Tompkins County Energy Roadmap

Evaluating Our Energy Resources

March 2016

Tompkins County Planning Department

Energy Roadmap Steering Committee

The Tompkins County Energy Roadmap was identified as a priority action in the Tompkins County 2020 Energy Strategy (2010) and was developed over a number of years, beginning with a series of projects by Cornell University graduate students from 2011 to 2013. In 2014 a steering committee was created and Professor Max Zhang from the Cornell School of Engineering was hired to complete the project. The steering committee brought together a group of individuals, listed below, who represent the breadth of experience, interest and perspectives within the community regarding our energy future.

- Martha Armstrong, VP & Director of Economic Development Planning, TC Area Development
- Peter Bardaglio, President, Black Oak Wind Farm & Coordinator, TC Climate Protection Initiative
- Scott Bochenek, Manager of Smart Grid Programs, Iberdrola USA/Avangrid
- Carol Chock, Tompkins County Legislator
- Linda Copman, Climate Action Coordinator, Cornell University
- Lew Durland, Director of Energy Management and Sustainability, Ithaca College
- Brian Eden, Tompkins County Environmental Management Council Energy Committee
- Nick Goldsmith, Sustainability Planner, City and Town of Ithaca
- Jerry Goodenough, Chief Operating Officer, Upstate New York Power Producers
- Tony Ingraffea, Dwight C. Baum Professorship in Engineering, Cornell University
- Tim Mount, Dyson School of Applied Economics and Management, Cornell University
- Gay Nicholson, President, Sustainable Tompkins
- Bob Pass, Manager of Regional Outreach and Development, NYS Electric and Gas
- Leslie Schill, University Planner, Cornell University
- Ken Schlather, Executive Director, Cornell Cooperative Extension of Tompkins County
- Ian Shapiro, Chairman, Taitem Engineering

Draft resource potential and scenario chapters were reviewed by the committee and then offered for public review and comment. The draft Energy Roadmap was presented to 18 different community groups, organizations and the public during the summer and fall of 2015. The Steering Committee oversaw completion of the final documents by Professor Zhang, his assistants and staff of the Tompkins County Planning Department and endorses the recommendations for future action.

The Planning Team

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Evaluating Our Energy Resources

March 2016, Tompkins County Planning Department

The purpose of the Tompkins County Energy Roadmap is to evaluate local energy resources and develop scenarios to meet our County's 80% greenhouse gas (GHG) emission reduction goal and projected energy needs through 2050. The study was conducted on behalf of all residents, businesses and institutions in the community and is meant to help inform decisions regarding Tompkins County government operations as well as the actions of others in the community working to create a new green energy future. It is hoped that the Roadmap will provide support for current activities and inspire additional immediate action to reduce energy use and transition to renewable energy. Immediate actions are critical, as reductions achieved now will continue to accrue in future years and have greater impact on future greenhouse gas concentrations in the atmosphere.

The Roadmap has two objectives:

1. To evaluate whether achieving 80% emission reductions is possible primarily using local renewables and demand reduction.
2. To identify local actions that can be taken in the short and long term to achieve our goal.

Our evaluation focuses on technical feasibility and undertakes rigorous analyses to quantify both the potential to reduce energy demand and the potential to produce energy using local renewable resources. The Roadmap quantifies the potential energy that could be generated from solar, wind, micro-hydro, and biomass resources within Tompkins County.

The Roadmap demonstrates that, in spite of the fact that Tompkins County has no exceptional renewable energy resources, it is possible to achieve our goal.

Table 1: Percent of 2008 demand that could be met by local energy resources

	Energy Resource	Annual Energy Potential	% of 2008 Electricity Demand[1]	% of 2008 Thermal Demand[2]	% of 2008 Total Energy Demand[3]
Renewable Supply	Wind	2,646 GWh	327%	n/a	63%
	Solar	2,453 GWh	303%	n/a	58%
	Micro-Hydro	726 GWh	90%	n/a	17%
	Biomass	3,626,477 MMBtu	n/a	59%	25%
Demand Reduction	Building Efficiency: Heating Portion	3,350,604 MMBtu	n/a	54%	23%
	Building Efficiency: Electrical Portion	401 GWh	50%	n/a	9%
	New Construction to Code	1,152,880 MMBtu	n/a	19%	n/a

[1] The grid supplied 809 gigawatt hours (GWh), a measure of electrical energy, of electricity in the community in 2008.

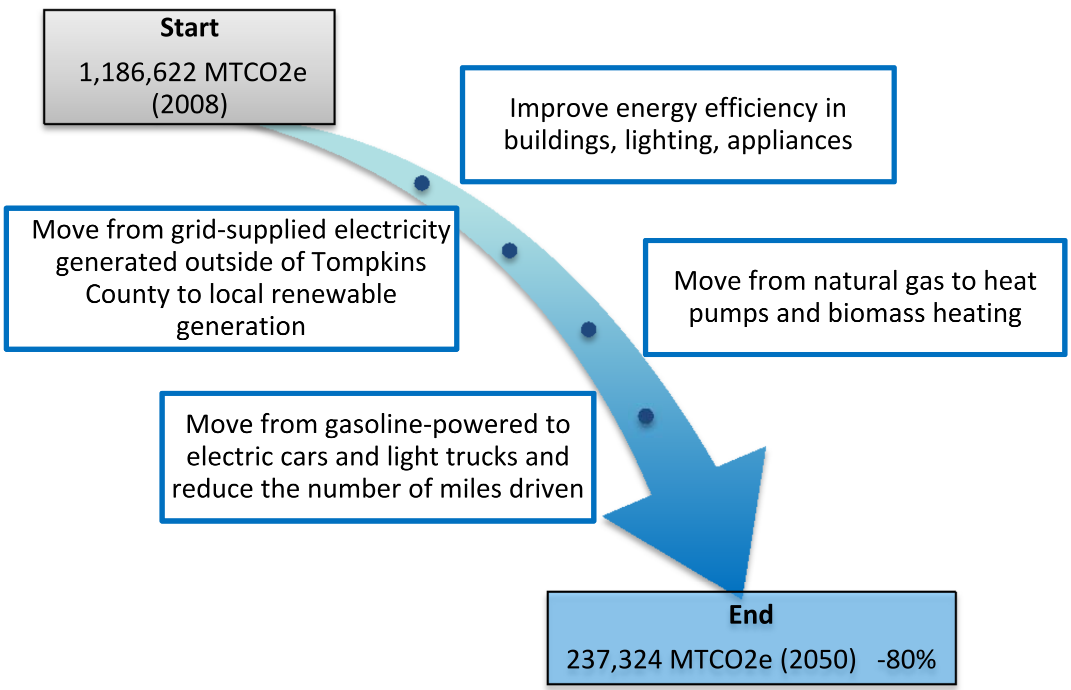
[2] In 2008, the thermal demand in the community was 6,169,985 million British Thermal Units (MMBtu), a measure of the energy content in fuel.

[3] Total energy demand, including electrical, thermal and transportation, was 14,438,224 MMBtu, or 4,231 GWh in 2008.

In addition to the thermal and electrical demand, the Roadmap also analyzes the potential to reduce transportation emissions by transitioning light-duty vehicles to electric and reducing the number of vehicle miles traveled (VMT) with strategies such as transit, car sharing, walking, biking, etc. The Roadmap finds that all 37.6 million gallons of gasoline used in 2008 could be replaced with electricity, though this transition would require an additional 21% of electricity over 2008 levels. Transportation demand management could eliminate 48% of the projected VMT in 2050.

The Roadmap presents three alternative energy scenarios that utilize local potentials to reduce greenhouse gas emissions by 80% and meet the County's projected energy needs in 2050. To develop these three scenarios, we used a model which balances grid-supplied electricity and fossil fuel energy with local renewable energy generation and energy efficiency/demand reduction. The three scenarios represent a wide range of conditions which reflect the divergent ways that energy systems might evolve in the next 35 years but all include the elements shown in Figure 1. Any of the three scenarios will still allow the County to meet its 80% emissions reductions goal.

Figure 1: Key strategies for reducing GHG emissions in Tompkins County[4]



The first scenario, "Business As Usual," serves as a point of reference to illustrate where we will be in 2050 if no further changes are made to the current energy system. The BAU and three alternative energy scenarios are summarized here:

- The **Business As Usual (BAU) Scenario** quantifies GHG emissions and energy consumption in 2050 assuming that no particular actions to reduce emissions, other than those already implemented or planned by 2015, are taken. Emission reductions of 31% are achieved based on

[4] MTCO2e is million metric tons of carbon dioxide equivalent – a measure of the combined ability of emitted GHGs to trap heat.

adopted U.S. EPA Corporate Average Fuel Efficiency standards and New York State's Renewable Energy Portfolio Standard and Energy Conservation Construction Code. These assumptions are applied to all of the scenarios.

- The **Mixed Scenario** assumes that energy services are provided by a mixture of fossil fuel and renewable resources and that the total amount of natural gas used equals that used by the industrial sector in 2008. This means that this scenario caps future natural gas use at 10% of the volume of natural gas consumed in 2008. This approach requires 2.7 times more electricity generation in 2050 compared to the 2008 baseline, due to increased demand and the need to provide excess renewable energy capacity to account for intermittent availability of some of these resources.
- The **All-Electric Scenario** assumes that all energy services (except heavy-duty and medium-duty vehicles) are provided by electricity. Moving to an all-electric energy system requires 3 times as much electricity generation in 2050 compared to 2008.
- The **Half-Natural Gas Scenario** maintains half the amount of natural gas used by the community in 2008. This approach requires 2.4 times more electricity generation in 2050 compared to the 2008 baseline.

New York State's plan to generate half of grid-supplied electricity from carbon-free sources by 2030 will help, but it will not be enough to achieve Tompkins County's 2050 emission reduction goal. Meeting our 80% emissions reduction goal will require us to go beyond the State's goals and further reduce our reliance on natural gas and on electricity generated from a grid based on centralized generating plants.

Tables 2 and 3, below, summarize the findings of the three scenarios, as well as business as usual.

Table 2: Three future energy scenarios and business as usual

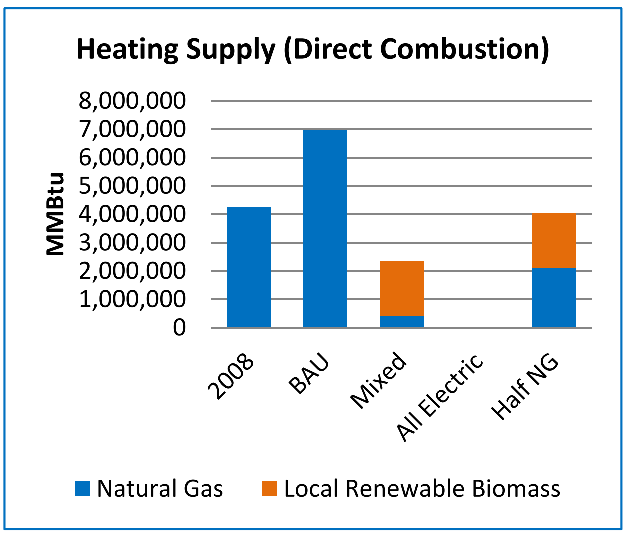
Scenarios	Business As Usual	Mixed	All Electric	Half Natural Gas
% of 2008 Natural Gas Usage Maintained	164%	10%	0%	50%
% of Heating Demand Met by Local Renewables (including heat pump systems and biomass)	0%	67%	72%	29%
% of Projected Energy Demand Provided by Efficiency Improvements	4%	25%	25%	31%
% of Transportation Demand Met by Light-Duty Electric Vehicles	0%	36%	71%	71%
% of Electricity Demand Met by Local Renewables	3%	63%	49%	71%
% of MTCO2e Reduction	31%	80%	80%	80%

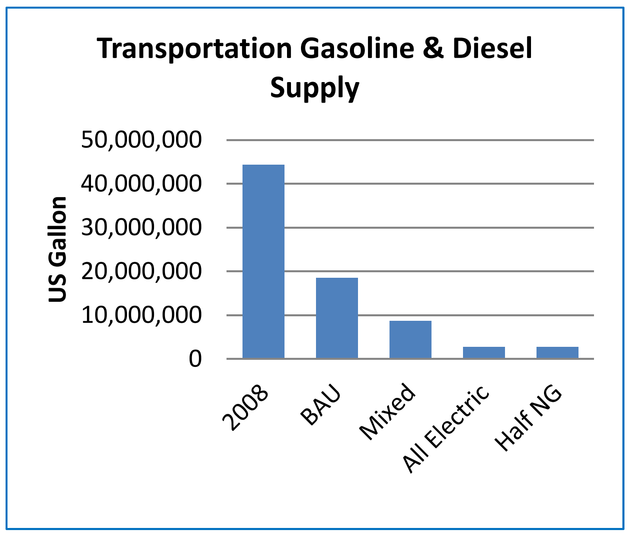
Table 3: Energy sources and GHG emissions—BAU, and three future energy scenarios

		BAU	Mixed	All Electric	Half NG
Heating (Direct Combustion) (MMBtu)	Natural Gas	6,966,253	427,810	0	2,130,034
	Local Renewable Biomass	0	1,923,505	0	1,923,505
Transportation (US Gallon)	Gasoline & Diesel	18,509,924	8,654,674	2,742,849	2,742,849
Electricity (Including Heat Pumps and EVs) (kWh)	Grid	946,530,985	237,815,624	618,313,764	50,678,194
	Local Renewable Electricity	59,099,648	1,941,064,889	1,820,724,109	1,868,823,694
CO2e Emissions (MT)		815,165	237,311	237,322	237,324

The Heating Supply table in Figure 2 below shows that natural gas use will need to be curtailed under any of the future energy scenarios that allow the community to achieve its GHG reduction goals. The decreases in Transportation Sector Supply shown below result from the transition to electric vehicles and the reduction in vehicle miles traveled envisioned in the Roadmap, combined with projected decreases resulting from federal Corporate Average Fuel Efficiency standards.

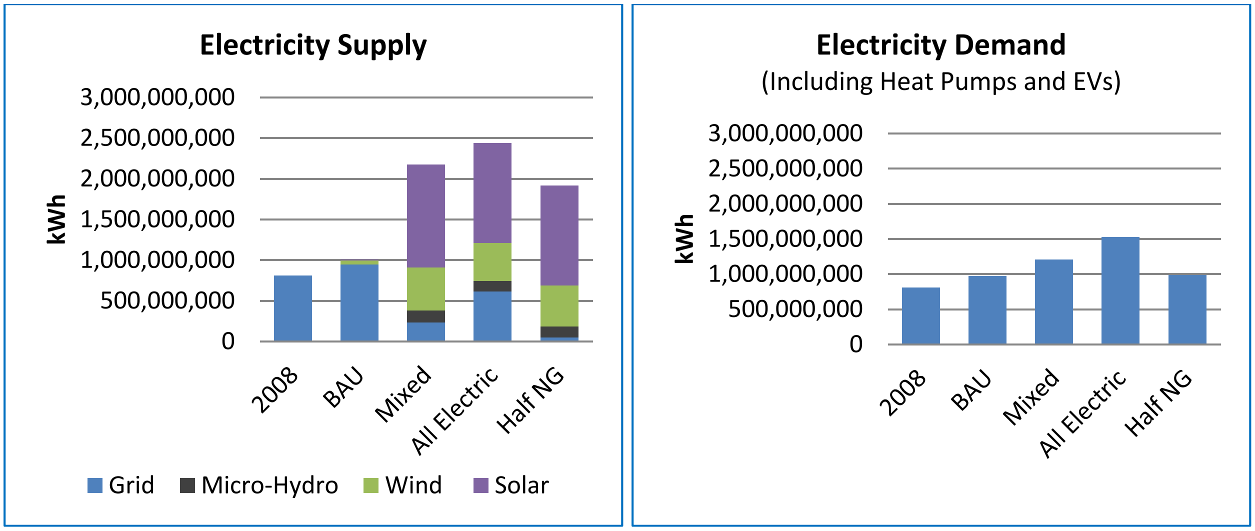
Figure 2: Heating and Transportation supply for 2008, BAU and the three future energy scenarios





The renewable systems in the Roadmap were designed to generate 2 MWh for every 1 MWh of demand in order to compensate for the intermittent nature of renewables and the need to serve peak loads. The 2x design factor causes the electricity supply to be greater than the demand. This can be seen in the charts below.

Figure 3: Electricity supply and demand for 2008, BAU, and the three future energy scenarios



Due to limited resources this Roadmap does not include a financial feasibility analysis or try to predict future government policy or forecast future energy markets. Lifecycle emissions from the production of fossil fuels or renewable energy generation equipment are not included, nor are emissions associated with methane leaks from the natural gas transmission and distribution system. The scenarios incorporate emissions from automobiles and trucks, but do not include rail or air travel. Other sources of emissions such as solid waste and agriculture are accounted for in the scenarios, but potentials for reducing these emissions are not evaluated or included.

The Conclusions and Recommendations section of the Roadmap identifies priority actions the County must take to meet our 2050 energy needs and emissions goal. The following interim goals will help inform our work over the next several months as we update the Tompkins County's Energy Strategy:

- Reducing natural gas use by 50% and grid electricity generated outside of Tompkins County by 24% from current levels.
- Developing 50% of solar potential, 20% of wind potential and 20% of micro-hydro potential.
- Developing 50% of biomass potential, and installing significant numbers of ground and air source heat pumps particularly in new construction; buildings that use fuel oil, propane, or electric resistance heat; or when existing heating systems have surpassed their useful life.
- Achieving efficiency potentials averaging 35% in existing buildings should be a high priority for short-term action.
- Transitioning 50% of light vehicles from gasoline to electric and avoiding any growth in vehicle miles traveled.

Moving forward, the goals, assumptions, and opportunities identified in the Roadmap will be reviewed periodically and adjusted as necessary to reflect future climate science, government policies, and economic factors.

Conclusions and Recommendations

The Energy Roadmap undertakes rigorous analyses to:

A. Quantify both the energy production potential of local renewable energy resources and the potential to reduce energy demand through air-sealing and insulating existing buildings and upgrading lighting, appliances and building systems, and
B. Develop alternative future energy scenarios that tap the identified potentials to both meet the projected energy needs of the community and reduce greenhouse gas emissions 80% by 2050.

The intent is for the analysis, conclusions and recommendations in the Roadmap to be used as the basis for updating the County's Energy Strategy, scheduled for 2016, which will identify concrete action steps to achieve the goals outlined in the Energy Roadmap.

Conclusions

1. The GHG emissions goal of an 80% reduction from 2008 levels by 2050 is feasible to achieve. This transition will require willpower, resources and work, but it is possible to do, even in an area with moderate energy resources and primarily relying on local efforts to develop renewable energy resources and reduce energy demand through efficiency.
2. Federal and State policies, especially around energy changes that require no overt decision-making by consumers, have huge impacts on GHG emissions reductions. This can be seen in the Business As Usual Scenario, which results in a 31% reduction in emissions by 2050 simply based on applying Federal CAFE vehicle emissions standards and New York State's Renewable Portfolio Standard and Energy Conservation Construction Code.
3. It may be possible to maintain up to 50% of the 2008 levels of natural gas use and still achieve GHG emissions goals. However, this would require achieving levels of efficiency and deployment of local renewables that would be extremely challenging. In addition, maintaining such a level of natural gas use will require addressing fugitive methane emissions from the production and transmission of natural gas.

Recommendations to Consider in Developing the Energy Strategy

Energy Strategy Update: The Energy Roadmap will be one of the major inputs to an update of the Tompkins County Energy Strategy which was initially adopted in 2010. In evaluating near term priorities for action, the Energy Strategy should conduct an economic feasibility assessment of these recommendations to consider which are the most feasible. This should be contrasted with the expected costs that will be incurred if global GHG reduction goals are not met. The Strategy may also include actions to pilot demonstration projects to prove the feasibility of some of these recommendations, such as development of medium scale wind and micro-hydro facilities. Development of the Strategy will also be the appropriate process for setting interim goals.

Reducing demand for energy is critical to address GHG emissions, especially in the long-term. Less demand means less need to build new and costly infrastructure and renewable energy systems. By 2050, we should:

1. Achieve a 35% reduction in energy use in existing buildings through retrofits and upgrades. Approximately 2/3 of these savings, or 1.7 million MMBtu, are anticipated to come from reductions of thermal energy demand as a result of building envelope, insulation and HVAC system improvements. About 1/3, or 321 GWh, would likely come from improvements in electrical efficiency such as lighting and refrigeration.
2. Construct new buildings that are extremely energy efficient, aiming for a 70% reduction in energy use compared to the national median for comparable buildings, and increasing to net zero carbon emissions between 2030 and 2050. While the scenarios only included the 15% reduction in energy demand due to new construction built to the Energy Conservation Construction Code, building to these higher levels of efficiency would decrease demand and either lessen the need for development of renewable energy resources or further reduce emissions.
3. Hold vehicle miles traveled at roughly the 2008 level of 672.3 million miles despite anticipated increases in population.

Transitioning to Renewable Sources of **Energy** is also critical to address GHG emissions. Achieving emissions goals will require development of renewable energy systems to supply the majority of our energy needs. By 2050, we should:

4. Reduce natural gas use by at least 50% from 2008 levels, or 21 million therms, by reducing demand for thermal energy, deploying significant numbers of ground and air source heat pumps, and utilizing biomass resources.
5. Reduce demand for grid electricity generated outside of Tompkins County by at least 24% from 2008 levels, or at least 190 million kWh, primarily by reducing demand and transitioning to local renewables.
6. Develop at least 50% of the identified solar energy production potential, or at least 1,225 GWh of solar production. One way this deployment could be achieved is by doing all of the following: 1 in 4 urban residential properties install a 4 kW PV system, 1 in 2 suburban and rural properties install a 7 kW system, 30% of commercial, institutional and industrial roof areas install PV, and 944 MW of PV farm capacity developed on 4,720 acres, or 1.5% of the County’s land area.
7. Develop at least 20%, 530 GWh, of identified wind energy production potential. One way this deployment could be achieved is by installing 300 medium-scale 500-KW turbines and 20 large-scale 2.3-MW turbines.
8. Develop at least 20%, 145 GWh, of identified micro-hydro energy production potential. This could be achieved by installing 60 micro-hydro 300 kW systems.
9. Develop up to 50%, 1.8 million MMBtu, of identified biomass energy production potential. One way this deployment could be achieved is by doing all of the following: managing 36,700 forest acres for sustainable biomass yield, planting 15,600 acres of inactive agricultural or grasslands in energy crops, and managing 12,900 acres of crop or forage land for sustainable crop residue harvesting
10. Transition at least 50% of light-duty vehicles from gasoline to electric, or at least 33,500 vehicles, from the 67,000 that could be on the road in 2050, if automobile ownership rates remain at 2008 levels.

Setting interim goals and tracking progress is crucial to keeping us on track to achieving our long-term goal and encouraging us to re-evaluate policies and program direction in an ever evolving energy future. In the years between 2016 and 2050, we should:

11. Set interim GHG emissions goals for 2020, 2025, 2030 and appropriate intervals thereafter, and track progress in achieving them. Every 2 years review scenarios and update as necessary to reflect changes in technology, government policies, climate science, economic conditions, or other factors. These interim goals should be set by the Tompkins County Planning Department when the Energy Strategy is updated in 2016.
12. Semi-annually convene stakeholders to evaluate progress, opportunities and barriers to achieving these recommendations, with a particular focus on whether the positive and negative impacts of the energy transition are being distributed equitably throughout the community.

Guidance for Energy Planning

Use of Natural Gas and Grid Electricity Generated Outside of Tompkins County: The scenario that maximizes natural gas usage accounts for 26% of future thermal demand from natural gas which amounts to the equivalent of 50% of 2008 usage, or 21 million therms. The scenario that envisions an All Electric future requires that three times as much electricity be generated in 2050 compared to 2008, with 25% of that future electric demand coming from grid electricity generated outside of Tompkins County, requiring that 618 million kWh be supplied by the grid in 2050. This is still a 24% reduction from the amount of grid electricity used in 2008, due to the anticipated use of locally generated renewable electricity.

These two "bookends" should be considered to be the maximum amounts of outside energy for the purposes of long range energy planning. Given the current assumptions of the Roadmap, we would not be able to meet an 80% reduction in emissions if we maintained both 50% of current natural gas use and 76% of electrical energy generated outside of Tompkins County from the grid. These constraints should serve as a solid framework in which to operate over the next 15 years, as we take strong action to achieve the penetration levels necessary for locally generated electricity, biomass, and demand reduction.

- Reducing natural gas use by 50% and grid electricity generated outside of Tompkins County by 24% from current levels are appropriate intermediate planning goals.

Renewable Deployment, Electrical: The scenarios also consider varying amounts of renewable energy development in the county. Generally it is anticipated that 53% of solar potential, 20% of wind potential and 20% of micro-hydro potential would be needed to meet local energy demand and also achieve an 80% reduction in GHG emissions. This is based on grid energy generated outside of Tompkins County reaching, and staying at, 50% renewable low- or no-emission sources in accordance with the NY State Energy Plan. If higher levels of renewable energy became available from the grid this could decrease the need for as much local renewable generation. However, given that the NY State Public Service Commission's Reforming the Energy Vision (REV) process envisions more distributed energy generation, and that larger metropolitan areas may have a more difficult time generating as much of their energy needs locally, we should plan for ultimately reaching the level of deployment of local renewables suggested in the Roadmap. Identifying specific appropriate locations for solar, wind and micro-hydro development should begin immediately and be incorporated into both current and long-range land use planning efforts.

- Developing 50% of solar potential, 20% of wind potential and 20% of micro-hydro potential and tracking progress are appropriate intermediate planning goals.

Renewable Deployment, Thermal: With respect to thermal energy, the Roadmap envisions a transition away from natural gas and other fossil fuels to high efficiency electrical systems including ground and air source heat pumps for anywhere from 6% to 72% of future needs. Biomass is also an important thermal resource that could reasonably supply up to 23% of future thermal energy needs by utilizing 53% of its potential. Given the particular characteristics of these energy sources it may be appropriate to initially focus biomass deployment in rural areas. Some types of industrial applications may continue, at least for the near future, to require high heat output which can be best achieved with fossil fuels and, in some instances, biomass.

- Developing 50% of biomass potential, and installing significant numbers of ground and air source heat pumps particularly in new construction; buildings that use fuel oil, propane, or electric resistance heat; or when existing heating systems have surpassed their useful life, are appropriate intermediate planning goals.

Efficiency: The Roadmap also relies upon improvements in efficiency to contribute to greenhouse gas emissions reductions. In general, existing residential buildings could achieve up to a 67% improvement in overall efficiency with 29% of that coming from electrical efficiency improvements and 71% from thermal efficiency. With existing commercial buildings the overall potential is a 55% reduction and about 71% of that potential coming from thermal energy and 29% from electrical energy. The Roadmap envisions achieving 50% of the thermal potential and 80% of the electrical efficiency potential resulting in overall building efficiency improvements of about 35% on average. Ground or air source heat pumps may be appropriate in urban, suburban and rural areas depending on the characteristics of specific sites and needs of individual residents or businesses. Efficiency improvements are often the most cost-effective means of energy and emissions reductions and should be emphasized in near term planning

- Achieving efficiency potentials averaging 35% in existing buildings should be a high priority for short-term action.

Transportation: The Transportation component of the Roadmap largely relied on a transition to electric vehicles and a 24% reduction in projected vehicle miles traveled by 2050. This essentially means keeping VMT at 2008 levels in spite of projected growth. The level of electric vehicle deployment required varies based upon the level of emissions reductions achieved from efficiencies in building energy use. Under every scenario at least half of light duty vehicles will need to be electric by 2050. Building an electric vehicle friendly community should be a high priority for near term action. To achieve reductions in VMT several strategies will be necessary. Land use planning needs to focus on providing housing closer to places of employment, services and commuter transit routes. Transit service will need to be expanded as will other Transportation Demand Management options such as ride sharing, parking policy and pricing, guaranteed ride home, etc.

- Transitioning 50% of light vehicles from gasoline to electric and avoiding any growth in vehicle miles traveled are appropriate intermediate planning goals.

Evaluation: The energy environment in which this analysis was developed is dynamic and uncertain. The Roadmap should be revisited at least every two years to determine if changes in State or Federal policy, technology, economic or other factors impact the underlying assumptions of the Roadmap and require adjustments to the 2050 scenarios.

Other Emission Reduction Strategies: The Energy Roadmap examined only those GHG emissions associated with fossil fuel energy use in Tompkins County. There are also potentials to reduce emissions associated with agriculture and waste management, as well as strategies to sequester greater amounts of carbon in soils and forests. These should also be explored and specific strategies identified that can complement and enhance efforts at energy GHG reductions.

Using the Roadmap

While the Energy Roadmap is primarily intended to present somewhat hypothetical options for meeting our long-term greenhouse gas emissions reduction goals, it contains detailed analyses that can inform decisions about specific projects, as well as the development of public policy to help hasten and smooth the energy transition that is needed to achieve emissions reduction goals. It identifies and discusses the opportunities and constraints that will impact future development of renewable energy resources and improvements in efficiency. It also identifies challenges that must be overcome and may suggest areas for further analysis and research. Finally, it is hoped that the Roadmap helps make thinking about a clean energy future more tangible, and that it provides hope that we can take concrete steps locally, which complement needed action at the state, national and global levels, to avert the most disastrous impacts of climate change.

Future Energy Scenarios

Xiyue Zhang, Mark Romanelli and K. Max Zhang

The objective of this chapter is to explain the scenario generator model that was developed to assess different options to meet the county's 2050 greenhouse gas (GHG) emissions reduction goal, and describe the Business As Usual Scenario and three possible future energy scenarios. The scenarios all contemplate changes in the energy infrastructure from 2015 to 2050. It should be recognized that this 35-year timeframe is roughly a generation – so contemplating the transition envisioned in the scenarios from the eyes of a baby in 2015 to an adult in 2050 is a helpful way of describing the impacts of these scenarios, illustrated in Figure 4.

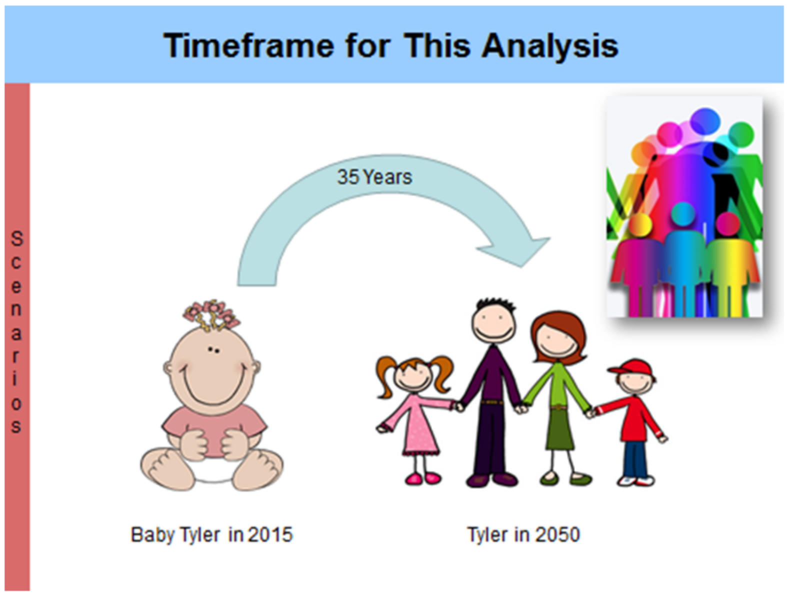


Figure 4 Thirty-five year timeframe for the Energy Roadmap

Components of the Scenario Generator Model

The model for future energy scenarios separated energy demand into three different sectors: Heating, Transportation and Electricity.

- Heating: Providing energy for thermal comfort in the winter seasons. Heating demand was accounted for in MMBtus (Million Metric British Thermal Units) and only GHG emissions resulting from providing heating with direct fossil fuel combustion were considered. The emissions associated with electricity-powered heating, such as using a ground- or air-source heat pump, were accounted for in the Electricity section.
- Transportation: Allowing members of the community to get from place to place and goods to be transported within the county. Transportation demand was recorded in Vehicle Miles Traveled (VMT) and only emissions that resulted from directly burning fossil fuel were considered for the transportation emission profile of the county. Emissions associated with VMT from electric vehicles (EVs), for instance, were accounted for in the Electricity section.
- Electricity: Electrical energy provided for the electric devices, lighting, heating, transportation, and other electrical needs in the county. Electricity demand was accounted for in terms of kWh.

We considered only the demand side so inefficiencies in the production and transmission of electricity were not considered.

To achieve the 80% GHG reduction goal, the overall GHG emissions in the county should not exceed ~237,324 MTCO2e by 2050. The main strategies for reducing GHG emissions were illustrated in Figure . Within the three sectors described above, the scenario generator model balanced grid-supplied electricity and fossil fuel energy with renewable energy generation potential and energy efficiency/demand reduction potential to create energy scenarios.

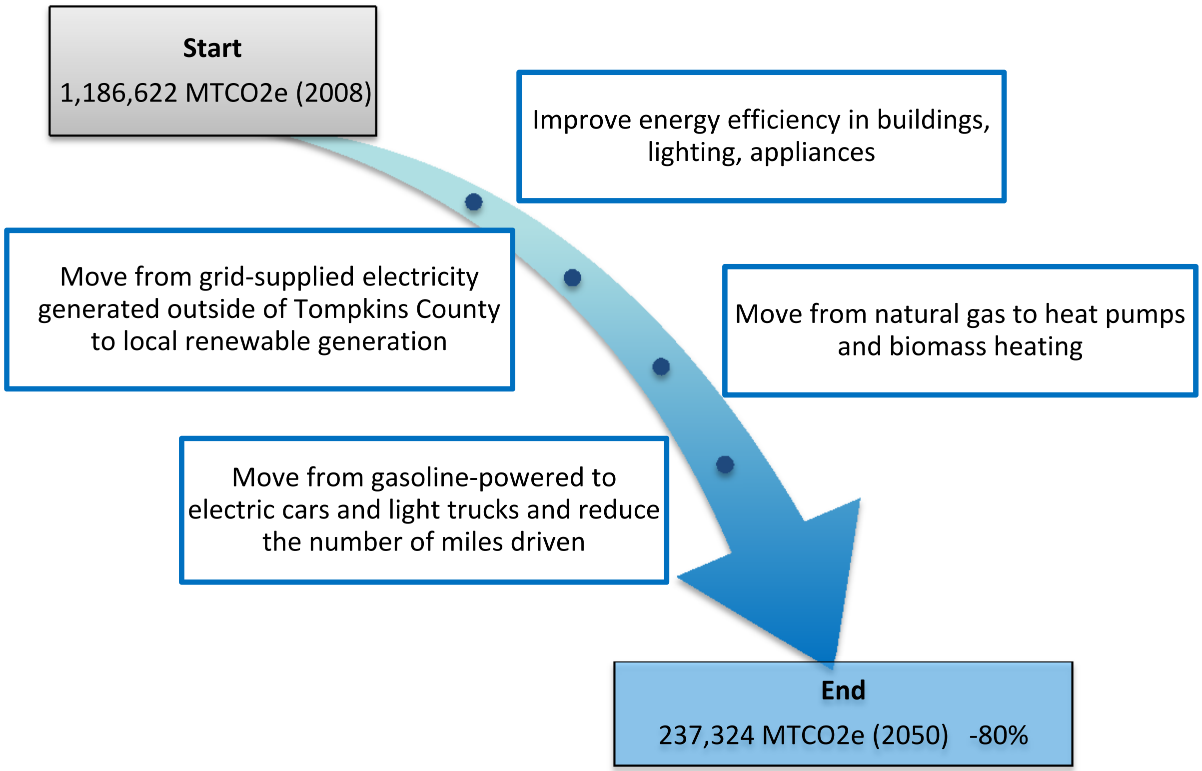


Figure 5 Main strategies for reducing GHG emissions in Tompkins County

Renewable Energy Generation Potential

Several chapters of the Energy Roadmap assess the renewable resources and technologies that could aid the county in reaching its goal. The findings of those chapters are summarized in Table 4 and

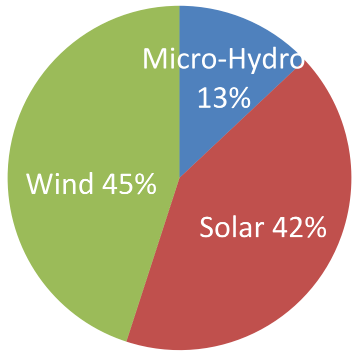


Figure 6.

Table 4 Summary of local renewable generation potential

Energy Sources		Electricity		Number of Household Powered
		Installed Capacity (MW)	Annual Energy Output (GWh)	
Solar Photovoltaics	Residential - Urban	15	16	1,863
	Residential - Rural	98	109	12,534
	Commercial	120	133	15,329
	Industrial	19	21	2,425
	Public and Community Services	73	81	9,279
	PV Farms	1,888	2,093	240,932
	Subtotal	2,212	2,453	282,361
Wind Energy	Small-Scale	18	33	2,348
	Medium-Scale	746	2,097	95,150
	Large-Scale	140	516	17,869
	Subtotal	904	2,646	115,367
Micro-Hydro		89	726	11,295
Local Renewable Electricity Generation Potential		3,205	5,825	409,024
Energy Sources		Heating (MMBtu/yr)		Number of Household Heated
Biomass Energy		3,626,477		39,851
Deep Geothermal Energy		Unlimited		N/A

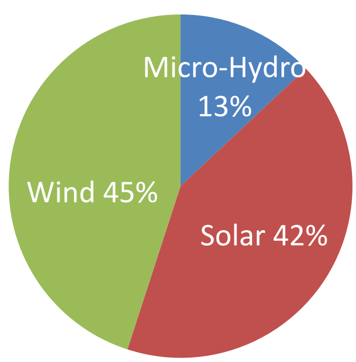


Figure 6 Local renewable electricity generation potential: 5824.7 GWh annual output

Energy Efficiency/Demand Reduction Potential

Other chapters of the Energy Roadmap assess the energy efficiency and demand reduction potential that could aid the county in reaching its goal.

- Existing Buildings: The Demand Side Management Chapter calculates the potential of energy saving from efficiency improvements in the existing building stock. Heating efficiency improvements include insulation and air sealing of the building envelop. Electrical efficiency improvements include upgrading appliances and lighting systems in buildings.

Table 5 Potential of energy saving from efficiency improvements in existing buildings

	Energy Saving Potential
Heating Efficiency Improvements	3,350,604 MMBtu/yr
Electrical Efficiency Improvements	1,368,557 MMBtu/yr, or 401 GWh

- New Construction: The ability to construct new buildings to higher energy efficiency standards will be significantly influenced by the currently adopted building codes (International Energy Conservation Construction Code 2012 as modified by the 2014 Supplement for commercial buildings and the 2010 Energy Conservation Construction Code for residential) which have been moving incrementally to be more energy efficient over time. Applying the building codes to new construction, it is projected that the overall average heating EUI would reach 7.7 Btu/hr per sq. ft. in 2050. This results in a EUI that is 15% below the 2008 baseline, equivalent to 1,152,880 MMBtu of energy saving.
- Transportation: 23.8% of the projected Vehicle Miles Traveled (VMT) can be reduced by transportation demand management, which includes encouraging transit, public bicycle and walking systems, carpooling and vanpooling assistance, car-sharing systems, employee/residential shuttle service, roadway/congestion pricing, and parking pricing and restrictions.

In summary:

Table 6 Percent of 2008 demand that could be met by local energy resources

	Energy Resource	Annual Energy Potential	% of 2008Electricity Demand[5]	% of 2008 Thermal Demand[6]	% of 2008 Total Energy Demand[7]
Renewable Supply	Wind	2,646 GWh	327%	n/a	63%
	Solar	2,453 GWh	303%	n/a	58%
	Micro-Hydro	726 GWh	90%	n/a	17%
	Biomass	3,626,477 MMBtu	n/a	59%	25%
Demand Reduction	Building Efficiency: Heating Portion	3,350,604 MMBtu	n/a	54%	23%
	Building Efficiency: Electrical Portion	401 GWh	50%	n/a	9%
	New Construction to Code	1,152,880 MMBtu	n/a	19%	n/a

[5] The grid supplied 809 gigawatt hours (GWh), a measure of electrical energy, of electricity in the community in 2008.

[6] In 2008, the thermal demand in the community was 6,169,985 million British Thermal Units (MMBtu), a measure of the energy content in fuel.

[7] Total energy demand, including electrical, thermal and transportation, was 14,438,224 MMBtu, or 4,231 GWh in 2008.

Scenarios

We created four scenarios representing a wide range of conditions of how the energy systems in the Tompkins County could evolve in the next 35 years, with three of them showing how that evolution could meet the County's GHG emissions goal.

- **Scenario A - Business As Usual (BAU):** The BAU Scenario quantifies greenhouse gas emissions and energy consumption in 2050 assuming that no particular actions, other than those already implemented or planned by 2015, are taken to reduce GHG emissions. Emission reductions of 31% are achieved based on adopted U.S. EPA Corporate Average Fuel Efficiency (CAFE) standards and New York's Renewable Energy Portfolio Standard and Energy Conservation Construction Code. These assumptions are applied to all of the Scenarios.
- **Scenario B – Mixed:** The Mixed Scenario assumes that energy services are provided by a mixture of fossil fuel and renewable resources, and that the amount of natural gas used by the industrial sector is at its 2008 level.
- **Scenario C – All Electric:** The All Electric Scenario assumes that all energy services (except heavy-duty and medium-duty vehicles) are provided by electricity.
- **Scenario D – Half Nature Gas:** The Half Natural Gas Scenario maintains half the amount of natural gas used by the community in 2008.

1. Scenario Generator Model Design

Major Assumptions Applied to All Scenarios

Many assumptions were made in creating scenarios. The model:

- Is based on analysis of potential of renewables and technology that are more viable in Tompkins County and that are commercially available today
- Only accounts for direct emissions. It does not quantify life-cycle emissions associated with any of the resources or technologies discussed
- Does not consider changes in weather patterns in the future based on impacts of climate change
- Analyzes a static point in time, 2050. It does not consider points along the way, and does not consider how quickly to achieve emissions reductions
- Only considers emissions from fossil fuels and therefore does not consider changing emissions from waste and agriculture. Non fossil fuel greenhouse gas emissions are assumed to remain constant between 2008 and 2050
- Does not consider emissions from air or rail travel due to limitations of data and accepted methodology for tracking those emissions
- Does not consider the costs of actions to achieve scenarios. Those costs are identified broadly as challenges in each topic chapter
- Does not consider future energy pricing and its impact on the consumer choices
- Acknowledges that there are many grid-level issues, such as interconnection, energy storage, peak demand, balancing renewable generation, infrastructure limitations and utility rate structure, that need to be solved to incorporate such high renewable penetration, but does not limit scenarios based on those challenges.

1.1 Estimating Growth Rates

In developing scenarios for the Roadmap, the future energy demand based on growth rates was incorporated into the scenario generator. Energy demand was evaluated in three sectors, namely heating, transportation and electricity.

Electricity demand growth was based on estimates provided by the U.S. Energy Information Administration. In its 2015 Outlook, the EIA estimated a 0.7% annual growth rate for electricity demand[1]. Extrapolating that for the 42 years between 2008 and 2050, resulted in a projected growth rate of 34.04% between 2008 and 2050.

Heating demand growth was assumed to parallel household growth rates in the county. The household growth rate, based on 2000-2010 Census figures and assumed to hold into the future, is projected to be 0.6783% annually [2] until 2050. Extrapolating that for the 42 years between 2008 and 2050, resulted in a projected growth rate of 32.83% between 2008 and 2050.

Utilizing the EPA Motor Vehicle Emissions Simulator (MOVES) model, VMT in the county is projected to grow by 34.2% over 2008-2050 [(8)]. This rate is larger than the projected growth of the county's population over the same period, i.e., 23.96% [2], based on the model's expectation of continued growth in a dispersed geographical pattern consistent with recent historical trends.

1.2 Scenario Generator Model Setting and Constraints

Heating [(9)] Renewables for Heating: Three renewable energy options were considered for meeting the heating demand: ground-source heat pumps (GSHP), air-source heat pumps (ASHP), and biomass combustion. For the purposes of the model, we assumed that GSHPs and ASHPs create no direct emissions but require an input of electricity, so emissions from heat pumps are included in the electricity sector. It should be noted that although the coefficient of performance (COP) for a GSHP can reach 5.0-7.2 and an ASHP COP can reach 2.2-3.8 under the right conditions we chose to use 3.5 for GSHP and 2.5 for ASHP in the model to make conservative estimates. The biomass resources quantified assumed sustainable harvest rates below the rates of carbon sequestration from plant and tree growth. Further, it was assumed that biomass heating is carbon neutral on an annual basis and there are no net emissions for the purposes of the model.

Reducing Heating Demand: The potential for reducing the heating demand in the existing building stock was also evaluated. This included improving building energy efficiency, i.e., insulation and air sealing, and other similar improvements. From the energy Demand-Side Management chapter, we found that 4,719,161 MMBtu/yr is the total energy saving potential from building energy retrofits within one year. The potential of heating efficiency improvements is 71% of that total, so 3,350,604 MMBtu/yr. In addition, for the purposes of accounting, energy efficiency was treated as an emission-free method of heating.

[(8)] Tompkins County Transportation Council MOVES simulation results. The simulation started from 2015, and it was assumed that the growth rate holds true for a simulation starting from 2008.

[(9)] For energy supplies to meet the heating demand of the county several sources were considered. Natural gas was the primary thermal energy source in the county in 2008, accounting for 69.0% of total demand. For modeling purposes, we assumed that natural gas is the only form of fossil fuels used for meeting heating demand in the county in 2050. In other words, fuel oil and propane would be totally replaced by 2050.

Energy efficiency for new construction based on the adopted NY Energy Conservation Construction Code was also incorporated into the model and applied to new construction assumed to be built through 2050. As is explained in the Demand-Side Management chapter, the model assumed that 15% of the heating demand could be met by constructing new more efficient buildings from 2008 to 2050, equivalent to 1,152,880 MMBtu of energy saving.

Adding these reductions together for existing and new buildings makes the total potential of non-electrical efficiency improvements 3,350,604+1,152,880=4,503,484 MMBtu.
Table 7 concisely lists all of our heating sources and assumptions. The "Maximum Deployment Percentage" is the maximum percent of the county's heating demand projected in 2050 (8,193,741 MMBtu) that can be supplied by each energy source's "Energy Potential". The "Energy Potential" is the actual amount of energy that this source of energy can theoretically supply based on the assessments in the resource chapters. Natural gas is assumed to be limited to 2008 levels.

Table 7 Heating assumptions

Heating Source	Maximum Deployment Percentage	Energy Potential (MMBtu/yr)	Emission Factor ($MTCO_2e/MMBtu$)	Electricity Demand ($MMBtu_{electricity}/MMBtu_{heat}$)
Natural Gas	100.0%	4,257,152 (2008 usage level)	0.053	N/A
Ground-Source Heat Pump	100.0%	N/A	0*	3.5 (typical COP of a GSHP)
Air-Source Heat Pump	100.0%	N/A	0*	2.5 (typical COP of an ASHP)
Biomass	44.2%	3,626,477	0	N/A
Non-Electrical Efficiency Improvements	55.0%	4,503,484	N/A	N/A

*Accounted for in electricity

Transportation Three types of fuels, i.e., diesel, gasoline, and electricity, and three vehicle classes, i.e., light-duty (LD), medium-duty (MD), and heavy-duty (HD), were considered for this analysis. Due to the constraint of only using commercially available technology, it was assumed that MD and HD vehicles could not be transitioned to electric in the future because that technology is not yet available.

In 2009, ~3.4% of VMT was by MD vehicles and ~1.3% of VMT was by HD vehicles [3]. Advised by transportation planners from the Ithaca-Tompkins Transportation Council, we assumed that those proportions were also valid from 2008 to 2050.

Table 8 VMT by vehicle classes

Vehicle Types	2009	Fraction
Light-duty Cars and Trucks	640,336,111	95.24%
Medium-duty	23,109,397	3.44%
Heavy-duty	8,874,046	1.32%

Light-Duty Vehicles: Additionally, the National Highway Traffic Safety Administration (NHTSA) and Environmental Protection Agency (EPA) have mandated that the Corporate Average Fuel Economy (CAFÉ) for LD vehicles (including passenger cars, SUVs, vans, and pickup/Classes 1-3 light trucks) reach at least 54.5 miles per gallon (MPG) by model year (MY) 2025 [4]. The penetration of hybrid electric vehicles, plug-in hybrid electric vehicles, and battery electric vehicles by MY 2025, as included by NHTSA and EPA in their compliance demonstration, is 5%, 0% and 2% respectively. Since the fleet of EVs considered is minimal, it was reasonable to assume that by 2025 the average MPG of new LD gasoline vehicles within the county will comply with this standard and that the average for all LD vehicles would achieve 54.5 MPG by 2050. Since no new CAFÉ standards have been announced, the current CAFÉ standards are assumed to hold beyond MY 2025.

Medium-Duty Vehicles: There are 8 classes of trucks based on gross vehicle weight rating (GVWR). Typically, Classes 4-6 are called MD (GVWR 14,001 lb – 26,000 lb) and 7-8 called HD (GVWR 26,001 lb and above) [5]. The fuel economy for MD trucks is regulated as "gallons of fuel/1,000 ton payload mile". The proposed regulation for fuel economy for MD vehicles calls for ~27.5 gallons per 1000 ton-mile effective 2027[6]. 1 ton of payload roughly corresponds to 36.4 MPG, and 2 tons of payload corresponds to 18.2 MPG [7]. An analysis by Khan and coworkers suggested an average MPG for "heavy-duty pick-up/vans" of 15.5 MPG by 2025 [8]. For the scenario generator model, we assumed an average of 20 MPG for medium-duty trucks by 2050.

Heavy-Duty Vehicles: DOE's SuperTruck project is one of several initiatives that are part of the 21st Century Truck Partnership. The goal of the SuperTruck Initiative was to develop a tractor that could meet or exceed 10 MPG – where tractors at this point are averaging between 5.5 and 6.5 mpg [9,10]. Advances in engines, aerodynamics and more helped the tractor project increase its fuel economy. For this model, we assumed an average of 10 MPG for heavy-duty trucks by 2050.

Electric Vehicles: The kWh/mile for EVs used in the model were based on the best practices at present and assumed to be carried into the future to 2050. Table 9 specifies the assumptions.

Table 9 Assumed kWh/mile for electric vehicles

Electric Vehicles	kWh/mile
Light-Duty	0.3
Medium-Duty	0.8
Heavy-Duty	1.3

Reducing Vehicle Miles Traveled: We also considered options to reduce the amount of light-duty vehicle miles driven altogether. Transportation Demand Management (TDM) is a broad field that involves reducing the overall demand for transportation by single-occupancy vehicles, while still providing a community with practical transportation solutions. A successful TDM plan does not limit the community's mobility, but instead expand options for sustainable, low emissions travel.

Examples of TDM include transit subsidies, roadway/congestion pricing, parking pricing and restrictions, public bicycle and walking systems, carpooling and vanpooling assistance, car-sharing systems, and employee/residential shuttle service. There are multiple benefits for TDM such as reduced congestion, safer roads, more capacity for other modes (bikes), reduced personal transportation costs, etc. Tompkins County already has a number of successful TDM programs including Ithaca Carshare, Zimride, and Way2Go. The Way2Go program, in particular, helps encourage people to seek varying types of transportation methods, overcome transportation barriers and make smarter transportation choices by offering educational programs, engaging in transportation dialogue, and working on collaborative projects. There are, however, significant challenges with TDM given that a large number of commuters live in rural and low-density suburban areas. For example, designing better public transit services for commuters requires a better understanding of common working hours, particularly within a sector or geographic area; however, collecting such information is often difficult.

For the purposes of accounting, each mile of travel reduced was considered to be emission-free. The maximum deployment percentage of TDM is half of for the total VMT for all light-duty vehicles, or 47.6% of all VMT. For the model, it was assumed that at most 50% of light-duty VMT could be reduced by TDM.

Table 10 below concisely lists all of our transportation options and assumptions. The “Maximum Deployment Percentage” is the maximum percent of the county’s VMT that can be served by this vehicle type. The definition for “Energy Potential” is the same as those defined above in the Heating section.

Table 10 Transportation assumptions

Vehicle Type		Maximum Deployment Percentage	Energy Potential (VMT)	Emission Factor (lb CO_2e/gallon)	Miles per Gallon	Electricity Demand [kWh/mile]
EV LD		95.2%	95.2% of the 2050 usage level	0	N/A	0.3
Gasoline LD		95.2%	N/A	19.8	54.5	N/A
Diesel	MD	3.4%	N/A	22.6	20.0	N/A
	HD	1.3%	N/A	22.6	10.0	N/A
TDM		47.6%	47.6% of the 2050 usage level	N/A	N/A	N/A

Electricity It addition to accounting for projected growth in electricity consumption, it was critical to account for increases in electricity use due to scenarios that called for conversion to electric vehicles or switching to heat pumps.

Renewable Design Factor: In 2008, the vast majority of electricity in the county came from the grid. Figure 7 shows the load duration curve (LDC) for Tompkins County. It was constructed by down-scaling the 2008 load data for NYISO Zone C by the population fraction in Tompkins County over the total population in Zone C, which is ~6.3%. The LDC showed the peak load of 184 MW and the average load of 119 MW in Tompkins County in 2008. Peak load was about 1.54 times the average load. Strategies such as demand response may reduce the peak demand, while others such as meeting heating demand with heat pumps might increase the peak demand, or change the timing of peak from summer to winter.

In the scenario generator model, we assumed that the shape of the load duration curve will remain unchanged in 2050. In other words, demand might grow in the future, but the ratio of the peak load over the average load will not change over time and will remain roughly 1.54.

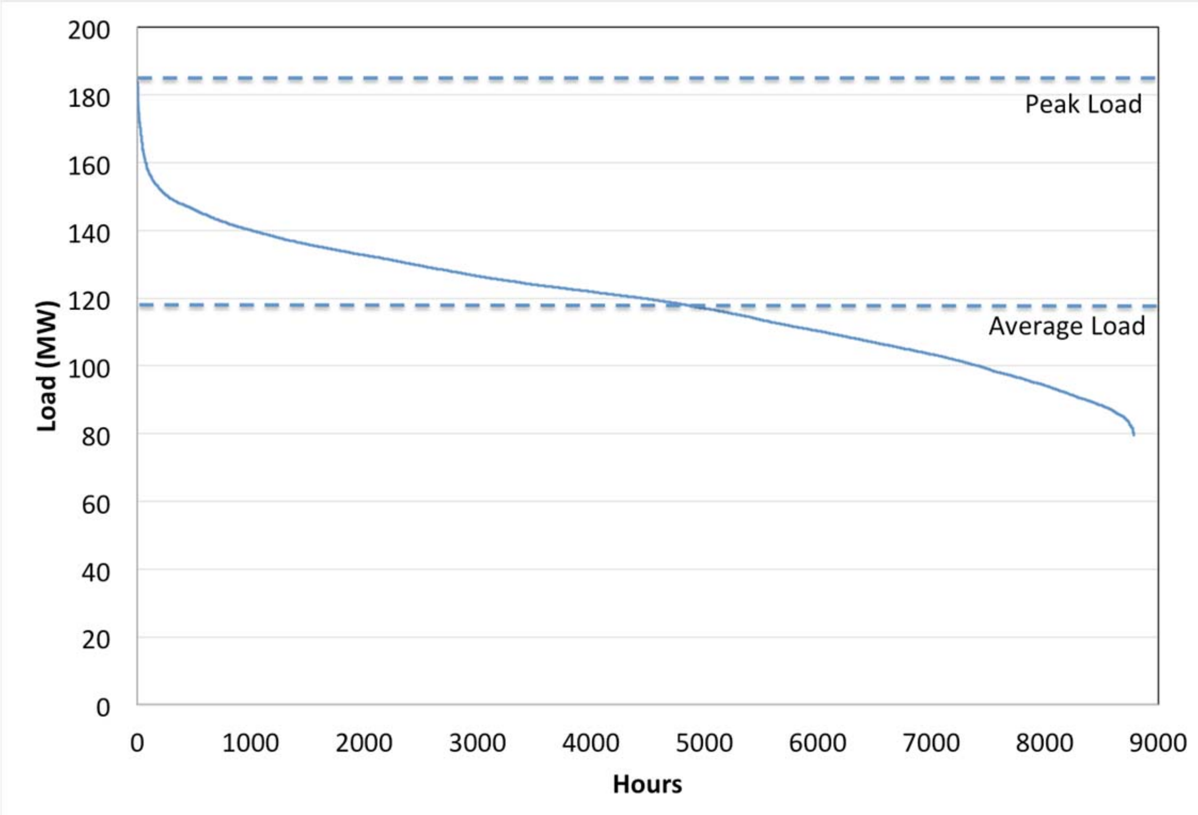


Figure 7 Tompkins County Load Duration Curve [11–13]

In the scenarios developed for 2050, we assumed that some portion of the electricity demand would be met with local generating capacity such as solar, wind, and micro-hydro, which are intermittent resources. To properly size the generation capacity of intermittent resources, we considered the following aspects:

- The sizes of the renewable systems should be based on capacity factors, not just the installation capacity. In other words, 1 MW of solar PV farm is treated as an effective 150 kW system if the capacity factor is 15% for meeting annual average load.
- The peak to average load ratio (1.54) should be incorporated so that the peak demand can be served if the entire electricity demand is powered by renewable systems.
- A reserve margin (above peak load) needs to be included to account for the fact that electricity generation from various forms of local renewable systems are not coincidental (i.e., depending on the availability of renewable resources). For the current power system (dominated by dispatchable generation systems) in New York State, the average reserve margin has been around 17% over the past 15 years [14]. For renewable systems, we increased the reserve margin to 30% to account for the intermittency.
- By considering the aspects described above, we adopted a design factor of 2 (=1.54*1.3) for renewable systems. Therefore, to meet 1 MWh of annual electricity demand, we sized the renewable systems to be able to generate 2 MWh of electricity on an annual basis.
- This design factor is a conservative assumption, and one that should be revisited frequently in the future as we better understand the ability to reduce peak demand using flexible storage, demand pricing and other demand response.

Greening the Electric Grid: Governor Andrew Cuomo announced in the fall of 2015 that the State Department of Public Service has been directed to design and enact a new Clean Energy Standard mandating that 50 percent of all electricity consumed in New York by 2030 comes from clean and renewable energy sources [15]. We assumed in our 2050 Business as Usual scenario, and all other scenarios that this standard was achieved and that grid electricity was generated from a fuel mix of 50% renewable energy and 50% natural gas running on highly efficient combined cycle technology. This assumption is due in part to the uncertainty of nuclear power with most plant licenses expiring during the coming decades. These assumptions yield a grid carbon intensity of approximately 0.44 lb/kWh [16,17], or 2.0×10^{-4} MTCO2e/kWh. In comparison, the grid carbon intensity of Tompkins County in 2008 was 5.0×10^{-4} MTCO2e/kWh [18], 2.5 times of the projected level.

Reducing Electric Demand: We accounted for the potential reduction in electricity demand due to appliances and lighting becoming more energy efficient. For the BAU scenario, it was conservatively assumed that we will achieve a 10% reduction in electricity use by 2050 due to increased use of more efficient lighting and appliances. The ENERGY STAR website states that ENERGY STAR labeled appliances [19] use 10%-25% less energy than conventional models and ENERGY STAR CFL/LED light bulbs use 70%-90% less energy than fluorescents. Assuming this is the best practice now and all electric appliances and lighting systems will reach these energy efficiency levels by 2050, a conservative value of 10% reduction in energy consumption was chosen and applied to all scenarios

The other scenarios also included this 10% assumption, but expanded that potential to be more reflective of work that could be done to retrofit electric systems in buildings. Based on the analysis in the energy Demand-Side Management chapter, 29% of the total energy saving from building energy retrofits is achieved by electrical efficiency improvements, such as lights and appliance upgrades. Therefore the potential of electrical efficiency improvements used in Scenarios B, C, and D is 29% × 4,719,161 MMBtu/yr = 1,368,557 MMBtu/yr or 401 GWh, in which 4,719,161 MMBtu/yr is the total energy saving potential from building energy retrofits within one year.

Table 11 summarizes these assumptions. The definition for "Energy Potential" is the same as that defined above in the Heating section.

Table 11 Electricity assumptions

Electricity Source	Energy Potential (GWh)	Carbon Intensity ($MTCO_2e/kWh$)	Design Factor
Grid	N/A	2.0×10^{-4}	N/A
Solar	2,453	0	2
Wind	2,646	0	2
Micro-Hydro	726	0	2
Non-Heating Efficiency Improvements	401	N/A	N/A

1.3 Scenario Generator Model Validation

In order to demonstrate the effectiveness of the model, we used it to reproduce the emissions levels of the county in 2008, the date of the most recent community-wide greenhouse gas emissions inventory. 2008 is also the base year for the County's 80% reduction by 2050 emissions reduction goal. Parameters in the model setting were reverse engineered from the county's Community GHG Emissions Report [18] as shown in Table 12.

