A Carbon Neutral Maine by 2050: What Would It Take?

by

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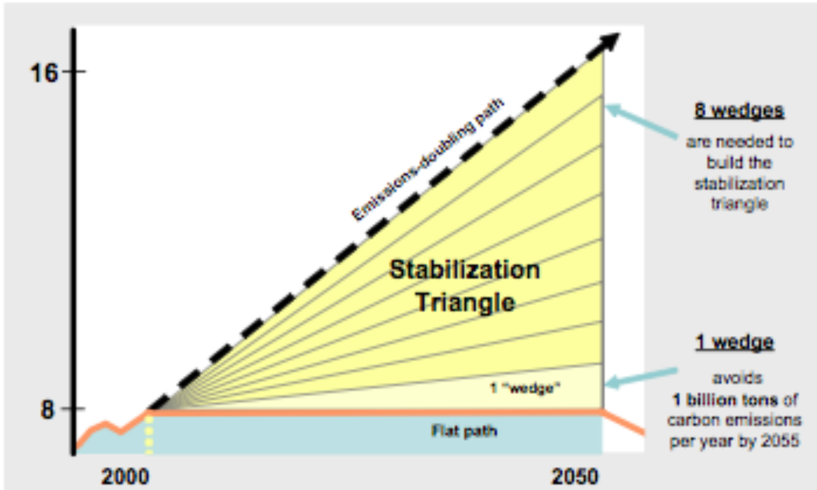
Introduction

As the negative impacts of climate change become more obvious and we approach a 2°C tipping point, the need for clean energy and carbon neutrality increases. This need for change has been stressed by the Intergovernmental Panel on Climate Change (IPCC) [1]. In their climate assessment reports released in the spring of 2014, they warn that "to avoid dangerous interference with the climate system, we need to move away from business as usual as quickly as possible." The American Academy for the Advancement of Science similarly states that "we are at risk of pushing our climate system toward abrupt, unpredictable, and potentially irreversible changes with highly damaging impacts" [2]. To avoid a 2°C increase in average global temperature, the IPCC calls for a 40 to 70% reduction in global CO2 emissions by 2050 and a reduction to near zero by the end of the century [3]. After focusing on the consequences of global climate change for three months, our sophomore class set out to answer the question, *what would it take to make Maine carbon neutral by 2050?*

Inspired by the 2014 Maine Climate Solutions Summit in Augusta, which set a strategic objective of "making Maine an alternative energy leader in the eastern United States by 2020" [4], and our own research on global climate change, we have created an exercise modeled off of the Carbon Mitigation Initiative developed by Robert Socolow and Steven Pacala of Princeton University in 2006 [5]. They reasoned that to keep carbon emissions flat we would need to offset our carbon emissions by a total of eight gigatons by 2050. They then identified fifteen carbon reduction strategies or "wedges", with each wedge equal to one gigaton of global carbon emissions. If you combine any eight out of the fifteen wedges and complete each task by 2050, we could prevent a doubling of CO_2 in the atmosphere and then work to reduce emissions further. Socolow and Pacala call this the stabilization triangle.

Our system works similarly, but has been adapted to fit Maine and to make the state completely carbon neutral as opposed to just stabilizing our current emissions. Instead of using a triangle, we are using a pie, where each wedge is a renewable or noncarbon option.

