into five portfolios, each representing a complementary group of offerings with common areas of energy-related focus and objectives.

Energy Efficiency and Renewable Energy Deployment

Helping New York State to achieve its aggressive energy efficiency and renewable energy goals – including programs to motivate increased efficiency in energy consumption by consumers (residential, commercial, municipal, institutional, industrial, and transportation), to increase production by renewable power suppliers, to support market transformation, and to provide financing.

Energy Technology Innovation and Business Development

Helping to stimulate a vibrant innovation ecosystem and a clean-energy economy in New York State – including programs to support product research, development, and demonstrations; clean-energy business development; and the knowledge-based community at the Saratoga Technology + Energy Park® (STEP®).

Energy Education and Workforce Development

Helping to build a generation of New Yorkers ready to lead and work in a clean energy economy – including consumer behavior, youth education, workforce development, and training programs for existing and emerging technologies.

Energy and the Environment

Helping to assess and mitigate the environmental impacts of energy production and use in New York State – including environmental research and development, regional initiatives to improve environmental sustainability, and West Valley Site Management.

Energy Data, Planning, and Policy

Helping to ensure that New York State policymakers and consumers have objective and reliable information to make informed energy decisions – including State Energy Planning, policy analysis to support the Regional Greenhouse Gas Initiative and other energy initiatives, emergency preparedness, and a range of energy data reporting.

Energy Efficiency and Renewable Energy Potential Study of New York State

Volume 3: Renewable Energy Methodology and Detailed Results

Final Report

Prepared for:

New York State Energy Research and Development Authority

Carl Mas, Senior Project Manager

Prepared by:

Optimal Energy, Inc

Philip Mosenthal, Partner – Principal in Charge

Steve Bower, Managing Consultant – Project Manager, Commercial Efficiency Lead

American Council for an Energy-Efficient Economy

Dan Trombley, Senior Analyst – Industrial Efficiency Lead

Vermont Energy Investment Corporation

David Hill, Managing Consultant – Renewable Energy Lead

Nick Lange, Consultant – Residential Efficiency Lead

NYSERDA Report 14-19 NYSERDA Contract 24799 April 2014

Notice

Abstract

This study presents the potential for increased adoption of energy efficiency and renewable energy technologies in New York State. It focuses on the long-term potential using a twenty-year study period, 2013–2032. Efficiency potential results are presented in terms of "achievable potential" and "economic potential" (the cost-effective energy savings). The report presents these results statewide as well as separately for each of four regional zones (Long Island, New York City, Hudson Valley, and Upstate). The efficiency portion of the study includes electricity, natural gas, and petroleum fuels in the building and industrial sectors, but excludes transportation energy use. For renewable energy, the study analyzes the economic potential and the "bounded technical potential," a measurement of what theoretically would be possible if cost were not a factor. These figures are for renewable resources serving the energy needs of buildings and electric generation. The major renewable resource categories include biomass, hydro solar, and wind. The study also assesses alternative allocations between various renewable technology options. Overall, the study finds that large amounts of energy efficiency and renewable energy potential exist through the study period. Pursuing additional cost-effective clean energy potential in the State is anticipated to result in long-term net benefits to New York citizens.

Table of Contents

Notice ii
Abstract ii
List of Figures vi
List of Tables vii
Structure of the Full Report ix
1 Overview and Approach 1
1.1 Bounded Technical Potential and Economic Potential 1
1.1.1 Economic Potential 3
1.2 Technology Characterization 4
1.3 Technology Learning Curves 7
1.4 Federal Investment and Production Tax Credits 12
2 Renewable Energy High-Level Results 13
2.1 Primary Energy 13
2.2 Economic Potential 17
2.3 Emissions Impacts 20
3 Biomass 22
3.1 Overview 22
3.2 Bioenergy Approach and Methods 22
3.2.1 Biomass Resource Streams 23
3.2.2 Biomass Resources 24
3.2.2.1 Lignocellulosic Biomass 25
3.2.2.2 Liquid Biofuels: Biodiesel 26
3.2.2.3 Biogas 28
3.2.3 Bioenergy Constraints 31
3.2.3.1 Land Use Conversions and Management 31
3.2.3.2 Sustainability and Air Quality 31
3.2.3.3 Market Infrastructure and the Ability to Ramp-Up 32
3.2.3.4 Transportation and Regionalization of the Technology Mix 32

3.2.4 Bioenergy Conversion Technologies 32
3.2.5 Bioenergy Electric Conversion (including Combined Heat and Power) 32
3.2.5.1 Direct-fired Biomass Generation 32
3.2.5.2 Co-firing Biomass at Coal Plants 33
3.2.5.3 Combined Heat and Power – Commercial and Industrial Scale 34
3.2.5.4 Landfill Gas 35
3.2.5.5 Anaerobic Digesters 35
3.2.6 Bioenergy Thermal 36
3.2.6.1 Residential Stove, Boiler, Furnace 36
3.2.6.2 Commercial & Industrial Boilers 37
3.2.6.3 Biodiesel 39
3.2.7 Economics and Technology Learning 40
3.3 Bioenergy Results 40
3.3.1 Summary of Potential for Bioenergy 40
3.4 Bioenergy Development Paths and Investment 50
4 Hydro 52
4.1 Overview 52
4.2 Hydro Approach and Methods 52
4.2.1 Hydro Resources 52
4.2.1.1 Run of the River 53
4.2.1.2 Undeveloped Sites Requiring a New Dam and Repowering Existing Dams 54
4.2.1.3 Non-Powered Existing Dams 54
4.2.1.4 Tidal Energy 55
4.2.1.5 Wave Energy 56
4.2.2 Hydro Constraints 57
4.2.3 Hydro Conversion Technologies 58
4.2.4 Hydro Economics and Technology Learning 58
4.3 Hydro Results 59
4.4 Hydro Development Paths and Investment 64

5 Solar ... 65
5.1 Overview ... 65
5.2 Solar Electric Approach and Methods ... 66
5.2.1 Saturation ... 67
5.2.2 Market Growth ... 67
5.2.3 Area ... 68
5.2.4 Conversion Technologies ... 69
5.2.5 Energy Generation ... 69
5.2.6 Economics and Technology Learning ... 70
5.3 Solar Electric Results ... 72
5.4 Solar Electric Development Paths and Investment ... 76
5.5 Solar Thermal Approach and Methods ... 78
5.5.1 Solar Thermal Resource ... 78
5.5.2 Saturation ... 78
5.5.3 Market Growth ... 78
5.5.4 Area ... 79
5.5.5 Conversion Technologies ... 79
5.5.6 Solar Thermal Economics and Technology Learning ... 80
5.6 Solar Thermal Results ... 80
5.7 Solar Thermal Investment ... 83
5.8 Advanced Solar Homes ... 84
6 Wind ... 88
6.1 Overview ... 88
6.2 Wind Approach and Methods ... 89
6.2.1 Wind Resource ... 89
6.2.2 Wind Constraints ... 91
6.2.3 Conversion Technologies ... 93
6.2.4 Wind Economics and Technology Learning ... 96
6.3 Wind Results ... 97

6.4 Wind Development Paths and Investment ... 101
7 Energy Storage Research Module ... 103
7.1 Grid Connected Energy Storage ... 104
7.2 Transportation and Vehicle to Grid ... 107
7.2.1 Strategies for Optimal Control of PEV Charging ... 107
7.3 Thermal Storage ... 108

List of Figures

Figure 1. Bounded Technical Potential. ... 2
Figure 2. Economic Potential. ... 4
Figure 3. 2010 Mix of Renewable and Non-Renewable Primary Energy. ... 15
Figure 4. Bounded Technical Potential 2030 – Renewable Share of Total Primary Energy. ... 15
Figure 5. 2030 Economic Potential – Renewable Share of Total Primary Energy. ... 18
Figure 6. New York State Land Cover – Renewable Fuels Roadmap: 2011 Update. ... 24
Figure 7. New York State Municipal Waste Water Treatment Plants. ... 29
Figure 8. Active landfills in New York State. ... 30
Figure 9. Bioenergy Cumulative Annual Thermal Potential by Year and Zone. ... 42
Figure 10. Bioenergy Cumulative Annual Electric Potential by Year and Zone. ... 43
Figure 11. Bioenergy Thermal BTP – 2020 by Technology (Total 53 TBtu). ... 45
Figure 12. Bioenergy Thermal BTP – 2030 by Technology (Total 120 TBtu). ... 45
Figure 13. Bioenergy Electric BTP – 2020 by Technology (Total 1,091 GWh). ... 46
Figure 14. Bioenergy Electric BTP – 2030 by Technology (Total 2,592 GWh). ... 46
Figure 15. Bioenergy Thermal Economic Potential – 2020 by Technology (Total 52 TBtu). ... 48
Figure 16. Bioenergy Thermal Economic Potential – 2030 by Technology (Total 117 TBtu). ... 48
Figure 17. Bioenergy Electric Economic Potential – 2020 by Technology (Total 532 GWh). ... 49
Figure 18. Bioenergy Electric Economic Potential – 2030 by Technology (Total 1,371 GWh). ... 49
Figure 19. Hydro Cumulative Annual BTP and Economic Potential by Year and Zone. ... 60
Figure 20. New Hydro Economic Potential- 2020 by Technology (Total 560 GWh). ... 62
Figure 21. New Hydro Economic Potential - 2030 by Technology (Total 7,454 GWh). ... 63
Figure 22. Solar Resource in NYS. ... 65
Figure 23. Cumulative Capacity of PV. ... 68
Figure 24. PV System Cost Projections. ... 71
Figure 25. Solar Electric Cumulative Annual Potential Generation by Year and Zone. ... 73

Figure 26. Cumulative Capacity of Solar Thermal (MWth). 79
Figure 27. Solar Thermal Cumulative Annual Potential by Year and Zone. 81
Figure 28. New York Onshore Wind Resource at 80m. 89
Figure 29. New York Offshore Wind Resource at 90m. 90
Figure 30. Net Cumulative Annual BTP and Economic Energy Generation by Year and Zone. 98
Figure 31. Capacity of bulk energy storage in United States. 104
Figure 32. Energy storage technologies and applications. 105

List of Tables

Table 1. Bioenergy Technologies and Applications. 5
Table 2. Hydro Technologies and Applications. 5
Table 3. Solar Technologies and Applications. 6
Table 4. Wind Technologies and Applications. 6
Table 5. Biomass Technology Cost and Performance Changes. 8
Table 6. Hydro Technology Cost and Performance Changes. 9
Table 7. Solar Cost and Performance Changes. 10
Table 8. Wind Cost and Performance Changes. 11
Table 9. Federal Production Tax Credit Phase Out. 12
Table 10. Federal Investment Tax Credit Phase Out. 12
Table 11. New York State Renewable Energy Bounded Technical Potential (TBtu of Primary Energy). 14
Table 12. Renewable Energy Bounded Technical Potential Electricity Generation (GWh). 16
Table 13. Renewable Energy Bounded Technical Potential Electric Installed Capacity (MW). 17
Table 14. Renewable Energy Economic Potential (TBtu of Primary Energy). 18
Table 15. Economic Electricity New Nameplate Capacity (MW) and New Generation (GWh). 19
Table 16. BTP and Economic – New Renewable Thermal End Uses (TBtu). 19
Table 17. BTP and Economic – New Renewable Electric Generation (GWh). 19
Table 18. BTP and Economic – New Renewable Electric Installed Capacity (MW). 20
Table 19. Annual Emissions Reductions, Bounded Technical Potential, 2020 and 2030 21
Table 20. Annual Emissions Reductions, Economic Potential, 2020 and 2030 21
Table 21. Direct Fired Biomass Electric Generation Characteristics. 33
Table 22. Biomass Co-firing Electric Generation at Coal Plants Characteristics. 34
Table 23. Commercial/Large Scale Combined Heat and Power Characteristics. 34
Table 24. Landfill Gas Electric Generation Characteristics. 35
Table 25. Anaerobic Digester Electric Generation Characteristics. 36

Table 26. Biomass Bounded Technical Potential: Thermal and Electric Potential (Assuming All Resources Are Dedicated to Either Electricity or Heat). 41
Table 27. Bioenergy Thermal Potential 42
Table 28. Bioenergy Electric Potential by Technology (DC Nameplate Capacity). 43
Table 29. Bioenergy Electric Potential Cumulative Annual Generation by Zone. 43
Table 30. Bioenergy Cumulative Annual BTP by Technology. 44
Table 31. Bioenergy Cumulative Annual Economic Potential by Technology. 47
Table 32. Bioenergy Technologies Total Investment 51
Table 33. Hydro Cost and Performance Characteristics. 58
Table 34. Hydro 2030 Bounded Technical Potential. 59
Table 35. Hydro Potential Nameplate Capacity (MW) by Application and Year. 59
Table 36. Hydro Potential – New Cumulative Annual Generation (GWh) by Zone and Year. 60
Table 37. Hydro Summer Peak Capacity (MW). 61
Table 38. Hydro Net Levelized Cost of Energy per KWh (2012$/kWh). 61
Table 39. Hydro Potential Cumulative Annual Generation by Technology (GWh). 62
Table 40. Net Cumulative Annual Peak MW Savings by Technology, 2020, 2030. 63
Table 41. Hydro Technologies Total Investment 64
Table 42. Capacity Limit (MW) by Bound and Year. 66
Table 43. PV Technology and Market Characterizations. 69
Table 44. PV Solar Electric Characteristics. 69
Table 45. Locations of Representative Solar Sites in New York. 70
Table 46. PV System Cost Projections 2012$/kW DC. 71
Table 47. Solar Electric Potential by Year (DC Nameplate Capacity). 72
Table 48. Solar Electric Cumulative Annual Energy Generation by Zone. 72
Table 49. Solar Electric Cumulative Summer Peak Capacity by Zone (MW). 73
Table 50. Solar Electric Cumulative Annual Generation by Technology (GWh). 74
Table 51. Solar Electric Cumulative Summer Peak Capacity by Technology (MW). 74
Table 52. Solar Electric Net Levelized Cost of Energy per KWh (2012$/kWh). 75
Table 53. Solar Electric Installed Nameplate Capacity by Technology (MW). 75
Table 54. Photovoltaic Development Path Results Economic Potential Generation (GWh). 76
Table 55. Photovoltaic Development Path Economic Potential Installed Nameplate Capacity (MW). 77
Table 56. Solar PV Technologies Total Investment 77
Table 57. Solar Water Heating Installed Cost over Time (2012$/MWth). 80
Table 58. Solar Thermal Cumulative Annual Energy Savings by Zone (TBtu). 81
Table 59. Solar Thermal Cumulative Annual Energy Savings by Fuel Type. 81
Table 60. Solar Thermal Cumulative Potential Annual Natural Gas and Fuel Oil Savings (TBtu). 82
Table 61. Solar Thermal Cumulative Potential Annual Electric Savings (GWh). 82

Table 62. Net Levelized Cost of Energy per kWh for SWH Systems Displacing Electricity (2012$/kWh). 83
Table 63. Net Levelized Cost of Energy per MMBtu for SWH Systems Displacing Natural Gas and Petroleum (2012$/MMBtu). 83
Table 64. Solar Thermal Total Investment 84
Table 65. Passive Solar Measures' Approximate Savings and Cost. 85
Table 66. Technical Potential of Increased Efficiency of Residential New Construction. 87
Table 67. Summary of Wind Technology Scales and Applications Evaluated. 94
Table 68. Wind Technology Cost Profiles. 96
Table 69. Wind Potential Incremental Installed Capacity. 97
Table 70. Wind Potential Cumulative Annual Energy Generation by Zone. 97
Table 71. Wind Potential as Share of Total Electric Generation. 98
Table 72. Wind Cumulative Summer Peak MW by Zone. 99
Table 73. Wind Potential Nameplate Capacity by Technology. 99
Table 74. Wind Cumulative Annual Generation by Technology. 99
Table 75. Wind Cumulative Summer Peak Capacity by Technology. 100
Table 76. Wind Net Levelized Cost of Energy per kWh (2012$/kWh). 100
Table 77. Wind Development Path Results 101
Table 78. Wind Technologies Total Investment 102
Table 79. Energy Storage Classification. 103

Structure of the Full Report

The full report is presented in six parts:

- Summary
- Volume 1: Study Overview
    - Background and Purpose of Study
    - Study Scope and General Approach
    - High-Level Results
- Volume 2: Energy Efficiency Methodology and Detailed Results
    - Study Scope
    - Portfolio-Level Results
    - Residential /Commercial / Industrial Efficiency (methodology and detailed results by sector)
- Volume 3: Renewable Energy Methodology and Detailed Results
    - Overview and Approach
    - Biomass / Hydro / Solar / Wind (methodology and detailed results by technology)
- Volume 4: Energy Efficiency Technical Appendices
- Volume 5: Renewable Energy Technical Appendices

1 Overview and Approach

New York has an abundance of renewable energy resources available to meet its energy needs. This study assesses the potential for the major renewable energy technologies and resources to provide electricity generation and to meet building energy needs during the next two decades.

This study provides an analysis of the bounded technical potential (BTP) and economic potential for renewable energy resources usable to meet energy needs for buildings and for electric generation (both customer on-site and utility scale). The major renewable resources included in the analysis are biomass, hydro, solar, and wind. Geothermal heat pumps are considered in the energy efficiency sections of the study.

The study also includes a specific set of development path analyses that examine alternative allocations between various renewable technology options. The development path analyses examine the possible impacts of different forms of market development and/or policies to encourage and catalyze renewable energy development.

This volume provides the bounded technical and economic potential for each renewable resource as well as details of the analysis for arriving at these results. These sections also include several development path analyses. The potential for Advanced Solar Homes, and Energy Storage technologies are also presented.

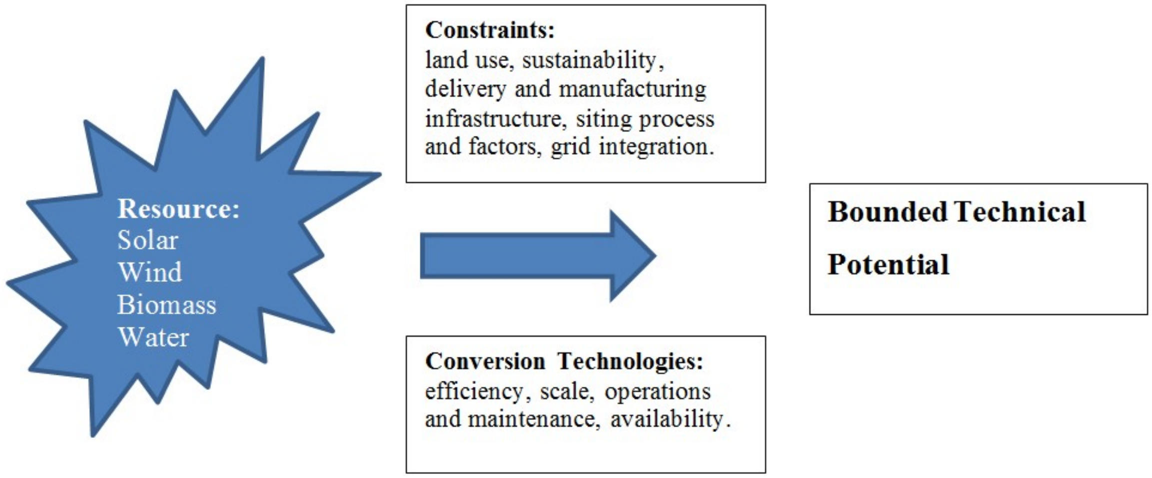
1.1 Bounded Technical Potential and Economic Potential

The BTP for a given resource is an estimate of the total thermal or electric energy available to meet needs in the building sector, or directly for electric generation based on consideration of the primary physical, social and technological factors at play. The BTP is estimated without accounting for economic factors of the costs and benefits of the required investments. The BTP also does not account for the costs and benefits from the customer's perspective, nor does it account for the market prices for the systems being installed.

The BTP provides a base for further economic analysis, but by itself, does not account for the economic dimension. Note that there is still an important role for BTP in the energy planning process to help define alternative scenarios of the magnitude of renewable energy resources and available technologies – and to characterize the potential contributions towards meeting the State's overall energy needs.

Figure 1 illustrates the general elements of the BTP. More detailed description of the constraining factors and the selected conversion technology applications and scales are presented in the applicable section of the report.

Figure 1. Bounded Technical Potential.



The analysis for each resource began with a review of the resource base. This study did not include any new primary research on renewable resources but draws upon existing resource assessments. Over the past several decades a great deal of research and investment has gone into detailed measurement, assessment and prediction of renewable energy resources. As a result there is much better spatial and temporal resolution available to inform macro (state or regional) level planning as well as individual site and project assessment. Details on the renewable resource base are provided in the appropriate sections of the report.

The next step of the analysis was to consider what constraints exist on the use of a given renewable resource. For example, the wind resource in wilderness areas, such as the Adirondack Park, were excluded from the estimate of the BTP and therefore also from the economic potential estimate. Sustainability of harvests is a key factor determining the biomass resource available for bioenergy, as are current fundamental land use patterns. There were no assumed large scale conversions of forests to non-forest or conversion of existing agricultural lands. The resource constraint assessments are also based on the expected viability of a given resource within the study horizon. Therefore, some renewable resources, such as wave energy or the use of algal biomass were not included in the BTP and economic potential results.

This study is also focused on renewable resources that are located in New York State or its nearby offshore waters under federal jurisdiction. Renewable resources or electricity imported from outside of New York would increase the estimates of the BTP and could also increase the economic potential.

The use of renewable resources for non-energy applications also informs the resource assessments. Biomass is the best example, where the resource is also used to produce food, durable goods, and fiber, and therefore only portions of the available resource are available for bioenergy. Even within the study there were allocation issues, for example, between the use of biomass resources for the production of electricity versus use to provide thermal energy. This study is also limited in scope to the use of energy for meeting electric generation and building energy needs. Transportation is not included. The potential demands for, and economic uses for renewable energy will be influenced by transportation markets as technologies for renewably derived transportation fuels and other alternatives, including the electrification of transportation (using renewable or non-renewable sources), continue to evolve.

Physical and human infrastructures are required to make use of renewable energy resources. Therefore, the BTP estimates consider how rapidly a resource can be developed. This includes consideration of issues such as the need for siting and permitting for large projects. In the case of new hydro developments or offshore wind, the time required to bring a new resource to market is an important consideration.

The technical and market status of the equipment required to convert renewable energy resources also contributes to our analyses. The technologies characterized in the study are generally well understood, commercially available and proven. Expected cost declines and /or performance improvements for individual technologies were used over the course of the study horizon.

Integrating increasing levels of renewable energy, particularly into the electric grid, provides a number of operational, regulatory and market issues and opportunities. Intermittency of solar and wind resources presents challenges to maintain system stability and reliability. This study did not include any primary research on system stability or operability, but the potential estimates do include saturation limits for intermittent resources and references to other markets and research.

1.1.1 Economic Potential

The BTP for each resource serves as a basis for analysis of the economic potential. The economic potential compares the societal costs and benefits of each measure within the BTP against system wide avoided costs. This economic potential analysis identifies the portion of the BTP that provides positive net economic benefits over the study horizon in comparison to the avoided cost base case. Further details on the general structure of the cost effectiveness modeling are provided in Volume 1 of this report, and more details on each specific renewable technology are provided in the applicable sections of Volume 3. This study does not “optimize” or dispatch energy resources based on economic or operational criteria. Rather it evaluates the societal economic cost effectiveness for a given scenario of renewable energy (and in the other volumes – energy efficiency) resources. Figure 2 illustrates the elements of the economic potential analysis.

Figure 2. Economic Potential.

Based on the economic potential results the study also includes a specific set of development path analyses, which examine alternative allocations between various renewable technology options. The development path analyses can be useful to help examine the possible impacts of different forms of market development and/or policies to encourage and catalyze renewable energy development.

Consistent with the energy efficiency elements of this study, our approach to renewable energy screening was to adopt a societal economic cost effectiveness framework. Federal tax incentives available to support and encourage renewable energy development were counted as cost reductions and improve the economic potential of the resources analyzed. From the State perspective, the Federal incentives are an external incentive that reduces the costs of implementation for the State's economy. State level incentives were not included in the economic potential analysis.

Project level financing costs were also not directly accounted for in either the efficiency or the renewable analyses in this study. The development of renewable resources, and implementation of energy efficiency measures, are often capital intensive requiring an upfront investment to capture long-term savings. Financing is a key element to promote these markets. However, in the societal economic screening framework of this study, financing is viewed as a transfer payment (similar to state or program level incentives) that can be used to help reduce barriers to the adoption of economically desirable projects.

1.2 Technology Characterization

A total of twenty-five technologies across the four resource classes were selected to be used as the basis for estimating renewable energy potential in New York through 2030 (Tables 1-4, below). For each technology a representative scale was selected for the analysis of typical cost and performance characteristics. In some cases, a technology is limited to specific time periods or to specific analysis zones of the State to match expectations on applicability. It is important to note that the technologies and applications selected are meant to be representative, but they are not a complete or an exclusive list of what will be developed in the market by 2030.

Table 1. Bioenergy Technologies and Applications.

Resource	Technology	Scale Analyzed	Location	Energy Output	Zones[1]	Time Periods
Biomass	*Residential Direct Combustion (pellet, wood chip, and cord wood)*	0.04 MMBtu/hr	Customer Sited	Thermal	UP and HV	All
	Residential Blended Fuel Oil (B5 blend)	n/a	Customer Sited	Thermal	All	All
	Commercial Direct Combustion (pellet and wood chip)	1 MMBtu/hr	Customer Sited	Thermal	UP and HV	All
	Commercial Blended Fuel Oil (B5 blend)	n/a	Customer Sited	Thermal	All	All
	Farm waste, food waste, and wastewater digesters	300 kW	Customer Sited	Electric/ Thermal	All	All
	Co-Firing with Coal	5%	Central Plant	Electric (Fuel Switch)	UP	2014-2019
	Direct Fire Biomass	45 MW	Central Plant	Electric	UP and HV	All
	Commercial CHP	2 MWe[2]	Customer Sited	Electric/ Thermal	UP and HV	All
	Landfill Gas	3 MW	Central Plant	Electric	UP, HV and LI	All

Table 2. Hydro Technologies and Applications.

Resource	Technology	Scale Analyzed	Location	Energy Output	Zones	Time Periods
Hydro	*New Run of the River sites*	100 kW - 30 MW	Central Plant	Elec	UP, HV and LI	2017+
	New Production at New Dams	> 100kW	Central Plant	Elec	UP and HV	2017+
	New Production Non-powered Dams	> 1 MW	Central Plant	Elec	UP and HV	2017+
	Repowering and Upgrading	> 100 kW	Central Plant	Elec	UP and HV	2017+
	New Hydrokinetic Tidal	> 30 kW	Central Plant	Elec	LI and NYC	2017+

1 Analysis zones are Upstate (UP), Hudson Valley (HV), Long Island (LI) and New York City (NYC). Further details and characteristics for the zonal analysis are provided in Volume 1, Table 1.

2 MWe is megawatt electrical, the electrical output of a system in megawatts.

Table 3. Solar Technologies and Applications.

Resource	Technology	Scale Analyzed	Location	Energy Output	Zones	Time Periods
Solar	*Residential PV*	3 kW-7 kW	Customer Sited	Elec	All	All
	Small Commercial PV	30-50 kW	Customer Sited	Elec	All	All
	Large Commercial PV	> 50 kW	Customer Sited	Elec	All	All
	Grid Scale PV	> 1 MW	Central Plant	Elec	All	All
	Residential SHW	80 gallons per day – 3.8kWth	Customer Sited	Therm	All	All
	Commercial SHW	240 gallons per day – 11.4kWth	Customer Sited	Therm	All	All

Table 4. Wind Technologies and Applications.

Resource	Technology	Scale Analyzed	Location	Energy Output	Zones	Time Periods
Wind	*Residential*	10 kW	Customer Sited	Elec	LI, UP and HV	All
	Commercial	100 kW	Customer Sited	Elec	LI, UP and HV	All
	Cluster	1 MW - 30 MW	Central Plant	Elec	LI, UP and HV	All
	Utility	> 30 MW	Central Plant	Elec	LI, UP and HV	All
	Offshore	300 MW	Central Plant	Elec	LI and NYC	After 2019

1.3 Technology Learning Curves

During the study horizon, renewable energy technologies and markets are expected to continue evolving. The core analysis conducted for this study is based on currently available technologies. Technology learning can improve performance (e.g. longer measure life, greater output per unit of installed capacity) or reduce the costs (initial or ongoing operations and maintenance). Technology learning can occur through improvements in the supply chain, business models, primary materials research, as well as operation controls and procedures.

The core analysis for this study includes projections for continuing cost declines and performance improvements for some technologies (most significantly for photovoltaic, solar thermal and offshore wind) but the analysis is based on continuation and moderation of existing cost reduction trends rather than on the emergence of completely new "disruptive" technologies. The relative performance of commercial wind and direct fire biomass electric generation are also projected to improve during the study horizon.

Tables 5-8 below summarize the cost and performance learning incorporated in the core analysis of BTP and economic potentials.[3]

---

[3] Further details and documentation of the inputs used in the analysis are provided in Volume 5, Appendix A.

Table 5. Biomass Technology Cost and Performance Changes.