Table 12 Model settings derived from the 2008 CO_2e inventory

Growth Percent	0.00%
$MTCO_2e$/MMBtu Heating Fuel Mix Usage	0.070259183
Avg. MPG for MD and HD Diesel (VMT/Gallons	4.7
MPG for LD Gasoline (VMT/Gallons Consumed)	17.0
$MTCO_2e$/kWh Electricity Usage	0.000321158

Table 13 2008 model validation

Sector	Energy Sources	Percent of Demand	Percent of Potential	Energy/VMT Supply*	CO2e Emissions (MTCO2e)	Contribution to the Emissions Reduction
Heating (MMBtu) (incl.Cornell heating demand)	Natural Gas	100%	145%	6,169,986	433,498	0%
	Ground-Source Heat Pump	0%	N/A	0	0	
	Air-Source Heat Pump	0%	N/A	0	0	
	Biomass	0%	0%	0	0	
	Non-Electrical Efficiency	0%	0%	0	0	
	Subtotal	100%	N/A	6,169,986	433,498	
Transportation (Mile)	Electric Light-Duty	0%	0%	0	0	100%
	Diesel Heavy-Duty	1%	N/A	8,874,618	19,356	
	Diesel Medium-Duty	3%	N/A	23,127,793	50,444	
	Gasoline Light-Duty	95%	N/A	640,317,143	338,793	
	Transportation Demand Management	0%	0%	0	0	
	Subtotal	100%	N/A	672,319,554	408,593	
Electricity (kWh)	Grid	100%	N/A	809,112,378	259,853	0%
	Solar	0%	0%	0	0	
	Wind	0%	0%	0	0	
	Micro-Hydro	0%	0%	0	0	
	Non-Heating/Cooling/Transportation Efficiency	0%	0%	0	0	
	Subtotal	100%	N/A	809,112,378	259,853	
Others (CO2e emissions from waste, agricultural activities, and Groton electricity purchase)		N/A	N/A	N/A	85,801	0%
Total CO2e Emissions (MTCO2e)		1,187,745				
Percent Change		0.1%				

As shown in Table 13, we can reproduce the 2008 CO_2e emissions inventory within ~.1% of the inventory value. With an error margin that slim, we determined that the model was valid and could be used to adequately predict the emissions within the county in 2050 given changing variables.

2. Scenarios and Discussion

The Scenario Generator Model serves as a tool to define probable scenarios under which the county's 80% GHG reduction goal could be reached. Four scenarios were generated: 1) Business as Usual, 2) Mixed, 3) All electric, and 4) Maintaining half of 2008 natural gas use. The rationale behind each scenario is explained below. In addition, in order to inform further decision-making the following information is provided: details about the percent of demand met by each energy source in the three sectors; the percent of energy potential reached by each source of supply; the energy supply and MTCO2e emissions from each energy source; total and each sector's' contribution to the emissions reduction; and opportunities and challenges influencing the actions to be taken under each scenario.

Table 14 and Table 15 summarize the main results from the scenarios.

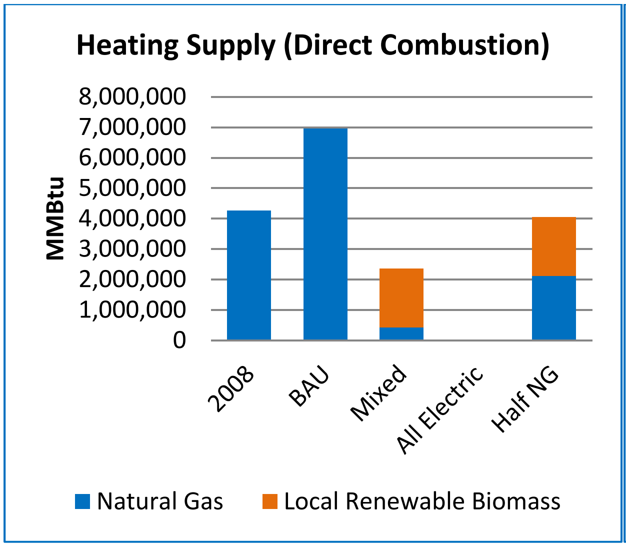
Table 24 Three future energy scenarios and business as usual

Scenarios	BAU	Mixed	All Electric	Half Natural Gas
% of 2008 Natural Gas Usage Maintained	164%	10%	0%	50%
% of Heating Demand Met by Local Renewables (including heat pump systems and biomass)	0%	67%	72%	29%
% of Projected Energy Demand Provided by Efficiency Improvements	4%	25%	25%	31%
% of Transportation Demand Met by Light-Duty Electric Vehicles	0%	36%	71%	71%
% of Electricity Demand Met by Local Renewables	3%	63%	49%	71%
% of MTCO2e Reduction	31%	80%	80%	80%

Table 15 Energy sources and GHG emissions – BAU, and three future energy scenarios

		2008	BAU	Mixed	All Electric	Half NG
Heating (Direct Combustion) (MMBtu)	Natural Gas	4,257,152	6,966,253	427,810	0	2,130,034
	Local Renewable Biomass	0	0	1,923,505	0	1,923,505
Transportation (US Gallon)	Gasoline & Diesel	44,344,145	18,509,924	8,654,674	2,742,849	2,742,849
Electricity (Including Heat Pumps and EVs) (kWh)	Grid	809,112,378	946,530,985	237,815,624	618,313,764	50,678,194
	Local Renewable Electricity	0	59,099,648	1,941,064,889	1,820,724,109	1,868,823,694
CO2e Emissions (MT)		1,186,621	815,165	237,311	237,322	237,324

The Heating Supply table in Figure 8 below shows that natural gas use will need to be curtailed under any of the future energy scenarios that allow the community to achieve its GHG reduction goals. The decreases in Transportation Sector Supply shown below result from the transition to electric vehicles and the reduction in vehicle miles traveled envisioned in the Roadmap, combined with projected decreases resulting from federal Corporate Average Fuel Efficiency standards.



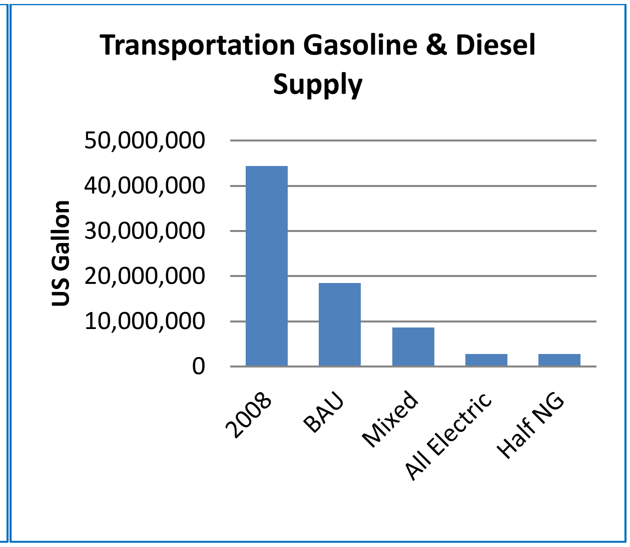
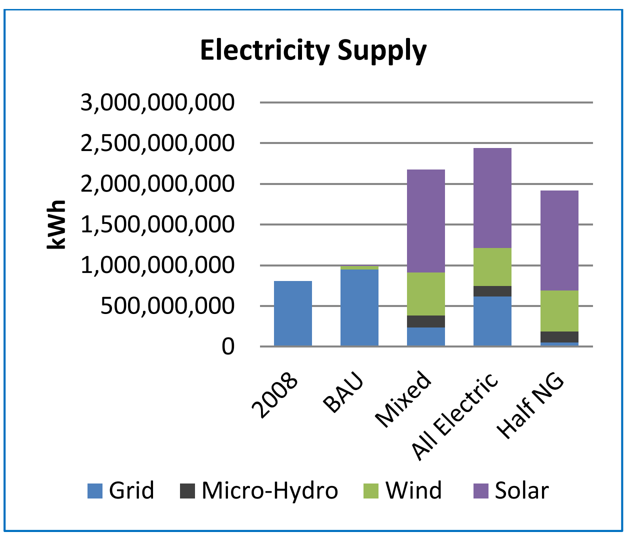


Figure 8 Heating and Transportation supply for 2008, BAU and the three future energy scenarios

As stated earlier, the renewable systems in the Roadmap were designed to generate 2 MWh for every 1 MWh of demand in order to compensate for the intermittent nature of renewables and the need to serve peak loads. The 2x design factor causes the electricity supply to be greater than the demand. This can be seen in the charts below.



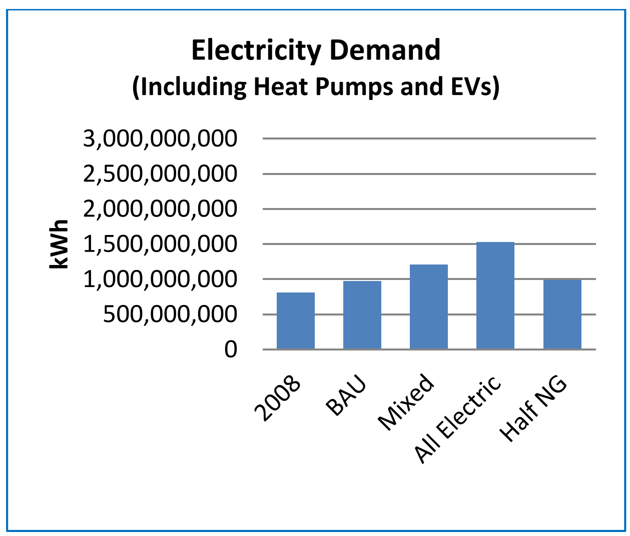


Figure 9 Electricity supply and demand for 2008, BAU, and the three future energy scenarios

Scenario A - Business As Usual

The Business As Usual (BAU) Scenario quantifies greenhouse gas emissions and energy consumption in 2050 assuming that no particular actions, other than those already implemented or planned by 2015, are taken to reduce GHG emissions.

The BAU scenario includes the following assumptions:

1. Uses projected growth rates of 33-34% (2008-2050) for electricity, heat and transportation based on Census, EIA, and MOVES software estimates.
2. New York State achieves its stated goal of half of its electric grid generation coming from renewable power sources by 2030.
3. Federal vehicle efficiency standards for increased MPGs of gasoline- and diesel-powered vehicles, as specified in the previous section, are assumed to be achieved.
4. Federal ENERGY STAR appliance and lighting efficiency standards, as specified earlier, are assumed to be achieved and a conservative 10% reduction in energy consumption was applied.
5. All new construction will be built to the adopted building code (Energy Conservation Construction Code) with heating EUI 15% below the 2008 baseline, equivalent to 1,152,880 MMBtu of energy saving.
6. Renewable energy projects that are in process as of 2015 are assumed to have been built by 2050. This includes the solar farms developed by Cornell, Tompkins Cortland Community College and the City of Ithaca, as well as the Black Oak Wind Farm. The capacity of PV systems installed, under construction, and/or planned in the county as of February 2015 was 10.8 MW, which is ~0.49% of the potential of solar electricity in the county that was quantified in the Solar chapter. The capacity of the Black Oak Wind Farm is 16.1 MW. This is ~1.8% of the potential of wind electricity in the county.

Table 16 Scenario A - Business as Usual

Sector	Energy Sources	Percent of Demand	Percent of Potential	Energy/VMT Supply*	CO2e Emissions (MTCO2e)	Contribution to the Emissions Reduction
Heating (MMBtu) (incl.Cornell heating demand)	Natural Gas	85%	164%	6,966,253	370,517	17%
	Ground-Source Heat Pump	0%	N/A	0	0	
	Air-Source Heat Pump	0%	N/A	0	0	
	Biomass	0%	0%	0	0	
	Non-Electrical Efficiency	15%	27%	1,229,339	0	
	Subtotal	100%	N/A	8,195,592	370,517	
Transportation (Mile)	Electric Light-Duty	0%	0%	0	0	64%
	Diesel Heavy-Duty	1%	N/A	11,909,738	12,209	
	Diesel Medium-Duty	3%	N/A	31,037,498	15,909	
	Gasoline Light-Duty	95%	N/A	859,305,606	141,821	
	Transportation Demand Management	0%	0%	0	0	
	Subtotal	100%	N/A	902,252,841	169,938	
Electricity (kWh)	Grid	87%	N/A	946,530,985	188,909	19%
	Solar	1%	0%	11,977,001	0	
	Wind	2%	2%	47,122,646	0	
	Micro-Hydro	0%	0%	0	0	
	Non-Heating/Cooling/Transportation Efficiency	10%	27%	108,453,423	0	
	Subtotal	100%	N/A	1,114,084,055	188,909	
Others (CO2e emissions from waste, agricultural activities, and Groton electricity purchase)		N/A	N/A	N/A	85,801	0%
Total CO2e Emissions (MTCO2e)		815,165				
Percent Change		-31%				

The results of the BAU Scenario indicate that without particular actions other than those already implemented or planned by the Federal and State governments, by 2050 GHG emissions will be 31% less than the 2008 level in spite of the growth in energy demand. This level of reduction, however, is far less than the county's 80% goal. Therefore, more aggressive scenarios need to be created to provide guidance to actions that should be taken by the county.

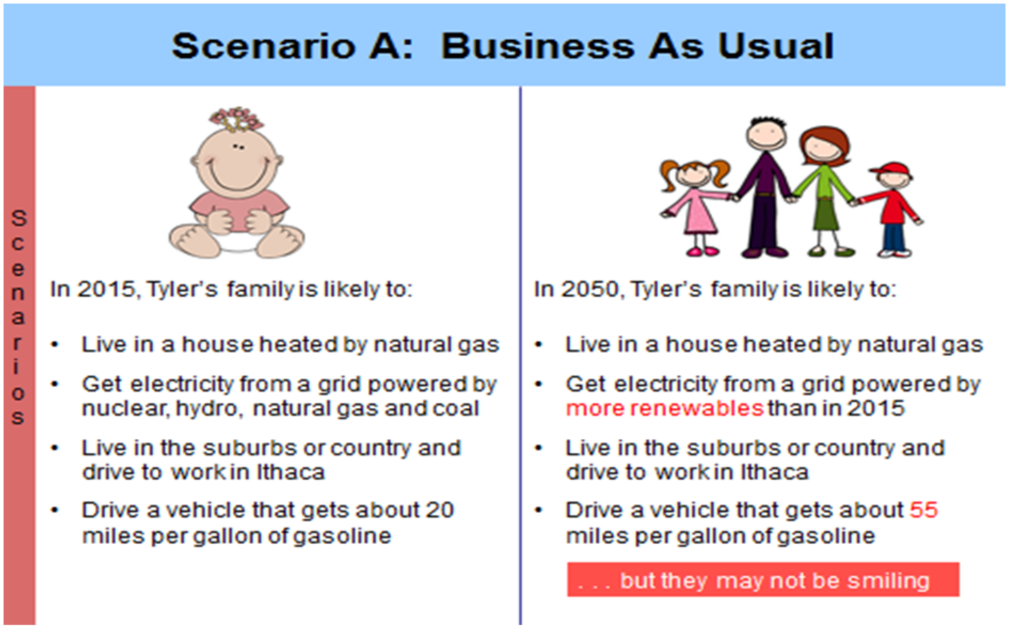


Figure 10 Tyler's future family in 2050 under BAU

Table 17 GHG emissions and energy consumption under BAU

	2008	2050 BAU
Emissions, MTCO2e	1,186,621	815,165
Heating (all fossil fuels) MMBtu	6,169,985	6,966,253
Grid Electricity, kWh	809,112,378	946,530,985
Transportation, miles	633,860,456	902,252,841

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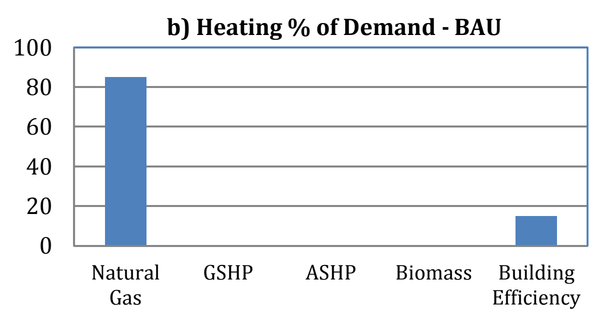

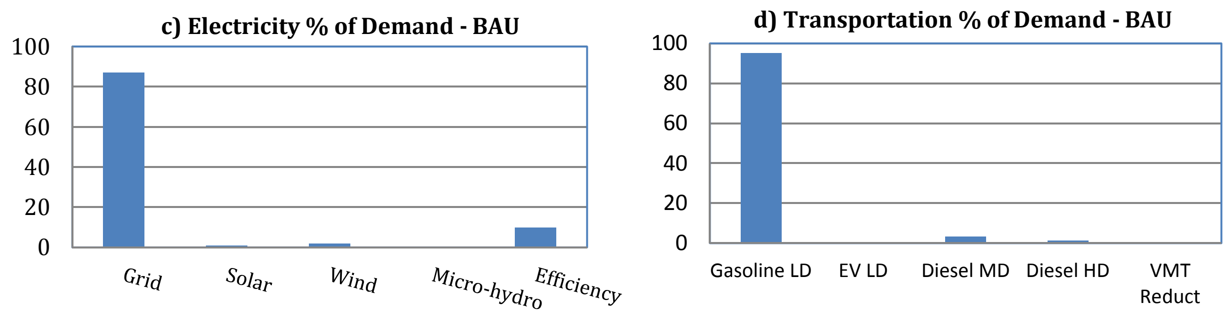

Figure 11 BAU: GHG emissions, heating sources, electricity sources and transportation

Three Future Energy Scenarios that Meet the 80% GHG Reduction Goal

For these future energy scenarios, renewable energy potential and energy efficiency potential were brought together to develop scenarios that could achieve the County's GHG reduction goal. It should be noted that several of the technologies and resources identified in the chapters were not included in these scenarios because they can be deployed in many different ways and in tandem with other resources and technologies mentioned. These include District Energy Systems, Battery Storage, and Deep Geothermal. Deep Geothermal, in particular, is not discussed because it has not yet been proven to work in the Northeast US so it is not yet a commercially viable technology in this region.

Assumptions built into each of the three future energy scenarios include:

- Uses all of the assumptions in the BAU Scenario as a base.
- Assumes that Solar achieves no more than 53% of its total potential.
- Assumes that Biomass achieves no more than 53% of its total potential.
- Assumes that Micro-hydro achieves no more than 20% of its total potential. As is analyzed in the Micro-hydro chapter, there are many restrictions to the employment of micro-hydro in the county, so a modest percent of potential is assumed.
- Assumes that Wind achieves less than the 53% of potential, and closer to 20% or less. This reflects the concern that visual impacts may make it difficult to achieve full potential of wind power and a more modest tapping of this resource is conservative.
- Non-electrical building energy efficiency (building retrofits and new construction built to code) achieves 50%-80% of potential.
- Transportation Demand Management achieves no more than 50% of potential.
- Electric medium-duty and heavy-duty vehicles are not considered as viable replacements to their diesel counterparts in 2050 because there is no proven technology at this point to allow for the conversion, so MD and HD vehicles continue to rely on diesel.
- Non-heating/transportation efficiency (lighting and appliances) achieves no more than 80% of potential.
- Balance the percent of heating demand met by ground source heat pumps and air source heat pumps, reflecting the fact that each technology has its advantages in different situations.

Scenario B - Mixed

The Mixed Scenario quantifies greenhouse gas emissions and energy consumption in 2050 using the following assumptions, in addition to those identified for all scenarios, above:

1. Maintains the amount of natural gas used by the industrial sector at its 2008 level, i.e., 10% of the total amount of natural gas used in the county in 2008 in 2050. This recognizes that alternatives to natural gas use may not be as easily achieved in the industrial sector and maintains gas use equivalent to 2008 industrial use levels.
2. Assumes that 50% of the gasoline light-duty vehicles employed in 2008 are to be replaced by electric light-duty vehicles in 2050, and balance the percent of transportation demand met by gasoline light-duty vehicles and electric light-duty vehicles.
3. Assumes that Wind achieves 20% of potential, well below the 53% achieved by solar and biomass.

Table 18 Scenario B - Mixed

Sector	Energy Sources	Percent of Demand	Percent of Potential	Energy/VMT Supply*	CO2e Emissions (MTCO2e)	Contribution to the Emissions Reduction
Heating (MMBtu) (incl.Cornell heating demand)	Natural Gas	5%	10%	427,810	22,754	43%
	Ground-Source Heat Pump	22%	N/A	1,795,244	0	
	Air-Source Heat Pump	22%	N/A	1,795,244	0	
	Biomass	23%	53%	1,923,505	0	
	Non-Electrical Efficiency	28%	50%	2,253,788	0	
	Subtotal	100%	N/A	8,195,592	22,754	
Transportation (Mile)	Electric Light-Duty	36%	37%	322,194,490	0	34%
	Diesel Heavy-Duty	1%	N/A	11,909,738	12,209	
	Diesel Medium-Duty	3%	N/A	31,037,498	15,909	
	Gasoline Light-Duty	36%	N/A	322,194,490	53,175	
	Transportation Demand Management	24%	50%	214,916,627	0	
	Subtotal	100%	N/A	902,252,841	81,293	
Electricity (kWh)	Grid	16%	N/A	237,815,624	47,463	22%
	Solar	41%	52%	1,265,393,231	0	
	Wind	17%	20%	530,382,370	0	
	Micro-Hydro	5%	20%	145,289,288	0	
	Non-Heating/Cooling/Transportation Efficiency	21%	80%	321,012,859	0	
	Subtotal	100%	N/A	2,499,893,371	47,463	
Others (CO2e emissions from waste, agricultural activities, and Groton electricity purchase)		N/A	N/A	N/A	85,801	0%
Total CO2e Emissions (MTCO2e)		237,311				
Percent Change		-80%				

The prominent feature of the Mixed Scenario is the fairly balanced mix of energy sources and technology transition required to achieve the GHG reduction goal. It envisions utilizing all of the major sources of renewable energy, maintaining some degree of natural gas use, drawing on electricity from the power grid, and transitioning to a significant degree to EVs and heat pumps.

The major challenges in the Mixed Scenario are 1) deploying renewables at the scale required to achieve 80% reduction in emissions, 2) achieving the TDM and building retrofit assumptions, 3) achieving the transition to half light-duty electric vehicles, and 4) uncertainty regarding whether the natural gas supply can be maintained if it is providing only 5% of demand – it may not be available or a more cost-effective form of a distributed supply chain like current propane delivery could be required.

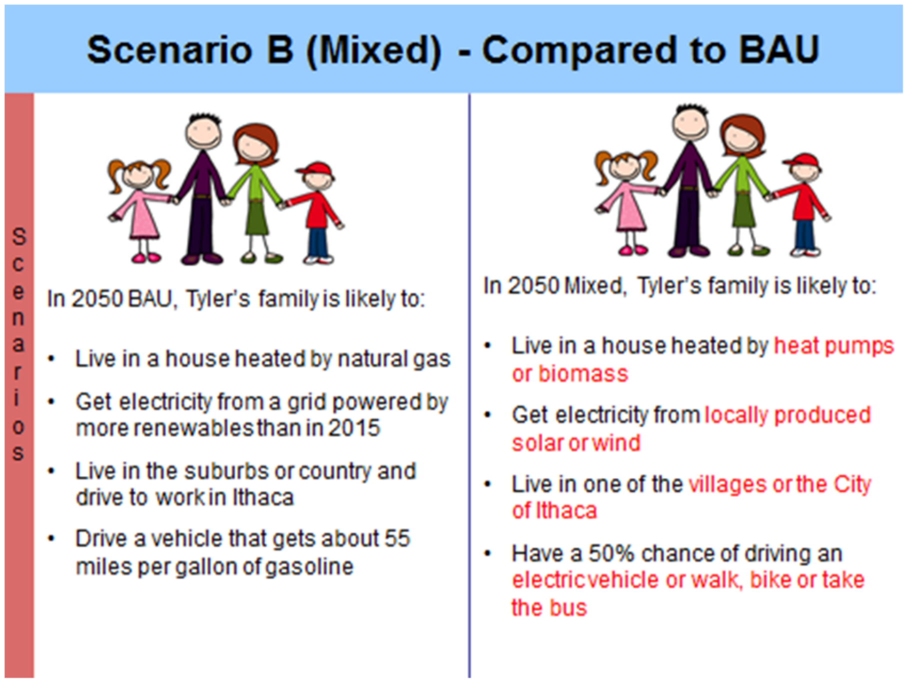

Figure 12 Tyler's future family in 2050 under the Mixed Scenario B

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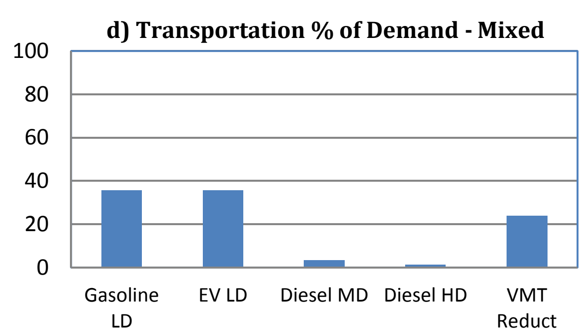

Figure 13 Mixed: GHG emissions, heating sources, electricity sources and transportation

Scenario C - All Electric

The All Electric Scenario quantifies greenhouse gas emissions and energy consumption in 2050 using the following assumptions, in addition to those identified for all scenarios, above:

1. All three sectors rely on electricity as their source of energy.
2. Heating demand is primarily met by GSHP and ASHP in equal amounts.
3. There is no biomass used for heating.
4. All of the light-duty vehicles are electric.
5. Assumes that Wind achieves 18% of potential, well below the 53% achieved by solar.

Table 19 Scenario C- All Electric

Sector	Energy Sources	Percent of Demand	Percent of Potential	Energy/VMT Supply*	CO2e Emissions (MTCO2e)	Contribution to the Emissions Reduction
Heating (MMBtu) (incl.Cornell heating demand)	Natural Gas	0%	0%	0	0	46%
	Ground-Source Heat Pump	36%	N/A	2,970,902	0	
	Air-Source Heat Pump	36%	N/A	2,970,902	0	
	Biomass	0%	0%	0	0	
	Non-Electrical Efficiency	28%	50%	2,253,788	0	
	Subtotal	100%	N/A	8,195,592	0	
Transportation (Mile)	Electric Light-Duty	71%	75%	644,388,979	0	40%
	Diesel Heavy-Duty	1%	N/A	11,909,738	12,209	
	Diesel Medium-Duty	3%	N/A	31,037,498	15,909	
	Gasoline Light-Duty	0%	N/A	0	0	
	Transportation Demand Management	24%	50%	214,916,627	0	
	Subtotal	100%	N/A	902,252,841	28,117	
Electricity (kWh)	Grid	33%	N/A	618,313,764	123,403	14%
	Solar	33%	50%	1,227,749,557	0	
	Wind	13%	18%	465,353,704	0	
	Micro-Hydro	3%	18%	127,620,849	0	
	Non-Heating/Cooling/Transportation Efficiency	17%	80%	320,901,699	0	
	Subtotal	100%	N/A	2,759,939,573	123,403	
Others (CO2e emissions from waste, agricultural activities, and Groton electricity purchase)		N/A	N/A	N/A	85,801	0%
Total CO2e Emissions (MTCO2e)		237,322				
Percent Change		-80%				

The prominent feature of the All Electric Scenario is the complete transition of power for heating and transportation to electricity. Since there is great potential for generating electricity with renewable energy, this approach allows for GHG reductions to be achieved. It also, however, requires a significant increase in the use of grid-electricity if the local renewable potentials are held to 53% and 20%, as described above, so achieving greater GHG reductions would require the grid to become even greener by 2050. Overall, there is about 2.6 times the amount of power required to be supplied from the grid in the All Electric Scenario than in the Mixed Scenario.

The major challenges in the All Electric Scenario are 1) deploying renewables at the scale required to achieve 80% reduction in emissions, 2) achieving the TDM and building retrofit assumptions, 3) achieving the transition to 100% light-duty electric vehicles, and 4) the impact on the electric grid of adding transportation and heating demand to such a degree.

Regarding the impact on the electric grid, one concern, highlighted in a 2007 study conducted by Oak Ridge National Lab, is that EVs will result in an increase in power demand and a change in power usage patterns that will have to be accommodated by the grid. There is, however, an opportunity to influence power usage patterns by consumers.. If EV owners choose to plug in their cars in the early evening when demand is highest, the result is an increase in peak load and the overload of certain lines or substations [20]. On the other hand, if EV owners plug in their cars to charge during the night, the effect is an increase in base load power generation. There is even speculation that EV batteries could work as battery storage appliances for power storage.

A recent report from Pecan Street, a research and development organization based in Austin, Texas, has overturned some of the assumptions regarding EVs [21]. Most importantly, it found that there was a much broader distribution in charging times and, when EV drivers were subjected to time-of-use energy pricing, only 12% of all charging occurred during peak hours. Additionally, it found that EV owners rarely waited for their batteries to fully discharge; rather they would opt to charge their vehicles a little each day. This study shows that EV owners are willing to alter usage patterns given the right incentive.

A related problem is the issue of clustering. EVs tend to be unevenly distributed geographically. Residents of more affluent and/or environmentally conscious areas are more likely to purchase EVs than residents in other areas. This means that certain areas within the county will likely have big changes in electricity demand when compared to areas that are slower to buy EVs. If these neighborhoods then begin charging their vehicles all at once, there could be a significant strain placed on the local distribution lines. The MIT Technology Review suggests that communication between utilities, automakers and EV owners could help utilities act proactively to prevent these issues [22].

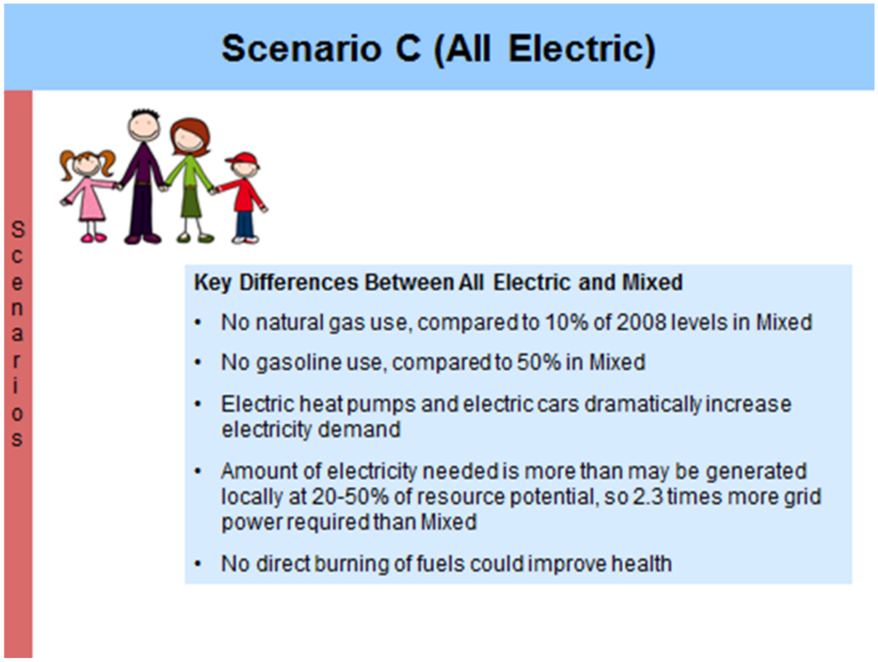

Figure 14 Tyler's future family in 2050 under the All Electric Scenario C

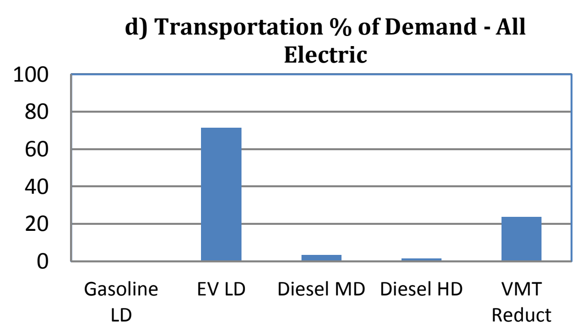

Figure 15 All Electric: GHG emissions, heating sources, electricity sources and transportation

Scenario D - Maintaining Half of 2008 Natural Gas Use

The Maintaining Half of 2008 Natural Gas Use Scenario quantifies greenhouse gas emissions and energy consumption in 2050 using the following assumptions, in addition to those identified for all scenarios, above:

- Maintains half the amount of natural gas used by the community in 2008.
- Non-electrical building energy efficiency (building retrofits) must be increased from 50% of potential to achieving 80% of potential.
- All of the light-duty vehicles are electric.
- Assumes that Wind achieves19% of potential.

Table 20 Scenario D - Maintaining Half of 2008 Natural Gas Use

Sector	Energy Sources	Percent of Demand	Percent of Potential	Energy/VMT Supply*	CO2e Emissions (MTCO2e)	Contribution to the Emissions Reduction
Heating (MMBtu) (incl.Cornell heating demand)	Natural Gas	26%	50%	2,130,034	113,291	34%
	Ground-Source Heat Pump	3%	N/A	268,815	0	
	Air-Source Heat Pump	3%	N/A	268,815	0	
	Biomass	23%	53%	1,923,505	0	
	Non-Electrical Efficiency	44%	80%	3,604,421	0	
	Subtotal	100%	N/A	8,195,592	113,291	
Transportation (Mile)	Electric Light-Duty	71%	75%	644,388,979	0	40%
	Diesel Heavy-Duty	1%	N/A	11,909,738	12,209	
	Diesel Medium-Duty	3%	N/A	31,037,498	15,909	
	Gasoline Light-Duty	0%	N/A	0	0	
	Transportation Demand Management	24%	50%	214,916,627	0	
	Subtotal	100%	N/A	902,252,841	28,117	
Electricity (kWh)	Grid	4%	N/A	50,678,194	10,114	26%
	Solar	47%	50%	1,227,770,669	0	
	Wind	19%	19%	502,863,519	0	
	Micro-Hydro	5%	19%	138,189,507	0	
	Non-Heating/Cooling/Transportation Efficiency	25%	80%	321,048,968	0	
	Subtotal	100%	N/A	2,240,550,856	10,114	
Others (CO2e emissions from waste, agricultural activities, and Groton electricity purchase)		N/A	N/A	N/A	85,801	0%
Total CO2e Emissions (MTCO2e)		237,324				
Percent Change		-80%				

The prominent feature of the Maintaining Half of 2008 Natural Gas Use Scenario is the ability to allow for significant natural gas use in the future while still achieving the 80% reduction in GHG emissions goal. However, in order to continue using that amount of fossil fuel energy requires that much more of the building retrofit potential be achieved, that 100% of light-duty vehicles transition to EVs, and that more wind power be built than in other scenarios.

The major challenges in the Maintaining Half of 2008 Natural Gas Use Scenario are 1) deploying renewables at the expanded scale required to achieve 80% reduction in emissions, 2) achieving the TDM and the heightened building retrofit assumptions, and 3) achieving the transition to 100% light-duty electric vehicles.

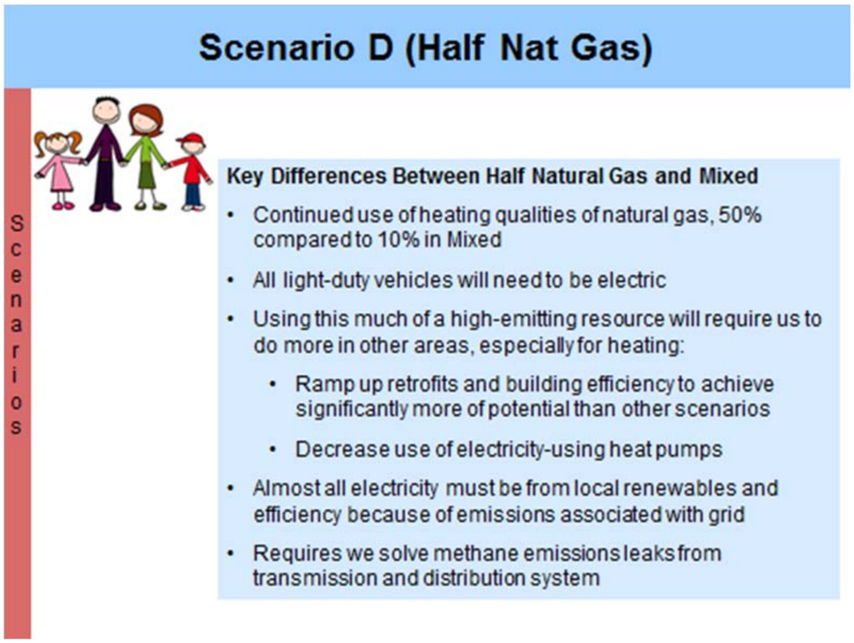

Figure 16 Tyler's future family in 2050 under the Half Natural Gas Scenario D

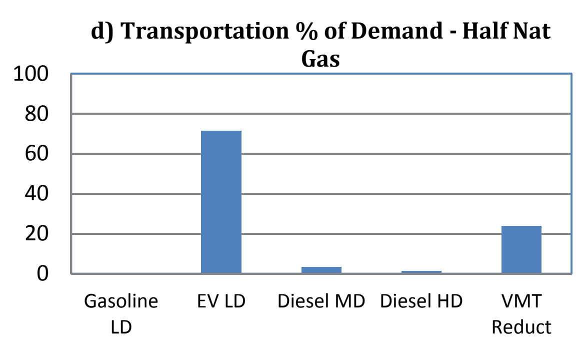

Figure 17 Half Natural Gas: GHG emissions, heating sources, electricity sources, transportation

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Overview of Tompkins County Energy System

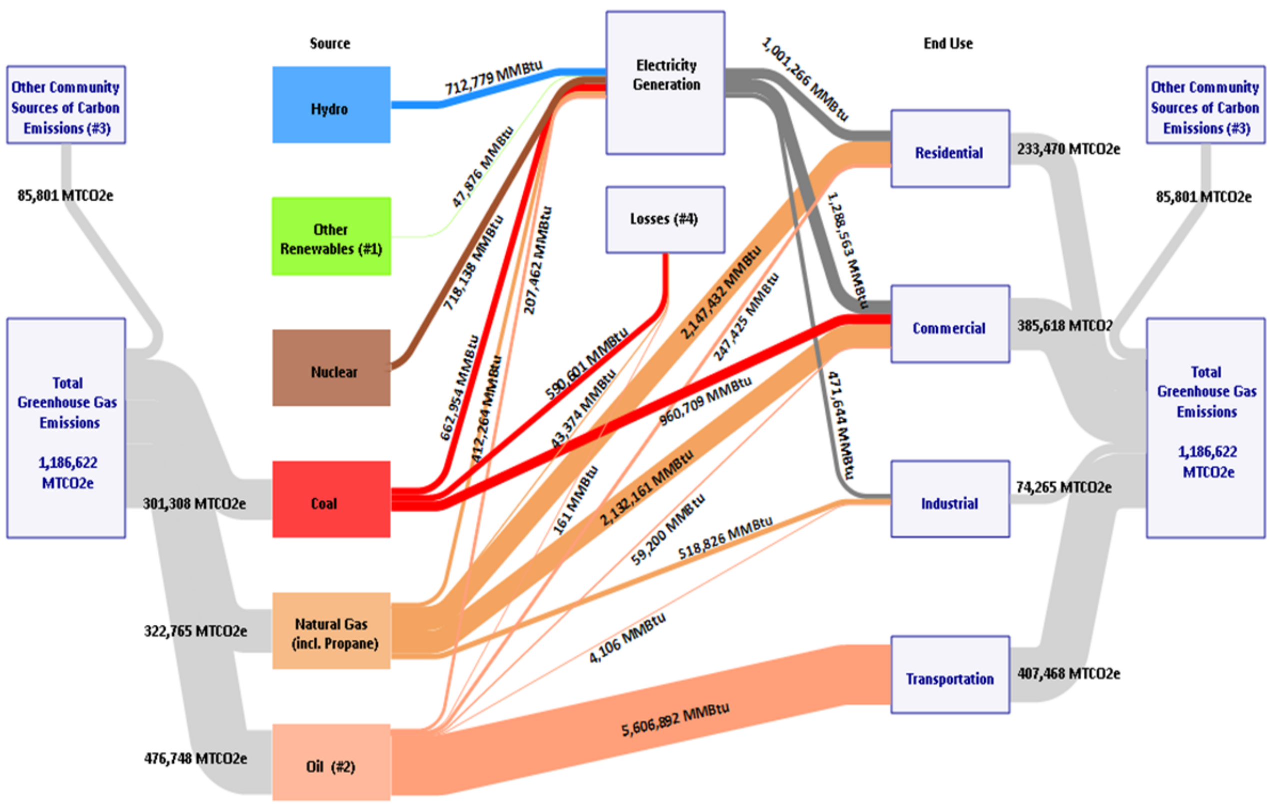
Xiyue Zhang and K. Max Zhang

Executive Summary

In this section, we present and analyze energy consumption and greenhouse gas (GHG) emissions in Tompkins County in 2008, the most recent year inventoried, by their primary sources and end-use sectors. Essentially, this overview describes the baseline for the Energy Roadmap.

The Tompkins County 2008 Greenhouse Gas Emissions Inventory [1] documents community energy use and GHG emissions. The information is illustrated as flows of energy and GHG emissions shown in Figure 18.

2008 Tompkins County Energy Flow and Greenhouse Gas Emissions



Data Sources:
Energy use by sectors and greenhouse gas emissions sources from Tompkins County 2008 GHG Emissions Inventory, developed using the 2009 version of ICLEI's Clean Air Climate Protection (CACP) software. Electricity fuel sources used for Tompkins County 2008 GHG Emissions Inventory is EPA eGRID Profiler, Year 2005 eGRID Subregion Resrouce Mix, NPCC Upstate NY: Nuclear 27%, Hydro 26.4%, Coal 21.5%, Natural Gas 15.5%, Oil 7.8%, Biomass 1.2%, Other Fossil Fuel 0.4%, and Wind 0.1%. Energy use of Cornell University is accredited to the Department of Energy & Sustainability and the Department of Facilities Management under the Cornell Infrastructure Properties and Planning.

Notes:
#1. Other Renewables include solar, wind, biomass, and geothermal energy sources.
#2. Oil includes heating fuel, diesel, gasoline, motorcycle gasoline, and transit bus diesel.
#3. Other Community Sources of Carbon Emissions include Waste (41,792 MTCO2e), Agriculture (43,996 MTCO2e) and Groton Electricity Use (13 MTCO2e).
#4. Energy losses in the conversion from fossil fuel to electricity and/or thermal energy.

Figure 18 Tompkins County energy flow and greenhouse gas emissions, 2008

Heating Energy sources for heating include heating oils (included in category "oil"), propane (included in category "natural gas"), coal, and natural gas. Other sources of heating energy such as solar thermal, biomass (wood), and geothermal are not included, primarily due to limitations of data and the limited use of those fuels. For example, less than 2% of residential buildings in the county used biomass (mainly wood) as a source for heating energy [2] in 2008, making it fairly insignificant compared with the consumption of natural gas and oil for heating over all sectors.

Electricity It is worth noting that we treat electricity consumption as site energy use. In other words, the conversion loss in generating electricity and transmission/distribution losses are not accounted for in the energy flow. However, the conversion loss is considered in calculating the GHG emissions associated with electricity consumption. And it is further assumed that electricity used by electric vehicles was negligible in 2008.

GHG Emissions The total GHG emissions in the county in 2008 was 1,186,622 metric ton (MT) CO2e, out of which 1,100,820 MTCO2e was from energy use. This includes electricity usage, fuels for heating/cooling and transportation, and local power generation. GHG emissions from Cornell University, Ithaca College (IC), and the Tompkins County Community College (TC3) in 2008 were about 267,100 MTCO2e [3] (out of which 153,537 MTCO2e were from operation of the Cornell central energy plant [4]; without accounting for air travel), 30,000 MTCO2e (without accounting for air travel) [5], and 2,366 MTCO2e (without accounting for ground transportation and air travel) [6], respectively.

2008 site energy uses and CO2e emissions in the residential and transportation sectors are presented in Table 21 below. In comparison, the New York State average GHG emission per capita is ~ 8.1 MTCO2e and the U.S. average is ~17.6 MTCO2e. Thus, even at the 2008 level, the Tompkins County average GHG emission per capita was relatively low. To maintain a stable climate, it's commonly estimated that global per capita emissions must be reduced to no more than 2 MTCO2e by 2050 [7].

Table 21 Site energy use and MTCO2e emissions, 2008

Sector	Residential	Transportation	Total
MTCO2e/Household	6.24	10.88	17.12
MTCO2e/Person	2.31	4.03	6.34
MMBtu/Household	91	150	241
MMBtu/Person	34	55	89
kWh/Household	7,835	N/A	7,835
kWh/Person	2,901	N/A	2,901

* In 2008, the county had 37,443 households [8] and a population of 101,136 [9].

1. Energy Supply by Fuel Types

1.1 Electricity

The county's electricity is generated from a variety of sources, most of which are located outside of the local area. Electrons are indistinguishable from one another once they are fed into the grid, making it impossible to determine the exact source of the electricity being imported into the county from outside generating stations. The electricity fuel mix for the region, however, provides a reasonable proxy that is bounding and tractable. Upstream emissions caused by energy losses from electricity transmission, delivery, and storage are not accounted for in the emission inventory. The one exception to this is with the Cornell Central Energy Plant, which produces and delivers electricity to the Cornell campus. Losses associated with this electricity production are shown in Figure 18 as "Losses".

1.1.1 2008 Fuel Mix

The total electricity consumed in the county in 2008 was 809,112,378 kWh. This includes 220,000,000 kWh of electricity Cornell University purchased from the grid[4] as well as electricity produced by Cornell on site. In 2008, Cornell consumed 65,420 short tons of coal, 1,211,000 therms of natural gas, and 3,200 gallons of fuel oil for energy (i.e., electricity and heat) generation at its Central Energy Plant[1]. In addition, Cornell generated 3,100,000 kWh of electricity from its hydroelectric plant in 2008, all of which was consumed on site[4].

The hydro power purchased by the Groton Electric Department is not directly included in the county's electricity fuel mix either since that purchase agreement is a financial transaction and does not necessarily mean that the Village of Groton is physically using the hydro power. This is due to the aforementioned characteristics of the grid, where electrons are indistinguishable from one another.

According to the EPA eGRID Profiler Sub-region Resource Mix for Upstate NY, the estimated electricity fuel mix for the county in 2005 (the year utilized by the Clean Air Climate Protection software used to prepare the 2008 GHG emissions inventory) is presented in Table 22 [10].

Table 22 Tompkins County electricity fuel mix used in the 2008 emission inventory

Energy Sources	Nuclear	Hydro	Coal	Natural Gas	Oil	Other Renewables	Other Fossil Fuels
Percent	27.0%	26.4%	21.5%	15.5%	7.8%	1.3%	0.5%

In perspective, in 2013, New York State's electricity fuel mix was 41% gas and oil, 32% nuclear, 18% hydro, 3% coal, and 3% wind in 2013 [11]. It is striking that the electricity generated from coal-fired power plant has diminished. Accordingly, the carbon intensity of grid electricity has greatly decreased since 2008. However, it should be noted that due to methane emissions associated with the hydro-fracking process, emissions from hydro-fracked natural gas may be a more potent greenhouse gas than coal in the short-term, making grid-generated greenhouse gas emissions worse in the short-term [12].

1.1.2 Developments from 2008 until Present

Cornell University generates electricity for on-site use at its hydroelectric plant and central energy plant (CEP). The hydroelectric plant, with a total rated capacity of 1,870 kW, was built on campus in 1904 when Beebe Lake was created [13]. CEP, now fueled by natural gas with a nameplate capacity of 30 MW, was originally constructed in 1922 [13]. Both facilities went through multiple renovations over the years. At the time of the 2008 GHG emissions inventory, the CEP was powered mostly by coal. Emissions from the CEP were 153,537 MTCO2e and are added to the overall Tompkins County GHG emissions inventory under the "Commercial" category.

Cornell Combined Heat and Power Plant (CCHPP), the newest and most significant addition to CEP, was commissioned in December 2009. CCHPP has an operating efficiency of ~75% [13], compared to 33% on average for conventional electricity generation [14]. The central energy and hydroelectric plants combine to meet ~86% of the university's annual electricity needs, which total ~215,000 MWh annually, leaving

~35,000 MWh to be purchased from the grid through the university substation each year [13]. Since CCHPP was not commissioned until end of 2009, its GHG emissions are not counted in the 2008 inventory.

Cayuga Power Plant, formerly known as AES Cayuga, was commissioned in 1955. The plant is fueled by coal and has a capacity of 306 MW [15]. Though the Cayuga Power Plant is an important constituent of the county's electricity fuel mix, GHG emissions from the Cayuga Power Plant are not double-counted in the inventory because the plant supplies electricity to end-users through the public power transmission and delivery system, and those emissions are already counted in the inventory at end use. In 2014, two competing proposals regarding the future of the Cayuga Power Plant were submitted to the New York State Public Service Commission (PSC) [16]. NYSEG supports upgrading the electrical transmission system to bring external electricity to the region, which would result in the ultimate retirement of the power plant. Cayuga Power Plant, on the other hand, proposes retrofitting the plant to a gas-fired facility to improve the power grid's reliability [17]. The final decision will be made by PSC.

Black Oak Wind Farm, located in the Town of Enfield, is expected to have an installation capacity of 16.1 MW (enough to power about 5,000 homes per year) from seven 2.3 MW GE turbines after its planned construction in 2016 [18]. In fall 2014, Cornell agreed to purchase all electricity to be generated by the proposed wind farm through a power purchase agreement.[19] The purchase will provide about 20 percent of Cornell's annual electricity use, and it will reduce the university's GHG emissions by about 5 percent [20].

Solar power is also quickly increasing its share in the county's electricity fuel mix. In addition to several large-scale solar PV farms, solar has taken root in the community, largely through efforts such as Solar Tompkins. The 2013-2014 pilot program in 3 towns resulted in 108 homes installing PV systems for a total of 651 kW. The program was expanded to the entire county in 2014-2015 and resulted in over 400 homes installing PV for a total over 3 MW [21]. Many public and commercial buildings have installed solar photovoltaic systems in the past few years as well. The Tompkins County Library was a leader in this work with its 147 kW PV installation in 2000, one of the largest in the county [22].

The Cornell Snyder Road Solar Farm is adjacent to the Ithaca Tompkins Regional Airport and was completed in September 2014. The 10-acre site has a rated capacity of 2 MW, which will produce ~1% of Cornell's electricity needs and reduce carbon pollution by more than 600 tons per year [22]. This is a significant addition to Cornell's existing solar systems, which include a 15 kW system on the roof of Day Hall and a 2.2 kW system at the Cornell Store. These two systems started operating in late 2007 and mid-2008 respectively [23,24].

In June 2015, the Tompkins Cortland Community College (TC3) completed a 2.6 MW solar farm on approximately 10 acres of land. The solar farm is expected to meet 90% of TC3's annual electricity needs [25]. It's estimated that the solar farm will help reduce TC3's GHG emissions by more than 890 metric tons per year [26].

1.2 Thermal Energy

The total amount of heating energy consumed in the county in 2008 was 6,169,985 MMBtu. In 2008, Cornell consumed 65,420 short tons of coal for power generation [1], out of which about 960,709 MMBtu [4] was converted to steam. Cornell also uses a small amount of fuel oil for heating. In 2008, the consumption was 3,200 gallons [4].

Table 23 Tompkins County thermal fuel use by type, MMBtu, 2008

Energy Sources	Natural Gas	Coal	Propane	Heating Oil	Electricity
Percent	69.0%	15.6%	8.8%	5.0%	1.6%

Tompkins County homes and businesses use numerous fuel sources for thermal energy including natural gas, propane, fuel oil, electricity, and coal as shown in Table 23. In 2008, natural gas provided the overwhelming majority of thermal energy to the community, comprising roughly 69% of the fuel mix. Propane accounted for ~9% and fuel oil ~5%.

2014 Real Property Tax Assessment records indicate that 11% of residential tax parcels use electricity directly for heating. Assuming that those units are about average size in electricity consumption, it is further assumed that in the residential sector, 10% of electricity is used for heating. Therefore it is estimated that electricity provides ~2% thermal energy to the community and overlaps with electricity use in section 1.1 above.

1.3 Transportation Fuels

Table 24 Energy consumption data for the transportation sector

Transportation MMBtu	Transportation MTCO2e	Transportation Vehicle Miles Travelled	Transportation Gasoline (US Gal)	Transportation Diesel (US Gal)
5,606,892	407,469	672,319,554	37,556,802	6,787,343

In 2008, the community consumed nearly six million MMBtus of energy to fuel its transportation needs to drive 672 million miles over the course of the year. Gasoline accounted for roughly 85 percent of fuel used at roughly 38 million gallons, and diesel accounted for 15 percent at nearly seven million gallons [1]. Average consumption of energy for transportation in Tompkins County in 2008 was 55 MMBtu per person (based on a population of 101,136 in 2008) per year. By comparison, the annual per capita use in NYS in 2008 was 57 MMBtu [9 27], and in the overall U.S. it was 92 MMBtu [9,28]. This lower use for the county is due in part to a successful public transportation system, but also to the fact that there are no interstate highways located in Tompkins County.

The reasons for travel can be broken down into five primary categories with the percentage values in the parentheses representing the portion of the trips as of 2009: traveling for work/to earn a living (22.7%), family or personal matters (38.6%), education or religious purposes (7.0%), social or recreational purposes (29.9%), or other (1.8%). The principal reason for travel is for family or personal matters, which makes up 38.6% of the total trips in Tompkins County. One of the largest components of this category is for shopping purposes.

The growth of the electric vehicle population in Tompkins County compares well against that of the entire United States and the state of New York. Given Tompkins's total vehicle population of 59,810, the county's sixty-three electric vehicles constitute a 0.105% market penetration, approximately equal to the nationwide figure of 0.115% and more than twice that of New York State's market penetration of 0.045%. Tompkins's electric vehicle market penetration ranks third among all New York counties, trailing behind only the counties of New York City and Albany. There is an ample amount of electric vehicle infrastructure in Tompkins County as its EV to charging station ratio of 4.20 is far superior to the nationwide ratio of 31.43 and the New York state ratio of 10.74. Nevertheless, both EV charging stations and the population in Tompkins County is concentrated in Ithaca; it is found that the charging station density in Ithaca is 0.759 per km^2 which is comparable with Albany.

Figure 19 Locations of existing EV charging stations in Tompkins County [29]

In terms of the EV infrastructure, there are a total of fifteen EV charging stations in Tompkins County: thirteen located in Ithaca, one in Lansing, and one in Freeville, as illustrated in Figure 19. These stations amount to twenty-two plugs in all, eighteen of which are public and three of which are residential. The public stations are all free or cost only a small $1 fee. All but one of the plugs features the J1772 connector, which is compatible with the Tesla Model S, Chevrolet Volt, Ford Focus Electric, Toyota Prius, Nissan Leaf, Honda Fit, Cadillac ELR, Mercedes-Benz B-Class, and the BMW i3. The only plug without the J1772 connector has the CHadeMO connector, which is compatible with the Nissan Leaf and Mitsubishi i-MiEV.

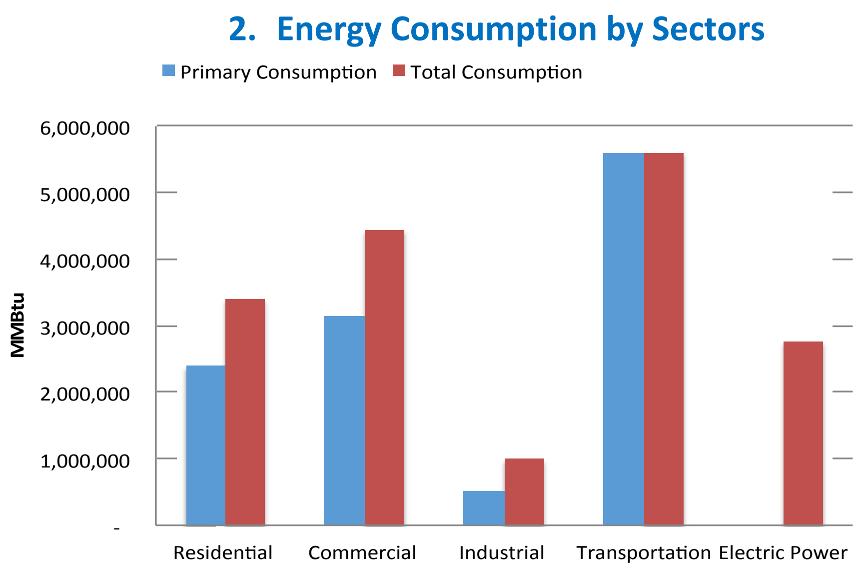


Figure 20 Primary and total energy consumption in Tompkins County, 2008

Figure 20 illustrates the primary and total energy consumption in four end-use sectors, i.e., Residential, Commercial, Industrial and Transportation. Primary energy is energy in the form that it is first accounted for in a statistical energy balance before any transformation to secondary or tertiary forms of energy [30]. Coal, natural gas, and petroleum are examples of primary energy. Electricity is a form of secondary energy. The sum of primary energy consumption and electric power consumption in each sector gives the total site energy consumption for that sector. Separating the two energy forms emphasizes their different functions in end-use sectors. For example in the residential sector, primary energy is mainly used for heating/cooling and cooking, while electric power is mainly used for powering appliances and lighting. Figure 20 also depicts the electricity consumed in the County as a separate column. It adds up the difference between total and primary consumption in the four end-use sectors and distinguishes secondary energy from the primary energy that generates it. Once again, it is in terms of site energy (actual electricity consumed), not source energy (i.e., the primary energy consumed to generate electricity).

2.1 Overall Energy Consumption

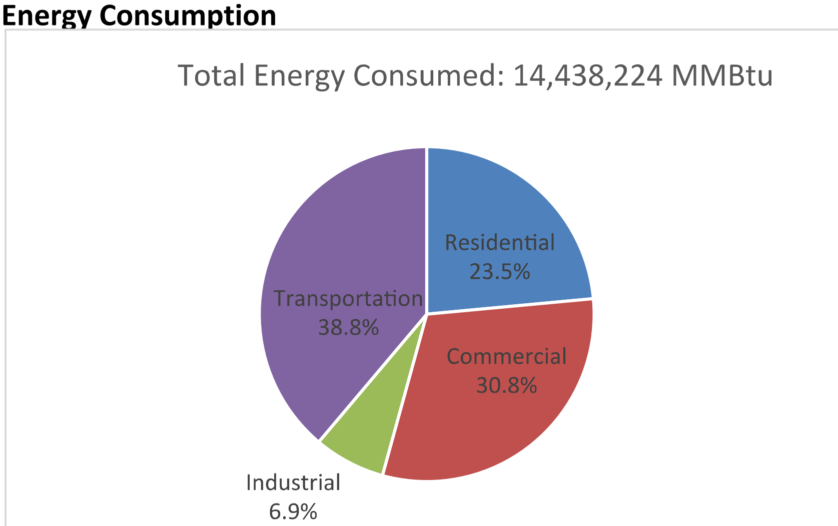


Figure 21 End-use sectors of total energy consumption, MMBtu, 2008 [31]

Figure shows that the transportation sector dominates the total energy consumed in the county and energy consumed in the commercial sector comes in second.

By combining Tables 22, 23 and 24, Tompkins County's energy end use by fuel types can be created, as seen in Table 25.

Table 25 Tompkins County energy end use by fuel types, MMBtu, 2008

Energy Sources	Oil	Natural Gas	Coal	Nuclear	Hydro	Other Renewables
Percent	42.4%	36.1%	11.2%	5.0%	4.9%	0.3%

2.2 Electricity

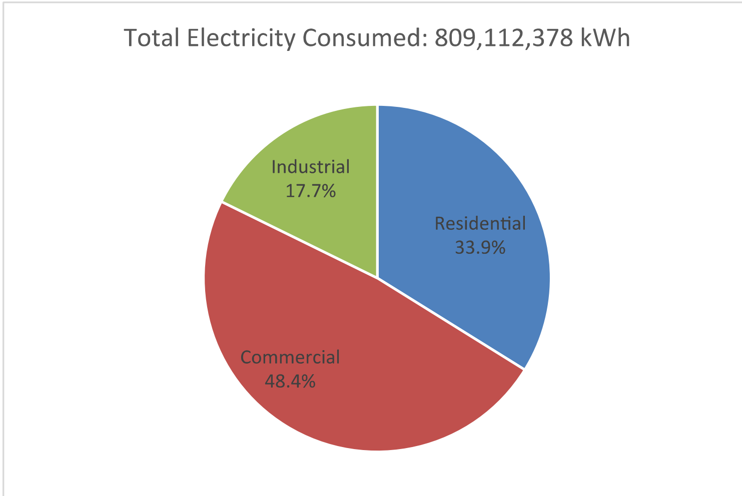


Figure 22 End-use sectors of electricity consumption, kWh, 2008 [31]

The total electricity consumed in Tompkins County in 2008 was 809,112,378 kWh. Figure 22 depicts that the bulk of that usage (48.4%) was by the commercial sector, which includes educational and institutional users.

Commercial Cornell University consumes ~250,000,000 kWh annually, accounting for ~64% of the commercial total. The amount purchased from the grid was ~220,000,000 kWh in 2008 [4]. Ithaca College (IC) represents ~7% of the commercial total, with usage of ~29,000,000 kWh annually [32], though it should be noted that IC's usage data is based on its 2010-2011 fiscal year and therefore is not perfectly congruent with the data set for the overall county energy usage discussed here, which is for 2008.

Residential Annual residential electricity usage in the county averaged 7,835 kWh per household (based on 37,443 households in 2008). In 2008, that figure was 6,870 kWh for NYS [8,33] and 12,201 kWh for overall U.S. [8,34]The densely populated New York Metropolitan Area is likely to contribute to the lower per capita statewide average than that of the County.