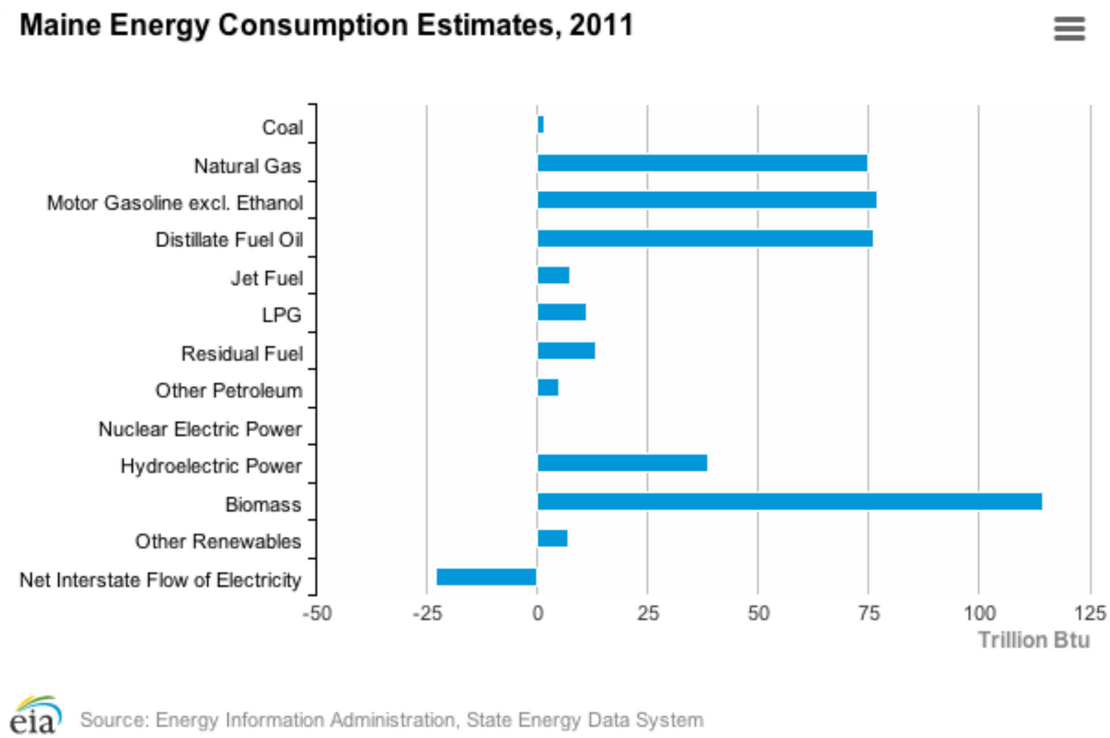


The eight "wedges" of Socolow and Pacala's stabilization triangle [6]

Our work is very preliminary and our numbers are approximate, but our findings suggest that becoming carbon neutral by 2050 is achievable. Maine has an unusual abundance of renewable energy and is becoming a leader in wind and ocean energy. It is our hope this analysis will promote conversation on one of the most critical topics facing our generation and provide a broader sense of what is possible.

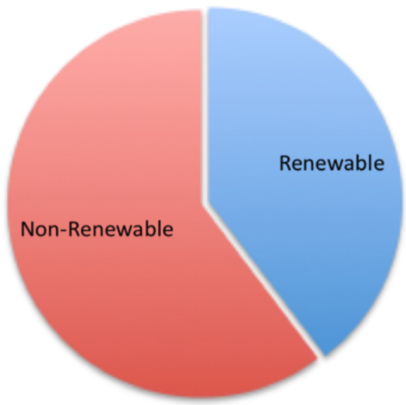
Methods

The purpose of this paper is to quantify what it would take to make Maine carbon neutral. We started by looking at how much energy Maine consumes now. According to the U.S. Energy Information Administration, Maine used 413 trillion Btus of energy in 2012 [7]. Of this, 253 trillion Btus (about 61%) come from fossil fuels such as natural gas, fuel oil, and gasoline. We also use much smaller amounts of coal, propane, jet fuel, and other petroleum products (see following graph). Renewable energy, primarily hydropower and biomass, accounts for 160 trillion Btus, or 39% of our energy use [7]. While, Maine has wind, solar, and other renewable energy sources, most of our renewable energy comes from hydroelectric and biomass generation. Of these, biomass is by far the larger power source, generating 114.4 trillion Btu's annually, more than any energy source in Maine, renewable or otherwise [7].