	Technology	Costs (2012$)	Performance	Measure Life	Tax Incentives[4]
Biomass	*Residential Direct Combustion (pellet and cord wood)*	No Changes - $225,776/MMBtu/hr	Weighted average efficiency Improves from 80% to 84% over study horizon	23 years	None
	Residential Blended Fuel Oil (B5 blend)	Incremental cost 2013: $0.58/MMBtu declines to 2030: $0.04/MMBtu - but remains more expensive than conventional over study horizon	No Changes - straight fuel switch	1 year	None
	Commercial Direct Combustion (pellet and wood chip)	No Changes - $311,176/MMBtu/hr	Weighted average efficiency improves from 78% to 90% over study horizon	30 years	None
	Commercial Blended Fuel Oil (B5 blend)	Incremental cost 2013: $0.58/MMBtu declines to 2030: $0.04/MMBtu - but remains more expensive than conventional over study horizon	No changes - straight fuel switch	1 year	None
	Farm waste, food waste, and wastewater digesters	No Changes - $7,200,000/MW	No Changes - 6,136kWh/kW 70% capacity factor	30 years	ITC
	Landfill Gas	No Changes - $3,883,000/MW	No Changes - 90% capacity factor	30 years	PTC
	Co-Firing with Coal	No Changes - $500,000/MW of cofired capacity	Straight fuel switch – no net electric generation benefits – only off set coal	Limited to 6 years with all installs before 2020 due to retiring coal fleet	PTC

4 In Tables 5 to 8, the Federal Investment Tax Credit (ITC) remains at 30% through 2016, then declines 3% per year to 15% in years 2021 and beyond. For photovoltaic systems the ITC continues to decline at 3% annually until it is phased out in 2026.The Federal Production Tax Credit (PTC) declines to 80% of current 2013 levels in 2015, 70% in 2016, 60% in 2017 and 2018, and is eliminated in 2019 and beyond.

Table 5 continued

	Technology	Costs (2012$)	Performance	Measure Life	Tax Incentives[5]
	Direct Fire Biomass	No Changes - $3,377,750/MW	Heat Rate improves 0.4%/yr. starting at 6,136kWh/kW 70% capacity factor	50 years	PTC
	Commercial CHP	No Changes- $4,535,225/MW	No Changes - 80% heating efficiency, 25% electrical efficiency	30 years	ITC

Table 6. Hydro Technology Cost and Performance Changes.

Resource	Technology	Costs (2012$)	Performance	Measure Life	Tax Incentives
Hydro	*New Run of the River sites*	No Changes - $3,850,000/MW	No Changes - 40% capacity factor	50 years Deployed starting 2017	PTC
	New Production at New Dams	No Changes - $5,000,000/MW	No Changes - 52% capacity factor	50 years Deployed starting 2017	PTC
	New Production Non-powered Dams	No Changes - $4,200,000/MW	No Changes - 52% capacity factor	50 years Deployed starting 2017	PTC
	Repowering and Upgrading	No Changes - $2,000,000/MW	No Changes - 52% capacity factor	50 years Deployed starting 2017	PTC
	New Hydrokinetic Tidal	Declines by 5.2% for first five years, then 4.1% for five years, followed by 1.3% annual decline after 2023. 2013: $5,574,240/MW 2020: $3,970,771/MW 2030: $3,288,889/MW	No Changes - 38% capacity factor	20 years	PTC

[5] In Tables 5 to 8, the Federal Investment Tax Credit (ITC) remains at 30% through 2016, then declines 3% per year to 15% in years 2021 and beyond. For photovoltaic systems the ITC continues to decline at 3% annually until it is phased out in 2026.The Federal Production Tax Credit (PTC) declines to 80% of current 2013 levels in 2015, 70% in 2016, 60% in 2017 and 2018, and is eliminated in 2019 and beyond.

Table 7. Solar Cost and Performance Changes.

<table>
<tr><th>Resource</th><th>Technology</th><th>Costs (2012$)[6]</th><th>Performance</th><th>Measure Life</th><th>Tax Incentives</th></tr>
<tr><td rowspan="6">Solar</td><td>Residential PV</td><td rowspan="4">Annual decline of 8% for 3 years, 5% for 2 years, 4% for 2 years, 2% for 3 years, and 1.5% for 7 years. Starting costs vary by zone: NYC 25% higher for res, 9% for commercial, and 16% for MW scale. LIPA also 5% higher than Upstate for MW scale. See Vol. 5, Appendix I.</td><td rowspan="4">No Changes- annual estimated output varies by analysis zone. 0.5% annual degradation</td><td rowspan="4">25 years</td><td>ITC</td></tr>
<tr><td>Small Commercial PV</td><td>ITC</td></tr>
<tr><td>Large Commercial PV</td><td>ITC</td></tr>
<tr><td>Grid Scale PV</td><td>ITC</td></tr>
<tr><td>Residential SHW</td><td>First 3 years no change and then declines 3% per year from 2016 to 2030. From $8,000 to $4,800 for average system.</td><td>No Changes</td><td>20 years</td><td>ITC</td></tr>
<tr><td>Commercial SHW</td><td>First 3 years no change and then declines 3% per year from $17,500 to $10,500 for average system.</td><td>No Changes</td><td>30 years</td><td>ITC</td></tr>
</table>

6 Installed cost by scale, analysis zone, and year are given in Appendix I in Volume 5.

Table 8. Wind Cost and Performance Changes.

Resource	Technology	Costs (2012$)	Performance	Measure Life	Tax Incentives
Wind	*Residential*	Varies by analysis zone average $7,121,000/MW No Changes	Varies by analysis zone, average capacity factor 19% remains constant	20 years	ITC
	Commercial	Varies by analysis zone average $3,224,000/MW No Changes	Varies by analysis zone, average capacity 29% improves to 35% over 20 years	20 years	PTC
	Cluster	Varies by analysis zone average $3,138,000/MW No Changes	Varies by analysis zone, average capacity factor 33% improves to 39% over 20 years	20 years	PTC
	Utility	Varies by analysis zone average $2,381,000/MW No Changes	Varies by analysis zone, average capacity factor 33% improves to 40% over 20 years.	20 years	PTC
	Offshore	$4,339,000/MW Year 1 turbine and balance of plant costs from Draft NYS Offshore Wind Study plus transmission adders from Atlantic Wind Connection, 2012 Report by IHC, "Assessment of the Economic Benefits of Offshore Wind in the Mid-Atlantic." Turbine and balance of plant costs decline 0.9%/yr from 2013. Cost reductions not applied to transmission and interconnection costs which are based on a fully built out offshore transmission backbone.	Varies by analysis zone, average capacity factor 39% improves to 47% over 20 years.	25 years First deployed in 2019	None

1.4 Federal Investment and Production Tax Credits

Federal investment and production tax credits (ITC and PTC) were treated as a reduced cost in the analyses. The ITC and PTC are projected to respectively decline in the study following the profiles presented in Table 9 and Table 10.

Table 9. Federal Production Tax Credit Phase Out.[7]

Technologies	2013-2014	2015	2016	2017	2018	2019 and after
Grid supply biomass (direct fire and co-fire), Grid supply Wind, Hydro	100%	80%	70%	60%	60%	0%

Table 10. Federal Investment Tax Credit Phase Out.

Technologies	2013-2016	2017	2018	2019	2020	2021 and after
Solar Thermal, Customer Sited Wind, Digesters	30%	27%	24%	21%	18%	15%
Combined Heat and Power	10%	9%	8%	7%	6%	5%
Photovoltaic	30%	27%	24%	21%	18%	15% and Continue to decline 3% annually to reach 0% in 2026

7 The anticipated reductions in the PTC and ITC are consistent with assumptions for the preliminary results from the NYSERDA 2013 RPS Main Tier Program Review Cost Study.

2 Renewable Energy High-Level Results

2.1 Primary Energy

If fully developed, the BTP for the renewable resources and applications described in this report could meet 20% of New York's projected primary energy needs in 2020 and 41% in 2030, which are estimated to be approximately 3,852 and 3,962 trillion British thermal units (TBtu), respectively.[8]

Wind and solar resources provide the greatest potential for growth with hydro and biomass providing significant incremental resources, but lower growth. and Figure 3 and Figure 4 illustrate that in comparison to 2010 when Hydro and Biomass are the dominant renewable resources, by 2030 renewable energy supplies in New York State could be more evenly distributed across the four major resource categories.

Table 11 includes energy used for transportation in the totals. If this energy was excluded and renewable energy was just compared to energy used for heat and electricity, then the share of renewable resources increases to 54% of New York's projected energy needs in 2030.

---

8 The energy sales forecasts used in this study are discussed in Volume 1 page 7, and tables presenting the full forecasts are found in Volume 4, Appendix G.

Table 11. New York State Renewable Energy Bounded Technical Potential (TBtu of Primary Energy).

Resource		2010		2020		2030	
		In-State Use (TBtu)	% of Total Primary Energy Use	BTP (TBtu)	% of Total Primary Energy Use	BTP (TBtu)	% of Total Primary Energy Use
Hydro	*Conventional*	227	6%	254	7%	325	8%
	Hydro Kinetic	0.0	0%	3.8	0%	19	0%
Bioenergy	*Biomass*	74	2%	133	3%	205	5%
	Biogas	6.6	0%	70	2%	25	1%
Wind	*Onshore*	25.3	1%	87	2%	187	5%
	Offshore	0.0	0%	20	1%	244	6%
Solar	*Solar PV*	n/a	n/a	176	5%	509	13%
	Solar Thermal	0.0	0%	20	1%	97	2%
Total		**332**	**9%**	**762**	**20%**	**1,611**	**41%**

Table notes:

1. TBtu/GWh factors differ by technology and year. These are calculated on the "Demand" worksheet in the NYS RE Potential Summary spreadsheet
2. 2010 in-state use data is derived from the 2014 Draft New York State Energy Plan, and does not include customer sited resources
3. Biomass primarily designates forestry- and agriculture-based sources of non-fossil plant materials that could be processed into various energy products. Biogas designates the methane produced from the anaerobic decomposition of biomass from sources such as landfills, wastewater treatment plants, manure, and other agricultural byproducts, and food processing facilities.
4. Biomass TBtu figures are actual, not converted to Primary Energy.
5. Primary energy totals include transportation energy.

Figure 3 below shows current market penetration of renewable energy sources with the bounded technical potential, relative to New York's primary energy consumption. This can be compared to Figure 4, which shows the bounded technical potential for the renewable share of primary energy in 2030. These data show that in-state renewable energy sources have the potential to increase more than fourfold between 2010 and 2030. Figure 3 and Figure 4 also show how the proportional makeup of the renewable energy resources could change over the same time period.

Figure 3. 2010 Mix of Renewable and Non-Renewable Primary Energy.

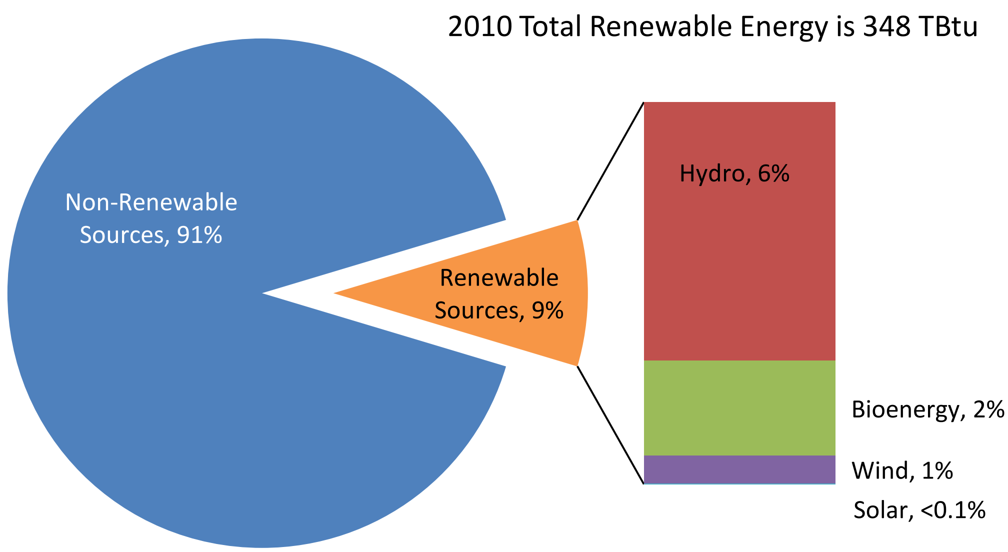


Figure 4. Bounded Technical Potential 2030 – Renewable Share of Total Primary Energy.

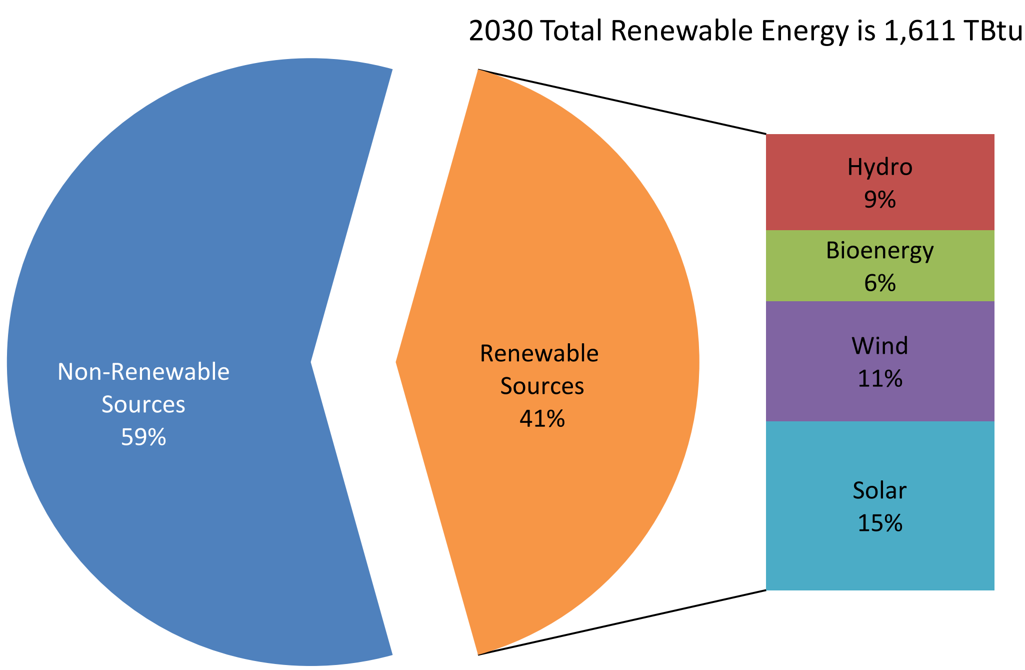


Table 12 shows that renewable resources have the BTP to provide more than one third of projected electric use by 2020 and over two thirds of projected use by 2030.

Table 12. Renewable Energy Bounded Technical Potential Electricity Generation (GWh).

Resource		2010		2020		2030	
		In-State Electricity Generation (GWh)	% of Projected Electricity Generation	Projected BTP Electricity Generation (GWh)	% of Projected Electricity Generation	Projected BTP Electricity Generation (GWh)	% of Projected Electricity Generation
Hydro	*Conventional*	24,214	15%	26,176	15%	34,021	17%
	Hydro Kinetic	n/a	n/a	427	0%	2,118	1%
Bioenergy	*Biomass*	315	0%	795	0%	1,396	1%
	Biogas	708	0%	1,320	1%	2,219	1%
Wind	*Onshore*	2,596	2%	8,911	5%	19,169	10%
	Offshore	0	0%	2,042	1%	25,025	13%
Solar	*Solar PV*	n/a	n/a	18,700	11%	54,100	27%
	Solar Thermal	0	0%	194	0%	928	0%
Total		**27,898**	**17%**	**58,565**	**33%**	**138,975**	**70%**

Table notes:

1. Wave energy is not included in the BTP for hydro due to the early stages of technical and commercial development. If wave energy becomes feasible it could add significant resource of about 17,000 GWh by 2030, which is equivalent to an additional 8% of projected use in that year.
2. 2010 in-state use data is derived from the 2014 Draft New York State Energy Plan.

Table 13. Renewable Energy Bounded Technical Potential Electric Installed Capacity (MW).

Resource		Existing In-State Installed Capacity (MW)	2020 Projected BTP Installed Capacity (MW)	2030 Projected BTP Installed Capacity (MW)
Hydro[1]	*Conventional*	4,314	4,821	6,852
	Hydro Kinetic	1	128	636
Bioenergy[2]	*Biomass*	337	522	719
	Biogas	112	200	326
Wind[3]	*Onshore*	1,274	3,285	6,251
	Offshore	0	561	6,399
Solar[4]	*Solar PV*	178	14,478	42,643
	Solar Thermal	0	100	515
Total		**6,216**	**24,095**	**64,341**

Table notes:

1 Existing In-state Hydro data from EIA. 2010. New York Renewable Energy Profile.

2 Existing In-state Bioenergy data from EIA. 2012. Electric Power Annual. Table 4.7.B, total for 2011. Biogas capacity estimated from several sources cited in the biomass resource section of the text.

3 Existing In-state Wind data from NYISO. 2012. Power Trends 2012. Figure 21.

4 Existing In-state Solar data from SEIA. 2012. New York State Solar Policy.

2.2 Economic Potential

Economic potential results indicate that a significant share (53%) of the identified BTP is found to be cost effective by 2030. Statewide thermal and electric economic potential compared to the BTP are presented in Table 14 through Table 17 and Figure 5.

More than half of the BTP is economic for several reasons. First, the BTP is much lower than a typical "technical potential estimate" and therefore the relative share of economic potential to BTP is higher than it would be if compared directly to an unbounded technical potential. Second, some technologies, most importantly PV, are projected to have cost declines during the study period and much of the deployment occurs in years when these technologies have become cost effective.

Table 14. Renewable Energy Economic Potential (TBtu of Primary Energy).

Resource		2010		2020		2030	
		In-State Production (TBtu)	% of Total Primary Energy Use	Economic Potential (TBtu)	% of Total Primary Energy Use	Economic Potential (TBtu)	% of Total Primary Energy Use
Hydro	*Conventional*	236	6%	241	6%	303	8%
	Hydro Kinetic	0	0%	0	0%	0	0%
Bioenergy	*Biomass*	75	2%	132	3%	201	5%
	Biogas	11	0%	65	2%	15	0%
Wind	*Onshore*	25	1%	39	1%	99	2%
	Offshore	0	0%	0	0%	25	1%
Solar	*Solar PV*	0.6	0%	33	1%	125	3%
	Solar Thermal	0	0%	12	0%	78	2%
Total		**348**	**9%**	**522**	**14%**	**847**	**21%**

Figure 5. 2030 Economic Potential – Renewable Share of Total Primary Energy.

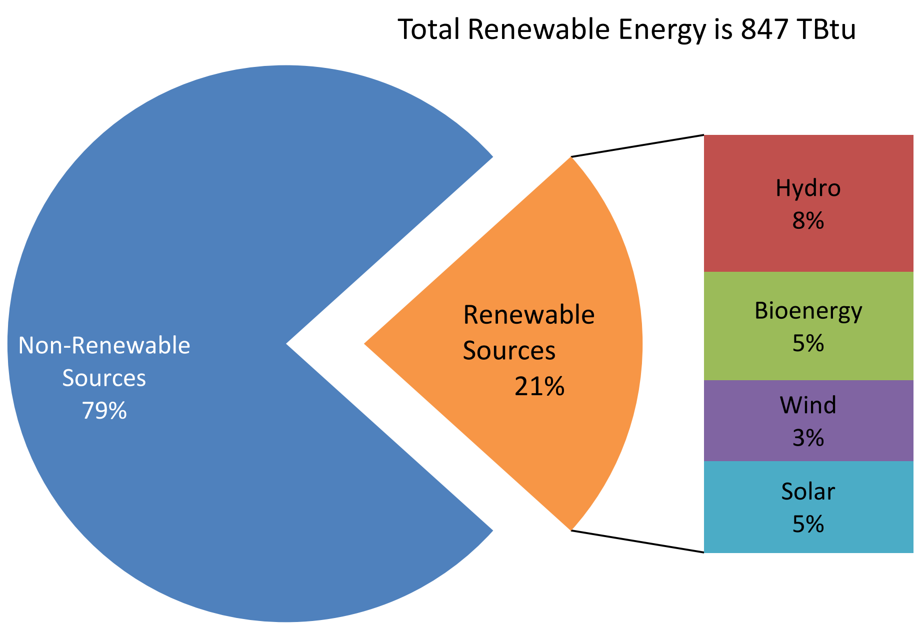


Table 15. Economic Electricity New Nameplate Capacity (MW) and New Generation (GWh).

Resource		2020 MW	2020 GWh	2020 GWh as % of Projected Electricity Generation	2030 MW	2030 GWh	2030 GWh as % of Projected Electricity Generation
Hydro	*Conventional*	135	560	0%	1,905	7,454	4%
	Hydro Kinetic	0	0	0%	0	0	0%
Bioenergy	*Biomass*	144	399	0%	324	898	0%
	Biogas	17	133	0%	62	473	0%
Wind	*Onshore*	441	1,403	1%	2,170	7,517	4%
	Offshore	0	0	0%	630	2,571	1%
Solar	*Solar PV*	2,511	3,421	2%	9,988	13,259	7%
Total		**3,248**	**5,916**	**3%**	**15,079**	**32,172**	**16%**

Table 16. BTP and Economic – New Renewable Thermal End Uses (TBtu).

	Thermal Energy (TBtu)			
	2020		2030	
Resource	BTP	Economic	BTP	Economic
Bioenergy	53	52	119	117
Solar Thermal	18	11	88	70
Total	**71**	**62**	**208**	**186**

Table 17. BTP and Economic – New Renewable Electric Generation (GWh).

		Total GWh			
		2020		2030	
Resource		BTP	Economic	BTP	Economic
Hydro	*Conventional*	1,962	560	9,807	7,454
	Hydro Kinetic	423	0	2,114	0
Bioenergy	*Biomass*	480	399	1,081	898
	Biogas	612	133	1,511	473
Wind	*Onshore*	6,315	1,403	16,573	7,517
	Offshore	2,042	0	25,025	2,571
Solar	*Solar PV*	18,639	3,421	54,039	13,259
	Solar Thermal	194	194	928	928
Total		**30,667**	**6,110**	**111,078**	**33,100**

Table 18. BTP and Economic – New Renewable Electric Installed Capacity (MW).

Resource		Total MW			
		2020		2030	
		BTP	Economic	BTP	Economic
Hydro	*Conventional*	508	135	2,538	1,905
	Hydro Kinetic	127	0	635	0
Bioenergy	*Biomass*	185	144	382	324
	Biogas	88	17	214	62
Wind	*Onshore*	2,011	441	4,978	2,170
	Offshore	561	0	6,399	630
Solar	*Solar PV*	14,299	2,511	42,465	9,988
	Solar Thermal	100	100	515	515
Total		**17,879**	**3,348**	**58,126**	**15,594**

2.3 Emissions Impacts

We assessed the emissions impacts associated with energy savings for four categories of emissions. Greenhouse gas reductions were assessed in terms of CO_2-equivalent, or the equivalent amount of CO_2 representing various greenhouse gases. In addition, we assessed the reductions of two primary criteria pollutants, nitrogen oxides (NOx) and sulfur dioxide (SO_2), which are precursors to smog and acid rain, and cause other health hazards. Finally, we assessed the increased emissions of particulate matter (PM) due to combustion of biofuels.

Emissions were calculated from the corresponding energy savings using emission factors for each fuel type: electric energy, natural gas, petroleum fuels, and bioenergy. The factors only account for the end use consumption of fuels. The upstream impacts of extraction, refinement, and transportation of primary fuels were not included in the analysis. For the specific values applied and their sources, see Appendix J in Volume 4.

Table 19 provides projected emissions reductions for the bounded technical potential in 2020 and 2030, and Table 20 provides the same for the economic potential. The estimated 2030 BTP and economic CO_2e emissions reductions are equivalent to removing 7.2 and 2.8 million vehicles, respectively, from the road that year.[9]

9 Assuming 4.8 t-CO_2e/vehicle/year, as calculated in EPA Clean Energy Calculations and References, accessed March 2014: http://www.epa.gov/cleanenergy/energy-resources/refs.html

Table 19. Annual Emissions Reductions, Bounded Technical Potential, 2020 and 2030

Sector	BTP, 2020			BTP, 2030		
	CO_2e ($MMtCO_2e$)	NOx (t)	SO_2 (t)	CO_2e ($MMtCO_2e$)	NOx (t)	SO_2 (t)
Hydro	0.61	721	858	3.05	3,606	4,288
Bioenergy	0.28	(2,975)	4,755	0.66	(6,467)	10,757
Wind	2.13	2,528	3,006	10.63	12,581	14,962
Solar	6.10	7,572	8,505	20.45	25,966	28,390
Total	9.12	7,846	17,124	34.78	35,686	58,397

Notes: t = metric tons, $MMtCO_2e$ = million metric tons of CO_2 equivalent. Negative values for bioenergy indicate increased emissions.

Table 20. Annual Emissions Reductions, Economic Potential, 2020 and 2030

Sector	**Economic, 2020**			**Economic, 2030**		
	CO_2e ($MMtCO_2e$)	**NOx (t)**	**SO_2 (t)**	**CO_2e ($MMtCO_2e$)**	**NOx (t)**	**SO_2 (t)**
Hydro	0.14	169	201	1.90	2,255	2,681
Bioenergy	0.14	(2,535)	4,885	0.35	(5,636)	11,065
Wind	0.36	424	505	2.58	3,051	3,628
Solar	1.69	2,211	2,331	8.67	11,651	11,895
Total	**2.33**	**269**	**7,922**	**13.51**	**11,321**	**46,570**

Note: t = metric tons, $MMtCO_2e$ = million metric tons of CO_2 equivalent. Negative values for bioenergy indicate increased emissions.

Bioenergy utilizes combustion-based conversion technologies that result in substantial increased emissions of particulate matter (PM). While this study focused on the development of high-efficiency and relatively clean biomass technologies, PM emissions are still a concern due to their potential health impacts. The total gross PM emissions from bioenergy technologies are estimated to be 1,290 metric tons for the BTP and 1,245 metric tons for the Economic potential in 2020, and 2,868 metric tons for the BTP and 2,806 metric tons for the Economic potential in 2030. These increased PM emissions would be somewhat offset by the corresponding reduced use of petroleum fuels, but combustion of petroleum fuels has substantially lower PM emissions relative to combustion of solid and liquid biofuels.

3 Biomass

3.1 Overview

Biomass and its derivative products, such as biogas and liquid biofuels, are organic, non-fossil plant materials initially produced through photosynthesis that can be utilized in liquid, solid or gaseous forms for bioenergy production. As a renewable energy resource, biomass includes organic material cultivated or harvested directly for energy production, as well as organic waste streams. In 2011, approximately 123 TBtu of biomass energy were consumed in New York State, accounting for 3% of the total estimated energy consumption.[10] While direct combustion and use of biomass for heat and light dates to the earliest periods of human civilization, there continue to be a wide variety of new possibilities and potential for biomass to contribute to New York's energy future.

This study estimates the potential for in-state biomass resources to contribute to electric and thermal energy production in New York through 2030. This study does not address the use of biomass resources for the production of transportation fuels. The comprehensive Renewable Fuels Roadmap[11] (Roadmap), and update [12] directly examine biomass derived fuels for transportation applications. It is important to note that the biomass resources assessed and allocated by this study and the Roadmap overlap – and therefore the energy potential results from the two studies cannot be simply added. The resources directed to electric and thermal end uses in this study would not be available to produce renewable transportation fuels, and vice versa.

3.2 Bioenergy Approach and Methods

The following section details our approaches to estimating the bounded technical and economic potentials for biomass resources, resource estimates by type, conversion paths and constraints, costs, performance and learning curves, and development paths and barriers. Bioenergy includes many possible resource streams, competing uses, conversion technologies, and end-uses. Biomass resources are also diverted to non-energy uses such as durable goods (wood furniture, lumber, etc.), food, animal feed, compost, etc. The following paragraphs provide an overview of the methodology used to estimate the bounded technical potential.

---

10 Energy Information Administration. 2011. State Profile and Energy Estimates. http://www.eia.gov/state/?sid=NY#tabs-

11 NYSERDA. Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply. Report 10-05, 10994. Prepared for New York. April 2010.

12 NYSERDA. Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply. Prepared for New York. Report 40817, Update to the Final Report. 2011

3.2.1 Biomass Resource Streams

The following biomass resource streams are most applicable to electric generation and thermal bioenergy end uses:

- Lignocellulosic (woody and herbaceous) Forestry and Agricultural Resources
    - Silviculture, silviculture residues, mill residues, site conversion residues, wood separated from the municipal solid waste stream (such as woody yard trimmings, construction and demolition residues, pallets and other waste wood)
    - Bioenergy crops (e.g. willow, hybrid poplar, etc.)
    - Agricultural residues (e.g. corn stover, straw residue)
- Liquid Biofuel (Biodiesel)
    - Agricultural oils (primarily soybean oil)
    - Recycled cooking oils and animal fat
- Biogas
    - Livestock wastes
    - Landfill gas
    - Municipal wastewater
    - Other food wastes

For the purpose of this study, the first resource stream, lignocellulosic, is the source for solid bioenergy fuels. Woody materials are processed and combusted as cord wood, wood chips, or wood pellets to produce electricity and for thermal applications. Pellets are also created from herbaceous material and can similarly be used for electric generation or thermal applications.

Liquid biodiesel is the bioenergy output from the second resource stream. Biodiesel can be used in a number of blends with conventional fuels and for a range of applications – including transportation, electric generation or thermal.