2.3 Thermal Energy

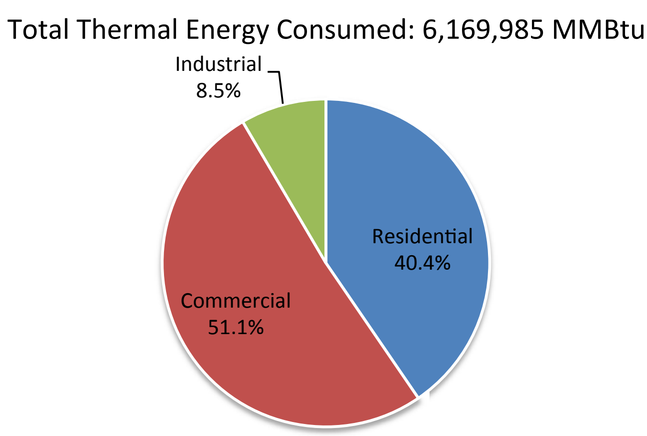


Figure 23 End-use sectors of thermal energy consumption, MMBtu, 2008 [31]

The total thermal energy consumed in Tompkins County in 2008 was 6,169,985 MMBtu. **Figure** 23 reveals that the top users are the commercial sector at 51.1%, which again includes educational and institutional users, and the residential sector at 40.4%. The industrial sector accounted for 8.5% of total thermal energy use.

Residential While natural gas provided the majority of thermal energy in Tompkins County, as indicated in Table 26, the residential sector still relied heavily on electricity, fuel oil, and propane in 2008. Table 26 breaks down the number of occupied housing units in Tompkins County by heating fuel type.

Table 26 Number and percent of residential buildings by heating energy source, 2008 [2]

Fuel Type	Count	Percent
Natural Gas	9,392	42.24%
Fuel Oil	4,922	22.14%
Propane	4,478	20.14%
Electric	2,646	11.90%
Wood	348	1.57%
Coal	79	0.36%
Geothermal	13	0.06%
Solar	8	0.04%
None	170	0.76%
Blank	177	0.80%
Total	**22,233**	**100.00%**

Note: “None" means there is no central heating, and "Blank" means that there is no information on file for that property.

Annual residential thermal energy consumption in Tompkins County (assuming 10% of residential electricity use was for space and/or water heating) averaged 67 MMBtu per household (based on 37,443 households in 2008). This is lower than the average annual consumption level in 2009 in the Northeast U.S., which was 77 MMBtu per household [35].

In the commercial sector, Cornell University’s annual thermal energy consumption on average is ~961,000 MMBtu [4], accounting for ~30% of the commercial total. IC’s annual natural gas consumption was ~168,470 MMBtu [36]. Assuming that it is utilized as thermal energy, IC accounted for ~5% of commercial thermal energy use in the county.

3. Energy Distribution Systems

3.1 Electricity

Figure 24 illustrates the power transmission system in New York State and Tompkins County.

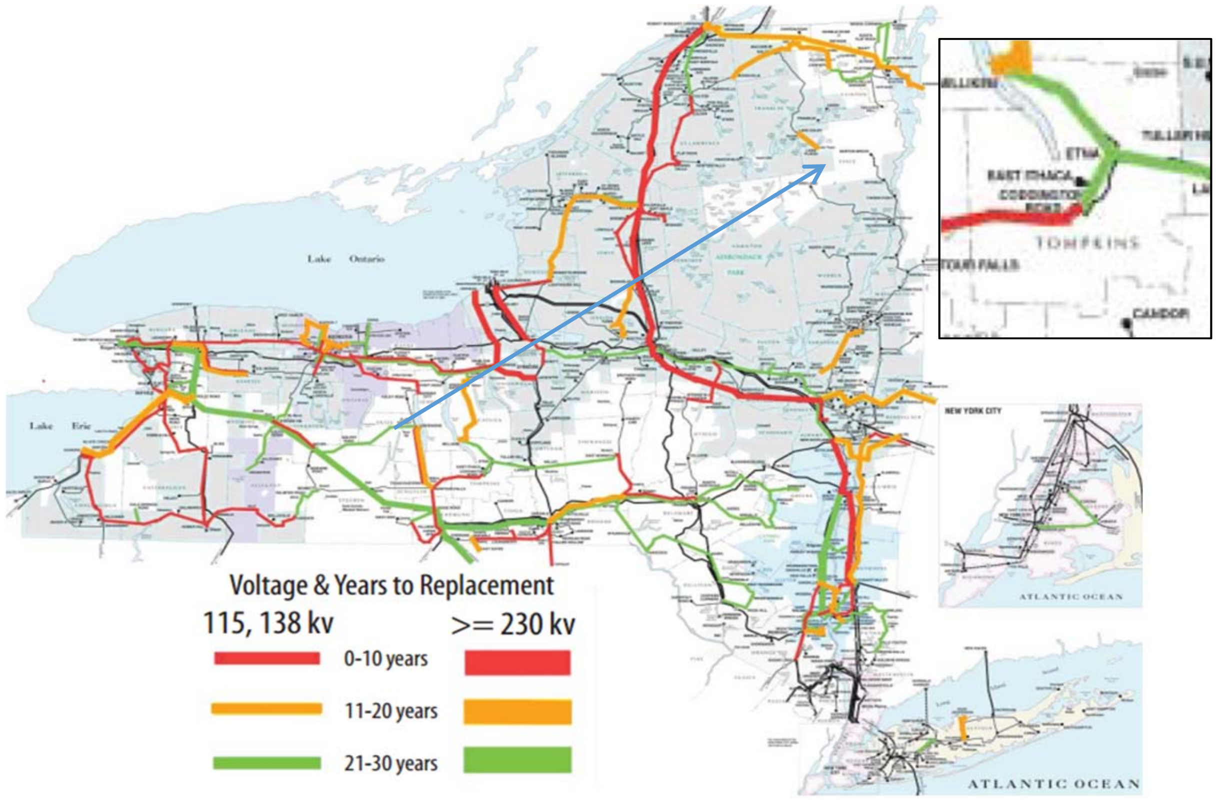


Figure 24 a) New York State and b) County transmission assessment condition [37]

The Village of Groton Electric Department was established in 1896. It has undergone several transformations since then, and today it owns and operates its electricity distribution system within the village [38]. The department has full utility responsibilities that include billing, maintenance, and metering [39].

Since 2003, Groton purchases 4,483 kWh of hydroelectric power monthly allocated by the New York Power Authority (NYPA) from the Niagara Power Project [40,41]. NYPA is a state public power organization that operates generating facilities and transmission lines [42]. The village purchases incremental power as needed through the New York Municipal Power Agency (NYMPA) [40]. NYMPA is a joint action agency of 36 state municipal members that bind themselves to each other by contract to accomplish their purposes [43]. In addition, a charge is paid by Groton to NYSEG for transmission [44].

Village of Groton's arrangement with NYPA is beneficial to Tompkins County since it provides the residents of Groton with low electricity rates and defers revenue from carbon intensive generators to hydropower.

3.2 Gas and Oil

Natural gas is delivered from wellheads to final customers through many infrastructure assets. Figure 25 provides a basic overview of the natural gas processing, transportation, and storage system.

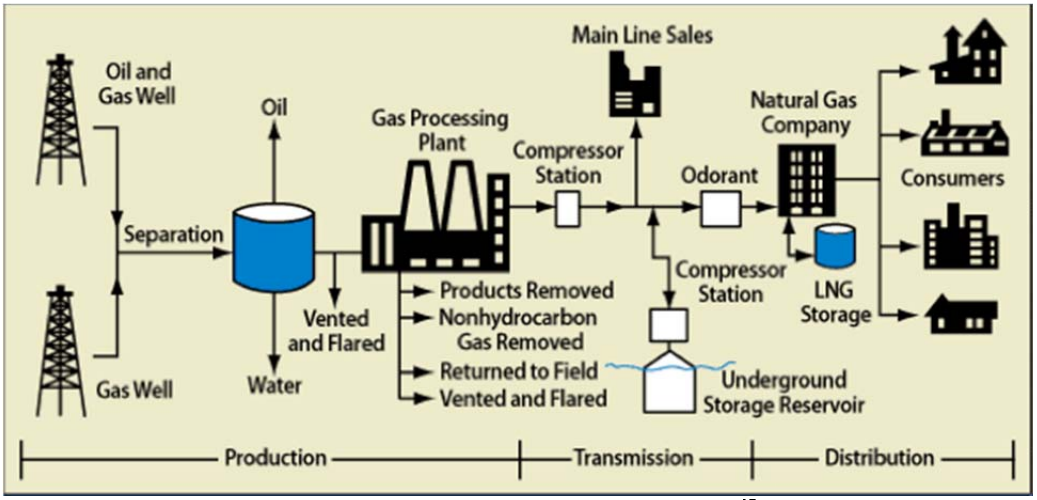


Figure 25 Natural gas delivery system [45]

Natural gas transportation and storage assets in Tompkins County are operated by Dominion Transmission, Inc. [46]. The distribution system is operated by NYSEG [44]. Figure 26 illustrates the network of natural gas (blue) and hazardous liquid (red) transmission pipelines in Tompkins County. The pipelines transport natural gas to NYSEG for distribution, as well as to main line users such as the Cornell CEP.

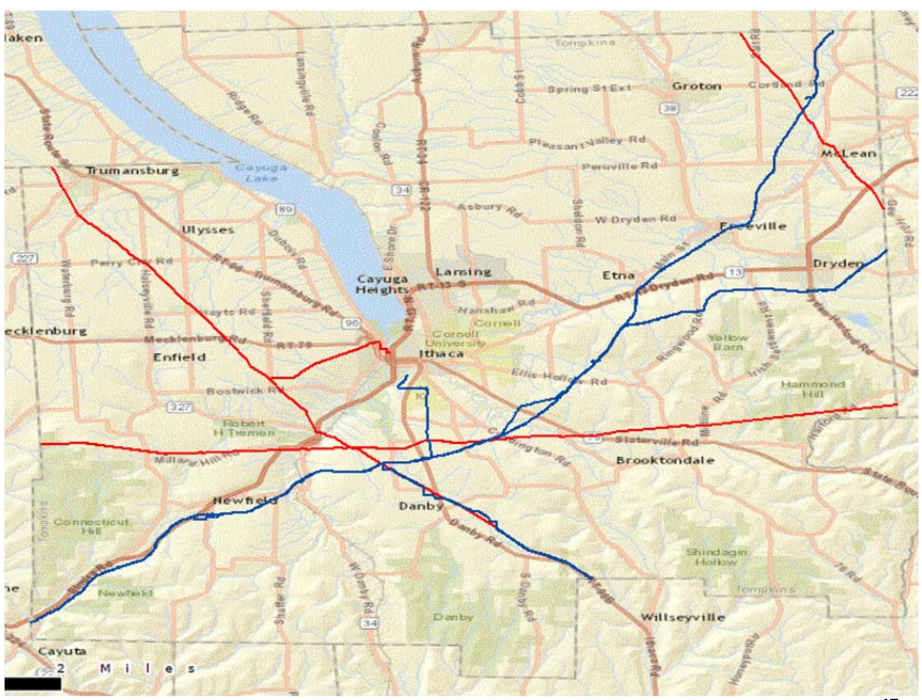


Figure 26 Tompkins County natural gas and hazardous liquid pipelines [47]

Fuel oil and propane are provided to users in Tompkins County through a series of independent distributors, which include Ehrhart Energy and AmeriGas [48]. The hazardous liquid pipelines transport petroleum products, for instance, to the distributors.

4. Greenhouse Gas Emissions

4.1 Sources of Greenhouse Gas Emissions

It should be noted that GHG emissions from local power/energy generation that produce electricity exclusively consumed locally are counted in the emission inventory. One main example is the Cornell CEP. And as mentioned earlier, the Cayuga Power Plant is physically located in the County, but the electricity generated is sent directly to the public transmission grid. Therefore, the GHG emissions from the power plant are not double-counted in the emissions inventory.

And as shown in Figure 27, waste and agriculture are both important GHG emission sources, but the amount they account for are much less than those from energy sources. And that the hydro power purchased by Village of Groton is only transactional. Therefore, energy sources and Cornell power generation are the major sources of GHG emissions in Tompkins County.

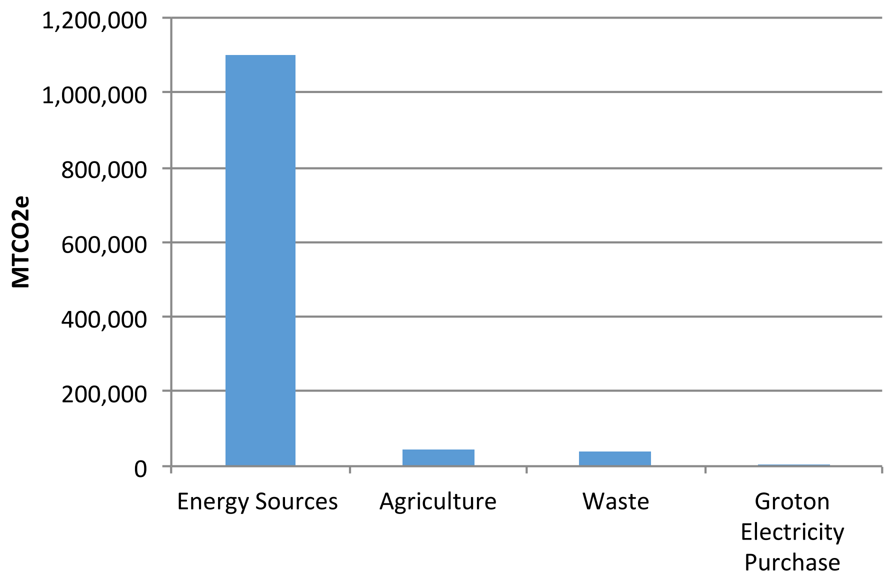


Figure 27 Sources of greenhouse gas emissions in Tompkins County, 2008

4.2 Greenhouse Gas Emissions by Types of Fossil Fuels

Within the Energy Sources category above, the contributions from three types of fossil fuels to GHG emissions are depicted in Figure 28. As assumed in Figure 18, “oil” includes transportation fuels and “natural gas” includes propane. In addition, GHG emissions from electricity generation are divided into each source of fossil fuel taking authoritative conversion factors into account [49].

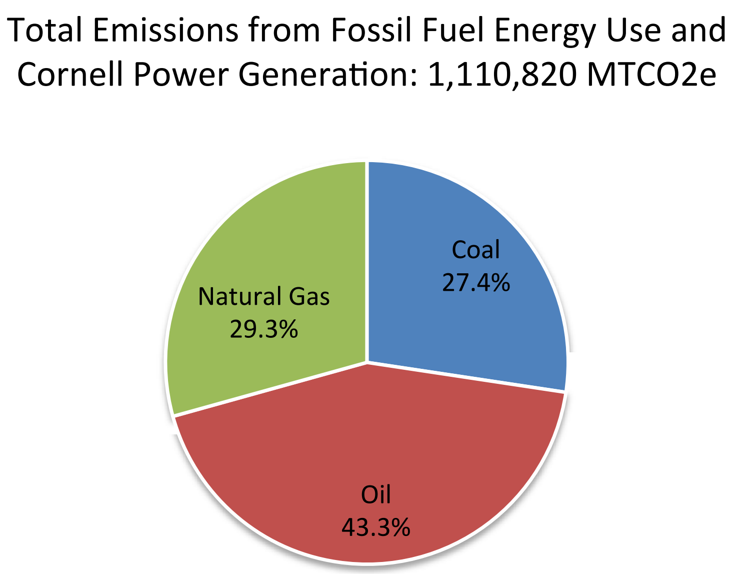


Figure 28 Greenhouse gas emissions in Tompkins County, MTCO2e, 2008

4.3 Greenhouse Gas Emissions by Sectors

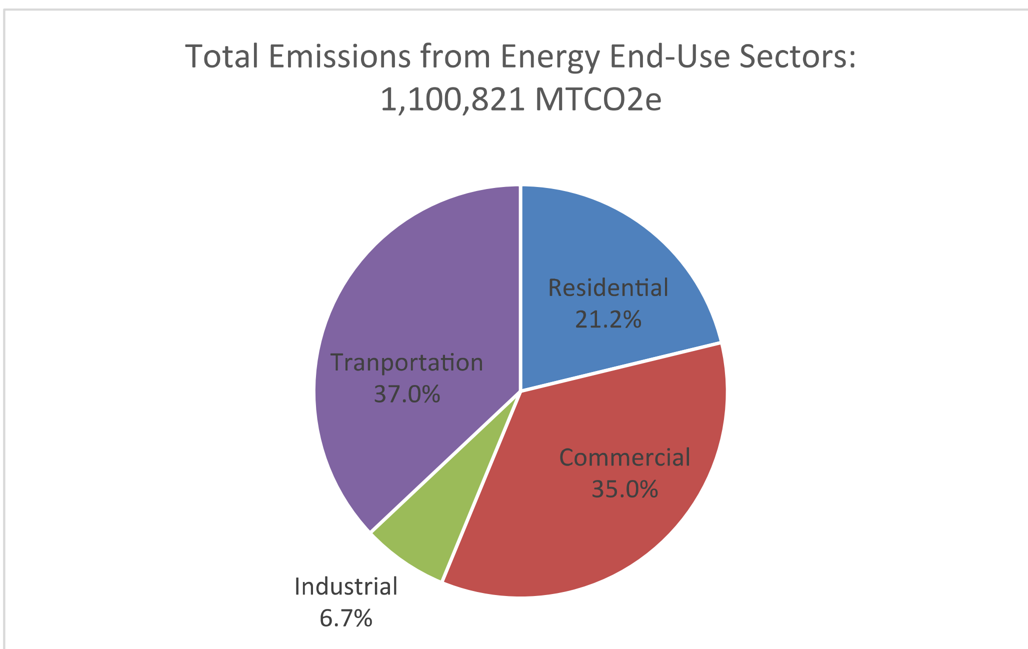


Figure 29 Greenhouse gas emissions by sectors in Tompkins County, MTCO2e, 2008 (excluding waste, agriculture, and Groton electricity purchase)

Figure 29 illustrates the GHG emissions from different end-use sectors. The transportation sector is the largest GHG emitter in the county, followed by the commercial sector.

GHG emissions associated with air travel and rail travel are not included in the County emissions inventory, mainly due to lack of commonly accepted methodologies and resources for tracking emissions in those sectors.

Cornell University accounts for ~25% of the County GHG emissions and is considered part of its commercial sector. It should be noted that Cornell's Climate Action Plan, developed by Cornell faculty, students and staff in 2009, seeks to cut carbon emissions to net zero by 2050. There is a comprehensive set of 62 actions identified by Cornell to reach this target, 16 of which are under the "Energy" category. This category includes solar power, Central Energy Power Plant steam turbine upgrades, hydroelectric power, the regional wind power and campus smart grid that are under development, and two proposed systems: enhanced geothermal and biomass gasification. Since 2008, Cornell has reduced gross carbon emissions by nearly 32 percent [50].

It should be noted, however, all of the greenhouse gas emissions figures in this chapter are calculated using the Environmental Protection Agency's (EPA) global warming potential figure for methane that was in place when the 2008 inventory was performed and follow the 100-year Global Warming Potential (GWP) time horizon that was adopted in the Kyoto Protocol and is now used widely as the default metric. Since 2008, many scientists have focused research on methane emissions and it appears that it would be more accurate to use a much greater GWP for methane to reflect its extreme potency on a 20-year time horizon, when reductions will help most in limiting warming that may result in a cascade of uncontrollable negative impacts [12].

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Wind Energy

K. Max Zhang, Benjamin Koffel and Mark Romanelli

Executive Summary

Total Potential

Energy Source	Electricity (GWh)	Percent of Total 2008 Electricity Demand
Wind Energy Potential		**327.0%**
Small-scale Wind	32.7	
Medium-scale Wind	2097.1	
Large-scale Wind	515.8	
Total	**2645.6**	
2008 Community Demand	809.1	

Major Assumptions

	Small-scale Wind	Medium-scale Wind	Large-scale Wind
Turbine Size/Type	1-25 kW, Bergey Excel 10 10kW model, 30 m hub height	25-500 kW, EWT DW54 500kW model, 50 m hub height	>500 kW, GE 2.5 MW 10 model, 85 m hub height
Land Excluded	• Unique Natural Areas • Slopes >15% • Ithaca Tompkins County Regional Airport approach and clear zones • Audubon-designated Important Bird Areas • DEC-designated Critical Environmental Areas • State forests, parks and wildlife management areas • Municipal parks and open space • Cornell University Natural Areas • County-owned Forestlands		
	• Lands with wind speeds under 5.25 m/s • Parcels smaller than 2 acres • All buildings that fall within residential land uses • Tax parcel property classes: Wild, Forested, Conservation Lands and Public Parks; Vacant Land – including	• Lands with wind speeds under 5.25 m/s • Parcels smaller than 6.5 acres • Lands in Distinctive and Noteworthy Scenic Viewsheds • Tax parcel property classes: Residential; Wild, Forested,	• Lands with wind speeds under 6.5 m/s • Parcels smaller than 35 acres • Lands in Distinctive and Noteworthy Scenic Viewsheds • All buildings that fall within residential land uses • Land further than 6 miles from a high-

	abandoned agricultural land	Conservation Lands and Public Parks • Parcels identified as suitable for large-scale wind	voltage transmission line
Number of Turbines	1 per tax parcel	1 per tax parcel	1 per 145 acres
Min. Wind Speeds	5.25 m/s at 30m	5.25 m/s at 50m	6.5 m/s at 80m

The overall objectives of this section are 1) to quantify the generation potential of implementing wind power, for large-, small- and medium-scale energy production within Tompkins County, and 2) to identify challenges and opportunities for future implementation of wind power in the County. In this report, wind power systems have been divided into three categories based on their potential to create energy and probable uses. The distinctions between the different scales of wind power were chosen because of how net metering laws are currently structured in New York State. The maximum amount of power allowed to be net metered on residential properties is 25 kW, so that was the upper bound used for small-scale wind power. Agricultural land can be net metered for up to 500 kW of power, so that was the limit used for medium scale power [1].

More concisely, we defined the categories as follows:

- *Small-scale wind power*: turbines with a rated capacity between 1 kW and 25 kW. These will likely be used by individual homes.
- *Medium-scale wind power*: turbines with a rated capacity between 25 kW and 500 kW. These will likely be used for small businesses, especially agriculture, or for community-shared turbines.
- *Large-scale wind power*: turbines with a rated capacity above 500 kW. These will likely be used as wind farms with the electricity sold to utilities.

We used a Geographic Information System (GIS)-based model to determine potential wind power sites using information relating to wind speeds, parcel size and other considerations. Once we determined the number of turbines that could be erected in the county, we used the average wind speed, its standard deviation, and other information specific to the turbines to determine the probable Annual Energy Output (AEO) of wind-generated electricity in the county. Table 27 below summarizes the end results of this analysis assuming continuous operation with no degradation in efficiency. Thus, the numbers below do not include downtime for maintenance, and other similar occurrences.

Table 27 Total power, capacity, and annual energy output for 3 scales of turbines.

Scale	Installation Capacity	Capacity Factor	Annual Energy Output
Small-scale	18.4 MW	20.3%	32.7 GWh
Medium-scale	745.5 MW	32.1%	2097.1 GWh
Large-scale	180 MW	32.7%	515.8 GWh

Wind turbines have many opportunities for growth in the future if a concerted effort is made. Current siting laws in local municipalities could prevent the growth of wind power. Changes to these laws, particularly around medium-scale wind, would open up a new segment of wind turbines to public use. Maintenance costs of wind turbines are manageable at present and are poised to decrease as wind power becomes more ubiquitous. Wind power to some extent complements solar power and could make both renewable options more attractive. The role of wind energy is especially important in winter season as solar generation in the County generally decreases. Recent studies have found that wind power has only slight effects on bat and bird ecology, and minimal to no effects on human health [2,3]. Additionally, community owned wind power as a concept has begun to spread and will allow wind power to enter into an entirely new subset of the market.

1. Introduction

Wind turbines convert energy from the wind into usable electrical energy. As wind speeds vary diurnally and seasonally, the electricity generation from wind turbines is inherently intermittent. Currently, the majority of wind power systems are grid tied, meaning they are interconnected with the electrical grid. In most of the small- and medium-scale systems, the grid can act as a kind of battery, accepting any extra electricity that wind power system produces that is higher than the demand and supplying electricity if the wind power system does not meet the demand.

Wind power is governed by one important equation. The equation describes the power that can be extracted from the wind:

$$P = \frac{1}{2} C_P \rho \pi r^2 u^3$$

where *P* is the power (in the wind), C_P is the efficiency of the turbine, ρ is the density of the wind, *r* is the radius of the wind turbine, and *u* is the speed of the wind. Essentially the equation measures the flow rate of the wind using the area, density and the velocity. By multiplying the flow rate by velocity squared we get a formula for total power in the wind. The efficiency factor takes the power in the wind and determines how much power can be extracted by a specific turbine. Because wind power scales with the cube of wind speed, finding sites with high wind speeds is of utmost importance to creating successful wind turbines.

Wind turbines can come in a variety of shapes. They have blades that spin either on a horizontal or on a vertical axis as seen in Figures 30(a) and 30(b). They can vary based on hub height (i.e., how high the tower the turbine sits on is), and blade radius (i.e., the length of the blades). Since wind speeds increase as height above the ground increases and as described above power is related to the cube of wind speed, electricity generated is related to the hub height at a site. Since wind can only be used if it passes through the sweep of the blades, a longer blade radius allows more power to be generated.

It is important to note that rated capacity does not necessarily correspond to energy generated at any given time. Unlike rated capacities for thermal power plants that can run at maximum capacity any time, a wind turbine's rated capacity instead represents a maximum power that can be generated if the wind is blowing sufficiently fast. Because of this, wind turbines will generally generate less than their rated capacity. While this intermittency cannot be foreseen on a day-to-day basis into the future, the yearly output of a turbine can be generally predicted based on the mean wind speed of a site and the variation of that speed.

Figure 30 (a) A horizontal axis wind turbine; (b) A vertical axis turbine

There are three characteristic wind speeds for wind turbines: the cut-in speed, the rated wind speed and the cut-out speed. The cut-in wind speed is the lowest possible wind speed, measured at hub height, which the turbine can use to generate power. The rated wind speed is the wind speed at which the turbine produces the output it is rated for. The cut-out wind speed is the maximum wind speed at which the turbine can generate power. In between the cut-in speed and the rated wind speed, the power output of the turbine increases. Figure 31 shows a typical output of a wind turbine for several speeds.

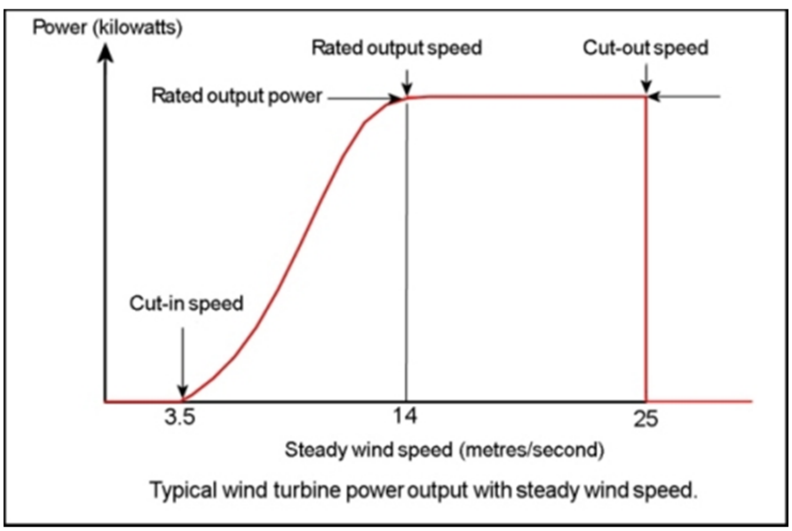


Figure 31 A typical power curve for a wind turbine [4]

Recently, wind power has experienced an increase in public interest. The US Department of Energy has made studies into the efficacy of wind power. Their conclusion is that the US could move to 20% wind power within the next 30 years [5]. There has been one major development in the state of wind power in Tompkins County. The Black Oak Wind Farm in Enfield, NY is slated to start construction in 2016. The 16.1 MW wind farm will use seven GE 2.3 MW turbines and is projected to provide the equivalent of

5,000 homes with electricity. Black Oak is the first community owned wind farm to be built in New York State and may serve as a model for future community owned wind farms in New York [6].

The rest of the report is organized as follows. First, we will elaborate the methodologies and results in estimating the wind power potential in Tompkins County (Section 2). Then, we will discuss the opportunities and challenges (Section 3) in future wind power development in the County.

2. Wind Power Potential of Tompkins County

According to the American Wind Energy Association, as of October 1, 2015, New York State was ranked 12th in the nation for installed wind capacity with 1,749 MW. This represented 2.9% of the State's energy production in 2014. However, in NYSERDA's assessment of wind potential on a county basis, Tompkins County was not deemed to have high enough average annual wind speeds to be considered a prime spot for wind development when compared with other regions of the state [7]. Figure 32 shows the wind resource profile of New York and demonstrates that Tompkins County is not among the areas with the highest potential, however, Figure 33, shows that there are many areas suitable for wind development at various scales. In order to calculate the wind power potential of the County, we used GIS software to determine areas with sufficient wind speeds to spin turbines. In order to determine the wind speeds throughout the county, we used a wind resource map of Tompkins County at 80m, illustrated in Figure 33, created by AWS Truewind and obtained through the Cornell University Geospatial Information Repository [8]. The map in Figure 33 was generated using MesoMap, which used a series of measurements and a simulation of atmospheric physics to predict average wind speeds at every point in the county. This map was chosen over a similar one made with 100m height data because the process of scaling down the wind speeds to lower heights (necessary for small and medium scale wind resources analysis) can be a source of uncertainties. By choosing a map at a lower elevation (i.e., 80 m compared to 100 m), we were able to reduce the uncertainties from such an approximation. Other GIS map data was taken from CUGIR, the GEDDeS lab at Cornell University, the Tompkins County Planning Department and the Audubon Society of New York.

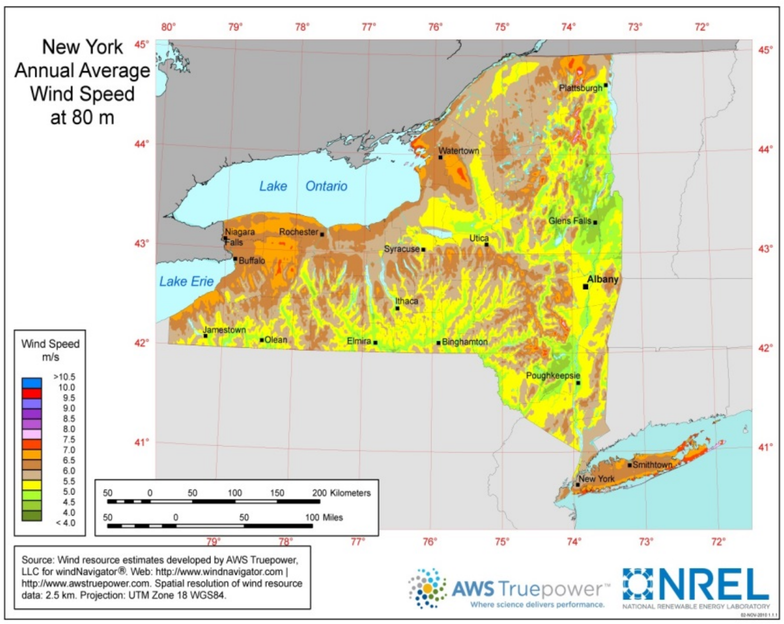


Figure 32 Wind resource map of New York State

Source: NREL. "Wind Powering America." (2010). windpoweringamerica.gov/images/windmaps/ny_80m.jpg

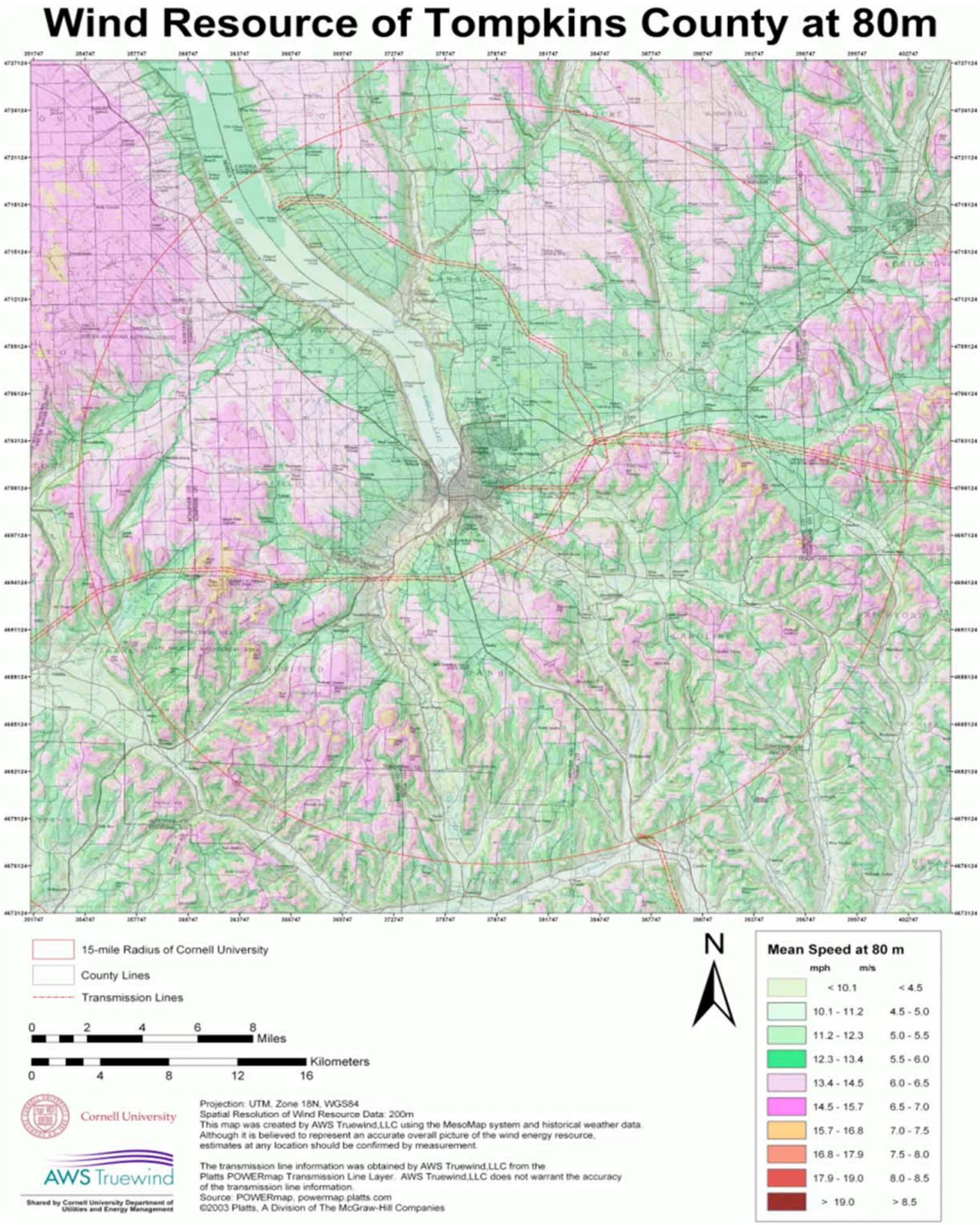


Figure 33 Wind resource map of Tompkins County at 80m

Source: AWS Truewind

In order to look at the wind resource of Tompkins County, we adopted several general criteria based off the physics of wind turbines, and local and federal laws:

- Locations with wind speeds lower than 5.25m/s at 30m of elevation were omitted for small-scale wind and at 50m for medium-scale wind as they are unsuitable for those types of wind power. Similarly, wind speeds lower than 6.5m/s at 80m were omitted for large-scale wind development. According to American Wind Energy Association (AWEA), installers of small-scale wind turbines recommend sites with average wind speeds of at least 12 mph (5.36m/s) [9]. Lands with 5.25m/s of wind were chosen despite being beneath the AWEA recommended limit to account for potential improvements to wind technology.
- We excluded lands deemed to be sensitive to wind development for the various scales, as summarized in each section below.
- We assumed that there would only be one turbine installed per tax parcel for small- and medium-scale. This is because of net metering limits and practical constraints involved with a private residence or small business buying more than one turbine.

There were other considerations for each unique scale of wind power. Those will be dealt with in their individual sections.

2.1 Wind Calculations Methodology

Since the wind data that we gathered was for an elevation of 80m, the wind data had to be scaled down to the hub height. Wind speeds have a relation to height that follow the general formula:

$$\frac{u_1}{u_2} = (\frac{h_1}{h_2})^{\alpha}$$

where u_1 and h_1 are the wind and height at one height, u_2 and h_2 are the wind and height at a second height, and α is the power law exponent. Inputting the appropriate values for α, u_1, h_1 and h_2, we found the proper wind speeds for a wind turbine for any height.

The annual energy output (AEO) produced by each turbine is estimated with the following formula:

$$AEO = P_{ave} \times 8760,$$

where P_{ave} is the average power out of the turbine over a year, and 8760 is the number of hours in a year. Power from the wind turbine follows the following equation:

$$P_{avg} = \int_{u_{cut-in}}^{u_{cut-out}} P(u)p(u)du$$

Where P_{ave} is the average power, $p(u)$ is the probability density function of a given wind speed based on the Weibull distribution and P(u) is the power in the wind based on the power curve for a given wind speed u (such as that illustrated in Figure 31). In practice, P_{ave} is evaluated by binning wind speed and power curve into discrete intervals [10]. The Weibull distribution follows the formula:

$$p(u) = (\frac{k}{c})(\frac{u}{c})^{k-1}e^{-(\frac{u}{c})^k},$$

where *k* is the shape parameter of the Weibull Distribution, *c* is the scale parameter of the Weibull Distribution, and the rest of the symbols are defined above. *k* can be determined through the following formula [11]:

$$k = (\frac{\sigma_u}{u_{ave}})^{-1.086},$$

where σ_u is the standard deviation of wind speed, and u_{ave} is the average wind speed. *c* can be determined by:

$$c = \frac{u_{ave}}{\Gamma(1+\frac{1}{k})},$$

where *Γ* describes the gamma function. Thus the performance of a wind turbine can be calculated using the average wind speed, the standard deviation of that wind speed, and factors relating to the specific wind turbine.

For ease of use, we can combine the above formulas into a single formula for the capacity factor. Capacity factor (CF) reflects the percentage of power that can be produced by the turbine relative to the maximum, or rated, power of the turbine. Thus,

$$CF = P_{avg}/P_{rated}$$

where CF is the capacity factor and the remaining components are listed above.

For this equation, we needed to determine the proper value for the α parameter in the power law equation. The typical value for the power law parameter is 1/7, however the hilly terrain of the County combined with the high degree of tree cover could lead to a higher value for α. We excluded forested properties in our analysis for small and medium scale wind energy, where alpha was needed. Therefore, we set the value of alpha to 1/7 throughout our analysis. We also ran a sensitivity analysis on the power law parameter to see the effect the choice of power law exponent had on the scaled down wind speed. For a change from 80m to 30m, which is the change needed to find the average wind speeds for small-scale turbines, we found that a 10% change in α resulted in a 1.0% to 2.2 % change in the calculated average wind speed at 50 m and 30 m. From this analysis, we can deduce that even if the value of α is uncertain, the results will not be overly swayed by this uncertainty.

The standard deviation of the wind speed was determined to be 43% of the average wind speed based on the wind data recorded at Ithaca College in 2009 [12]. The Ithaca College measurements were taken at a height of 50m and were extrapolated to fit an 80m height. There was another set of data taken at Ithaca Airport that could have been considered. This data was taken at an elevation of 10m and found the standard deviation of the wind speed to be 72%. Because of the low height of the data collection and the relatively high value of the power law exponent in Tompkins County, we decided to not consider the Ithaca Airport data in our analysis. Thus value of a 43% standard deviation in wind speed was used for all of our calculations.

2.2 Small-Scale Wind Power

Small-scale wind power is defined as turbines designed for home energy production. Because of the typical needs of homes, we capped this category at 25 kW rated turbines. In addition to the constraints listed above, we added several more considerations to the analysis.

Fall Zone Requirements: These constraints were developed primarily based on the small wind energy facilities constraints identified in the Town of Ithaca's zoning ordinance. In order to determine the minimum amount of land needed to incorporate a fall zone for small-scale turbines, we used the zoning ordinance as a guide, which states "No small wind energy facility shall exceed 145 feet in height … The fall zone around any ground-mounted tower constructed as part of a small wind energy facility shall be a circular area around the tower … with a radius at least equal to the facility's height plus 10 feet. The entire fall zone may not include public roads, overhead transmission lines, aboveground fuel storage or pumping facilities, or human-occupied buildings and must be located on property owned by the tower owner or for which the owner has obtained an easement or deed restriction. The minimum setback between the center of the base of the tower and any unoccupied buildings or other structures is 15 feet."

We used a 145 ft. turbine height (from base to blade tip) for our calculations and the larger buffer of 15'. Therefore, the radius needed for a small turbine would be 160'. This translates to an area of 80,424sf, or 1.8 acres. This meant that only parcels that were able to contain a 2 acre circle free of human occupied structures and property lines were included in the analysis of suitable lands for small-scale wind. Note that this is a conservative assumption as it rounds the area up from 1.8 to 2 acres, and it assumes the 145' maximum turbine height, though the calculations are based on a turbine that is 100' high.

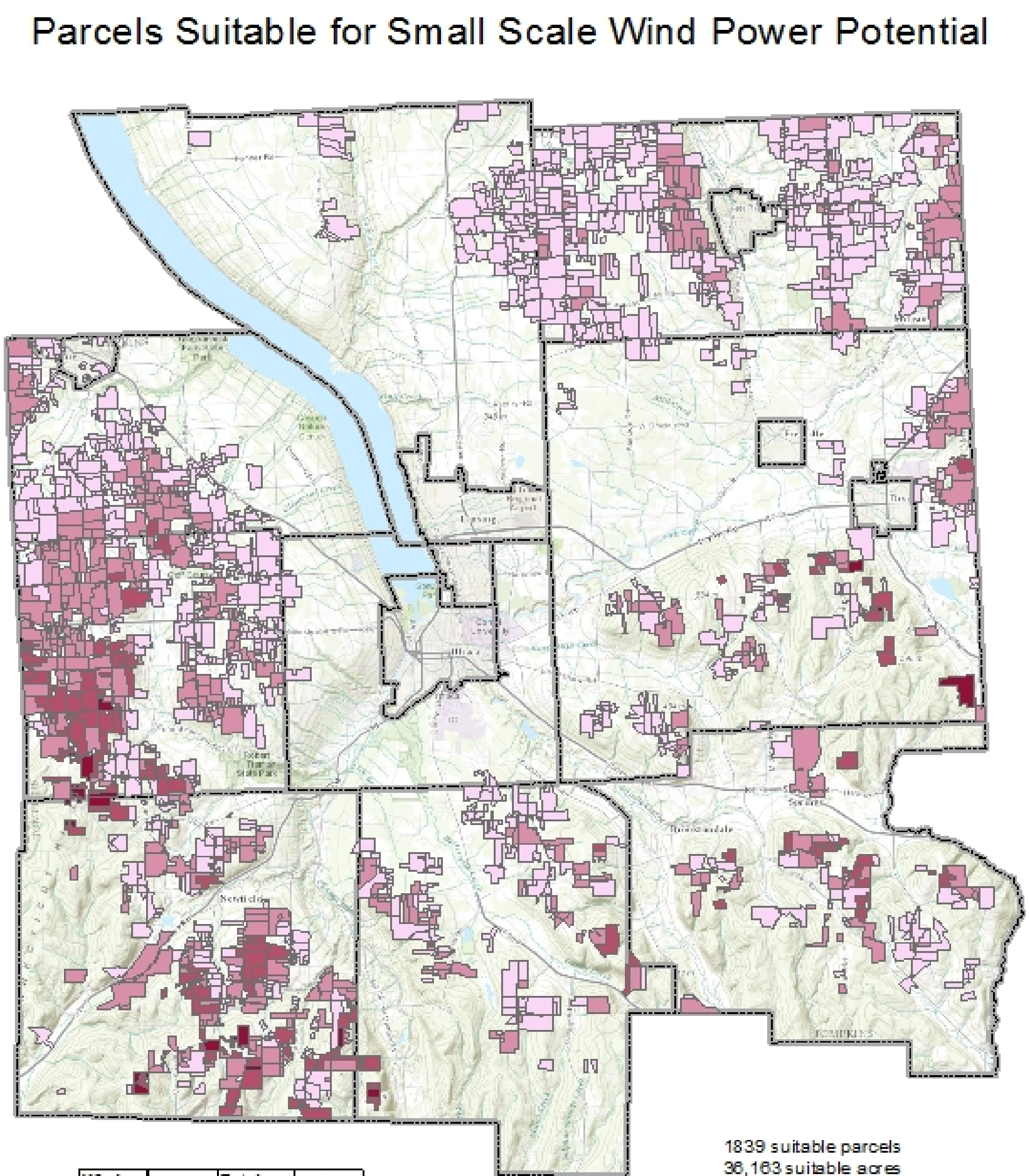
Lands Deemed Appropriate for Small-scale Wind: Many land uses may be acceptable for developing small-scale wind power, with the limiting factor being human use of the land to take advantage of the small amount of wind power generated. This analysis identified the following tax parcel property classifications as being appropriate for hosting small-scale wind:

- Residential
- Agriculture
- Commercial
- Industrial
- Public Services – includes water treatment facilities, bus terminals, pipelines, landfills, electric and gas facilities
- Community Services – includes schools, libraries, colleges, churches, hospitals, government buildings and parking lots, correctional facilities and cemeteries
- Recreation – includes fairgrounds, racetracks, golf courses, riding stables, camping facilities and picnic grounds

Lands Deemed Inappropriate for Small-scale Wind:

- Lands with wind speeds under 5.25 m/s
- Unique Natural Areas
- Slopes >15%
- Ithaca Tompkins County Regional Airport approach and clear zones
- Audubon-designated Important Bird Areas
- DEC-designated Critical Environmental Areas
- State forests, parks and wildlife management areas
- Municipal parks and open space
- Cornell University Natural Areas
- County-owned Forestlands
- Parcels smaller than 2 acres
- All buildings that fall within residential land uses
- Tax parcel property classes:
    - Wild, Forested, Conservation Lands and Public Parks
    - Vacant Land – includes abandoned agricultural land

In order to estimate wind power potential, we scaled down the wind speed from the 80m height to 30m for small-scale hub height using the GIS software. Figure 34 illustrates the potential sites for deploying small-scale wind turbines.



Wind Speed at 30 m/s	Number of parcels	Total Acres of those parcels	Total Suitable Acres
5.25-5.5	1076	39270	20118
5.5-5.8	563	22376	12339
5.8-6.1	171	6149	3172
6.1-6.4	29	978	534
Total	1839	68773	36163

Figure 34 Suitable parcels for small-scale wind

For this analysis, we needed to choose a specific wind turbine as the average of all small-scale turbines that could be installed within the county to get specific numbers for power and energy production. The Bergey Excel 10 wind turbine [13] was selected for this purpose. This specific turbine has a cut-in speed of 2.5 m/s, a rated speed of 12 m/s, and no cut-out speed. It has a blade radius of 3.5m and a hub height of 30m (110' from base to blade tip).

Based on our analysis and calculations described above, we estimated the potential for small-scale wind turbines as 18.4 MW and the corresponding annual energy output as 32.7 GWh. The results are summarized in Table 28.

Table 28 Small-scale wind power breakdown

Type of Parcel		Number of Parcels	Installation Capacity (MW)	AEO (GWh)	Capacity Factor
Agriculture	Dairy Farm	87	0.87	1.52	0.200
	Field Crops	158	1.58	2.77	0.200
	Vacant Farmland	142	1.42	2.54	0.204
	Others	27	0.27	0.47	0.198
	Subtotal	414	4.14	7.30	0.201
Residential		1348	13.48	23.98	0.203
Others		77	0.77	1.38	0.205
Total		1839	18.39	32.66	0.203

2.2 Medium-Scale Wind Power

Medium-scale wind power was defined to exist in the range between large-and small- scale power. This would include turbines that generate more energy than a typical home would use but not enough energy to be worth investment for a large-scale wind farm. Energy production on this scale is suitable for businesses, especially farms, and possibly educational or institutional facilities. This range of turbine size represents a large store of untapped potential within the County. For the purposes of this analysis, we modeled all medium-scale wind turbines after EWT's DW54, a 500kW Wind Turbine. It also has a rated wind speed of 10m/s, a cut-in wind speed of 3m/s and, a cut out wind speed of 25m/s [14]. This turbine was chosen because it has a low cut-in speed, which means that it can collect a wide range of wind, and a large hub height, which means that it has access to higher elevation, and thus faster, wind speeds. This turbine has a 27m blade radius and a 50m hub height (so 250' from base to blade tip).

Fall Zone Requirements: In order to collect more energy than small-scale wind turbines, medium-scale wind turbines will have larger hub heights and bigger blade radii. Because of this height difference, medium-scale wind power requires larger parcel sizes to allow for bigger fall zones. There are few guidelines on an appropriate buffer to use for medium-scale wind turbines, but one can see that it will be in the range of 2 acres for small-scale to 35 acres for large-scale based on regulations in place that specifically address those scales. This analysis chose to use 6.5 acres, based on assuming the need for a 50' buffer in addition to the 250' turbine height. A 300' turbine height (from base to blade tip) translates to an area of 288,280 sq.ft., or 6.5 acres. This meant that only parcels that were able to contain a 6.5 acre circle free of human occupied structures and property lines were included in the analysis of suitable lands for medium-scale wind.

Lands Deemed Appropriate for Medium-scale Wind:
Many land uses may be acceptable for developing medium-scale wind power. This analysis identified the following tax parcel property classifications as being appropriate for hosting medium-scale wind:

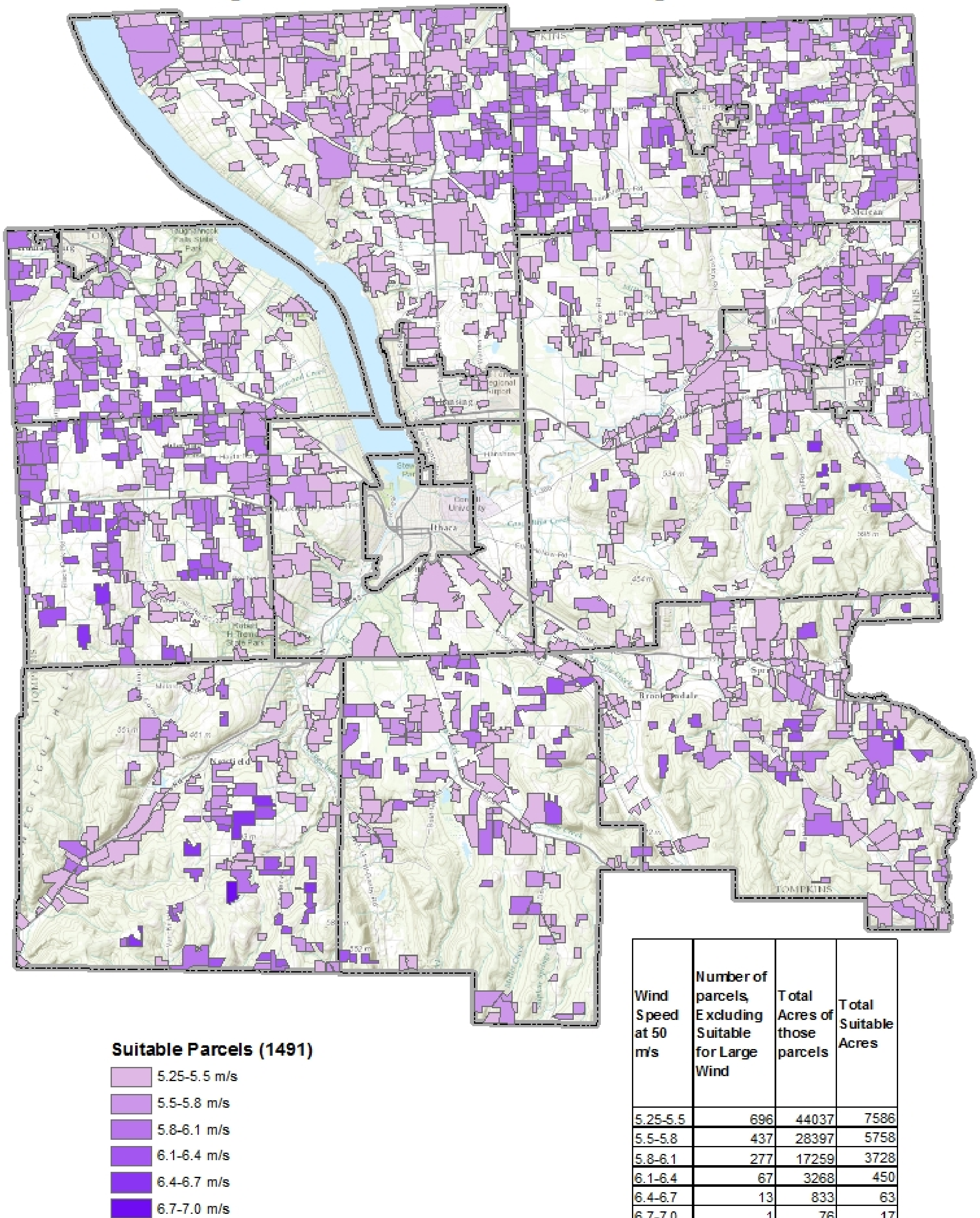
- Agriculture
- Commercial
- Industrial
- Public Services – includes water treatment facilities, bus terminals, pipelines, landfills, electric and gas facilities
- Recreation and Entertainment – includes fairgrounds, racetracks, golf courses, riding stables, camping facilities and picnic grounds
- Vacant Land – includes abandoned agricultural land
- Community Services – includes schools, libraries, colleges, churches, hospitals, government buildings and parking lots, correctional facilities and cemeteries

Lands Deemed Inappropriate for Medium-scale Wind:

- Lands with wind speeds under 5.25 m/s
- Unique Natural Areas
- Slopes >15%
- Ithaca Tompkins County Regional Airport approach and clear zones
- Audubon-designated Important Bird Areas
- DEC-designated Critical Environmental Areas
- Tompkins County Distinctive and Noteworthy Viewsheds
- State forests, parks and wildlife management areas
- Municipal parks and open space
- Cornell University Natural Areas
- County-owned Forestlands
- Parcels smaller than 6.5 acres
- Parcels identified as suitable for large-scale wind
- Tax parcel property classes
    - Residential
    - Wild, Forested, Conservation Lands and Public Parks

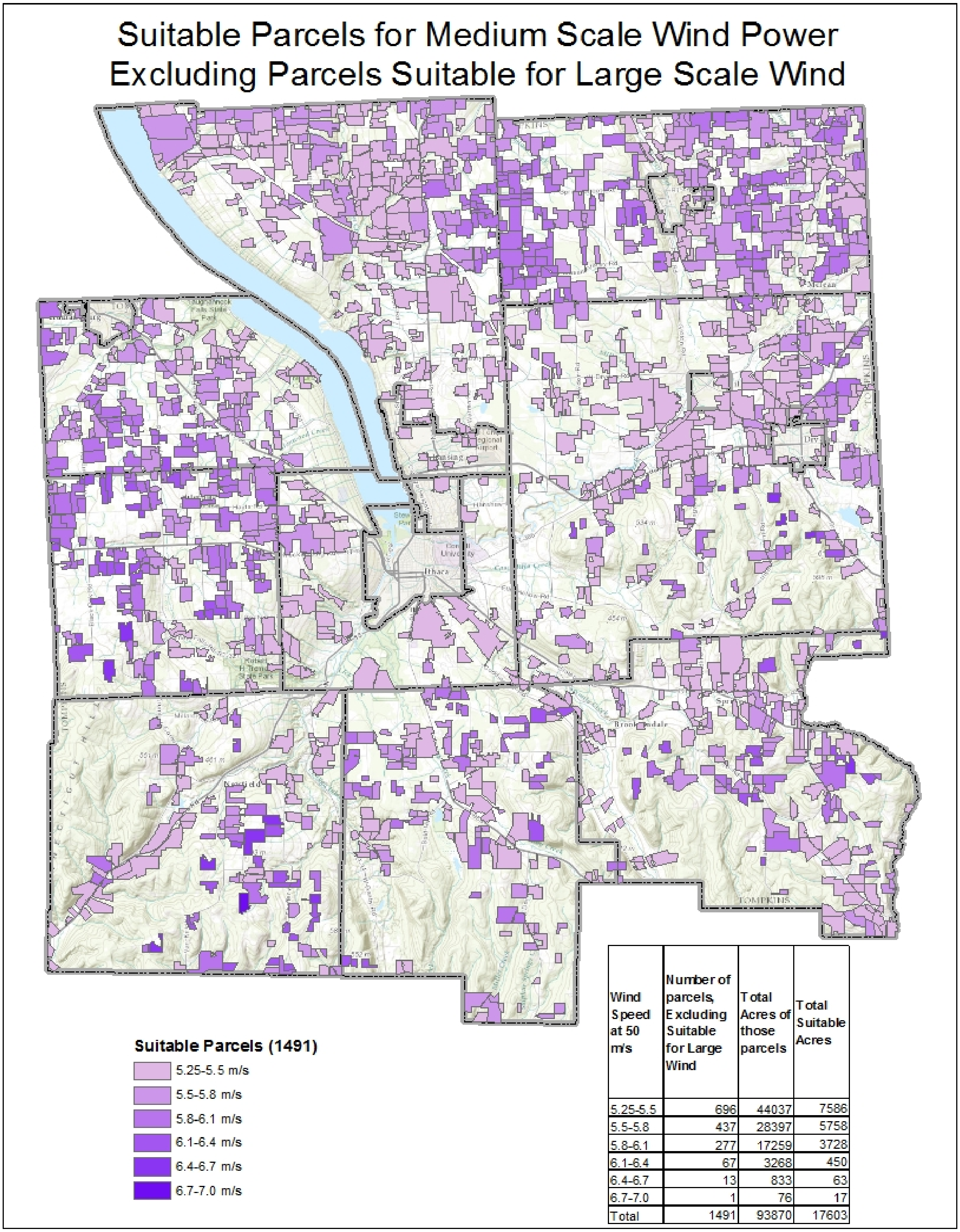
In order to estimate wind power potential, we scaled down the wind speed from the 80m height to 50m for medium-scale hub height using the GIS software.

Suitable Parcels for Medium Scale Wind Power Excluding Parcels Suitable for Large Scale Wind



Wind Speed at 50 m/s	Number of parcels, Excluding Suitable for Large Wind	Total Acres of those parcels	Total Suitable Acres
5.25-5.5	696	44037	7586
5.5-5.8	437	28397	5758
5.8-6.1	277	17259	3728
6.1-6.4	67	3268	450
6.4-6.7	13	833	63
6.7-7.0	1	76	17
Total	1491	93870	17603

Figure 35 illustrates the potential sites for deploying medium-scale wind turbines.



Wind Speed at 50 m/s	Number of parcels, Excluding Suitable for Large Wind	Total Acres of those parcels	Total Suitable Acres
5.25-5.5	696	44037	7586
5.5-5.8	437	28397	5758
5.8-6.1	277	17259	3728
6.1-6.4	67	3268	450
6.4-6.7	13	833	63
6.7-7.0	1	76	17
Total	1491	93870	17603

Figure 35 Suitable parcels for medium-scale wind in Tompkins County

Based on our analysis and calculations, we estimated the potential for medium-scale wind turbines as 745.5 MW and the corresponding annual energy output as 2,097.1 GWh. The results are summarized in Table 29. In comparison, the County-wide annual electricity consumption in 2008 was 809.1 GWh.

Table 29 Medium-scale wind power breakdown

Type of Parcel		Number of Parcels	Installation Capacity (MW)	AEO (GWh)	Capacity Factor
Agriculture	Cattle Farm	17	8.5	23.7	0.318
	Dairy Farm	150	75	210.4	0.320
	Field Crops	279	139.5	397.4	0.325
	Vacant Farmland	248	124	357.7	0.329
	Others	22	11	31.7	0.329
	Subtotal	716	358	1020.9	0.326
Commercial		36	18	47.8	0.303
Community Services		98	49	138.0	0.322
Vacant		590	295	822.6	0.318
Others		51	25.5	67.7	0.303
Total		1491	745.5	2097.1	0.321

2.3 Large-Scale Wind Power

Large-scale wind turbines are normally tied directly into the utility grid, and can generate electricity to power a large number of consumers. There are significant siting requirements associated with larger turbines to ensure the safety of people and buildings, minimize any nuisance to abutting land owners, and protect other land uses.

In 2005, The Tompkins County Environmental Management Council (EMC) published a "Model Municipal Ordinance for Utility-Scale Wind Energy Conversion Systems." The model ordinance was designed to assist municipalities in the county that expect to host utility-scale wind projects and serve as a guideline for land use considerations. The ordinance defines a utility-scale wind energy conversion system as having at least one of three characteristics: [15]

1. A rated capacity of 500kW or greater
2. 200 feet or greater in height
3. The purpose of such energy generated is for commercial sale

These guidelines are consistent with the installed capacity and height of modern wind turbines used in commercial wind farms.