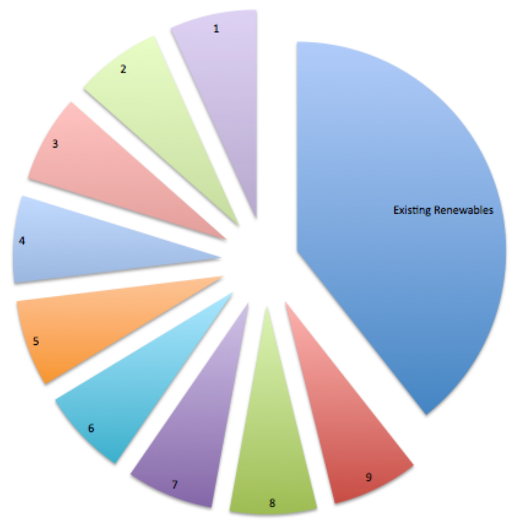


We then looked at projections of energy use in the future. Energy consumption in the U.S. is projected to increase by 0.4% a year through 2040 [8]. Compounding this increase over the next thirty-six years, and assuming that we increase renewable and fossil fuel use at the same pace, we will be using 292 trillion Btus' worth of fossil fuels by 2050. To become carbon neutral by 2050, all 292 trillion Btus from these fuels will have to be replaced with renewables.

Maine's annual CO_2 emissions from fossil fuel are about 18 million metric tonnes annually [7]. To equate energy use to emissions, we decided to divide Maine's projected nonrenewable energy use of 292 trillion Btus into nine wedges, each representing about two million metric tonnes of CO_2 emissions into the atmosphere each year if not replaced with a clean energy source. We would therefore need nine "wedges" to replace the fossil fuel portion of Maine's energy pie, with each wedge equal to about 32 trillion Btus, the equivalent of about 5,000,000 barrels of oil [9].



Maine's current energy mix:
39% renewables; 61% fossil fuels



9 carbon reduction wedges of renewable or carbon neutral energy are needed to replace energy from fossil fuels; each wedge is worth 32 trillion Btus

The next step was to research what renewable energy and carbon neutral options exist in Maine. We came up with sixteen carbon reduction wedge options all from technologies that are currently being used in Maine or are in the research and development stage. These are summarized in the following table. For each option, we attempted to figure how much potential capacity there was in Maine and how much power could be generated in a year. We then converted this number to Btus. Our numbers are preliminary and approximate, since data for the different options was not always consistent or complete and there are still many unknowns. We reviewed our methods and many of our numbers with Dr. Tom Tietenberg, Professor Emeritus of Economics at Colby College and Jennifer Albee of ReVision Energy. Our calculations, where relevant, along with sources, are included in the report Appendix. Any combination of nine wedges would result in carbon neutrality for Maine.

Results

We identified the following sixteen carbon reduction options that, if phased in over the next three and a half decades, would result in a carbon neutral Maine. These are described in greater detail in Appendix A.

Table 1. 16 Carbon Reduction Wedge Options for Maine

▽ Efficiency and Conservation ▽ Fuel Switch ▽ Renewables ▽ Carbon Neutral ▽ Noncarbon/nonrenewable

(Number in parentheses in Wedge column indicates the approximate number of wedges this option could produce)