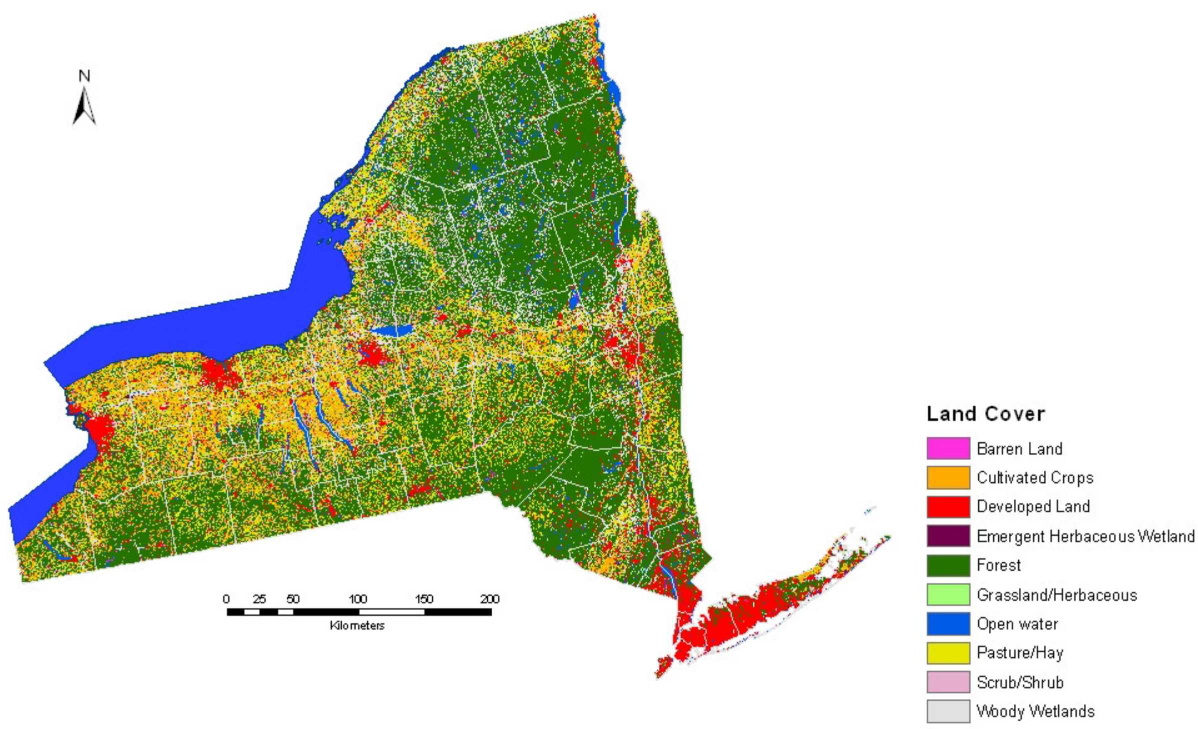
Anaerobic digestion of organic wastes – producing methane that can be used for electric generation or thermal applications is the third resource stream.

3.2.2 Biomass Resources

New York has a significant biomass resource base. Forests cover more than half of the State and the forestry industry is already well established. Nearly 15.8 million acres of the State's forest lands are producing, or are capable of producing, woody biomass (excluding areas in the State such as the forest preserves in the Adirondacks and Catskills where harvesting is restricted).[13] Additionally, almost a quarter of the State's land is used for agricultural purposes. Between one million and 1.68 million acres of non-forest land could be used for energy crop production in New York.[14] Figure 6 illustrates the distribution of agricultural and forest related biomass resources in New York.

The waste stream in urban areas is large and spatially concentrated. For example, New York City's 14 wastewater facilities alone process 1.3 billion gallons of wastewater a day. Because the State produces a vast amount of organic waste, utilizing some of it for energy production could result in many additional benefits.

Figure 6. New York State Land Cover – Renewable Fuels Roadmap: 2011 Update.



Source: National Land Cover Database (NLCD) 2001 (http://www.mrlc.gov)

---

13 NYSERDA. Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply. Prepared for New York. Update to the Final Report. 2011.

14 Ibid

The Roadmap biomass assessment estimated that the New York agricultural industry currently produces approximately 12 million dry tons annually (Mdt/year) of biomass and New York forests grow at a rate that produces another 9.5 Mdt/year of biomass.

Much of this biomass is already being used by other industries. The current forest products industry uses 2.5 Mdt/year. Corn provides the greatest amount of biomass from a single agricultural crop in the State (60%) and much of this is used by the New York dairy industry.

3.2.2.1 Lignocellulosic Biomass

As described in more detail below, the total lignocellulosic biomass (wood and grasses) estimated to be available for thermal and electric generation is 14.6 million dry tons per year[15], which is equivalent to 233 TBtu per year, using an average Btu content specific to each resource.[16, 17, 18] A 2012 Forest Inventory Analysis showed 2.3 times as much net annual growth as removal.[19] The bounded technical potential analysis increases the use of wood from New York forest by significantly less than that (80%).

Forests: Silviculture and Wood Industry

A sustainable harvest of forests implies that no more than the annual growing stock is harvested each year; however, estimates of forest growth available for bioenergy can vary according to a number factors and assumptions that were beyond the scope of this study to treat in detail. Therefore, we adopted the New York State Renewable Fuels Roadmap (Roadmap)[20] estimates of forest growth yield and availability. Of the 9.5 Mdt/year of yield from non-exclusionary lands, 8.9 Mdt/year can be harvested, and 6.4 Mdt/year are estimated to be available for energy use in New York. This value includes the use of mill residues, logging residue, and timber.

---

15 Ibid, Tables ES1- and 4-1 p. 35.

16 Meister Consultants Group. March 2012. Massachusetts Renewable Heating and Cooling Opportunities and Impacts Study. Prepared for: Massachusetts Department of Energy Resources, Massachusetts Clean Energy Center.

17 NYSERDA. September 2011.New York State Renewable Portfolio Standard Biomass Power Guide. http://www.nyserda.ny.gov/Page-Sections/Research-and-Development/Energy-Resources/~/media/Files/EDPPP/Energy%20and%20Environmental%20Markets/RPS/RPS%20Documents/rps-biomass-guide.ashx.

18 BERC. 2011. Woodchip Heating Fuel Specifications in the Northeastern United States.

19 Widmann R.H. 2013. New York's Forest Resources, 2012. Res. Note NRS-181. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. http://www.nrs.fs.fed.us/pubs/rn/rn_nrs181.pdf

20 NYSERDA. Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply for New York. 2011 Update to the Final Report – estimates apply to Scenarios 2 and 3. 2011.

Woody Energy Crops (willow) and Grasses, Herbaceous Crops, Stover, and Straw

Agricultural land potential, which includes feedstocks of corn stover, straw, and dedicated energy crops such as grass or willow, amounts to 8.2-million dry tons of biomass.[21] Willow, hybrid poplars, and other fast growing tree species can be grown, harvested on a short rotation basis, chipped, and used for energy. Willow yields are typically 4 oven dry tons (odt)/acre/year in the first rotation and 5 odt/acre/year in subsequent rotations. Of the 7.5 million acres of agricultural land cover, 1-2 million are under-utilized and could be used for willow biomass production. [22]

Clean Wood from Municipal Solid Waste

In 2009, 10.6 million tons of solid waste was disposed of in New York State landfills.[23] Approximately 8% of solid municipal waste is wood.[24] Our analysis estimates that one half of this total is clean enough to be used for energy and can be recovered from the waste stream, adding approximately 0.4 million dry tons/year to the available resource base.

3.2.2.2 Liquid Biofuels: Biodiesel

Approximately 33 million gallons of biodiesel could be available statewide, equivalent to approximately 3.9 TBtu. This total would be comprised of 6 million gallons of biodiesel from agricultural crop oil (~0.8 TBtu), and 26 million gallons of biodiesel from recycled cooking oil and animal fat (~3.1 TBtu). More details are provided below on the assumptions used for the two biodiesel resources. The production of biodiesel from algae may increase supplies of biodiesel over the next 20 years, but it was not included in the core analysis.

Liquid biofuels other than biodiesel may be used for building heat and power generation in the future. Pyrolysis is an emerging technology that can produce pyrolysis oil, which, in the next 20 years, may be used for co-firing or direct firing boilers. Ten New York counties concentrated in the northwest part of the State account for more than 85% of total New York soybean production. [25] Used cooking oil on the other hand is expected to be more readily available in large quantities in urban areas downstate. Biodiesel production and blending are expected to take place centrally in plants and in refineries rather than at the consumption site. Therefore, we assumed that biodiesel would be available statewide.

---

[21] Roadmap Scenarios 2 and 3.

[22] Timothy A. Volk, Thomas Buchholz, Philip Castellano, Lawrence Abrahamson and Lawrence Smart. 2009. http://www.biomassthermal.org/resource/PDFs/Woody%20Biomass%20from%20Forests%20and%20Fields.pdf. *Woody Biomass from Forests and Fields*. Presentation at Heating the Northeast, Nashua, NH, April 29 -30, 2009.

[23] New York Department of Environmental Conservation. Solid Waste Landfills. http://www.dec.ny.gov/chemical/23681.html. Accessed August 4, 2013.

[24] U.S. Environmental Protection Agency Region 9. Anaerobic Digestion of Food Waste. Prepared by East Bay Municipal Utility District. Final Report. http://www.epa.gov/region9/organics/ad/EBMUDFinalReport.pdf. March 2008.

[25] NYSERDA. 2006. Evaluating Potential Biodiesel Manufacturing Sites in New York State, Interim Report 04-22.

Agricultural Oil

New York farmers harvest ~4 .6 million bushels (51 million pounds) of soybeans on average.[26] The Renewable Fuels Roadmap estimated 6.5 million gallons of biodiesel can be produced from soybean oil. Our study allocates all of this biodiesel to non-transportation energy applications resulting in 0.8 TBtu of available biomass resource, based on an energy content of 118,700 Btu/gallon of biodiesel.

Other oilseed crops are suitable for production in the State, such as winter canola and sunflowers. However, high levels of other oilseed crop production would reduce soybean production as the acreage in production would shift from one crop to the other.

Recycled Cooking Oils and Animal Fat

The NYSERDA biodiesel feasibility study (2003)[27] estimated that if recoverable yellow grease (used cooking oil) were directed to biodiesel production, this would provide for 24 million gallons of biodiesel production. Grease production from restaurants only would result in 182-183 million pounds of yellow grease. The NYSERDA biodiesel potential study (2006)[28] estimated that 70-95% of the available yellow grease is now being collected in metropolitan areas. The supply of brown grease (grease collected from traps in the wastewater system) in New York State suitable for processing into biodiesel ranges from 13 to 25.7 million pounds annually.

The average amount of oil produced per person per year is 22 pounds (9 pounds of yellow grease and 13 pounds of brown grease). New York City's12 million residents alone produce 264 million pounds of waste grease annually, which could be converted to 34.4 million gallons of biodiesel.

Currently, 87.24 million pounds of waste grease per year are being recycled or used for other uses (recycle rate: yellow grease: 75%, brown grease: 4%). This leaves 176 million pounds of grease not already being collected.[29] While residential yellow grease would be difficult to collect because it is not centralized, ~90% of restaurant grease can be collected.

[26] NYSERDA. June 2003. Statewide Feasibility Study for a Potential New York State Biodiesel Industry, Final Report 04-02.

[27] Ibid

[28] NYSERDA. June 2006. Evaluating Potential Biodiesel Manufacturing Sites in New York State. Interim Report 04-22.

[29] Ibid

For this study we adopted assumptions from the Roadmap resulting in 150 million pounds of yellow grease being available and allocated to biodiesel production. The resulting resource is 24 million gallons of biodiesel from yellow grease or 2.8 TBtu based on an energy content of 118,700 Btu/gallon of biodiesel. In addition, a previous Biodiesel analysis estimates that 1.9 million gallons of biodiesel can be produced by slaughterhouse (animal fat) in New York.[30]

3.2.2.3 Biogas

Approximately 32 TBtu of potential energy is estimated to be available statewide from the following resources.

Farm Digesters

There are approximately 625,000 cows in New York. Of those cows, more than 70% belong to herds of 100 animals or greater and more than 30% belong to herds of 500 animals or greater.[31] While digesters for small farms are being developed, existing technology favors larger concentrations of animals.

The average rated capacity per cow at existing farm digesters is 0.172 kW/ cow.[32] This could result in 107 MW of power available from farm digesters. We assumed that 95% of that production could actually be captured but 20% of the manure would be used as field fertilizer directly. Currently, installed farm anaerobic digesters in New York have a combined capacity of 2.5 MW.[33]

Waste Water

As illustrated in Figure 7, there are approximately 610 municipal wastewater treatment plants (WWTP) in the state with broad geographic distribution. New York City's 14 facilities process 1.3 billion gallons of wastewater a day, while small village systems may treat less than 100,000 gallons per day.[34]

---

30 NYSERDA. June 2006. Evaluating Potential Biodiesel Manufacturing Sites in New York State. Interim Report 04-22.

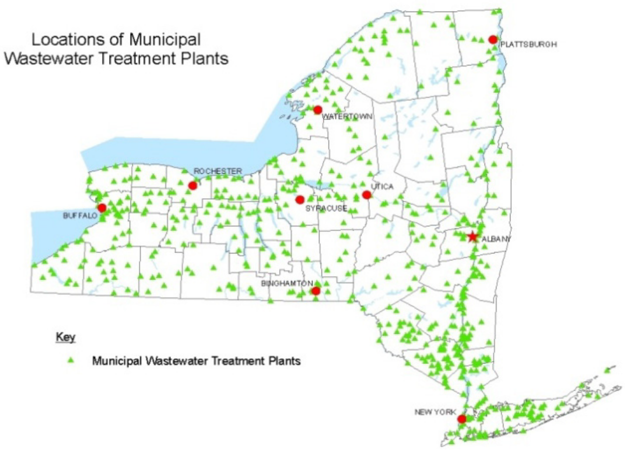
31 Overton, Thomas R. The New York Dairy Industry and Cornell. http://www.nyscfp.org/docs/activities/Tom%20Overton_%20New-York-Dairy-Industry-and-Cornell.pdf. Accessed August 4, 2014.

32 Norm Scott, Ph.D., Jennifer Pronto, Curt Gooch, P.E., Department of Biological and Environmental Engineering Cornell University. Biogas Casebook: NYS On-farm Anaerobic Digesters", Prepared for NYSERDA. http://www.manuremanagement.cornell.edu/Pages/Topics/General_Docs/Case_Studies/Northeast_Biogas_Case_Study_Book.pdf . July 2010.

33 Ibid

34 New York Department of Environmental Conservation. Wastewater Infrastructure Needs of New York State Report. http://www.dec.ny.gov/chemical/42383.html. Accessed August 4, 2013.

Figure 7. New York State Municipal Waste Water Treatment Plants.



The potential electric capacity of the 145 WWTPs with existing anaerobic digestion facilities is an estimated 24 megawatts (MW). The potential capacity of the State's 590 waste water treatment plants, if they all installed digestion and electrical generating facilities, is estimated to be 31 MW.[35] The BTP estimate is based on 90% of the treatment plants installing a biogas-fueled generation system.

The current installed capacity of WWTPs with digester-fueled generation capacity (17 facilities), is approximately 9 MW, providing nearly 45,000 megawatt-hours per year (MWh/yr) of generation.[36]

Food Waste

Previous research in New York estimated that 128 active food and beverage manufacturing facilities have a biogas production potential of 3.8 billion cubic feet per year (cf/yr), with a corresponding theoretical heating value of 2.1 TBtu, and the ability to generate 154GWh/yr.[37] The BTP estimate in this study is based on 15% of this waste stream being diverted to competing uses (e.g. composting) and 90% of the remaining potential being captured for energy production.

[35] NYSERDA. November 2007. Market Characterization Report: Anaerobic Digester Gas-to-Electricity for the Municipal Wastewater Sector in New York. Report Number MC 08-02.

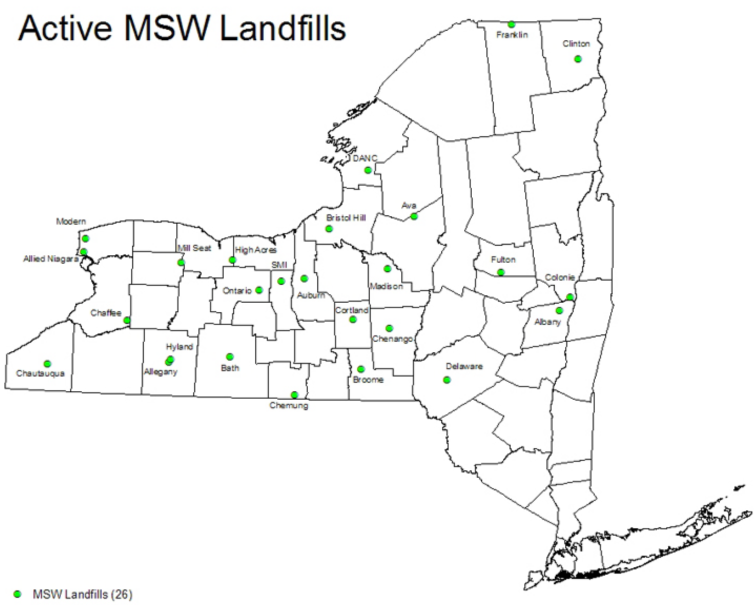
[36] Ibid

[37] Ibid

Landfill

In 2010, 7.7 million tons of solid waste was disposed of in New York State landfills. As of June 2010, there were 27 active municipal solid waste landfills, 16 active industrial/commercial waste landfills, 14 construction and demolition (C&D) landfills, and 3 active ash monofill landfills.[38] Figure 8 identifies the geographic distribution of active landfills. Twenty-five of these landfills [39] (municipal or other, active or inactive) have a biogas generation system in place, and reported 774 GWh of generation in 2010. [40] The average capacity of landfill gas plants currently interconnected to the grid is 4.9 MW.[41] Active landfills that did not report electric generation in 2010 reported 803,653 tons of solid waste received in 2010, with remaining permitted capacity at these sites of more than 36 million tons. The estimated available BTP resource would support 45MW of nameplate capacity, in addition to the approximately100 MW reporting generation in 2010.

Figure 8. Active landfills in New York State.[42]



---

[38] http://www.dec.ny.gov/chemical/23681.html

[39] U.S. Environmental Protection Agency, Landfill Methane Outreach Program (LMOP). 2009. An Overview of Landfill Gas Energy in the United States.

[40] NY DEC Landfill Gas Recovery Facility Data. 2009 Annual Report Data. http://www.dec.ny.gov/chemical/48873.html

[41] NYISO interconnection queue

[42] http://www.dec.ny.gov/chemical/32501.html

3.2.3 Bioenergy Constraints

This study did not conduct primary research of biomass resources or availability and competing uses for those resources. Biomass resource availability accounts for the proportion of the biomass potentially available in the State to what is actually available for consumption. For example, not all trees that can be harvested are actually harvested: not all forest stands are accessible due to environmental conditions or absence of right of way.

For resource estimates, resource availability, and competing uses (with the important exception of renewable transportation fuels) the assumptions used in this study are consistent with the work conducted for the Roadmap.

3.2.3.1 Land Use Conversions and Management

The available biomass resource estimates in this study do not require or result in macro scale changes in existing land use patterns (conversion from forestry to agriculture or vice versa). As assessed, the increased use of biomass would require micro-scale changes in crops cultivated, management practices, and yields within the agricultural and forested land use areas. This study does not include detailed biomass management or production modeling, but as an example, the potential for woody energy crops is based on placing underutilized agricultural land into willow crop production.

3.2.3.2 Sustainability and Air Quality

As a renewable energy, the estimates of biomass resources used for electric and thermal energy production in this study account for environmental sustainability of the harvest and land management practices. For example, some forested sites may require slash or tree tops to remain on site, to maintain soil carbon pools or reduce deer browse. Sustainability requires biomass harvest rates are less than annual incremental growth rates.

This study did not include any primary research or detailed analysis of air emissions from bioenergy combustion. The analysis and approach for this study is to emphasize the adoption and use of higher efficiency and low emission boilers and stoves. Several studies have been conducted to examine potential air quality impacts, concerns and strategies for promoting market development for efficient and low emission technologies in New York.[43]

[43] For example: NYSERDA, (2010b). "Spatial Modeling and Monitoring of Residential Woodsmoke Across A Non-Urban Upstate New York Region." NYSERDA report 10-02. Prepared by the Northeast States for Coordinated Air Use Management (Paul Miller) for NYSERDA: Albany, NY (February 2010). Additional biomass and air quality references are included in the Volume 5 Bibliography.

3.2.3.3 *Market Infrastructure and the Ability to Ramp-Up*

Increasing the use of bioenergy requires business and physical infrastructure that is not available overnight. For example, pellet or wood chip distribution infrastructure requires fuel dealers to purchase new trucks (e.g. bulk vacuum pellet trucks). As a result, the estimates of increased biomass usage include ramp up rates to account for market and infrastructure development. Our core analysis is based on steady adoption rates for bioenergy technologies over the twenty year study horizon.

3.2.3.4 *Transportation and Regionalization of the Technology Mix*

Transportation of biomass feedstocks is a limiting factor for the zonal bioenergy BTP. The potential for direct combustion is greater in Upstate New York due to the greater availability of lignocellulosic crops. Our analysis limits the solid biomass fuels (pellets, wood chips, and cord wood) potential to Upstate and the Hudson Valley. Municipal solid waste, farm and food waste, and wastewater residue are not transported between analysis zones but are utilized statewide.

3.2.4 Bioenergy Conversion Technologies

The bioenergy analysis includes three utility scale electric generation technologies: 1) direct fired biomass generation, 2) co-firing biomass with coal, and 3) landfill gas. Electricity generation for two customer sited applications[44] were also considered: 1) commercial and industrial scale combined heat and power, and 2) generation from anaerobic digester fueled systems.

3.2.5 Bioenergy Electric Conversion (including Combined Heat and Power)

3.2.5.1 *Direct-fired Biomass Generation*

Stand-alone direct fire biomass power generation power plants typically range from 30 to 50 MW of installed capacity, in part due to the consideration of an economic “fuel shed” for biomass supply. For this study 45 MW was adopted as a typical scale for a utility power plant. Table 21 summarizes the characteristics for a direct fired biomass electric plant.

---

[44] The distinction between customer sited and grid scale systems is meant to characterize the most likely applications, recognizing that there may be variations on a project by project basis.

Table 21. Direct Fired Biomass Electric Generation Characteristics.[45]

Nameplate Capacity	Installed Cost (Million 2012$)	Annual O&M (non-fuel)	Annual Output/Capacity Factor	Heat Rate (MMBtu /MWh)	Zones
45 MW	$3.378/MW	$109,733 per MW-yr[46]	6,136 MWh/MW 70% capacity factor[47]	15.43 [48]	UP and HV

Based on these inputs, the typical 45 MW plant analyzed in has the following characteristics:

- Total capital investment of $148.5 million
- Annual biomass (wood chip) fuel consumption of 4.2 TBtu/yr
- Annual electric generation of 276 GWh

3.2.5.2 Co-firing Biomass at Coal Plants

Solid fuel biomass co-firing systems can generally be described as either: 1) blended fuel feed systems (the fossil fuel, typically coal, and the biomass are blended prior to injection into the boiler), or 2) separate injection systems (biomass is injected through dedicated burners separately from the fossil fuel).

The 2013 NYISO Gold Book identifies 960 MW of existing nameplate coal fired capacity, with 422 MW of this capacity proposed or scheduled for retirement or mothballing. Reflecting the downward trend in coal fired generation, the analysis applies only to 538 MW of coal capacity that is not currently proposed or scheduled for retirement or mothballing.[49] All new co-firing capacity was also estimated to be installed by 2017 and to have a 6 year measure life. Table 22 summarizes the inputs for biomass co-firing.

45 Appendix A in Volume 5 provides a detailed table of the inputs used for each renewable energy technology in the study.

46 National Academies. 2009. Electricity from Renewable Resources.

47 VT PSB/ NARUC. August 2009. "Memo: Analysis of Vermont Feed-in Tariff: Scenarios of technology carve outs and tiered size queue for the 50 MW program," http://www.cclbl.com/Sem14Abril2011/JohanAlbrecht.pdf

48 NREL, 2000, Lessons Learned from Existing Biomass Power Plants, http://www.nrel.gov/docs/fy00osti/26946.pdf

49 New York ISO. April 2013. *2013 Load & Capacity Data: Gold Book.* Table IV-3c, p.60.

Table 22. Biomass Co-firing Electric Generation at Coal Plants Characteristics.

Nameplate Capacity	Installed Cost (Million 2012$)	Annual O&M (non-fuel)	Annual Fuel Savings	Zones
Per MW co-fired capacity	$0.500/MW[50]	No change from existing plant	58,530 MMBtu/MW coal – offset by increase in biomass fuel	UP

Biomass co-firing is modeled as a fuel switching measure and results in no new net generation or electric capacity. The benefits and costs are based on coal fossil fuel savings which are off-set by an energy equivalent increase in biomass fuel consumption.

3.2.5.3 Combined Heat and Power – Commercial and Industrial Scale

Table 23 summarizes the costs and performance characteristics, per MW for a 2 MW plant – with a 87% heat, 13% electric output profile. The plant was thus assumed to be primarily thermal load following, with 2,500 hours of annual operation.

Table 23. Commercial/Large Scale Combined Heat and Power Characteristics.

Nameplate Capacity	Installed Cost (Million 2012$)	Annual O&M (non-fuel)	Annual Output/Capacity Factor	Heat Rate (MMBtu/MWh)	Zones
2 MW	$4.535/MW [51]	$0.04/kWh-yr[52]	2.5 GWh and 57,286 MMBtu per MW-yr[53]	15.43	UP and HV

Due to availability of solid biomass fuels, commercial scale CHP deployment was limited to the Hudson Valley and Upstate zones with the allocation split by the percentage of population in each zone (27% HV, 73% UP).

50 IRENA, 2013 Biomass Cofiring Technology Brief.

51 Average O&M costs in VEIC analysis of 5 facilities in the Northeast, normalized by capacity: WJ Cowee, City of auburn, Power Pallet, Griffiss Utility Service Corp, Middlebury College.

52 EPA, Combined Heat and Power Level 1 Feasibility Analysis, Table 6

53 Capacity weighted average of 5 facilities in the Northeast: WJ Cowee, City of Auburn, Power Pallet, Griffiss Utility Service Corp, Middlebury College.

3.2.5.4 Landfill Gas

The study adopted 3 MW as a typical scale for landfill gas electric generation plants. [54] Landfill gas plants often produce energy evenly throughout the day and year-round, resulting in relatively high capacity factors. Table 24 presents a summary of the inputs used for the analysis of landfill gas generation.

Table 24. Landfill Gas Electric Generation Characteristics.

Nameplate Capacity	Installed Cost (Million 2012$)	Annual O&M	Annual Output/Capacity Factor	Heat Rate (MMBtu/MWh)	Zones
3 MW	$3.883/MW	$118,000 per MW-yr[55]	7,889 MWh/MW 90% capacity factor[56]	15.43 [57]	UP, HV, and LI

The analysis showed the potential for an additional 45 MW of new landfill gas capacity. Analysis zones where technology is applicable was assumed to be areas with active landfills: HV, 31%; UP, 49%; and LI, 20%.

3.2.5.5 Anaerobic Digesters

The capacity of digesters installations currently on the market ranges from 20 kW to 3 MW.[58, 59] The scale analyzed for this study is 300 kW of nameplate capacity applicable to project development in farm, food waste, and wastewater settings with characteristics as summarized in Table 25.

---

54 U.S. Environmental Protection Agency, Landfill Methane Outreach Program (LMOP). 2009. "An Overview of Landfill Gas Energy in the United States". Indicates applications ranging from 0.01-18 MW.

55 Preliminary results from the NYSERDA 2013 RPS Main Tier Program Review Cost Study.

56 VT PSB/ NARUC. August 2009. "Memo: Analysis of Vermont Feed-in Tariff ." http://www.cclbl.com/Sem14Abril2011/JohanAlbrecht.pdf.

57 Jeffery Pierce, SCS Energy. August 2005. Designing Landfill Gas to Energy Project: Intermountain CHP application Center Workshop presentation.

58 20 kW to 1.1 MW: Forcier, Aldrich, and Associates, April 2009, "University of Vermont Miller Farm Anaerobic Digester Feasibility Study"

59 Synergy Dairy, a 2,000-head dairy farm in Covington, Wyoming County. It's the largest on-farm co-digestion biogas project in the state, one of 17 New York biogas plants together turning waste from 20,000 cows into a generating capacity of 3 megawatts, https://www.greentechmedia.com/articles/read/rising-demand-is-giving-biogas-a-big-lift/

Table 25. Anaerobic Digester Electric Generation Characteristics.

Nameplate Capacity	Installed Cost (Million 2012$)	Annual O&M	Annual Output/ Capacity Factor	Heat Rate (MMBtu/MWh)	Zones
300 kW	$7.200/MW [60]	$360,000 per MW-yr[61]	6,136 MWh/MW 70% capacity factor[62]	15.43 [63]	All

3.2.6 Bioenergy Thermal

3.2.6.1 Residential Stove, Boiler, Furnace

New York State's residential sector consumed 49.4 TBtu of wood in 2010.[64] This wood and additional wood made available in the future could be utilized in a variety of processes described below.

Biomass residential central heating systems consist of wood pellets, wood chips, or cord wood used in a stove, furnace, or boiler system. System efficiencies can range from 60% to greater than 90%. Many high-efficiency European systems can achieve efficiencies in excess of 90%.[65] Note that this study does not include outdoor wood boilers, which are estimated to have operating efficiencies ranging from 28% to 55%[66] and are typically subject to greater concerns over excessive smoke and emissions.