In 2009 NYSERDA published the "Wind Energy Toolkit" to assist municipalities and developers in constructing wind power facilities [7]. The toolkit outlines a series of recommendations for selecting sites for large-scale wind power. NYSERDA suggests that five characteristics of a site must be considered when assessing its appropriateness for wind energy generation:

1. Wind Conditions: The site must have average wind speed of 6.5m/s
2. Proximity to Transmission Line: The site should be able to access a high voltage transmission line without significant impacts on nearby land uses

3. Terrain Favorable for Construction: The site must not be built on an excessive slope, and must have soils that can support large structures as well as construction machinery
4. Land Use and Environmental Compatibility: The site should not significantly disrupt other land uses or the natural environment
5. Sufficient land area: The site should have sufficient land area to accommodate turbines and other structures

Small variations in wind speed can have significant impacts on the electrical output of a turbine, due to the fact that the cube of the wind speed is used to calculate the power output from a turbine. A higher wind speed makes a project more financially attractive to a developer, as it indicates that more electricity can be produced. The threshold speed for wind power suitability varies across studies, with some studies using values as low as 5m/s for wind speed. This analysis uses the NYSERDA and NREL-suggested threshold speed of 6.5m/s [7]. In general, the wind conditions in the county are rather low, with a maximum average wind speed of approximately 7.6m/s, according to the AWS Truewind estimates.

Large-scale wind turbines are tall structures. A turbine with an 80m hub height can have a blade diameter of up to 50m, bringing the total height to 105m (345 feet). Therefore, the safety of nearby structures, utility connections, and rights of way must be considered. Section 6.9 of The Tompkins County EMC's Model Wind Ordinance specifies five setback criteria for siting turbines [15]:

1. Inhabited structures: Each turbine shall be set back from the nearest inhabited structures by 1.25 times its total height at all times.
2. Property lines: Each turbine shall be set back from adjoining property lines by 2 times its total height at all times, unless the applicant receives written consent or a land lease/wind access easement from affected neighbor(s).
3. Public roads: Each turbine shall be set back from the nearest public road a distance of no less than 1.25 times its total height.
4. Communication and electrical lines: Each turbine shall be set back from the nearest existing above-ground public electric power line or telephone line a distance of no less than 2 times its total height.
5. Designated scenic roads/highways: Each turbine shall be set back from a state or locally designated scenic highway or road a distance of no less than 2 times its total height.

In addition to the Tompkins County EMC's Model Wind Ordinance, the Town of Enfield Wind Ordinance specifies the following setbacks for Wind Turbine Generators [16]:

1. Inhabited structures: 450' or 1.1 times the total turbine height, whichever is greater
2. Property lines: 100' or 1.1 times the blade sweep radius, whichever is greater
3. Other turbines: 450' or 1.1 times the total turbine height, whichever is greater
4. Wetlands: 100' from mapped wetlands.

These setback requirements are similar to those suggested by NYSERDA and the AWEA.

Fall Zone Requirements: With a hub height of 80m (240 ft.) and an estimated blade radius of 50m (135 ft.), a maximum height of approximately 345 ft. for a turbine with an 80m hub height can be expected. This total height is consistent with many turbine models with an 80m hub height.[10]

[10] See appendix for listing of turbines surveyed for this analysis

Assuming a maximum total height of 375 feet, the minimum setbacks range from 438 feet on all sides for criteria 1 and 3 of the EMC's model wind ordinance, to 700 feet for criteria 2, 4, and 5. If the setback criteria from the Enfield Wind Ordinance are applied, these setback distances would somewhat larger, with the 450ft. value being larger than 1.1 times the estimated height of 375 ft.

This analysis follows the setback criteria established in the Tompkins County EMC's Model Wind Ordinance, as this ordinance will likely serve as a guideline for interest municipalities within the County. Under these criteria, a radius of 700ft. is applied to each turbine, representing the largest setback requirement of the ordinance. Given that few roads cross parcel lines, the 700 ft. buffer from a parcel line would also accommodate the restrictions on public roads and scenic highways.

Setting 700 feet as the radius around a turbine equates to a minimum area of 1,539,380sf, or a 35-acre circle that does not intersect adjacent properties. This meant that only parcels that were able to contain a 35 acre circle free of human occupied structures and property lines were included in the analysis of suitable lands for large-scale wind.

A study was conducted by the National Renewable Energy Laboratory to access land-use requirements of modern wind farms [17], which identified the total area requirements for wind farms to be between 22-247 acres/MW, with the vast majority lying between 25-75 acres/MW. Black Oak Wind Farm, currently under development in Tompkins County, is a 16.1 MW wind farm being developed on 930 acres, so 58 acres/MW (or 145 acres/2.5 MW turbine) was deemed to be a reasonable guide for land use assessment.

Lands Deemed Appropriate for Large-scale Wind: All land tax classifications were deemed appropriate if the parcel was big enough (>35 acres).

- Agriculture
- Vacant Land – includes abandoned agricultural land
- Wild, Forested, Conservation Lands and Public Parks
- Residential
- Commercial
- Industrial
- Public Services – includes water treatment facilities, bus terminals, pipelines, landfills, electric and gas facilities
- Community Services – includes schools, libraries, colleges, churches, hospitals, government buildings and parking lots, correctional facilities and cemeteries
- Recreation and Entertainment – includes fairgrounds, racetracks, golf courses, riding stables, camping facilities and picnic grounds

Lands Deemed Inappropriate for Large-scale Wind: We eliminated all parcels that have 50% of their land area covered by any of these exclusions:

- Lands with wind speeds under 6.5 m/s
- Unique Natural Areas
- Slopes >15%
- Ithaca Tompkins County Regional Airport approach and clear zones
- Audubon-designated Important Bird Areas
- DEC-designated Critical Environmental Areas
- Tompkins County Distinctive and Noteworthy Viewsheds

- State forests, parks and wildlife management areas
- Municipal parks and open space
- Cornell University Natural Areas
- County-owned Forestlands
- Parcels smaller than 35 acres
- All buildings that fall within residential land uses
- Land further than 6 miles from a high-voltage transmission line, based on a survey of model ordinances that used 10km from a transmission line as the maximum allowable distance to allow for a financially viable project.

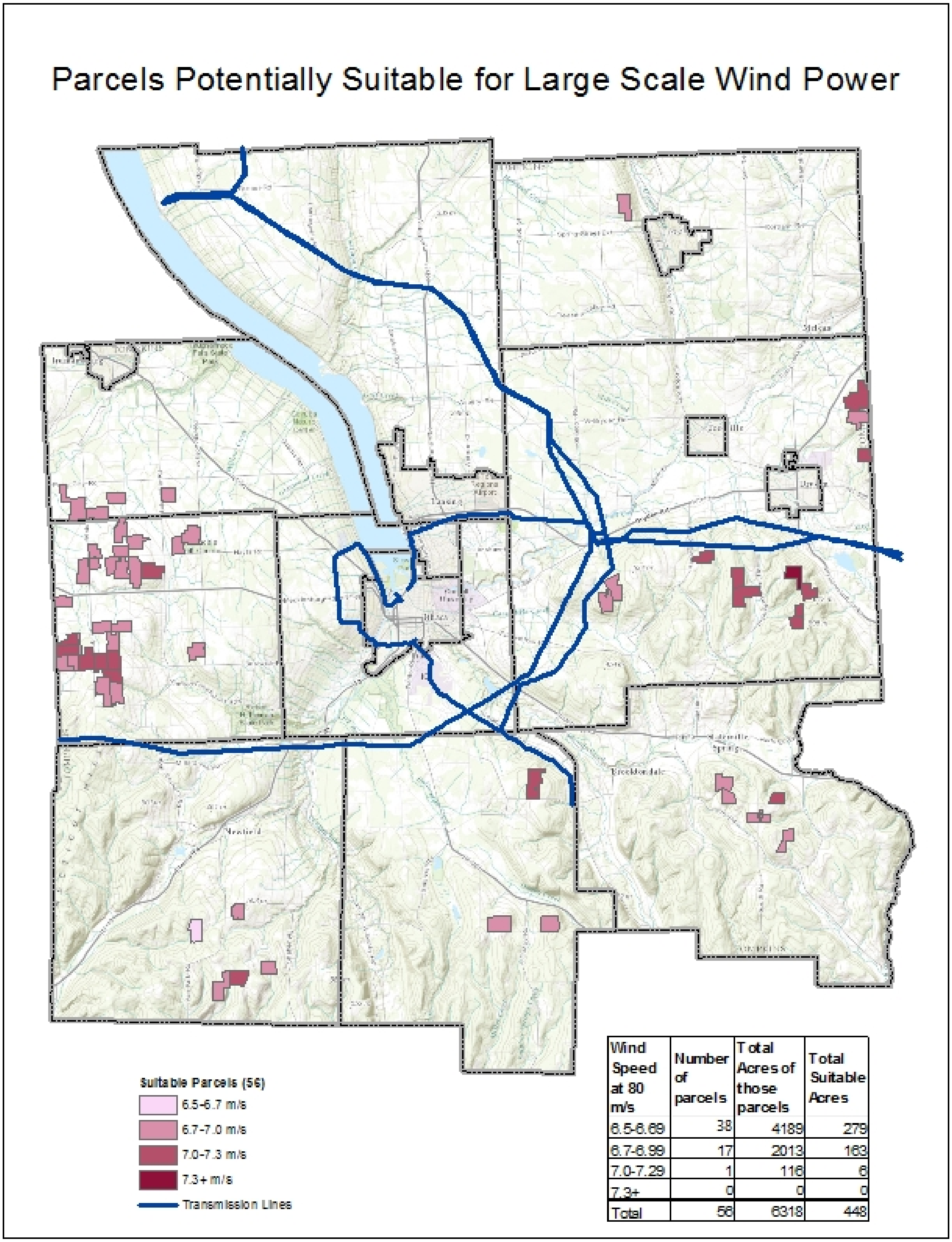
Since the wind power GIS data was for 80m hub height, there was no need to scale down the data prior to analysis. Figure 36 illustrates the potential sites for deploying large-scale wind turbines. Please note that the parcels identified are reflective of the GIS analysis and the above-detailed constraints. The wind resource is much more expansive in the County and there are likely many other geographical opportunities for development of large-scale wind than are identified on the map.

For the energy generation analysis of these sites, we used the GE 2.5 MW Turbine, similar to those being adopted at the Black Oak Wind Farm [18]. The turbine has a rotor radius of 52m, a hub height of 85 m, a cut in speed of 3m/s, a rated speed of 12m/s and a cut out speed of 25 m/s. Because the hub height was very close to the height as the wind data we used, we did not need to scale down the wind speeds for large-scale wind.

Based on this analysis and calculations, we estimated the potential for large-scale wind turbines as 180 MW and the corresponding annual energy output as 515.8 GWh.

Table 30 Large-scale wind power breakdown

Type of Parcel	Number of Parcels	Installation Capacity (MW)	AEO (GWh)	Capacity Factor
Agriculture	26	90	256.3	0.325
Forest	4	12.5	35.4	0.326
Recreation	1	2.5	7.7	0.353
Residential	22	62.5	180.4	0.330
Vacant	3	12.5	36.0	0.326
Total	**56**	**180**	**515.8**	**0.327**



Wind Speed at 80 m/s	Number of parcels	Total Acres of those parcels	Total Suitable Acres
6.5-6.69	38	4189	279
6.7-6.99	17	2013	163
7.0-7.29	1	116	6
7.3+	0	0	0
Total	56	6318	448

Figure 36 Suitable parcels for large-scale wind in Tompkins County

3. Challenges and Opportunities

3.1 Challenges

The regulatory structure for wind turbines is governed primarily at two levels – the state and local level. For large-scale wind installations, the state is significantly involved in siting through the Power Facilities Siting Act, also known as Article X [19], and the State Environmental Quality Review Act (SEQR) [20]. For small-scale turbines, the primary government entity is the municipality, which may create their own regulations for height restrictions, zoning, and special use permits.

3.1.1 Regulations

3.1.1.1 State Regulations

The regulations on large-scale energy development in New York State changed with the Power NY Act of 2011 and the reinstatement of Article X. Under Article X, a multi-agency Siting Board was formed and charged with streamlining the permitting process for power plants of 25 MW or greater, centralizing authority for site approval of large projects with the state. Facilities with an installed capacity of less than 25 MW are permitted under the SEQR process, granting more authority for smaller projects with local governments [21].

Article X requires any project with a capacity of 25 MW or more to submit an application to the state siting board. This application must discuss potential health and safety impacts, emissions, demographics of the host community, alternative locations for the power source, measures needed to be taken to minimize environmental impact, a list of additional studies to be conducted and required permits. There is also a fee of $350/MW to cover costs of the approval process. This has no effect on small or medium scale wind power and per this law large scale wind power is subject to the same rules as every other large capacity power source. Additionally, Enfield is the only site that has the potential to have 25 MW of capacity and thus is the only site potentially affected.

SEQR addresses some of the environmental aspects of new energy projects. SEQR requires an environmental review of projects. It grants local municipalities, state agencies and other involved entities the right to request modifications, such as relocation of turbines or reduction in the number of turbines, and even grants them the right to halt the project at any point in development if necessary. Again, this process is only likely to affect large-scale wind farms.

3.1.1.2 Local Regulations

The greatest control that a local community can exercise over wind power development is through its zoning, land use provisions, and permitting procedures. By creating regulations that address wind turbines and provide an efficient and easily understandable permitting process, municipalities can encourage more development of small, medium and large-wind in their jurisdictions, and restrict certain types of development to specified districts.

Each of the towns within Tompkins County has the authority to enact local laws defining the limitations on the implementation of wind power within town borders. As of early 2012, the statuses of these laws were as follows:

- Ithaca: Small-scale wind facilities are permitted in all zones provided they are less than 145 ft. tall and operate within a defined decibel range.

- Groton: Small-scale wind power is permitted provided the installed capacity is less than 10 kW; the height is less than 120 ft., and the turbine falls within a property line setback of 1.5 times the height of the turbine.
- Dryden: Small-scale wind turbines may be installed provided they are under 50 ft. in total height and under 10 kW in capacity. All projects larger than that require special use permits.
- Lansing: Wind turbines require special considerations and a special use permit, except within areas zoned for medium density residential and all commercial districts where they are not permitted.
- Newfield: No provisions for wind turbines could be found.
- Ulysses: No provisions for wind turbines could be found.
- Caroline: No provisions for wind turbines could be found, however the Comprehensive Plan for the town identifies renewable energy technologies as an area of interest for the town. Additionally, Caroline does not have any zoning laws [22].
- Danby: No provisions for wind turbines could be found [23].
- Enfield: According to the Enfield Wind Ordinance, a Wind Energy Permit is required in order to construct any wind turbine, regardless of size, or any meteorological tower [16]. The only exception to this rule is for turbines that are exclusively used in an agricultural zone. For turbines larger than 100kW a Wind Energy Permit Application must include a description of the project, site plans, turbine information, decommissioning plan, landscaping plan, Part 1 of a Full Environmental Assessment Form (EAF) with visual impact addendum, and a construction schedule. For a turbine under 100 kW, the Wind Energy Permit application must include turbine information, a visual analysis, evidence that the utility provider has been informed of the electrical interconnection, electrical diagrams, and evidence that the primary use of the turbine will be for reducing on-site electric demand. For both permits, the fee schedule appears below:
    - WTG Wind Energy Permit: $250 per WTG.
    - Wind Measurement Towers Wind Energy Permit: $200 per tower.
    - Small WTG Wind Energy Permit: $150 per WTG.
    - Wind Measurement Tower Wind Energy Permit renewals: $50 per WTG.
    - Additionally, the town may charge the project owner any fees associated with the inspection by an expert. The town reserves the right to negotiate a PILOT with the owner of a turbine. As Enfield does not have zoning, there are no specifications on the allowable locations of wind turbines.

In these cases, the lack of standardized laws regarding wind power within the county may be impeding its development. If vendors must navigate very different processes depending on which town the turbine is being built in, it may increase the time it takes to complete the process and increase the overall cost of the project.

An example for future consideration could come from Europe. A release from the European Wind Energy Association gives a practical guideline for wind turbine siting. While it does list considerations made for auditory, visual, and environmental impact, it is notably silent on setback recommendations [24]. Instead, it recommends that turbines be placed so they do not have undue impact on the noise in the area. This does add a little work for installers, but could give potential sites for wind turbines the leeway they need to install a turbine. Further investigation would be needed to determine if this change in requirements would appreciably impact small-scale wind power adoption within the county.

3.1.2 Net Metering and Grid Integration

Net metering allows the owners of wind power systems to generate power, and gain credit for energy they generate but do not use. This allows the owner to be billed only for net energy used. At present there are 3 different segments that have different net metering limits in New York:

- Residential: <25 kW
- Farm-based: <500 kW
- Non-residential: <2 MW

These net metering limits provide a practical limit to the installed capacity of a property. For many properties this may present no issue because the wind resource is not strong enough to warrant larger installations, but for large farms within Tompkins County, this may limit the amount of wind power capacity that can be installed [1].

3.1.3 Maintenance

One point that is brought up when comparing wind power to solar power is the maintenance costs associated with wind power. Maintenance represents an unavoidable issue with wind power because turbines require moving parts to operate. An installed turbine can be expected to last more than 20 years and in that time will require annual to semi-annual maintenance. This maintenance may involve changing oil or filters, torqueing bolts, and inspecting other components. Some parts involved in wind turbines may need to be replaced every 5 to 15 years [25].

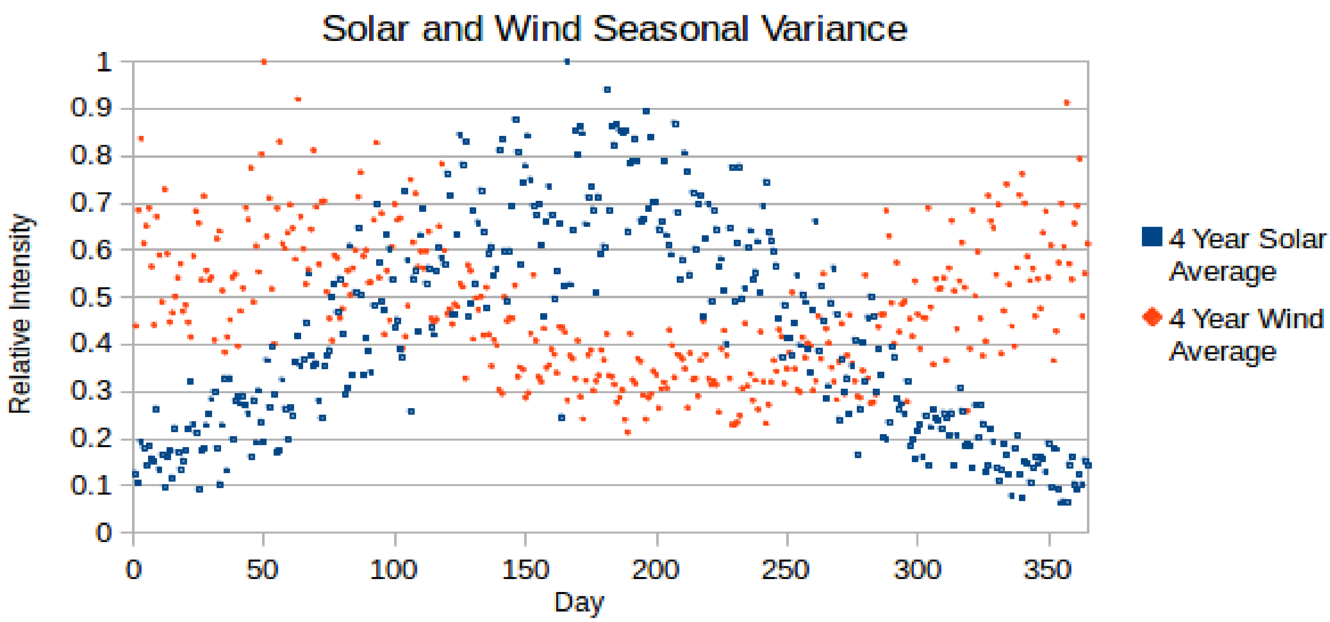
Maintenance can be expected to cost about 20 to 25 percent of the total cost per kWh over the lifetime of a turbine [26]. Other sources place this number closer to 1.5 to 2 percent of the initial investment per year, with the cost rising as the turbine ages [27]. The AWEA lists the cost of a small wind turbine to be $30,000 on average [9]. With this number as the installation cost, maintenance should cost between $6,000 and $7,500 over the lifetime of the turbine or between $450 and $600 each year. As wind power grows in prominence and more workers are trained to maintain turbines, maintenance costs are likely to decrease.

Our analysis revealed relatively low average capacity factor, around 13.5%, for small-scale wind in the County. This average capacity factor is only slightly higher than that of solar PV in the County, which is around 12.7%. However, small-scale wind turbines typically require much more maintenance than solar PV. In addition, community marketing efforts such as those pushed forward by Solar Tompkins has further brought down the costs of solar PV installation. No such efforts targeted at wind energy. As a result, all local renewable energy companies except one in the County have stopped offering small-scale wind turbines to customers.

3.2 Opportunities

3.2.1 Complementary Relationship with Solar Power

A major boon to wind power is its relationship to potential solar power. By analyzing four years of data from the Western Regional Climate Center, we have determined that wind and solar power reach their maximum annual values at different periods [28]. These data comes from Harford, NY, which while technically located in Cortland County, is the closest location to Tompkins County that records both wind speeds and solar insolation. Wind speed reaches a maximum in mid-February. Solar insolation on the other hand reaches a maximum in the beginning of July, while wind speeds are approaching a minimum. While these variances do not exactly compensate for each other, it does suggest that using a combination of wind and solar power could help overcome one of both power sources' biggest weaknesses, their variable nature. Figure 37(a) shows a visual representation of this trend.



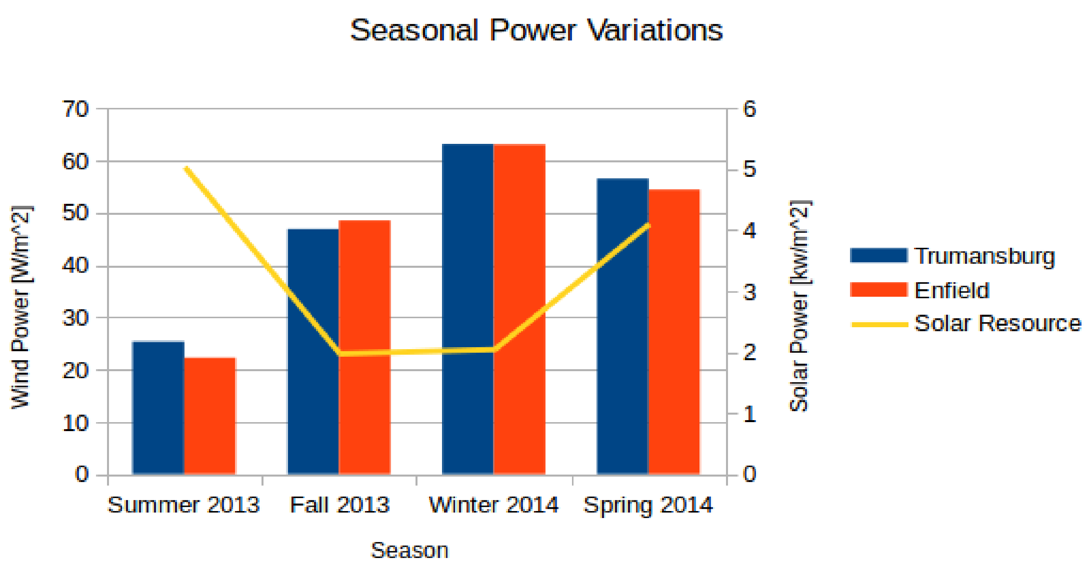


Figure 37 (a) Relative wind intensity vs. relative solar intensity for Harford, NY and (b) Solar power seasonal variations represented by the yellow line compared to wind power seasonal variations represented by the two bar graphs at two locations [29]

We then performed analysis of the data to determine the correlation coefficient between solar and wind power. Correlation coefficients show the level to which a change in one data set can be observed in another. A coefficient of 1 would describe two data sets that are completely correlated, and a coefficient of -1 would describe two data sets that have a complete negative relationship, that is one rises while the other falls. Finally a coefficient of 0 would describe two data sets that are completely unrelated. In order to properly compare these data sets, we had to make sure both data sets had a linear relationship with power. Solar insolation values already had a linear relationship with power, but wind speed has a cubic relationship with power. This means that in order to compare like values we had to compare the cube of wind speed with solar radiation. The wind and solar data sets have a correlation coefficient of -.28 which denotes a weakly negative correlation between solar and wind power.

Because wind power varies so much with location, we also did an analysis for two locations within Tompkins County. Using seasonal average wind speeds provided by Weaver Wind Energy, we found the average seasonal wind power for Trumansburg and Enfield. We compared these data to the solar data from the Harford station. While Harford is not within the county, solar intensity varies by location to a much smaller degree than wind does so solar data from Harford is valid for our analysis. Figure 37(b) shows that solar power peaks in the summer and reaches a minimum in fall and winter while wind power peaks in winter and reaches a minimum in the summer.

3.2.2 Effects on Populations

Numerous studies have been done to examine the effects of wind turbines on human health. A meta-analysis of existing data published in Frontiers in 2014 found: "The available scientific evidence suggests that electromagnetic fields, shadow flicker, low-frequency noise, and infrasound from wind turbines are not likely to affect human health" [2] The article looked at almost 60 studies related to the effects of wind power on audible noise, low-frequency noise, infrasound, electromagnetic fields and shadow flicker. The studies were not filtered based on date so the majority of them have come from the current decade as wind power has come into prominence. The methods and results of all of these studies were compared, questioned and analyzed.

The same article found that some people may be annoyed by the noise produced by turbines, but the majority of issues connected with turbines can be explained by the nocebo effect, where the mere suggestion of side effects can bring on negative symptoms. This finding suggests that most reported negative health effects from wind turbines can be overcome with proper planning and development guidelines and thus they should not be regarded as an insurmountable problem with wind power. The article lists some general guidelines for wind development to overcome the nocebo effect, including: the setting of sound level based rather than distance based setbacks, and closer monitoring of projects in development to make sure noise levels stay within acceptable limits [2].

Another point of concern has been the effect of wind turbines on bird and bat populations. A paper published in PLOS ONE studied the effect of turbines on these populations. The end result of the study showed that the installation and operation of turbines had no threat to survival on overall bird populations. Bat populations were affected only if turbines were placed within very close proximity to their habitats. The study recommended that turbines be placed no closer than 20 m to known bat habitats [3].

3.2.3 Community Invested and Community Owned Wind Power

Community owned wind power presents several opportunities. A brochure from the National Renewable Energy Laboratory spells out the following advantages for wind projects that are either owned by the municipality or by groups of local individuals:

- Community wind projects allow local control over projects. Communities can be sure that their best interests are being served by the projects because they are in full control over them.
- Community wind projects can stabilize the price of energy in a region. Wind power requires no fuel and small maintenance costs so the price of electricity from wind power is fixed and predictable.
- Community wind projects can be easily connected to the grid compared to utility-scale wind farms. This is because they tend to be smaller in size than utility-scale wind projects and often do not require transmission line upgrades [30].

The Black Oak Wind Farm in Enfield represents a new opportunity in community wind power. Typically in the US, wind energy tends to be project financed. In project finance, the initial capital for the project is borrowed against the future revenue streams. This financing option often requires extra diligence in assessing sites but is often chosen because it shifts much of the risk from the developer to the creditors. In Europe, groups of citizens will share equity in a more modest scale turbine and sell the power to the grid. This system does not allow for the same economies of scale that the current US model does. On the other hand, it does allow wind developers to interact with private investors, a largely new market. It also places more power in the hands of individuals in the community thereby increasing public support for planned projects. The Black Oak Wind Farm appears to be financed in a hybrid between these two models possibly opening the door to future ventures with similar models [31].

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Figure Sources

Figure 30 (a): http://www.yougen.co.uk/i/blog/125042938409762.jpg
Figure 30 (b):http://plainswindeis.anl.gov/images/photos/wind_450KW_turbine_IA_V_13764.jpg

Solar Energy

K. Max Zhang, Xiyue Zhang, Mark Romannelli, Camelia Hssaine, Aaron Benedict

Executive Summary

Total Potential

Energy Source	Electricity (GWh)	Percent of Total 2008 Electricity Demand
Solar Energy Potential		**303.2%**
Residential	125.1	
Non-residential	234.9	
PV Farms	2,093.4	
Total	**2,453.4**	
2008 Community Demand	809.1	

Major Assumptions

	Residential PV Systems	Non-Residential PV	PV Farms
Solar Panel Type	Yingli Energy YL255P-29b, 255W, efficiency of 14.5 W/ft^2 [1]	Yingli Energy YL255P-29b, 255W, efficiency of 14.5 W/ft^2 [1]	Yingli Energy YL255P-29b, 255W, efficiency of 14.5 W/ft^2 [1]
Annual Electricity Output Calcs	Binghamton, NY solar radiation, DC/AC derate factor of 0.77, array tilt/azimuth of 42.2/180	Binghamton, NY solar radiation, DC/AC derate factor of 0.77, array tilt/azimuth of 42.2/180	Binghamton, NY solar radiation, DC/AC derate factor of 0.77, array tilt/azimuth of 42.2/180
Mounting	Urban – roof-mount only, Rural – both roof-and ground-mounts. Assumed 1 PV system per tax parcel in rural areas	Roof-mount only	Ground-mount only
Land/Buildings Included	Single family house, duplex, multi-family up to 5-units, Roof areas >1,000sf, Urban – land within City and Villages, Rural – land outside of those areas	Commercial (including apartment buildings with 5-units or more), Community and Public Service and Industrial buildings with roof areas >1,000sf	Undeveloped parcels .10 acres, within 1 mile of a utility substation
Land/Buildings Excluded	Larger apartment buildings, manufactured homes	Buildings owned by IC and TC3	Unique Natural Areas, Slopes >20%, Important Bird Areas, Publicly owned open space, Critical Environmental Areas, Designated Distinctive scenic viewsheds, Airport approach and clear zones
Constraints	Roofs with moderate to severe shading were excluded, as were roofs	Only used percent of roof areas suitable for PV based on analysis of	n/a

	with predominantly facing north, northeast, and northwest surfaces	building types (54.6%-71.2% range of suitability), Small apartment buildings were analyzed per residential urban PV systems	
System Sizes	Urban – 4kW, Rural – 7kW	Tied to roof area per structure	Minimum 2 MW systems

The overall objectives of this section are 1) to quantify the technical potential of solar photo-voltaic (PV) systems with practical constraints in Tompkins County including roof-mounted and ground-mounted solar systems, and 2) to identify challenges and opportunities for future solar PV penetration in the County. Solar PV systems convert sunlight into electricity, and can be roof- or ground-mounted. We categorize the solar PV systems, loosely according to the convention by the New York State Energy Research and Development Authority (NYSERDA), as Residential Systems, Nonresidential Systems, and PV Farms.

- *Residential Systems*: roof-mounted systems in urban areas and roof- or ground-mounted systems in rural areas, typically smaller than 25 kW.
- *Nonresidential Systems*: roof-mounted systems in the commercial, industrial and educational sectors, typically smaller than 2 MW
- *PV Farms*: Ground-mounted, large arrays of PVs, typically 2 MW or larger and corresponding to the very high end of NYSERDA-defined large nonresidential systems (2 MW) and large renewable projects (>2 MW)

Table 31 summarizes the potential for the three categories of solar PV systems to generate electricity in Tompkins County. The overall annual electricity generation (~2453.4 GWh) is more than three times the annual electricity demand in Tompkins County at the 2008 level (~809.1 GWh) according to the Tompkins County Greenhouse Gas Emissions Report, 1998-2008. Among the three types of PV systems, PV Farms alone could generate electricity that amounts to almost three times the annual electricity demand in terms of kWh. The data, methodologies and assumptions to derive those estimates are detailed in Section 2.

Table 31 Potential of solar PV in Tompkins County

Category		Installation Capacity (MW)	Annual Electricity Output (GWh)
Residential	Urban*	14.6	16.2
	Rural	98.2	108.9
Nonresidential#	Commercial	120.1	133.2
	Industrial	19.0	21.0
	Community and public services	72.7	80.7
PV Farms		1,887.7	2,093.4
Total		**2,212.3**	**2,453.4**

*Urban areas are defined in this chapter as the City of Ithaca and the 6 Villages
Not including buildings at Ithaca College and Tompkins Cortland Community College

While we have learned that there is significant solar PV potential in Tompkins County, there are challenges to achieving that potential. Obstacles to deployment include high capital investment, shading, limited solar resources and integration of intermittent solar energy into power systems. In particular, there is a need to upgrade the power system infrastructure at both the distribution level and the transmission level.

These challenges are significant, but there are reasons for confidence in an expanded solar energy future. Government policies and incentives at both the State and Federal level are encouraging more solar projects to be installed. Technological development in solar cells, energy storage, power electronics, and energy management paves the way for high levels of solar penetration. Tompkins County is already a leader in solar PV installation in New York State. The example of Solar Tompkins, the nonprofit county-wide community solar program, has shed light on how to facilitate the widespread adoption of residential solar in a small region like Tompkins County.

1. Introduction

Photovoltaic (PV) panels convert sunlight to electricity directly. As solar insolation varies diurnally, seasonally and with meteorological conditions, the electricity generation from PVs is inherently intermittent. Currently, the majority of PV systems are grid tied, meaning they are interconnected with the electricity grid. In most of the Residential and Nonresidential Systems, the grid can act as a de facto battery, accepting any extra electricity the PV system produces that is higher than the demand, and supplying electricity if the PV system does not meet the demand. It should be noted that under future scenarios with high PV penetration the grid may not be able to absorb an influx of a large amount of solar power without compromising the grid stability, as suggested by countries with high renewable installation [2]. Upgraded Infrastructure, energy storage and demand-side management can play important roles in managing solar intermittency.

Figure 38 Ground-mounted system, Roof-mounted system and PV Farm

PV systems are installed on the ground, roofs, and in large-scale PV farms, see Figure 38.

Over the past few decades, the United States has seen rapid growth in solar energy. In 2013, there were 4,751 MW of new photovoltaic capacity installed; a 41 percent increase from 2012 and nearly 15 times the amount installed in 2008 [3]. According to the United States renewable energy attractiveness indices, which provide scores for state renewable energy markets, New York is tied with Maine, Pennsylvania, and Nevada for 8th most attractive state in the country for developing renewable energy [4].

Table 32 Solar PV installed or under construction in Tompkins County as of Feb 2015

Sectors		Installation Capacity (MW)	Average size (kW)
Residential		5.2	6.7
Nonresidential	Commercial/industrial	1.2	22.3
	Public and community services	0.4	27.2
PV Farms		4.0	2,000
Total		**10.8 MW**	

Table 32 lists the existing and ongoing solar installations in the County as of February 2015. The County had 874 residential and non-residential solar PV systems (not including PV Farms) with total installation capacity of 6.8 MW, including 806 residential, 52 commercial/industrial, and 16 government/non-profit. According to NYSERDA PowerClerk, Tompkins County is a photovoltaic leader in central New York, as may be seen in Table 33.

Table 33 Solar PV systems (not including PV Farms) installed or approved in neighboring counties as of Feb 2015

County	Installation Capacity (MW)	Average size (kW)
Cayuga	1.6	12.5
Cortland	0.76	8.2
Tioga	0.93	8.9
Chemung	0.86	12.3
Schuyler	0.32	8.1
Seneca	0.86	16.2
Tompkins	**6.8**	**7.8**

A more recent development is the construction of two solar farm projects and the planning for several others. In September 2014, Cornell University began generating electricity from a 2 MW PV Farm constructed on 11 acres of land in the Town of Lansing. It is expected to reduce the university's annual GHG emissions by 625 metric tons per year. In 2015, Tompkins Cortland Community College (TC3) completed a 2.6 MW solar system on the main college campus in Dryden. The system, installed on approximately 10 acres, is expected to meet 90 percent of the college's electricity needs. Cornell University is currently planning an additional 8 MW of PV Farms. Tompkins County and the City of Ithaca are working with the Municipal Electric and Gas Alliance and contractor Solar City to develop a NYSERDA-supported 2 MW PV project that will be built on 10 acres of County land adjacent to the Ithaca Tompkins Regional Airport. The project will supply energy to the City of Ithaca per an agreement between the City and Solar City. The County will lease the land on which the PV project will be built to the City and Solar City will build and own the PV Farm.

The report is organized as follows. First, we explain the methodologies and results in estimating the solar PV potential in Tompkins County (Section 2), and then we discuss the opportunities and challenges in future solar PV development in the County (Section 3). It should be noted that this report does not discuss solar thermal systems, which can be coupled with geothermal or air-source heat pumps to provide heating or hot water. The related discussion will be presented in the report on energy efficiency.

2. Solar PV Potential of the Tompkins County

The overall PV potential for the county was broken down into Residential Systems, Nonresidential Systems and PV Farms. Nonresidential Systems are divided by sectors, namely, commercial, industrial and community and public services. The PV potential is represented by both installation capacity (MW) and annual electricity output (GWh).

The installed capacity is the nameplate DC power rating of the PV system (typically consisting of multiple panels) determined under Standard Testing Conditions (STC, e.g., 1000 W/m^2 direct insolation, 25 ^oC temperature and 1.5 air mass). PV systems do not necessarily reach installed capacity due to factors such as lower insolation values (i.e., <1000 W/m^2), unfavorable weather conditions, shading, soiling and DC to AC conversion losses.

We chose a mainstream polycrystalline solar panel manufactured by Yingli Energy (YL255P - 29b) with DC rating as 255 W for our analysis. Dividing the STC rating by the panel surface area gives 156 W/m^2 (or 14.5 W/ft^2) [1]. Later on, we used this number to convert roof area to installed capacity of solar panels for the Nonresidential Systems.

We used an online PV calculator, PVWatt, developed by the National Renewable Energy Laboratory (NREL), to estimate the annual electricity output [5]. PVWatt calculates the electricity production of a grid-connected photovoltaic system based on a few user inputs including location, DC rating, array tilt, etc. For our analysis, we selected the location as Binghamton, NY, the closest city to Ithaca that has historical solar radiation measurements; the DC to AC derate factor as 0.77 (accounting for conversion loss from DC current to AC current); and the array tilt and array azimuth as 42.2^o and 180^o respectively. Based on those assumptions, the expected AC electricity that could be generated from the installed capacity is approximately 1,109 kWh annually per installed kW. The installation capacity is then converted to annual electricity output by multiplying the installation capacity by the 1,109 kWh per installed kW.

2.1 Residential Systems

Residential units considered in this section included all single-family houses, duplexes, and multi-family units up to 5-units per building. Not included were apartment buildings, which were treated as commercial properties described in Section 2.2, and manufactured homes, which were assumed to be not suitable for PV installation due to their temporary nature. Different methodologies were employed to analyze PV potential for residences in urban areas and potential in rural areas.

Urban Residential Systems – For this section, we defined “urban areas” in Tompkins County as the City of Ithaca, and the Villages of Cayuga Heights, Dryden, Freeville, Groton, Lansing and Trumansburg, which are all primarily characterized by closely spaced houses and limited roof areas. The rest of the County was defined as “rural areas”.

The overall methodology for analyzing the potential of urban residential PV systems is described as follows.

- First, we acquired a list of all 6,456 residential buildings in the urban areas with roof areas greater than 1000 ft^2,

- Second, we randomly selected 287 buildings out of the updated list and conducted individual analysis of suitability for installing PVs. The sample size led to a margin of error of 5% at 90% confidence level [6]. Two main criteria were used to determine if a roof was suitable for solar PV:1) low-to-moderate shading from surrounding structures and vegetation (and assumed that home owners would be willing to trim/remove vegetation to mitigate shading); and 2) availability of south-, west- and east-facing roofs (in other words, north-, northeast- and northwest-facing roofs are not suitable). We conduct the analysis using two online imaging tools, Pictometry [7] and Google Earth. It should be noted that we are unable to estimate roof strength from aerial images. According to the Solar Tompkins program, less than 2% of the homes evaluated as part of that program needed structural support or major upgrade to hold a PV system. Out of the 287 randomly selected buildings, 162 were estimated to be suitable for PV installation. In other words, we estimate that 56.4% +/- 5% of the residential buildings with roof areas larger than 1000 ft^2 (or 3,641 buildings) are suitable for PV systems.
- According to the Solar Tompkins Program, the current average size of a PV system in the urban areas is ~ 4 kW. We multiplied 4 kW by 3,641 buildings to arrive at 14.6 MW +/- 1.3 MW. The underlying assumption is that only roof-mounted PV systems are suitable in urban areas. Applying the conversion factor of 1,109 kWh per installed kW, the annual electricity output is estimated to be 16.2 GWh +/- 1.4 GWh.

Rural Residential Systems – The general methodology for rural systems analysis is similar to that for urban systems analysis with some major differences:

- In contrast to urban areas, rural homes tend to have much more roof area and/or land area to install a PV system. Thus, both roof-mounted and ground-mounted PV systems can be viable options. According to the Solar Tompkins Program, the current average size of a PV system in rural areas is ~7 kW, and most of them are ground-mounted. Therefore, 7 kW was selected as average PV size for rural areas.
- Instead of conducting analysis based on a list of buildings, we obtained a list of residential tax parcels for rural areas. The underlying assumption is that a rural resident may own multiple buildings, but chooses to install a single PV system on the property. Then we randomly selected 266 parcels out of a total of 14,695 for individual analysis. 249 of the 266 parcels were identified as having either sufficient suitable roof areas or land areas, i.e., 93.7% +/- 5% of the rural residential parcels (or 14,030 parcels) are estimated to be suitable for 7 kW PV systems.
- We multiplied 7 kW by 14,030 parcels to arrive at 98.2 MW +/- 5.2 MW. Applying the conversion factor of 1,109 kWh per installed kW, the annual electricity output is estimated to be 108.9 GWh +/- 5.8 GWh.

Table 34 summarizes the results from the residential PV systems analysis.

Table 34 PV potential of urban and rural residential systems

	Urban	Rural
Number of units	6,456[a]	14,965[b]
Average PV size (kW)	4	7
Fraction of suitable units	56.4% +/- 5%	93.7% +/- 5%
Installation capacity (MW)	14.6 +/- 1.3	98.2 +/- 5.2
Annual electricity output (GWh)	16.2 +/- 1.4	108.9 +/- 5.8
Total installation capacity (MW)	112.8	
Total Annual electricity output (GWh)	125.1	
Fraction of annual electricity consumption in the County at 2008 level	16%	

[a]: Number of buildings on residential lots with roof areas > 1000 ft^2, not including apartments and mobile homes.
[b]: Number of residential parcels on rural areas

2.2 Nonresidential Systems by Sectors

The analyses for Nonresidential systems are conducted in three sectors, commercial, industrial and community and public services.

2.2.1 Commercial

We acquired a list of commercial buildings from the Tompkins County Planning Department. Then we selected those with roof areas larger than 1000 ft^2, and further grouped them into three categories, i.e., non-apartment buildings, large apartment buildings (with roof areas larger than 3,500 ft^2) and small apartment buildings (with roof areas smaller than 3,500 ft^2).

- The solar PV potential on the rooftops of Cornell University buildings was evaluated by Cornell University Sustainable Design group in 2014 [8]. It is estimated that the top 10 buildings on campus could have a total installation capacity of 0.946 MW.
- For the rest of the County, we randomly selected 240 out of 1,671 non-apartment commercial buildings (>1000 roof areas), and conducted imaging analysis. Because they usually have flat roofs, we estimated the fraction of the total roof area for each building that can host PVs. The area selection tools in Pictometry facilitated our analysis, which showed that 54.6% +/- 5% (at 90% confidence level) of the roof areas are suitable for PVs. Applying this fraction to the total areas of 1,671 buildings and the conversion factor of 14.5 W/ft^2, we estimated the potential to be 85.7 MW +/- 7.8MW, and 95.0 GWh +/- 8.7GWh.
- We applied the same methodology described above to large apartment buildings. We estimated the potential to be 21.3 MW +/- 1.9 MW, and 23.6 GWh +/- 2.0 GWh, respectively.
- We applied the methodology described for urban residential buildings to the small apartment buildings, because they mostly either are converted residential buildings or resemble residential buildings. We estimated the potential to be 2.2 MW +/- 0.2 MW, and 2.4 GWh +/- 0.2 GWh, respectively.

Table 35 summarizes the results from the commercial PV systems analysis.

Table 35 PV potential of commercial buildings

Type	Non-Apartment	Large Apartment Buildings	Small Apartment Buildings	Cornell University
Number of buildings [a]	1,671	407	934	10[b]
Total roof area (ft^2)	10,818,950	2,591,233	1,964,396	N/A
Fraction of suitable units	N/A	N/A	60.0% +/- 5%	N/A
Fraction of suitable roof areas	54.6% +/- 5%	56.7% +/- 5%	N/A	N/A
Installation Capacity (MW)	85.7 +/- 7.8	21.3 +/- 1.9	2.2 +/- 0.2	0.95
Annual Electricity Output (GWh)	95.0 +/- 8.7	23.6 +/- 2.0	2.4 +/- 0.2	1.0
Total Installation Capacity (MW)	120.1			
Total Annual Electricity Output (GWh)	133.2			
Fraction of annual electricity consumption in the County at 2008 level	17.1%			

[a]: Not including those with roof areas smaller than 1000 ft^2

b: Only top 10 most suitable buildings are included in the analysis[8]

2.2.2 Industrial

We obtained a list of 112 industrial buildings with roof areas larger than 1000 ft^2 from the Tompkins County Planning Department. We applied the same methodology for non-apartment commercial buildings to each of the industrial buildings on the list (i.e., random sampling is not applicable). Table 36 summarizes the results.

Table 36 PV potential of industrial buildings

Number of Buildings [a]	112
Total roof area (ft^2)	1,836,722
Fraction of suitable roof areas	71.2%
Installation Capacity (MW)	19.0
Annual Electricity Output (GWh)	21.0
Fraction of annual electricity consumption in the County at 2008 level	2.7%

[a]: Not including those with roof areas smaller than 1000 ft^2

2.2.3 Community and Public Services

The community and public services sector includes banks, hospitals, schools, governments, etc. The Tompkins County Planning Department provided a list of buildings with roof areas larger than 1000 ft^2. We deselect the buildings owned by Ithaca College and TC3 from the list because the higher educational institutions all have plans to achieve carbon neutrality and it is assumed each will maximize the contribution from their buildings to achieve this goal. Cornell rooftop PV potential was included as it had been quantified previously. For the remaining list of 769 buildings, we randomly selected 221 for individual analysis with margin of error at 5% at 90% confidence level. The same methodology for non-apartment commercial buildings was applied here. Table 37 summarizes the results.

Table 37 PV potential of community and public services buildings

Number of Buildings [a]	769
Total roof area (ft^2)	7,057,200
Fraction of suitable roof areas	64.1% +/- 5%
Installation Capacity (MW)	72.7 +/- 5.7
Annual Electricity Output (GWh)	80.7 +/- 6.3
Fraction of annual electricity consumption in the County at 2008 level	10.3%

[a]: Not including those with roof areas smaller than 1000 ft^2

2.3 PV Farms

A multi-criteria GIS model was developed to identify areas suitable for developing PV Farms. Those criteria include:

- Land acreage: We selected lands of sufficient size to host a PV array installation. We choose 10 acres (for a 2 MW system) as the minimum size. Smaller size is typically not economically attractive.
- Land availability: We selected undeveloped lands that were not forests, water or wetlands. If multiple properties had contiguous suitable lands, we treated them as a single parcel. In other words, even if a vacant property was smaller than 10 acres, it could be part of a site that is larger than 10 acres. Our underlying assumption was that developers will work with multiple owners of connected vacant parcels for PV Farm projects. We omitted lands identified by the Audubon Society of New York as Important Bird Areas, by the Tompkins County Environmental Management Council as Unique Natural Areas, and local parks, State Forests, State Wildlife Management Areas, State Parks, Critical Environmental Areas, Conservation Easements, Nature Preserves, and Cornell University Natural Areas. This is because it is not desirable to locate such a facility in those areas.
- Lands with slopes greater than 20% were also omitted, as they would make installation of solar farms impractical.
- Transmission: Proximity to medium voltage power lines and substations should be considered for controlling interconnection costs. Considering there are only 19 substations in the County, proximity to substations (i.e., rather than proximity to medium voltage power lines) likely becomes a limiting factor. In this analysis, we set the maximum distance between a viable site

for a PV Farm and the nearest substation to be 1 mile. In addition, we do not have information on the available capacity of the substations and power lines to accommodate PV Farm interconnections, which we assumed is not a limiting factor.

Figure 39 shows the suitable lands for potential PV Farm development based on this analysis. 171 contiguous sites are identified with a total area of 10,487 acres. Next, we applied a conversion factor of 0.18 MW (AC) per acre (based on the Cornell Snyder Road Solar Farm) to estimate the potential. Table 38 summarizes the results. Overall, PV Farms have the largest potential among the three types of PV systems we analyzed. PV Farms alone can provide close to three times the annual electricity demand in the County at the 2008 level.

Table 38 Potential of PV Farms in Tompkins County

Number of Contiguous Sites	171
Total area (acres)	10,487
Installation capacity (MW)	1,887.7
Annual electricity output (GWh)	2,093.4
Fraction of annual electricity consumption in the County at 2008 level	270%

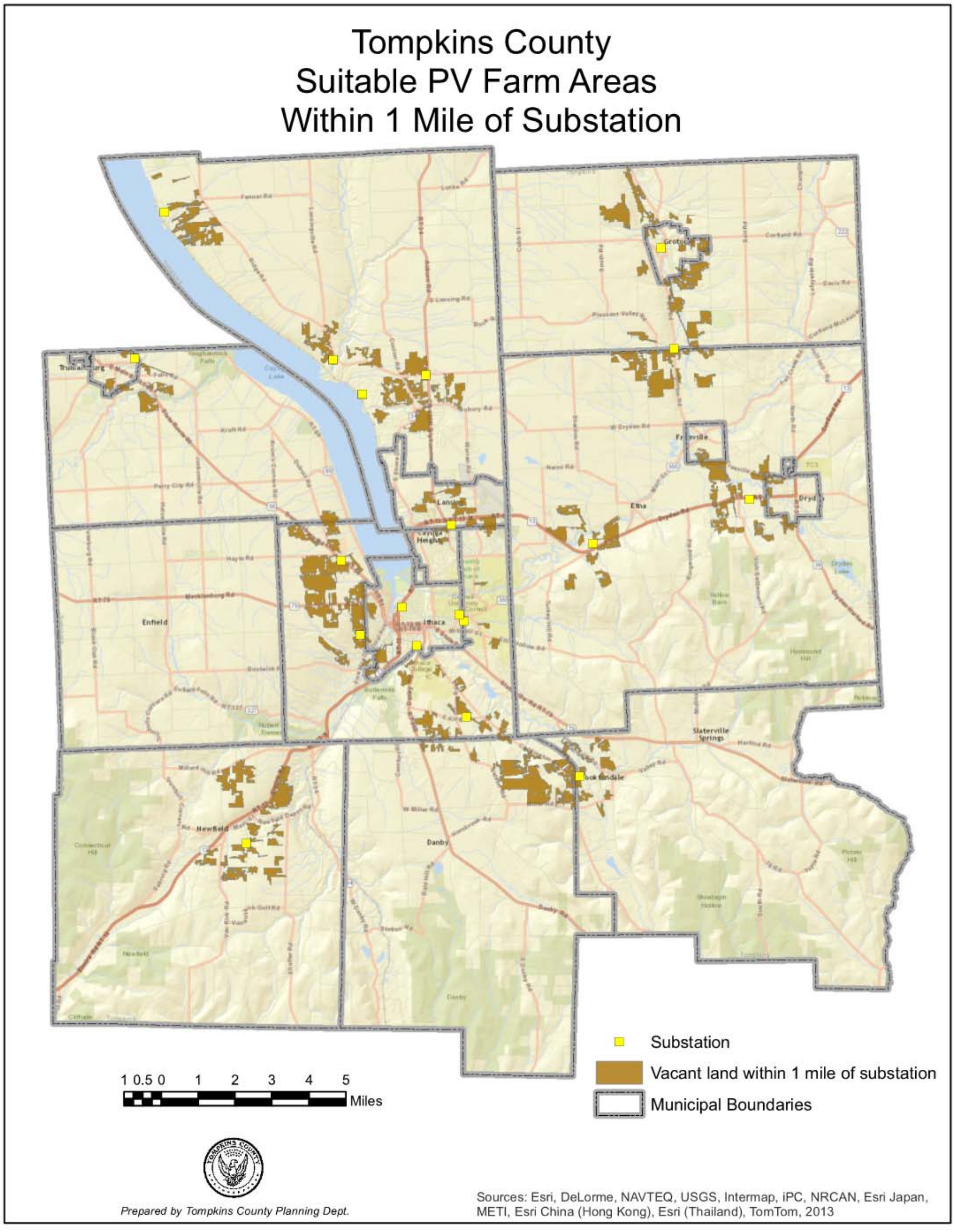

Figure 39 Lands suitable for PV Farms within 1 miles of substations

3. Opportunities and Challenges

3.1 Shading, landscape service and solar-friendly landscaping designs

One of the major challenges for siting a PV system in Tompkins County (and most of the Eastern U.S.) is shading. Even small amounts of shading, such as leafless tree branches or small rooftop obstructions, can have dramatic impacts on the solar electricity generation. The vast majority of the urban residential buildings identified as unsuitable for PV systems in our analysis are due to shading from surrounding vegetation. According to a survey from Solar Tompkins, many homeowners with moderate shading are willing to trim or remove trees that interfere with solar collection. However, homeowners are responsible for the landscape services, adding to the costs of installing PVs. Solar Tompkins has considered working with homeowners as a group to negotiate the prices for landscaping services. An alternative approach is to transfer the responsibility of shading mitigation to PV installers, who can potentially negotiate the prices for landscaping services much more effectively than individual homeowners.

Since removing shading from vegetation will potentially increase the cooling demand for electricity in summer, a study on the net benefit of shading mitigation is needed. Furthermore, solar-friendly landscaping designs for new construction will avoid the need to cut down trees in order to install PVs in the future.

3.2 Less competitive solar incentives in Tompkins County

The New York Independent System Operator (NYISO) divides New York State into eight zones based on differential energy pricing. Tompkins County, located in the Central Zone, has lower electricity prices than other New York State regions such as the Capital Zone and the Hudson Zone. For solar developers, lower prices in Tompkins County generate less competitive revenue than other regions where electricity prices are higher.

Beyond electricity prices, solar insolation in central New York is not as abundant as in the Hudson Zone. As a result, larger amounts of solar energy can be utilized by the same solar system installed in Middletown, NY than in Ithaca. This makes it more difficult for solar companies to finance projects in Tompkins County.

3.3 Solar parking lots

Commercial buildings usually have spacious parking lots with little shading, and can be potentially converted to covered-parking with solar PV. One example of a solar parking lot can be found on Long Island. The Eastern Long Island Solar Array has added 8.25 MW of solar capacity while at the same time providing shading for commuter parking for the Long Island Railroad [9].

Frequently, large chain stores do not give local managers the authority to decide to install solar panels on the rooftops or in parking lots, and it can be cumbersome to get such a decision from a regional or corporate headquarters. While this challenge persists, there seems to be more corporate interest in solar, and chain stores have begun to adopt solar power more widely. There is great potential for growth if head offices give their blessing for solar installations, or grant local managers more autonomy in making such decisions [10].

3.4 A model for community marketing: Solar Tompkins

Solar Tompkins is a local non-profit solar initiative in Tompkins County. Its public launch was in the spring of 2014, and it has been focused on facilitating solar power adoption by homeowners and small businesses in the County. The program seeks to eliminate the few remaining barriers to solar adoption by providing: attractive 20% lower-than -market pricing, a simple process with vetted technology and installation partners, grassroots-led educational outreach events to build enthusiasm, and deadlines to generate the impetus for adoption. The program has been very successful. As of the summer of 2014, Tompkins County had around 2.2 MW of residential solar installed. By end of 2014, this number, including contracts signed for installation in 2015, was 5.2 MW. In other words, Solar Tompkins was able to more than double the amount of residential solar with over 3 MW of new installations in Tompkins County in less than a year.

3.5 Availability of land for PV Farms

In the near term, the biggest challenge for deploying PV farms is likely to be the availability of land. Most of the substations, shown in Figure 39, are located in areas that are likely to have relatively high land values. The lease rates for land for PV farms may be too low to be competitive with the value of land for other purposes, except where land use is constrained, such as in the airport runway clear zone, or is owned by an entity such as the County or Cornell where the use of the land in this way supports organizational objectives.

3.6 Power System Integration

New York State has adopted very effective net metering policies, which make the installation of renewables more attractive to homeowners and businesses. Net metering allows residential and commercial customers who generate their own electricity from solar power to feed electricity they do not use back into the electric grid, and credits solar energy system owners for the electricity they add to the grid.

While net metering is an important step to encourage deployment of renewables, it does affect overall grid function and stability in various ways, depending on the level of penetration on a distribution circuit and the size (capacity and voltage) of said distribution circuit [11]. Medium and high levels of distributed solar penetration can create safety and grid stability concerns [11]. These concerns include:

- Excess Load at Substations – Occurs when distributed generation systems produce more power than the circuit is consuming. This causes “power to flow from the substation to the transmission grid, creating a reverse power flow that grids are not designed to handle. This could lead to high voltage swings and other stress being placed on electrical equipment.” [11]
- Grid Stability Problems – Occurs if there is a high level of distributed generation penetration and grid frequency fluctuates past the distributed generation system’s trip point. Once that occurs, all distributed generation systems could simultaneously trip causing huge grid fluctuations or, even worse, blackouts [12].
- Load and System Planning Uncertainty – Grid operators generally have no way to evaluate or monitor distributed generation systems. This makes grid forecasting and planning especially difficult since operators cannot decipher between load changes and solar output changes [11].
- Other potential hazards and negative effects of medium and high levels of distributed solar penetration may include higher voltage at point of distributed generation [12] and unintentional islanding of the distributed generation system from the grid [11].

Because of these potential strains on the grid, the Federal Energy Regulatory Commission (FERC) requires that distributed generation within a line section (i.e., distribution circuit) must not exceed 15% of the annual peak load of the line section [12]. Generally speaking, the 15% threshold is meant to prevent distributed generation capacity from exceeding the maximum load in a distribution circuit.

However, with rapid growth in PV systems, foreseeably the grid will need to integrate more electricity generated from distributed solar sources in the future. The 15% rule may become a significant constraint in the County. To embrace distributed energy generation, the FERC will need to update their regulations, which in turn will make it necessary for utilities to make further capital investment in system upgrades (e.g., a distribution system with bidirectional power flows) to proactively address the safety and grid stability concerns.

We foresee that technology development in the next decades will overcome many of the challenges associated with power systems integration of solar energy.

- Power electronics – Smart grid-ready micro-inverters typically have a digital architecture, bidirectional communications capability and robust software infrastructure. They are capable of providing a suite of advanced grid functions such as ramp rate control, power curtailment, fault ride-through and voltage support through reactive power control. Those advanced grid functionalities will allow remote system upgrades and engage utilities in PV deployment and smoothing out the electricity system when lots of solar gets installed in concentrated areas [13].
- Demand-side management – A PV system coupled with energy storage (e.g., battery or thermal energy storage) and smart appliances can allow home owners to utilize more of the energy its solar panels produce, thereby reducing the reliance on net metering. The ongoing development of home automation software, energy management systems, and sensor technologies will greatly enhance the capability of demand-side management, providing great synergy with solar PV penetrations.
- Bulk transmission systems – The New York Independent System Operator (NYISO) has begun assessing strategies to offset the reliability issues with increasing renewable penetration into the power system. Technologies being investigated include: flexible hydro and gas turbines that can quickly be ramped up, new energy storage technologies, and introducing policies to improve demand-side management [14]. It is expected that the electricity grid of the future will able to handle high levels of intermittency from renewable generation.

3.7 Policy and Incentives

New York State and the federal government have several programs under consideration and in place to support the adoption of solar power. The Shared Clean Energy Bill will make it easier for homeowners with properties in non-optimal locations to adopt solar power. Remote Net Metering allows solar technologies to be built in one location and gain benefits in another. Federal and state tax credits allow for an effective reduction in the capital cost of solar systems.

Shared Renewables Initiative - Also referred to as community distributed generation, was passed in 2015 and is being rolled out in phases. The first phase of Shared Renewables will focus on promoting low-income customer participation and installations in areas of the power grid that can benefit most from local power production. New York State residents will now be able to buy local solar energy without having solar panels installed on their individual properties, or needing to remove shade trees to allow for such installations. By subscribing to local off-site solar energy projects and receiving a utility bill credit for their portion of the energy produced, all residents will be able to participate in building more sustainable and clean communities whether they own or lease their houses or apartments. With respect to the initiative's economic implications, a shared renewable energy program has the potential to unlock a new market and establish significant new private investment in New York State solar energy systems.

Reforming the Energy Vision (REV) - New York State Department of Public Service (DPS) has proposed a plan, known as "Reforming the Energy Vision" (REV), to transform New York's electric industry [15]. The centerpiece of REV is to integrate Distributed Energy Resources (DERs) into the New York electricity market, via a Distributed System Platform (DSP) framework. In this context, DERs include Energy Efficiency (EE), Demand Response (DR), and Distributed Generation (DG) including solar PV[8]. The promise of integrating DER is to offer customers the opportunity to manage their usage and reduce their bills while at the same time creating important system and societal benefits, moving towards an energy landscape that is increasingly decentralized with consumers playing a more active role in energy decisions. Although REV is still in the proposal stage, it has the potential to greatly facilitate the penetration of solar PV through improving regulations and creating new market products.