WEDGE	Description	1 wedge could come from...
1. Building Efficiency (1-2)	Increase insulation, furnace efficiency, and lighting efficiency; increase number of net zero buildings	...increasing energy efficiency of half of Maine's buildings by 50%
2. Combined Heat and Power (cogeneration) (1)	Using industrial waste heat as a fuel source to generate electricity; or capturing heat produced during electricity generation to heat buildings	... installing cogeneration at ~100 new sites (quadrupling CHP capacity in Maine from 1130 MW to 4017 MW)
3. Transport Efficiency (2)	Increase vehicle efficiency (decrease energy used per mile traveled)	…doubling mileage of half of Maine's vehicles
4. Conservation Transport (1)	Reduce miles traveled by passenger and freight vehicles through mass transit, bike paths, zip cars, telecommuting, carpooling	...cutting vehicle miles traveled by half
5. Electric Transport (from renewable electricity) (4)	Replace gasoline and diesel powered vehicles with all electric vehicles (EVs)	...powering 25% of Maine's vehicles with electricity
6. Fuel Switch to Hydrogen (2)	Hydrogen fuel replaces petroleum fuels; would be produced from wind or ocean energy	...powering 25% of Maine's vehicles with hydrogen
7. Fuel Switch to Biofuels (1-2?)	Ethanol production from waste wood and/or round wood	...powering half of Maine's vehicles with biofuels (to equal one wedge both waste wood and round wood may need to be harvested)
8. Ground-source Geothermal (2)	Using the heat stored under ground from the sun to heat buildings and hot water	...installing ground-source geothermal in half of Maine's houses (additional potential for commercial buildings)
9. Offshore Wind Electricity (9+)	Floating wind turbines take advantage of higher, more consistent wind speed away from land.	...installing 2 GW of capacity (four 500 MW wind farms)
10. Onshore Wind Electricity (3)	Wind turbines in windy areas on land. In Maine this most often means mountainous areas.	... doubling Maine's current and in queue capacity (installing 3.6 GW worth of new turbines)
11. Tidal/Ocean Wave Electricity (3)	Placing underwater turbines in tidal lagoons or tidal streams; placing turbines on offshore ocean surface to capture wave energy	...developing 1/3 of tidal/ocean energy potential
12. Solar Electricity - Rooftop Photovoltaic (1)	Switch from oil heating to heating with solar electricity used to drive heat pumps	...converting heating systems of half of Maine's homes from oil to solar combined with heat pumps
13. Solar Electricity from Solar Farms (9+)	Install large numbers of ground-mounted solar arrays (also called rural utility-scale PV)	... installing solar farms on about 0.1% of Maine's land (5.6 GW of capacity on ~ 116 km^2)
14. Hydropower Electricity (2)	Hydropower from existing dams currently not producing energy, increased power output at developed sites, and/or new low head (<30 ft; < 1 MW) and low power (<100 kW) dams using new technologies.	... developing ~40% of Maine's potential hydropower sites (this could come primarily from dams that are already in place but not producing power)
15. Biomass powered electricity (1+?)	Burning or gasifying biomass to generate electricity or heat.	...doubling biomass energy production (Considered carbon neutral only if plants burn waste wood that would otherwise decompose and emit CO_2)
16. Nuclear Electricity (9+)	Replace existing fossil fuel electric power plants and increase Maine's electric generation capacity with nuclear plants	...building one 1200 MW nuclear reactor

Maine's current use by energy sector breaks down as follows [7]:

- Residential: 86 trillion Btus
- Commercial: 64 trillion Btus
- Industrial: 140 trillion Btus
- Transportation: 123 trillion Btus

As the carbon reduction wedge table shows, certain wedges apply to certain sectors. Two areas where there is huge room for energy reductions are transportation (by using more fuel efficient vehicles), residential and commercial heating (which could switch from heating oil to renewables and more efficient furnaces), and industrial (which could take advantage of technologies that combine heat and power). In addition, conservation by individuals (simply using less) could play an important role in reducing Maine's energy consumption.

Each carbon reduction wedge is briefly summarized in the following table, which also identifies some of the opportunities and challenges associated with each wedge. The list is not exhaustive - there are probably other options we did not consider, and technology is changing so quickly in the energy field, that there will probably be new options available well before 2050.