The operational characteristics and costs for residential systems in this analysis are based on a blended average of systems representing high performing units, for each market segment and using best in class fuels. The residential market is assumed to be dominated by automated pellet systems, with cord wood representing 30% of the market. Of the pellet systems automated boilers with thermal storage are the dominant application, accounting for 80% of the pellet use, while pellet stoves account for 20%. Pellet fuels are assumed to be premium pellets with no bark. In the analysis the weighted average seasonal efficiency of residential systems installed in the next 20 years is

---

60 Average of anaerobic digester Capital cost = $1.5 million (no substrates), $1.75 million (with substrates).-250 kW generator set "Innovation Center for US Dairy, October 29-30, 2009, Capitalizing on Energy Opportunities on New York Dairy Farms Participant Briefing Paper: Opportunity Analysis", Dairy Power New York Summit: Creating a Greener, Cleaner Future.

61 EPA Fair Oaks Dairy Digester 2 and William Lazarus, University of Minnesota, 2009 Anaerobic Digester Technology

62 VT PSB/ NARUC. August 2009. "Memo: Analysis of Vermont Feed-in Tariff: Scenarios of technology carve outs and tiered size queue for the 50 MW program." http://www.cclbl.com/Sem14Abril2011/JohanAlbrecht.pdf.

63 http://www.nrel.gov/docs/fy00osti/26946.pdf

64 NYSERDA. Patterns and Trends New York State Energy Profiles: 1997-2011. Table 2-9b.

65 Meister Consultants Group. March 2012. Massachusetts Renewable Heating and Cooling Opportunities and Impacts Study. Prepared for Massachusetts Department of Energy Resources, Massachusetts Clean Energy Center.

66 Northeast States for Coordinated Air Use Management (NESCAUM). March 2006. Assessment of Outdoor Wood-Fired Boilers. Page 2-2.

estimated to be 82%. The typical scale analyzed for this study is 0.04 MMBtu/hr for stoves and 0.1 MMBtu/hr for boiler/furnaces. Wood stoves are often used in supplement to another heating system that operates during the shoulder seasons, and operates in conjunction with the wood stove during peak heating demand. The measure characterization applies a weighted average for bioenergy fuel types in the residential market of 70 % pellet fuel, and 30% cord wood systems. The weighted average fuel cost for residential biomass fuels is $19.03/MMBtu initially and is estimated to rise to $20.64 by 2035.

The following weighted average costs were used in the analysis, per MMBtu/hr of residential system capacity:

- Installed Costs: $225,776[67]
- Operation and maintenance costs (non-fuel): $1,406 [68]

The annual fossil fuel savings are calculated based on 1,209 effective full load hours[69] and the average nameplate capacity, divided by the efficiency.[70]

Analysis zones where technology is applicable were assumed to be HV (Hudson Valley) and UP (Upstate), split by the percentage of population in each zone (27% HV, 73% UP). This analysis focused on the replacement of petroleum fuels in the residential heating markets – based on consideration of comparative economics and resource availability. The amount of residential fuel oil to be displaced by biomass thermal systems is a binding factor in the analysis, and the amount of biomass resource needed to offset oil use for residential thermal applications is not a binding constraint.

3.2.6.2 Commercial & Industrial Boilers

The analysis is based on a weighted average cost and performance estimates for pellet and woodchip boilers suitable for commercial and industrial applications. Pellet systems are assumed to be more applicable for smaller applications with an average nameplate system size of 1.8 MMBtu/hr. Pellet systems are estimated to account for 70% of the commercial and industrial market. Wood chip systems are estimated to have a larger capacity (3.2 MMBtu/hr) and to account for 30% of the potential market. The resulting weighted average costs and performance per MMBtu/hr are used in the analysis:

---

67 Cost estimates are based on preliminary analysis conducted for the New York State Biomass Thermal Energy Roadmap and with experience from Biomass Energy Resource Center.

68 Interviews conducted by Efficiency Vermont

69 New York State Technical Reference Manual effective full load hours for residential heating.

70 Efficiency estimates consistent with preliminary analysis for New York State Biomass Thermal Roadmap.

- Installed Costs: $311,176[71]
- Operation and maintenance costs (non-fuel): $2,031[72]

The annual fossil fuel savings are calculated based on 1,078 effective full load hours[73], and the nameplate capacity divided by the efficiency[74].

Analysis zones where technology is applicable were assumed to be HV (Hudson Valley) and UP (Upstate), split by the percentage of population in each zone (27% HV, 73% UP).

The average estimated efficiency of a C&I biomass system in the analysis is 84%. Flue gas condensation, decreasing oxygen content of the flue gas, reducing the organic carbon content in the ash, and decreasing the flue gas temperature at the boiler outlet could all have the potential to further increase system efficiency.

Design and system improvements are likely to improve performance of this technology bundle in the next 20 years. One such improvement includes Organic Rankine Cycle (ORC) systems. These use organic oil or refrigerants rather than water as the process medium. These fluids have lower boiling points than water, allowing ORC systems to be operated at relatively low temperatures. Organic Rankine Cycle Systems are widely used in Europe, but are not yet widely available in the U.S. [75] They are expected to be more readily available in the next 20 years and increase the average system efficiency.

Additional improvements will likely take place in the near future for storage and pre-processing, which would also improve the overall efficiency or decrease the costs. However, the efficiency of fossil fuel powered systems is also expected to increase, and therefore increased efficiency of the biomass systems does not affect the analysis. The fuel mix for new commercial biomass systems in the analysis is 70% wood chips and 30% pellets. The weighted average cost for commercial biomass fuels is $6.36/MMBtu initially, rising to $7.74 by 2035.

---

71 Consistent with preliminary estimates from New York State Biomass Thermal Roadmap, and informed by Biomass Energy Resource Center estimate for relative market shares.

72 VEIC, 2012, "Analysis of Vermont schools biomass systems for NYPA".

73 New York State Technical Reference Manual effective full load hours for commercial heating, Upstate and Hudson Valley.

74 Seasonal weighted average efficiency for C/I biomass systems of 84% for biomass and 80% for oil consistent with preliminary analysis for New York Biomass Thermal Energy Roadmap.

75 Pace Energy And Climate Center. October 2009. Guide For Siting Small-Scale Biomass Projects in New York State, Final Report 09-07. Prepared for the New York State Energy Research And Development Authority.

3.2.6.3 Biodiesel

Ethanol and biodiesel are the two liquid biofuels primarily used for energy. Ethanol was excluded from our analysis because it is assumed to be used exclusively in the transportation sector. Biodiesel is used in both transportation and building energy and we only investigated the building heat use of biodiesel. Because of the decreasing reliance on oil for electricity generation, we did not analyze biofuel to electric power potential.

Biodiesel is manufactured from organic waste oils and greases, plant oils, and animal fats. It is produced through a process called trans-esterification, where oil or fat is reacted with an alcohol in the presence of a catalyst (usually sodium hydroxide or potassium hydroxide). Pure (100%) biodiesel is typically blended with petroleum-based heating oil to create a biodiesel blend. Such blends are commonly identified by the ratio of conventional oil to biodiesel. For example, “B5” refers to a mixture of 95% fuel oil and 5% biodiesel. In space heating applications, blends of B5 and below are common. Blends up to B20 are more common in transportation applications. As biodiesel has higher viscosity than oil, in cold climates higher blends of biodiesel may be problematic if the fuel is stored outside. At ratios greater than 30% biodiesel, there is a risk that the rubber seal in the fuel pump can break. Manufacturers are now incorporating better seals in new pumps to overcome this.[76] Many European-made pumps can handle blends up to B100, though these and other European-made products currently have a limited presence in the US.[77]

The incremental cost of biodiesel was calculated using data from the National Academies Press (2009).[78] The incremental cost of biodiesel declines from +$0.58/MMBtu to +$0.04/MMBtu over the study horizon due to expected economies of scale and increase in the price of distillate oil. As a B5 blended fuel switch the biodiesel does not have incremental capital or non-fuel incremental operating costs – and it has a measure life of one year.

[76] John W. Bartok, Jr. "Heating with Bioheat and Waste Oil." NRME Dept., University of Connecticut, http://hrt.msu.edu/Energy/Notebook/pdf/Sec4/Heating_with_Bioheat_and_Waste_Oil_by_Bartok.pdf

[77] Meister Consultants Group. March 2012. Massachusetts Renewable Heating and Cooling Opportunities and Impacts Study. Prepared for: Massachusetts Department of Energy Resources, Massachusetts Clean Energy Center.

[78] The National Academies Press. 2009. Electricity from Renewable Resources: Status. Prospects, and Impediments. Prepublication copy.

3.2.7 Economics and Technology Learning

Bioenergy conversion relies on a set of proven and mature technologies. Capital costs for dedicated electric power production are not expected to decline – consistent with preliminary analysis conducted on costs of RPS compliance for New York, and also consistent with the NREL Electricity Futures Study.[79] As costs are expected to remain steady, improvement in heat rates – due to higher efficiency and possible advances with gasification are projected by NREL to improve overall performance per unit of installed biopower capacity.[80]

3.3 Bioenergy Results

3.3.1 Summary of Potential for Bioenergy

Bioenergy has significant potential to contribute to New York's energy mix. As outlined above, agricultural land potential, which includes feedstocks of corn stover, straw, and dedicated energy crops such as grass or willow, amounts to 8.2-million dry tons of biomass.[81] Forest land potential, which includes mill residues, logging residue, and available timber, amounts to 6.4 million dry tons of biomass.[82] In addition, 0.8 million dry tons could be available in the form of wood residue recovered from the municipal solid waste stream. Together, these feedstocks could provide approximately 233 TBtu of primary energy to New York's energy mix. Agricultural oil, yellow oil and brown grease can supply another 3.5 TBtu. Energy from organic waste recovered from food waste, farms, wastewater plants, and landfills adds up to another 31 TBtu. The total BTP for bioenergy is estimated to be 269 TBtu. If all resources went to thermal uses, 253 TBtu of heat could be generated. If all resources went to electricity production, 17,334 GWh of electricity could be generated (see Table 26).

---

79 NREL Electricity Futures Study Volume 2: Figure 6-13.

80 Ibid. Figure 6-14.

81 Renewable Fuels Roadmap scenarios 2 and 3

82 Renewable Fuels Roadmap scenarios 2 and 3

Table 26. Biomass Bounded Technical Potential: Thermal and Electric Potential (Assuming All Resources Are Dedicated to Either Electricity or Heat).

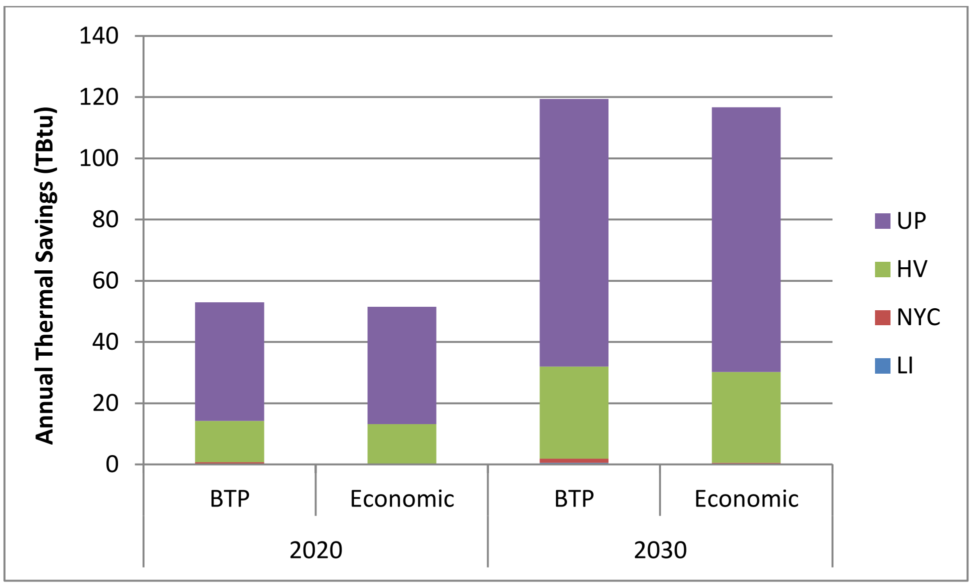
Resources Stream		Total Potential (TBtu)	Thermal Potential (TBtu)	Electric Potential (TBtu)	Electric Potential (GWh)
Lignocellulosic Biomass	*Hardwood and softwood chips*	102.2	102.2	102.2	6,626
	Woody energy crop (willow)	49.9	49.9	49.9	3,233
	Clean wood from MSW	6.2	6.2	6.2	399
	Warm season grasses	70.7	70.7	70.7	4,583
	Corn stover	4.5	4.5	4.5	292
	Subtotal	**233.5**	**233.5**	**233.5**	**15,133**
Biodiesel	*Agricultural oil*	0.7	0.7	0.0	0
	Recycled cooking oils and animal fat	2.8	2.8	0.0	0
	Subtotal	**3.5**	**3.5**	**0.0**	**0**
Waste stream	*Farm*	10.3	10.3	10.3	710
	Wastewater	3.5	3.5	3.5	244
	Food waste	2.1	2.1	2.1	145
	Landfill	16.0	0.0	16.0	1,101
	Subtotal	**31.9**	**15.9**	**31.9**	**2,201**
Total		**268.8**	**252.9**	**265.4**	**17,334**

To more accurately reflect resource and market conditions, an allocated BTP has also been estimated to reflect an allocated share between thermal and electric end uses for bioenergy as well as the zonal distribution, with the larger share of solid biomass resources available Upstate. For the lignocellulosic resources the shares used for this allocation were 80% percent to thermal applications, and 20% to electric generation including CHP. The biodiesel was allocated to thermal uses, and all of the waste stream resources were allocated to electric generation. The results for the allocated BTP and economic potential for bioenergy resources are illustrated in Table 27 and Figure 9.

Table 27. Bioenergy Thermal Potential

	2020 TBtu		2030 TBtu	
Zone	**BTP**	**Economic**	**BTP**	**Economic**
Long Island	0.2	0	0.5	0.1
New York City	0.6	0	1.4	0.4
Hudson Valley	13.4	13.2	30.1	29.7
Upstate	38.8	38.3	87.4	86.5
Statewide	**53**	**52**	**119**	**117**

Figure 9. Bioenergy Cumulative Annual Thermal Potential by Year and Zone.



The results indicate the bioenergy thermal potential is resource limited and that almost all of the identified BTP passes economic screening. The exception is the B5 blend, which is not cost effective until late in the study period. Table 28 presents the nameplate capacity of bioenergy measures that generate electricity.

Table 28. Bioenergy Electric Potential by Technology (DC Nameplate Capacity).

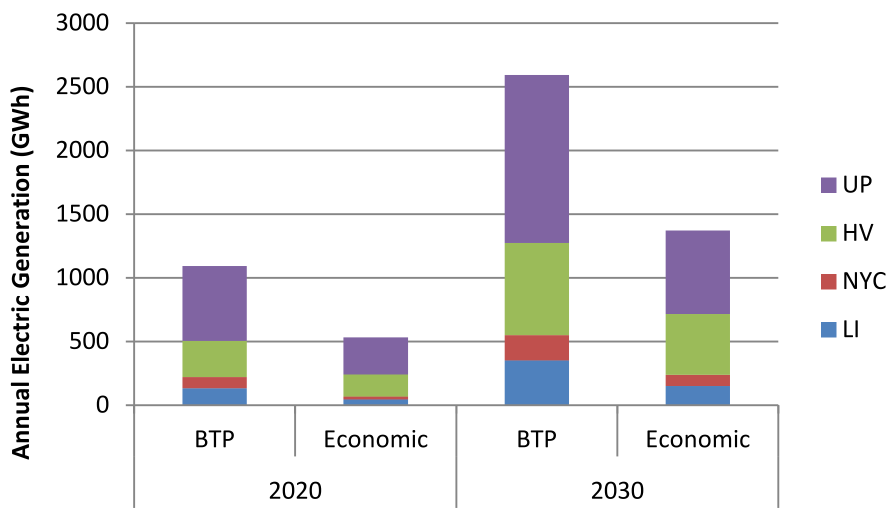
Technology	2020 BTP (MW)	2020 Economic (MW)	2030 BTP (MW)	2030 Economic (MW)
Farm waste, food waste, and wastewater digesters	74	3	165	13
Landfill Gas	14	14	49	49
Co-Firing with Coal	28	0	28	0
Direct Fire Biomass	13	0	30	0
Commercial CHP	144	144	324	324
Total	**273**	**161**	**596**	**386**

Table 29 and Figure 10 present the allocated bioenergy potential for electric generation.

Table 29. Bioenergy Electric Potential Cumulative Annual Generation by Zone.

Zone	2020 BTP (GWh)	2020 Economic (GWh)	2030 BTP (GWh)	2030 Economic (GWh)
Long Island	132	44	350	151
New York City	88	15	199	88
Hudson Valley	285	175	725	477
Upstate	586	291	1319	656
Statewide	**1,091**	**525**	**2,593**	**1,372**

Figure 10. Bioenergy Cumulative Annual Electric Potential by Year and Zone.



Roughly half of the identified bioenergy electric potential passes economic screening. Table 30 represents the BTP by technology and time period for both thermal and electric end uses.

Table 30. Bioenergy Cumulative Annual BTP by Technology.

			Statewide 2020		Statewide 2030	
Resource	**Technology**	**Scale Analyzed**	**BTP Thermal (TBtu)**	**BTP Elec (GWh)**	**BTP Thermal (TBtu)**	**BTP Elec (GWh)**
Biomass	*Residential Direct Combustion (pellet and cord wood)*	0.04 MMBtu/hr	22.5	n/a	50.6	n/a
	Residential Blended Fuel Oil (B5 blend)	n/a	0.8	n/a	1.9	n/a
	Commercial Direct Combustion (pellet and wood chip)	1 MMBtu/hr	20.8	n/a	46.8	n/a
	Commercial Blended Fuel Oil (B5 blend)	n/a	0.7	n/a	1.5	n/a
	Farm waste, food waste, and wastewater digesters	300 kW	n/a	501	n/a	1,126
	Landfill Gas	3 MW	n/a	111	n/a	385
	Co-Firing with Coal	5%	n/a	0	n/a	0
	Direct Fire Biomass	45 MW	n/a	81	n/a	183
	Commercial CHP	2 MW	8.2	399	18.5	898

Figure 11 through Figure 14 illustrate the share of the estimated bioenergy BTP by technology and time period, as presented in Table 31.

Figure 11. Bioenergy Thermal BTP – 2020 by Technology (Total 53 TBtu).

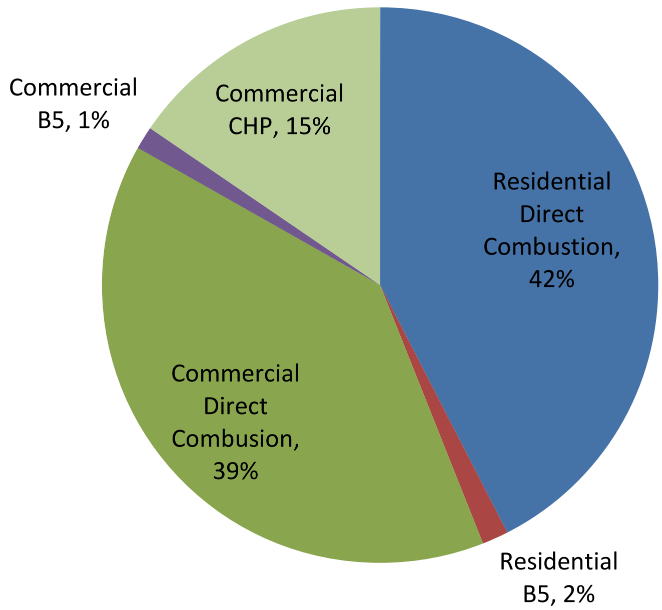


Figure 12. Bioenergy Thermal BTP – 2030 by Technology (Total 120 TBtu).

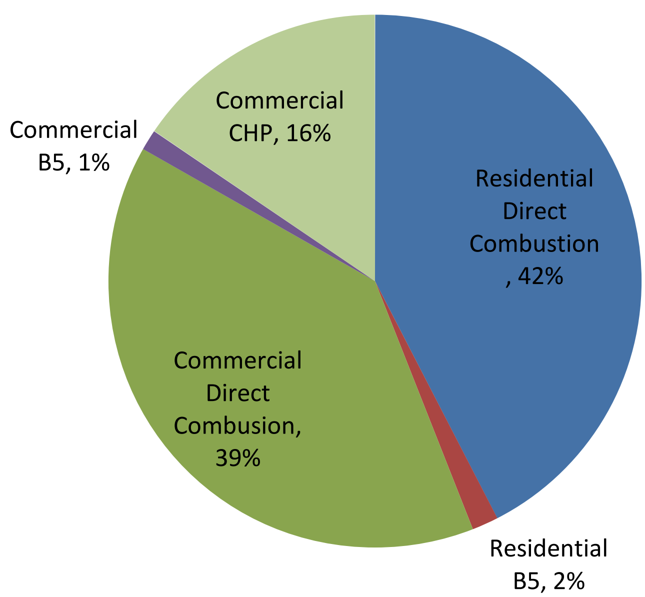


Figure 13. Bioenergy Electric BTP – 2020 by Technology (Total 1,091 GWh).

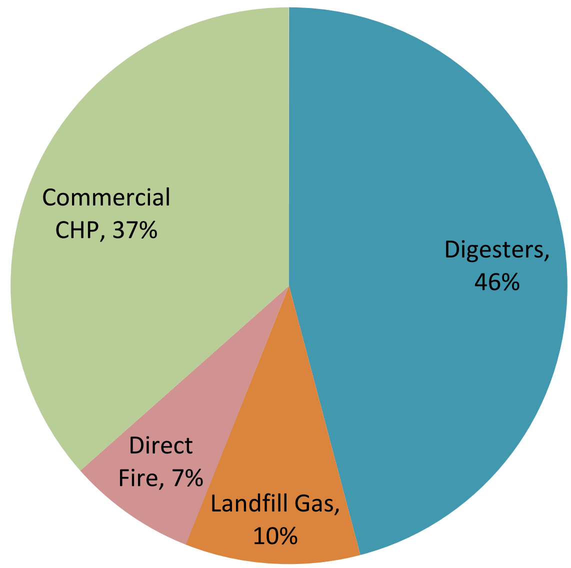


Figure 14. Bioenergy Electric BTP – 2030 by Technology (Total 2,592 GWh).

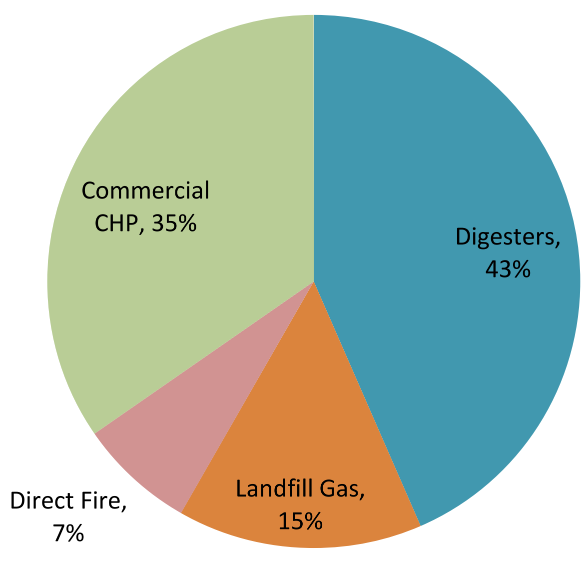


Table 31 presents the bioenergy economic potential for thermal and electric end uses, by technology and time period, using the same format as Table 30, which identified the allocated bounded technical potential.

Table 31. Bioenergy Cumulative Annual Economic Potential by Technology.

			Statewide 2020		Statewide 2030	
Resource	**Technology**	**Scale Analyzed**	**Economic Thermal (TBtu)**	**Economic Electric (GWh)**	**Economic Thermal (TBtu)**	**Economic Electric (GWh)**
Biomass	*Residential Direct Combustion (pellet and cord wood)*	0.04 MMBtu/hr	22.5	n/a	50.6	n/a
	Residential Blended Fuel Oil (B5 blend)	n/a	0	n/a	0.5	n/a
	Commercial Direct Combustion (pellet and wood chip)	1 MMBtu/hr	20.8	n/a	46.8	n/a
	Commercial Blended Fuel Oil (B5 blend)	n/a	0	n/a	0.3	n/a
	Farm waste, food waste, and wastewater digesters	300 kW	n/a	22	n/a	88
	Landfill Gas	3 MW	n/a	111	n/a	385
	Co-Firing with Coal	5%	n/a	0	n/a	0
	Direct Fire Biomass	45 MW	n/a	0	n/a	0
	Commercial CHP	2 MW	8.2	399.	18.5	898

Figure 15 through Figure 18 illustrate the share of bioenergy economic potential for thermal and electric end uses by technology for 2020 and 2030.

Figure 15. Bioenergy Thermal Economic Potential – 2020 by Technology (Total 52 TBtu).

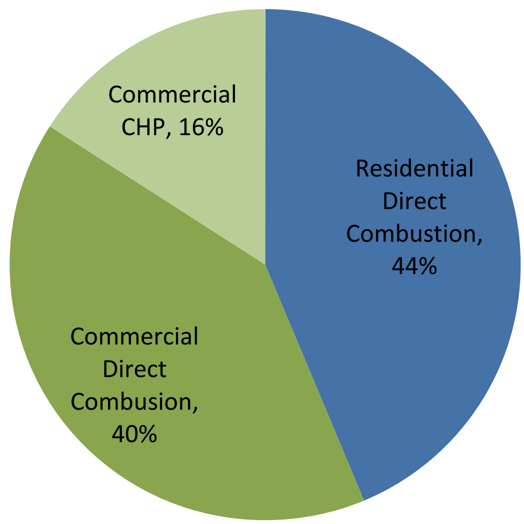


Figure 16. Bioenergy Thermal Economic Potential – 2030 by Technology (Total 117 TBtu).

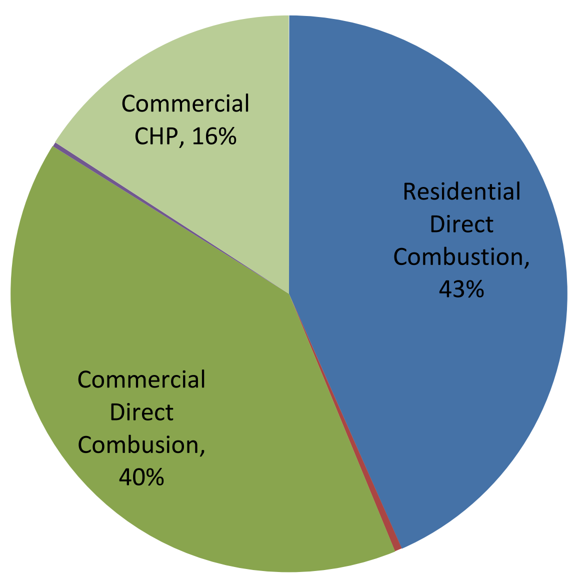


Figure 17. Bioenergy Electric Economic Potential – 2020 by Technology (Total 532 GWh).

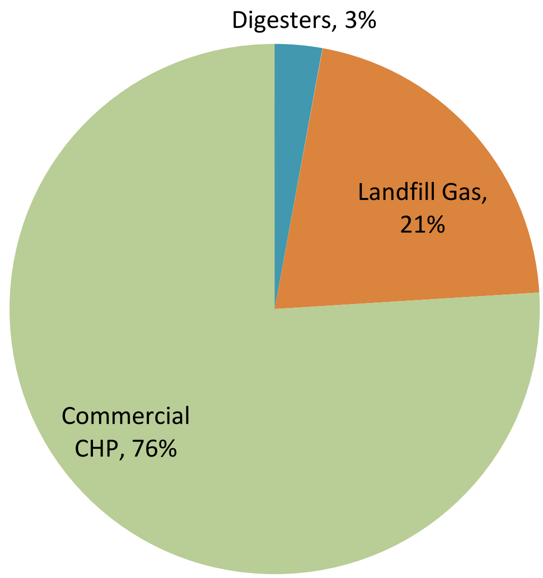
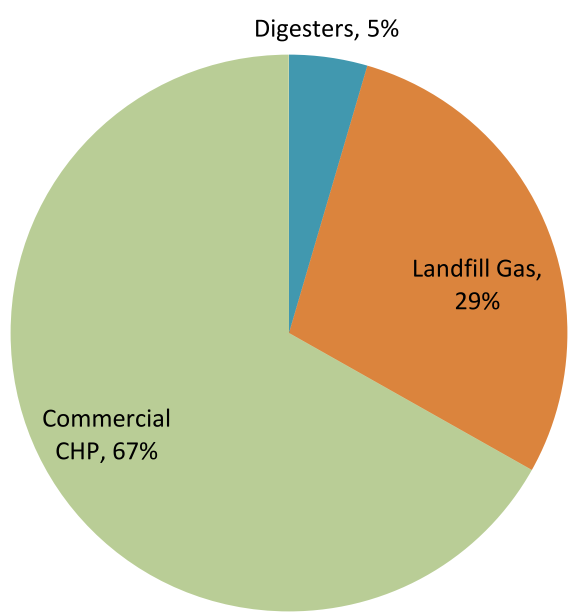


Figure 18. Bioenergy Electric Economic Potential – 2030 by Technology (Total 1,371 GWh).