Remote Net Metering - In the process of securing approvals to construct its solar farm project on Snyder Road, Cornell University filed a petition with the NYS Public Service Commission (PSC) seeking clarification on how "remote net metering" rules had to be applied by electric distribution companies [16]. Remote net metering allows an entity to build a renewable energy project (e.g., solar, wind, etc.) where it has space that is well-suited for this purpose, and to credit the energy value generated by the project towards consumption of energy at another location. In a ground-breaking ruling the PSC determined that: utilities must credit electricity at the same rate they charge for electricity at a particular location; the customer does not have to have an account at the particular location of generation prior to the installation of the renewable energy project; and there is no minimum electrical load required [17]. The PSC ruling was extended to apply to all utilities and types of renewable generation projects throughout New York State. This ruling means that there are now many more options for siting renewable projects at locations with electricity rates that make such projects economically feasible [16].

NYSERDA incentives - Governor Andrew Cuomo launched the NY-Sun Initiative on August 21, 2014, to consolidate New York State's existing solar incentive programs into a single support scheme, aimed at adding 3GW of solar generation capacity by 2023 [18]. A key part of the NY-Sun Initiative is the "the MW block system". The intention is to ultimately transform New York's solar market into a self-sustaining industry. The state is divided into three regions – Con Edison territory, Long Island and Upstate. Each region is assigned separate MW blocks and incentive levels for residential solar projects up to 25 kilowatts (kW) and small non-residential solar projects up to 200 kW. When the MW target for the first block in each sector (residential or small non-residential) within a region is reached, that block is closed and a new block for the sector is started with a new MW target and a lower incentive level. Once all of the blocks for a particular region and sector are filled, an incentive for that region and sector will no longer be offered. The program for non-residential systems larger than 200 KW is yet to be announced.

New York State Tax Credits and Property Tax Exemption - In addition to direct incentives, there are also tax credits and incentives that can be applied to residential solar systems. Since tax issues can become very complicated, only a basic overview of the tax opportunities available will be presented here. New York State offers a tax credit of 25% of the system expenditures (after incentives have been applied) capped at $5000. The system must be grid-tied and net-metered, and any excess credits can be carried forward five years (DSIRE, Residential Solar Tax Credit). New York State also recognizes that a PV system may increase the value of a property. If the municipal assessor's office determines that it does, this would increase the homeowner's property tax burden. As such, the state provides 15 year property tax exemptions for systems purchased and installed before January 1, 2025 [19]. The total amount of the exemption is equal to the increase in assessed value attributable to the solar system.

Federal Tax Credits - Finally, the federal government also offers a tax credit of 30% for residential PV systems. Due to recently passed legislation, there is now no cap on the amount that may be claimed. The tax credit is calculated from the net cost of the system after any direct incentives, such as the NYSERDA incentive, which are not federally taxable. There is a degree of subtlety to the federal tax credit, though, because it is only a credit against federal taxes owed. It is not a line item deduction to lower a homeowner's tax liability nor an automatic refund from the government. The homeowner must owe federal taxes, and the tax credit is simply carved out of that. If the tax credit is larger than the homeowner's federal tax burden for the year, the remaining balance may be rolled over one more year, but no more. So if, for example, a homeowner owes $5,000 in federal taxes in the two years following the installation of a PV system, and the federal tax credit comes to $6,000, then the homeowner will have lost that extra $1,000 credit. This is why it is imperative for homeowners to speak with tax professionals before committing to a PV system to ensure they are receiving the full benefit.

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Figure Sources

Figure 38:
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http://www.seia.org/research-resources/solar-industry-data

Figure 39 Data layer resources:

Tompkins County Tax Parcel (2013)	Albert R. Mann Library
Tompkins County Buildings	Tompkins County Planning Department
Land Use	Tompkins County Planning Department
Transmission Lines	Tompkins County Planning Department

Micro-Hydro Energy

Robin Eugenio Rodriguez, Kevin J Kircher and K. Max Zhang

Executive Summary

Total Potential

Energy Source	Installation Capacity (MW)	Annual Energy Output (GWh)	Percent of Total 2008 Electricity Demand
Micro-hydro Electricity Generation Potential	88.5 (+/- 18.6)	**725.7**	**89.7%**
2008 Community Demand	NA	809.1	

Major Assumptions

- We set the threshold for classifying a location as having high potential to generate hydropower as those in the upper 20% of both flow accumulation and slope steepness. This was selected to be certain that the sites obtained have a non-stop, continuous flow of water.
- Only water flow due to precipitation was considered. Evaporation and soil filtration data were not included in the analysis.
- We adopted a ratio of 8,200 kWh/year for 1 kW of hydro to convert installation capacity to annual electricity generation. The ratio was based on studies conducted in Madison County, NY.

The large number of streams, abundant rainfall and hilly topography in Tompkins County could provide an excellent resource for low-impact micro hydroelectric (referred to as "micro-hydro") power generation. The objective of this study was to quantify the micro-hydro capacity potential in the County. We utilized a Geospatial Information System (ArcGIS) to pinpoint locations with high potential for producing clean renewable energy and estimate the run-of-river generation capacity of said sites.

We identified 232 potential sites, and estimated the total generation potential as 88.5 (+/- 18.6) MW. The generation potential at individual sites varied from 114 kW to 2950 kW. One-hundred ninety-nine sites could generate between 100kW to 600kW individually. In 2008, the Tompkins County residential sector consumed 293,371,081 kWh of electricity. Professor Phillip Hofmeyer, Assistant Professor at Morrisville State College, has had vast experience with the installation process of micro-hydro. Professor Hofmeyer states that 1 kW of hydro can generate 8,200 kWh/year. If we were to tap in to the estimated capacity of all 232 potential sites, in theory this could lead to a total generation of 725,700,000 kWh per year.

Micro-hydro presents both opportunities and challenges to achieving the County's greenhouse gas reduction goal. It offers many benefits over solar and wind, including relatively continuous generation, long-term system affordability, high efficiency and system reliability. In addition, micro-hydro avoids many of the environmental concerns associated with large-scale hydroelectric development (e.g., dams, siltation, and ecological disruption).

However, micro-hydro is a technology where site-specific conditions need to be met in order to achieve successful implementation and maintain operating conditions. One of the challenges is that such systems should be located on a site that is easily accessible and that is closely located to the community, home, or business to which it will be supplying energy. Additionally, micro-hydro faces financial challenges that other renewables do not, as it has not yet been recognized as a form of renewable energy that qualifies for incentives by New York State, except for qualifying for net metering. Thus it is essential that the State make micro-hydro eligible for the same subsidies and tax rebates solar and wind energy receive in order to move support for a more widespread adoption of this technology.

1. Introduction

Hydropower has the potential to provide viable renewable energy in Tompkins County due to the large number of streams and relatively steep terrain found here. However, there have been no previous studies to quantify the hydropower generation potential from water resources.

Hydropower is currently the most important renewable energy worldwide, providing ~16% of the global electricity generation [1]. However, large hydropower generators require the construction of dams and flooding of land to create a reservoir where water is abundant for continuous operation. Micro-hydro, or low-head hydro, is a type of hydropower that looks to reduce this environmental impact and still produce sufficient clean energy at the community level. It is smaller, localized, and more ecologically friendly than its larger counterparts. A micro-hydro unit is typically designed to generate between 10kW and 500kW, and can last for 50 years with light maintenance [2].

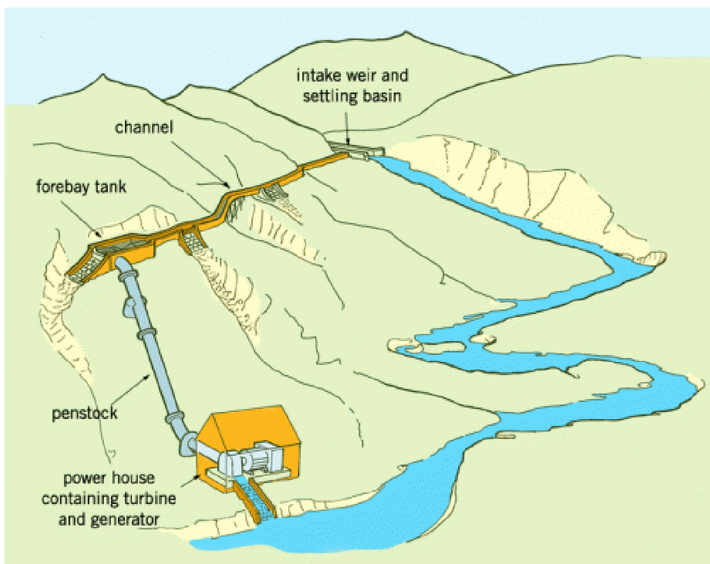

Figure 40 Example of a micro-hydro generator model with a water reservoir [3]

As shown in Figure 40, micro-hydro may or may not require a small reservoir. For this study, we quantified the hydrological potential for applications that require no dams, called "run-of-river" systems, and identified associated challenges and opportunities. We hope this study can serve as a model for other communities that aspire to assess their micro-hydro potential.

2. Micro-Hydro Potential in Tompkins County

Tompkins County has 304,704 acres of land that contains a vast network of running water. Unfortunately, there are only five stream gauges that provide the stream flow measurements needed for a proper hydrologic analysis. The purpose of our analysis was to determine sites with the highest potential for micro-hydro production and estimate the average annual power output. Some of the promising sites are locations without gauges. Thus, part of the study was to look at historical data and analyze how the stream flow is influenced by certain conditions such as elevation change and rainfall. Given a model of these influences, we were able to estimate annual stream flow values and determine the annual average power generation capabilities for these sites without gauges.

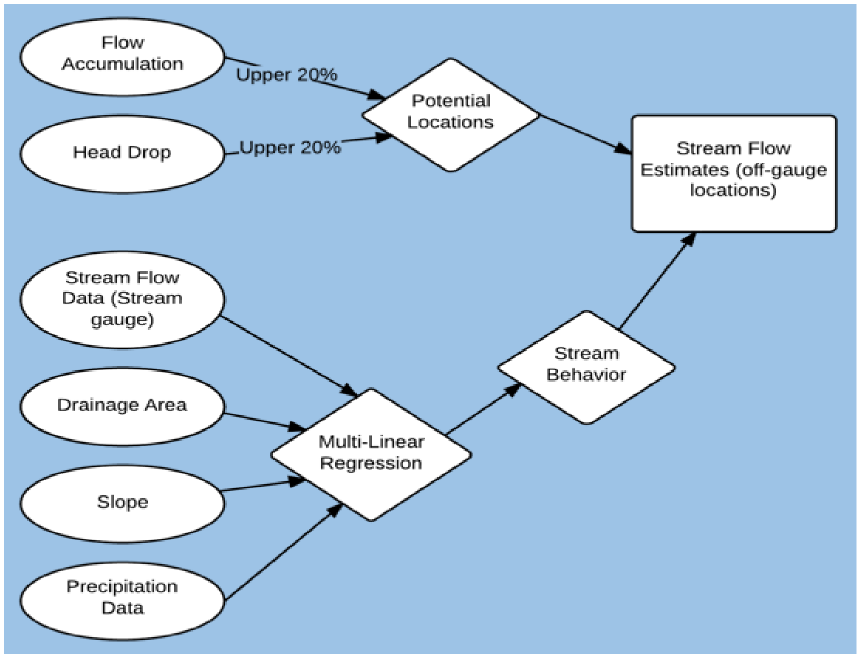

Figure 41 Steps to determine stream flow estimates in ungauged sites.

2.1 Potential Sites

The first step for the hydrologic analysis was to determine potential locations most favorable for micro-hydro applications, i.e., where there is a sufficient amount of running water and elevation drop, also known as head. Head determines the amount of potential energy in water that can be transformed into kinetic energy.

For this study, a Geographic Information System program, ArcGIS, was to determine and pinpoint locations with hydrologic potential in the County. The main input to the ArcGIS analysis was a Data Elevation Model (DEM) raster, which models the height of elevation in each cell. Two sets of DEM were obtained for our study, however only one was used. The first had a resolution of $1m^2$ per cell, but only contained data inside of the County's boundaries. The other had a resolution of $100m^2$ and included elevation data for the surrounding counties. Since some of the watersheds' land areas extended beyond the boundaries of the County, and the entire amount of water draining into the County's streams needed to be taken into consideration, the $100m^2$ dataset was utilized for this study.

ArcGIS contains a Hydrology System Toolbox with various tools that can help determine where rainfall water accumulates and forms river streams [4]. The first step was to fill any sinks in the DEM that might cause discontinuity in the flow raster by using the Fill Sink tool as shown in Figure . The fill sink simulates when the water fills and overflows to continue the stream path (the new filled value will only be as tall as the adjacent cell with the lowest elevation). By filling this sink, the flow will be continuous, and the entirety of the stream can be modeled.

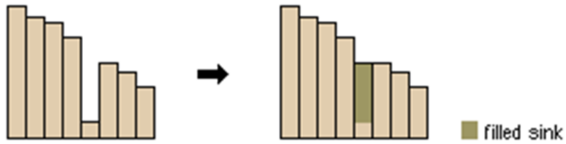

Figure 42 Shows the DEM Fill Sink process

After obtaining the DEM with the sink corrections, the next step was to determine the direction in which water would flow through each cell. ArcGIS can create a raster of flow direction from each cell to its steepest adjacent cell as shown in Figure 43.

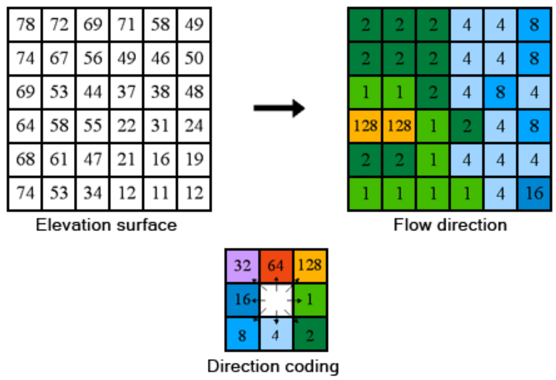

Figure 43 Shows how a Flow Direction raster is created from the DEM

The next step was to obtain the accumulation of flow which helped us simulate stream flow. This step calculates the number of contributing cells that flow into each other cell and creates a raster for it, as shown in Figure 44. In other words, the Flow Accumulation raster indicates a value of contributing area where rainfall water drains or collects. Areas with higher flow accumulation values are most likely streams, rivers, ponds, or other bodies of water.

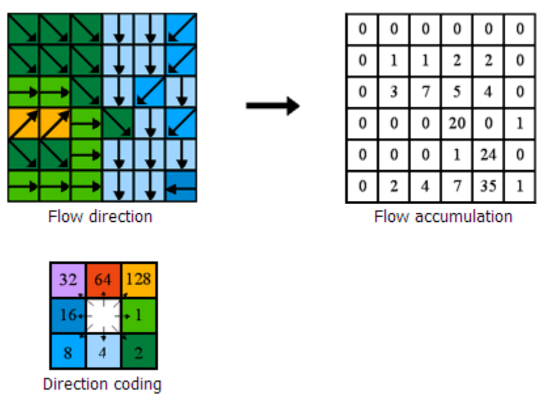

Figure 44 Shows how a Flow Accumulation raster is created from the Flow Direction Raster

The final dataset needed to determine sites with high hydrologic potential, was head drop. However, ArcGIS has no accurate tool to determine the head drop along a non-linear stream. To get around this, we used the Slope tool, found in the Hydrology Toolbox, to determine the drop percentage (rise/run) between the steepest adjacent cells. Rise is the vertical change in elevation calculated for that cell, while run is the horizontal distance for which the elevation is calculated. A higher percentage would signify a steeper slope and a higher head drop rate for a set distance.

After analyzing all the necessary datasets, the locations with good micro-hydro potential were determined. A site with sufficient water accumulation and head drop was considered a potential location for micro-hydro. Evaluation of these potential locations can be done in many ways, but after careful consideration we set the threshold for classifying a location as having high potential site potential to generate hydropower as those in the upper 20% of both flow accumulation and slope steepness was to be certain that the sites obtained have a non-stop, continuous flow of water. A wider selection (for example, to 30%) would increase the chances of including sites where the stream is not continuous all year long and could also include sites with small generation potential but with relatively large uncertainties. The Raster Calculator tool was used to map the points where both of these criteria were satisfied, and 232 locations were identified. Figure 45 shows that although all the watersheds in Tompkins County were evaluated, most of the potential points fall predominantly throughout four streams: Fall Creek (118), Taughannock Creek (57), Six Mile Creek (37), and Salmon Creek (20).

2.2 Stream Flow Estimation

This section explains the procedure used to estimate unmeasured flow rates based on utilizing historical data from the five streams for which gauge data was available to other streams in the County. The five gauges used for this study were the following:

- USGS 04234000 – Fall Creek near Ithaca
- USGS 0423401815 – Salmon Creek near Ludlowville
- USGS 04233286 – Six Mile Creek at Brooktondale
- USGS 04233300 – Six Mile Creek at Bethel Grove
- USGS 04233255 – Cayuga Inlet at Ithaca

Two estimation approaches, i.e., the Drainage-Area Ratio method and the multiple linear regression method, were considered. The Drainage-Area Ratio assumes that the stream flow of an unmetered site for the same stream or watershed can be deduced from the drainage area [5]. This assumption only makes sense for unmetered sites not far from a gauged site. It assumes 1) that all conditions are equal except for the amount of contributing water drainage area, and 2) that the estimated stream flow is a ratio of the drainage area of both metered and unmetered sites. This method requires that the potential sites share a watershed with a gauged stream. There are a total of 18 separate watersheds in Tompkins County. This would mean that we would at least need a minimum of 18 gages, each located in a different watershed. However, this presented a problem because, as Figure 45 shows, there are only 5 stream flow gauges with stream data.

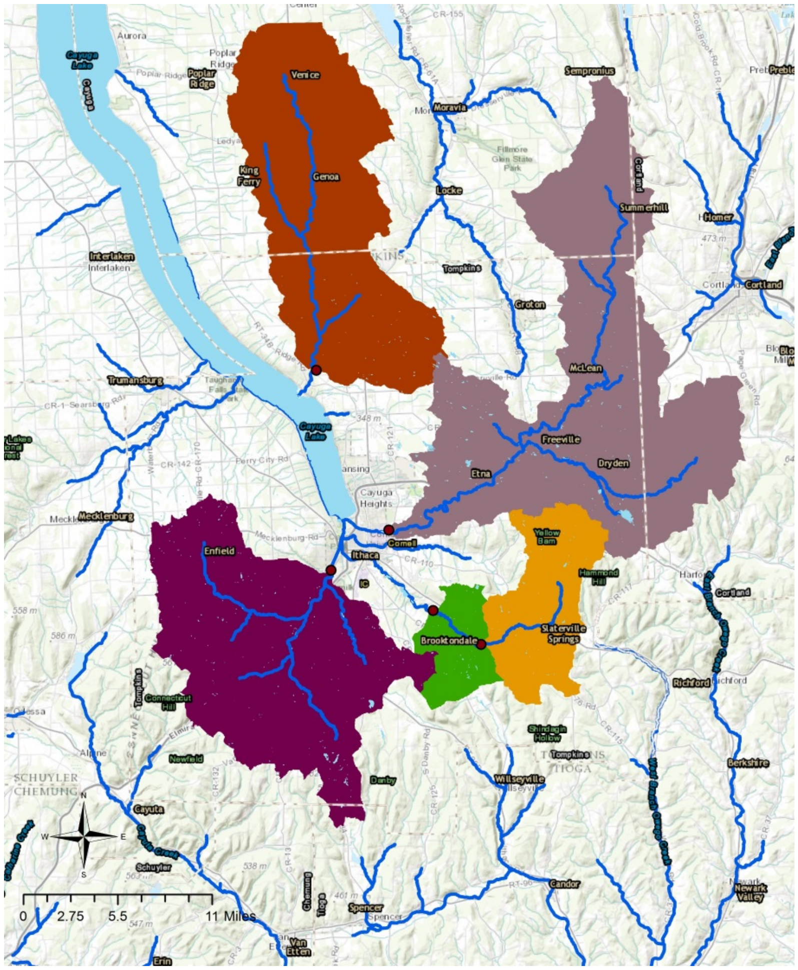

Figure 45 Stream Gage locations (red points), and corresponding Drainage Area (colored polygons).

Because the Drainage-Area Ratio method was impractical, we adopted the multiple linear regression method. This method has been used by USGS and many hydrology researchers [5]. The regression fits a linear model that relates stream flow to a variety of predictors. The multiple linear regression model is

$$y= b_1x_1 + b_2x_2 + \cdots + b_nx_n + \in$$

where,

$$n = number\ of\ independent\ variables$$
$$x_n = n^{th}\ independent\ variable$$
$$b_n = n^{th}\ coefficient\ corresponding\ to\ x_n$$
$$y = dependant\ variable;\quad \in = residual$$

The regression develops an equation that represents the behavior of the stream flow and how that behavior changes. Three predictors were selected to study: slope (head drop), flow accumulation (drainage area), and precipitation (rainfall).

Monthly grid precipitation raster data and monthly stream flow data for all gauge locations were obtained from the PRISM climate group [6] and USGS, respectively, from 2006 to 2013. The precipitation data has a resolution of 4km. The multiple linear regression was performed with MATLAB, and our equation was,

$$y_{fr} = b_{prec} \cdot x_{prec} + b_{DA} \cdot x_{DA} + b_{sl} \cdot x_{sl} + \in$$

Our independent variables were,

$$x_{prec} = precipitation\ (mm)$$
$$x_{DA} = drainage\ area\ (cell\ count\ of\ contributing\ area)$$
$$x_{sl} = slope\ \%\ \left(\frac{rise}{run} \times 100\right)$$

And our dependent variable was,

$$y_{fr} = flow\ rate\ (cfs)$$

After undergoing the multiple linear regression we obtained,

$$b_{prec} = 0.25285\ ;\ b_{DA} = 1.4774 \times 10^{-5}\ ;$$
$$b_{sl} = 10.130\ ;\ \in = 13.241$$

And the resulting equation was,

$$y_{fr} = 0.25285(x_{prec}) + 1.4774 \times 10^{-5}(x_{DA}) + 10.130(x_{sl}) + 13.241$$

This equation can be used to predict streamflow behavior at the ungauged sites.

2.3 Statistical Analysis of Multiple Linear Regression

A statistical analysis was made to quantify the uncertainty of the multiple linear regression model. Utilizing MATLAB, a computational numeric analysis was made which calculated an estimate of the Error Variance ($\hat{\sigma}^2$), the Coefficient of Determination (R^2), and the P-value (P).

An estimated Error Variance ($\hat{\sigma}^2$) of 10,000 was obtained. The error variance was used to calculate the Standard Error ($\hat{\sigma}$), which is the value of possible variation in the dependent variable obtained from the regression equation. The standard error calculated was $\hat{\sigma}$=100. This means that the obtained stream flow-rate has a variation of +/-100 cfs (cubic feet per second). The coefficient of determination was then calculated to explain the variance.

The coefficient of determination is the percentage of variance explained by the regression. It determines the multiple linear regressions precision to predicting the dependent variable (y_{fr}) to the independent variables (x_{prec}, x_{DA}, and x_{sl}). Our regression model had a coefficient of determination, R^2=0.174. In theory, the regression equation should predict correct flow rate values roughly 17.4 percent of the time. This signifies that 82.6% of the total variation of the values of y_{fr} is unexplained by the variation in the 'x' variables, which poses challenges for predicting precise values.

On the other hand, the P-value was calculated to determine if changes in the independent variables in the multiple linear regression were related to changes in the dependent variable. A low P-value signifies that differences in the response variable (y_{fr}) were not coincidental. Whereas a large P-value means that the changes in the response may not be related to changes in the output variable (x_{prec}, x_{DA}, x_{sl}).

P-values below 0.05 are considered to be statistically significant [7]. The P-Value returned after the computational analysis was of 5.7861×10^{-14}. This means that the regression is very significant and a change in the dependent variable is more than likely explained by a change of the independent variables, with a certainty greater than 99.9%.

In conclusion, the low coefficient of determination is of concern since the predicted variables may have large uncertainties. However, the low P-value indicates a strong relationship between the independent and dependent variables. Thus, when the regression shows a low R^2 and low P-value, including more predictor variables may help increase the precision of the response. Predictor variables such as evaporation rate and soil filtration rate may improve the precision based on a runoff flow rate. The runoff flow is the actual net flow of the water due to precipitation minus the water lost due to evaporation or soil filtration. For this project, only the water flow due to precipitation was considered. To include the total runoff flow rate, separate studies must be conducted where it can determine the evaporation rate changes with the seasons, and the different types of soils found throughout the Tompkins County and their ability, or lack thereof, to filtrate water.

2.4 Average Annual Stream Flow-Rates

A total of 232 sites were identified as having good potential for hosting micro-hydro. They are shown in Figure 46 below. The most critical sites, a subset of the 232 listed potential sites, were selected for study. These critical sites represent the highest available power generation potential of a group of sites that lie within the same stream and precipitation grid area. That is to say, if multiple potential sites lie within the same stream and precipitation data grid, the site with the highest generation potential (the “critical site”), was studied to measure the peak power output of that general area. The critical sites are those that have the highest Head (slope) and Flow-rate values. The critical locations of interest summed to be a total of 17 sites. The average of these flow rate values was determined per site as shown in Table 39.

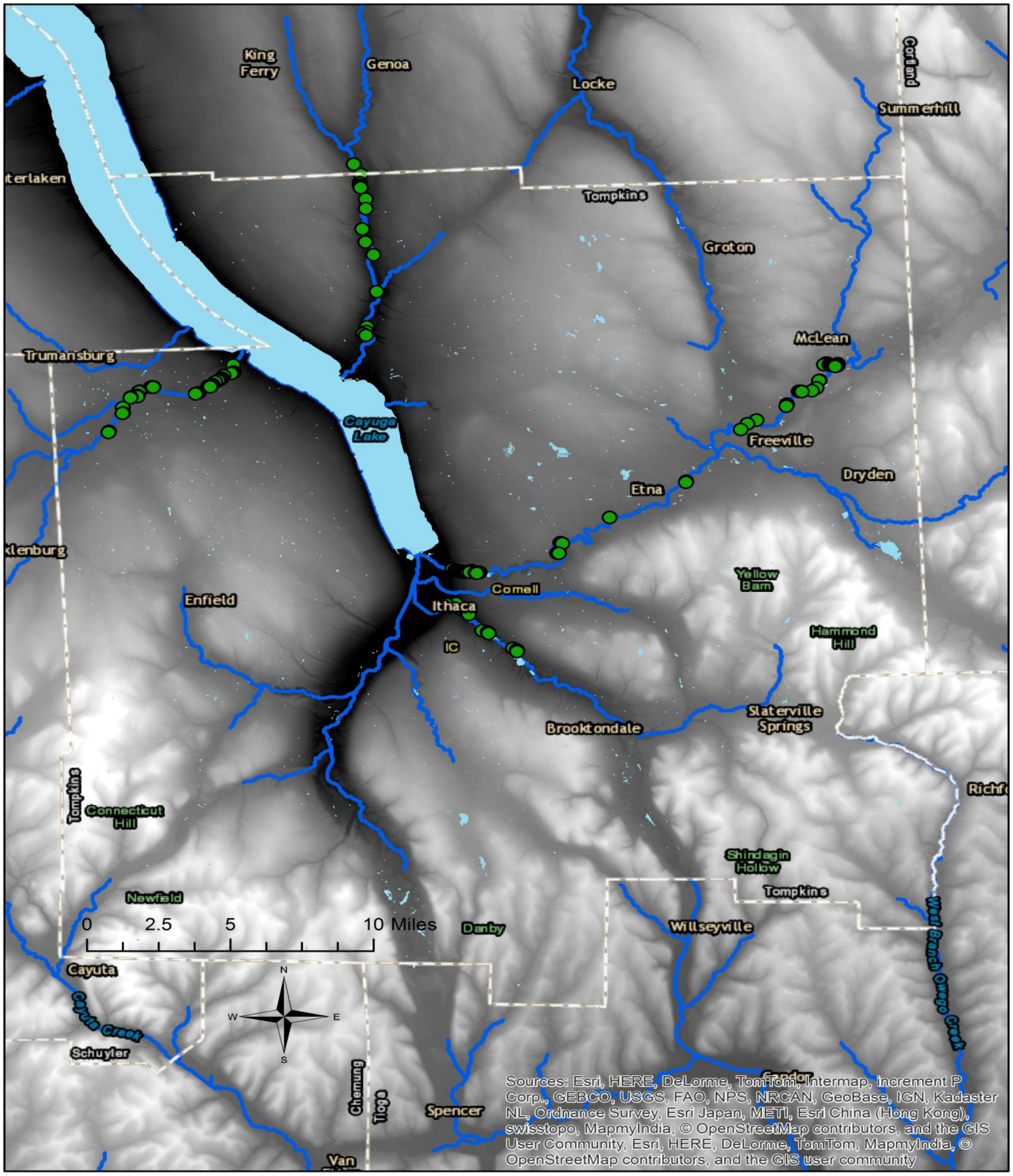

Figure 46 Critical Study Point Locations in red with corresponding "point ID" number.

Table 39 Critical study point locations
The Point ID acts as an indicator where each number is assigned to a different site. The Point ID's found in this table correspond to the number bubbles in Figure 46. Each site corresponds to a different precipitation grid area.

Stream Location	Point id	Longitude	Latitude	Slope (rise/run %)	Drainage Area (cell count)	Avg Annual Streamflow Rate (cfs)
Fall Creek	47	76° 17' 56.3" W	42° 32' 30.5" N	31.4	1255028	373.0
Fall Creek	125	76° 19' 2.5" W	42° 31' 49.6" N	26.4	1297108	322.4
Fall Creek	139	76° 20' 52.1" W	42° 30' 50.2" N	20.7	1424728	266.3
Fall Creek	140	76° 22' 31.1" W	42° 29' 29.0" N	22.5	2808127	304.2
Fall Creek	143	76° 24' 50.5" W	42° 28' 32.5" N	25.5	3099050	339.6
Fall Creek	148	76° 26' 16.7" W	42° 27' 51.9" N	40.1	3179347	487.4
Fall Creek	161	76° 29' 28.3" W	42° 27' 9.6" N	41.9	3254563	504.7
Taughannock	35	76° 36' 12.8" W	42° 32' 19.8" N	54.7	1710603	610.2
Taughannock	69	76° 36' 38.0" W	42° 32' 7.9" N	57.7	1708396	641.1
Taughannock	110	76° 39' 7.8" W	42° 31' 42.3" N	39.3	1577532	454.1
Taughannock	137	76° 40' 0.6" W	42° 30' 45.5" N	24.9	1101818	302.1
Six Mile Creek	218	76° 29' 36.8" W	42° 26' 19.2" N	41.4	1291523	470.3
Six Mile Creek	237	76° 29' 6.2" W	42° 26' 1.1" N	48.2	1275442	540.0
Six Mile Creek	250	76° 27' 38.6" W	42° 25' 2.6" N	69.7	1157130	757.2
Salmon Creek	6	76° 32' 22.8" W	42° 37' 7.6" N	26.5	1364797	322.1
Salmon Creek	13	76° 31' 53.4" W	42° 34' 25.6" N	22.2	1851364	285.1
Salmon Creek	19	76° 32' 13.2" W	42° 33' 17.3" N	41.2	2022059	478.8

2.5 Estimated Hydro Generation Potential

With the stream flow estimates calculated in section 2.4, we then had sufficient data to predict the micro-hydro power output for each of the 18 Critical Sites. The resulting equation for determining the raw power output of a hydro-generator is determined by the following equation:

$$P = \eta \rho g h \dot{q}$$

Where,

$$P = power\ (W)$$
$$\eta = water\ to\ wire\ efficiency$$
$$\rho = 1{,}000\ \left(\frac{kg}{m^3}\right);\ density\ of\ water$$
$$g = 9.81\frac{m}{s^2}\ ;gravity$$
$$h = net\ head\ (m)$$
$$\dot{q} = flow\ rate\ \left(\frac{m^3}{s}\right)$$

First, an appropriate turbine must be selected that can function within all conditions of the site locations. The Turbine Selection Chart seen in Figure 47 establishes the parameters to which each turbine functions efficiently.

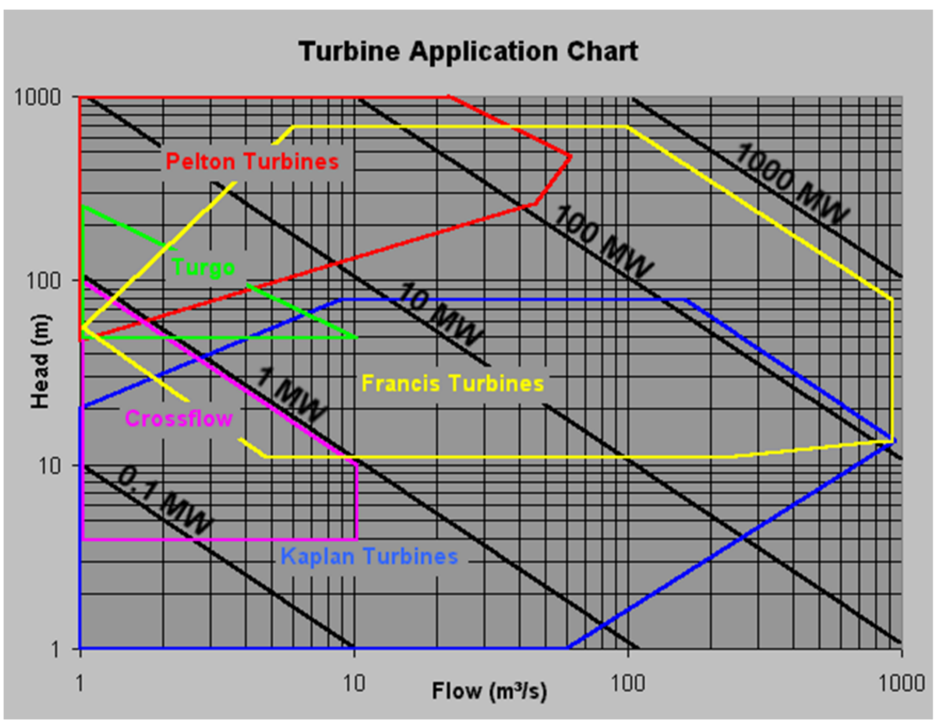

Figure 47 Demonstrates the range of Head and Flow at which the corresponding turbine would function efficiently [8].

These parameters are Head (m) and Flow Rate$\left(\frac{m^3}{s}\right)$. However, due to the limitations of the data, we only have the rise over run percentage value of the slope rather than the actual Head in meters. An estimated Head was calculated for the run distance of the cell from which the slope was obtained. It was decided that the run distance would be the length of the cells resolution, which was 10m. Multiplying this length by the slope, we obtained the head value for that cell.

The appropriate turbine that fell within the parameters of the calculated Head and Flow Rate was selected. The Kaplan Turbine was decided as the best fit for the calculated values. This turbine is usually designed to function efficiently in low-head applications. It will also function for the variations of the Flow Rate, as determined by the Standard Error. Of course, the head is not an exact value of the entire stream. Thus, for higher head, the Francis Turbine might be more appropriate. Both turbines have an efficiency of 90%.

With the obtained Turbine Efficiency, Head, and Flow Rate, the next step was to calculate the Power generation, as seen in Table 40, which shows the power potential of the Critical Sites in each Precipitation Grid area.

Table 40 Turbine power generation for each site shown in Figure 46
Each site corresponds to a different precipitation grid area and has the highest Power generation potential for its respective precipitation grid area. (*Is a site located at the edge of a waterfall drop).

Stream Location	point id	Slope	head [10m run]	Avg Annual Streamflow Rate		Turbine	Uncertainty
		(rise/run %)	(m)	(cfs)	(m^3/s)	Power (KW)	(+/-KW)
Fall Creek	47	31.4	3.14	373.0	10.6	293.2	78.60
Fall Creek	125	26.4	2.64	322.4	9.1	213.0	66.1
Fall Creek	139	20.7	2.07	266.3	7.5	137.9	51.8
Fall Creek	140	22.5	2.25	304.2	8.6	170.8	56.2
Fall Creek	143	25.5	2.55	339.6	9.6	216.8	63.8
Fall Creek	148	40.1	4.01	487.4	13.8	488.9	100.3
Fall Creek	161	41.9	4.19	504.7	14.3	528.9	104.8
Taughannock	35	54.7	5.47	610.2	17.3	834.4	136.7
Taughannock	69	57.7	5.77	641.1	18.2	924.1	144.1
Taughannock	110	39.3	3.93	454.1	12.9	445.9	98.2
Taughannock	137	24.9	2.49	302.1	8.6	188.0	62.2
Six Mile Creek	218	41.4	4.14	470.3	13.3	486.6	103.5
Six Mile Creek	237	48.2	4.82	540.0	15.3	650.2	120.4
Six Mile Creek	250	69.7	6.97	757.2	21.4	1319.1	174.21
Salmon Creek	6	26.5	2.65	322.1	9.1	213.1	66.15
Salmon Creek	13	22.2	2.22	285.1	8.1	158.0	55.41
Salmon Creek	19	41.2	4.12	478.8	13.6	493.4	103.06

We estimate the total power generation potential of all 232 sites combined and its uncertainty as 88.5 +/- 18.6 MW. In Table 41, we can see how these sites are distributed according to their capabilities. The generation potential at individual sites varies from 114.4 kW to 2950.6 kW. One-hundred ninety-nine sites generate between 114kW to 600kW individually. It is important to note that sites that have a capability of 1000kW or more are sites that contain waterfalls or are near them. Thirteen of these sites are found just downstream of Beebe Lake while the other two are located right after the Ithaca Reservoir.

Table 41 Distribution of sites according to amount of power generation

Power	No. of Sites
114-150 kW	44
151-200 kW	73
201-400 kW	60
401-600 kW	22
601-800 kW	9
801-1000 kW	9
1001-1500 kW	5
1501-2000 kW	1
2001-2500 kW	6
2501-2950.6 kW	3

2.6 Limitations

It is important to emphasize that these results are very rough estimates with considerable uncertainties due to various factors. The most important one is the lack of USGS gauge data. There are only 5 gauged sites for the entire 1,233 km^2 area that is Tompkins County. Furthermore, additional predictor variables such as evaporation rate and soil-filtration rate should be included as part of the regression analysis to calculate the actual net flow. Also, the PRISM precipitation data has a very low resolution due to it being obtained from a precipitation grid-map intended to show the precipitation throughout the entire country. And the last factor was the complicated method for obtaining an adequate Head value. It is possible to obtain the desired head value by building a small reservoir upstream of the turbines' location, as shown in Figure 40. The height difference will determine the total hydraulic head. In conclusion, periodical on-site stream flow measurements are needed to reduce uncertainty and to determine real quantifiable values for a more precise analysis on ungauged locations. Despite all this, the study helps as a model to locate interesting sites for further research.

3. Opportunities and Challenges

There are both opportunities and challenges that may affect successful and acceptable implementation of micro-hydro in Tompkins County. Various factors, such as the unpredictability of weather and high initial installation costs, may present complications. Weather is expected to be highly unpredictable in the future due to climate change and stream flow which tends to vary considerably with the seasons. Drought may cause low-flow in streams, whereas very abundant rainfall may cause overflowing and flooding. In addition, very cold weather may cause water to freeze which may affect the functionality of the turbine or generator house. As for installation costs, micro-hydro can range between $1,500 to $2,500 per kilowatt of installed capacity [9]. "Systems that are less than 5 kW in power output, the cost per kW is approximately $2,500 or higher because of the smaller size and the cost of additional components" [9]. Because our power output is over 100kW, we can assume that "typical" system will cost

$1,500 per kilowatt of installed capacity. Therefore, assuming this condition, a system of 5-10 kW to power a home, for example, would cost $7,500 to $15,000, and a larger 100 kW to 600 kW would cost $150,000 kW to $900,000 kW. Thus, we must study what range of kilowatt capacity is economically feasible.

A factor in favor of micro-hydro is that it has the capability to generate significant amounts of electrical energy because of its continuous generation due to an unlimited source of running water. Because of this, the installation costs become reasonably affordable due to a shorter payback time as compared to solar energy (which only produces energy when there is sufficient sunlight), and wind energy (which can vary based on wind velocity and turbulence intensity). In addition, the micro-hydro generators produce energy even when energy consumption is very low (e.g., during the night). Currently, micro-hydro is qualified for net metering, capped at 20 kW for residential units, and 2 MW for non-residential units. This factor may help with the economics of these installations.

On the challenge side is that, the New York State Energy Research and Development Authority (NYSERDA) classifies micro-hydro as a form of renewable energy, meaning that it should be eligible for incentives and tax rebates from New York State [10]. However, NYSERDA does not provide any financial support towards micro-hydro. In addition, The US Department of Agriculture (USDA)'s Rural Energy for America Program (REAP) recently added micro-hydro to the list of renewable energy infrastructure projects that are eligible for low-interest federal loans. It is essential that New York State and NYSERDA follow the federal government's lead and make micro-hydro eligible for the same subsidies and tax rebates solar and wind receive.

Finally, geographical accessibility and public opinion may present both a challenge and an opportunity. The micro-hydro site should not be too distant from the community, home, or business to which it will be supplying energy, as distance may present a problem for transferring the energy to the user. Also, for means of easy maintenance, the site should be easily accessible whether on vehicle or on foot. Public opinion is probably the most important factor for successful implementation. Some may find it positive to change to renewable as a means of clean energy. However, some may relate micro-hydro to the civil work done on large scale hydro-generation plants that, due to their size and necessity to flood the area, are ecologically harmful. A public forum is needed to discuss the implications and inform the community of the project by discussing how micro is different from typical, large scale, hydro generators and how the environmental impact is minimal.

Acknowledgements

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Biomass Energy

Guillermo Metz and K. Max Zhang

Executive Summary

Total Potential

Energy Source	Heating (MMBtu/yr)	Percent of Total 2008 Heating Demand
Biomass Energy Potential	**3,626,477**	**58.8%**
2008 Community Demand	6,169,985	

Major Assumptions

	Land Suitable for Woody Biomass	Land Suitable for Dedicated Energy Crops	Land Suitable for Waste Agricultural Products
Types of Biomass	Cordwood, wood pellets, wood chips	Wild or fallow-field grasses, switchgrass, reed canary grass, etc.	Corn stover, other agricultural waste products from forage-land
Land Included	"Forests" in 2012 Land Use Land Cover Analysis	"Grassland", "Brushland", "Inactive Ag" in 2012 Land Use Land Cover Analysis	"Active Ag" in 2012 Census of Agriculture, Tompkins County
Land Excluded	Unique natural areas (UNAs), slopes >15%, 100' buffers both sides intermittent and perennial streams and roads, and parcels <10 acres	UNAs, slopes >15%, 100' buffers both sides intermittent and perennial streams and roads, and parcels <10 acres	No land classified as Active Agricultural lands were excluded
Harvest Rate	Average of 0.5625 cord/acre/year can be sustainably harvested	Switchgrass yields 3-8 dry tons/acre/year; used 5 dry tons/acre/year for analysis	2012 Census of Ag's "Top Crops Grown in Tompkins County." NY corn yields 130-150 bu/ac, 42 bu corn grain produces 1 dry ton of stover, so 3 dry tons of stover/acre. Forage-land low-quality hay yields 1.7 ton/ac yields 27,737 tons/yr
Heat Value of Biomass	12.9 MMBtu/ton based on the heat density in dry wood in County-owned forestlands, 2007	15.5–16.5 MMBtu/ton heat value for Switchgrass	15.5 MMBtu/ton heat value for corn stover and 15 MMBtu/ton for hay
Sequestration	Discussed but not quantified for potential	Discussed but not quantified for potential	Discussed but not quantified for potential

Biomass is an important part of the energy sector, with significant growth potential to decrease our use of fossil fuels, particularly for space heating. As such, biomass utilization has many benefits over fossil fuels, as well as some other advantages over other renewable energy technologies.

The main objective of this section is to evaluate the potential at both the supply and demand sides of the utilization of biomass for residential and commercial space heating in Tompkins County, as well as provide a discussion of the various types of available combustion technologies. Biomass can also be used effectively for certain types of process heating, and even space *cooling*, but these are not included in this analysis.

Lands that can produce biomass resources include 1) Forests, 2) Inactive Agricultural Lands, Brushland and Grassland, and 3) Active Agricultural Lands. Forests can provide cordwood, wood pellets, and wood chips. Inactive Agricultural Lands, Brushland and Grassland can supply wild or fallow-field grasses and can be planted in dedicated energy crops such as switchgrass, reed canary grass, etc. Active Agricultural Lands can provide agricultural residues such as corn stover and other agricultural waste products.

As will be discussed, while significant work has been done to quantify the gross potential for growing and harvesting agricultural biomass from Active and Inactive Agricultural Lands, Brushland and Grassland, the combustion equipment for utilizing this resource is less evolved than that for woody biomass. Therefore, this report separates out the potential for woody biomass from that of dedicated energy crops to meet some portion of the community's energy needs. Based on current trends, however, we expect that the efficient combustion of agricultural biomass (growing and processing, as well as combustion equipment) will be significantly more mature within the next 10 years, allowing this feedstock to become a major energy source within the timeline of this roadmap.

The analysis of the biomass production potential in the county shows the following results:

Woody Biomass from Forests:

- Applying constraints such as the physical ability to harvest, we estimate there are roughly 69,775 acres of forested land available for woody biomass harvest.
- With roughly 50% of the land yielding 1/2 cord/acre/yr; 25% yielding 1/4 cord/acre/yr; and 25% yielding 1 acre/cord/yr (producing an average yield of 0.5625 cord/acre/yr) that can be sustainably harvested (and about 2.5–3 green tons, or 1.5 dry tons/cord), this results in roughly 58,873 dry tons of woody biomass being available for harvest annually in the county.
- Based on the heat value of that wood, and an adjustment for some proportion of the forests providing higher-value timber over time, forests in the county could yield roughly 454,191 MMBtu/year of thermal energy on a renewable basis.

Energy Crops on Inactive Agricultural Lands, Brushlands and Grasslands:

- Our analysis shows that Tompkins County has roughly 29,668 acres of inactive agricultural, brush and grass lands that could potentially be available for dedicated energy crop harvest.
- Growing dedicated energy crops, such as switchgrass, on inactive agricultural, brush and grass lands within the county could provide roughly 148,340 tons of biomass each year for 2,373,440 MMBtu/year.

Active Agricultural Lands:

- Waste residues from active agricultural lands (e.g., corn stover), while currently not utilized to any great degree, have the potential to become significant sources of energy, even accounting for the need to retain agricultural residues on the land to enhance soil health and reduce erosion.
- This sector has the greatest potential for growth in terms of what materials can be utilized and the combustion equipment that can handle it.
- Active agricultural land in the county totals 43,547 acres. Applying appropriate constraints, this can provide roughly 798,846 MMBtu/year.

Table 42 Total annual biomass energy potential in Tompkins County

Type of Biomass	Land Cover Category	Total Acreage	Suitable Acreage	Yield (tons) †	MMBtu/yr ‡
Wood	Forest	141,056	69,775	58,873	454,191*
Energy Crop	Brushland	27,431	15,304	76,520	1,224,320
	Grassland	11,938	6,822	34,110	545,760
	Inactive Ag	9,984	7,542	37,710	603,360
	Subtotal		29,668	148,340	2,373,440
Ag Waste	Active Ag	43,547	24,548	52,433.2	798,846
Total					**3,626,477**

Sources:†(1) USDA Forest Service, Forest Inventory and Analysis. 2012. (2) Sustainable Corn Stover Harvest. Ertl, D. Iowa Corn Promotion Board. 2013. (3) New York Crop and Livestock Reports for October 2012 and November 2013. USDA National Agricultural Statistics Service, New York Field Office.‡ (1) Fuel Value Calculator. Forest Products Laboratory. 2004. Available at www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf. (2) Properties of Biomass, Appendix to Biomass Energy Fundamentals, EPRI Report TR-102107. Jenkins, B. 1993. Available at cta.ornl.gov/bedb/appendix_a/Heat_Content_Ranges_for_Various_Biomass_Fuels.xls.

* Total energy potential from the yield shown here is roughly 756,985 MMBtu/yr but over the timeframe of this roadmap, the expectation is that proper forest management will result in a larger proportion of high-value timber. We take an average value of 60% of total yields going to bioenergy with about 40% being higher-value timber over time (out to 2050).

In addition, an oft-overlooked resource, waste wood, could be used for heating facilities. The City of Ithaca, alone, currently removes approximately 100 tons of wood in the form of dead trees or other removals each year, which could easily be used to heat a facility.

Biomass thus represents an opportunity to significantly reduce the county's carbon emissions, while also providing several additional environmental and economic advantages over fossil fuels, as well as presenting some significant challenges.

Opportunities

- The region has ample woody biomass resources. Managing the region's forests for biomass in a sustainable and responsible way can not only increase forest productivity but lead to higher overall biodiversity, and, ultimately, healthier ecosystems. Biomass is considered a very low-carbon energy source, with an estimated <5% embodied energy in cordwood and <10% embodied energy in wood pellets, depending on how far they travel and, in the case of pellets, the source of the feedstock (most of the pellets produced regionally derive from mill waste).

- If properly managed, biomass derived from forests and non-crop agricultural lands can become not just a low-carbon fuel but create a net carbon-sequestering paradigm, since properly managed forests and fields are more productive at sequestering carbon than non-managed ones.[10]
- Utilizing the ample local rural resources creates and strengthens local jobs in forest management, harvesting, transportation, processing, etc.; offers a source of income for rural landowners; and keeps money circulating within the region, further supporting and strengthening the community.
- Currently available combustion equipment, particularly on the large residential and commercial scale, is far better and cleaner burning than what was available just a few years ago. As interest in this type of equipment has increased, and fuel oil and propane costs have risen, more and more home and business owners are switching to biomass.
- Oil and propane delivery companies are starting to become interested in offering bulk delivery of biomass (usually in pellet form).

Challenges

- The greatest challenge with utilizing biomass for energy is controlling emissions. Much of the existing combustion equipment currently in use predates the 1990 EPA Phase II regulations governing wood stoves, as well as the EPA's early 2015 release of updated emissions regulations governing a much broader range of combustion equipment, including wood-burning cook stoves, pellet stoves, etc. However, since the early 1990s, there have been significant advances in the equipment itself, most importantly at the scale of residential and commercial boilers. Modern two-stage-combustion cordwood and pellet boilers have emissions that can be as low as those seen with oil- and propane-fired equipment. The challenge is educating sectors of the community who think about the older, more polluting equipment when they hear about heating with wood—making them aware of the existence of this equipment and helping homeowners make the transition.
- Biomass has less energy per volume than fossil fuels, requiring larger storage containers and/or more frequent deliveries. Because of this and the emissions concerns, significant expansion of biomass for space heating may not be appropriate in certain urban settings.
- Another challenge that utilizing biomass for energy faces is resistance to seeing our forests more actively managed. In large part, this is based on a lack of understanding about the current health of these forests and what sustainable, responsible forest management looks like. Because of a long history of mismanagement (or non-management) following a period of clear-cutting within the past hundred-or-so years, nearly all of the county's forestlands have grown up with a preponderance of non-native species in a situation analogous to a garden overrun with weeds. Because of this, simply leaving the forests to grow back "naturally" will not result in truly natural or healthy forests. In fact, biodiversity and overall forest health can be improved with greater forest management, which can include significant ongoing harvests of biomass. However, in order to avoid resistance, the public will have to be educated to this reality.
- The need to educate residents about the benefits of utilizing biomass for heating, and of the available technologies, is significant. The vast majority of forestland statewide is privately owned[17] and much of that forestland is found in relatively small family plots.

1. Introduction

In 2011, hydropower (4657 MW), wind (1403 MW), and biomass (512 MW) accounted for the greatest amount of renewable energy in New York State (NYS).[32] The state has 6.031 million tons of biomass resources, with potentially between 1 million and 1.68 million acres of non-forest land that can be used for bioenergy feedstock production.[33] Biomass resources include woody sources from forests, which currently contribute both cordwood and wood chips (and to a lesser extent, the feedstock for wood pellets); woody sources derived primarily as waste from the lumber industry (wood pellets); agricultural byproducts such as corn stover and other agricultural waste; and dedicated energy crops such as switchgrass, miscanthus, and shrub willow, as well as wild or fallow-field grasses, that can grow on land not suitable for or otherwise not currently in agricultural production.

Current combustion technologies are able to handle a variety of biomass feedstock—particularly different forms of woody biomass—with extremely low emissions and high efficiencies. The main forms of biomass for thermal applications are cordwood (used in wood stoves and boilers), pellets (used residentially and commercially in pellet stoves and boilers), and chips (used commercially in biomass boilers). (See *Combustion Technologies*, below, for more information.)

Figure 48 Cayuga Nature Center, in Ithaca, NY, has a 0.5 MMBtu wood chip-fired boiler (housed in a shipping container outdoors) that heats the main building, saving them about $15,000 each year on propane costs

Pellets can be derived from forest products, agricultural residues, and dedicated energy crops. Currently, sawmills are the greatest source of wood chips and sawdust that make up the vast majority (>80%) of the raw material for wood pellets. The main local producer of wood chips is Wagner Lumber, based in Owego, which is also the largest local sawmill close to Tompkins County, actually managing three sawmills and one log yard. Wagner owns more than 3,000 acres of forestland and employs over 250 people. It is the largest manufacturer of hardwood lumber in the Northeast United States, selling hardwood globally, with an annual total production of 60 million board feet. It is also the largest purchaser of hardwood logs in the Northeast.[47] Wood chips are a natural by-product of sawn lumber and represent 20% of the average saw log by volume. Sales of Wagner's wood chips are now being divided between medium-density fiberboard manufacturers, pulp and paper manufacturing operations, particleboard producers, and commercial biomass boilers (including the chip boilers at Cayuga Nature Center and the Town of Danby highway barn). In addition, Mesa Reduction, based in Auburn, NY, has been in the business of aggregating biomass feedstock since 2000, and has been expanding into the delivery of wood chips to biomass boiler facilities for the past few years. (Mesa is also working on chip-drying systems, since one of the greatest challenges with wood chips is their high moisture content, which can result in increased emissions in much of the existing wood chip-fired heating equipment.)

Wood pellets are made mostly (~85%+) from sawmill sawdust (every sawn log yields about 10% sawdust), which is typically kiln-dried, heated with steam under pressure, extruded through a die, and cut (or, more accurately, allowed to break) into short lengths. Most of the pellet plants in Central New York and northern Pennsylvania are associated with a sawdust-producing lumber-related retail business such as pallets or furniture. (Life-cycle analyses of wood chips show extremely favorable greenhouse gas emission reductions for pellets derived from such manufacturing waste when replacing natural gas.[11]) The largest of these pellet plants, New England Wood Pellets (NEWP) with facilities in Schuyler and Deposit, NY, primarily uses a mix of mill residues and waste wood from logging operations. The other pellet plants are medium-sized pellet mills that report production around 35,000 tons/year. Currently, there is an enormous global wood pellet market with 3.2 million tons of pellets exported by the US in 2013, primarily for use in European power plants (primarily from mills in the southeastern US).[45]

Agricultural biomass varies widely and is still in its infancy both in terms of equipment that can effectively and cleanly burn the material and in understanding and controlling the emissions from the various materials. Researchers at Cornell University and Brookhaven National Laboratories, among other institutions, are studying emissions from agricultural biomass, with others working on improving combustion equipment design to better handle the feedstock and burn it more cleanly.

Issues with agricultural biomass (including dedicated energy crops) include higher ash, nitrogen and phosphorus content, as well as naturally occurring chlorine and other salts, depending on the crop and inputs added to increase yields and combat natural competitors and pests. These result in higher

Figure 49 Biomass comes in many forms, the most common of which are saw logs from local harvests, which are turned into cordwood, wood chips, or lumber. Wood pellets are made mostly from waste wood from local lumber mills

emissions related to these components (e.g., NOx). The higher chlorine content can be corrosive to combustion equipment. In addition, naturally occurring silica found in many of the grasses used for energy leads to the formation of “clinkers”—hard deposits similar to volcanic glass—that can harm the combustion equipment. While the feedstock presents inherent challenges not found with wood, advances in combustion technology are already addressing many of these.

2. Potential of Biomass Production in Tompkins County

2.1 Amount of Land Available

The Tompkins County Planning Department’s recent GIS analysis (conducted in 2014) of 2012 Land Use Land Cover Data shows that, for the purposes of biomass supply, Tompkins County can be divided generally into forested land suitable for production of woody biomass; inactive agricultural, brush and grass lands suitable for planting dedicated energy crops; and active agricultural lands suitable for harvest of agricultural waste products. Of the total 305,666 acres of land in Tompkins County (not counting the 9,408 acres in Cayuga Lake), there are roughly 141,056 acres of forested land; 11,938 acres of grassland, 27,431 acres of brushland, and 9,984 acres of inactive agricultural land; and, from the 2012 Census of Agriculture, there were 43,547 acres of active agricultural land. The remaining areas are not generally viable for biomass production.[43]

A GIS-based analysis was conducted to identify "suitable" lands for biomass production. All of the forest, brush, grass and inactive agricultural lands identified by the 2012 Land Use Land Cover data had the following features removed to determine suitable acreage: designated Unique Natural Areas, lands with slopes greater than 15%, 100 foot buffers on either side of intermittent and perennial stream centerlines, 100 foot buffers on either side of road centerlines, and parcels smaller than 10 acres in size. The analysis concluded that of the total forested land, roughly 49.5% was available for biomass harvest. Similarly, roughly 55.8% of the brushland, 75.5% of the inactive agricultural land and 57.1% of the grassland was suitable for biomass production. Figure 50 illustrates the areas suitable for biomass harvest, showing 69,775 acres of suitable forested land, and 29,668 acres of general inactive agricultural, brush and grass land.

As for the potential for biomass harvests on active agricultural lands based on agricultural residues, a detailed analysis would have to be made of the types of agricultural products currently being grown on those lands to arrive at the biomass products they could yield (e.g., lands producing hay can produce high-quality feed hay or low-quality hay used for bedding; the latter which can also be pelletized and used for heating). This is beyond the scope of this report, but a rough estimate follows.

As shown in Table 43, active agricultural land in the county totals 43,547 acres. Of those acres, roughly 8,232 acres are in corn for grain. It is important to differentiate corn grown for grain, as harvesting methods results in corn stover being left in the field, as opposed to corn grown for silage, which results in harvesting the entire aboveground portion of the plant, leaving no stover or residual that can be taken off-site for other uses. Another 24,474 acres of the active agricultural land are forage-land, including hay and haylage, grass silage, and greenchop.[2] Most of the forage-land produces only low-quality hay, which currently only has a market as bedding for livestock, but it is suitable for pellets that can be used in pellet stoves and boilers (and, on a larger scale, briquettes and bricks that can be used in commercial boilers). Taking 2/3 of the forage-land as available for this type of harvest, based on an assumption that 1/3 of the land could produce adequate amounts of bedding material to meet needs, results in 16,316 acres of forage-land for a total of 24,548 acres of land used to grow corn for grain and forage-land, both appropriate for biomass harvest.

Table 43 Top crops grown in Tompkins County

Crop	Acres
Forage-land used for all hay and haylage; grass silage; and greenchop	24,474
Corn for grain	8,232
Corn for silage	6,951
Soybeans	2,561
Vegetables harvested, all	1,329
Total	**43,547**

Source: 2012 Census of Agriculture, Tompkins County, NY. US Department of Agriculture. National Agricultural Statistics Service. 2013.