Definition of Terms and Abbreviations Used in Table 1 and Appendix A

Btu British Thermal Unit – a measure of power equal to the amount of energy needed to cool or heat 1 pound of water 1°F (the energy in 1 match stick). In North America, heat value (energy content) of fuels is expressed in Btus

W watt – a unit of power equal to 1 joule per second. The work done to produce 1 W of power for 1 second

kW kilowatt – one kilowatt equals 1000 watts

MW megawatt – one megawatt equals 1 million watts

TW terawatt – one terawatt equals 1 trillion watts

GHG green house gas

EV electric vehicle

PV photovoltaic cell used to collect solar energy

Power and energy are frequently confused. Power is a rate – energy used per unit time, e.g., a 100 W light bulb turned on for 1 hour (100 kWh).

Discussion

Does Maine have the resources to rely completely on renewable energy and become carbon neutral? Would the benefits out weigh the deficits? Would this be useful for our economy? Based on our preliminary analysis, the answer to these questions is yes. With some of the best energy resources and conditions in the East combined with substantial action, we could make Maine carbon neutral.

Maine is rich in renewable resources. We have 30% more solar energy hitting our land than Germany, the world's leader in solar energy installations [10]. We have hundreds of dams that are dormant when they could be developed to produce more energy than all the active ones put together. We have one of the best wind resources in the world and the third best ocean energy resource in the United States. Wind and ocean energy alone are enough to power the state many times over. In addition, we are 88% forested [11]. Waste wood is considered a carbon neutral energy source that can be used to produce electricity, heat and biofuel.

Probably the most cost effective wedges relate to energy efficiency and conservation. Seven in ten Maine homes use fuel oil for heating. Many houses are old and poorly insulated. Industrial and transportation consumption, along with heating our homes through long winters, makes Maine the most petroleum intensive economy in New England [7]. Investing in energy efficient buildings, heating systems, and vehicles will not only reduce the state's overall energy consumption, but would save Mainer's money and create spaces that are more comfortable and healthier.

Maine clearly has the energy resources to become carbon neutral, but the transition from carbon based to non-carbon based energy will be challenging. It will mean that what is now powered by oil will have to switch to electricity. This includes heating, cars, energy production, and more. Rather than spending money on infrastructure for fossil fuels, such as pipelines, we will need to invest in efficient buildings, electric charging stations, transmission cables from offshore wind farms to land, and other infrastructure. This shift will have a positive impact on the environment and, in the long run, will result in a more stable and cheaper way of powering the state. Oil is a finite source, however solar, wind, tidal, geothermal, and hydro would be nearly impossible to use up. When oil runs out, we do not want to be dependent on a non-existent energy source.

One of the sixteen wedges—biomass—is controversial. While it is a valuable source of electricity, burning wood emits carbon dioxide in amounts comparable to coal. It is considered carbon neutral only if the biomass comes from wood waste such as bark, sawdust and other wood byproducts which would have rotted soon, releasing carbon into the atmosphere whether or not they were burned for electricity. Wood-burning can be sustainable and carbon neutral, but only if we plant trees to replace all we take and use only waste wood as the fuel source.

One of the biggest challenges facing wind power and other energy sources that take up space is the attitudes of the people that live nearby. Cables linking turbines to shore can cross the fishing grounds of local fishermen, causing conflicts. And many people may support the idea of wind power or other renewables, but do not want to look at turbines or solar installations, even if they are far away (this is often referred to as NIMBY or "not in my back yard"). There are also challenges related to energy storage, especially for solar and wind, because the amount of wind and sun a turbine or solar panel receives varies from day to day. However, we are assuming that battery storage technology, which is advancing quickly, will be figured out well before 2050. Tidal power, wind power, and hydropower have negative effects on surrounding ecosystems. The challenge here will be to minimize these and keep in mind that environmental impacts of warming air and water temperatures due to global climate change will likely be greater than impacts of these projects. There will definitely be trade-offs.