For thermal end uses, comparing the BTP and economic results (Figure 11 and 12 compared to Figure 15 and 16) shows little difference, indicating that most of the applications pass the economic screening. A comparison of the BTP and the economic results for the electric applications (Figures 13 and 14 compared to Figure 17 and 18) illustrates a different pattern. Direct fire generation does not pass economic screening and digesters do not pass economic screening for much of the study horizon. Therefore the economic potential results as illustrated in Figure 17 and 18 show much greater shares for commercial CHP and landfill gas applications.

3.4 Bioenergy Development Paths and Investment

This study documents the potential for the increased use of bioenergy resources in New York to meet building thermal energy and electricity generation needs. As the available resource is developed, there will be continuing market competition (both within the sector analyzed and with transportation and other non-energy uses) for biomass resources.

The results of our study, as presented above, illustrate several potential development paths. For illustrative purposes, an unallocated BTP that assumes all of the available bioenergy resources are used to generate electricity or to meet thermal needs was presented in Table 26. This result is informative but does not reflect the market structure and realities that indicate that bioenergy resources will likely be used to meet a combination of the electric and thermal needs rather than being restricted to only one or the other.

The allocated BTP addresses a more likely development path – that both thermal and electric markets will be supported with bioenergy resources in the future. Finally, the development path illustrated by the economic potential analysis illustrates the more favorable economics of thermal and customer sited electric generation and as a result, a greater allocation of resources towards those applications and relatively less towards the development of grid scale electric generation.

The total annual level of investments required to develop the estimated economic bioenergy potential is approximately $1.3 billion. Table 32 shows the annual and cumulative investments for the economic potential case during the study horizon for bioenergy technologies.

Table 32. Bioenergy Technologies Total Investment

		Total Private and Public Investment (Million 2012$)		
Resource	**Technology**	**Annual Investment 2020**	**Annual Investment 2030**	**Cumulative Investment 2030**
Biomass	*Residential Direct Combustion (pellet, wood chip, and cord wood)*	554	576	7,905
	Commercial Direct Combustion (pellet and wood chip)	675	670	12,115
	Farm waste, food waste, and wastewater digesters	0	12	93
	Landfill Gas	11	14	190
	Commercial CHP	82	82	1,468
	Total	**1,322**	**1,354**	**21,771**

4 Hydro

4.1 Overview

New York has a long history with hydroelectric energy. The first direct current (DC) power plant was constructed in 1882 at Niagara Falls and was followed by an alternating current (AC) power plant that was completed in 1895. It is a very mature and well understood technology. Today, a total of 4,790 MW of conventional hydro capacity is installed in New York State, operating at a capacity factor of about 60%. There is an additional 1,407 MW of pumped storage hydro capacity, the majority of which is from the Blenheim Gilboa facility[83]. Pumped storage facilities are important energy storage resources (see Energy Storage Module in this Volume) but they are excluded from the analysis of new and potential hydropower. The 4,790 MW of installed conventional hydropower capacity provides approximately 15% of the total amount of electricity used in New York.

A 1.05 MW capacity installation in the East River in New York City[84] represents an emerging hydropower technology. Horizontal axis propellers, anchored to the bottom of the river, are spun by the moving tides to produce electricity. This type of technology, called hydrokinetics, is an offshoot of conventional hydro projects, and harvests energy from tidal and in-stream current.

4.2 Hydro Approach and Methods

4.2.1 Hydro Resources

The hydro energy resource has already been well developed in New York, but significant potential still remains at a number of different types of sites. The potential for hydro energy depends on a number of factors, the most critical being the availability of moving water. This availability is the first bounding factor. The second bounding factor is the ability to develop a site in order to produce hydro energy. Many sites are more valuable to society for their wildlife, navigation, recreation, or scenic qualities than for hydropower. Finally, there are number of economic, geologic, and technical issues that may make a site unsuitable for development.

The following methods and sources were used to estimate the bounded technical and economic potentials.

83 New York ISO. April 2013. 2013 Load & Capacity Data: Gold Book. Table II-1, p.21.

84 http://www.theriteproject.com/

4.2.1.1 Run of the River

Run of river hydro plants divert some of the river's flow info a penstock and do not use a dam that completely blocks the water flow. A weir may extend across the river, but is designed to allow water to flow over the top. The penstock parallels the rivers flow for some distance to allow for sufficient head to develop, and then the water flows through a turbine and is returned to the river. While this kind of application is less disruptive to the river's flow, it also has limited storage capability, so at times of low flow the capacity of the hydro installation may be reduced significantly.

The bounded technical potential for these sites came from a Department of Energy report written by the Idaho National Laboratory and completed in 2006 titled: *Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plant.* The method for determining bounded potential is further described below. This assessment calculated the gross power potential for all natural streams in the United States. Sites already developed or that were in protected areas such as a park were excluded.

Following the water resource assessment, a further set of criteria including site accessibility, existing grid proximity, and land and environmental factors were applied to identify feasible sites. For run of river projects, additional criteria required that no dam was needed, that a penstock running parallel to the river was not longer than comparable penstocks in the region, and power was limited to between 1 and 30 MW. In addition, the potential was limited to half the flow rate of the river or 30 MW, whichever was less.

In our analysis, new run of river projects were assigned an average annual capacity factor of 40%. Because run of the river sites do not have the capability to store water behind a dam, the capacity factor is lower than that of a conventional site with a dam. Individual plant capacity factors are highly site specific and weather dependent. The NREL Electricity Futures Study includes a range of capacity factors of 13% to 75% for hydropower,[85] and research for the New York Renewable Portfolio Standard Cost Study Update[86] estimates low impact hydro to have a capacity factor of 46%.

---

85 NREL Electricity Futures Study. Vol.1: Table A-1. Cost and Performance Estimates for Renewable Energy.

86 http://www.nyserda.ny.gov/Publications/Program-Planning-Status-and-Evaluation-Reports/-/media/Files/EDPPP/Energy%20and%20Environmental%20Markets/RPS/RPS%20Documents/2013/2013-09-05_rps_vol3.pdf

4.2.1.2 Undeveloped Sites Requiring a New Dam and Repowering Existing Dams

The bounded technical potential estimates for undeveloped sites that would require a new dam or the repowering of existing dams came from a US Department of Energy report written by the Idaho National Laboratory and completed in 1998. This report is titled: U.S. Hydropower Resource Assessment for New York. The bounded potential was determined as follows:

Forty-four existing dam sites that could have increased generation capacity and ninety-six undeveloped sites with potential were identified. The nameplate capacity of these sites was calculated using stream flows and head.

Idaho National Laboratory applied Hydropower Evaluation Software (HES) to the identified sites to rate them for suitability for increased capacity or for development. The HES process looks at factors such as environmental, geologic, recreation, cultural, recreation and scenic concerns. It results in a Project Environment Suitability Factor (PESF) which is then multiplied against the identified potential.

We adopted the Idaho National Laboratory's estimated average capacity factor for new sites of 52%. There are two points of interest regarding the undeveloped sites identified in this report. First, 367 MW of the 652 MW identified are at one site on the Lower Niagara River. Second, many sites listed as undeveloped have names such as Barge Canal Lock and Dam 16 and Mohawk Dam 12, which would indicate that these are not untouched, pristine sites. Of the 353 sites identified in the Idaho National Lab's study, seven have been granted FERC licenses since 1997.

4.2.1.3 Non-Powered Existing Dams

There are also many dams in the United States that were built for reasons other than generating power, such as for flood control, or for use in the past to power mills by mechanical means, but they do not generate power today. These Non-Powered Dams represent a great opportunity for hydropower because there are fewer expense and permitting issues as compared with constructing a new dam. The New York State canal system has numerous non-powered dams that have been evaluated for power potential and have been included in this analysis. The evaluation of power production potential at existing non-powered dams typically accounts for non-energy uses, such as flood control, through adjustment to annual capacity factors and/or the generation capacity.

The bounded technical potential for these sites came from a Department of Energy report published by Oak Ridge National Laboratory in 2012.[87] This report includes a database listing all identified existing dam sites that do not currently have power generating capacity. The bounded potential was determined as follows:

The database was filtered for all New York State sites. The total annual megawatt hours of estimated energy production for the identified 33 New York sites was summed. The production was estimated using stream flow averages by month for a ten year period. The Oak Ridge Report accounts for non-power production services – such as navigation, flood control or irrigation, by not varying historic flow or use patterns, but by simply assuming that the water passing through the facility would be available for power production. The total energy production was adjusted by a 52% capacity factor based on Idaho National Laboratory estimate, similar to new dam sites to estimate nameplate capacity.

4.2.1.4 Tidal Energy

Two reports that specifically identify tidal energy opportunities for New York State are very different in their assessments.

A report conducted by Georgia Tech Research Corporation lists ten specific sites along with estimates of potential for each identified site. The total estimated potential is 280 MW.[88] The second report written by E3 evaluated 485 sites. Of these, twenty sites were chosen as most likely to be developed due to their high tidal stream speeds and their proximity to the electrical grid. However, the E3 report provides only a general estimate for the potential of these twenty sites as 500 MW, and states that a single site probably accounts for 400 MW of that potential. These estimates are based on the assumption that 1.3% of the viable cross sectional area of the tidal flows is used to capture the energy.[89]

While both studies provide latitude and longitude locations for the identified sites, location names differ and the coordinates do not always align exactly. Thus, while there is significant overlap in the identified sites between the two reports, they do not match completely. For this study, the 280 MW figure from the Georgia Tech report was adopted as the more conservative of the two estimates.

---

[87] ORNL. April 4, 2012. U.S. Hydropower Potential from Existing Non-powered Dams (> 1MW subset). NHAAP_NPD_FY11_1MW. http://nhaap.ornl.gov/content/non-powered-dam-potential.

[88] Georgia Tech Research Corporation. 2011. Assessment of Energy Production Potential from Tidal Streams in the United State, Final Project Report. Award Number: DE-FG36-08GO18174. June 29, 2011.

[89] E3. 2007. Long Island Tidal and Wave Energy Study: An Assessment of the Resource. Page 55.

Additionally, it a 1 meter per second minimum flow was assumed in order to activate tidal power generation. No tidal barrages were assumed (no dams). Power is generated by placing a turbine in the tidal current (Tidal in Stream Energy Conversion, sometimes known as TISEC).

An average capacity factor of 38% was applied based on analysis of tidal installations conducted by EPRI.[90]

4.2.1.5 Wave Energy

The wave energy resource was quantified by EPRI in a 2011 study entitled *Mapping and Assessment of the United States Ocean Wave Energy Resource.* The annual energy potential from wave energy is given as 16,000 GWh along the outer shelf and 12,000 GWh along the inner shelf.[91] The recoverable portion of this energy depends on how densely equipment is spaced, or packed in the areas where the wave energy is present. Typically, wave energy is given as kilowatt per meter, where the kinetic energy of one meters' width wave is captured and transformed into kilowatts of electricity by the generating device. When discussing the wave energy along a coastline such as New York's Long Island, the metric is more appropriate in megawatts per kilometer (MW/km).

The EPRI report minimum packing density of 10 MW/km was applied in our analysis. Using the minimum packing density, the technically recoverable energy for the outer shelf is 58% and 63% for the inner shelf. Multiplying the recoverable percentage against the potential yields 9,280 and 7,650 GWh for the outer and inner shelves respectively. The average capacity factor for wave devices of 29% was calculated based on examples of wave power installations as reported by EPRI.

Production from wave energy technologies is not reported in the bounded technical potential or economic potential results as the technology is still developing and is not yet widely deployed. However, a characterization based on preliminary information, is shown in Volume 5, Appendix A: Summary of Inputs for the Renewable Energy Analysis.

[90] EPRI. 2006. North American Tidal In-Stream Energy Conversion Technology Feasibility Study.

[91] EPRI. 2011. "Mapping and Assessment of the United States Ocean Wave Energy Resource."

4.2.2 Hydro Constraints

There are a number of barriers to the growth of hydro generation. A limited number of viable sites, along with competing interests make it difficult to consider building new dams at undeveloped sites. In fact, many dams throughout the US are being removed to improve recreation and wildlife habitats. Equipping existing non-powered dams with turbines is a much simpler option, and repowering existing dams with new equipment so they make more energy is even more straightforward. There is also the consideration of scale. While there are numerous potentially viable low power sites, the permitting and development costs per kW are higher for these installations because all projects need to go through the same federal permitting process regardless of the size or generating capacity of the installation.

Run of the river impoundments also require infrastructure and a potentially expensive permitting process. The infrastructure required may include a weir to help divert water to the intake. It is also imperative for any hydro project that a transmission line be available or be able to be built in order to move the electricity to market. If a potentially viable site is in a remote place, or easements cannot be obtained from landowners to run a transmission line, this issue can stop development. Recognizing the time required for hydro developments new hydro capacity is limited to after 2017 in our analysis.

Hydrokinetic technology such as the East River installation presents different challenges in that it must be attached to the bottom of the river. Depending on the depth of the installation, it may present a navigational hazard or become fouled with debris. Some tidal hydrokinetic installations may require a diversion weir to be effective, or may also present navigational or environmental challenges. There are number of competing technologies to turn wave energy into power. None have yet emerged as the front runner as the technology is still being commercialized. Also, because the number of hydrokinetic installations is small, the costs are high and wave energy installations are not currently cost effective. However, there are eight wave and thirty-four tidal projects in the United States going through the Federal Energy Regulatory Commission (FERC) for licensing, so market experience and capacity is growing.

4.2.3 Hydro Conversion Technologies

Hydropower is the ability to make electrical energy by means of moving water. For conventional systems, the water is falling vertically. Tidal hydrokinetic systems make electricity from water that is moving horizontally. Wave hydrokinetic systems use a variety of innovative methods to turn the motion of waves into electricity. Table 33 summarizes the cost and performance characteristics for the hydropower technologies included in this study.

Table 33. Hydro Cost and Performance Characteristics.

See Appendix A in Volume 5 for detailed inputs for all Hydro technologies.

Resource	Technology	Installed Cost (2012$)	Capacity Factor	Measure Life	Years Deployed
Hydro	*New Run of the River sites*	$3,850,000/MW	40%	50 yr	2017-2030
	New Production at New Dams	$5,000,000/MW	52%	50 yr	2017-2030
	New Production Non-powered Dams	$4,200,000/MW	52%	50 yr	2017-2030
	Repowering and Upgrading	$2,000,000/MW	52%	50 yr	2017-2030
	New Hydrokinetic Tidal	$5,574,000/MW -5.2%/yr 2013-2017 -4.1%/yr 2018-2022 -1.3%/yr 2023-2030	38%	20 yr	2017-2030

4.2.4 Hydro Economics and Technology Learning

With the exception of hydro kinetic, the hydro technologies and applications included in the analysis are considered mature and do not have cost declines or performance improvements over the study period. This is consistent with base case analysis conducted on New York's Renewable Portfolio Standard Cost Study. It is also consistent with the NREL Electricity Futures Study assumptions for hydro under the incremental and evolutionary technology development cases.

4.3 Hydro Results

The 2030 estimated BTP nameplate capacity for new hydro resources in New York is presented in Table 34.

Table 34. Hydro 2030 Bounded Technical Potential.

Hydro Resource	Nameplate MW	Capacity Factor	GWh
New Run of the River[92]	1,631	40%	5,717
Undeveloped Sites[93]	562	52%	2,534
Non-powered Dams[94]	206	52%	928
Repowered Dams[95]	139	52%	628
Tidal Energy[96]	635	38%	2,114
Total New NY Hydro Potential	**3,173**	**43%**	**11,921**
Existing Conventional Hydro	4,790	60%	25,176

In addition, an estimated wave energy potential of 6,665 MW of nameplate capacity would produce 16,930 GWh of energy at an assumed capacity factor of 29%. However, due to the still early stages of development, wave energy is not included in the following results. As illustrated in Table 35, much of the conventional new hydro resources pass the economic screening, while none of the tidal hydro kinetic is economic by 2030.

Table 35. Hydro Potential Nameplate Capacity (MW) by Application and Year.

	2020		2030	
Technology	BTP (MW)	Economic (MW)	BTP (MW)	Economic (MW)
Conventional	508	135	2,538	1,905
Hydro Kinetic	127	0	635	0
Total	***635***	***135***	***3,173***	***1,905***

92 DOE. 2006. "Feasibility Assessment of the Water Energy Resources of the United States for New Low Power and Small Hydro Classes of Hydroelectric Plants."

93 DOE. 1998. "U.S. Hydropower Resource Assessment for New York."

94 DOE. 2012. "An Assessment of Energy Potential at Non-Powered Dams in the United States."

95 DOE. 1998. "U.S. Hydropower Resource Assessment for New York."

96 GA Tech. 2011. "Assessment of Energy Production Potential from Tidal Streams in the United States."

Table 36 and Figure 19 present the potential hydro generation in 2020 and 2030 by analysis zone. Long Island has some conventional hydro resources, but the majority of Long Island's BTP is hydro kinetic. Therefore, Long Island's economic potential compared to the BTP is relatively low. For New York City all of the estimated BTP is hydro kinetic and although it approached cost effectiveness by 2030 (with a benefit cost ratio of 0.94 for installations in 2030) it does not pass economic screening.

Table 36. Hydro Potential – New Cumulative Annual Generation (GWh) by Zone and Year.

	2020		2030	
Zone	BTP (GWh)	Economic (GWh)	BTP (GWh)	Economic (GWh)
Long Island	443	32	2,213	162
New York City	13	0	63	0
Hudson Valley	262	262	1,310	1,310
Upstate	1,667	265	8,337	5,984
Statewide	**2,385**	**559**	**11,923**	**7,456**

Figure 19. Hydro Cumulative Annual BTP and Economic Potential by Year and Zone.

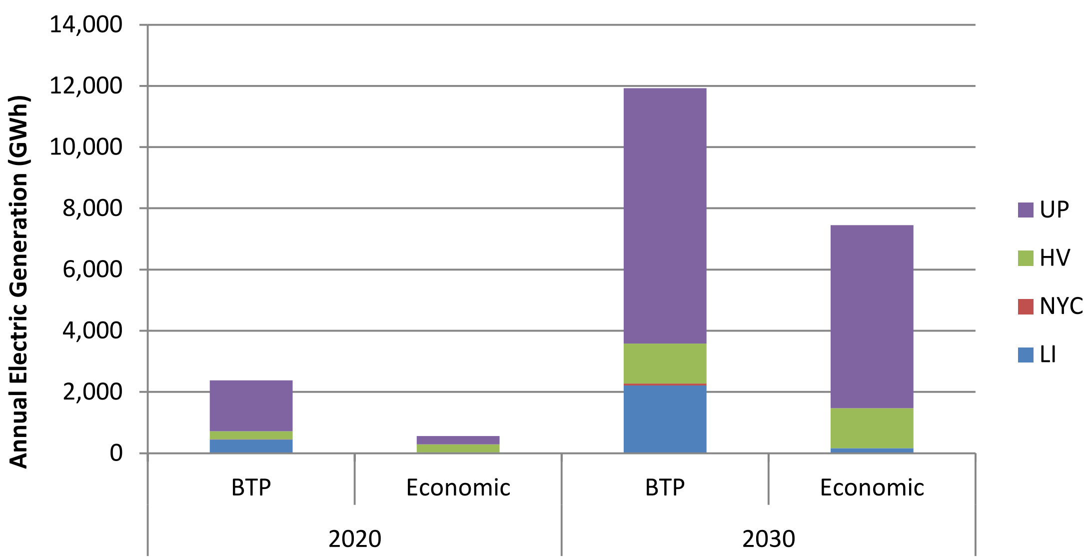


Table 37 illustrates the estimated summer peak coincidence potential for hydropower in 2020 and 2030.

Table 37. Hydro Summer Peak Capacity (MW).

	2020		2030	
Zone	BTP (MW)	Economic (MW)	BTP (MW)	Economic (MW)
Long Island	47.6	3.3	238.2	16.6
New York City	1.4	0	6.9	0
Hudson Valley	24.1	24.1	120.5	120.5
Upstate	155.3	21.1	776.7	548.9
Statewide	**228**	**49**	**1,142**	**686**

Appendix tables in Volume 5 present the net benefits, benefit-cost ratios and levelized costs of energy by year for hydropower resources.

The estimated levelized cost of energy per kWh for new hydro resources are presented in Table 38.

Table 38. Hydro Net Levelized Cost of Energy per KWh (2012$/kWh).

Technology	2013	2020	2030
Run of the River	0.07	0.07	0.07
Undeveloped Sites 100+ kW	0.07	0.07	0.07
Non-Powered Dams 1+ MW	0.06	0.06	0.06
Re-Powered Dams 100+ kW	0.03	0.03	0.03
Tidal Energy 30 kW+	0.16	0.12	0.11

Table 39 presents the net cumulative generation by technology for the BTP and economic hydropower resources, and Figure 20 and Figure 21 present the share by technology for the estimated economic hydropower generation in 2020 and 2030.

Table 39. Hydro Potential Cumulative Annual Generation by Technology (GWh).

Resource	Technology	Scale Analyzed	Statewide 2020 BTP (GWh)	Statewide 2020 Economic Potential (GWh)	Statewide 2030 BTP (GWh)	Statewide 2030 Economic Potential (GWh)
Hydro	*New Run of the River sites*	10 kW - 30 MW	1,143	172	5,717	3,967
	New Production at New Dams	> 100 kW	507	76	2,534	1,931
	New Production Non-powered Dams	> 1 MW	186	186	928	928
	Repowering and Upgrading	> 100 kW	126	126	628	628
	New Hydrokinetic Tidal	> 30 kW	423	0	2,114	0
	Existing Conventional Hydro		25,469	25,469	25,469	25,469
	Existing Hydrokinetic Tidal		3.5	3.5	3.5	3.5

Figure 20. New Hydro Economic Potential- 2020 by Technology (Total 560 GWh).

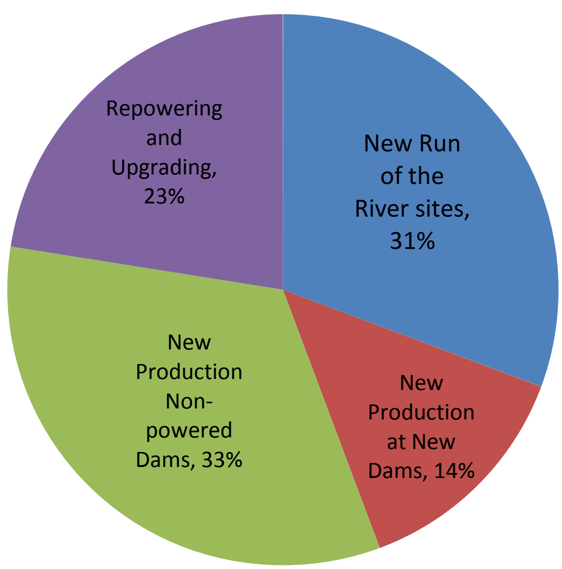
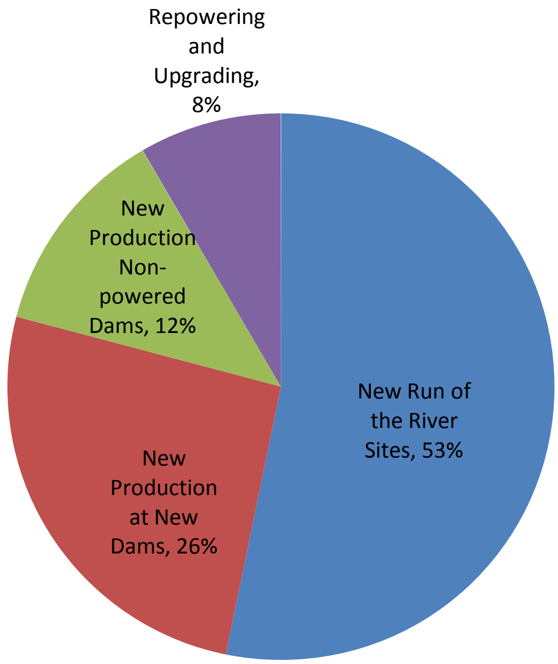


Figure 21. New Hydro Economic Potential - 2030 by Technology (Total 7,454 GWh).



The estimated new hydro summer peak capacity by technology, and time period is illustrated in Table 40.

Table 40. Net Cumulative Annual Peak MW Savings by Technology, 2020, 2030.

			Statewide 2020		Statewide 2030	
Resource	**Technology**	**Scale Analyzed**	**BTP Summer Peak MW**	**Economic Potential Summer Peak MW**	**BTP Summer Peak MW**	**Economic Potential Summer Peak MW**
Hydro	*New Run of the River sites*	10 kW - 30 MW	118	18	587	408
	New Production at New Dams	> 100 kW	40	6	202	154
	New Production Non-powered Dams	> 1 MW	15	15	74	74
	Repowering and Upgrading	> 100kW	10	10	50	50
	New Hydrokinetic Tidal	>30kW	46	0	228	0
	Existing Conventional Hydro		117	117	587	587
	Existing Hydrokinetic Tidal		40	40	202	202

4.4 Hydro Development Paths and Investment

The results presented above include new hydro capacity installed after 2017and do not include the significant potential generation that could come from the commercial development of wave energy technologies and markets.

The total level of investment required to develop the estimated economic hydropower potential reaches more than $800 million per year by 2030. The cumulative investment for developing the estimated economic potential hydro resources is $7.6 billion. Table 41 shows the annual and cumulative investments for the economic potential case during the study horizon for hydro technologies.

Table 41. Hydro Technologies Total Investment

		Total Private and Public Investment (Million 2012$)		
Resource	**Technology**	**Annual Investment 2020**	**Annual Investment 2030**	**Cumulative Investment 2030**
Hydro	*New Run of the River sites*	77	502	4,360
	New Production at New Dams	34	225	2,140
	New Production Non-powered Dams	69	69	864
	Repowering and Upgrading	22	22	279
	Total	**202**	**818**	**7,643**

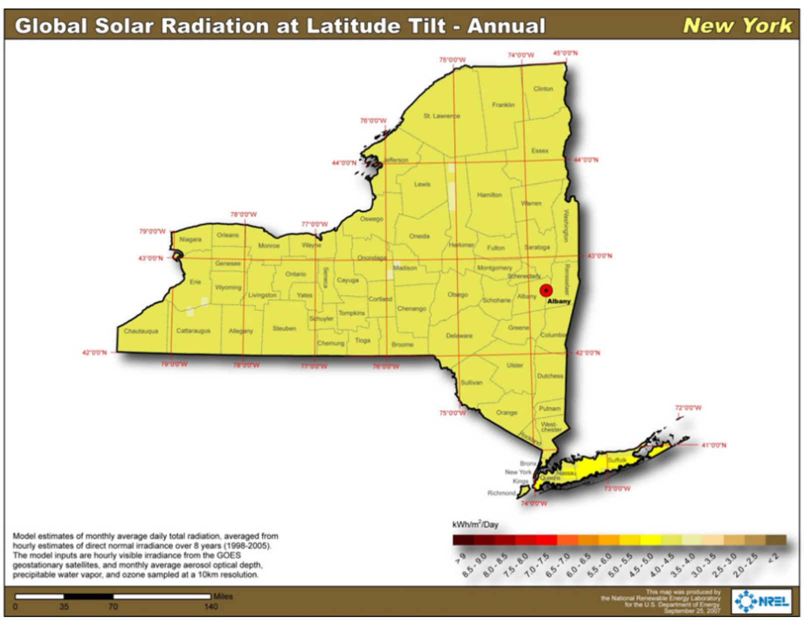
5 Solar

5.1 Overview

The solar resource potentially available for customer sited electric generation in New York is very large, with more than 187 million GWh of solar energy falling on New York each year.

The estimate of the available solar resource is determined by multiplying the annual average daily solar radiation in New York by the area and the number of days per year. Figure 22, from the National Renewable Energy Laboratory (NREL)[97], shows solar radiation is fairly consistent across the State, with a slightly lower resource in a few places Upstate and slightly higher resource on Long Island. The map displays radiation hitting a surface tilted at the same angle as the latitude.

Figure 22. Solar Resource in NYS.



[97] NREL. 2007. “Global Solar Radiation at Latitude Tilt – Annual.” http://www.nrel.gov/gis/images/eere_pv/eere_pv_newyork.jpg.

The estimated total solar resource for the state is based on an average Global Horizontal Irradiance (GHI) of 3.63 kWh/(m2×day) and an area of 141,300 km^2. The resulting solar resource of 187 million GWh is more than 1,200 times larger than New York's total annual electric use. The map and the solar resource estimate highlight the magnitude and widespread availability of solar in New York, but they do not provide an estimate of how efficiently nor how much of this energy can reasonably be captured. Factors limiting how much of the solar resource can be captured, such as saturation of solar on the grid and market growth rates are discussed under the BTP estimate presented in the following section.

5.2 Solar Electric Approach and Methods

To estimate the bounded technical potential for the solar resource, the following limits and constraints were considered:

- Saturation – how much electricity generation can be provided by intermittent sources?
- Market growth – how fast can solar be installed, and how fast can more installers be trained?

The potential capacity in megawatts (DC nameplate) according to each bound over the analysis period is presented in Table 42. The limiting factor for each timeframe is highlighted.

Table 42. Capacity Limit (MW) by Bound and Year.