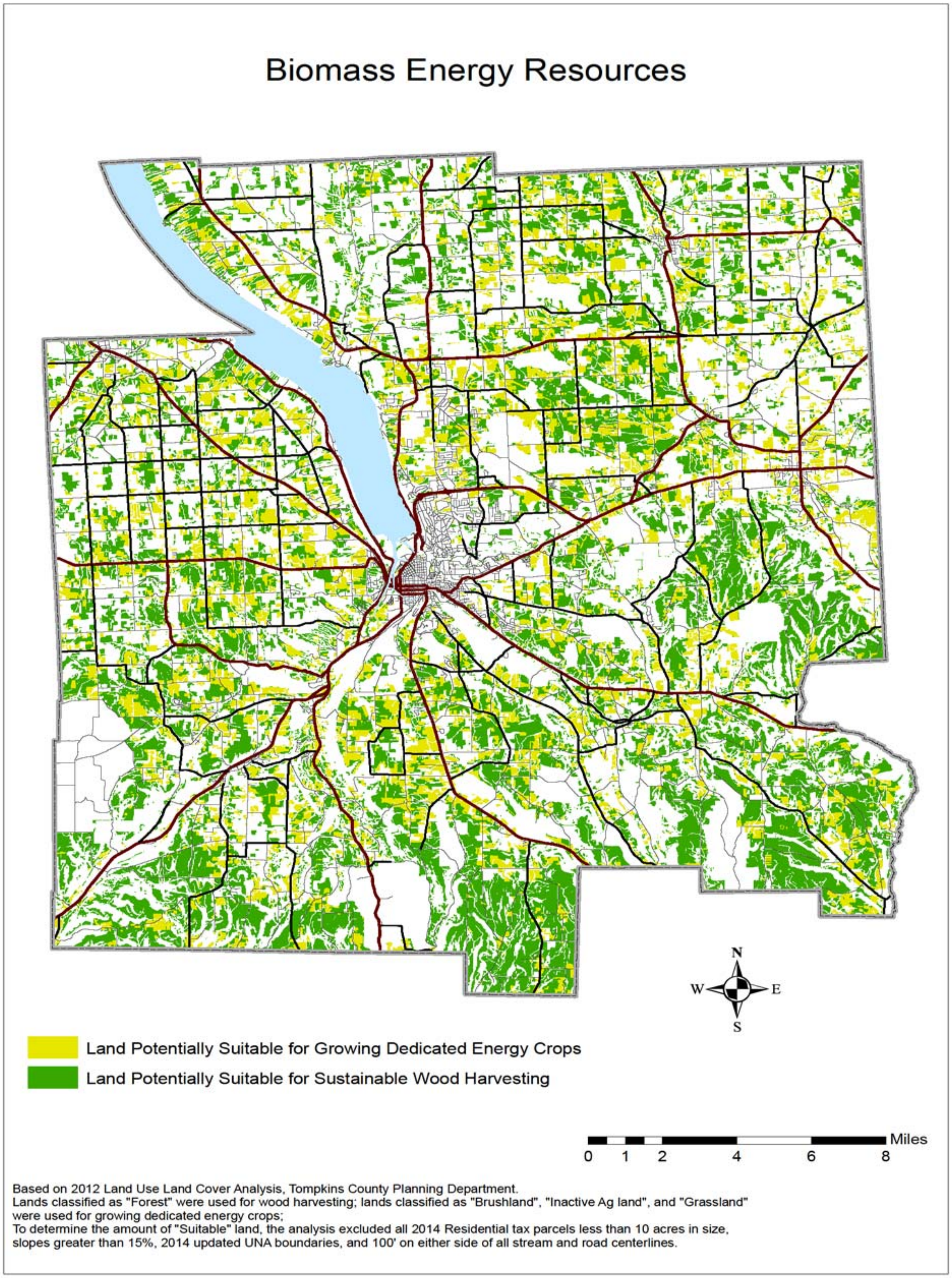


Figure 50 Land in Tompkins County suitable for biomass harvest, TC Planning Department, 2015

2.2 Energy Potential of Biomass in Tompkins County

Woody Biomass from Forests: The amounts of harvestable wood per acre of forests on a sustainable basis vary significantly. Many plots could support harvests of more than 1 cord per acre per year, while others could, without improvements and because of poor soil, support only 0.3 or fewer cords/acre/year. According to Dr. Peter Smallidge, Director of Arnot Teaching and Research Forest at Cornell University, roughly 50% of the forest land in upstate New York could yield 1/2 cord/acre/yr; 25% could yield 1/4 cord/acre/yr; and 25% could yield 1 acre/cord/yr. Based on this estimate, each acre of forest can produce, generally, about 0.5625 cords of wood on a sustainable basis each year. Each cord of dry wood weighs roughly 1.5 tons (2.5–3 tons green). Therefore, the 69,775 acres of harvestable forestland in Tompkins County could yield roughly 58,873 dry tons/year. The 2007 Tompkins County Forest Management Plan provided an analysis of the mix of trees growing on 600 acres of county-owned forestland in the Towns of Newfield and Caroline. The analysis revealed that they contained an average heat value of 6,429 Btu/lb (based on the heat density in dry wood).[39] Therefore, the harvestable biomass from forests in the county could yield a heating value of roughly 756,985 MMBtu/year of thermal energy on a renewable basis.

Note that this represents the total amount of biomass that could be removed and converted to energy. But proper forest management practices will surely result in a higher ratio of high-quality timber, which will give landowners a higher-value product than low-value trees used for energy. Therefore, early interventions will result in larger amounts, proportionately, of biomass suitable for heating, with a trend over time toward higher-quality timber. Where this ratio ultimately levels out will depend on site characteristics, management practices and landowner preferences. For our analysis, over the timeframe covered by the Road Map (out to 2050), we use a value of 60% being available for bioenergy. This brings the total thermal energy available from county forests to roughly 454,191 MMBtu/year.

Dedicated Energy Crops from Inactive Agriculture, Brush and Grass Lands: Researchers and farmers across the state (and the world) have been growing dedicated energy crops for decades. The most promising for our region are grasses, such as switchgrass (*Panicum virgatum*), reed canary grass (*Phalaris arundinacea*), and miscanthus (*Miscanthus giganteus*), and short-rotation trees such as shrub willow (*Salix* spp.). These generally require relatively little in the way of herbicides to allow them to establish or fertilizers to produce sufficient yield. One of the more promising, switchgrass, can yield between 3 and 8 dry tons/acre/year, with a heat value of roughly 15.5–16.5 MMBtu/ton.[18,29] Taking middle values of 5 dry tons/acre/year and 16 MMBtu/ton, Tompkins County's 29,668 acres of inactive agricultural, brush and grass lands could thus provide roughly 148,340 tons of biomass/year, which can offer 2,375,440 MMBtu/year. Shrub willow has a similar energy profile, with an average of 4.7 dry tons per acre and roughly 15.5 MMBtu/ton, while being lower in ash [44,48].

Agricultural Waste from Active Agriculture: Looking at active agricultural lands, according to USDA estimates, New York corn yields have been between 130 and 150 bushels per acre.[25] For approximately every 42 bushels of corn grain produced, one dry ton of harvestable stover is produced.[35] Therefore, roughly 3 dry tons of corn stover can be taken from every acre, resulting in roughly 24,696 dry tons of corn stover from the 8,232 acres currently growing corn for grain. Using the value of 16,316 acres of forage-land that can produce low-quality hay, with a yield of roughly 1.7 tons per acre [25], this results in roughly 27,737.2 tons per year. With a heat value of roughly 15.5 MMBtu/ton for corn stover and roughly 15 MMBtu/ton for hay [29], in all, at current usage characteristics, biomass from active agricultural lands therefore has the potential to provide roughly 798,846 MMBtu/year.

It must be noted that, particularly regarding corn stover, not all of the material can be removed, as some should stay in the fields to return nutrients to the soil. Leaving an adequate amount of material is included in the production figure of 3 dry tons of stover per acre, above. Some studies have shown that when the stover is the main source of nutrients back into the soil, there is an allowable stover harvest rate of as low as 0.73 tons/acre to as high as 1.9 tons/acre (depending on the root: shoot ratio).[6] Alternatives include using manure or a rotation crop such as alfalfa, both of which are commonly done in our area and both of which allow for greater total stover harvest.

It should also be noted that, according to the Renewable Fuels Roadmap and Sustainable Biomass Feedstock Supply report,[33] changes in land use and improvements in fertilizer technology and land use management are expected to result in greater yields on existing active agricultural lands, with a similar increase in productivity of inactive lands with a potential to grow dedicated energy crops, so that the potential for heating homes with biomass from dedicated crops grown on both active and inactive agricultural lands in the county will be even greater in 2020 and beyond. Finally, changes in moisture and temperature (as well as pests and diseases, CO_2 levels, and other factors) due to climate change are expected to result in altered agricultural patterns in our area, though it is difficult to know exactly which crops may benefit from these and which ones may be harmed, and to what extent.[9]

In summary, the total thermal energy that can be sustainably retrieved from forests and inactive and active agricultural lands in Tompkins County is approximately 3,626,477 MMBtu/year, with 454,191 MMBtu/year coming from forestlands, 2,373,440 MMBtu/year from inactive agricultural, brush and grass lands, and 798,846 MMBtu/year from active agricultural lands.

Based on the 2008 Tompkins County Greenhouse Emission Inventory, the average heating demand per household is 67 MMBtu/yr for the 37,443 households. It should be noted that the total heating demand in the County, ~*6,169,985* MMBtu/yr at the 2008 level, includes the residential, commercial and industrial sectors, not just the residential sectors.

In addition, other oft-overlooked resources, such as waste wood, could be used for heating facilities. According to Jeanne Grace, Ithaca City Forester, the city harvests approximately 100 trees, with an average diameter at breast height (DBH) of about 25".[27] Most of this wood is now mulched and given away for free to city residents (a small amount is burned in a wood stove in a facility in Stewart Park and some is taken home for burning by city employees). At roughly a ton per tree of this size, this represents roughly 100 tons of wood from within the city alone. This is not included in any of the estimates in this report, but could be considered in the future, and expanded to the county-wide level.

2.3 Existing Combustion Equipment Efficiencies and Relative Sizes

While not incorporated into this analysis, efficiencies of the combustion equipment will increase the potential of biomass to supply heat because while the raw feedstock can provide a given amount of energy, increases in the combustion equipment's efficiency will reduce the total amount needed accordingly. Current combustion equipment varies in efficiency from as low as 30% or less for an outdoor wood boiler and as low as 50% or less for a pre-1990 wood stove (when EPA emissions regulations went into effect) to 80–85% for many pellet stoves and greater than 90% for pellet boilers and some wood boilers. According to 2011 U.S. Census estimates, there were nearly 2,000 wood stoves in operation in Tompkins County at that time. The number of pre-1990 wood stoves in operation in the U.S. is estimated to be in excess of 70%, so we can assume that more than half of the 2,000 wood stoves in the county function at efficiencies at or below 50%. However, heating with wood is increasing in popularity, so the proportion of more-efficient wood stoves is almost certainly higher and should continue to grow in the future. Further, the EPA released revised regulations for all wood-combustion equipment in early 2015, with even stricter emissions levels that will have to be met by 2020 (while not always perfectly aligned, emissions are generally inversely related to efficiencies, so as emissions drop, efficiencies increase).[36]

We do not have any reliable data for numbers of pellet stoves and boilers currently being used in Tompkins County. However, through informal surveys with local wood and pellet stove retailers, we believe the proportion of biomass-fired heating equipment in the county overall to be roughly 60% wood stoves, 30% pellet stoves, about 5% outdoor wood boilers, and less than 1% for both advanced pellet and wood boilers. Again, the total number and proportion of higher-efficiency equipment is expected to increase substantially over the next 10–20 years.

2.4 Carbon Sequestration

It is important to consider that forests and even dedicated energy crops can also help sequester carbon, since properly managed forests and fields are more productive than non-managed ones. As one study noted:

> "Northeastern forests sequester 12 to 20 percent of annual CO_2 emissions from the region, mostly in living plants and soil. This sequestration capacity figure includes all management regimes—practices that enhance carbon sequestration, are carbon neutral, or actually result in net carbon emissions. By expanding excellent forestry [forestry that is ecologically, economically, and socially responsible] in northeastern forests, the percent of annual emissions that can be sequestered by forests can be substantially raised. Excellent forestry can help increase the amount of carbon sequestered in forests while also harvesting wood products and protecting ecological values."[10] (See also *Forest Management*, below.)

In a recent study of eight counties across the Northeast and Mid-Atlantic and the city of Baltimore, researchers concluded that "The rural counties (those with populations under 100 people per km^2)[Tompkins has 76 people per km^2] could offset a significant portion of current CO_2 emissions (up to 42%) by expanding forest CO_2 sinks and, in some cases, by growing bioenergy crops, but protecting existing forests from overharvest and land-use conversion will be critical."[24] They go on to say that "Forests are the largest potential CO_2 sinks in rural counties and sequester 18%–420% of annual CO_2 emissions in the studied counties (77,000–511,000 Mg [84,878–563,281 tons] of carbon per year)." [24] In summary, "Together, afforestation and bioenergy could offset 0.3%–28% of the CO_2 emissions in rural counties." [24]

In previous studies, some of the same researchers looked in more detail specifically at carbon mitigation strategies in Tompkins County alone and found that 133,379.7 tons carbon/year could be sequestered by the county's forests and active and inactive agricultural lands (including soils).[4]

The authors also point out the importance of considering the albedo effect, or the variability among materials (and land cover) to reflect or absorb the sun's energy. Commercial development of forests or agricultural lands, particularly when adding a large amount of blacktop, contributes considerably to localized warming, which can increase localized summertime cooling needs and, taken cumulatively, can have a significant global effect.

3. Opportunities and Challenges

Biomass represents an opportunity to significantly reduce the county's carbon emissions, but it also has several additional environmental and economic advantages over fossil fuels, as well as some significant challenges.

3.1 Demand from the Various Sectors

The greatest near-term opportunity for biomass utilization locally is to replace oil and propane for space and process heating. Home heating oil and propane are currently the most expensive fuels and there are still many homes and businesses in Tompkins County using both.

According to 2011 U.S. Census estimates, there were nearly 2,000 wood stoves in operation in Tompkins County. Many provide primary heat to homes at least part of the year. For primary heat, each home/wood stove burns an average of 3–5 cords of wood per season, with some burning considerably more. State law limiting the transport of wood to 50 miles means all of this is derived from forests within or neighboring the county. The unpredictable and generally increasing costs of fossil heating fuels have resulted in an increase in the number of homes using wood (cordwood and pellets) to meet at least some of their heating needs. Newer combustion technologies have significantly improved emissions and efficiencies over older wood stoves, so an increase in the use of more efficient wood stoves should result in less of an increase in demand for wood (and emissions) than would be extrapolated from current wood stove use.

It is estimated that up to 70% of wood stoves in operation nationally were built before 1991, predating the Phase II EPA certification process governing most of the wood stoves that fall under any regulations. Wood stoves conforming to the latest EPA rules released in early 2015 are almost non-existent at this time, but will slowly begin making inroads into the market (although manufacturers are not required to meet the new limits until 2020, many already offer equipment that meet those limits today). NY State recently introduced a program—Renewable Heat NY—that includes significant incentives for changing out older wood stoves for pellet stoves and outdoor wood boilers for advanced two-stage gasification wood boilers or advanced pellet boilers. These are intended to address air quality issues arising from older wood stoves and boilers, but will also effectively reduce the demand for cordwood per unit. In addition, because pellets are primarily derived from mill waste, converting to pellet stoves will further reduce this demand.

With these conditions in mind, it is difficult to forecast future demand on our forests for cordwood; however, we were able to estimate the existing demand to be about 192,870 MMBtu[11], or approximately 42.5% of the total potential energy from forest biomass available for heating of 454,191 MMBtu. (Note that an unknown proportion of this is currently derived from neighboring counties.)

In addition to the growing demand for firewood and wood pellets as a result of rising fossil fuel costs, another force acting on the biomass market is the changing demographic of wood stove owners. Many people who heat with cordwood harvest it from their own woodlots; even for those who purchase cordwood, there is a significant amount of physical labor involved. However, an aging population is less able and willing to meet the physical demands required of heating with cordwood, whether from one's

[11] 5 cords/hh x 2,000 hh using woodstoves = 10,000 cords of wood/year countywide. 1.5 dry tons per cord of wood x 10,000 cords = demand for 15,000 tons per year of wood. Average heat value for local trees of 6,429 Btu/lb dry wood x 15,000 tons x 2,000 lb/ton x 1 MMBtus/1,000,000 Btu = 192,870 MMBtu of current wood energy demand per year in Tompkins County

own forests or having it delivered. Median age in the Southern Tier counties (with the exclusion of two college student-populated areas, Cortland and Tompkins Counties) is 41–44 years (versus 38 years across New York State and 37 years in the U.S. as a whole).[1] This group is ripe for conversion to wood pellets, especially if bulk delivery of pellets becomes a reality. It represents a population that, unable or unwilling to continue heating with wood, could convert to oil or propane (if natural gas is not available) or, worse, coal, which, in addition to increasing their net carbon emissions, will result in a significant increase in their heating expenses in the case of oil and propane.

The need to educate residents about the benefits of utilizing biomass for heating, and of the available technologies, is significant. The vast majority of forestland statewide is privately owned[17] and much of that forestland is found in relatively small family plots. Research has shown that many county residents would like to make more use of their land than they are currently doing, including harvesting biomass. For example, in the fall of 2010, Cornell researchers working with Extension agents and others developed a questionnaire that was sent to 2,400 NY State woodland owners.[26] Results, based on 893 completed questionnaires, revealed that 38% of respondents had no interest in selling woody biofuels (representing 42,940 landowners and 2,390,820 wooded acres statewide), 16% had already sold woody biofuels (representing 18,080 landowners and 2,642,485 wooded acres), and 46% were interested in doing so but had not yet done so (representing 51,980 landowners and 3,321,695 wooded acres). The authors noted that, considering non-response bias, the percent with no interest is likely higher. In addition, it should be noted that a significant proportion of those not interested in selling woody biomass were already using wood from their properties for their own personal use.[26]

Similarly, the changing demographic of woodland owners means an aging population that is increasingly pressured to sell forested land, particularly in the absence of viable markets for the forest products. According to some reports, over the next 25 years, three million acres of forestland in the Northeast may be lost to development.[12]

Currently, prices paid for woody biomass are very low, and are unlikely on their own to provide much revenue for landowners. However, improved management of a forest parcel for long-term production of high-value sawlogs, with biomass produced as a residue from pre-commercial thinning, removal of undesirable species, and tops and limbs from sawlog harvest, could create a favorable scenario for everyone involved.

The other consideration when looking at forces acting on the amount of wood available for biomass from our forests is that we are already seeing the effects of invasive pests, including hemlock woolly adelgid and emerald ash borer. In the future, these types of stresses are expected to become more commonplace.[3] Historically, here and in other areas of the country, this has led to periods of significantly higher rates of harvesting.

3.2 Combustion Technologies

There have been tremendous advances in wood-burning equipment over the past 20 years. Outdoor wood boilers (a.k.a., hydronic heaters), which are notoriously highly polluting, inefficient, and generally a nuisance and significant source of harmful particulate matter in many communities across the state, are being replaced with modern two-stage gasification wood boilers that can provide heat much more efficiently with emissions that can be on-par with oil-fired systems.[13] Some experts in the field see a tremendous growth potential from these units, stating that, “Heating with wood using modern, small-scale high-efficiency/low-emission boilers is the next significant economic opportunity in New York in terms of wood energy."[38] These units allow homeowners to heat their homes efficiently and with low emissions with a boiler or furnace that uses a fuel they may be able to access from their own woodlots.

While pellets and woodchips are not something most homeowners can make themselves, they do offer two main advantages over cordwood: they can be sourced from mill waste and small-diameter forest residues left over from logging operations, and, as a fuel, they can flow in mechanized systems for automatic feed to the combustion equipment, resulting in very little physical labor at the combustion source. Pellets offer the additional advantage of being a relatively uniform, dry, and dense fuel, resulting in typically higher combustion efficiencies and lower emissions than cordwood in wood stoves and boilers. Compared to wood stoves, pellet stoves also take the operator out of the equation—whereas even the newest, most advanced wood stove can be abused by the owner, who may burn wet wood or other even more harmful materials that can result in high levels of dangerous emissions, pellet stoves simply do not operate on anything but dry pellets. Pellet stoves and boilers have oxygen sensors that control the burn, they often come with or can be connected to a thermostat, and require only a small amount of electricity to run (with some models now coming with battery backup and kits available for the ability to provide battery-backup power to any pellet stove). Pellet boilers can also be fed automatically, with either augured or pneumatic feed systems. Such systems are available at scales from as small as roughly 50,000 Btu/hr up to more than 1.5 MMBtu/hr for single pellet boilers (and the boilers can be connected in series to meet virtually unlimited demands).

Currently, CCETC is working on a Cleaner Greener Communities program to bring bulk wood pellet delivery to the Southern Tier Region. This will allow residential and commercial end-users to convert to fully automated, advanced pellet boilers, which in effect mimic their current experience with oil or propane in that they are automatically fed from storage containers that are typically housed outside and are filled on a delivery schedule just as propane or oil is. Operators will have to empty their boiler's ash pan roughly once to twice a month, but otherwise, from the home- or business owner's perspective, the systems operate much like their oil or propane boiler—yet they will be realizing significant financial and carbon savings compared to oil or propane.

Figure 51 Pellets can be delivered in bulk to home- and business owners with residential and commercial boilers, creating the ease of use of oil and propane at about a third of the cost

Chip systems are most effective in the commercial and industrial sectors, at heating loads of greater than 2 MMBtu/hr (although there are chip systems as small as 100 KBtu/hr). Chips are typically cheaper than pellets since they require less processing, but their up-front expense can be considerably higher than other systems owing to the need for more robust augers, moving tables, loaders, and other management systems to effectively feed the fuel to the boiler (but because of low fuel costs, chip systems can be cost-competitive over time). Wood chip boilers can be scaled up to provide several million Btu/hour very cost-effectively and, depending on scale, with added scrubbers and/or precipitators, with very low emissions.

There are local and regional examples of each of these, with a growing number of residential wood stoves and advanced two-stage combustion wood boilers, as well as pellet stoves and advanced pellet boilers. At the larger scale, local examples include, among others, the following:

- a 0.5 MMBtu wood chip boiler heating Cayuga Nature Center since 2009;
- another similar but smaller boiler at the Danby Highway Department's main barn (which due to significant design issues has had operational problems that are currently being resolved);
- a 1.7 MMBtu wood pellet boiler recently installed at a ~50K sq. ft. greenhouse in Triangle, NY (Broome County), as part of the Cleaner Greener Communities-funded Bulk Wood Pellet Infrastructure Boost Program, that has saved them more than $40K in heating bills in its first season;
- a combined heat and power (CHP) chip boiler (actually two 350 hp boilers) at the 1-million-square-foot VA Medical Center in Canandaigua that has been operational since 2013 and can provide 345 kW of power and 604 KBtu; and
- a similar CHP system on which it was based located at the Lockheed Martin facility in Owego consisting of two 600 hp wood chip boilers that provide space heat to the 1.8-million-square-foot facility as well as steam to absorption chillers to provide cooling in the summer (on-line since 2008).

Combined heat and power (CHP; also called "cogeneration") systems such as these may have the greatest potential to make efficient use of our biomass resources, particularly at large scales. While not uncommon in Europe, these systems are only now starting to become economically viable in the United States, but, because of rising fossil fuel costs, are expected to be more so in the future, and could certainly come to maturity within the timeframe of this roadmap. These systems distribute the heat produced by electricity production for more efficient energy capture. Conversely, heating systems can be fitted with small generators to produce electricity that can be used on-site or put back into the grid. CHP systems currently exist at scales ranging from residential to industrial and utility scale (systems <5 MW and considerably smaller are sometimes referred to as "modular CHP systems" because they are typically put together from pre-engineered components that can be assembled on-site). Currently, particularly with respect to the smaller systems, biomass-fired CHP is not economical. But CHP systems running on natural gas are growing in popularity, and as fossil fuel costs continue to increase and equipment costs drop, biomass-fired CHP is expected to become economically competitive.[37] An estimate of the electricity-production potential of biomass-fired CHP systems is beyond the scope of this report, but these systems may, within the timeframe of this road map, provide a considerable part of our electricity demand.

Another important consideration is that costs of purchasing biomass-fired CHP systems tend to be higher than those for fossil fuel-fired systems. Fuel costs can give biomass systems a significant financial advantage over time, but up-front costs can be a barrier to their wider adoption. Efforts are being made to have biomass-fired heating equipment included in incentive programs with other renewable energy systems; something that would help significantly both in bringing their costs down and bringing them to broader attention. And, of course, as they become more common, costs will come down, due to increased competition, a shared knowledge of how to design and manufacture the units, and economies of scale.

Biomass CHP systems, particularly at the larger scale, also tend to require more maintenance than fossil fuel-fired systems. Therefore, institutions that have on-site personnel who can clean out and adjust the systems as needed are best suited for their implementation—although in many cases installers offer maintenance plans.

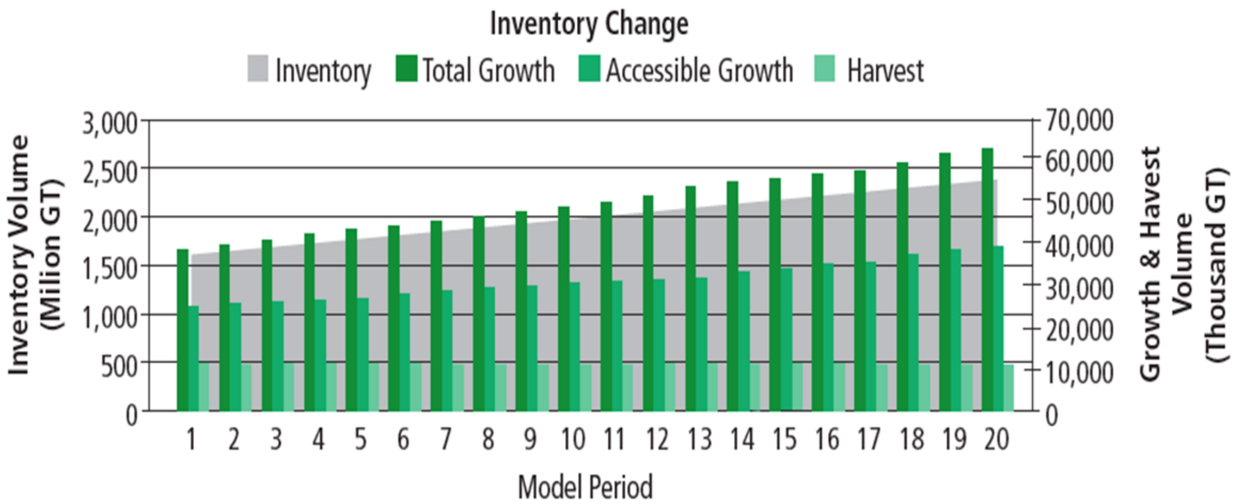
3.3 Forest Management

Currently, our forests are not managed to any great degree. For many years, growth in NYS forests has been significantly greater than harvests, with estimates ranging from 2.1:1 to 2.5:1 for the past several years.[17] This has resulted in a high proportion of low-quality and densely stocked stems due to past land use. Approximately 20% of NEWP's feedstock is derived from debarked and bark-on bole chips, processed from low-grade and generally small-diameter trees that are harvested during forest management operations on both public and private forestlands.[25] These trees are misshapen, diseased or of small diameter, and do not have higher-value markets. As NEWP utilizes only the bole portion of the tree, the nutrient-dense tops and branches of these trees are severed in the woods to recycle nutrients into the soil. The removal of these trees during harvesting is vital to creating healthier forests, since they otherwise would be left behind to become the future forest of poor-quality trees. With good low-grade markets, foresters and loggers can conduct proper thinning operations that leave behind good stocking of higher-quality stems that will become future high-value "crop" trees.

According to the Cleaner Greener Southern Tier Regional Sustainability Plan, land use changes in the Southern Tier from 2005–2010 "resulted in a net sequestration of 6,922,505 $MTCO_2e$. Given the high rate of sequestration and the region's plentiful forest resources, improved forest management and targeted reforestation can help increase carbon stocks in the Southern Tier."[8] Indeed, there is significant potential for carbon offsets by improving carbon sequestration in our forests—according to some estimates, as much as two to seven times the carbon offset benefits of emissions reductions planned in some climate action plans (e.g., Canada's) could be generated by forest management practices.[7]

Further, the vast majority of the forests in New York State, and within Tompkins County, are in a phase with a preponderance of mature trees following previous land clearing.[17] In terms of carbon sequestration, this is a period of slower growth (and therefore carbon uptake, with effectively zero carbon capture in a fully mature forest). This provides an opportunity, with good forest management, to increase carbon sequestration and harvest/thinning for long-term management.[10,28] Therefore, while total forest growth has exceeded harvest by a factor of between 2.1 and 2.5:1, [17,38] resulting in an increase in standing volume of timber of approximately 8% from 2005 to 2012,[15] better forest management could increase forest growth (and, thus, carbon sequestration) even further, even with increased harvests. Figure 52 shows the expected change in total biomass in NY State forests over the next 20 years at the present rate of growth and harvest.

Climate change is also expected to add stresses to forests, most notably with changes in temperature and rain patterns, which themselves can add other stresses such as competing invasive plants and harmful invasive pests. Better forest management, including increased harvesting, can "increase forests' resistance, resilience, and adaptation to climate change." [10]



†Inventory totals are for all live, above-ground biomass on timberland.

Source: The Economic Importance of New York's Forest-Based Economy. North East State Foresters Assn. 2013.

Figure 52 Change in total biomass in NY State forests, 2013–2033†

3.4 Environmental Opportunities and Challenges

In addition to the improved forest aspects and carbon emissions reductions possible through converting to biomass for thermal energy needs, contrary to the concerns of some, if used properly, such a conversion can lead to improved overall air quality. Burning heating oil emits "ambient concentrations of fine particles, … [which] have adverse health and environmental impacts."[21] Although there is a move toward low-sulfur oil, high levels of sulfur in heating oil are "a significant source of sulfur dioxide emissions in the region—second only to power plants. Regionally, the burning of high sulfur heating oil generates approximately 100,000 tons of SO_2 annually—an amount equivalent to the emissions from two average-sized coal-burning power plants." Heating oil is also a considerable source of particulate matter (PM), oxides of nitrogen (NO_x), carbon monoxide (CO), and mercury. The multi-agency group that produced that report, which looked at converting to biomass for thermal applications in the Northeast, concludes that, "A significant transition to biomass combustion in thermal applications can reduce acid rain-causing sulfur dioxide emissions as well as mercury emissions."[21]

Of course, biomass can itself be a significant source of harmful emissions, particularly when fuels such as green wood are burned in old, inefficient combustion equipment. According to the NYS Department of Health, wood smoke is the largest source of carbonaceous $PM_{2.5}$ in rural New York.[14] But an important caveat is that their study focused on outdoor wood boilers, by many orders of magnitude the most polluting home heating option. Modern pellet stoves and boilers, in particular, have greatly reduced emissions, on par with some fossil fuel systems—and education of wood burners so that they learn of the dangers of creating high levels of particulate matter and are made aware of advanced combustion equipment is an ongoing initiative through Cornell Cooperative Extension and others. Across all Northeastern states, there has been an increase in the number of homes using wood as their primary heating source, with New York showing an increase of about 70% between 2005 and 2012.[22] The effects of large increases in the number of irresponsible wood burners should not be underestimated, but because of improvements in the equipment over the past 25 years and tighter emissions standards like those enacted in April 2015, the vast majority of additional biomass combustion will be with advanced, lower-emitting equipment, increasingly pellet stoves and boilers at the residential scale and even cleaner-burning pellet and chip boilers at larger scales.

One area currently receiving considerable attention is the natural off-gassing from pellets, particularly of carbon monoxide. When stored in an enclosed space within an inhabited building (e.g., house, school), this could become a problem. For this reason, NYSERDA is currently requiring outdoor storage (enclosed storage of pellets but in an outdoor silo, shed, or similar structure) for all systems installed under the Renewable Heat NY and Bulk Wood Pellet Infrastructure Boost Programs. However, results from recent studies have concluded that the risk is low and easily mitigated.[50, 51] But for those home- and business owners who choose to store their pellets in outdoor hoppers that can feed their boilers automatically, the aesthetics of the hoppers may become an issue (we have heard this from homeowners in particular) (there are outdoor hoppers housed in small garden-type sheds and these types of non-industrial hoppers may appeal to some of these homeowners.)

Biomass is also a much less energy-dense fuel than fossil fuels, even when densified into pellets. By volume, biomass can require 6 times as much space as fossil fuels, or more, for the same amount of energy. At least currently, it can also not be transported through pipelines, so truck traffic would be expected to increase. This will add wear on the roads and increase truck-related hazards as well as carbon inputs unless the trucks are run on a carbon-free source. It also means some home- and business owners, particularly in densely populated areas, may not have properties that can easily accommodate the large amount of material storage required.

Further, the inherent environmental damage caused by fossil fuel extraction and the well-documented, commonly occurring leaks during processing and transportation of fuels like methane, although not currently borne to any great extent by the county, contribute to their negative impacts at the local level and globally through their high carbon footprint. Additionally, spills and accidents of fossil fuels should be part of the analysis, with the scale of any biomass "spills" being negligible by comparison.

3.5 Economic Opportunities and Challenges

Increased utilization of biomass from area forests will have several economic advantages, including increased revenue and jobs in the harvesting, processing, and transportation of the fuel; new markets for low-grade timber; installation and maintenance of combustion equipment; potentially, local manufacturing of combustion equipment; and monies saved by consumers currently heating with more expensive fuels such as oil or propane.

According to the Northeast Forest State Foresters Association's latest report, "The annual value of sales or output of New York's forest products industry totals over $9.9 billion while the forest-based recreation economy is worth $8.2 billion. Approximately 43,912 workers are employed in the forest products, maple and Christmas tree sectors while another 31,926 jobs are found in the sectors that include and support the forest recreation economy."[38] More specifically to woodland owners, the report states that, "The sale of timber products in New York provide[s] forest owners with around $250 million of revenue annually. Many owners rely on these funds to pay real property taxes related to their ownership." [38] With a very limited forest products industry locally, this attribute has not been realized to any great degree; improved local markets for forest products would give forest owners incentive to keep those lands in productive forest.

Several studies have shown that utilizing biomass and other renewables creates more jobs than fossil fuels. For example, a 2009 study concluded that, "All non-fossil fuel technologies (renewable energy, EE, low carbon) create more jobs per unit energy than coal and natural gas."[30] The authors add that, "An increasing number of studies are finding that greater use of renewable energy (RE) systems and energy efficiency provides economic benefits through job creation, while at the same time protecting the economy from political and economic risks associated with over-reliance on a limited suite of energy technologies and fuels.” [30] (While their analysis focused on utilizing biomass to produce electricity, they found that biomass resulted in 0.21 total average job-yr/GWh, which is not only more than fossil fuels, but also more than wind, nuclear, and carbon capture and storage.)

While we cannot predict the future, we expect carbon pricing to be another factor that can benefit—or harm—the transition to renewable energy and the broader use of biomass for energy. Proposed carbon tax legislation was introduced in the state legislature in the fall of 2015. As currently written, it lumps biomass together with fossil fuels as something that would be priced. Conversations with the drafters of that legislation have made it clear that this is intended to limit the wide-scale use of biomass for electricity production, rather than small-scale residential and commercial space heating—something we agree on. But, rather than promoting the use of biomass for energy, as currently written, this legislation could seriously limit its broader adoption.

4. Summary & Recommendations

Biomass is an important part of the renewable-energy sector, with significant potential to provide affordable heating, reduce greenhouse gas emissions, create local jobs, contribute to the local economy, and improve forest health and biodiversity. Advances in combustion equipment will result in lower emissions, the main concern with increased use of biomass for heating. Additionally, advances in combined heat and power systems will make them more viable for both small- and large-scale applications.

While by far the oldest renewable energy technology in use (unless you count simple solar heating), new high-efficiency, low-emissions equipment, coupled with rising fossil fuel costs for heating, are expected to make biomass for heating attractive to a new generation of both home- and business owners.

Tompkins County should encourage the wider, responsible use of biomass for home and business heating. There remain concerns about the appropriateness of using biomass for heating, particularly in urban settings. Improved combustion equipment already available is making the technology more widely practical. Judging by significant advances in equipment design over the past decade that reduce emissions and improve fuel handling (in the case of pellets and wood chips), the biomass-fired heating equipment of the future (within the timeframe of this roadmap) could allow widespread use of our local biomass resources for home and business heating without significant negative impacts. That said, biomass should certainly not be considered the only answer in every situation, but rather an important and significant part of our future clean energy mix.

But, as a bulletin from the Forest Products Laboratory concluded:

> “The technology to generate energy from wood has entered a new millennium, with virtually limitless possibilities. As public and private sector support increases, the availability of small modular biomass systems ranging from 3 kWe for homes to 5 MWe for large sawmills will flourish. Future systems will be capable of utilizing a variety of waste residue.”[49]

We are already seeing some of these systems. Stakeholders, including Cornell Cooperative Extension of Tompkins County, should continue to educate homeowners about the responsible use of biomass for heating in order to limit harmful emissions. Various sectors of the community also need to be informed about the available technologies so that older equipment is replaced with advanced, cleaner-burning appliances, and new adopters are aware of the benefits of buying the latest equipment. These efforts are underway and continuing and should lead to wider adoption of biomass, particularly for heating.

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Definition of terms: (mostly taken from the Renewable Fuels Roadmap, 2010)[33]

Agricultural Residue: Agricultural crop residues are the plant parts, primarily stalks and leaves, not removed from the fields with the primary food or fiber product. Examples include corn stover (stalks, leaves, husks, and cobs); wheat straw; and rice straw.

Bioenergy: The production, conversion, and use of biomass to manufacture fuels and substitutes for petrochemical and other energy-intensive products.

Biofuels: Biomass converted to liquid fuels such as ethanol and biodiesel.

Biogas: A gaseous mixture of carbon dioxide and methane produced by the anaerobic digestion of organic matter.

Biomass: Any plant-derived organic matter. Biomass available for energy on a sustainable basis includes herbaceous and woody energy crops, agricultural food and feed crops, agricultural crop residues, wood residues.

Bioheat: Thermal energy (heat) provided by burning of biomass.

Bioproduct: Ancillary products made through processing biomass, usually through chemical or thermal conversion to its basic sugars (include products such as cosmetics, plastics, etc. commonly made with petrochemicals).

British Thermal Unit (Btu): The amount of heat energy needed to raise the temperature of one pound of water by one degree Fahrenheit.

Corn Stover: The refuse of a corn crop after the grain is harvested, including stalks and cobs.

Dry Ton/Oven-Dry Ton: Two-thousand pounds of biomass on a moisture-free basis, meaning material without any water content that can be removed by oven drying.

Feedstock: Raw materials that may be treated or converted to create fuels. Biomass feedstock in New York includes forestry products, crop residues, municipal waste streams, manure and food processing waste.

Forest/Forest Land: Areas dominated by trees generally greater than 15 feet tall, and greater than 20% of total vegetation cover.

Forestry Residues: Includes tops, limbs, and other woody material not removed in forest harvesting operations in commercial hardwood and softwood stands, as well as woody material resulting from forest management operations such as pre-commercial thinning and removal of dead and dying trees.

Gasification: Any chemical or heat process used to convert a feedstock to a gaseous fuel.

Green Tons: A term used in the forest products industry for a U.S. ton or metric ton (tonne) of freshly cut timber, bark mulch; i.e., un-dried biomass material. A dry ton weighs less than a green ton (conversion used in the Roadmap: dry tons are calculated as 60% of green tons).

Herbaceous Energy Crops: Perennial non-woody crops that are harvested annually, though they may productivity. Examples include: Switchgrass (*Panicum virgatum*), Reed Miscanthus (*Miscanthus x giganteus*), and Giant reed (*Arundo donax*).

Particulate Matter: Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions. It is usually separated into PM10 and PM2.5, which are particles of diameter equal to or less than 10 and 2.5 micrometers (μm), respectively.

Short Rotation Woody Crops: Trees such as poplar and willow that can be used as feedstock for biofuel. Benefits over traditional row crops include improved soil quality and stability, cover for wildlife, and lower inputs of energy, water, and agrochemicals.

Volatile Organic Compounds (VOCs): Organic compounds that evaporate readily and contribute to air pollution directly or through chemical or photochemical reactions to produce secondary air pollutants, principally ozone and peroxyacetyl nitrate. VOCs embrace both hydrocarbons and compounds of carbon and hydrogen containing other elements such as oxygen, nitrogen, or chlorine.

Deep Geothermal Energy

K. Max Zhang, Mark Romanelli and Camelia Hssaine

Executive Summary

The main objective of this section is to examine the potential of enhanced geothermal systems (EGS) in serving the heating demand in Tompkins County, and the opportunities and challenges in implementing EGS. The U.S. Department of Energy has broadly defined EGS as engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or porosity geothermal resources at depths of 2 km (or 6,500 feet) or more. Compared to hydrothermal geothermal systems, EGS can be adopted in areas with low-grade geothermal resources and not enough natural fluid or permeability.

It is important to distinguish EGS from Geothermal heat pumps (GHPs), sometimes referred to as ground-source heat pumps (GSHP), which also utilize low-grade thermal energy from the earth, but at much shallower depth, typically 2-200 m (or ~7 to 600 feet), than EGS. Soil temperature typically does not vary with seasons at depths beyond 2 m. GSHPs are treated as energy efficiency measures rather than as an energy supply in the Energy Roadmap, and discussion of their potential may be found in the Demand-side Management and Energy Efficiency chapter. While EGS are still in the demonstration stage, GSHPs are readily available commercially and for that reason, EGS potential is not factored into the scenario development, but GSHPs are included.

Tompkins County has modest temperature gradient around 25 ^{o}C/km +/- 1 ^{o}C/km. In other words, ground temperatures within the County reach around ~140 ^{o}C at 5 km (or 3.7 miles). Although it is possible to generate electricity using low-temperature power cycles, direct use of geothermal heat in district heating systems could be a viable option for meeting the heating demand in the County, which accounts for approximately 40% of the County's primary energy consumption. There are several benefits for this option. Geothermal heat is not intermittent, and does not require energy storage. Geothermal systems have a small footprint and virtually no emissions, including greenhouse gases. Other environmental impacts such as radioactive wastes and micro-seismic activities typically range from negligible to manageable.

Although EGS has the potential to meet the entire heating demand in the County, implementation is currently limited by the small number of existing district heating systems to facilitate EGS use, lack of governmental incentives, absence of demonstration projects in the Eastern U.S., and skeptical public perception. A proposed hybrid system that combines EGS and biomass gasification on Cornell University campus would provide a much needed demonstration project to help the community understand and utilize geothermal resources in the County. The proposed Cornell system would supply 98% of the heating demand on Cornell campus with 94,000 metric tons of avoided CO_2 emissions.

1. Introduction

Geothermal heat originates from two main mechanisms: 1) Upward convection and conduction of heat from the Earth's mantle and core, and 2) Heat generated by the decay of radioactive elements in the crust, particularly isotopes of uranium, thorium, and potassium [1]. Thermal energy in the earth is distributed between the constituent host rock and the natural fluid that is contained in its fractures and pores at temperatures above ambient levels. Thermal energy is extracted from the reservoir by convective heat transfer in porous and/or fractured regions of rock and conduction through the rock itself. Typically, hot water or steam is produced and its energy is converted into a marketable product (electricity, process heat, or space heat). Any waste products must be properly treated and safely disposed of to complete the process.

A naturally occurring geothermal system, known as a hydrothermal system, is defined by three key elements: heat, fluid, and permeability at depth [2]. People often associate geothermal energy only with regions of high grade, high gradient hydrothermal reservoirs such as Iceland, New Zealand, or Yellowstone National Park, and neglect to consider geothermal energy opportunities in other regions. As shown in Figure 53, geothermal resources are not evenly distributed in the U.S. An Enhanced Geothermal System (EGS) is a man-made reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation. The U.S. Department of Energy has broadly defined EGS as engineered reservoirs that have been created to extract economical amounts of heat from low permeability and/or porosity geothermal resources [2].

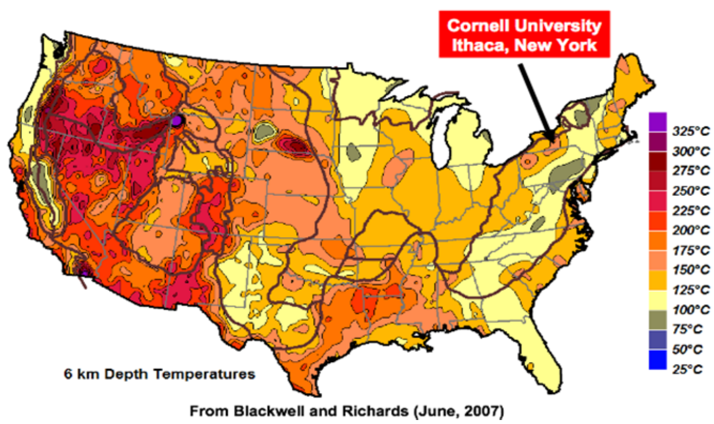


Figure 53 The geothermal resource of the continental United States [3]

In an EGS, fluid is injected into the subsurface under carefully controlled conditions, which cause pre-existing fractures to re-open, creating permeability. Increased permeability allows fluid to circulate throughout the now-fractured rock and to transport heat to the surface where electricity can be generated [2]. In other words, EGS can be implemented in areas with low-grade geothermal resources and not enough natural fluid or permeability. As depicted in Figure 54, fluid is pumped down into the rock and fractures it, creating permeability [2]. In principle, conduction-dominated EGS systems in low-permeability sediments and basement rock are available all across the United States.

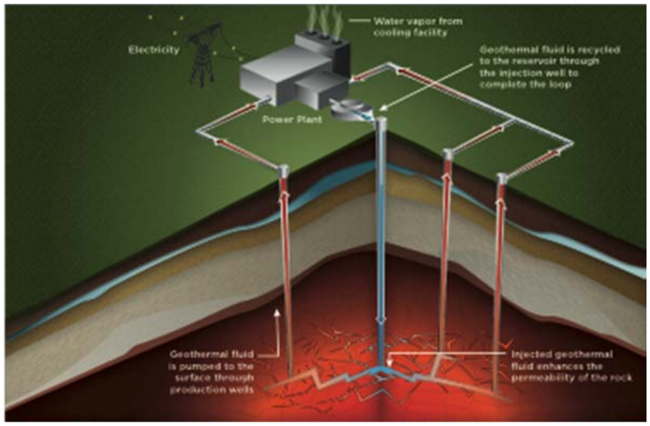


Figure 54 Enhanced Geothermal System where fluid injection enables low-permeability hot rock to become a geothermal resource [2]

Geothermal energy has two typical uses: direct use of heat or electricity generation. Heat generation by geothermal energy is fairly straightforward. Fluid is cycled through a closed loop that runs between Earth's crust and a building to be heated. While the fluid is in the crust, it picks up the heat that naturally exists there and brings it to the surface. The heated fluid is then used to supply space or process heating.

Electricity generation works by a slightly different mechanism. In its most general case, warm water is pushed into the crust. Geothermal energy heats up the water, forming steam. That steam is then used to turn a turbine which generates electricity. The steam then cools into water and while it is still hot it is put back into the crust [4]. There are other variations that can be implemented based on regional requirements.

While EGS technologies are young and still under development, EGS has been successfully realized on a pilot scale in Europe and now at several DOE-funded demonstration projects in the United States [5]. One of the well-known projects is Altarock Energy in Bend, Oregon. At Altarock Energy, three separate zones of fluid flow were created from a single well. There are other demonstration areas in Churchill County, Nevada, Middletown, California, and Raft River, Idaho. It can be noted that none of these sites are located near the Northeastern United States. Geothermal energy of this scale would be a pilot program for this region.

2. Potential

Figure 55 shows the estimated geothermal gradient for New York State and Pennsylvania [6]. Tompkins County records modest gradients, greater than 25 ^{o}C/km and with a precision within 1 ^{o}C/km, indicating that ground temperatures within the County reach around ~140 ^{o}C at 5 km. In comparison, the average estimated geothermal gradient for New York State is 22.5°C/km, and the average estimated geothermal gradient for Pennsylvania is 23.9°C/km. Relative to other areas in Eastern U.S., Tompkins County has above-average gradient, but much lower than the gradients seen in the Western U.S [7] Because temperatures do not reach as high as areas in the Western and Southern United States, geothermal electricity generation is most likely not economically competitive for the County, however direct use of geothermal heat for space heating could be a viable option for the County. In perspective, about 30% of US energy use occurs at temperatures < 160^{o}C [7] and most of it comes from burning natural gas and oil.

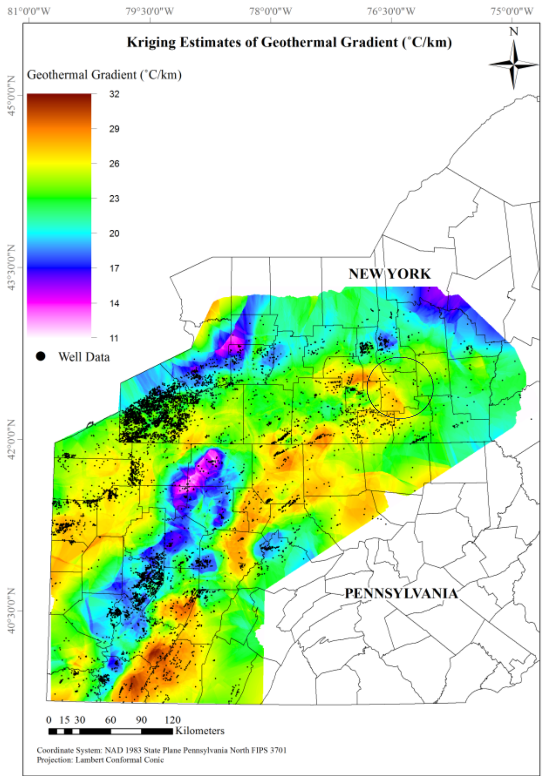
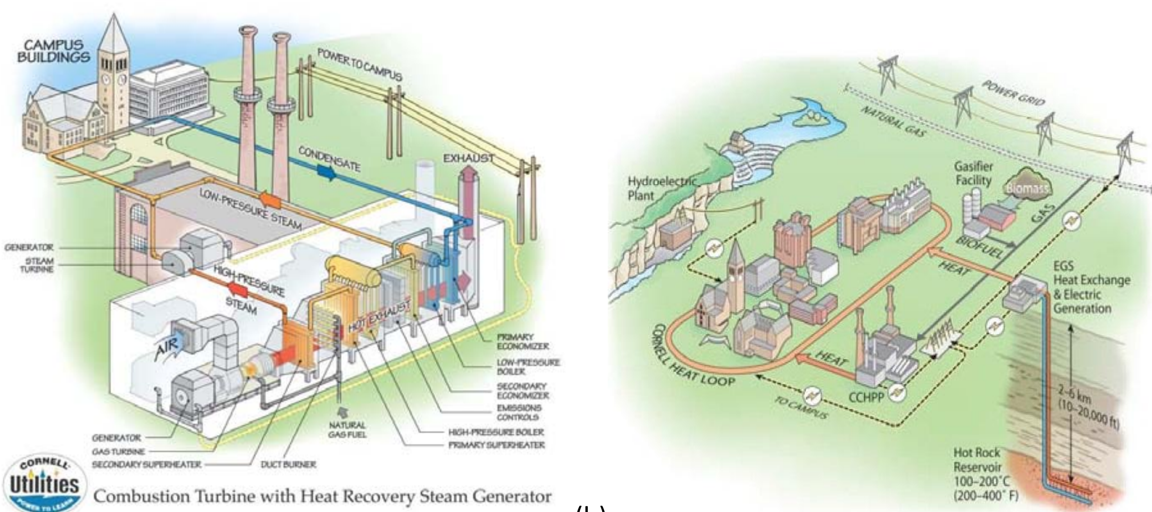


Figure 55 Kriging estimates of geothermal gradient (˚C/km) for NY and PA, with individual well locations shown as black diamonds. Data sources: SMU; PA Geological Survey; NYS Museum; NYSDEC, 2011. Blank areas indicate no estimates

(a)



(b)

Figure 56 (a) The current district heating system with CHP at Cornell University [8]; (b) The proposed district heating system with EGS and biomass [8].

Currently, Cornell University owns and operates a combined heat and power (CHP) plant and a district heating system, illustrated in Figure 56(a), which utilizes two dual-fueled combustion turbines (mostly running on natural gas), designed to operate under full load. This current system is capable of covering 90% of the peak heat demand, and 70% of total electricity demand. The remaining heat is covered by peaking boilers and the electricity can be purchased from the grid. District heat is delivered as superheated steam to campus buildings. The steam passes through heat exchangers, condenses and returns to the CHP plant.

The 2009 Cornell University Climate Action Plan (CAP) proposes a Hybrid Enhanced Geothermal System (HEGS) to reduce the reliance on natural gas for heating on campus [9]. The HEGS is critical to Cornell's goal to become carbon neutral by 2050. It is assumed that by 2050, the district heating system will extend to all of the campus buildings and that all natural gas consumption will be eliminated. In Figure 56(b), the proposed HEGS combines two demonstration-scale research projects: EGS and Biomass Gasification [9]. The EGS would include two well pairs and heat extraction/delivery systems, tied into the campus distribution system for direct use of geothermal heat. The Biomass Gasification system would convert the feedstock produced on Cornell-owned land to biogas, which would be then used to supply the additional heating needs of campus when the ambient temperature drops below -8^{o}C, the design value of EGS at which EGS alone can cover the total heat demand. In other words, EGS would be the base-load heat provider, and biomass would serve as an auxiliary heating source for cold winter days [10].

In addition, to avoid having the system be less productive during the summer, 7% of electricity demand would be generated using an Organic Rankine Cycle (ORC). The remaining heat, after the district heating system or the ORC extracts it, would be used to dry the biomass. Cornell land offers a variety of biomass feedstock, such as food waste, manure, harvested forest products and bio-energy crops including willow and switchgrass [10]. However, the main biomass source is willow, because it can be sustainably cultivated on Cornell land, has high yields, and low carbon intensity in the processes of production, harvest, transportation, and conversion.

3. Opportunities and Challenges

3.1 Utilization of low-grade geothermal resources

Utilization of low-grade geothermal resources provides both challenges and opportunities for Tompkins County.

Heat instead of electricity

In general, geothermal resources in the Eastern U.S. are large in terms of their stored thermal energy but they are at greater depth than those available in the Western U.S. Thus, wells need to be deeper (and costlier) in the East than in the West to tap the same amount of thermal energy. Moreover, converting low-grade thermal energy to electric power is typically inefficient, so use of geothermal to produce electricity in the Eastern U.S. is not effective. In contrast, integrating EGS into a district heating system for direct use of geothermal heat makes the geothermal resource available in the East more economically attractive.

Minimal greenhouse gas emissions

In Tompkins County, heating demand accounts for approximately 40% of the primary energy consumption. EGS has the potential to serve the heating demand in the County cost effectively with small amounts of greenhouse gases emissions if fossil fuels are used to power EGS (e.g., pumping, injecting, etc.).

Land use and visual impacts
Furthermore, compared to biomass heating, EGS requires a much smaller land use footprint. EGS is one of the few renewable energy resources that can provide continuous base-load energy with minimal visual and other environmental impacts (discussed in Section 3).

Price fluctuations for fossil fuels
In the shorter term, having a significant portion of our base load supplied by geothermal sources would provide a buffer against the instabilities of gas price fluctuations and supply disruptions, as well as nuclear plant retirements.

Need for additional research
Although EGS technology has advanced since its infancy in the 1970s, Research, Development, and Demonstration (RD&D) in certain critical areas, such as drilling technology, power conversion technology, and reservoir technology, could greatly enhance the overall competitiveness of EGS [1]. For example, the main constraint for EGS is creating sufficient connectivity within the injection and production well system in the stimulated region of the EGS reservoir to allow for high per-well production rates without reducing reservoir life by rapid cooling. Increasing production flow rates by targeting specific zones for stimulation and improving downhole lift systems for higher temperatures, and increasing swept areas and volumes to improve heat-removal efficiencies in fractured rock systems will lead to immediate cost reductions by increasing output per well and extending reservoir lifetimes.

3.2 Lack of governmental incentives

There are currently many incentives at both the federal and state level available to installers of solar photo-voltaics, solar thermal, hydroelectric, wind power, biomass, anaerobic digestion, geothermal heat pumps, and many more. While geothermal heat pumps are eligible for many of these incentives, there are currently no similar incentives for commercial scale EGS-based district heating systems. The creation of incentives to encourage growth of EGS could act to dramatically increase installation and development. For example, a recent report indicates that government or state incentives that would cover 30 percent of the capital costs would make retrofitting for EGS-based district heating systems immediately economically viable in a number of New York State communities. The 30 percent incentive level is typical of what is currently offered for other renewable energy technologies [11].

In addition, creative implementation strategies would also help overcome the cost barriers that exist today for EGS by focusing initially on developing the infrastructure needed for district heating and CHP systems at a community scale. These district energy systems could be designed to initially utilize conventional fuels and waste biomass feedstock and later transition to using geothermal energy as their primary energy source [12].

3.3 Public Perception of EGS
As there are no EGS demonstration projects anywhere near the Eastern U.S., the public understanding of EGS has been limited compared to other forms of renewable energy generation.

Cornell has conducted significant research in the local community to gain a better understanding of the public sentiment with respect to their Climate Action Plan (CAP). In April and May of 2009, questionnaires were mailed to 2,200 local property owners in Tompkins County [13]. The overall response rate was 34% (N=677). Respondents received one of six versions of a questionnaire seeking to measure their attitudes toward Cornell's CAP, which included EGS. Specifically related to EGS, the results found that respondents generally considered themselves least familiar with EGS compared to other approaches. In terms of beliefs, EGS was perceived as the costliest of the elements, somewhat 'limited' (39% versus 18% responding 'not limited'), somewhat 'safe' (43% versus 15% responding 'dangerous'), reliable (45% versus 13% responding 'unreliable'), 'able' to solve energy problems (53% 'able' versus 15% 'unable'), a 'good way' to address climate change (53% versus 13% 'bad way'). The results found moderate support if it were to occur somewhere in Tompkins County (but not near where they live): 14% oppose (strongly or slightly), and 45% favor (slightly or strongly). This level of support decreased somewhat when asked if it were near where they live (18% oppose and 38% favor). Support increased slightly if it were to only be on Cornell lands: 11% opposed and 53% supported. Support increased fairly strongly if it were to produce community benefits: only 5% opposed and 62% supported.

3.4 Radioactive waste

There is some concern over radioactivity when considering a geothermal system. As explained above, the primary source of heat in geothermal energy comes from radioactive decay. When drilling holes for geothermal, there is a danger of exposure to radioactive materials. The EPA lists geothermal drilling as a potential source for Technologically-Enhanced, Naturally-Occurring Radioactive Materials (TENORMs), similar to those associated with oil and gas production [14]. There is a protocol for safe handling of TENORMs and radiation doses from them are expected to be very low. With the highest radiation levels expected to be around 250 picoCuries per gram, for comparison a 150 gram banana emits almost 520 picoCuries [15]. Consequently, this danger can be regarded as low and with proper planning should not have any major impact on health.

The other concern for radioactivity is the contamination of the geothermal fluid. On open loop systems, the fluid that runs through the rock can acquire trace amounts of radioactive elements. This risk can be mitigated by using a heat exchanger for the geothermal fluid and preventing the fluid from entering buildings. It can be avoided entirely by using a closed loop system where fluid never comes in direct contact with the rock.

3.5 Micro-seismic activities

The Ithaca area is bordered by the Clarendon-Linden fault zone to the west, the Adirondack Mountain to the northeast, the NW-SE Boston-Ottawa seismic belt, and the SW-NE seismic region related to Appalachian structures. The regions considered for developing these systems have historically had no seismic events, and indicate a high degree of tectonic stability. Even though no intra-plate region can be considered risk-free, it is acceptable to assume that this area under consideration is aseismic on both the local and regional scale. The potential for induced seismicity is low, relative to sites that are tectonically unstable. In preparation for EGS development, the following investigations should be carried out to minimize risk:

- Microzonation of the region, i.e. subdividing possible seismic zones with respect to their geological characteristics
- Monitoring of background seismicity.
- Geophysical mapping of bedrock structure [16]

A successful geological site assessment and seismic monitoring would be necessary to geothermal development and public acceptance.

3.6 "Fracking" for EGS

Creating artificial geothermal reservoirs for an EGS involves using hydraulic pressure to create a network of small, interconnected fractures in the rock that act as a radiator, transferring the heat in the rock to water circulating through the system [17]. Although similar on its face, natural gas fracking and EGS fracking are fundamentally different. The oil and gas industry injects water and a proppant (a mix of sand and chemicals), at a very high pressure of around 9,000 psi or more, which breaks through the rock and holds the cracks open [18]. In contrast, EGS uses water to shear the rock and cause a "slip", often referred to as "hydro-shearing". Fractures form where there are existing deformities in the rocks. With very small fractures very deep in the earth and chemical-free fracking fluid, the long-term impact of hydro-shearing is typically negligible.

Acknowledgment

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Demand-Side Management

Xiyue Zhang, Mark Romannelli, Camelia Hssaine and K. Max Zhang

Executive Summary

Demand-side management (DSM) encourages end users to modify their level and pattern of energy use. The objective of DSM is to provide cost-effective energy and capacity resources to help defer or avoid altogether the need for new sources of power, including generating facilities, power purchases, and transmission and distribution capacity additions [1]. In this section, we define DSM broadly to include energy efficiency, demand response, and distributed energy storage. Within energy efficiency, we study the potential for retrofitting existing buildings, constructing new energy efficient buildings, and utilizing heat pumps and solar thermal as energy efficient appliances. The main findings are summarized as follows.

Retrofitting Existing Buildings

Table 44 Summary of energy savings potential from energy retrofits in existing residential and commercial buildings

	Residential	Commercial	Total
	MMBtu/yr	MMBtu/yr	MMBtu/yr
Total Energy Savings Potential	2,268,059	2,451,102	4,719,161
Thermal Energy Savings Potential	71%	71%	3,350,604
Electrical Energy Savings Potential	29%	29%	1,368,557 (or 401 GWh)

We first estimated the County-wide average site Energy Use Intensity (EUI) for residential and commercial buildings, respectively, based on utility and square footage data to use as baseline values. Then we compared the County-wide site EUIs against highly efficient building benchmark values to quantify the potential for energy savings.

For commercial buildings, we adopted 65 kBtu/sq.ft. yr as the benchmark value. The potential was estimated to be 2,451,102 MMBtu in energy saving, or 55.2% reduction from the 2008 level.

For residential buildings, we adopted as the benchmark value the site EUI of a local office retrofitted from an old house in Downtown Ithaca. The potential was estimated to be 2,268,059 MMBtu in energy saving, or 66.8%reduction from the 2008 level.

The total potential for retrofitting existing buildings is therefore 4,719,161 MMBtu, which is about 32.7% of the total energy consumption (including transportation) in the County.

Retrofitting existing buildings has the largest potential among all energy efficiency measures, but is also the most challenging due to factors such as the large proportion of older housing stock in the County, lack of financial incentives for building insulation or home energy performance in general, and split incentives between tenants and landlords for energy efficiency in rental properties. On the other hand, there are a number of local initiatives being developed to help address those challenges such as the

Residential Energy Score Project, Ithaca 2030 District, and South Hill Outreach for Rental Experience project. Buildings considered prime candidates for energy retrofits in these times of low natural gas costs are those with heating systems that: 1) are at the end of their useful life or 2) use fuel oil, propane, electric resistive or steam.