Expense is another major challenge. Upfront costs for most wedge options will be high, but most have a relatively short pay back period. If we could move money from fossil fuel subsidies to renewables through rebates and tax credits, we could help offset these costs. In addition, retrofitting old houses, building energy efficient new ones, and rebuilding our energy infrastructure could create a lot of jobs and boost Maine's economy. Installation is one factor, as well as equipment, material costs, assembly, and maintenance. We have not analyzed the economics of the different wedge options, but believe that if we can look past the upfront costs, we will end up with a more reliable, consistent, cheaper and stable source of energy to power our state.

Conclusion

We believe we should heed the warnings of the majority of the world's scientists and work to become a carbon neutral state by 2050. We also believe that Maine has more than enough renewable resources to meet our needs. We can choose among many wedges to find the most reliable, effective, and environmentally-sound mix. Whether it is solar, wind, or tidal power, each wedge will not only help Maine have a sustainable economy but will lead to energy independence and security. The key is to consider all the options together, not just one at a time. We hope that our work will provide a new way of looking at the issue of carbon neutrality in Maine.

Literature Cited

[1] IPCC (2014). Climate Change 2014: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

[2] The AAAS Climate Science Panel (2014). What We Know: The Reality, Risks and Response to Climate Change. American Academy for the Advancement of Science.

[3] IPCC (2014). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

[4] Maine Climate Solutions Summit. 2014. The Climate Solutions Summit Purpose and Outcomes. www.climatesolutions.me.org/event-program-summit-outcomes/

[5] Socolow, R.H. and S.W. Pacala. 2006. A plan to keep carbon in check. Scientific American pp. 49-57.

[6] Hotinski, R. 3011. Stabilization Wedges: A Concept and Game. Carbon Mitigation Initiative, Princeton Environmental Institute, Princeton University, Princeton, New Jersey.

[7] U.S. Energy Information Administration State Energy Data System. Maine Energy Profile http://www.eia.gov/state/?sid=me

[8] U.S. Energy Information Administration. 2013. Annual Energy Outlook 3013 with Projections to 2040. www.eia.gov.forecasts/aieo.

[9] Rigzone. 2014. Oil and Gas Conversion Calculator. http://www.rigzone.come/calculator/default.asp#calc

[10] ReVision Energy website: http://www.revisionenergy.com/index.php

[11] McCaskell, G.L., Lausten, K.M., McWilliams, W.H. 2013. Maine's Forest Resources, 2012. Res. Note NRS-179. Newton, Square, PA: US Department of Agriculture, Forest Service, Northeastern Research Station.

Note: References for wedges are included in a separate appendix.

Appendix A. 16 Carbon Reduction Wedge Options for Maine

(Number in parentheses in Wedge column indicates the approximate number of wedges this option could produce)