	2020 (MW)	2030 (MW)
Saturation	39,000	43,000
Growth	14,000	43,000

5.2.1 Saturation

Dramatically increasing the amount of intermittent solar energy supplied to the electric system requires additional investment in controls and storage. The solar saturation limit depends on how geographically dispersed the solar generation is, and therefore how likely the installations are to be under clouds or sun at the same time, as well as the composition of the rest of the generation and storage facilities on the grid. A recent NREL study included a scenario (2050 SunShot) with solar providing about 27% of U.S. annual energy consumption and showed that electricity supply and demand could be balanced for every hour of the year, in every region.[98] For this study we applied this 27% saturation factor to the projected baseline electric generation forecast of 186,000GWh and then calculated 43,000 MW of installed capacity based average production of 1,174 kWh/kW of installed capacity.[99] This value has been adopted as the limiting upper bound for technical potential in this study, but it is important to note that the NREL analysis did not conclude that higher levels of solar saturation, would not be possible.

5.2.2 Market Growth

The solar market in New York and across the nation has been growing rapidly as the cost of modules fall and new financing models such as leasing become available. In 2010, 23 MW of PV was installed in New York. In 2011, New York annual installations grew two and half fold to 59 MW.[100] Even with this large rate of growth, an early limit to the bound technical potential is the pace at which solar can be installed. The market growth is partially limited by permitting and interconnection, but also by training workers, setting up supply chains, and other regular steps for business growth. The rate of installations was modeled based on sigmoidal and exponential growth models calibrated to New York's solar installations to date and the saturation limit. The resulting curve and variable growth rate is shown in Figure 23.

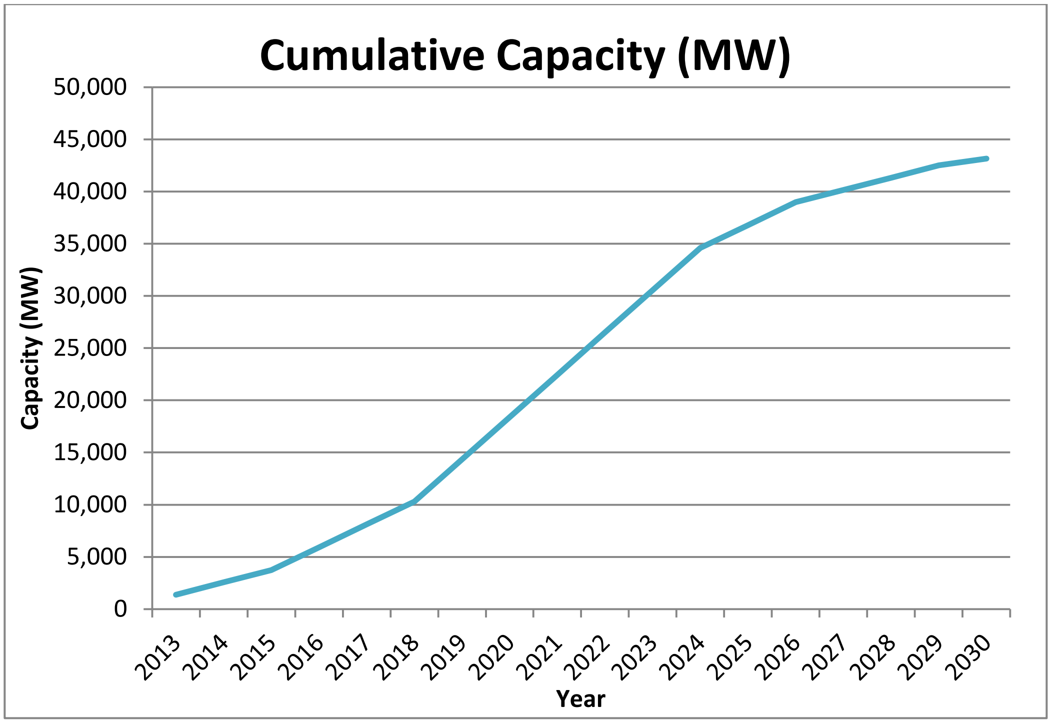
---

98 NREL. 2012. *Grid Modeling for the SunShot Vision Study*. www.nrel.gov/docs/fy12osti/53310.pdf. February 2012.

99 New York Solar Study, January 2012, Tables 5 and 6 Actual and Expected capacity and production for PV as of December 31, 2011.

100 Ibid. Figure 2: Annual PV Capacity Additions in New York 2002-2011. p. 2-11.

Figure 23. Cumulative Capacity of PV.



Incremental annual capacity additions for the growth curve in Figure 23 start at 171 MW in 2013-2014, and reach a maximum of more than 4 GW per year from 2018 through 2024. The incremental growth rates are higher in the earlier years as the market continues to ramp up and then slow in the later years as the saturation limit is approached. The total growth of the market is the equivalent of a constant compound annual growth rate (CAGR) of 32%.

5.2.3 Area

The area required for PV to generate 27% of New York's electricity was calculated using the average production of existing installations in the State, the solar radiation from NREL, an assumed future array efficiency of 20%, and a 47% space utilization factor calculated from rows of panels at 20 degree tilt. Individual installations will vary, but this gives the order of magnitude of the area required as 350 square kilometers, which is equivalent of 0.2% of the State's total land area.

5.2.4 Conversion Technologies

For this potential study, four prototypical systems were chosen to represent the market for solar electric. Following the New York Solar Study,[101] they are: utility, large commercial, small commercial, and residential. Full definitions can be found in that study, but briefly the utility model is multi-megawatt scale on the utility side of the meter. The rest are net-metered, on the customer side of the meter. The large commercial measure is based on systems above 50 kW, small commercial is between 30 kW and 50 kW, and residential is between 3 kW and 7 kW. Table 43 and Table 44 present the PV market and technology characteristics used in the study.

Table 43. PV Technology and Market Characterizations.

Resource	Technology	Scale Analyzed	Location	Zone	Time Periods
Solar	*Residential PV*	3-7 kW	Customer Sited	All	All
	Small Commercial PV	30-50 kW	Customer Sited	All	All
	Large Commercial PV	> 50 kW	Customer Sited	All	All
	Grid Scale PV	> 1 MW	Central Plant	All	All

Table 44. PV Solar Electric Characteristics.

Resource	Technology	Scale Analyzed	Output (MWh/MW)	O&M (2012$/kW-yr)
Solar	*Residential PV*	3-7 kW	1,211	2.2
	Small Commercial PV	30-50 kW	1,189	2.2
	Large Commercial PV	> 50 kW	1,204	2.2
	Grid Scale PV	> 1 MW	1,298	2.4

5.2.5 Energy Generation

Consistent with industry standards and the New York Solar Study, PVWatts[102] was used to estimate the output of PV systems. The same inputs as the New York Solar Study were used and the same 0.5% degradation per year was used. The locations used to represent each analysis zone were chosen as centers of the population and representative of the zone's solar resources, and are presented in Table 45.

[101] NYSERDA. 2012. *New York Solar Study: An Analysis of the Benefits and Costs of Increasing Generation from Photovoltaic Devices in New York*. http://www.nyserda.ny.gov/Publications/Energy-Analysis-Reports/Solar-Study.aspx. January 2012.

[102] NREL. "PVWatts." http://mapserve3.nrel.gov/PVWatts_Viewer/index.html

Table 45. Locations of Representative Solar Sites in New York.

Zone	PVWatts Site
Upstate	Syracuse hourly site
Hudson Valley	Grid cell at Newburgh
New York City	NYC hourly site
Long Island	Grid cell at Brentwood

The potential capacity was divided by sector (type of installation) and analysis zone. The sector division is consistent with current U.S. market trends: 15% residential, 20% small commercial, 45% large commercial, and 20% utility. A development path analysis – examining the impact of a higher share of utility MW scale installations is presented at the end of this section.

The bounded technical potential was allocated to the regional analysis zones taking into account each region's share of electric consumption and other factors including electric costs, solar resource, and solar accessibility. Starting with share of electric consumption, the Upstate potential was roughly cut in half because of lower electric costs, Long Island's potential was doubled because of good solar resource and higher electric costs. NYC was greatly reduced because high density development often limits solar accessibility. The Hudson Valley was assigned a potential higher than its relative share of electricity consumption, because of somewhat higher electric costs, reasonable installation costs, and the possibility of siting PV plants here for power sales to New York City. The resulting allocations for the BTP are: 28% in Long Island, 10% in New York City, 43% in the Hudson Valley and 20% Upstate.

5.2.6 Economics and Technology Learning

Figure 24 and Table 46 illustrate estimated cost declines for PV by system type and location. The initial values are adopted from preliminary research conducted for the 2013 update of the New York State Solar Study. Cost declines of 8% per year from 2014 to 2016 are followed by annual declines of 5% per year from 2017 and 2018, 4% per year from 2019 to 2020, 2% per year for 2021 and 2023, finally reaching and maintaining an annual decline of 1.5% per year from 2024 through 2030. The projected cost declines adopted for this study are more conservative than recent cost declines and are consistent with the near term projections for the Solar Study Update.

Figure 24. PV System Cost Projections.

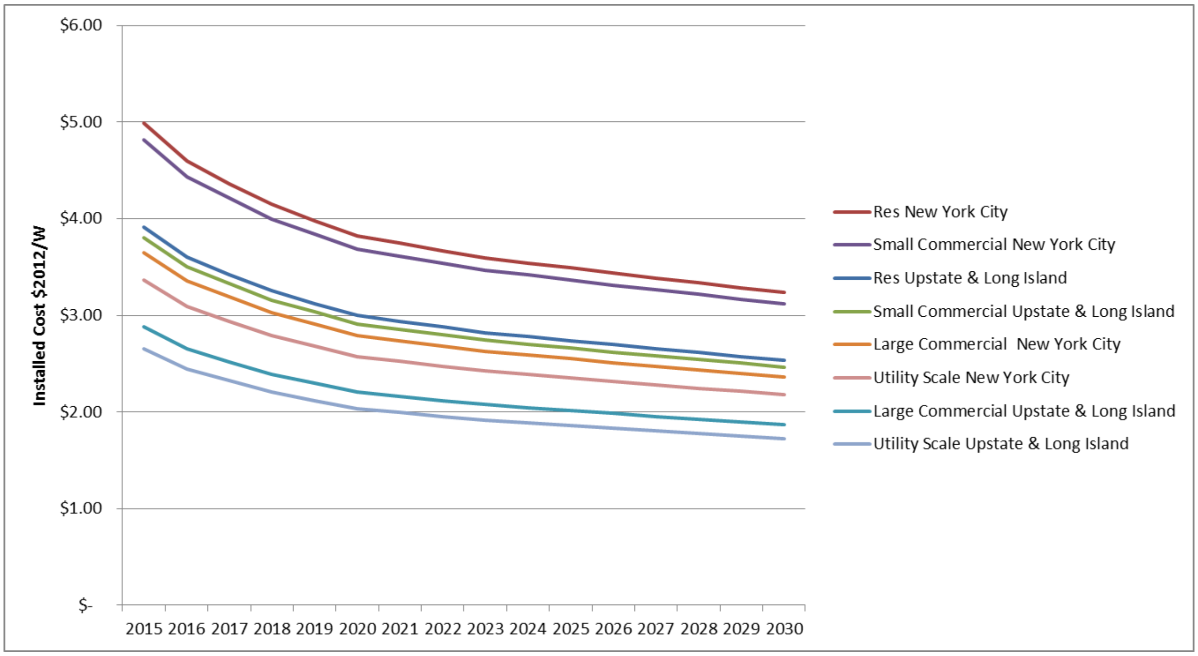


Table 46. PV System Cost Projections 2012$/kW DC.

	2015	2020	2025	2030
Residential Upstate/Long Island	$3,915	$2,996	$2,736	$2,537
Residential New York City	$4,993	$3,821	$3,489	$3,235
Small Commercial Upstate/Long Island	$3,805	$2,912	$2,659	$2,466
Small Commercial New York City	$4,816	$3,685	$3,365	$3,120
Large Commercial Upstate/Long Island	$2,882	$2,206	$2,014	$1,868
Large Commercial New York City	$3,648	$2,792	$2,549	$2,364
MW Upstate/Long Island	2,658	2,034	1,857	1,722
MW New York City	3,364	2,574	2,351	2,180

5.3 Solar Electric Results

The BTP and Economic potential results for PV are presented in Table 47 and Table 48.

Table 47. Solar Electric Potential by Year (DC Nameplate Capacity).

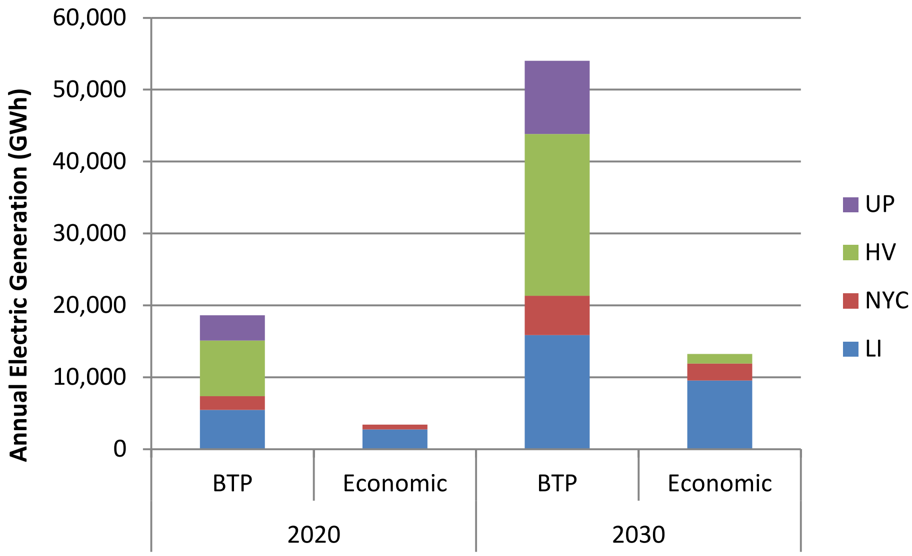
	2020		2030	
Technology	BTP (MW)	Economic (MW)	BTP (MW)	Economic (MW)
Customer Sited PV	11,439	1,869	33,972	7,705
Utility Scale PV	2,860	642	8,493	2,283
Total	**14,299**	**2,511**	**42,465**	**9,988**

Table 48. Solar Electric Cumulative Annual Energy Generation by Zone.

	2020		2030	
Zone	BTP (GWh)	Economic (GWh)	BTP (GWh)	Economic (GWh)
Long Island	5,479	2,768	15,884	9,557
New York City	1,877	653	5,443	2,363
Hudson Valley	7,770	0	22,527	1,339
Upstate	3,513	0	10,185	0
Statewide	**18,639**	**3,421**	**54,039**	**13,259**

The potential annual PV generation and the comparison between the BTP and Economic potential is illustrated in Figure 25.

Figure 25. Solar Electric Cumulative Annual Potential Generation by Year and Zone.



The summer peak capacity potential for PV is presented in Table 49, followed by the annual generation by system type and summer peak potential by system type in Table 50 and Table 51.

Table 49. Solar Electric Cumulative Summer Peak Capacity by Zone (MW).

	2020		2030	
Zone	BTP (MW)	Economic (MW)	BTP (MW)	Economic (MW)
Long Island	1,611	803	4,785	2,843
New York City	575	202	1,709	746
Hudson Valley	2,417	0	7,177	419
Upstate	1,151	0	3,418	0
Statewide	**5,754**	**1,005**	**17,089**	**4,008**

Table 50. Solar Electric Cumulative Annual Generation by Technology (GWh).

Resource	Technology	Scale Analyzed	Statewide 2020 BTP (GWh)	Statewide 2020 Economic Potential (GWh)	Statewide 2030 BTP (GWh)	Statewide 2030 Economic Potential (GWh)
Solar PV	*New Residential*	3-7 kW	2,836	0	8,223	0
	New Small Commercial	30-50 kW	3,706	0	10,745	0
	New Large Commercial	> 50 kW	8,447	2,558	24,492	10,264
	New Utility	>1 MW	3,648	824	10,578	2,958
	Existing Solar		204	204	204	204
	Total		**18,841**	**3,586**	**54,242**	**13,426**

Table 51. Solar Electric Cumulative Summer Peak Capacity by Technology (MW).

Resource	Technology	Scale Analyzed	Statewide 2020 BTP Summer (MW)	Statewide 2020 Economic Potential Summer (MW)	Statewide 2030 BTP Summer (MW)	Statewide 2030 Economic Potential Summer (MW)
Solar PV	*New Residential*	3-7 kW	881	0	2,615	0
	New Small Commercial	30-50 kW	1,174	0	3,487	0
	New Large Commercial	> 50 kW	2,642	767	7,845	3,163
	New Utility	>1 MW	1,058	237	3,142	845
	Existing Solar		70	70	70	70
	Total		**5,825**	**1,074**	**17,159**	**4,078**

Appendix tables in Volume 5 present the net benefits, benefit-cost ratios and levelized costs of energy by year for photovoltaic technologies. The net levelized costs for PV are presented in Table 52 and installed capacity by technology is presented in Table 53.

Table 52. Solar Electric Net Levelized Cost of Energy per KWh (2012$/kWh).

Measure Name	Zone	2015	2020	2025	2030
Residential PV	LI	0.14	0.12	0.13	0.13
Residential PV	NYC	0.17	0.15	0.16	0.15
Residential PV	HV	0.15	0.13	0.14	0.14
Residential PV	UP	0.16	0.14	0.15	0.14
Small Commercial PV	LI	0.14	0.12	0.13	0.13
Small Commercial PV	NYC	0.16	0.14	0.16	0.15
Small Commercial PV	HV	0.15	0.13	0.14	0.13
Small Commercial PV	UP	0.15	0.14	0.15	0.14
Large Commercial PV	LI	0.10	0.09	0.10	0.09
Large Commercial PV	NYC	0.11	0.10	0.11	0.10
Large Commercial PV	HV	0.11	0.09	0.10	0.10
Large Commercial PV	UP	0.11	0.10	0.11	0.10
Utility Scale PV	LI	0.11	0.09	0.10	0.10
Utility Scale PV	NYC	0.14	0.12	0.13	0.13
Utility Scale PV	HV	0.11	0.10	0.11	0.10
Utility Scale PV	UP	0.12	0.11	0.11	0.11

Table 53. Solar Electric Installed Nameplate Capacity by Technology (MW).

			Statewide 2020		Statewide 2030	
Resource	Technology	Scale Analyzed	BTP Nameplate (MW)	Economic Potential Nameplate (MW)	BTP Nameplate (MW)	Economic Potential Nameplate (MW)
Solar PV	*New Residential*	3-7 kW	2,145	0	6,370	0
	New Small Commercial	30-50 kW	2,860	0	8,493	0
	New Large Commercial	> 50 kW	6,435	1,869	19,109	7,705
	New Utility	>1 MW	2,860	612	8,493	2,254
	Existing Solar		178	178	178	178
	Total		**14,478**	**2,659**	**42,643**	**10,137**

5.4 Solar Electric Development Paths and Investment

The core analysis results presented above are based on allocating 20% of the anticipated BTP to utility MW scale projects. As the U.S. PV market has continued to grow rapidly during the last several years, the share of installed capacity represented by the utility sector (typically projects greater than 1MW of size, ground mounted) that are not net metered has grown most rapidly.[103] The development path analysis for PV examines the impact on the economic potential results if 40% of the BTP is allocated to the utility market segment, 40% allocated to large commercial, 10% to residential and 10% to small commercial. By increasing the relative shares of investment for larger scale systems with the lowest costs, the development path analysis results (Table 54) increases the amount of economic PV generation in 2030 by approximately 15%. Note that the development path includes community and shared solar ownership models as a means for enabling residential and small commercial customers to directly participate and invest in expanded economic potential capacity.

Table 54. Photovoltaic Development Path Results Economic Potential Generation (GWh).

Resource	Technology	Economic Statewide 2020 (GWh)	Economic Statewide 2030 (GWh)
Solar - PV	*Customer Sited Residential and Small Commercial*	0	0
	Customer Sited Large Commercial	2,558	10,264
	Utility Scale	824	2,958
	Development Path – Including Community and Shared Solar		
	Customer Sited – Community/Shared Solar	455	1,825
	Customer Sited Large Commercial	1,819	7,298
	Utility Scale – Community/Shared Solar	330	1,183
	Utility Scale	1,318	4,733

103 Solar Electric Industries Association, Solar Market Update 1Q 2013, Figure 2.1 PV Installations by Market Segment.

As an example, in the development path, if community and shared solar business models account for 20% of the total economic capacity in 2030, this would represent roughly 2.4 GW of installed capacity (Table 53), which is sufficient to provide 486,000 customers each with the shared solar output equivalent of 5 kW individual systems.

Table 55. Photovoltaic Development Path Economic Potential Installed Nameplate Capacity (MW).

Resource	Technology	Economic Statewide 2020 Nameplate (MW)	Economic Statewide 2030 Nameplate (MW)
Solar - PV	*Customer Sited Residential and Small Commercial*	0	0
	Customer Sited Large Commercial	1,869	7,705
	Utility Scale	612	2,254
	Development Path – Including Community and Shared Solar		
	Customer Sited – Community/Shared Solar	380	1,520
	Customer Sited Large Commercial	1,510	6,060
	Utility Scale – Community/Shared Solar	250	910
	Utility Scale	1,020	3,650

The total level of investment required to develop the estimated economic photovoltaic potential is more than $1 billion annually, totaling more than $21.6 billion by 2030. Table 56 shows the annual and cumulative investments for the economic potential case during the study horizon for solar PV technologies.

Table 56. Solar PV Technologies Total Investment

		Total Private and Public Investment (Million 2012$)		
Resource	Technology	Annual Investment 2020	Annual Investment 2030	Cumulative Investment 2030
Solar - PV	*New Residential*	0	0	0
	New Small Commercial	0	0	0
	New Large Commercial	882	980	17,179
	New Utility	249	198	4,515
	Total	**1,131**	**1,178**	**21,694**

5.5 Solar Thermal Approach and Methods

5.5.1 Solar Thermal Resource

The resource available to provide solar thermal energy for buildings to meet hot water, space conditioning or process loads is the same as the solar radiation described in the previous section for photovoltaic electricity. The solar thermal analysis in this study has focused on solar hot water for commercial and residential applications. Additional applications for solar thermal space heating, cooling via absorption chillers, and process heat are not addressed in this analysis.

5.5.2 Saturation

Thermal solar energy is generally used on site, and solar water heating must be matched to the hot water needs of the host building. To estimate the BTP for solar thermal water heating, this study started with a saturation limit based on total domestic water heating energy consumption. To account for solar access and site applicability, 50% of the total residential and commercial water heating energy consumption was considered suitable for solar water heating. For applicable sites, the fraction of a site's water heating provided by solar depends on the temperature of water required, water storage space available, collector mounting space, shading, and other factors. Typical design and market practices are to provide systems with solar fractions between 60% and 80%.[104]

5.5.3 Market Growth

The current solar thermal market in New York is relatively small. New York's Solar Thermal Roadmap[105] estimates the current market size as approximately 6 MWth[106] and sets a goal of growing the market to 2,000 MWth by 2020. For this study, the rate of potential market growth was based on sigmoidal and exponential growth models calibrated to New York's solar installations to date with growth towards the estimated saturation limit of 10,000MWth in 2030. The resulting growth curve is consistent with the Solar Thermal Roadmap target of 2,000 MWth by 2020, and is shown in Figure 26.

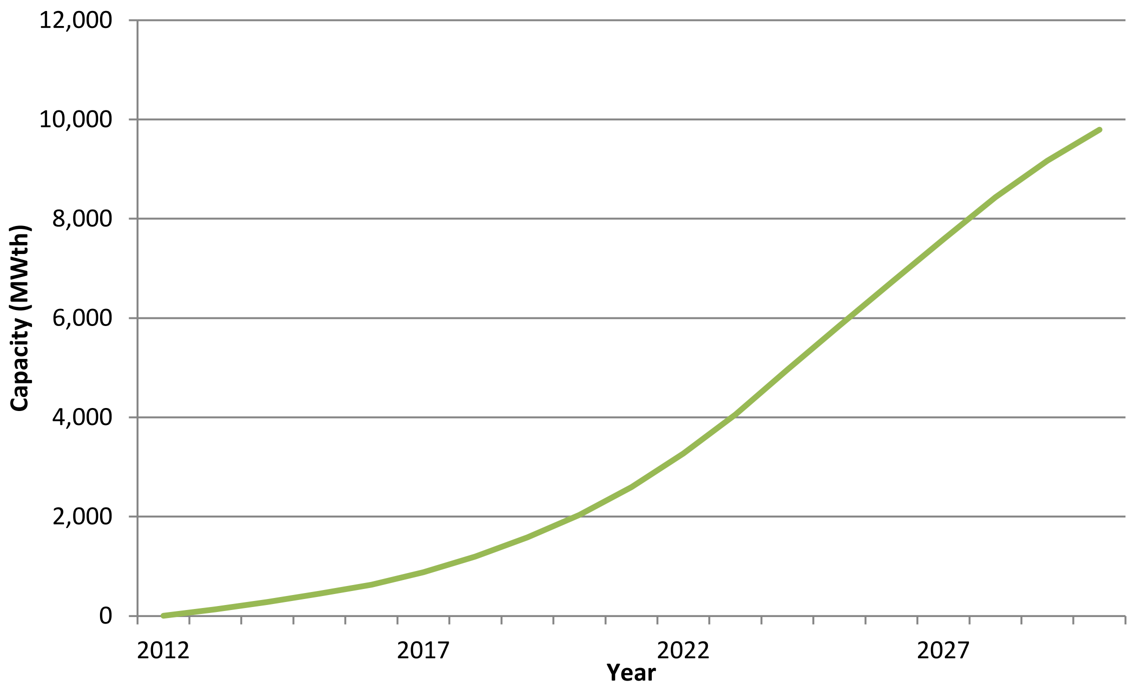
---

104 McNamara, A., J. Perlman and R. Perez. 2008. *Simulated Performance of Solar Domestic Hot Water Technologies in New York State*. http://www.asrc.cestm.albany.edu/perez/publications/Other%20Papers%20and%20Applications/simulated-performance-ofpDHW-technologies-in-new-york.pdf.

105 New York Solar Thermal Consortium. 2010. *New York's Solar Thermal Roadmap*. http://www.clarkson.edu/camp/NYS_SolarThermal_Roadmap.pdf.

106 MWth is Megawatt of thermal capacity.

Figure 26. Cumulative Capacity of Solar Thermal (MWth).



5.5.4 Area

The rooftop or land area required to site 10,000 MWt_h of solar water heating energy in New York was calculated using the average production of existing commercial installations in the region. Individual installations will vary, but this gives the order of magnitude of the area required as 66 square kilometers, or 0.05% of the State.

5.5.5 Conversion Technologies

For this potential study, a residential system and a commercial system were modeled following the Solar Thermal Roadmap[107] providing 80 and 240 gallons per day of hot water respectively. Data from the Solar Thermal Roadmap, project data from solar water heating installations on large multifamily buildings in Washington, D.C., Vermont's Small Scale Renewable Energy Incentive Program, and other sources[108, 109] were used to characterize the cost and savings of the systems.

---

107 Ibid.

108 Vermont SSREIP Data, Average Installed Cost for 2012 SWH installations

109 Thermo Dynamics. 2012. "Solar Boiler." http://www.thermo-dynamics.com/solar_boiler.html.

5.5.6 Solar Thermal Economics and Technology Learning

Solar water heating is an established technology with small penetration and stagnant costs. In this study, the cost of a solar water heating system for a typical residence falls 3% per year from 2016 to 2030, from $8,100 to $4,800. Table 57 illustrates the installed cost of a MW-thermal over the study period. Note that 263 residential systems provide 1MWth of capacity and 88 commercial systems are equivalent to 1 MWth of capacity.

Table 57. Solar Water Heating Installed Cost over Time (2012$/MWth).

Resource	Technology	2015 ($/MWth)	2020 ($/MWth)	2025 ($/MWth)	2030 ($/MWth)
Solar Thermal	*Residential SWH*	2,134,312	1,889,491	1,622,570	1,393,356
	Commercial SWH	1,537,920	1,361,510	1,169,175	1,004,010

NREL is involved in R&D to reduce the initial cost to $1,000-$3,000 per system for a residential two collector system.[110] Such efforts must be successful if the technology is to survive the introduction of high efficiency heat pump water heaters and to compete with inexpensive natural gas. As more water heating systems are switched to these more cost effective technologies, the potential of solar water heating will be limited.

5.6 Solar Thermal Results

Solar thermal BTP and Economic potential are presented by analysis zone in Figure 27 compares the BTP and Economic potential for solar thermal in 2020 and 2030, with the contribution by zone. Table 59 presents the solar thermal potential results by displaced fuel type.

[110] NREL. 2012. "Low-Cost Solar Water Heating Research and Development Roadmap."

Table 58. Solar Thermal Cumulative Annual Energy Savings by Zone (TBtu).

Solar Thermal	2020		2030	
Zone	BTP (TBtu)	Economic Potential (TBtu)	BTP (TBtu)	Economic Potential (TBtu)
Long Island	5	2	25	18
New York City	2	1	9	7
Hudson Valley	7	6	37	31
Upstate	4	1	18	13
Statewide	**18**	**11**	**88**	**70**

Figure 27. Solar Thermal Cumulative Annual Potential by Year and Zone.