Constructing New Buildings

The ability to construct new buildings to higher energy efficiency standards will be significantly influenced by the adopted building code (NY Energy Conservation Construction Code), which has been moving incrementally to be more energy efficient over time. Applying the building code to new construction, it is projected that the overall heating EUI would reach 7.7 Btu/hr per sq. ft. in 2050. This results in an EUI that is 15% below the 2008 baseline, equivalent to 1,152,880 MMBtu of energy saving. Another driver for more efficient buildings is the development of new standards, such as Passive House construction. We have seen in recent years that Passive House and other extremely energy efficient buildings are possible to construct in this area, so climate is not a major barrier.

Heat pumps

The All Electric scenario evaluates serving the entire heating and cooling demand in the County by Air-Source Heat Pumps (ASHP) and Ground-Source Heat Pumps (GSHP). The All Electric scenario would lead to significant increases in electricity consumption of ~382 GWh and ~273 GWh, respectively. In perspective, the total electricity consumption in the County at the 2008 level is ~809 GWh. One major technical challenge for AHSPs is the operation at extremely low ambient temperature, as the most efficient ASHP models do not operate below -13 °F. Supplemental heating sources are often needed for ASHPs. In comparison, GSHPs have no major technical challenges in operating at low temperature, but the installation costs for GSHPs are high compared to AHSPs.

Solar thermal

Even though solar thermal water heating is an efficient way to create hot water, lack of effective energy storage and siting flexibility makes solar thermal less appealing to residential and commercial customers. For buildings with substantial hot water usage, solar hot water heating systems remain a viable option to reduce the reliance of fossil fuels. Also, for high renewable penetration scenarios where net metering is no longer feasible or for off-grid applications such as a micro-grid, solar hot water heating systems serve as an efficient way to generate domestic hot water.

Demand response

Demand response has played an important role in peak load reduction, and can potentially play a critical role in integrating intermittent renewable energy. We estimated the potential for demand response in the County based on a recent study on the effects of dynamic pricing on demand profiles in New York State [2]. The results for NYISO Zone C (where the County is located), adjusted by the fraction of Zone C population in Tompkins County were applied to the County. The potential for peak load reduction is ~22 MW. The major challenge for expanding demand response is lack of dynamic pricing options for customers. On the other hand, the development of automated demand response for commercial customers, home automation technologies and the Reforming Energy Vision (REV) initiative proposed by New York State will make demand response and dynamic pricing more accessible to the community in the near future.

Distributed energy storage

The role of energy storage is critical to improving system resilience and integrating renewable generation. We examined the feasibility of various types of energy storage, including thermal, mechanical, chemical, electrochemical, and magnetic, in Tompkins County. At present, only thermal storage systems have been implemented and only in the non-residential sectors. With intensive research efforts on energy storage currently being undertaken by universities in the Southern Tier Region and elsewhere in the world, and the potential development of a number of micro-grids in the region, the County may see more examples of distributed energy storage in the coming years.

1. Introduction

This chapter discusses the potential, as well as opportunities and challenges, for the following aspects of demand-side management (DSM) that are closely aligned with Tompkins County's sustainability goals:

- Building energy efficiency (including retrofitting existing buildings, constructing new energy efficient buildings, and utilizing heat pumps and solar thermal as energy efficient appliances);
- Demand response;
- Distributed energy storage

Building energy efficiency

- **Existing buildings**. In 2013, buildings' share of U.S. primary energy consumption was about 40.7% [3] and this figure was 54% in Tompkins County in 2008 for just the residential and commercial sectors; hence increasing energy efficiency in existing buildings is a critical step to address energy consumption and greenhouse gas emissions.
- **Energy efficiency in rental properties** is a particularly difficult problem due to split incentives, where investments in energy retrofits and benefits from ensuing energy saving are not properly aligned among landlords and tenants.
- **New construction**. New buildings can incorporate energy efficiency directly in their design and construction. It is more technically feasible and economical to design and build an energy efficient building than to retrofit that building at a later point in time [14]. Buildings can also be designed to be more suitable for renewable energy integration. For example, siting a building to have a south-facing roof that is wide, sturdy and gradually pitched, will allow for easier solar PV installation. A house that meets rigorous "passive house" standards for insulation and air sealing will reduce heat losses to an absolute minimum [4].
- **Heat pumps.** Heat pump systems, including air-source heat pumps (ASHP) and ground-source heat pumps (GSHP), are considered energy-efficient alternatives to furnaces and electric heaters. Heat pumps keep houses warm in winter and cool in summer by transferring heat between indoor and outdoor environments.
- **Solar thermal.** Solar water heating systems are mounted on rooftops, and provide an efficient way to generate domestic hot water.

Demand response

Demand response (DR) usually refers to reducing or shifting electricity usage by consumers during peak periods in response to time-based rates or other forms of financial incentives. DR programs are being used by electric system planners and operators as resource options for balancing supply and demand. Such programs can lower the cost of electricity in wholesale electricity markets, and in turn lead to lower retail rates. In the future, dynamic rate structures based on supply of intermittent renewable energy may incentivize flexible demand as forms of DR.

Distributed energy storage

Energy storage is crucial for DSM. Energy storage systems are designed to accumulate energy when production exceeds demand and to make that energy available at the user's request. Energy storage can help match energy supply and demand, exploit the variable production of renewable energy sources (e.g. solar and wind), and reduce greenhouse gas emissions [5].

2. Building Energy Efficiency

In this section, we describe the potential for improving energy efficiency for both existing buildings and new construction. In addition, we discuss the potential of deploying heat pumps and solar thermal as energy efficient appliances to meet the heat demand in the County.

2.1 Retrofits of Existing Buildings

Our approach for estimating the potential for energy savings through retrofitting existing buildings is to compare the baseline Energy Use Intensity (EUI) calculated for buildings in the County with some relevant benchmark values for highly efficient buildings. One of the key metrics to characterize the energy use of a building [6], EUI is calculated by dividing the total energy consumed by the building in one year (measured in kBtu) by the total gross floor area of the building. Generally, a lower EUI signifies better energy performance. Energy retrofits can reduce a building's EUI and save energy.

There is an important distinction between source EUI and site EUI. Source EUI is computed using source energy, which represents the total amount of raw fuel required to operate the building [6]. It incorporates all storage, transmission, delivery, and production energy losses. Site EUI, on the other hand, is computed using site energy, which is the amount of heat and electricity consumed by a building as reflected in the utility bills. Site EUI is always smaller than source EUI of the same building unit.

Building energy efficiency should be assessed by comparing equal performance metrics, i.e., comparing site EUI of buildings with site EUI of benchmarks, or comparing source EUI of buildings with source EUI of benchmarks. Unless otherwise noted, our analysis uses site EUI, since the energy consumption data at point of use (as quantified in utility bills) is readily available.

2.1.1 Potential for Existing Buildings

a. Baseline EUI's for the residential and commercial buildings

Table 45 summarizes annual energy consumption by buildings in the residential and commercial sectors and the corresponding EUIs. Total energy consumption is the sum of electricity consumption and primary energy (i.e., natural gas, fuel oil, etc.) consumption in MMBtu/year.

We utilized a database from the Tompkins County Assessment Department listing the square footage and the corresponding property class for buildings in the County. Some of these data needed to be manipulated for our purposes. First we removed apartment building square footage from the commercial data set to reflect that the utility categorizes apartments primarily as residential meters. Second, we verified with Cornell that in 2008 approximately 13 million square feet of building space was supported by the Central Energy Plant[7] and then used that figure in combination with the floor area of non-Cornell commercial buildings in the County (from the Assessment database) to estimate the total floor area in the commercial sector as shown in Table 45.

The energy consumption data came from two main sources. NYSEG provided the County-wide electricity and natural gas consumption data in 2008 by sectors (i.e., commercial, residential and industrial). The report on 2012 GHG emission inventory of Cornell University detailed the energy consumption data in 2008 at Cornell Central Energy Plant (CEP)[8]. In 2008, Cornell University still relied on coal combustion at CEP to provide district heating to its main campus, and small amounts of electricity was generated as a product of cogeneration. The Overview section elaborates our analysis of CEP generation data in 2008. Thus, we combined NYSEG data and Cornell CEP data to calculate the total energy consumption in the commercial sector in the County.

It should be noted that the industrial sector is not included in our analysis, because energy consumption there is largely driven by types of industrial process rather than building energy efficiency [9,10].

Table 45 Baseline EUIs in the residential and commercial sectors in Tompkins County in 2008 [11]

	Residential	Commercial
Electricity Consumption (kWh/year)	293,371,081	377,640,537
Electricity Consumption (MMBtu/year)	1,001,266[a]	1,288,563[a]
Primary Energy Consumption (MMBtu/year)	2,394,857	3,152,070
Total Energy Consumption (MMBtu/year)	3,396,123	4,440,633
Total Floor Area (sq. ft.)	39,720,816	30,608,155
EUI (kBtu/sq. ft. · year)	85.5	145.1

[a]: Converted from kWh of electricity consumption

b. Benchmark EUI for commercial buildings

We gathered relevant site EUI data for commercial buildings from various sources, illustrated in Figure 57.

- The Building Performance Database (BPD)[12] "combines, cleanses and anonymizes data collected by Federal, State and local governments, utilities, energy efficiency programs, building owners and private companies, and makes it available to the public"[13]. It is the largest dataset of information about the energy-related characteristics of commercial and residential buildings in the U.S. After deselecting "Parking Garage", "Vacant", "Unknown", "Uncategorized", and "Other" from all the buildings classified as "Commercial" in Ithaca, Syracuse, Binghamton, Corning, Rochester, and Elmira, the BPD gave the distribution of site EUI for 245 buildings in those locations. The EUI ranged from 4.0 kBtu/sq. ft. to 462.2 kBtu/sq. ft., with a mean of 91.0 kBtu/sq. ft. and a standard deviation of 69.1 kBtu/sq. ft. It is worth noting that a commercial building with a site EUI of 4.0 kBtu/sq. ft. is highly unlikely, which may suggest that the database is not entirely reliable. Figure 57 shows the mean of the EUI values with error bars representing the standard deviation.

- We also acquired from Cornell University Utilities and Energy Management the site EUI data of buildings having undergone retrofit, referred to as Energy Conservation Initiative[14]. Because of a majority of the cooling demand on Cornell campus is served by Lake Source Cooling (LSC), the practice for calculating EUI is to identify the "cooling energy" of a building, and convert that directly into appropriate energy units (kBtu/sq. ft. yr)[15]. This is different from most commercial buildings (especially those without district energy systems), which identify the "input energy" (electricity) operating their chillers. In other words, the Cornell EUI values appear slightly higher than those of same buildings without LSC.
- The Tompkins County Planning Department also provided site EUI data of several county government buildings[16].
- We also included the median site EUI of LEED-certified buildings in the U.S. LEED, or Leadership in Energy and Environmental Design, is a green building certification program that recognizes best-in-class building strategies and practices[17].

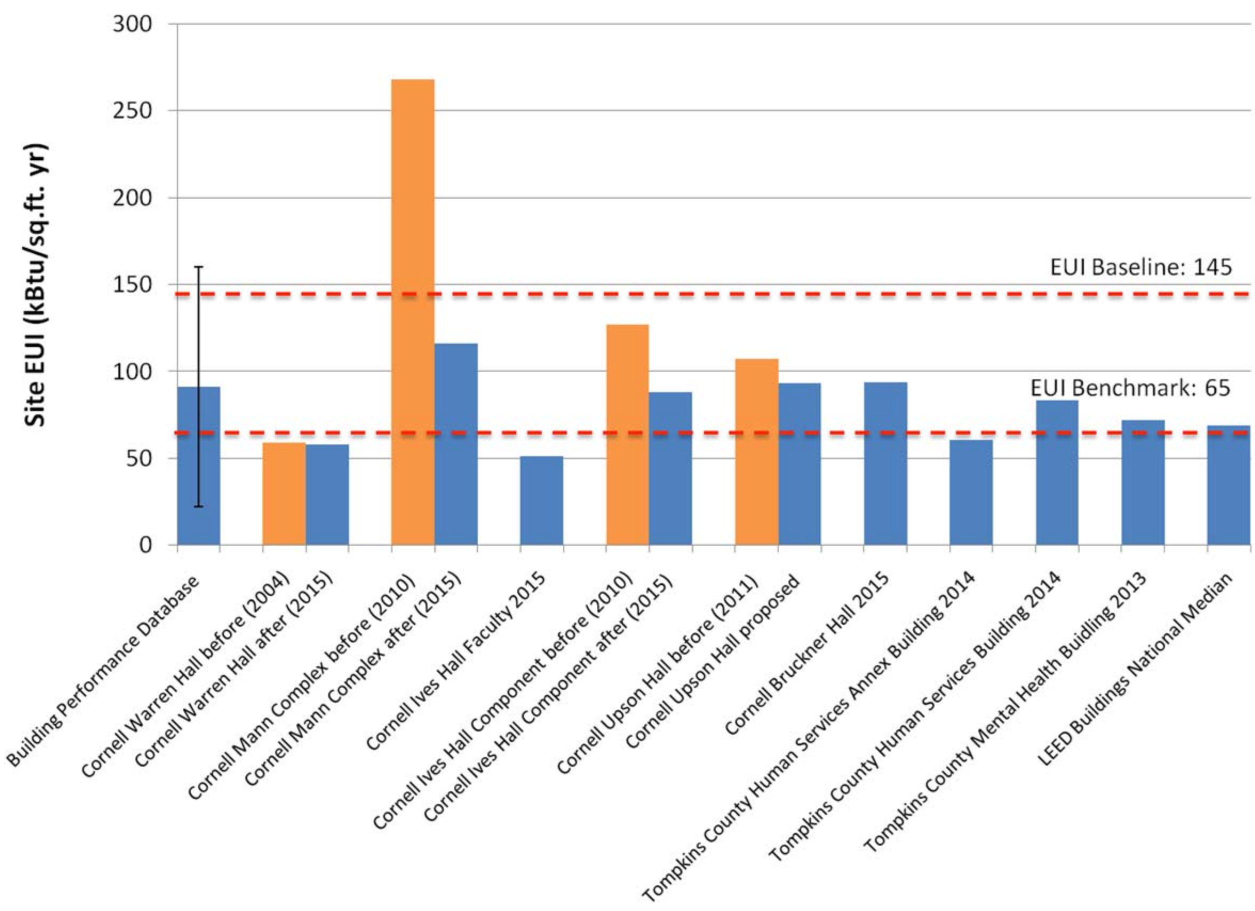


Figure 57 Site EUI of local commercial buildings

Figure 57 shows that the Ives Hall Faculty Wing on Cornell Campus, after significant improvements to the building envelope, reached 51 kBtu/sq. ft. in 2015. The Human Services Annex Building in downtown Ithaca received an ENERGY STAR score of 87 as of August 2015. Its site EUI is 60.7 kBtu/sq.ft. According to the report of Energy Performance of LEED for New Construction Buildings, the median EUI for all LEED buildings in the U.S. is 69 kBtu/sq. ft. We selected 65 kBtu/sq.ft. as the benchmark EUI for this study, as we believe it is a level that can be reached through significant retrofit. If all existing commercial buildings in the County were retrofitted to this level, potential energy savings are estimated to be 2,451,102 MMBtu, detailed in Table 46.

Table 46 Potential for energy saving in the commercial sector estimated using 65 kBtu/sq. ft. as benchmark

Commercial	
Baseline EUI (kBtu/sq.ft./year)	145.1
Benchmark EUI (kBtu/sq. ft./year)	65.0
Difference (kBtu/sq. ft./year)	80.1
Total Commercial Building sq.ft.	30,608,155
Potential for Energy Saving (Difference × Total Building sq. ft.) (MMBtu/yr)	2,451,102
Percentage Reduction from 2008 Thermal Demand	55.20%

Using the figures in Table 45 can help to understand the potential for thermal versus electrical energy savings in building retrofits. Dividing primary energy consumption in the commercial sector (3,152,070 MMBtu/yr) by total energy consumption for commercial buildings (4,440,633 MMBtu/yr) yields 71%. Applying that to Table 46 , we assume that after a retrofit in commercial buildings, 71% of the 2,451,102 MMBtu/yr potential for energy saving will come from heating energy and 29% from electricity.

c. Benchmark EUI for residential buildings

For the residential sector, Taitem Engineering's small office building on 109 S Albany Street, a re-purposed old house, was selected as the benchmark. The EUI of the building at 109 S. Albany Street was 115.9 kBtu/sq.ft. year in 2000, before any retrofit work was done. In 2013, after the deep energy retrofit work was completed, it was 28.4 kBtu/sq.ft. year [18]. A deep energy retrofit is a whole-building analysis and construction process that uses "integrative design" to achieve much larger energy savings than conventional energy retrofits, typically resulting in savings of 30% or more [19].

If all existing residential buildings in the County were retrofitted to reach the EUI level of 109 S. Albany Str., the potential of energy saving is estimated in Table 47.

Table 47 Potential for energy saving in the residential sector estimated using 109 S. Albany St. EUI as benchmark

Residential	
Baseline EUI (kBtu/sq. ft./year)	85.5
Benchmark EUI (kBtu/sq. ft./year)	28.4
Difference (kBtu/sq. ft./year)	57.1
Total Residential Building sq.ft.	39,720,816
Energy Saving Potential (Difference × Total Building sq.ft.) (MMBtu/yr)	2,268,059
Percentage Reduction from 2008 Thermal Demand	66.8%

Just as in commercial, using the figures in Table 45 for residential can help to understand the potential for thermal versus electrical energy savings in building retrofits. Dividing primary energy consumption in the residential sector (2,394,857 MMBtu/yr) by total energy consumption for residential buildings (3,396,123 MMBtu/yr) yields 71%. Applying that to Table 47, we assume that after a retrofit in residential buildings, 71% of the 2,268,059 MMBtu/yr potential for energy saving will come from heating energy and 29% from electricity.

In summary, for both commercial and residential buildings in the County, the total energy saving from energy retrofits within one year is 2,451,102 MMBtu + 2,268,059 MMBtu = 4,719,161 MMBtu. Assuming that building performance improvements apply equally to reducing heating energy and electricity use of a building, a weighted average of 71% by floor area of the two types of buildings was estimated to be the percent of total energy saving from heating efficiency improvements. Therefore the potential of heating efficiency improvements is 71% × 4,719,161 MMBtu/yr = 3,350,604 MMBtu/yr. The potential of electrical efficiency improvements is (1-71%) × 4,719,161 MMBtu/yr = 1,368,557 MMBtu/yr or 401 GWh.

Table 48 Summary of energy savings potential from energy retrofits in existing residential and commercial buildings

	Residential	Commercial	Total
	MMBtu/yr	MMBtu/yr	MMBtu/yr
Total Energy Savings Potential	2,268,059	2,451,102	4,719,161
Thermal Energy Savings Potential	71%	71%	3,350,604
Electrical Energy Savings Potential	29%	29%	1,368,557 (or 401 GWh)

2.1.2 Challenges and Opportunities for Existing Buildings

a. Efficiency measures for energy retrofitting

Proven technologies to improve building energy efficiency have been practiced in the County for almost 25 years.

Electricity Measures for improving a building's efficient electricity use include, for instance, upgrading lighting systems. Both using the right amount of light and using efficient light bulbs are important [18]. The measures also include upgrading appliances, such as refrigerators, dryers, televisions, and computers, to more energy efficient models. Installing smart meters and other monitoring sensors to manage electricity use in a building is another measure that is effective in further reducing electricity consumption.

Heating/Cooling Measures for improving a building's heating/cooling energy use efficiency include weather-stripping, installing storm windows, ductwork and envelope air sealing and insulation, and replacement of HVAC equipment [18].

ENERGY STAR recommends levels of insulation that are cost-effective for different climates where a wood-framed building is located [20]. The County lies in Zone 5 by ENERGY STAR's classification.

Table 49 Recommended insulation levels for existing wood-framed buildings

Zone	Add Insulation to Attic		Floor
	Un-insulated Attic	Existing 3-4 Inches of Insulation in Attic	
5-8	R49 - R60	Add to R38 - R49	R25 - R30

Heat recovery ventilation (HRV), as opposed to regular mechanical ventilation, is an effective measure to reduce heat losses in air exchange between indoor and outdoor environments. This is especially important for well-insulated and airtight buildings in a heating climate like that found in the County. Cornell University has invested ~$45 million since 2001 to improve heat recovery capacities in campus buildings. Average savings per year from reduced fuel and electricity consumption on the Cornell campus is ~$5 million. According to Lanny Joyce, Director of Cornell Utilities and Energy Management, most residential and commercial buildings (including both residential and commercial ones) in the County do not have heat recovery features, likely because of the high capital expenses. It is common for the HRV system of a very air-tight building to have an installation cost of $4,000 to $7,000 or more [21].

Other measures that are suitable for existing buildings in the County include aerosol air sealing that reduces duct leakage to below 30 cfm, installing instantaneous gas water heaters, and replacing central ventilation with ductless air source heat pumps [18].

All of these improvements can be handled by an energy service company (ESCO). ESCOs develop, install, and fund projects designed to improve energy efficiency and reduce operation and maintenance costs in their customers' facilities [22].

Buildings considered prime candidates for energy retrofits in these times of low natural gas costs are those with heating systems that: 1) are at the end of their useful life or 2) use fuel oil, propane, electric resistive or steam.

b. Challenges and Opportunities in the Residential Sector

Capital and labor costs Capital and labor costs for building energy retrofits are high. Considering residential and small office buildings for instance, costs could vary from hundreds to tens of thousands of dollars to have the conventional weatherization done professionally [18]. The final price depends on multiple aspects of the building itself, including total square footage, degree of energy efficiency before the retrofits, and the desired performance afterwards. Residential buildings in the County tend to be relatively small and old, making for a poor economy of scale. Currently, low natural gas prices create projections for very long payback periods from building energy retrofit investments. Ian M. Shapiro, Chairman of Taitem Engineering, thinks that this probably is a major drawback hindering actions being taken by homeowners locally [23].

Federal tax credits. At the same time, federal residential energy efficiency tax credits were not extended for most home performance measures after they expired on Dec. 31, 2013 [24]. NYSERDA is gradually replacing tax credits and rebates with more market-driven solutions such as low-interest loans and green bank resources [25]. It remains to be seen whether this approach results in more or less adoption of energy efficiency measures [25].

Contractors Home Performance with ENERGY STAR (HPwES) offers a comprehensive, whole-house approach to improving energy efficiency and comfort of homes. Participating contractors are seen by consumers as more thorough than their competitors because the HPwES program includes third-party quality assurance checks on their work. The program, however, is also cumbersome and has high overhead costs associated with it, making it difficult for contractors to implement [26,27]. Several participating contractors located in the County have withdrawn from the program over years, including ASI Renovations, Green Home Heros LLC, and Sunny Brook Builders [28]. Only a handful of HPwES participating contractors are still carrying out the program in the County, resulting in a deficit of supply in comparison with demand for retrofitting services.

Expected energy performance An additional challenge is that energy savings from building energy retrofits are not always predictable. Realization rates (i.e., delivered vs. predicted energy savings) range widely from 0% to more than 100%. Multiple causes contribute to this uncertainty, including commonly overestimating runtime of lighting fixtures, difficulty estimating the energy saving from air sealing and insulation, behavior of building occupants and many others.
Switching the conversation from simple payback to benefit/cost ratio, or return on investment, when contractors discuss the results of energy audits with customers may allow building energy retrofits to be accepted by more homeowners. For example, simple payback on a new air source heat pump is ~3 years [29]. The same heat pump has a benefit/cost ratio over its lifespan (~15 years) of 5, and a ROI of 400%.

Multiple incentives are currently in place from New York State that are important in promoting home energy retrofits, including:

- Free or reduced cost energy audits
- 50% subsidy for mid-to-low income households (up to $5,000/household) for basic retrofitting work

- Free electric and home performance measures for low income households through EmPower New York (up to $8,000/household)
- and NYSEG rebates on high-efficiency equipment [27]

The Residential Energy Score Project (RESP) Representatives from Danby, Caroline, Ulysses and the City and Town of Ithaca, as well as Tompkins County and Cornell Cooperative Extension, successfully applied for a NYSERDA grant to develop a program to encourage all houses to be evaluated and scored, so that home buyers could compare the energy efficiency of one house to another. RESP is currently being developed by a local consulting firm working with the consortium of partners.

Community marketing for energy efficiency The County can also take initiatives to incentivize home energy upgrades to supplement those available from the state. The Solar Tompkins Program is a good model for a community-based approach. It combines community marketing with NYSERDA quality control [30]. The program seeks to eliminate the few remaining barriers to solar adoptions by providing: 1) attractive lower-than-market pricing obtained through group buying, 2) a simple process with vetted technology and installation partners 3) educational outreach throughout the County on the practicality of solar PV and all-you-need-to-know-made-easy introductions to the technology, and 4) a community-wide program to build enthusiasm and generate the impetus for adoption now [30]. Indeed, the HeatSmart Tompkins 2015 program worked to do just that for building envelope improvements and air and ground source heat pumps – making it easier to understand and simpler for homeowners to move forward.

Trend in decreasing residential housing unit size It should be noted that the average size of residential housing units, including new and existing units, decreased between 2005 and 2009, though the causes behind this trend are unclear. The “great recession” may have influenced this trend, as well as increased interest in apartment living in urban areas. Data of average square footage for housing units within residential buildings in the northeast U.S. in years 2005 and 2009 are cited from Energy Information Agency Residential Energy Consumption Survey in Table 50.

Table 50 Average square footage for residential buildings in northeast U.S.[31]

Year	Housing Units	Avg Sq. Ft. Per Housing Unit			Avg Sq. Ft. Per Housing Member		
	Millions	Total	Heated	Cooled	Total	Heated	Cooled
2005	20.6	2,334	1,664	562	911	649	220
2009	20.8	2,121	1,663	921	836	656	363

c. Challenges and Opportunities in the Commercial Sector

Deep retrofits in small commercial buildings There are many opportunities to improve building energy efficiency in the commercial sector as well. A good example can be found in the retrofit work conducted by Taitem Engineering on its own office space in downtown Ithaca. Between 2002 and 2012, its engineering staff designed and implemented measures including weather-stripping, installation of storm windows, lighting improvements, ductwork and envelope air sealing and insulation, and HVAC plant replacement. After the energy retrofit work was completed, Taitem experienced electricity saving of 2,004 kWh/yr, gas saving of 1,033 therms/yr, and a 60% total reduction in energy use. The overall capital costs to do the work were about $40,800 over the 10 years, and annual cost saving from the energy savings is about $1,764 [18]. Comfort inside the building was significantly improved as well after the renovation. Additionally, staff reports that it is much quieter working inside, and the indoor temperature is now well-controlled.

Ithaca 2030 District Across North America, 2030 Districts are forming, with support from Architecture 2030, to help commercial property-owners use less energy and water in commercial buildings. 2030 Districts are unique private/ public partnerships that bring property owners and managers together with local governments, businesses, and community stakeholders to provide a business model for urban sustainability through collaboration, leveraged financing, and shared resources. Together they benchmark, develop and implement creative strategies, best practices and verification methods for measuring progress towards a common goal.

A group of people and organizations have been working for over a year to establish a 2030 District in Ithaca, aiming to reduce the energy usage of existing buildings in downtown Ithaca by 50% by 2030. So far the project has nine building owners committed to joining the District and is working on officially launching the District in 2016 [32]. By joining the District business leaders in the Ithaca community will gain three primary benefits: 1) the ability to share data and best practices regarding their efforts to improve building energy efficiency; 2) the ability to use the 2030 District brand name in marketing materials and 3) access to financing opportunities and bulk purchasing initiatives [33]. In 2015, the Ithaca 2030 District received a one-year planning grant from NYSERDA to further explore and develop the District and its potential to reduce energy use in the commercial sector.

Energize NY Commercial Property Assessed Energy Both the City of Ithaca and Tompkins County have adopted legislation to enable property assessed clean energy (PACE) commercial financing locally through a statewide program called Energize NY. The program offers low-cost long-term financing for energy efficiency and renewable energy projects, supporting up to the entire project cost, for owners of existing non-residential properties. Loan repayments are collected by the municipality through a charge on the annual tax bill. Having the costs and benefits of the energy improvements run with the land and repayment over many years may make it feasible for more building owners to make investments in energy retrofits.

Split incentives for energy efficiency in rental properties According to American Community Survey data, 42% of the housing units in Tompkins County are renter occupied. In rental properties there is a mismatch between who pays for the upgrade and who reaps the rewards of lower energy bills. Typically, renters pay utility bills and landlords pay for retrofits. With this system, landlords invest in their buildings, but see no payback through reduced utility bills since those are paid by renters. The only way for landlords to recoup the retrofit investment is for them to raise the rent, which can make it less attractive to new tenants. Conversely, if the landlord pays utility bills, there is little incentive for renters to save energy [34]. Such split incentives, also known as the landlord/tenant dilemma, is particularly striking in the City of Ithaca with its high proportion of housing units are student rentals [35]. Split incentives not only exist in residential buildings, but in commercial buildings especially rental office buildings as well.

One example of a successful pilot project that significantly increases energy efficiency in rental properties is the South Hill Outreach for Rental Experience (SHORE). This project runs an off-campus housing lottery system combined with workshops, quizzes and incentives such as cash rebates that can be applied to rent payments. The program educates Ithaca College students about energy efficiency in apartments/dormitories and encourages them to save energy. Energy savings are measured and cash prizes and rebates are awarded to students at the end of each academic year. Other aspects of the project focus on ways to motivate behavior change in both landlords and tenants. Actions, such as certifying tenants' energy use behaviors and creating an online platform that broadcasts each rental unit's energy use information, are being tested to gage behavior change.

Green leasing may be a promising opportunity to solving the energy conservation and efficiency problem in rental properties. A green lease is an attachment to a regular lease, so both tenants and the landlord would have the same information about the details, which include the investments required to improve the rental's energy efficiency, whichever party makes them, and what the calculated savings would be. The tenant accepts a higher rent for a period of time and gets the benefits of energy savings. Legislation is needed to clearly indicate how much the landlord can increase the rent and protect tenants' rights when accepting or rejecting the proposed rise in rent. The lease should eventually lead to reduced costs for both parties and a better image for the landlord's company (and possibly the tenants)[36].

Other than the contractual solution, some regulatory solutions to split incentives could help. These include requiring disclosure of building energy performance information (i.e., energy labeling) for tenants' reference and regulators' supervision, and municipal ordinances that outline minimum energy efficiency requirements for rentals (i.e., tightening the building codes) [35]. Integrated with local financing programs that target reducing initial energy upgrade costs, these approaches, tailored to rentals, may make positive contributions to overcoming the split incentives barrier [36]. At present, they are not sufficient at the state level, which is partly because of property rights issues [35]. In essence, finding the right motives to spur for behavior changes by both landlords and tenants is key to addressing the problem [12].

NYSERDA's Multi-Family Home Performance Program (MPP) In May of 2007 NYSERDA launched the Multi-Family Home Performance Program (MPP), which challenged all participating projects to reduce their total source energy consumption by 20% and awarded a "New York Energy $mart Building" performance indicator (in the form of a plaque) to each successful existing building project [37]. In order to evidence achievement of the performance target, projects are required to enter twelve months of pre and post retrofit energy usage into a benchmarking tool developed by Oak Ridge National Laboratory. The benchmarking tool converts this consumption data to source energy values using different factors for all fuel types, and then applies a regression analysis to it. The result is a weather-normalized total source energy reduction value, which is expressed as a percentage of the baseline year's use. Projects that achieve or exceed 20% reductions receive additional incentives from NYSERDA.

The program has achieved relative success thus far. The 20% target appears to be an excellent goal for the program. The observed average energy savings per project was 19.7%. Rather than providing a one-size-fits-all solution to different building types, the MPP allows for flexibility to install cost effective measures dependent upon the unique circumstances faced by each building. A review by NYSERDA of the first 17 projects to complete the MPP revealed that 59% of the projects in the dataset achieved the 20% performance target, while those that missed the target goal did so by a considerable margin. Because the Multifamily Performance Program was conceived to be a market transformation initiative, accurate savings predictions on a project-by-project basis are crucial [37]. Moving forward NYSERDA must

[12] A more detailed description and analysis of project SHORE can be found at the Appendix.

investigate the underlying causes behind deviations in modeled savings. Focusing in on these issues will allow for better protocols to meet energy savings in the future [37].

2.2 Energy Efficient New Construction

Ideally, a new building can be constructed to be very well-insulated, virtually air-tight, and primarily heated by passive solar gain and by internal gains from heat sources such as occupants, lighting, appliances and cooking [38]. Energy losses from these buildings are minimized and extraordinary reductions in carbon emissions can be achieved.

NYSERDA provides guidance for designing residential construction that is highly energy efficient. Low-cost efficiency measures include smaller building size, simplified building shape, orienting the long axis of the building to East and West to allow for passive solar gain and make it ready for solar PV installation, tuned glazing (higher Solar Heat Gain Coefficient on South wall, lower on West walls to reduce cooling loads), and distributed HVAC, in addition to the conventional measures introduced in the previous section on Retrofits of Existing Buildings. Incorporating these elements at the beginning of the design process impacts the building's comfort, durability, and resource consumption throughout the life of the building [39]. Of course, in addition to the actual design of the building, location of new homes and businesses in areas with available water and sewer infrastructure, robust transit service, and in close proximity to jobs and services will result in significant energy savings in the long-run.

2.2.1 Potential for New Construction

Foreseeable heating efficiency improvements for new construction can be quantified by assuming that the current building code (International Energy Conservation Construction Code 2012 as modified by the 2014 Supplement for commercial buildings and the 2010 Energy Conservation Construction Code for residential) will apply to all new construction through 2050.

In the current Energy Conservation Construction Codes [40,41], heating EUI at 3.4 Btu/hr per sq. ft. is considered low energy for both residential and commercial buildings. The heating EUI of residential buildings in the county is currently ~6.9 Btu/hr per sq. ft. and for commercial buildings, it is ~11.8 Btu/hr per sq. ft. Weighted averaging the two heating EUIs by their respective floor area, the current heating EUI of buildings in general in the county is ~9.1 Btu/hr per sq. ft.

The growth rate of new households in Tompkins County is projected to be 32.83% between 2008 and 2050. Assuming that: 1) the 2015 International Energy Conservation Code's 3.4 Btu/hr per sq. ft. is the best practice and that all new buildings constructed between 2008 and 2050 reach this level, 2) all of the new buildings have the same average floor area as existing buildings, and 3) existing buildings do not make efficiency improvements, then the overall heating EUI would reach 7.7 Btu/hr per sq. ft. in 2050. This EUI is ~15% below the 2008 baseline, which is equivalent to 1,152,880 MMBtu of energy saving.

Table 51 Estimation of overall heating EUI in 2050

	Existing Buildings	New Construction
Heating EUI in 2050 (Btu/hr per sq. ft.)	9.1	3.4
Number of Households in 2050	X = 37,443 (Number of households in 2008)	32.83% × X
Overall Heating EUI in 2050 (Btu/hr per sq. ft.)	7.7	

Beyond building code, there is potential for the construction of highly energy efficient commercial buildings and houses, including Passive House, that focus on interdependent thermodynamic components, extreme insulation, air sealing, and appropriate building elements that differ across climate zones. Although Passive Houses are discussed in detail below, the standards can also be applied to commercial buildings, so have widespread implications for energy efficient new construction potential in the county.

Passive House A house that is designed and built to a strict set of energy efficiency and construction guidelines can qualify to achieve Passive House Certification. These are very well-insulated, virtually air-tight buildings that are oriented for passive solar gain [38]. Energy losses are minimized and extraordinary reductions in carbon emissions are possible.

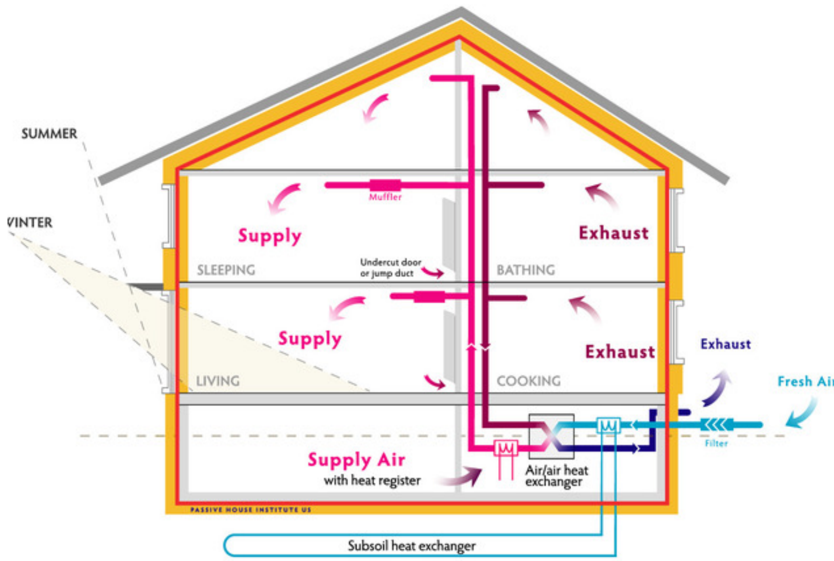


Figure 58 Passive house basics [38]

At present the County boasts an award-winning sustainable community, EcoVillage at Ithaca (EVI), and several other pilot projects following its model, such as the Aurora Street Pocket Neighborhood. The newest homes in EVI's Third Residential EcoVillage Experience (TREE) constitute the largest Passive House development in North America, with 7% of all Passive House units in the United States. The TREE homes showed an average savings of 78% over a typical Tompkins County household, and TREE homes that also opted to install solar PV achieved a 92% average savings, with several at or close to net-zero operation [42]. TREE and APN both received funding under the U.S. EPA's Climate Showcase Communities to document and publicize the performance of their buildings [43].

To learn about the energy systems of Passive Houses in the County, the Modisher/Frenay Residence on 200 Creamery Road, Brooktondale on was visited on Oct. 5, 2014. The house provides a living area of ~2,000 sq.ft. and was expected to be completed by the end of 2014. Some of its energy features include:

- Super insulated (R-90 roof, R-49 walls, R-20 below slab) and air-tight
- Triple pane European windows (R-7.8, double gasketed, no low-e coating, for heat gain from sunlight is encouraged in this climate)
- Domestic solar water heating (two panels on the barn next-door)
- Air-source heat pumps for primary heating and cooling (12,000 Btus * 2 indoor units)

- RenewAire ERV ventilation system, 85% heat recovery of outgoing air (once/3 hours) [44]
- All electric mechanicals, ready for PV system to create a net zero house (attached to the power grid for now)
- Heating EUI: 4.68 kBtu/sq.ft. year (reduced by 80%-90% compared to regular homes)
- Overall EUI: 15.2-26.7 kBtu/sq.ft. year

Currently, it is estimated that there are ~25 houses in the County that meet Passive House standards. Most of them are in EcoVillage. These homes have similar energy features. For instance, insulation R-values are consistently in the following ranges: R-50 - 60 for walls, R-20 - 40 for floors, R-70 - 120 for ceilings, and around R-7 for windows. Most of the houses have an overall EUI around 26 kBtu/sq.ft. year as well.

Recently, one year of energy consumption data was compared between one home in EVI, a 2013-generation Passive House, and another home there, a 2002-generation ENERGY STAR certified house. The results are summarized in Table 52, showing that the Passive House used slightly more electricity, but consumed no natural gas at all. Overall, the EUI of the Passive House is much smaller than that of the ENERGY STAR certified house.

Table 52 A comparison between a Passive House (336 Rachael Carson Rd., Ithaca, referred in chart as "336") and an Energy Star-certified house (223 Rachael Carson Rd., Ithaca, referred in chart as "223") based on one year worth of utilities data [45]

Address	Passive House Certified	ENERGY STAR Certified
Building Energy Feature	2013-generation Passive House	2002-generation ENERGY STAR certified house
Interior Conditioned Living Area	1,450 sq. ft.	1,800 sq. ft.
Electricity Consumption (Nov. 2013 – Oct. 2014)	3,032 kWh	2,596 kWh
Natural Gas Consumption (Nov. 2013 – Oct. 2014)	0	812 therms
Overall Site EUI	7.13 kBtu/sq. ft. year	50.02 kBtu/sq. ft. year

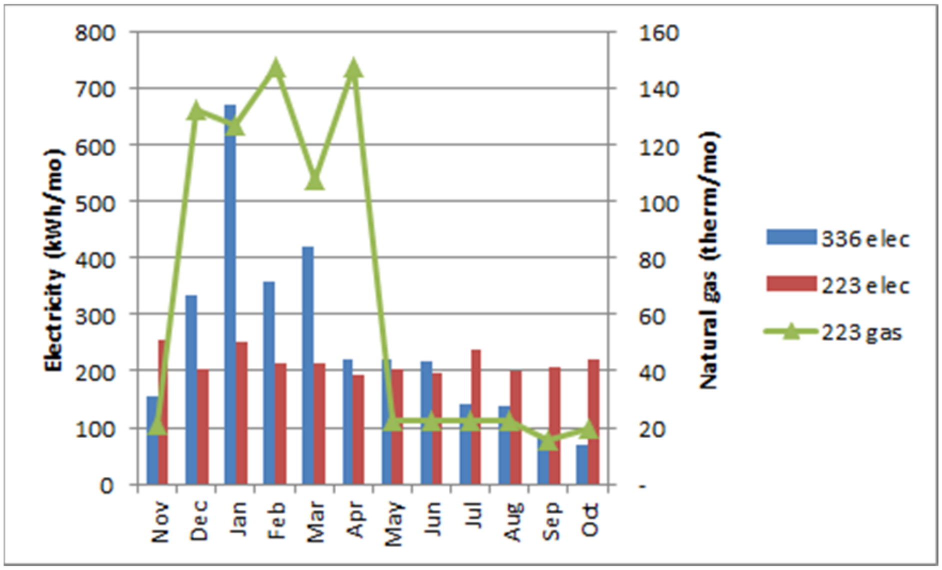


Figure 59 Energy consumption of a Passive House and an ENERGY STAR certified house [45]

The potential growth of Passive House construction in the County, however, is hard to determine, as Passive House building methods are new to this area but the ability to build extremely efficient homes in this area has been clearly documented.

In addition to Passive House, on November 18, 2014 the New York State Fire Prevention and Building Code Council voted to adopt an update to commercial provisions of the Energy Conservation Construction Code of New York State (ECCCNYS) [40]. The ECCCNYS establishes minimum requirements for energy-efficient buildings using prescriptive and performance-related provisions, and makes possible the use of new materials and innovative techniques that conserve energy. The ECCCNYS 2014, which will primarily affect Commercial building construction and renovation, has an effective date of January 1, 2015.

Although the building code has tremendous impact on energy efficiency in new construction, there are drawbacks. For example, the ECCCNYS only applies when at least 50 percent of an existing building's system is replaced, which means that most renovations in the County are not covered. Several local governments in the US have adopted more stringent energy codes to go further than state-adopted codes [46]. A notable example is the New York City Energy Conservation Code (NYCECC), which has undergone several changes since its adoption in 2009.

2.2.2 Challenges and Opportunities for New Construction

a. Economic

As stated earlier in this chapter, it is often costly to retrofit an existing building to become very energy efficient. This is not necessarily the case when constructing new buildings, where it can be a relatively minor incremental increase in capital investment to achieve significant energy efficiency levels. This sentiment was confirmed by Benj Sterrett, a technical consultant on the Modisher/Frenay Passive House residence from Ironwood Builders. Building the Modisher/Frenay residence costs only ~5% more per square foot than building a regular house in the County and homeowners see significant energy savings for the life of the home.

Another example is the Hickory Hall dormitory at Emory and Henry College, located in Emory, VA. Hickory Hall was designed by Adam J. Cohen, founder of Passive Structures, LLC [47], and was completed in 2012. Hickory Hall meets the Passive House standards and has energy features similar to the ones listed for the Modisher/Frenay residence. Yet Hickory Hall has two unique characteristics. One is capital cost. The cost of building Hickory Hall was $118.25/sq.ft., which is about $6.75/sq.ft. lower than that of Elm Hall, a LEED certified dormitory located in the same residential quad. Hickory Hall has much higher insulation values, energy recovery ventilation instead of raw outside air for ventilation, and geo- and solar-thermal heating. Passive House design allows Hickory Hall to minimize heat losses and maximize useful internal heat gain. Overall, Hickory Hall has a heating EUI of 1.62 kBtu/sq.ft. year and an energy performance ~62% below Elm Hall. Hickory Hall is also remarkable for its size as a passive house. It occupies ~40,000 sq.ft. and has a three-floor modular wooden construction. It proves the technical feasibility and opens up opportunities of passive house design for large buildings.

b. Technical

Similar to the situation for existing buildings, there is a need for more designers, contractors, and builders in the County to meet the growing demand for more energy efficient buildings, as well as Passive House buildings. Obstacles for Passive House, in particular, include very high, prescriptive standards that make certification difficult to obtain.

The high-tech design also requires careful maintenance, which may not be convenient or desirable. One concern is moisture control. Daily water uses contribute to indoor humidity. In a highly energy efficient and air-tight house, the moisture level is balanced mechanically by a dehumidifier or an energy recovery ventilation system, otherwise excess moisture can cause mold growth and air quality deterioration. Maintaining a healthy and comfortable living environment in an extremely air-tight building can require some management and attention.

2.3 Heat Pumps: Electricity-Powered Heating/Cooling Devices

2.3.1. Introduction

Heat pumps are essentially electricity-powered heating/cooling devices, extracting heat from outside to use inside a building for heating or in reverse for cooling purposes. Most heat pumps require indoor and outdoor components. For an Air-Source Heat Pump (ASHP), the outdoor component is usually a coil that transfers heat with outside air (Figure 60). For a Ground-Source Heat Pump (GSHP), the outdoor component is typically pipes buried in the ground that transfer heat with the earth (Figure 61).

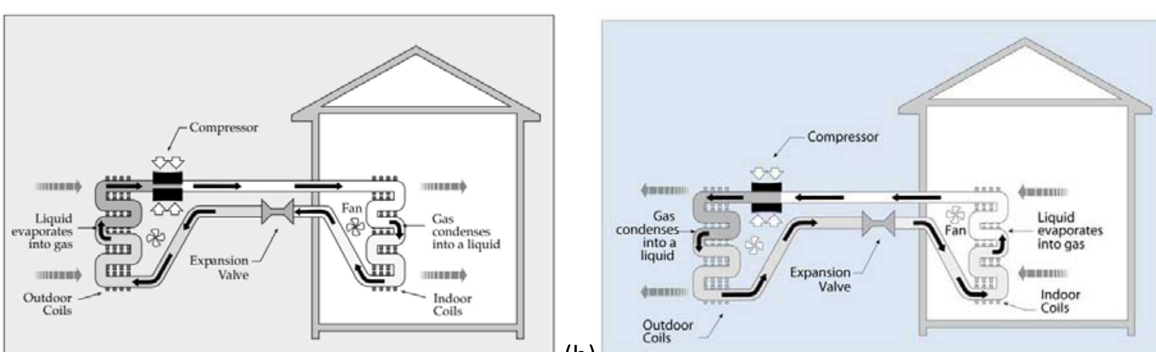
(a)


Figure 60 (a) A split-system air-source heat pump cooling cycle; (b) A split-system air-source heat pump heating cycle [48]

Compressors and expansion valves are often used to help circulate refrigerants between the outdoor and indoor parts. In a cooling cycle of an ASHP, as is depicted in Figure 60(a), the refrigerant is compressed before it enters the outdoor loop, so that it can release heat into outside air during the condensing process. The condensed refrigerant then goes through the expansion valve to enter the indoor loop, and evaporate to absorb heat. The cycle is reversed in winter by switching the refrigerant flow direction, as is depicted in Figure 60(b), so that it can bring heat from the outside to the indoor environment.

Most GSHP systems are closed-loop, circulating refrigerant through plastic (typically polyethylene) tubing buried in the ground or submerged in water. A heat exchanger transfers heat between the refrigerant in the heat pump and the refrigerant in the closed loop. The loop can be in a horizontal, vertical, or pond/lake configuration (Figure 61). A horizontal loop field installation usually occurs in more rural areas or yards with lots of space, and typically requires no drilling (and therefore has lower cost) is needed. The horizontal trenches are only a few feet deep (but below the frost line) in order to lay the piping. A vertical loop field is the most common installation for a GSHP that is installed on smaller properties. A series of holes are drilled, each between 50-400 feet deep.

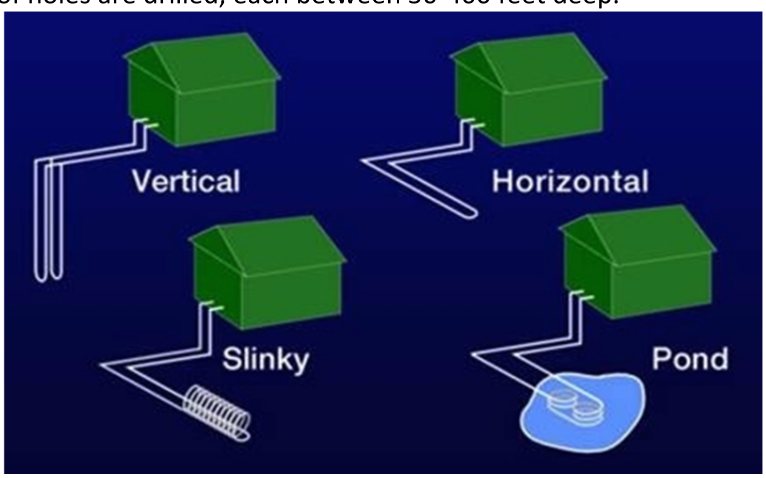


Figure 61 Types of heat exchangers for closed-loop geothermal heat pumps [49]

The ratio of useful heat movement per work input, i.e., heat gained versus electricity used, describes the performance of heating systems. It is also known as the coefficient of performance (COP). When properly installed, the COP of an ASHP can reach 2.2-3.8, the COP of a GSHP can reach 5.0-7.2, while the COP of an electric heater is only 1 [50]. This is due to the fact that instead of converting heat from electricity or fuel, heat pump systems move heat between different environments, which allows for higher efficiency.

Table 53 Comparison between GSHP and ASHP

Space Heating/Cooling Systems	GSHP	ASHP
COP	5.0-7.2 (low temperature output) [51]	2.2-3.8 [51]
Installation Cost	High	Low
Limitation	Local geology	Local climate
Operation	Simple	Simple
Expected Life Time	+20 [52]	10-15 [53]

The installation of GSHPs is currently expensive; a closed-loop GSHP might cost up to $20,000 [54]. Despite of the high installation cost, a GSHP has a higher COP than an ASHP and makes less noise. According to the U.S. Environmental Protection Agency (EPA), GSHPs can save up to 44% of energy compared with ASHPs [54]. This is because compared with the air, the earth has more constant temperatures, which support better system performance. Also, the temperature differences between heat sinks are usually smaller in a GSHP system [55]. It should be noted, however, that the installation of GSHPs always need more space than ASHPs.

ASHPs, on the other hand, have lower installation costs. Yet because heat pump efficiencies vary with the temperature differences between heat sinks, the cold climate in the Northern U.S. has been a barrier for ASHPs - in winter, the COP of an ASHP drops along with the outside air temperature and an ASHP system sometimes needs to be combined with extra space heating. However, newer ASHP models are addressing these concerns.

2.3.2 Potential for heat pumps

According to the 2008 Tompkins County Community Greenhouse Gas Emissions Report [56], the total energy demand for heating and cooling in 2008 was 6,169,985 MMBtu, which is about 43% of the County's total energy consumption. Assuming that heat pump systems could be used to meet all the space cooling, water heating, and space heating energy demand (again, assumed to be 10% of total electricity use), and adopting a conservative average COP of 2.5 for ASHP and 3.5 for GSHP [57], around 26% - 31% of the County's total energy consumption could be saved relative to the 2008 level.

Table 54 Electricity consumption for heating and cooling by using heat pumps

Sectors	Heating and Cooling Total [MMBtu]	ASHP Electricity Consumption for Heating and Cooling (GWh)	GSHP Electricity Consumption for Heating and Cooling (GWh)
Residential	2,494,984	441	274
Commercial	3,152,070	413	257
Industrial	522,934	101	63
Total	6,169,985	955	594

The analysis suggests that if the County met the total heating and cooling demand by either ASHP or GSHP, the amount of electricity consumed by heat pumps would be ~723 GWh or ~517 GWh annually, on the same order of magnitude of total electricity consumption at the 2008 level, which is ~809 GWh. Furthermore, extensive use of heat pumps will likely create high peak demand which the current power system may not be equipped to handle based on existing infrastructure.

69% of thermal energy use in the County in 2008 comes from natural gas, 8.8% from propane, and 5.0% from heating oil. Switching to GSHP, for instance, to meet the total heating and cooling demand would offset the use of ~42,571,520 therms of natural gas, 541,267 US gallons of propane, and 310,444 US gallons of heating oil consumed on site.

2.3.3 Challenges and opportunities for heat pumps

Integration with Renewable Electricity Heat pump systems are known for their high energy efficiency. The only energy a heat pump uses is electricity, which means when combined with renewable electricity, e.g., electricity generated from solar PV, a heat pump system will be able to provide high efficiency heating with zero greenhouse gas emissions.

Peak Demand Management It is well known that temperature-sensitive air conditioning (cooling) load drives summer peak electricity demand. Similarly, high penetration of heat pumps will create temperature-sensitive load in winter and consequently increase winter peak electricity demand. In addition, heat pumps-driven winter peak demand will likely occur in neighborhoods that never experienced peak demand before since the use of air conditioning is not substantial in the County. Managing the peak demand will require sufficient supply during peak time, adequate infrastructure (e.g., transformers in distribution systems) and peak-load reduction strategies. For example, integrating heat pumps with thermal storage turns heating demand to flexible demand, which allows end users and/or energy services providers to apply optimal control in order to reduce the impacts on power systems.

Operations at Low Ambient Temperature ASHPs equipped with variable speed compressors have greatly improved the efficiency at low ambient temperature. The most efficient ASHP models that are commercially available only begin to lose significant heating efficiency at 5°F, and continue to provide sufficient heat for typical homes down to -13 °F. In 2013, the National Renewable Energy Laboratory performed a study on the low temperature performance of air source heat pumps. In this study, they tested a specifically designed low temperature heat pump for two consecutive winters and evaluated its

COP for each winter. The pump was found to operate with a COP of between 2.68 and 3.29 for this time period, depending on season and calculation method, and economically preferable to a comparable oil heating method. This study indicates that air source heat pumps may be viable in low temperatures previously discounted [58]. GSHP's, on the other hand, have never had a major issue with low temperature performance. This is because they draw their heat from underground where temperatures are barely affected by changes in surface temperature [52].

Safety Another advantage of using heat pump systems instead of furnaces is safety. There is no need to worry about carbon monoxide or fire accidents. A heat pump system, especially a GSHP, is also very quiet and does not require much maintenance.

Versatility Heat pumps can provide not only space heating/cooling, but also domestic hot water. Air source heat pump water heaters are typically equipped with electric resistance elements that kick in whenever the heat pump cannot keep up with the demand for hot water [59]. According to a recent test of 15 heat pump water heaters in New England, the monitored COP was 1.9 [60], compared to an operating COP of 0.9 for electric-resistance water heaters. While efficiency is excellent, heat pump water heaters require installation in an indoor space with temperatures in the 40º–90ºF range year-round and at least 1,000 cubic feet of air space around the water heater [1,61].

Installation and maintenance ASHPs are often ductless, and installations are relatively straightforward. The outdoor portion of the ASHP is visible (and occupies space) and requires some maintenance. Because drilling and digging are required, installations of GSHPs are much more invasive. After installation, there are not visible outdoor structures. Some components of the GSHP systems such as water pumps and electronics need regular maintenance.

Aesthetics ASHPs are often installed in each room in a house and resemble air conditioner units located in the mid-to-upper area of the wall. This aesthetic can be unattractive to some homeowners.

2.4 Solar Thermal Systems

Solar energy can be harnessed by different types of solar thermal collectors to meet heating/cooling demand or to generate electricity. There are a broad spectrum of applications, such as solar water heating, solar space heating, solar cooling, and concentrated solar power. In this report, we focus on the most promising application in Tompkins County, which is solar water heating.

There are various kinds of solar water heating systems.

- **Controls**: Active solar water heating systems have circulating pumps and controls, and passive systems do not. Figure 62 illustrates an active residential solar water heating system. Passive systems are typically less efficient, but also less expensive and more reliable.
- **Collectors**: Flat-plate collectors are glazed, insulated boxes containing copper tubing mounted on black-painted copper absorber plates. Evacuated-tube collectors consist of an assembly of glass cylinders, each enclosing a partial vacuum. Flat-plate collectors typically cost less, and perform better than evacuated-tube collectors. Evacuated-tube collectors, however, perform better during cloudy weather.
- **Freeze-Resistant**: Solar water heating systems need to be protected against freeze damage. There are two general approaches to do this. A drainback system removes all the fluid from the

collector when the ambient temperature is low. An antifreeze system circulates an antifreeze solution through the collectors.

It should be noted that solar water heating systems almost always require a backup system for cloudy days and times of increased demand. The backup system can be an electric water heater or natural gas water heater.

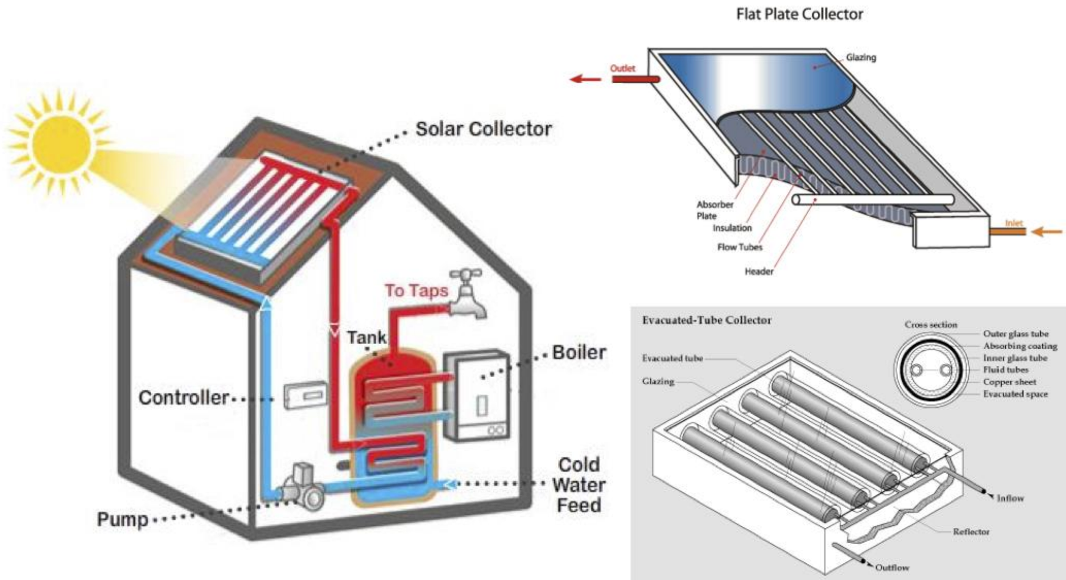


Figure 62 An illustration of a solar water heating system and two types of solar collectors

2.4.1. Potential for solar thermal

Given the constraints identified below, it was considered that the potential for deployment of solar thermal in Tompkins County was included in the analysis of solar PV.

2.4.2. Challenges and Opportunities for solar thermal

Lack of Energy Storage At present, most of the photovoltaic (PV) systems in Tompkins County are grid-tied, and net metering essentially allows PVs to use the grid as free, all-year-round energy storage, which is a big part of the incentive for installing PVs. In contrast, there is no effective energy storage for solar water heating systems, which typically produce more hot water than demanded in the summer, and less than needed in winter. Lack of effective energy storage makes solar water heating systems economically less attractive than PVs for residential customers, who usually cannot afford, or do not have enough roof area available, to install both PV and solar water heaters.

Viable applications For buildings with substantial hot water usage, or demand that coincides with times of high solar availability, solar hot water heating systems remain a viable option to reduce the reliance on fossil fuels. For high renewable penetration scenarios where net metering is no longer feasible or for off-grid applications such as a micro-grid, solar hot water heating systems serve as an efficient way to generate domestic hot water.

3. Demand Response

According to the Federal Energy Regulatory Commission, demand response (DR) is defined as "Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized." [62] Methods of engaging customers in demand response efforts include offering time-varying rates such as time-of-use pricing, critical peak pricing (CPP), variable peak pricing (VPP), real time pricing (RTP), and critical peak rebates [63]. CPP, VPP and RTP also belong to a category called dynamic pricing because the prices depend on utilities and market conditions.

Demand response also includes direct load control programs which provide the ability for power companies to cycle air conditioners and water heaters on and off during periods of peak demand in exchange for a financial incentive and lower electric bills. At present, both Independent System Operators/Regional Transmission Organizations that oversee the wholesale electricity markets, and utility companies that manage the retail electricity markets, offer demand response programs.

The New York Independent System Operator (NYISO) has four DR programs available to large institutional users or energy aggregators, namely the Emergency Demand Response Program, the ICAP Special Case Resources program, the Day Ahead Demand Response Program, and the Demand Side Ancillary Services Program. Commercial, industrial and institutional customers in Tompkins County who can reduce their electricity load by at least 100 kilowatts can participate in the Emergency Demand Response Program through New York State Electric and Gas Corporation (NYSEG)'s CA$HBACK (voluntary response) and CA$HBACK plus (obligated response) programs. Several institutions such as Cornell University and the Ithaca Area Wastewater Treatment Facility are currently participating in the Emergency Demand Response Program.