WEDGE	Description	1 wedge could come from...	Current and Planned Capacity in Maine	Opportunities	Challenges
1. Building Efficiency (1-2)	Increase insulation, furnace efficiency, and lighting efficiency; increase number of net zero buildings	...increasing energy efficiency of half of Maine's buildings by 50%	Maine has a goal in statute to weatherize 100% of homes and 50% of businesses by 2030	- long term cost savings - job creation (retrofitting is labor intensive) - some financing available - reduce need for heating assistance	- Maine has many big old drafty houses (28% were built before 1940) - building codes don't address efficiency - up front cost – more financing and incentives needed - poverty
2. Combined Heat and Power (cogeneration) (1)	Using industrial waste heat as a fuel source to generate electricity; or capturing heat produced during electricity generation to heat buildings	... installing cogeneration at ~100 new sites (quadrupling CHP capacity in Maine from 1130 MW to 4017 MW)	1130 MW at 30 sites (as of 2010) Examples: Eastern Maine Medical Center, Verso Pulp and Paper Mill in Bucksport	- long term cost savings - reduces energy consumption by ~50% - wide application in factories, commercial and municipal buildings, hospitals, universities, etc.	high up front costs (but relatively rapid payback)
3. Transport Efficiency (2)	Increase vehicle efficiency (decrease energy used per mile traveled)	…doubling mileage of half of Maine's vehicles	- National Fuel efficiency standards call for doubling mileage of all cars and light trucks by 2025	- long term cost savings	- car size and power - driving habits (lowering speed limit would increase efficiency) - fueling stations
4. Conservation Transport (1)	Reduce miles traveled by passenger and freight vehicles through mass transit, bike paths, car share, telecommuting, carpooling	...cutting vehicle miles traveled by half	Portland is investing in bike lanes; Amtrak (Boston to Brunswick), bus routes; intermodal stops in some cities where freight can be switched from trucks to trains	- cost savings - freight transport savings - proposed routes to Rockland and interior	- increased public transport needed - driving habits - lack of government support at state and federal level - infrastructure costs - rural state
5. Electric Transport (from renewable electricity) (4)	Replace gasoline and diesel powered vehicles with all electric vehicles (EVs)	...powering 25% OF Maine's vehicles with electricity	~ 300 all electric cars registered in ME as of 5/14; 18 public EV charging stations (lowest number in New England)	- potential cost savings - Federal tax credit - quiet	- less efficient in colder climates; but technology is improving - affordability - lack/cost of charging stations
6. Fuel Switch to Hydrogen (2)	Hydrogen fuel replaces petroleum fuels; would be produced from wind or ocean energy	...powering 25% of Maine's vehicles with hydrogen	0 hydrogen fuel stations in Maine as of 5/14	- no information	- expensive (cheaper to use electricity to power vehicles directly rather than produce fuel using electricity?)
7. Fuel Switch to Biofuels (1-2?)	Ethanol production from waste wood and/or round wood; biodiesel from used cooking oil; biofuel from algae	...powering half of Maine's vehicles with biofuels (to equal one wedge both waste wood and round wood may need to be harvested)	pilot facilities for wood ethanol (Old Town) and algae (Sebago); Maine Standard Biodiesel produces ~ 1 million gallons/yr from cooking oil	- Maine is ~ 88% forested - GHG emissions from wood ethanol 86% less than gasoline	- similar challenges to biomass - GHG emissions from burning, production and changes in land use - managing forest for ethanol production as well as other forest products - maintaining forest biodiversity
8. Ground-source Geothermal (2)	Using the heat stored under ground from the sun to heat buildings and hot water	...installing ground-source geothermal in half of Maine's houses (additional potential for commercial buildings)	- no data Examples: Camden Hills Regional High School; Knox County Regional Airport	- long term cost savings - emissions/household reduced by 50-80% - Federal tax credit - plenty of space because we are rural - put it under roads/driveways to help melt ice in the winter	- high up front cost - financing - no state incentives