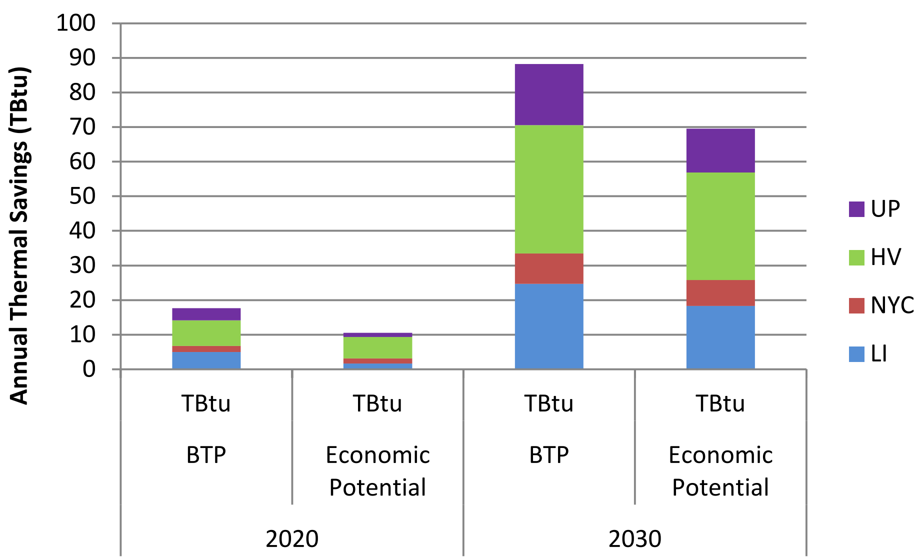


Table 59. Solar Thermal Cumulative Annual Energy Savings by Fuel Type.

Solar Thermal	2020		2030	
By Displaced/Back Up Energy Type	BTP	Economic Potential	BTP	Economic Potential
Electric (GWh)	194	194	928	928
Fuel Oil (TBtu)	6	6	30	30
Natural Gas (TBtu)	9	4	44	39

Table 60 presents the potential natural gas and fuel oil savings, followed by potential electric savings in Table 61.

Table 60. Solar Thermal Cumulative Potential Annual Natural Gas and Fuel Oil Savings (TBtu).

			Statewide 2020		Statewide 2030	
Resource	Technology	Scale Analyzed	BTP (TBtu)	Economic Potential (TBtu)	BTP (TBtu)	Economic Potential (TBtu)
Solar Thermal	*Residential SHW*	80 GPD	5	2	23	8
	Commercial SHW	240 GPD	13	9	66	61
	Total		**18**	**11**	**88**	**70**

Table 61. Solar Thermal Cumulative Potential Annual Electric Savings (GWh).

			Statewide 2020		Statewide 2030	
Resource	Technology	Scale Analyzed	BTP (GWh)	Economic Potential (GWh)	BTP (GWh)	Economic Potential (GWh)
Solar Thermal	*Residential SHW*	80 GPD	130	130	597	597
	Commercial SHW	240 GPD	64	64	331	331
	Total		**194**	**194**	**928**	**928**

Appendix tables in Volume 5 present the net benefits, benefit-cost ratios and levelized costs of energy by year for solar thermal technologies. The net levelized cost for solar hot water is presented in Table 62 and Table 63 by zone and displaced fuel type.

Table 62. Net Levelized Cost of Energy per kWh for SWH Systems Displacing Electricity (2012$/kWh).

Measure Name	Zone	2015	2020	2025	2030
Residential SWH – Elec	LI	0.08	0.08	0.08	0.07
Residential SWH – Elec	NYC	0.08	0.08	0.09	0.08
Residential SWH – Elec	HV	0.07	0.07	0.08	0.07
Residential SWH – Elec	UP	0.06	0.06	0.07	0.06
Commercial SWH – Elec	LI	0.04	0.04	0.04	0.04
Commercial SWH – Elec	NYC	0.05	0.05	0.04	0.04
Commercial SWH – Elec	HV	0.04	0.04	0.04	0.03
Commercial SWH – Elec	UP	0.03	0.04	0.03	0.03

Table 63. Net Levelized Cost of Energy per MMBtu for SWH Systems Displacing Natural Gas and Petroleum (2012$/MMBtu).

Measure Name	Zone	2015	2020	2025	2030
Residential SWH – NG	LI	15.48	15.97	16.69	14.67
Residential SWH – NG	NYC	16.38	16.91	17.67	15.54
Residential SWH – NG	HV	14.39	14.85	15.52	13.64
Residential SWH – NG	UP	12.23	12.62	13.19	11.60
Residential SWH – Petro	LI	13.80	14.24	15.55	13.67
Residential SWH – Petro	NYC	14.61	15.08	16.46	14.48
Residential SWH – Petro	HV	12.83	13.24	14.46	12.71
Residential SWH – Petro	UP	10.91	11.26	12.29	10.81
Commercial SWH – NG	LI	8.73	9.03	8.12	7.09
Commercial SWH – NG	NYC	9.25	9.56	8.60	7.51
Commercial SWH – NG	HV	8.12	8.39	7.55	6.59
Commercial SWH – NG	UP	6.90	7.13	6.42	5.60
Commercial SWH – Petro	LI	7.79	8.05	7.24	6.32
Commercial SWH – Petro	NYC	8.24	8.52	7.67	6.69
Commercial SWH – Petro	HV	7.24	7.48	6.74	5.88
Commercial SWH – Petro	UP	6.15	6.36	5.72	5.00

5.7 Solar Thermal Investment

The results presented above are based on a 35% decline in installed costs for residential and commercial scale solar water heating systems over the study horizon. Installed costs (not accounting for federal tax credits) are projected to be flat for the first three years followed by a 3% annual average decline as the market growth ramps up. The analysis also assumes a gradual decline of the Federal Investment Tax Credit,[111] which functions to increase the relative installed cost. The cost profile is consistent with the New York Solar Thermal Roadmap (ST Roadmap), but this study adopts a more conservative 3% annual decline as opposed to the 5% decline in the ST Roadmap.

The total level of investment required to develop the estimated economic solar thermal potential is nearly $550 million annually by 2030. Table 64 shows the annual and cumulative investments for the economic potential case during the study horizon for solar thermal technologies.

Table 64. Solar Thermal Total Investment

		Total Private and Public Investment (Million 2012$)		
Resource	Technology	Annual Investment 2020	Annual Investment 2030	Cumulative Investment 2030
Solar Thermal	*Residential SWH - Elec*	30	31	573
	Residential SWH - Petro	79	81	1,504
	Commercial SWH - Elec	11	11	203
	Commercial SWH - NG	153	295	4,816
	Commercial SWH - Petro	126	129	2,395
	Total	**399**	**547**	**9,491**

5.8 Advanced Solar Homes

Solar resources can also be utilized through building design, taking advantage of day-lighting and passive solar strategies. This study did not include a full analysis of advanced solar homes and passive design potential for New York, but this section provides an overview of the options and possible savings.

Passive solar homes and other high performance design and construction techniques can significantly reduce a home's energy requirements. Ancient civilizations in what is now Greece and the Southwest United States built homes oriented to the south to allow low angle winter sun to enter and to block the high summer sun, thereby keeping the homes more comfortable year round.

Passive solar design focuses on this seasonal change in solar angles. Glazing is concentrated on the south side of the building, where it can have a net energy benefit. Overhangs can be designed to specifically exclude summer sun and allow winter sun. The solar energy that passes through the window directly heats the air and strikes thermal mass that stores the energy until the sun is gone and the space cools. Once the air is cooler than the thermal mass, heat flows from the thermal mass into the space.

111 See Table 10, for the ITC phase out profile.

Passive solar design is a careful balance of the glazing area, thermal mass, room dimensions, overhangs, and insulation. Using modern insulation and building techniques, and technologies such as heat recovery ventilation, homes can be built with very low heating requirements that can be met by small solar gains. In total, these strategies can reduce the annual heating energy of a home by 20-50%.[112]

Passive house energy saving measures vary in cost and complexity. If added early in the design, significant savings can be achieved at no additional cost. Costs and savings depend on the whole house system, but an example that demonstrates the order of magnitude is presented in Table 65.

Table 65. Passive Solar Measures' Approximate Savings and Cost.[113]

Passive Solar Measure/Strategy	Example Savings (% of heating and cooling energy)	Cost
Orientation, concentrating windows on south side	20%	0
Increase in total glazing	10%	$$
Thermal mass, heat storage and distribution	Required for high glazing	$
Clear windows instead of low-e	5%	-$
High SHGC windows	5%	$$$
Airtight construction	10%	$
Heat recovery ventilation (HRV/ERV)	10%	$$
Extra insulation	10%	$$
Smaller HVAC equipment from reduced load	n/a	-$$

Orienting the house within 30 degrees of south and moving most windows to the south can save around 20% at no cost. The south facing windows should be clear, without a low-e coating that reduces the solar heat gain coefficient. This may reduce the cost of the windows, though sourcing clear windows can be difficult. Windows optimized for passive solar, with a high solar heat gain coefficient (SHGC) and low u-value, can be more than double the cost of standard windows.

---

112 Savings ranges will vary widely by site and project type, estimated range taken from Natural Resources Canada's RETScreen International, Passive Solar House Cost and Savings. http://www.retscreen.net/ang/speakers_notes_passive_solar_heating_project_analysis.php

113 Due to interaction between measures, total savings may not equal sum of individual measure savings.

Increasing the south facing glazing area increases the winter energy capture, but requires strategies to store and distribute the heat and to prevent overheating. Overhangs may be necessary to shade south facing windows at low cost. Thermal mass may be added as slab flooring for minimal cost. Airtight construction and high levels of insulation do add to the cost of an advanced solar home, but are becoming more common best practice, reducing the incremental cost of a high performance house.

The total incremental costs for a passive solar home will vary by site, contractor, and customer, and market data are still relatively scarce. Estimates from an industry trade group, and experience from building research and development staff working in New York, indicate an incremental cost range for passive solar construction compared to standard code compliant construction in the range of 10-20%.[114] Other design decisions such as finishes and materials can have a greater effect on the construction cost. People choosing high efficiency construction often chose a smaller design. This saves additional energy and reduces the total cost, allowing investment in efficiency measures. Finally, a more efficient home requires smaller heating and cooling systems and may not need distribution through ducts or pipes, further reducing costs. Many of the savings in passive solar homes have little to no cost, and there are diminishing economic returns achieving the highest savings levels.

Many of these measures would be very difficult and costly to change in existing building. The savings potential primarily relates to new construction, but some gains may be possible during renovations. A 2012 report on energy code compliance, NYSERDA Project Number 1720, reports an average of 15,600 residential new construction permits per year between 2007 and 2009. Code compliance was found to be around two thirds, and residential codes have since tightened. Several voluntary programs encourage more efficient construction including aggressive certifications like PassiveHouse and the Living Building Challenge; and more moderate targets including LEED, ENERGY STAR, and the National Home Builder’s National Green Building Program. As of 2012, 23% of new homes in New York were ENERGY STAR certified.[115] There are at least eight PassiveHouse certified homes in New York, concentrated in Brooklyn.

Efficient residential construction has significant savings potential on a per unit basis, but is limited compared to other efficiency programs by the rate of new construction and significant renovation. The effect of training, combined with consumer awareness and, most importantly, understanding of the importance of enforcement of building energy codes cannot be overstated.

---

114 Passive House Institute US. *FAQ*. http://www.passivehouse.us/passiveHouse/FAQ.html. Accessed September 30, 2013. Also communication with NYSERDA Building Research and Development staff.

115 NYSERDA. 2012. *New York Residential Green Building Program Annual Report*.

Table 66 shows an example of the magnitude of savings that could come from increased adoption of efficient home construction. In the table, future homes all meet code and by 2030, most achieve at least moderate green building certification, while a quarter achieve a higher performance standard. The Advanced Solar Homes row includes PassiveHouse, traditional passive solar homes, and net-zero homes.

Table 66. Technical Potential of Increased Efficiency of Residential New Construction.

		2013		2020		2030	
	Savings Potential per Household (MMBtu)	Market Share	Annual Savings (MMBtu)	Market Share	Annual Savings (MMBtu)	Market Share	Annual Savings (MMBtu)
Below code	-18.6	33%	-96,000	0%	0	0%	0
Code Compliant[116]	-	44%	-	15%	-	-	-
Moderate Green Building – New Code Compliant by 2030	25	23%	60,000	75%	200,000	75%	200,000
Advanced Solar Homes	45	0%	0	10%	70,000	25%	175,000
TOTAL			**-36,000**		**270,000**		**375,000**

The market share of passive solar homes is limited to some extent by sites with good solar access; however, modern buildings can be built so efficiently that the appliances and occupants provide a significant portion of the heating demand. With little need for solar input, other small, efficient heating sources may be used while still achieving drastically reduced energy consumption on any building site. However, in many instances where building energy codes are not understood, or are undervalued, the opportunity to effectively construct an efficient building envelope is lost at the time of construction. The initial construction period is the only cost effective opportunity to realize these potential energy savings

116 Note that more efficient homes are included in code compliant category, so for example in 2013 the total share of Code Compliant Homes is 44% + 23% = 67%. Also note that by 2030 code is expected to increase to be equivalent to the Moderate Green Building Standard.

6 Wind

6.1 Overview

New York has significant wind energy resources and potential. Estimates of the developable resource, as presented in this section, total more than 25,000 MW of onshore potential and more than 38,000 MW of offshore potential. If fully developed, this resource could provide more than 1.6 million GWh/year of annual electric generation, which is more than 8 times greater than New York's projected electric consumption for 2030. Of course, there are multiple constraints and challenges that limit the full development of this wind resource, among them is the ability to integrate intermittent wind energy into the electric grid. The places where wind resources are most abundant are not necessarily where most electricity usage takes place, so additional transmission capacity will also be required to develop higher levels of wind energy resources. In addition, wind energy siting and permitting can delay or prevent projects for a variety of reasons.

Despite the challenges, wind generation capacity in New York continues to grow. As of March 2013, there was 1,634 MW of installed wind generation capacity.[117] Wind turbines provided approximately 3,060 GWh of energy in 2012, which is equal to about 2% of New York's total use.[118] Wind capacity continues to grow and 220 MW of capacity was added in 2012. There is an additional 2,023 MW of proposed capacity in the NYISO interconnection queue for installation 2014-2016.[119]

[117] NYISO Gold Book 2013 Load and Capacity Data. Figure III-a, p. 52.

[118] Ibid. Figure III-2.p. 51.

[119] NYISO Interconnection Queue. December, 2012.

6.2 Wind Approach and Methods

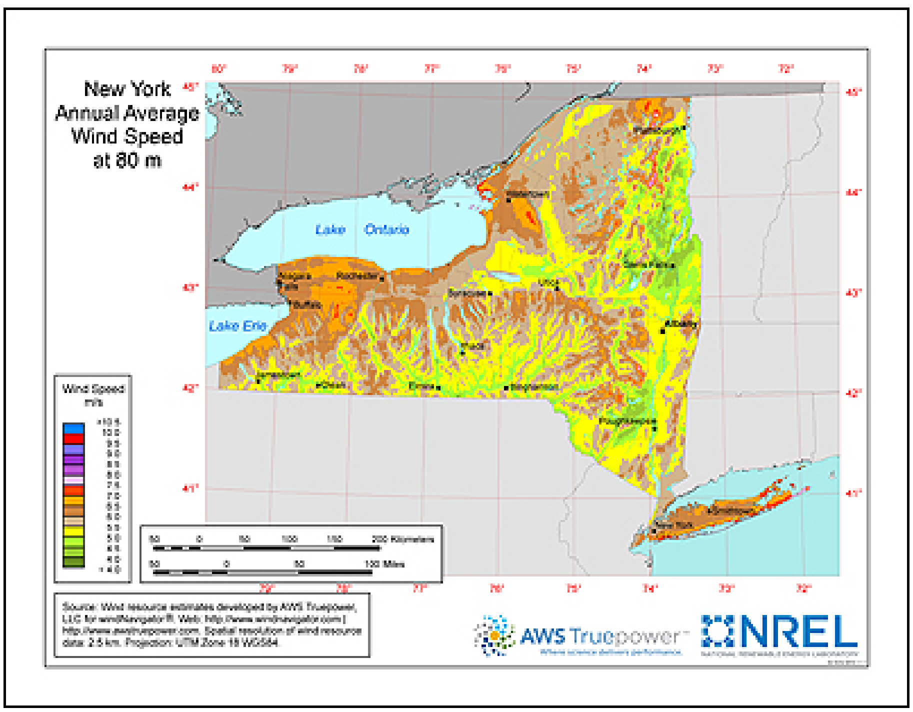
6.2.1 Wind Resource

Predicted mean annual wind speeds and the associated wind resource classes at an 80 meter height, which are common for utility scale applications, are presented in Figure 28.[120]

Areas with an average annual wind speed of greater than 6.5 meters per second are generally suitable for commercial development. The darker shaded areas in Figure 35 illustrate that onshore wind resources of this class are available in many areas.

New York also has developable wind resources off shore in Lake Erie, Lake Ontario, and off the coast of Long Island. The wind resource map for 90 m (Figure 29) illustrates offshore wind classes, distances from shore and water depth. Generally resources with an average annual wind speed greater than 7.0 meters per second are considered suitable for potential offshore development.[121]

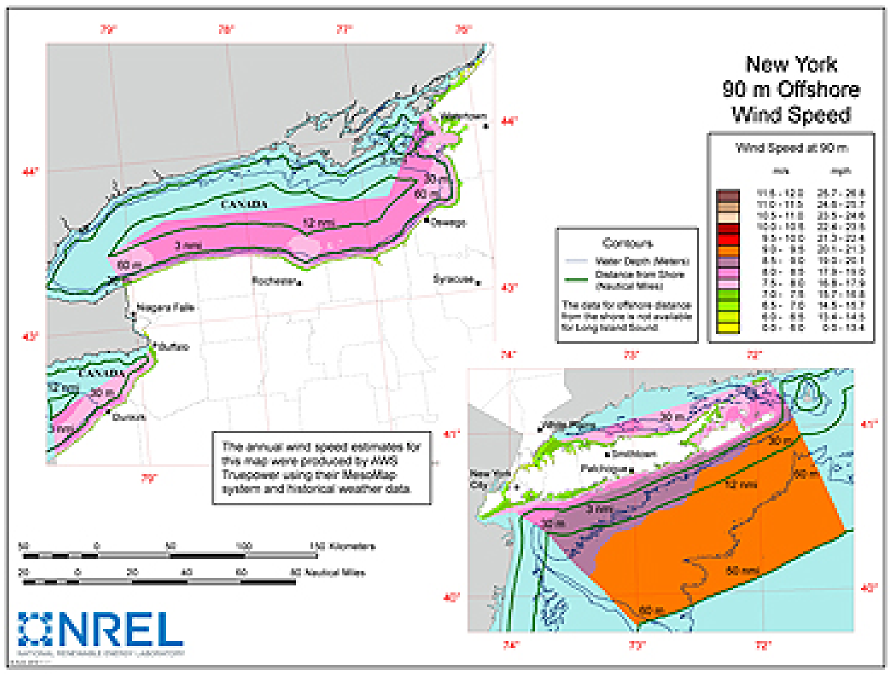
Figure 28. New York Onshore Wind Resource at 80m.



[120] http://www.windpoweringamerica.gov/wind_resource_maps.asp?stateab=ny

[121] http://www.windpoweringamerica.gov/windmaps/offshore_states.asp?stateab=ny

Figure 29. New York Offshore Wind Resource at 90m.



A number of recent studies have quantified the potential for both onshore and offshore wind:

NREL estimates that the onshore wind potential for New York, bounded by available wind and land, is 25, 800 MW. This estimate assumes a minimum average wind speed of 6.5 m/s at a height of 80 meters. It also assumes that 4.1% of the land area of the State of New York meets the criteria for inclusion, which is equal to 5,150 square kilometers. This shows that even after excluding the 71% of NYS land that has significant wind resources but is unsuitable for wind development a significant amount of potential remains.[122] Studies conducted in 2005 for NYSERDA[123] and in 2010 for NYISO[124] have looked at the amount of wind power New York's electric grid could accommodate. The 2005 study concluded that the grid could accept a 10% penetration rate, or 3,300 MW of onshore wind nameplate generation capacity, without compromising reliability. More recently, the 2010 'Growing Wind' study concluded that the installation of 6,600 MW of onshore wind nameplate generation capacity would not negatively impact reliability. Taking these factors into account, onshore nameplate capacity was limited to 6,600 MW. Considering 1,634 MW of existing plants in 2013, there is potential for 4,966 MW of additional onshore capacity.

---

122 NREL. 2011. Spreadsheet: Estimates of Windy Land Area and Wind Energy Potential, 80 m summary >30%

123 NYSERDA. 2005. *The Effects of Integrating Wind Power On Transmission System Planning, Reliability, And Operations, Report on Phase 2: System Performance Evaluation*.

124 http://www.uwig.org/growing_wind_-_final_report_of_the_nyiso_2010_wind_generation_study.pdf

NREL estimates that there is 38,900 MW of unbounded offshore wind potential off of Long Island and in the Great Lakes.[125] This estimate assumes a maximum water depth of 60 meters, a distance of between 12 and 50 nautical miles from shore, and a minimum wind speed of 7 m/s at a height of 90 meters. Preliminary results from a NYSERDA funded New York State Offshore Wind study show that approximately 47,000 MW of offshore wind potential exists off New York's shoreline, taking into account the fact that wind turbines will not be built in shipping lanes.

To be consistent with a planned update to New York State's Coastal Management Program, the potential was bounded to remove waters within 12 nautical miles of the shoreline. A 60 meter depth was used as a further bound since deeper waters would likely require floating turbine installations, a technology still in the early stages of development. These bounding factors combined are estimated to reduce the offshore potential to 17,000 MW. It is unlikely that enough turbines could be installed in the study timeframe to fully realize this potential, especially since no offshore wind has been installed in the United States to date, and the current permitting process for offshore wind development is time consuming. Assuming that the first 300 MW of wind turbines are installed in 2019, we estimate the offshore BTP to be 6,399 MW by 2030, with development during this time frame limited to the downstate resource. It should be noted that after 2023 our offshore BTP estimate includes the effects of the multistate Atlantic Wind Connection offshore backbone and exceeds the 1,400 MW of offshore wind modeled in the NYISO 'Growing Wind' study.[126]

Ongoing analysis of the opportunities and impacts for high levels of offshore wind resource development will be necessary. Other countries have successfully integrated high levels of wind energy into their electricity mix. Denmark, for example, has an annual average wind penetration rate of about 26%. An equivalent penetration rate in New York would be 16,000 MW of nameplate installed capacity.

6.2.2 Wind Constraints

There are a number of constraints that limit the potential development of wind energy in New York. These include: availability of wind; availability and suitability of land, lake or ocean on which to site a wind turbine; proximity and carrying capacity of transmission lines; capacity of the electric grid to absorb wind energy; local opposition to wind turbines; and permitting of new projects; among others. Challenges associated with these constraints are described in further detail below.

---

125 NREL. 2010. "Large-Scale Offshore Wind Power in the US: Assessment of opportunities and Barriers", Table 4-3, page 62. Bounding assumption to use 20% of available water area.

126 http://www.uwig.org/growing_wind_-_final_report_of_the_nyiso_2010_wind_generation_study.pdf

Certain conditions are necessary for wind to generate ample power**.** According to Wind Powering America, wind resources of 6.5 meters/second or greater at a height of 80 meters above the earth's surface has sufficient energy to be economically captured. For offshore installations, which are typically more costly, average wind speed must be at least 7 m/s for a site to be economically viable.

Addiionally, there may be a lack of suitable land, lake or ocean on which to site a wind turbine. Some land, despite having a sufficient wind resource, is unsuitable for a wind turbine installation. For example, restrictions on development in the Adirondack State Park and other sensitive areas limit wind potential. Ocean sites must not be in shipping lanes, in water that is not too deep (60 meters or less is the standard at the moment) and not too far from land. A new development is that the wind industry is looking to the oil and gas industry to develop floating platforms capable of supporting a wind turbine in deep water.

The proximity and carrying capacity of transmission lines is another potential limiting factor for wind energy potential. Energy generated by wind turbines must be transmitted via high voltage cables to where it can be used. The distance between a proposed turbine site and the closest transmission lines represents a cost to the project. The capital cost of connecting to the existing transmission lines is proportional to the length of the connecting transmission lines. In addition, the capacity of existing transmission lines is an important factor that limits how much power can be transmitted.

Also, the capacity of the electric grid to absorb wind energy can present a challenge for maximizing wind potential. Wind power is directly proportional to the cube of the wind speed. Therefore, a small variation in speed results in a large change in power output from the turbine. Because wind speed varies continuously, power output from wind turbines also varies. This presents a challenge to the operators of the grid, who must be sure demand and supply always match in order to ensure grid stability. The amount of available wind energy as compared to total grid demand is expressed as a percentage and called the *Wind Penetration.* The ability of the grid to absorb wind energy is dependent on a number of factors. The amount of wind penetration is a bounding factor.

Integration of wind energy into the grid involves scheduling, forecasting, and balancing the energy supply to meet the ever changing demand. Integration and balancing is critical to maintain the quality and timeliness of the electric power provided by the grid. Power must be available when needed to avoid brown or blackouts, and the fact that wind power is variable is a complication. Various studies put the costs of integration of wind energy anywhere from $1 to almost $10 per megawatt hour for wind penetrations of up to about 40% of the peak load.[127] Balancing the grid is the process of making sure that supply and demand are equal, which means that reserves must be available when wind is not. The projected reserves are dependent on the frequency of the scheduling; scheduling on a time

[127] Wiser and Bolinger (LBNL). US DOE. "2010 Wind Technologies Market Report." Page 69, Figure 40.

increment of less than 15 minutes requires less reserves. The NYISO report of 2010 predicts that less than 5% of reserves would be needed for wind penetration of up to about 27%. That means that for every 1,000 MW of nameplate installed capacity of wind turbines, there would be 50 MW or less of reserves required. Pumped hydro has traditionally represented one of the best methods for providing both balancing and reserve capacity.

Permitting of new projects can also be a barrier. For onshore installations, there can be opposition from local residents for a wide range of reasons. Objections to turbines as a detriment to the view are common. Environmental concerns are also typical, as the installation of a wind turbine can require a road to access the site, new or upgraded power lines to transport energy, and may require blasting to level a site or create a road if the site is at a higher elevation. There is also the possibility that a wind turbine may kill birds or bats, especially if the turbine is located in a migratory flight path. Offshore projects may also face opposition based on impacts to marine life, and marine navigation.

Offshore sites can face additional permitting challenges plus a range of cost, engineering and maintenance challenges particular to an offshore site. Offshore installations and wind turbine equipment costs more because of the difficulties of access, the need for specialized seaborne installation equipment, and wind turbines that have been built to withstand corrosion, ice, and waves. Offshore sites are regulated by the Federal Department of the Interior, which adds a layer of permitting complexity. Finally, access to offshore sites for maintenance is more difficult and can be weather dependent.

6.2.3 Conversion Technologies

Wind turbines can be located on land or in the water offshore. Turbines located on land are easier and cheaper to install and maintain because access is easier. However, wind over water encounters fewer obstructions and is therefore normally at a higher speed and less turbulent. All wind turbine installations in the United States are currently on land. One offshore project, Cape Wind, has been permitted for off the coast of Cape Cod in Massachusetts and other projects are moving through the process. Denmark first installed wind turbines offshore in 1991, and there is now at least 2,300 MW of capacity located offshore in Europe. An additional 50,000 MW of capacity is planned or in development for offshore installations worldwide.[128]

[128] NREL. 2010. Large-Scale Offshore Wind Power in the US: Assessment of opportunities and Barriers. Page 2.

Because wind is variable in speed and availability, a turbine normally operates at less than its rated maximum output power. Depending on the month of the year, turbines in New York were found to have capacity factors ranging from 10% to almost 36%[129] for the year 2009. The overall average capacity factor for New York wind turbines, calculated by comparing the total wind energy generated in 2010 with the installed nameplate wind capacity was 23.3%.[130] The location of a turbine also dictates its capacity factor. Offshore wind turbines average a higher capacity factor than turbines on land. One significant trend in wind energy technology is the increase in capacity factor in new turbines due to larger rotors and taller towers. Turbines built today and installed on land are expected to have capacity factors ranging from 32% to 45%, depending on the wind resource. Offshore capacity factors range from 35% to 50%.[131]

The peak coincidence for wind technologies is variable, from month to month and from year to year. Wind output tends to be higher during the winter months. For this study we have adopted capacity coincidence factors of 45% winter peak coincidence and 19% summer peak coincidence.[132]

Wind installations are comprised of individual turbines, most typically at a customer sited installation or as groups of turbines, in either a cluster or large scale wind farm. The applications and scales analyzed in this study are summarized in Table 67.

Table 67. Summary of Wind Technology Scales and Applications Evaluated.

Resource	Technology	Scale Analyzed	Location	Zone	Time Periods
Wind	*Residential*	10 kW	Customer Sited	LI, UP and HV	All
	Commercial	100 kW	Customer Sited	LI, UP and HV	All
	Cluster	1 MW - 30 MW	Central Plant	LI, UP and HV	All
	Utility	> 30 MW	Central Plant	LI, UP and HV	All
	Offshore	300 MW	Central Plant	NYC	First Deployed 2019

Residential scale turbines are typically sized to offset some or all of a residential annual electric energy usage.

---

129 NYISO. 2010. Growing Wind: Final Report of the NYISO Wind Generation Study. Appendix A, page 97.

130 Calculated using AWEA installed New York capacity nameplate data and NYSERDA wind energy data

131 Black and Veatch. 2012. Cost and Performance Data for Power Generation Technologies.

132 These factors are consistent with the assumptions from the 2003 Potential Study.

Commercial scale wind turbines can range from 3 kW to 1 MW in size. In this size range they could be used at a commercial site and could be net metered or provide power directly to the grid. They may be sized to offset the on-site usage if net metered, or sized based on some other criteria if metered separately. Commercial scale turbines are often sited at farms, institutions, manufacturing facilities, ski areas, and at municipal sites such as wastewater plants or landfills.