While most residential customers are paying flat electricity prices, NYSEG offers two time-varying rates to residential customers in the County, i.e., Day-Night Service Rate and Time-of-Use Rate. Residential customers have to sign up for those rates. Both of these are considered "dynamic pricing" because they vary with peak electricity demand. With the Day-Night Service Rate, the nighttime service rate per kwh is about two-thirds the cost of the daytime service rate. However, there is a higher monthly meter charge, and the cost per kWh for electricity used during the daytime service hours is higher than the regular residential service rate. The Time-of-Use Rate varies the service rate based on on-peak, mid-peak and off-peak usage. This approach incentivizes using electricity during mid-peak and off-peak periods. A local example that is using the Time-of-User Rate is Gun Hill Residences, an apartment complex near Cornell campus. All residents pay Time-of-Use Rate by default. All habitable rooms in the Gun Hill Residences are equipped with electric heaters with highly insulated storage cores of dense ceramic material that can store heat during off-peak hours and release heat when needed.

Energy storage is crucial for demand response. It is discussed separately in Section 4.

3.2 Potential for Demand Response

Dr. Zhang's research group at Cornell University conducted a study on the effects of dynamic pricing (specifically critical peak pricing, or CPP) on demand profiles for each NYISO zone based on the 2008 data. Tompkins County is in NYISO Zone C. Two cases were compared: flat price and dynamic price. The methodology used in the study is briefly described as follows.

First, electricity prices were calculated for each of 12 NYISO zones based on three components: energy charge, capacity charge and other non-generation charges. Energy and capacity charges were calculated separately for the flat price and dynamic price cases, while other charges were assumed to be the same for both cases. Then the charges were combined to determine flat and dynamic electricity prices.

Next, demand elasticity was applied to the ratio of dynamic to flat charges to evaluate the effects of dynamic pricing on the demand. Demand elasticity was derived based on the results from several pilot experiments on rate designs and price elasticity evaluation [64–66]. The relationship between dynamic/flat price ratio and the amount of peak reduction was quantified as a logarithmic model. The logarithmic model of elasticity curve was extrapolated to capture the load shifting in off-peak times, shown in Figure . The experiments with enabling technology, such as in-home displays and programmable thermostats, produced larger demand reduction, thus it was described in a different curve. The logarithmic model showed that the amount of demand reduction rose at a decreasing rate with the increasing of dynamic/flat price ratio. During peak time, the dynamic/flat price ratio was larger than 1, while during off-peak time, the ratio was smaller than 1. In our base case, the load reduction during peak time was up to 16% with the price ratio around 8, and the load increase during off-peak time was up to 7% with the price ratio around 0.36. In the base case with enabling technology, the maximum load drop is 23.7%.

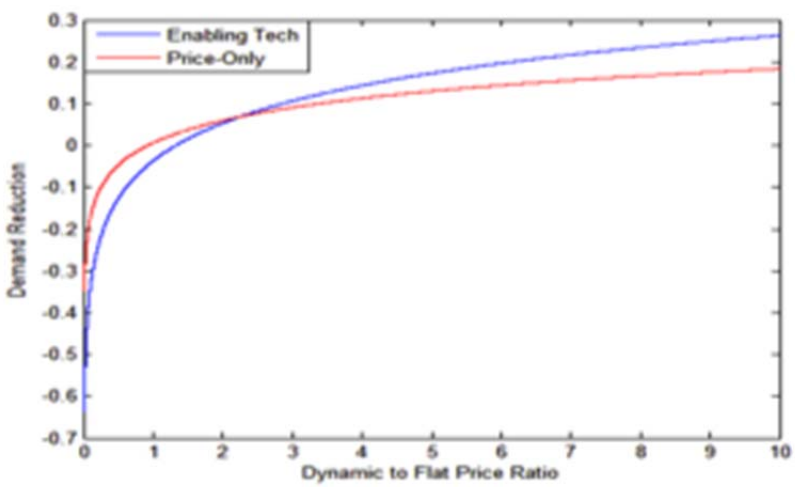


Figure 63 Demand curves derived from dynamic pricing pilot experiments [2]

Figure 64 illustrates the comparison of the load duration curves (LDV) for Tompkins County with and without dynamic pricing. We only show hours from June 1 to September 30, 2008, referred to as "summer hour". The baseline LDV was constructed by down-scaling the 2008 load data for Zone C by the population fraction in Tompkins County over the total population in Zone C, which is ~6.3%. The results suggest that the peak demand (i.e., the y-intercept on a LDV) can be reduced as much as 21.8 MW.

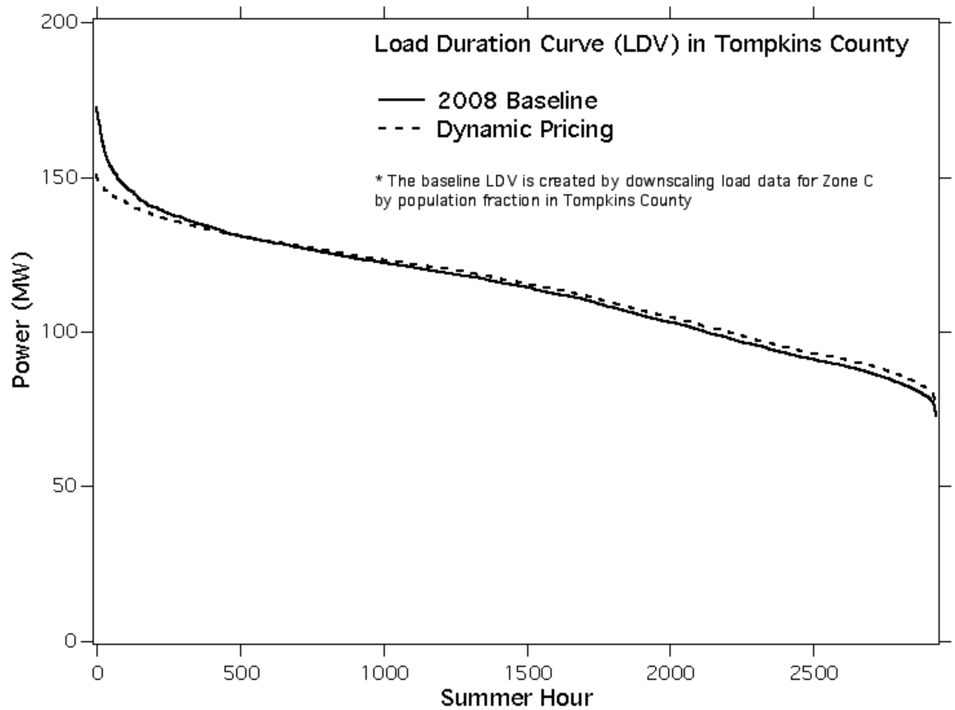


Figure 64 Tompkins County Load Duration Curve with and without demand response resulting from dynamic pricing [31,67]

3.2 Challenges and Opportunities for Demand Response

Dynamic pricing The key driver for demand response is pricing signals. Because a majority of the retail customers pay flat (or static) rates, the demand side of the electricity market has historically been unresponsive to the cost of supplying electricity, which varies significantly throughout the day and over the course of the year. In the near term, dynamic pricing gives customers greater control over their electricity bills by allowing them to modify their energy use patterns based on prices. In the intermediate term, dynamic pricing can help reduce greenhouse gas emissions by incentivizing shifting demand toward times when the electricity is generated by renewable resources. A major regulatory reform in Reforming the Energy Vision (REV), as proposed by New York State Department of Public Service, is rate design changes, providing "dynamic price signals that reflect system needs and costs over short and long term horizons". We expect to see more dynamic pricing options to retail customers in Tompkins County.

Technology development Utilities in California use a platform called Automated Demand Response (ADR) [68] to automate this energy curtailment process at commercial and industrial facilities. ADR makes it easier to participate in demand response programs and makes the response more reliable. Using modern control equipment such as building management systems and lighting control systems, utility companies can send a remote signal to demand response facilities to initiate an automatic, pre-configured curtailment sequence. On the residential side, home automation technologies and smart electricity meters will facilitate demand response from a large number of participants with small load. Another opportunity for demand response is the penetration of electric vehicles. Once integrated with home automation systems, electric vehicles can serve as distributed energy storage to enable more demand response from residential customers.

Energy aggregators Third-party aggregators enlist end users to participate in demand response curtailment and sell the combined load reduction to utilities and independent system operators. Executed properly, demand response aggregation programs spread the risk; load that is not curtailed from sites that opt out can be made up for by other facilities' participation. This aggregation also improves the financial outcome. Since demand response aggregators can almost guarantee to the utility the aggregated curtailment volume resulting from combining load across multiple buildings, the value is greater, which benefits the customer.

4. Distributed Energy Storage

4.1 Introduction

Energy storage is typically categorized based on the form of energy being stored, including thermal, mechanical, chemical, electrochemical, and magnetic, summarized in Table 55 [69].

Table 55 List of energy storage systems that are commercially available

Classification	Technology	Advantage	Disadvantage
Thermal	Chilled water tank	Can use existing chillers, High Capacity, Cost effective in larger systems [70]	Weight, location and space requirements, Continuous maintenance
	Electrical heating with thermal storage	Cost savings, Improved efficiency, Reduced servicing and maintenance cost	Energy losses, Improper sizing [71]
	Molten salts	Efficient, High Dispatchability, High Operating time	Spillage, High Complexity, No modularity, Effort and time for development, validation [72]
	Phase change materials including ice storage	Reduced thermal energy storage space , Colder supply water temperatures, Increased operational flexibility [73]	Low energy efficiency, Poor thermal conductivity of ice
Mechanical	Pumped Storage	High Capacity, Low Cost	Special Site Requirement
	Compressed Air Energy Storage (CAES)	High Capacity, Low Cost	Special Site Requirement, Need Gas Fuel
	Flywheels	High Power	Low Energy Density
Chemical	Hydrogen Storage	High Efficiency	Low Energy Density, Cost

Electrochemical (Battery)	Metal-Air	Very High Energy Density	Difficulty in Electric Charging
	Sodium Sulfur (NaS)	High Power & Energy Densities, High Efficiency	Production Cost, Safety Concerns
	Lithium ion (Li-ion)	High Power & Energy Densities, High Efficiency	High Production Cost, Requires Special Charging Circuit
	Nickel cadmium (Ni-Cd)	High Power & Energy Densities, Efficiency	High Production Cost
	Other Advanced Batteries	High Power & Energy Densities, High Efficiency	High Production Cost
	Lead-Acid	Low Capital Cost	Limited Cycle Life when Discharged
	Flow Batteries	High Capacity, Power and Energy Ratings	Low Energy Density
Magnetic	SMES (supermagnetic)	High Power	Low Energy Density, High Production Cost
Electric Field	E.C. Capacitors	Long Cycle, Life, High Efficiency	Low Energy Density

Energy storage systems can also be differentiated by location as they can be placed at any of the five major subsystems in the electric power system: generation, transmission, substations, distribution, and final consumers (i.e., behind-the-meter). Figure 65 summarizes the different types of services that an energy storage system can provide at specific subsystems. It is worth noting that electric vehicles can be treated as a form of behind-the-meter energy storage, even though their primary functionality is to provide electrified transportation.

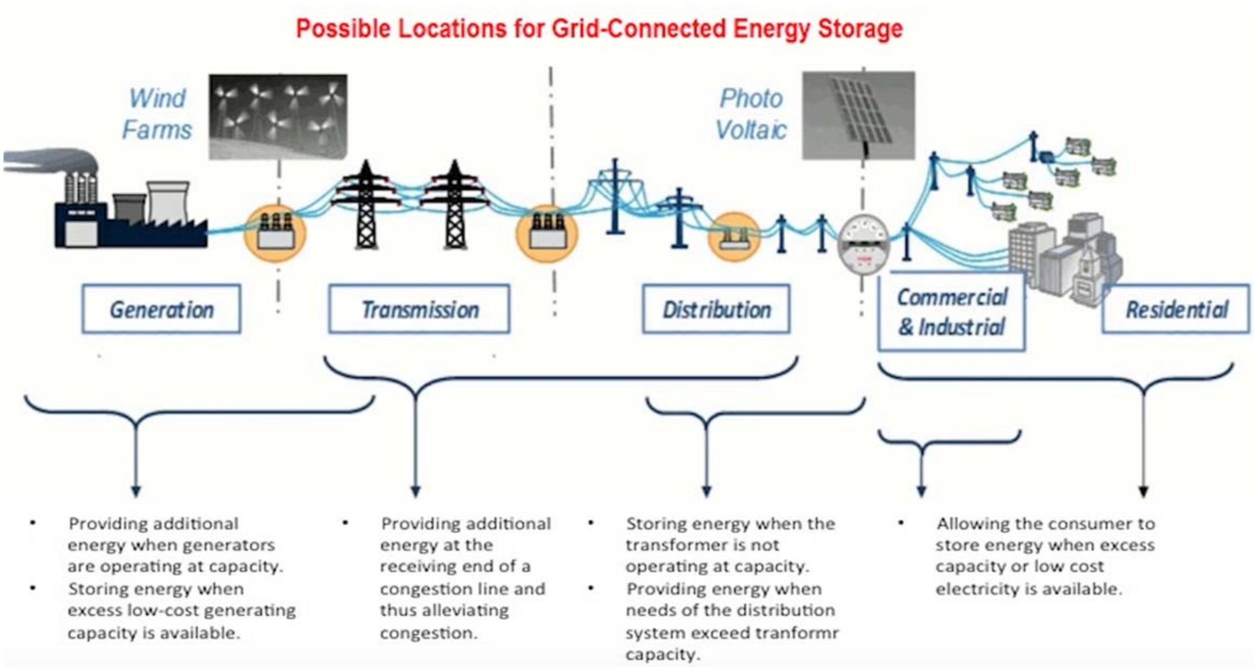


Figure 65 Different locations for energy storage system [74]

Important factors to consider when choosing a storage system are capital costs, energy, power, efficiency, and lifetime. Figures 66 and 67 below compare the different technologies in terms of these variables.

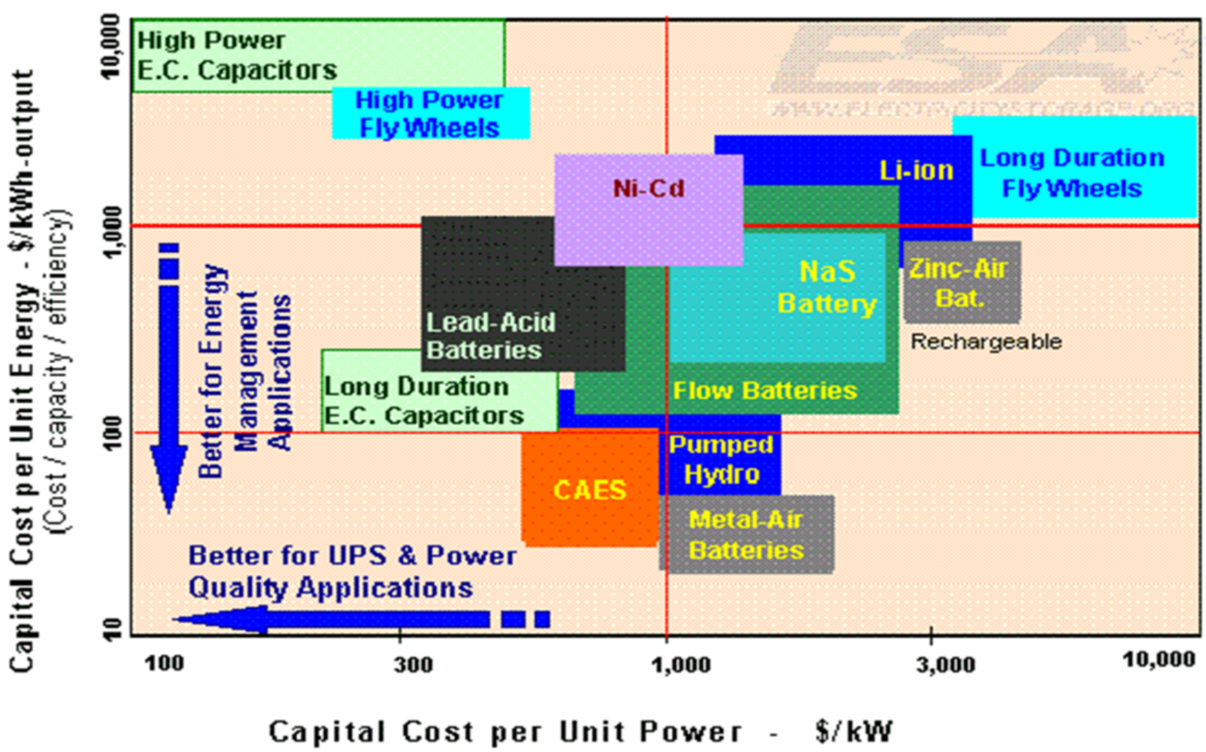


Figure 66 Capital cost per unit energy vs. per unit power (Energy Storage Association)

Figure 66 illustrates storage technologies according to their capital costs, power rating, and energy rating, in dollars per kilowatt ($/kW) and dollars per kilowatt-hour ($/kWh). Capital and operating costs, in addition to technical capabilities are key factors used to determine the financial viability of the storage technology.

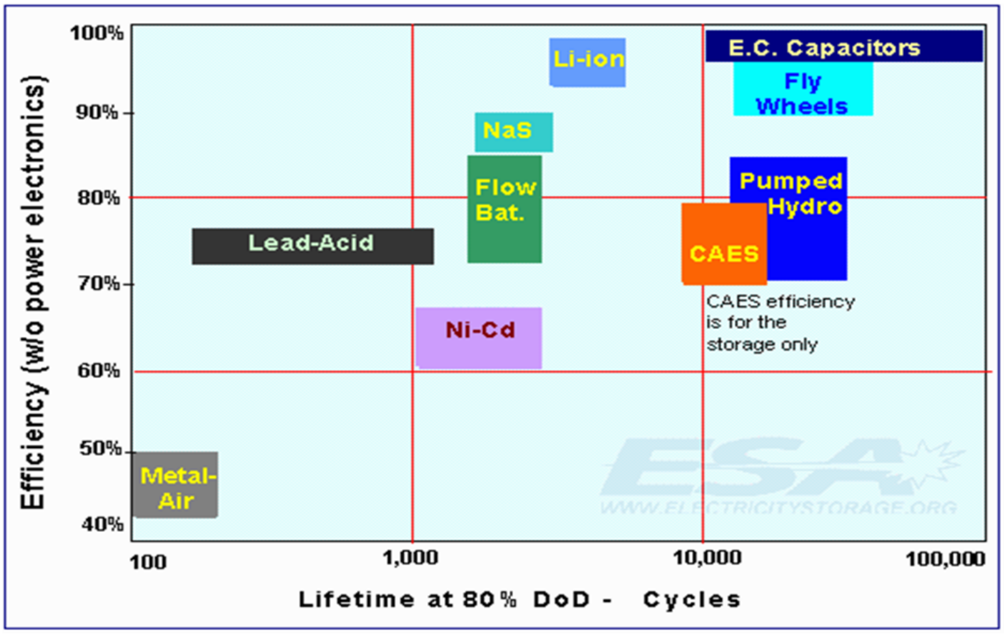


Figure 67 Efficiency and lifetime (Energy Storage Association)

Figure 67 illustrates the efficiency and lifetime of energy storage technologies. Cycle life refers to the number of charge and discharge cycles that a storage device can provide before performance decreases[75].

4.2. Potential for Energy Storage

4.2.1 Thermal Storage

Cooling with Thermal Storage Since 1991, Cornell University has operated a thermal storage tank, consisting of 4.4 million gallons of stratified chilled water. This thermal storage tank provides about 30-40,000 chilled water ton-hr, varying according to temperature changes. The tank was designed to provide a peaking displacement of about 8,000 tons using 59 degree F water [76]. It displaces 5,000 kW in chiller power from daytime to nighttime. Cornell's thermal storage tank system won an ASHRAE Technology Award in 1992 [77]. Currently, there are no other thermal storage systems in Tompkins County. For customers with large HVAC load, deployment of ice storage could be cost-effective as ice storage stores energy in form of latent heat (rather than sensible heat as in chilled water storage) and thus occupies less space.

Electric Heaters with Thermal Storage All habitable rooms in Gun Hill Residences, an apartment complex near Cornell campus, are equipped with electric heaters with a highly insulated storage core of dense ceramic material, which can store heat during off-peak hours and release heat when needed. Those electric heaters have been serving the residents with no major problems since late 1980s when the apartment complex was first built. Paying Time of Use (TOU) rate, the heating costs for residents in in Gun Hill Residences are typically similar to those living with natural gas heating. Gun Hill Residences' practice shows the cost-effectiveness of electric heating with thermal storage, which sets an example for the community when considering electric heating.

Electric Water Heaters Water heaters have been used for decades as simple load control devices by many utilities. Commercial products exist to charge water heaters to higher temperatures ("supercharging water heaters"), and use a blending valve to deliver normal hot water temperatures, which essentially turn electric water heaters into thermal storage.

Potential Applications of Thermal Storage Thermal storage can play an important role in achieving the greenhouse gas emission goal in the County. Integrating solar PV with hot thermal storage allows the solar energy to be used later. Air conditioning load is responsible for most of the peak use during the summer. Combing air conditioners with ice storage can effectively shift cooling demand to off-peak time, or match building-mounted solar PV generation with the system peak. The control of supercharging water heaters will enable the grid operator to manage electric water heating loads and use the storage capacity to provide power system services.

4.2.2 Mechanical Storage

The three types of mechanical storage commercially available are pumped hydroelectric storage, compressed air energy storage, and flywheels.

- A pumped hydroelectric energy storage system pumps water to a higher altitude where it is stored as gravitational potential energy. In order to convert the stored energy back into electricity, water is released and passed back through a turbine to a lower reservoir. Having cost-effective storage facility can greatly facilitate the transitioning to a renewable future. The island of El Hierro (one of Spain's Canary Islands off the coast of Africa) is powered entirely by wind and pumped storage hydro [78]. A local site near the Cayuga power plant has been discussed for a potential pumped storage hydro facility, but a detailed feasibility analysis is out of scope for the energy roadmap. The key to quantify the potential is to couple surface topology (to build ponds or locate existing ponds) and elevation changes. However, acquiring the permits to build the penstock and upper reservoir (avoiding wet lands, and deeded property) and the permit to move that volume of water under the current regulatory environment would be difficult.
- In compressed air energy storage, a large tank is buried underground. During times of low external electricity demand, electricity is used to compress air in the tank. During times of peak electricity demand, compressed air is released, heated with natural gas, and forced through a turbine to generate power [79]. NYSERDA's study on compressed air energy storage revealed that this technology may have a huge potential in Tompkins County [80]. It is the most financially attractive when a system provides sufficient power output and sufficient storage time. The Cargill Deicing Technology Cayuga Mine in Lansing may be an area to explore for application of compressed air energy storage, as it encompasses a thick, regional sandstone reservoir. Tompkins County has inactive mines, which may have an appropriate geological structure and are not too far from electric transmission infrastructure.
- Flywheels are charged using an electric motor to capture energy in a rotating mass. An electric generator then can extract the energy when needed. Because of their low energy density and short discharge time, flywheels cannot store enough energy to meet long duration energy demands.

4.2.3 Electrochemical Storage

The largest group of technologies for stationary applications is electrochemical storage. Electrochemical storage can efficiently store electricity in chemicals and reversibly release it when needed. The lead-acid battery has dominated market share in the past century. However, lead-acid batteries are sensitive to temperature and environmental conditions. Considering Tompkins County's long and harsh winter, design changes would need to be sensitive to this important aspect. Developers claim that their lithium-ion batteries will be the solution to long-duration energy storage and could provide energy to help regulate the power grid during times of high demand. It is already the dominant battery chemistry for consumer electronics and electric vehicles. The 1,000 MW projects under development would be capable of providing energy for two hours at less than $1000/kW, less expensive than a gas-fired power plant [81]. Furthermore, in the beginning of 2015, Eos commercialized a MW-scale Aurora (battery storage) system, employing zinc hybrid cathode battery technology, enabling low-cost electricity storage and long life [82]. Their simplicity of design and use of inexpensive materials contribute to the low-cost manufacturing models, making these batteries cost competitive. Micro-grids can utilize energy storage for clean and reliable power, integrating renewable energy with the grid to provide increased security, and operational capabilities. In San Diego, CA, Princeton Power System provides an energy storage system for Scripps Ranch, consisting of two Grid-tied Inverters and a 100 kWh lithium-ion battery rack [83]. The system is connected to a 30 kW PV array, from which the storage system collects power to store energy. During a power outage, the batteries and PV array provide backup power to the facility.

4.3 Challenges and Opportunities for Energy Storage

4.3.1 Energy Storage R&D in the Southern Tier Region

The following centers conduct research in energy storage technologies.

Table 56 Energy storage research centers in the Southern Tier Region

Name	Location	Description
Energy Materials Center at Cornell (EMC^2)	Cornell University, Ithaca, NY	R&D of energy conversion, storage, and properties of active materials and their interfaces
KAUST-Cornell Center for Energy and Sustainability (KAUST-CU)	Cornell University, Ithaca, NY	Investigating organic-inorganic hybrid nanomaterials for applications in energy storage [84]
NorthEast Center for Chemical Energy Storage	Binghamton University, Binghamton, NY	Research in the design of lithium batteries, developing an understanding on key electrode reactions in order to improve electrochemical performance. Awarded $12.8 million by Department of Energy to fund Energy Frontier Research Centers [85]
New York Battery & Energy Storage Technology Consortium (NY-BEST)	New York State	Testing, validation and independent certification of diverse forms of commercial energy storage

4.3.2 Hydrogen Storage

The creation of a hydrogen filling station in Ithaca, and the addition of a hydrogen fuel-cell bus were recently considered by Tompkins Consolidated Area Transit (TCAT). In 2013, the U.S. Department of Transportation allocated $13.6 million to promote fuel cell technology in U.S. transit buses. TCAT was selected to receive one of the three demonstration hydrogen fuel-cell buses in late 2014and Standard Hydrogen Corporation, has slated to partner with Cornell University to build the hydrogen filling station. However, due to a number of factors this project has been terminated. An advantage of hydrogen vehicles is that one fill-up would then allow the vehicles to run for 300 miles, before the next recharge. A hydrogen station would convert water to hydrogen and oxygen by using electricity from renewable sources and has the capacity to support 10 to 15 fuel cell cars a day [86].

4.3.3 Zinc Battery Manufacturing in Ithaca, NY

In 2013, Eos Energy Storage partnered with Incodema, an Ithaca based prototype manufacturing and full service rapid prototyping company, to produce a MW-scale low-cost zinc hybrid cathode battery technology. Eos chose to partner with Incodema, because their innovative battery enabled a scalable, low-cost, production process. This technology presents enormous opportunities for electrochemical storage. It addresses the most common challenge among battery manufacture, which is the high capital costs.

4.3.4 Economics and Environmental Impacts

Some challenges facing energy storage are universal to all storage types. Power densities (W/kg or W/liter) are still not high enough to balance the intermittent supply of renewable energy in large capacities given a limited operating space. Other notable constraints to storage in general are the high capital, operating and maintenance costs, as well as energy losses in self-discharge, rigid response time, recycling of materials, and safety issues [87]. In 2014, the Department of Energy developed a Strategic Plan ensuring energy storage safety and reliability. Essentially a roadmap for grid energy storage safety, the Plan addresses the range of utility, community and residential energy storage technologies being deployed across the Nation. It highlights safety validation techniques, incident preparedness, safety codes, standards, and regulations. As energy storage has a long term potential, it makes a list of recommendation for near- and long-term actions [88].

4.3.5 Related Policies: Energy Storage Mandate in California and REV in New York

In October 2013, the California Public Utilities Commission (CPUC) established an energy storage target of 1,325 MW by 2020 for the state’s big three investor-owned utilities, namely Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas and Electric, with installations required no later than the end of 2024.

One of the central components of the New York State Public Service Commission’s Reforming the Energy Vision (REV) project is the concept of the utility as a Distributed System Platform Provider (DSPP). Under REV rather than setting a specific numeric target (as in California), the Distributed System Platform Provider (DSPP) in conjunction with market participants will identify economic applications of storage, including, facilitation of clean intermittent generation. The utility as a DSPP is one of the central components of the REV vision.

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Addendum for the Demand-Side Management Chapter

Rental Properties Case Study: South Hill Outreach for Rental Experience

2.2.1 Background

In rental properties, tenants do not have the motivation to save energy if utility bills are paid by the landlord (i.e. gross leases), or to upgrade the energy system if they do have to pay the bills (i.e. net leases) but the lease term is shorter than the payback from energy saving. In this latter case, landlords do not have the incentive to invest in the upgrades either because the tenant is paying the bills [34]. Such split incentives, a.k.a. landlord/tenant dilemma, is particularly striking in the City of Ithaca where 73% of the housing units are student rentals [35]. Thanks to Ms. Anne Rhodes from the Cornell Cooperative Extension (CCE)-Tompkins County, we were able to know about a successful pilot project, South Hill Outreach for Rental Experience (SHORE), that significantly increases energy efficiency in rental properties.

2.2.2 Project Setting

Four major parties partner in this project. Ithaca College (IC) runs an off-campus housing lottery system, which is a critical incentive factor behind the project design. First years are required to live on-campus. Off-campus housing availability for other students is decided by lottery. Attendance at CCE-Tompkins' workshops about energy efficiency and getting high scores in the following quizzes increase one's chance of winning the lottery. At the same time, leadership training is a mandatory section in IC students' graduation structure. Concerned about energy efficiency in on-campus dormitories, one main topic of IC's leadership training is energy efficiency. Other topics IC students can choose from include transportation safety, waste management, and healthy food.

CCE-Tompkins is the project coordinator and provides a four-year education program about energy efficiency to IC students. As part of the leadership training, program takes place as workshops and quizzes, and is required in students' first year, while voluntary in their rest years in college. There are a number of collaborators to implement the education program, including Res Life, Peer Educators, Landlords, and the Neighborhood Association. In addition, PPM Homes is a rental properties complex where IC students gather off-campus. And NYSEG provides utility data of PPM Homes.

2.2.3 Mechanism

The driving mechanism behind the project includes net lease, flex lease, and cash rent rebate. Net lease indicates that students pay for their utility fees separately from rent. Monthly meter readings are compared with the energy use benchmark, which is the respective PPM unit's past two academic years' utility statistics provided by NYSEG. The gain in energy saving is accrued in terms of cash, which is rebated to students at the end of each academic year, i.e. the flex lease and cash rent rebate.

2.2.4 Future Development of Incentives

Indeed, SHORE is an exemplary project. Yet many more developments to it are expected to be carried out. From the students' side, enhanced energy use behaviors will be certified to build trusts between landlords and students. The trust can better motivate landlords to upgrade their energy systems. From the landlords' side, they are advocated to make up-front energy retrofits to reduce EUI of their houses, which can be an attractive feature in the rental market. Rent premium may be charged to recoup the investments, yet relevant regulations should clarify the amount of premium that is allowed, so that tenants are protected and can benefit as well from the energy savings and reduced utility bills in net leases. It is also important to help landlords form a concept that energy retrofits to reduce consumption is the right thing to do.

From the utility companies' side, stronger requirements and incentives to energy efficiency programs from the New York State Public Service Commission via its Energy Efficiency Portfolio Standard [89] are expected. NYSEG has just launched a new energy efficiency program - Blocking Bidding - in October. Based on specific qualification requirements, "The Block Bidding program is a sealed-bid, pay-as-bid auction. … Through the Block Bidding program, NYSEG purchases 'blocks' of electricity savings representing reduced electric usage- from eligible commercial, industrial and municipal customers or from third parties (aggregators) working with those customers." [90] In other words, hopefully NYSEG will become a primary payer for energy savings in more projects like SHORE in the County.

From the rental market, a website is intended to be built that broadcasts each rental unit's energy use information, in order to regulate the market towards having a more energy-conscious operation. And increasing the accommodation capacity is crucial to increasing market competition and reducing rents, which may make the feature of energy efficiency outstanding and a profitable asset. For example, three new large rental properties in downtown will soon be completed. They will receive property tax abatement for a certain period of time from the City of Ithaca through the Community Investment Incentive Tax Rebate Program, in order to keep their rents down and make the rental market more competitive [91].

From the policy context, a customized building code, which specifies energy settings in existing houses more stringent than the original version for NYS, will take effect in the County in January 2015. A detailed criteria and grading manual to enforce the codes is needed and is under development. Local code officers will be trained to follow the manual and enforce the codes. Local or state level financing programs that help reduce upgrade costs specifically in rental properties are also absent but desirable.

As mentioned at the beginning of this section, key to more general practices of similar projects is to find the right motives for behavior changes in both landlords and tenants. The motives may include reduced utility bills in net leases for tenants, and a market that emphasizes features of energy efficiency for landlords. Focus groups are doing surveys in East Hill and Cornell to find out occupants' current energy use behaviors, what they think about their behaviors, and what incentives can motivate behavior changes. Results are expected to come out by December 2014. Hopefully, the findings, together with the experience gained in SHORE will guide the development of successful energy efficiency projects in more rental properties in the County.

District Energy Systems

Camelia Hssaine, Runci Ma and K. Max Zhang

Executive Summary

The objectives in this section are 1) to provide an overview of the current district energy systems (DES) in Tompkins County, 2) to discuss the potential for future development of DES in the County, and 3) to identify the associated opportunities and challenges. We focus on two most relevant components in DES for the County, i.e., Combined Heat and Power (CHP) and Micro-grid systems.

District energy systems centralize the production of energy services (i.e., heating or cooling or power) for a neighborhood, community, or cluster of buildings. DES can play an important role in improving energy system efficiency and resilience, by integrating renewable energy sources into the production of energy, vastly reducing greenhouse gas (GHG) emissions. Because the equipment is shared by the consumers, DES can potentially result in savings in space, thereby reducing construction, operations, and maintenance costs.

One frequently adopted component of a DES is CHP. CHP systems utilize exhaust heat from power generation to provide space or processing heating. Another component of a DES is a micro-grid, which distribute the power locally within DES, and can serve as islands of reliability within the larger regional and national electricity grids, providing power in occurrences of natural disasters or power outages that impact the larger grids.

There are several existing CHP facilities located in the County, including the Cornell University campus, the Ithaca Area Waste Water Treatment Facility, and the South Hill Business Campus that is currently under construction. So far, Cornell University has the only micro-grid system in the County.

We identified a number of potential sites for deploying DES in the future, including the urban core, business parks, and large institutional ratepayers. The deployment of DES can bring many benefits including: high energy efficiency, high energy reliability, reduced energy bills, and reduced GHG emissions. However, implementation faces several challenges, including the existing infrastructure limitations, the perspectives of policy makers, and needs of facility owners. As explained later in this chapter, the construction of DES requires significantly rebuilding existing infrastructure, and correspondingly large capital and time investments. Statewide, there are few incentives to incorporate micro-grids in the current power grid system although the Public Service Commission's *Reforming the Energy Vision (REV)* contemplates policies and incentives to encourage micro-grids and the State's current NY Prize micro-grid competition grant awards are funding feasibility studies in Tompkins County and around New York State. At present, the lack of a favorable regulatory framework and relatively low electricity prices impinge on making progress. With current technology, the payback period of a new CHP system or a CHP-upgrading is still much longer than the typical business payback expectation, a barrier for the CHP implementation in commercial buildings.

1. Introduction

1.1 District Energy Systems

A District Energy System (DES) is a central system that provides essential energy services for a neighborhood or community. There are many different types of DES, given the various power generation methods (e.g., solar, geothermal, biomass, biogas or natural gas) and energy services (e.g., power, heating, and cooling) they provide. DES also consists of local distribution systems to deliver the energy services. Power can be distributed through a micro-grid, and steam, hot water or chilled water piped underground to individual buildings for space heating, domestic hot water use and air conditioning.

1.2 CHP

A Combined Heat and Power system (CHP) is a single integrated system that generates electricity and heat (or cooling) simultaneously. CHP captures the "waste heat" during the production of electricity, for hot water, space heating, space cooling, or process heat for industrial applications.

As is shown in Figure 68, energy released by fuel combustion (or chemical conversion through a fuel cell) first drives turbines or reciprocating engines to generate electricity. Then the exhaust gas of engines and turbines is collected to heat water or generate steam for heating purpose. Sometimes the steam is used to drive absorption chillers for cooling purpose.

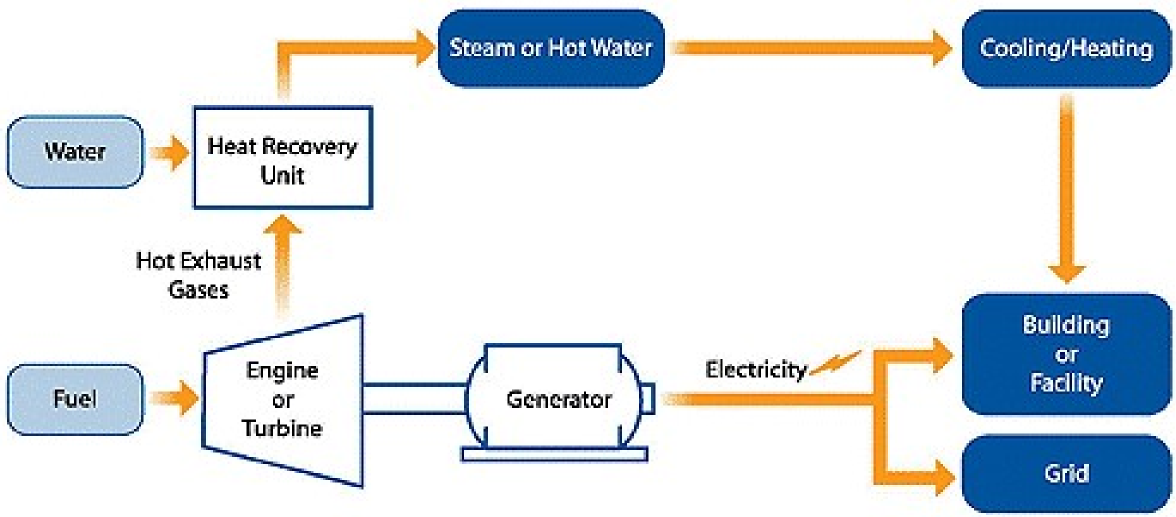

Figure 68 Combined heat and power system [1]

Due to the cascade use of waste energy, the energy conversion efficiency could reach as high as 95% with a well-designed scheme, compared to the maximum 40% efficiency that the latest coal technology (without waste heat utilization) could achieve [2]. Because of the high energy efficiency for the same energy demand, less fuel is consumed and greenhouse gas (GHG) emissions are also reduced.

Apart from high energy efficiency and low GHG emissions, CHP systems can also improve the energy system reliability. Working independently, CHP systems are not be affected by power grid failures and therefore reduce the impacts of power outages.

1.3 Micro-grids

A micro-grid is defined as a small, integrated energy system of interconnected loads and distributed energy resources (producing both electric and thermal energy), which can operate in parallel with the macro-grid or in an intentional island mode [3].

The schematic of the micro-grid in Figure 69 shows the Distributed Energy Resources (DER) that can be aggregated to meet regular demand, and different types of loads that operate within the macro-grid, or in island mode if possible. The micro-grid generates power locally or consumes power from the macro-grid. The dependent loads can be separated by their reliability type into three categories: sensitive, adjustable, and sheddable [4]. Sensitive loads, as the name suggests, are the most critical and should always be supplied power. Adjustable loads can be controlled in a given power interval. Sheddable loads can be disconnected if enough power is not generated enough at a particular moment in time [5]. CHP is often the centerpiece of reliable, clean, and economic micro-grids, but a CHP system can also operate without a micro-grid, and vice versa.

Another distinct feature of a micro-grid is that it uses a meshed distribution network instead of a radial network. An interconnected or meshed network is generally found in urban areas and has multiple connections to other points of power supply. The benefits include ease in identification and isolation of fault and high reliability [6]. A meshed network would be able to detect a fault in a bus segment and isolate that faulted section so that the system keeps operating without disabling the entire system.

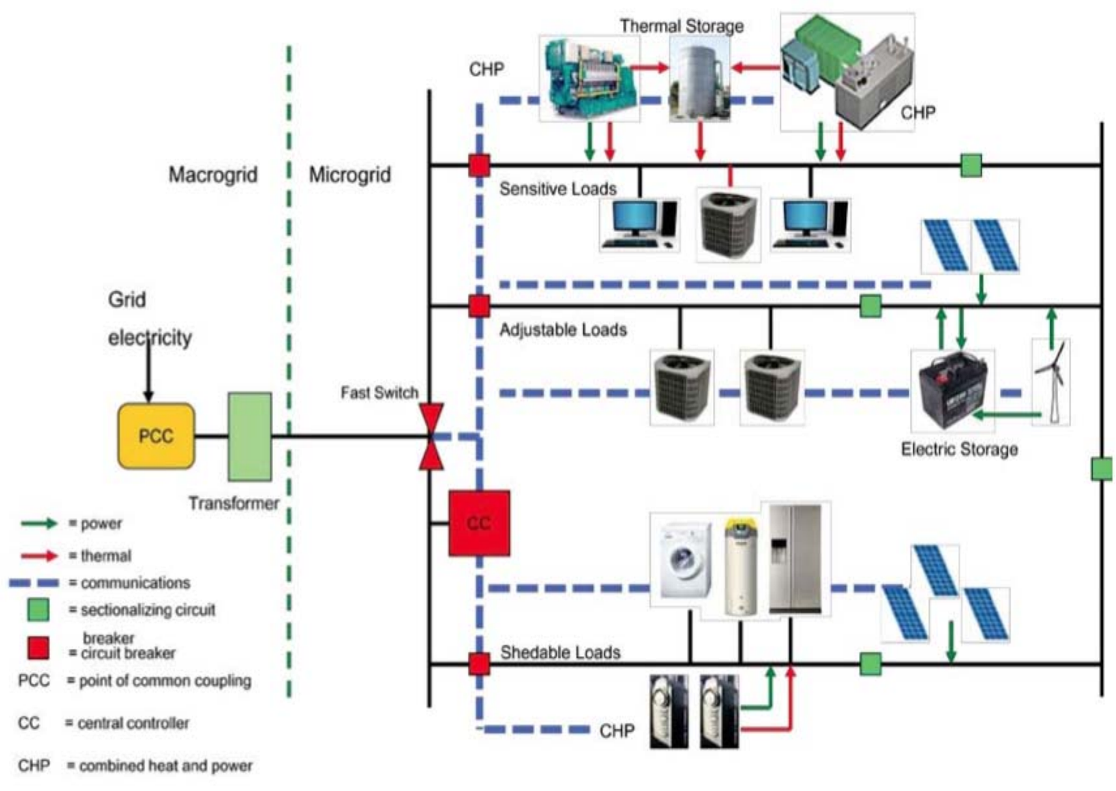

Figure 69 Micro-grid schematic [4]

1.4 Potential Benefits of District Energy Systems

District systems with micro-grid and CHP present multiple benefits. We list the major benefits in four categories: economic, reliability & power quality, environmental and security & safety.

1.4.1 Economic

Direct

- Energy cost reductions
- Reduced purchases of electric generation, transmission & distribution services
- Reduced purchases of fuel for on-site thermal energy demand
- Reduced purchases of ancillary services
- Participation in demand response programs designed to decrease electricity consumption from on-peak to off-peak periods
- Provision of ancillary services to the national grid to support the transmission of electric power from seller to purchaser

Indirect

- Reduced electric Transmission and Distribution (T&D) losses
- Reduced electric T&D capacity investments
- Support for deployment of renewable generation [4]

1.4.2 Reliability & Power Quality

Reduced power interruptions and enhanced power quality. Power quality refers to the reliability and quality of service. For example, when voltage deviates from specific quality standards, a high quality of service would not see much variation in the power output. Such events include voltage sags, harmonics, and spikes.

- o Voltage sags, typically called under-voltages, correspond to voltage levels that are reduced from the typical frequency (60 Hz) to last only from 0.5 to 30 Hz. These occurrences result from large momentary overload when large loads begin drawing power from the system [4]. This will especially affect sensitive loads, and disrupt their continuous operation.
- o Even though the US power system operates at 60 Hz, some equipment connected to the grid operates at other frequencies. This creates harmonics, increasing line losses and reducing equipment lifetimes.
- o Spikes, also called transients, are brief surges (in milliseconds) in voltages caused by the switching of large loads. This can damage the sensitive loads.

1.4.3 Environmental

Reduced emissions of greenhouse gases and criteria pollutants. Micro-grids can reduce the environmental impact of energy use by integrating technologies, such as CHP and renewables that are low-emission and increase the overall efficiency of the energy system.

1.4.4 Security & Safety

Safe havens during power outages. During extended power outages, micro-grids can provide public security and safety benefits. A community connected to the micro-grid can serve as a refuge for others dependent on the national grid. In addition, reducing the reliance on the macro-grid as the unique source of power may render the national grid a less attractive target for terrorist attacks.

2. Current District Energy Systems in Tompkins County

Table 57 Existing CHP facilities in the Tompkins County

Facility Name	City	Prime Mover	Primary Fuel	Capacity
Cornell University	Ithaca	Combustion Turbine	Natural Gas	37 MW
Ithaca Area Wastewater Treatment Facility	Ithaca	Micro-turbine	Biogas	220 kW
South Hill Business Campus	Ithaca	Reciprocal Engine	Natural Gas	500 kW

2.1 Cornell University

Today Cornell University has over 21,000 undergraduate and graduate students and more than 11,000 faculty and staff. The University's main campus includes 150 buildings, covering 14 million square feet of space. Advanced research, done in the Cornell facilities, requires highly reliable electricity services. If energy were to be lost, for even short periods, research could be adversely affected, with severe financial consequences.

The University's 37 MW micro-grid is powered by a dual-fuel combined heat and power (CHP) plant that can burn natural gas or diesel, plus 1 MW hydropower generator and a 2 MW solar installation. In addition, Cornell has a district cooling system, which uses Cayuga Lake as a heat exchanger [7]. Cornell's district energy system is estimated to reduce to 50,000 tons of CO_2 per year, 800 tons of SO_2 per year, and 250 tons of NO_x per year [4].

2.2 Ithaca Area Wastewater Treatment Facility

The advantages of on-site CHP systems for wastewater treatment plants have become more apparent throughout the years. The appeal stems from: 1) the need for reliability during utility power outages and shortage, 2) the availability of free fuel compared to high fossil fuel prices, 3) the awareness of utilizing renewable resources, and 4) the government incentives available to fund the systems.

Currently, the Ithaca Area Wastewater Treatment Facility, operating two 110-kW Caterpillar combined CHP systems, is able to generate 60 percent of its own energy (electricity and heating) by producing biogas [8]. The wastewater treatment plant harvests nutrients out of the water, in which a biological system absorbs nutrients and transforms them into a "bio-solid". The anaerobic digester uses this material to produces biogas. In the near future, the plant will start purifying the biogas for a lower carbon dioxide content, which would allow the fuel to be used for vehicles. Then, they would be able to sell the biogas. However, this market does not yet exist in Ithaca. If this possibility does present itself, the vehicles would have to be retrofitted to utilize purified biogas.

2.3 South Hill Business Campus

As of October 2014, a 500 kW(2-250 kW reciprocating engines) combined heat, cooling and power (CHCP) system with a 80 tonne absorber is under construction for the office wing (~14% of the entire campus) at the South Hill Business Campus. The estimated cost of the project is $1.1 million, which is expected to reduce national grid purchases from 5,500,000 kWh to approximately 3,900,000 kWh annually. The savings during the first year are estimated to be 16,117 CO_2e tonne, equivalent to the emissions of 2,616 cars [9]. The South Hill Business Campus CHCP is the first project awarded incentives under the Tompkins County Industrial Development Agency Energy-Related Investment Policy.

3. Potential District Energy Systems in Tompkins County

3.1 The Commons

Energize Ithaca is proposing a District Energy-Combined Heat and Power (DECHP) micro-grid in Ithaca, New York in order to increase energy efficiency, decrease energy costs and reduce greenhouse gas emissions. The size of the proposed project is a 12 MW grid to service 3.5 million square feet of building space in downtown Ithaca [10]. The DECHP system uses a centralized distribution system to provide heat and utilizes the waste heat for district heating. The system will generate electricity that will be available to the building owners and to tenants at a lower rate than from a utility. It is anticipated that the CHP system itself would be located in the Center Ithaca building and branch off to serve neighboring buildings.

3.2 Ithaca College

Currently, all of the Ithaca College buildings are heated by large, commercial-size boilers and cooled by chiller units that run water through a two-pipe piping system, meaning that only heated or chilled water can run through the pipes at any given time. For this reason, Ithaca College is interested in determining the feasibility of a central energy plant. The college's peak electricity load is approximately 6 MW.

3.3 Dairy Farms

In Tompkins County, there are 63 dairy farms with an average area of 244 acres [11]. We estimate the total energy consumption with the amount of cows each farm owns. For New York State, the majority of dairy farms are medium sized, with around 200 cows. Assuming that a cow requires 1,000 kWh per year, a medium dairy farm will consume around 200,000 kWh energy in total per year [12].

In Tompkins County, in 2008, the agricultural sector emitted nearly 44,000 tonnes CO2e. Cornell Agricultural Extension Service can connect farmers with the appropriate technical assistance, to appropriately deploy systems such as CHP. All of this methane could be used to fuel generators and produce thermal energy, in turn reducing the emissions in the atmosphere.

3.4 Cornell Business and Technology Park

The Cornell Business & Technology Park is a property of Cornell University and is managed by Cornell University Real Estate Department. An area of 300 acres, serving 26 buildings, this is an attractive location for a micro-grid. With over 90 companies residing in this park, a DES would offer energy savings and incorporate more renewables. Most importantly, it would offer energy security, and allow the companies operating at this Technology Park to maintain operations during blackouts. Additionally, Tompkins County operates several facilities in or adjacent to the park that provide critical community services and could benefit from the reliability and resilience provided by a micro-grid.

An example of such a project in Upstate NY is Burrstone Energy Center, owned by Cogen, in Utica, NY, that delivers power to St. Luke's Healthcare, St. Luke's Nursing Home, and Utica College. The 3.6 MW CHP plant was a viable solution for all three of these neighboring institutions, since they all require a reliable energy source [13]. The biggest challenge for Cogen Power Technologies was obtaining approval from the NY Public Service Commission to deliver power to Utica College. However, since a CHP facility near the Cornell Business & Technology Park would generate the power, it would not need to cross the public road to obtain approval, making the implementation of Cornell Technology Park much easier.

3.5 Healthcare Facilities

Hospital buildings operate around-the-clock, 7 days a week and have relatively high energy loads for heating and hot water. According to the U.S. Department of Energy's Hospital Energy Alliance, hospitals account for 8% of all of the energy consumed by commercial buildings in the U.S. They require guaranteed continuous power generation. For this reason, CHP is a great fit for hospitals. The CHP industry offers long-term energy services to hospitals, under which the hospital and the CHP provider share the energy cost savings over a 10 to 20 year period. For CHP to be economical, electricity and thermal energy needs to be utilized constantly. Hospitals represent some of the best examples in the marketplace today.

Cayuga Medical Center (CMC) has a thermal energy plant. Future expansion of this system could convert it to CHP. The peak electricity load for Cayuga Medical Center is ~2.2 MW. CMC completed the first phase of a CHP feasibility study in fall 2012 and conducted a technical study on assessing whether district heating for structures near the medical center could be incorporated into the system.

One example is the Cortland Memorial Hospital, in Cortland, NY, that has an islanded CHP system consisting of three 525 kW natural gas-fired reciprocating engines and three 190 kW diesel engines for backup. Another example of the success of CHP plants in hospitals is the Clifton Springs Hospital, in Clifton Springs, NY. First commissioned in 1994, the 425 kW plant has been on 24/7 operation ever since. The thermal output is used to heat the hospital and run a central absorption chiller of 300 tonnes. It offers over $190,000 of yearly energy savings, and 380 tonnes of CO2 reduction per year. The reciprocating engines, used in both Clifton Spring Hospital and Cortland Memorial Hospital to generate CHP, have a low initial investment, are a mature technology and are relatively small in size. Even though they have high maintenance costs, maintenance can be provided by local service organizations [14].

3.6 Retirement Communities

Kendal at Ithaca, a senior living community in Ithaca, owns 212 cottages of different sizes ranging from a studio to a two bedroom with den, a 36-room Enhanced Assisted Living Residence, and a 35-room Skilled Nursing Facility. Constant heat and electricity are also required for Kendal to provide reliable medical care and nursing services.

In Albany, NY, a CHP system has already been successfully installed in a retirement community: Avila. The 280,000 square feet Avila retirement community installed a 700 kW natural gas engine CHP Plant.

A different way to implement CHP systems for retirement communities is to cooperate with a power provider. The Green Hill retirement community in West Orange, New Jersey, provides an example: under the terms of the agreement, the power provider operates and owns the CHP system. The community, Green Hill, only needs to pay for the energy used by the facility at a guaranteed discounted rate. The contract lasts 15 years: the power provider receives a total revenue around $1,800,000 over the duration of the contract. The CHP system would offset 530 tonnes of carbon annually.

3.7 Hotels

Hotels and casinos have a number of characteristics that make them good targets for installing CHP systems. The facilities operate around the clock year-round; CHP is typically fitted to match the thermal demand of the hotel and usually provides 50% to 70% of a hotel's electricity needs. This approach maximizes both the efficiency and the return on investment for CHP. Hotels in the 100- to- 300 room size range can use small 60 to 250 kW CHP systems with reciprocating engines [15]. Larger hotels with central cooling systems can use larger CHP systems, 300 kW and greater.

The Doral Arrowwood Hotel in Rye Brook, NY receives its energy (electricity, heat, and hot water) from a 375 kW CHP system located at the resort, owned and operated by a company offering so-called on-site utility energy solution. On-site utility customers (e.g., The Doral Arrowwood Hotel) only pay for the energy produced by the system and receive a guaranteed discount rate on the price of the energy. All system capital, installation and operating expenses are paid by the company. This on-site utility energy solution allows the hotel to only pay for the energy they use and avoid all capital, installation and operating costs, in addition to maintenance and repair of the energy system.

Hotels in Tompkins County are usually small to medium-sized. Partnering with energy services companies for similar on-site utility solution can potentially avoid the additional costs, discussed above.

4. Opportunities and Challenges

4.1 Opportunities

DESs are usually designed to improve energy efficiency and reduce energy consumption. Two major synergistic opportunities are energy system resilience and integration of renewable energy.

4.1.1 Resiliency

DES can potentially play a critical role in strengthening the energy systems resiliency in the County.

When Superstorm Sandy hit New York City in 2012, nearly $20 billion was lost in interrupted business activity. The micro-grid of a residential building in Greenwich Village was able to maintain its power, water, and heat during the damaging storm and its aftermath. It was one of the few buildings that had lights on in the landscape of darkness after Con Edison cut power to almost one-third of Manhattan. The building's CHP system ran 24/7 for five days after the storm, maintaining operation of the central boilers, domestic water pumps, and elevator until power was restored [16].

Superstorm Sandy also revealed that the U.S. power delivery system is not designed to quickly recover from damaged power components. According to the PlaNYC "A Stronger, More Resilient New York" report, a single day without electricity can mean more than $1 billion in lost economic output for New York City [17]. Weather-related incidents remain the prime reason for power outages. The average outage duration in the U.S. is 120 minutes: 92 minutes per year in the Midwest and G14 minutes in the Northeast [18].

Because of their resiliency, micro-grids and CHP systems are an excellent solution to optimize available generation and make power available to a larger area during sudden power outages. A micro-grid can isolate itself via a utility branch circuit and coordinate generators in the area, instead of having each building operating independently of the grid and using backup generators. It creates a safe haven in the sense that it can sense loads and faulty conditions in order to reroute power to as many critical areas as possible given any situation.

Central Hudson Gas & Electric, a utility company, has proposed to build micro-grids for resiliency, both in areas with critical facilities and in remote regions of its service territory [19]. The micro-grids would be built and operated by the utility, and customers that are serviced by the micro-grids would pay a fee on the utility bill.

A recent development is that New York governor Andrew Cuomo has put $40 million in a competition bolstering the state's post-Hurricane Sandy storm resilience with community micro-grids [20]. This competition, named "NY Prize", is aimed at jumpstarting at least ten "independent, community-based electric distribution systems" across New York State. There are two Stage I winners in Tompkins County:

- **Village of Lansing** The project, submitted by Tompkins County, would ensure that the Ithaca-Tompkins Regional Airport and other local vital services would be able to continue operation in the event of a major power outage or other emergency. The proposed micro-grid would include up to 3 MW of multiple biomass- or biogas-based combined heat and power units, at least one MW of solar arrays, and 450 kW of multiple energy storage systems. Several electric generators, as well as existing solar systems on three county buildings, would be integrated into the micro-grid. The proposed micro-grid would power Tompkins County Emergency Response (E-911) Center; Tompkins County Public Safety Building, including the Sheriff's office and County Jail; Tompkins County Health Department; and the Ithaca-Tompkins Regional Airport. Other facilities under consideration include a health care campus, a business and technology park, and the main Ithaca branch of the U. S. Post Office.
- **City of Ithaca** The city and nearby communities, which suffered storm damage during Tropical Storm Lee, have already committed to adding a biogas-to-power system at the local wastewater treatment center. The proposed micro-grid would combine power from this system with existing back-up diesel power and proposed solar and combined heat and power systems. Users would include local schools, public works facilities, affordable housing, Ithaca College, the wastewater treatment center, possibly Cornell University, and other ratepayers.

4.1.2 Integration of Renewable Energy

"High-penetration renewable-based micro-grids" represent the future opportunity as Tompkins County moves to substantially reduce greenhouse gas emissions. Micro-grids of this kind incorporate renewable generation, energy efficiency, demand response, and energy storage that provide the benefits to owners, ratepayers, and utilities.

The California Energy Commission has started experimenting with "high-penetration renewable-based micro-grids," defined as projects that can incorporate "high amounts (up to 100%) of renewable energy to meet the facility/community load while avoiding adverse grid impacts, through the use of a micro-grid controller/energy management system." [21] While micro-grids of this kind are much rarer, they represent a large part of the coming market opportunity in micro-grids.

4.1.3 Cooperation with on-site utility providing companies

A new way to carry out CHP implementation is to cooperate with an energy provider. As is discussed in the retirement community and hotel sections, the energy provider is responsible for the system design, construction, operation and maintenance. The customer only pays for the amount of energy that it uses. This form of cooperation provides multiple benefits to private facility owners and small communities:

- All capital investments for system installation, operation and maintenance are borne by others;

- The system is installed and operated by experienced professionals, which brings more reliability and is also more time-efficient;
- The community does not need to hire their own professionals for implementation;
- A discount rate for electricity and thermal demand is guaranteed;
- The overall energy reliability is improved;
- The total GHG emissions are reduced.

4.1.4 Job Creation
Micro-grids are built and operated on site. Therefore, local construction, maintenance, and operating staff will need to be employed. This would help keep wages and income within the local community by reducing the money spent on energy imported from outside the community.

4.1.5 NYSERDA CHP Incentives
It is important to note that NYSERDA offers incentives for CHP development under their “The Combined Heat and Power Performance Program.” This provides further benefits to Tompkins County residents who wish to install CHP energy systems.

Additional Incentives are available for CHP Systems with an aggregate nameplate greater than 1.3 MW that provide summer on-peak demand reduction. These incentives are performance-based, determined annually over a two-year measurement and verification process period. Performance correspond to the summer-peak demand reduction (kW), energy generation (kWh), and fuel conversion efficiency (FCE) achieved by the CHP System [22].

4.1.6 Energy Smart Community in Ithaca
Iberdrola USA, the parent company of New York Electric and Gas (NYSEG), has selected the Ithaca region as the host location for the Energy Smart Community primarily due to its ongoing interest and proactive approach to energy and sustainability initiatives. Iberdrola USA quoted comprehensive energy and sustainability plans established by Tompkins County, the City of Ithaca, the Town of Ithaca and Cornell University, aligned with Reforming Energy Vision (REV) principles, as the key factor for this selection. The Energy Smart Community will enable Ithaca and Tompkins County to make significant strides toward their energy and sustainability goals. Leaders from these institutions and organizations have engaged with the Company and act as partners in the Energy Smart Community. It is hoped that development of the Energy Smart Community will greatly facilitate the implementations of micro-grids and other district energy systems.

4.2 Challenges

4.2.1 Physical Barriers
Relatively constant heating, cooling and electricity demand is a main limiting factor for CHP implementation. For most CHP systems, the electricity/heat ratio is adjusted twice a year (before winter and summer). If the energy demand is not stable, the CHP system might be working either overloaded or under-loaded. Both situations will sacrifice the system efficiency to a great extent.

For single buildings to install CHP systems, the energy demand needs to be both stable and large enough. Generally speaking, buildings with an annual energy bill over $500,000 dollars can consider installing a CHP system.

For district systems with CHP, there are more limiting factors. All the buildings in the district need to be connected by an independent electricity grid (micro-grid) and steam pipes. The distance between buildings should not be too large, because a great percentage of heat could be lost in the pipelines. A sparse district, therefore, cannot expect high energy efficiency from CHP. In addition, the cost of installing the pipes makes proximity advantageous.

Generally, four pipes will be needed for a CHP system: two for heating cycle and two for cooling cycle. The cost of local infrastructure has to be taken into consideration, as the construction could be both costly and time-consuming.

4.2.2 Economical and Regulatory Barriers

Economically, factors such as relatively low electric and natural gas prices and relatively high capital investment pose challenges for district systems to achieve cost savings even with improved efficiency and reduced energy consumption. The payback period of current CHP projects, usually around 10 years, is considered to be too long for many institutions.

Regulatory wise, legal boundaries and existing regulations would define many CHP/micro-grid projects as public utilities subject to the full burden of Public Service Commission statutes, regulations, and rules. Due to the complexity of this regulatory environment, simply trying to negotiate the regulatory requirements is beyond the capability of most local governments and project developers.

Acknowledgement

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