9. Offshore Wind Electricity (9+)	Floating wind turbines take advantage of higher, more consistent wind speed away from land.	...installing 2 GW of capacity (four 500 MW wind farms)	400 MW Maine Aqua Ventus pilot project is in planning stage at UMaine Maine has a wind energy development goal 8000 MW of installed capacity by 2030, at least 5000 MW of which would come from facilities in coastal waters and offshore	- Maine has one of the best offshore wind resources in the world, with 156 GW of capacity; one wedge represents less than 2% of total potential	- intermittent energy source/storage loss of fishing grounds - environmental impacts (marine, birds) - aesthetics - NIMBY - power transmission
10. Onshore Wind Electricity (3)	Wind turbines in windy areas on land. In Maine this most often means mountainous areas.	... doubling Maine's current and in queue capacity (installing 3.6 GW worth of new turbines)	413 MW As of 2013, Maine had 13 wind farms with 227 turbines, which provides for 7.6% of state's electricity; 1261 MW of wind power is in queue	- 11.2 GW of capacity - Can continue to grow crops/trees - One of the cheapest renewable energy sources at 4-6 cents/kWh - Maine has ~2,250 km^2 of windy land	- intermittent energy source/storage - environmental impacts (primarily birds) - aesthetics - noise - NIMBY - transmission from remote areas
11. Tidal/Ocean Wave Electricity (3)	Placing underwater turbines in tidal lagoons or tidal streams; placing turbines on offshore ocean surface to capture wave energy	...developing 1/3 of tidal/ocean energy potential	180 kW (tidal) 0 (wave) Maine's first tidal stream generator began operating off Lubec and Eastport in 2014 research on ocean energy underway at University of Maine	- Best tidal and wave energy resource in US after Alaska and Washington - tides are predictable and constant - wave energy on outer continental shelf potential 19 TWh; inner continental shelf potential 13 TWh - 15 identified tidal sites in Gulf of Maine with estimated capacity of 675 MW	- impact on tides in Gulf of Maine - impacts on marine ecosystems - cost of non-corrosive materials - noise - loss of fishing grounds - vessels
12. Solar Electricity - Rooftop Photovoltaic (1)	Switch from oil heating to heating with solar electricity used to drive heat pumps	...converting heating systems of half of Maine's homes from oil to solar combined with heat pumps	2.2 MW (total solar in Maine from all sources)	- Maine gets 30% more sun than Germany, a solar leader - heat pumps are much more efficient than thermal resistance heating	- paying for PV panels (ME is only New England state without a rebate program) - intermittent energy source - support for feed-in tariff - aesthetics
13. Solar Electricity from Solar Farms (9+)	Install large numbers of ground-mounted solar arrays (also called rural utility-scale PV)	... installing solar farms on about 0.1% of Maine's land (5.6 GW of capacity on ~ 116 km^2)	2.2 MW (total solar in Maine from all sources) Example: Bowdoin College is building 1.3 MW solar farm on 3 acres, plus roof tops	- Maine gets 30% more sun than Germany, a solar leader - 1 wedge represents less than 1% of Maine's available solar	- intermittent energy source - large footprint (some could come from land fill sites and parking lot canopies) - improving output of panels - aesthetics
14. Hydropower Electricity (2)	Hydropower from existing dams currently not producing energy, increased power output at developed sites, and/or new low head (<30 ft; < 1 MW) and low power (<100 kW) dams using new technologies.	... developing ~40% of Maine's potential hydropower sites (this could come primarily from dams that are already in place but not producing power)	733 MW produced from all hydro in Maine There are currently 74 sites developed without power; 24 sites that could produce more power; and 1353 undeveloped low head/low power sites	- 1069 MW from existing unpowered dam sites (e.g., the Megunticook); 83 MW from developed sites; 432 MW from new low head/low power sites -potential to improve/add fish passage as some dams are redeveloped	- impacts on fish populations/migration - changes in natural river flow, water temperature and chemistry, and ecosystems - tourism - public opposition (some of best sites for new dams are on the St. John, Penobscot, and Androscoggin Rivers)

15. Biomass powered electricity (from "waste" wood) (1+?)	Burning or gasifying biomass to generate electricity or heat. (Considered carbon neutral only if plants burn waste wood that would otherwise decompose and emit CO_2)	...doubling biomass energy production (we don't know how much waste wood is available)	768 MW (electricity); no data on biomass for heat Example: Colby College	Maine is ~ 88% forested; timber resource sufficient to increase Maine's current biomass capacity more than 100-fold in round wood is used, but would create a pulse of CO_2 emissions	- carbon neutral only if plants are powered by waste wood - limited waste wood supply; significant increase in capacity would require increase in forest harvesting - emissions profile of wood burning is similar to coal; carbon capture and storage would be needed to eliminate emissions
16. Nuclear Electricity (9+)	Replace existing fossil fuel electric power plants and increase Maine's electric generation capacity with nuclear plants	...building one 1200 MW nuclear reactor	0 Maine Yankee, a 900 MW nuclear power plant, was shut down in 1996	- no CO_2 emissions; - high power output per reactor	- public opposition - human health and environmental risks from mining, operation, and accidents - unsolved problem of nuclear waste - weapons proliferation risk - very expensive