Commercial scale turbines (up to 1MW of nameplate capacity) or larger machines with capacity up to 3 MW could also be installed in "cluster" or small scale wind farms with total capacity of up to 30 MW.

Utility scale wind turbines are designed to produce as much energy as is possible to provide power to the grid. Utility turbine sites can range from farmland to mountain ridge tops, to more urban areas. One example of an urban site is the Steel Winds project in the city of Lackawanna near Buffalo, New York. Fourteen wind turbines of 2.5 MW capacity each are sited on 30 acres of a 1,600 acre former steel mill brownfield site on the shores of Lake Erie.

Offshore wind turbines can be bigger and must be more robust than their counterparts on land. The open spaces allow for a larger size, but require specialized marine equipment in order to install and maintain the turbines. Offshore turbines must be designed to withstand ice, waves, storms and currents as well as increased corrosion from salt at ocean sites. Most turbines installed offshore have been in waters of 30 meters or less in depth, but technology and designs from the oil and gas industry for offshore platforms are being adapted for use by the wind industry for deep water installations. Submarine cables transmit the energy from the turbines back to shore. As presented below, offshore wind development costs reflect turbine and balance of plant costs consistent with preliminary results from the New York Offshore Wind Study. Transmission and interconnection costs are consistent with the development of a regional offshore wind infrastructure, and consistent with estimates from the Atlantic Wind Connection backbone transmission project.[133]

133 www.atlanticwindconnection.com

6.2.4 Wind Economics and Technology Learning

The installed costs for onshore wind technologies are not projected to decline during the study period, although technical improvements are expected to result in improved capacity factors and output per MW of installed capacity during the study period. Installed costs for offshore wind technologies are expected to decline by 14% over the study horizon[134], starting at levels consistent with the New York Offshore Wind Study analyses. Table 68 summarizes the cost and performance factors for wind technologies, and Appendix A in Volume 5 provides further details.

Table 68. Wind Technology Cost Profiles.

Resource	Technology	Installed Cost (2012$/kW)	Annual Capacity Factor – Varies by Zone	Measure Life	Incentive
Wind	*Residential*	$7,121/kW	18-20%	20 years	ITC
	Commercial	$3,224/kW	26-30%	20 years	PTC
	Cluster	$3,138/kW	28-35%	20 years	PTC
	Utility	$2,381/kW	30-35%	20 years	PTC
	Offshore	$4.339/kW Year 1 turbine and balance of plant costs from Draft NYS Offshore Wind Study plus transmission adders from Atlantic Wind Connection, 2012 Report by IHC, "Assessment of the Economic Benefits of Offshore Wind in the Mid-Atlantic"	39%	25 years	None – Assumption that PTC is phased out by 2019

134 Consistent with National Renewable Energy Laboratory "Renewable Electricity Futures Study, Vol. 2" Incremental technology improvement ("RE-ITI") for Offshore Wind. Figure 11-14, p. 11-31.

6.3 Wind Results

Table 69 presents the estimated BTP and economic potential for wind, by installed nameplate capacity, for onshore and offshore wind in 2020 and 2030.

Table 69. Wind Potential Incremental Installed Capacity.

	2020 Nameplate Capacity (MW)		2030 Nameplate Capacity (MW)	
Technology	**BTP**	**Economic**	**BTP**	**Economic**
Onshore	2,011	441	4,966	2,170
Offshore	561	0	6,399	630
Total	**2,572**	**441**	**11,377**	**2,800**

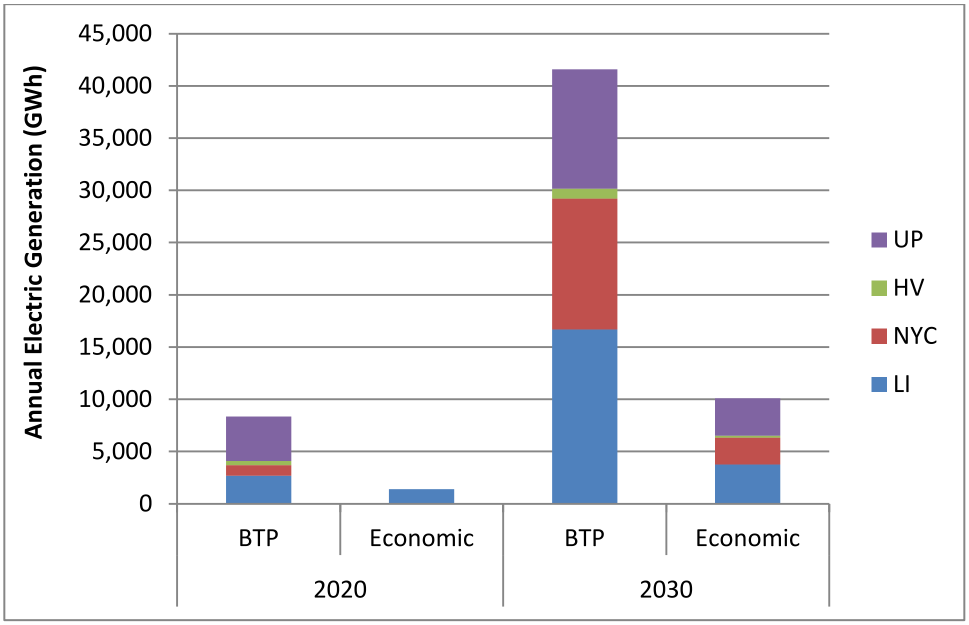
Note that 2010 wind installed capacity is 1,274 MW, 2010 generation is 2,596 GWh, and 2010 offshore wind capacity is 0 MW.

The estimated generation from the BTP and economic potential resources are presented by zone in Table 70 and Figure 30.

Table 70. Wind Potential Cumulative Annual Energy Generation by Zone.

	2020 Generation (GWh)		2030 Generation (GWh)	
Zone	**BTP**	**Economic**	**BTP**	**Economic**
Long Island	2,674	1,403	16,684	3,755
New York City	1,021	0	12,513	2,571
Hudson Valley	389	0	970	181
Upstate	4,274	0	11,431	3,582
Statewide	**8,358**	**1,403**	**41,598**	**10,089**

Figure 30. Net Cumulative Annual BTP and Economic Energy Generation by Year and Zone.



The projected share of total electric generation met from wind, including existing resources, is presented in Table 71.

Table 71. Wind Potential as Share of Total Electric Generation.

	2020		2030	
Technology	**BTP**	**Economic**	**BTP**	**Economic**
Onshore	3.6%	0.8%	8.3%	3.8%
Offshore	1.1%	0.0%	12.6%	1.3%
Total	**4.7%**	**0.8%**	**20.9%**	**5.1%**

Projected summer peak coincidence for wind by zone is presented in Table 72.

Table 72. Wind Cumulative Summer Peak MW by Zone.

	2020 Summer Peak (MW)		2030 Summer Peak (MW)	
Zone	BTP	Economic	BTP	Economic
Long Island	160	87	955	233
New York City	57	0	696	143
Hudson Valley	29	0	72	13
Upstate	265	0	710	222
Statewide	**511**	**87**	**2,433**	**611**

The BTP and economic potentials for wind by technology are presented in Table 73 (Installed Capacity) and in Table 74 (Cumulative Annual Generation).

Table 73. Wind Potential Nameplate Capacity by Technology.

			2020 Nameplate Capacity (MW)		2030 Nameplate Capacity (MW)	
Resource	Technology	Scale Analyzed (Plant Size)	BTP	Economic	BTP	Economic
Wind	*Residential*	< 10 kW	5	0	12	0
	Commercial	< 1 MW	6	0	13	2
	Cluster	1 MW - 30 MW	242	0	546	47
	Utility	> 30 MW	1,758	441	4,395	2,121
	Offshore	300 MW	561	0	6,399	630
	Existing		1,274	1,274	1,274	1,274
	Total		**3,846**	**1,715**	**12,651**	**4,074**

Table 74. Wind Cumulative Annual Generation by Technology.

			2020 Generation (GWh)		2030 Generation (GWh)	
Resource	Technology	Scale Analyzed (Plant Size)	BTP	Economic	BTP	Economic
Wind	*Residential*	< 10 kW	10	0	22	0
	Commercial	< 1 MW	17	0	41	6
	Cluster	1 MW - 30 MW	742	0	1,767	170
	Utility	> 30 MW	5,546	1,403	14,743	7,341
	Offshore	300 MW	2,042	0	25,025	2,571
	Existing		2,596	2,596	2,596	2,596
	Total		**10,953**	**3,999**	**44,194**	**12,684**

Summer peak capacity by technology is presented in Table 75.

Table 75. Wind Cumulative Summer Peak Capacity by Technology.

			2020 Summer Peak (MW)		2030 Summer Peak (MW)	
Resource	**Technology**	**Scale Analyzed (Plant Size)**	**BTP**	**Economic**	**BTP**	**Economic**
Wind	*Residential*	< 10 kW	1	0	2	0
	Commercial	< 1 MW	1	0	3	0
	Cluster	1 MW - 30 MW	48	15	114	11
	Utility	> 30 MW	347	87	922	457
	Offshore	300 MW	114	0	1392	143
	Total		**511**	**102**	**2,433**	**611**

Appendix tables in Volume 5 present the net benefits, benefit-cost ratios, and net levelized costs of energy by year for wind technology measures. The net levelized cost for wind energy technologies are presented in Table 76.

Table 76. Wind Net Levelized Cost of Energy per kWh (2012$/kWh).

Measure Name	Zone	2015	2020	2025	2030
Residential Wind (1-10 kW)	LI	0.24	0.28	0.29	0.29
Residential Wind (1-10 kW)	HV	0.26	0.30	0.30	0.30
Residential Wind (1-10 kW)	UP	0.25	0.28	0.29	0.29
Commercial Wind (3kW-1 MW)	LI	0.09	0.09	0.08	0.08
Commercial Wind (3kW-1 MW)	HV	0.10	0.10	0.09	0.08
Commercial Wind (3kW-1 MW)	UP	0.09	0.09	0.09	0.08
Cluster Wind (1-3MW)	LI	0.10	0.10	0.09	0.08
Cluster Wind (1-3MW)	HV	0.12	0.12	0.11	0.10
Cluster Wind (1-3MW)	UP	0.10	0.10	0.09	0.08
Wind Farm (2-5 MW)	LI	0.07	0.08	0.07	0.07
Wind Farm (2-5 MW)	HV	0.08	0.09	0.08	0.07
Wind Farm (2-5 MW)	UP	0.08	0.08	0.07	0.07
Offshore Wind (2-5 MW)	LI	n/a	0.12	0.11	0.10
Offshore Wind (2-5 MW)	NYC	n/a	0.12	0.11	0.10

6.4 Wind Development Paths and Investment

The BTP and economic potentials presented above are based on a distribution by technology type with less than 1% of total wind generation coming from customer sited facilities, roughly 6% from cluster (less than 30 MW) onshore wind farms, 39% from onshore wind farms greater than 30 MW and 55% coming from offshore wind installations. Note that this is new capacity. The total onshore (across scales) and offshore installed capacity would be 51% onshore and 49% offshore in 2030 under the projected potential estimates.

The development path analysis examines the impacts of increasing the share of cluster development (to 25% of total) and decreasing the share of large scale utility farms (to 19% of total new capacity). This analysis investigates how, if additional restrictions on the siting of large scale (greater than 30 MW of nameplate capacity) on shore wind farms arise, cluster scale developments could make up for some of the reduced development of large scale wind farms. Cluster scale developments, as characterized in this analysis, have higher costs and lower performance than larger scale wind farms. On the other hand, cluster scale development may be easier to site and permit, in part due to higher levels of public acceptance. Table 77 presents the wind development path analysis results.

Table 77. Wind Development Path Results

Resource	Technology	Economic GWh Statewide 2020	Economic GWh Statewide 2030
Wind	*Cluster < 30 MW*	0	170
	Wind Farm > 30 MW	1,403	7,341
	Development Path		
	Cluster < 30 MW	0	901
	Wind Farm > 30 MW	477	3,049

The results indicate that a development path concentrated on a greater share of cluster scale projects would reduce the economic potential by almost one half, with estimated economic potential for onshore wind generation reduced from 7,511 to 3,950 GWh in 2030. The cluster development path would likely result in a larger number of total projects, but relatively fewer large scale farms. For example, assuming an average of 15 MW for cluster projects and 200 MW for large scale wind farms, the core analysis results above would result in approximately 3 cluster projects and 10 wind farm projects. The development path would increase the number of cluster projects to 16, with 4 to 5 large scale wind farms. Thus the development path would result in a greater number of total projects (20 compared to 13) but with a reduction in the total estimated economic potential generation as reflected in Table 77.

The total level of investment required to develop the estimated economic wind potential grows steadily reaching more than $3 billion annually by 2030, and totaling close to $7.4 billion. Table 78 shows the annual and cumulative investments for the economic potential case during the study horizon for wind technologies.

Table 78. Wind Technologies Total Investment

		Total Private and Public Investment (Million 2012$)		
Resource	**Technology**	**Annual Investment 2020**	**Annual Investment 2030**	**Cumulative Investment 2030**
Wind	*Residential*	0	0	0
	Commercial	0	1	5
	Cluster	0	27	136
	Utility	135	633	4,811
	Offshore	0	2,438	2,438
	Total	**135**	**3,099**	**7,390**

7 Energy Storage Research Module

Energy storage encompasses various technologies and applications that make thermal or electric energy available at a time and/or place where it was not originally produced. All energy storage applications entail some loss of efficiency, but in return, provide benefits derived from the timing and/or location of the recovered energy. This section provides a brief overview of energy storage applications and their potential importance for New York's energy future. We begin with a focus on the potential importance of grid-tied electric storage, followed by a basic description and select examples of storage applications for transportation and building thermal applications. The scope of our research for this study did not include economic analysis of the cost-effectiveness of energy storage applications, but provides a summary overview of the important contributing role that energy storage technologies are likely to play in the coming decades.

The National Renewable Energy Laboratory used the classification summarized in Table 79 for three types of grid connected energy storage to help review available technologies, needs and potential benefits for storage in a high saturation renewable energy future:[135]

Table 79. Energy Storage Classification.

Class	Example Applications	Discharge Times Required
Power quality and regulation	Transient stability, reactive power, frequency regulation	Seconds to minutes
Bridging power	Contingency reserves and ramping	Minutes to ~1 hour
Energy management	Load leveling, capacity firming, T&D deferral	Hours

Energy storage can help to maximize the use of new and existing transmission and distribution infrastructure and delay or reduce the need for new investments. Storage can provide emergency back-up power, black start capabilities, and frequency regulation to improve system resiliency, reliability and power quality. Energy storage also enables higher saturation levels for intermittent renewable resources with short (seconds to minutes) and long (daily and seasonal) variability.

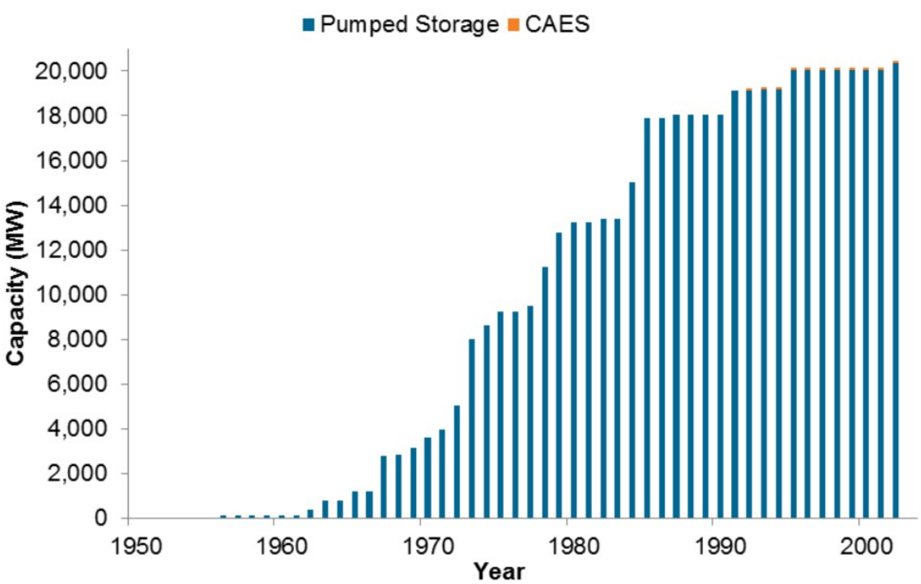
135 NREL Electricity Futures Study Volume 2: Renewable Electricity Generation and Storage Technologies: Table 12-2, page 12-4.

The potential and benefits for energy storage are magnified and complemented by the “smart grid” advances in communication and control systems which enable the coordinated control and dispatch-ability of stored energy. The smart charging and potential discharging of storage applications such as vehicle batteries, or the controlled charging of existing standard electric water heaters, provide examples of how storage, smart grid, and demand response applications can be closely interrelated.

7.1 Grid Connected Energy Storage

In New York, as elsewhere in the United States and globally, pumped hydropower is the predominant form of energy storage connected to the electric grid. In New York, for 2013, there are 1,407 MW of pumped storage summer capacity reported by the NYISO, representing 3.7% of the total capacity.[136] In 2011 the Energy Storage Association reported that pumped hydropower in the United States totaled roughly 22 GW of capacity, which accounted for 95% of the total storage capacity connected to the grid.[137] This trend is evident in Figure 31, which also illustrates how installed capacity has increased in step-like fashion since the 1970s with some leveling off of the rate of growth since the mid to late 1980s.

Figure 31. Capacity of bulk energy storage in United States.[138]



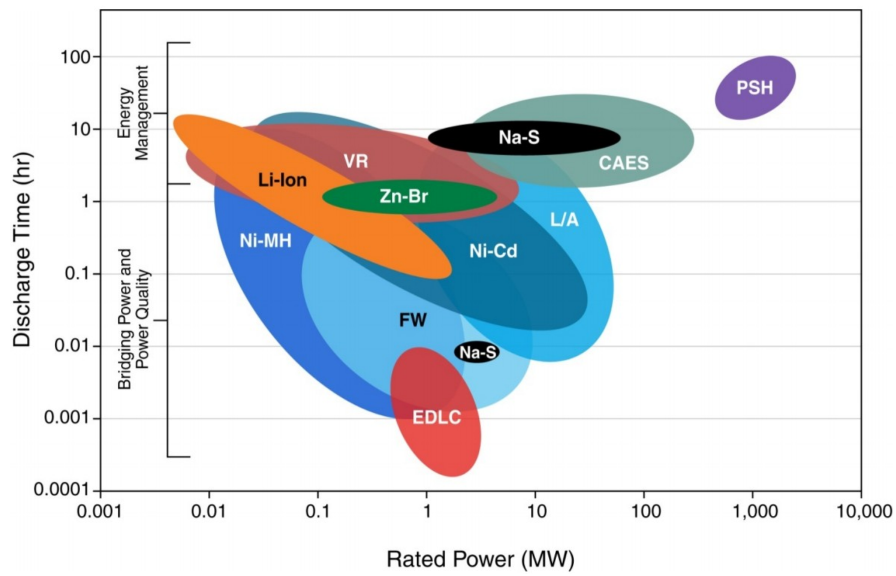
136 NYISO, 2013 Gold Book Table II-I.

137 Energy Storage Association as cited by Cowart, Electricity Storage, Status Prospects and Challenges: presentation to the Florence School of Regulation. http://www.raponline.org/document/download/id/4592 2011.

138 National Renewable Energy Laboratory. Electricity Futures Report, Volume 2: Figure 12-1, source data from Energy Information Administration.

New York's Energy Storage Roadmap identified a target of adding more than 1 GW of new grid connected storage capacity by 2022 using technologies other than pumped hydro.[139] These other technologies include batteries, compressed air, flywheels, and capacitors. Figure 32 illustrates the range of discharge times and capacities for various technologies, giving an indication of how each technology can be expected to contribute to each class of application as defined above in Table 74.

Figure 32. Energy storage technologies and applications.[140]



This chart is meant to represent a general range of storage technologies and is not inclusive of all technologies, applications, and possible sizes.

CAES Compressed air EDLC Dbl-layer capacitors FW Flywheels L/A Lead-acid Li-Ion Lithium-ion Na-S Sodium-sulfur	Ni-Cd Nickel-cadmium Ni-MH Nickel-metal hydride PSH Pumped-storage hydropower VR Vanadium redox Zn-Br Zinc-bromine

139 New York Battery and Energy Storage (BEST) Technology Consortium: New York Energy Storage Roadmap. September, 2012. http://ny-best.vm-host.net/sites/default/files/type-page/4254/attachments/NY-BEST%20Roadmap_final-1.pdf. Page 18.

140 National Renewable Energy Laboratory. 2011. *Electricity Futures Report*. Volume 2: Figure 12-2. Source data from Storage Association. (ESA, 2011).

The Energy Storage Roadmap's target of 1 GW of new non-pumped hydro energy storage can be compared in scale to demand response initiatives. For example, the 2009 State Energy Plan indicated that NYISO had approximately 2.5 GW of Special Case Resources and Emergency Demand Response Program resources enrolled.

Examples of non-pumped hydro energy storage in New York include: a 150 MW Compressed Air Energy Storage development in Reading;[141] a Lithium ion battery installation in Johnson City;[142] a Sodium-sulfur battery installation in Garden City Long Island;[143] and a 20 MW flywheel installation in Stephentown.[144]

The largest scale bulk energy storage and management systems, such as pumped hydro and compressed air systems, tend to be heavily dependent on the availability of favorable geographic and geologic resources and site conditions. New York has good potential resources for expanding both PSH (greater than 2GW) and CAES (greater than 1.5 GW) as identified in the NREL Electricity Futures Study. [145]

Battery and other storage technologies (which can range up to 10s of MW of capacity) are dependent on specific site conditions and should be sited based on potential economic value and system needs. Examples of large scale battery installations in the 10 MW+ range include a 27 MW NiCad storage system installed by the Golden Valley Electric Association in Alaska[146] and a 34MW Sodium sulfur battery system to provide load leveling for a 51 MW wind farm in Japan.[147]

The NYISO has implemented regulations to enable storage systems to participate in markets as frequency regulation providers. As the markets continue to grow the number of policy and pricing mechanisms that impact the economics of grid scale and customer sited energy storage will continue to evolve. Looking forward, it is highly likely that in New York and other markets, grid scale energy storage technologies will increasingly be combined with strategic decision making that influences grid dispatch and operations, renewable resource forecasting, investments in transmission distribution infrastructure, and investments in new renewable capacity. The NREL Electricity Futures study estimates that between 100 and 152 GW of energy storage will be needed nationally in scenarios where renewable energy generation reaches 80%+ of total by 2050.

---

141 http://www.smartgrid.gov/sites/default/files/new-york-state-electric-and-gas-oe0000196-final.pdf

142 http://green.blogs.nytimes.com/2011/01/07/hold-that-megawatt/?_r=0

143 Electric Power Research Institute. 2005. *Program on Technology Innovation: Long Island Bus NAS Battery Energy Storage System*. Annual Report 1013248.

144 http://www.nyenergyhighway.com/Content/documents/36.pdf

145 NREL Electricity Futures Study, Volume 2: Figures 12-9 and 12-10 for pumped storage hydro, and Figure 12-11 for compressed air energy storage systems.

146 http://www.gvea.com/energy/bess

147 http://www.cleanenergyactionproject.com/CleanEnergyActionProject/CS.Rokkasho-Futamata_Wind_Farm___Energy_Storage_Case_Study.html

7.2 Transportation and Vehicle to Grid

Transportation, and specifically vehicle electrification, is another emerging market for energy storage. Storage in the transportation fleet will primarily be used to serve the transportation application, but there are also important opportunities for transport oriented systems that are directly connected to the building energy markets and grid operations. Widespread use of Plug-in Electric Vehicles (PEVs) could greatly reduce fossil fuel consumption, transportation energy costs, and mobile source air pollution in New York. A shift from fossil fuels to the electric grid as the primary supplier of energy for transportation will pose new challenges for utility providers with regards to peak power management, but also new opportunities that, if harnessed, could result in an overall net benefit to the grid. One key advantage of PEVs is that vehicles are in use for mobility less than five percent of the time,[148,149] indicating that many PEVs connected to the grid would be a load that is highly flexible and well suited for demand side management. This "smart charging" of PEVs represents an important demand response/management option that is enabled by the vehicles' on-board battery storage.

A second potential advantage of PEVs is that they are capable of being retrofitted to allow bidirectional exchange of electricity between their battery systems and the electric grid.[150] This is known as Vehicle to Grid (V2G) power. If exploited, PEVs are technically capable of providing valuable ancillary services through V2G to support reliability, frequency regulation, and peak power management on the power grid.

7.2.1 Strategies for Optimal Control of PEV Charging

Maximizing the benefit of PEVs to the electric grid can be accomplished through either indirect or direct control of charging.[151,152] In a direct control scenario, a PEV owner would grant an external party, operating on behalf of the electric grid, the ability to directly control the flow of electricity to their vehicle while charging. This could involve stopping charging when the grid is reaching peak demand, engaging charging mode when a valley emerges in grid demand, or even modulating the current to the vehicle to achieve more fine-tuned load-leveling[153]. In an indirect control scenario, charging behavior of PEV owners would be more passively manipulated through the use

---

148 Galus Matthias D. et al. *The Role of Electric Vehicles in Smart Grids.* WIREs Energy Environ 2012. Doi:10.1002/wene.56

149 Kempton, Willett and Jasna Tomic. 2005. *Vehicle-to-Grid Power Fundamentals.* Journal of Power Resources. Science Direct, Elsevier.

150 Kempton, Willett et al. 2008. *A test of vehicle-to-grid (V2G) for energy storage and frequency regulation in the PJM system*. University of Delaware, Pepco Holdings, Inc PJM Interconnect, and Green Mountain College.

151 Ibid. Ref 2.

152 Alizadeh, Mahnoosh, Anna Scaglione, and Robert J. Thomas. 2011. *Direct Load Management of Electric Vehicles.* University of California, Cornell University.

153 Ibid Ref 16.

of price signals. Here, PEV owners would be subject to variable energy prices set by the transmission or distribution system operator based on grid demand. PEV owners would be responsible for balancing cost considerations and mobility needs according to prices[154]. This would presumably lead to charging behavior that minimized grid impacts.

The development of a smart grid is fundamental for enabling control of PEV charging, directly or indirectly, and maximizing PEVs benefits to the grid. The term “smart grid” is used to refer to the two way flow of information between users, distributors and producers of electricity. Advanced Metering Infrastructure (AMI) is needed for sub-metering of PEV charging. For indirect control of EV charging, AMI is needed to monitor EV charging times so that the appropriate rates can be applied. For direct control, electric vehicle charging equipment needs to be equipped with systems for controlling the flow of electricity and communicating with a grid operator.

7.3 Thermal Storage

Thermal energy storage has been used for ages to help meet the space conditioning needs in the built environment.[155] Applications and systems using phase change materials, such as ice storage or large capacity water heaters, can take renewable or non-renewable energy inputs and store thermal energy that can be released at a later time to match heating or cooling loads. These storage systems can benefit the grid by shifting demand, for example using ice storage to create ice using off-peak power and then using the ice to meet or reduce cooling loads during on peak cooling demand.[156] Other examples of thermal storage include “combi-style” solar thermal systems which are designed to reduce domestic hot energy consumption as well as to provide some reduction in space heating needs by providing thermal energy for low-temperature radiant heating distribution systems.[157] In these cases, water is heated when the sun is out, and stores the heat until there is demand for domestic hot water or space heating demand. Note that savings and load shifting are created even if the stored energy is providing only a fraction of the load. This shows that thermal storage can function as a hybrid resource that complements conventional or renewable supplies.

---

[154] Ibid Ref 2.

[155] See the Advanced Solar Homes Module in Volume 3.

[156] An example in New York is an ice storage system used for cooling by Morgan Stanley in Westchester County. This project, which was supported by NYSERDA and installed in 2007 provided 740kW of peak load reduction, and through improved efficiency of chiller equipment also lowered overall energy consumption. http://www.trane.com/Commercial/uploads/newsroom/PR_morganstanley.pdf

[157] Meister Consultants Group. March 2012. *Massachusetts Renewable Heating and Cooling: Opportunities and Impacts Study*. p.40.

NYSERDA, a public benefit corporation, offers objective information and analysis, innovative programs, technical expertise, and funding to help New Yorkers increase energy efficiency, save money, use renewable energy, and reduce reliance on fossil fuels. NYSERDA professionals work to protect the environment and create clean-energy jobs. NYSERDA has been developing partnerships to advance innovative energy solutions in New York State since 1975.

To learn more about NYSERDA's programs and funding opportunities, visit nyserda.ny.gov or follow us on Twitter, Facebook, YouTube, or Instagram.

New York State
Energy Research and
Development Authority

17 Columbia Circle
Albany, New York 12203-6399

toll free: 866-NYSERDA
local: 518-862-1090
fax: 518-862-1091

info@nyserda.ny.gov
nyserda.ny.gov

Energy Efficiency and Renewable Energy Potential Study of New York State

Volume 3: Renewable Energy Methodology and Detailed Results

Final Report
April 2014

New York State Energy Research and Development Authority
Richard L. Kauffman, Chairman | John B. Rhodes, President and CEO

State of New York
Andrew M. Cuomo, Governor