Briefing Paper on Definitions for the Ipswich Municipal Climate Resolution Goal
Prepared by the Ipswich Climate Resiliency Committee, October 2020

Purpose of Briefing Paper: During deliberations for the municipal climate resolution, the Climate Resiliency Committee (CRC) identified various options as it applied to the goal. The three primary options were Zero Carbon, Net Zero, and 100% Renewable. In order to better evaluate and select the most appropriate option for the goal, the CRC requested a briefing paper be prepared by some of the members that would define and evaluate the options, and consider the implications to the municipal government and the feasibility of meeting each option.

Background: Since early 2020, the Ipswich Climate Resiliency Committee (CRC) has been drafting a resolution that proposes climate goals for the municipal government. The purpose of the goal is to establish a vision and goal for climate resiliency throughout the municipal government. There are two primary strategies for climate resiliency: climate adaptation and climate mitigation.

Climate adaptation involves managing the effects of climate change that is occurring and will occur as a result of historic greenhouse gas (GHG) emissions since the beginning of the industrial revolution in the late 19th century. This includes rising sea levels, warming atmosphere, changes in the patterns, amount, and types of precipitation (i.e., rain vs snow), and extreme weather events. Adaptation may include changes to how existing and new buildings and roads are constructed; soft, vegetated buffers at the interface of land and ocean; and relocating infrastructure to less vulnerable areas.

The second strategy, climate mitigation, involves reducing the emissions of GHGs through energy conservation and efficiency, and replacing fossil-fuel energy (primarily natural gas and petroleum fuels for Ipswich) with non-carbon, renewable sources, such as wind and solar energy. Climate mitigation may also include carbon sequestration– the capturing of carbon dioxide from the atmosphere using both technological or biological approaches (e.g., reforestation and wetland restoration). Although carbon sequestration will be an important part of future climate mitigation, there are many technical and scientific questions remaining and we are focusing on reduction of GHG emissions in the current resolution and goal.

There are a number of different types of non-carbon energy sources available, some of which has its own environmental concerns, including nuclear energy and hydropower (see discussions below). Developing a concise and effective climate goal for the municipal government that considers the costs and benefits of the energy source options, as well as the terminology used for the goal, is complicated. This briefing paper attempts to define and explain the energy options and their costs/benefits as applicable to the climate goal.

The levelized cost of energy (LCOE) is one measure of a power cost that allows comparison of different sources of electricity generation on a consistent basis. The LCOE can be regarded as the minimum constant price at which electricity must be sold in order to break even over the lifetime of the project. LCOE includes capital costs, operations and maintenance (e.g., fuel and repairs), transmission, and tax credits, if applicable. Some criticism of using LCOE as a metric for comparing new generating sources include not considering the effects of the time required to match production and demand (e.g., dispatchability, or the ability of a generating system to come online, go offline, or ramp up or down, quickly as demand swings, and the extent to which the availability profile matches or conflicts with the market demand profile).[1]

This briefing paper will evaluate the following three primary options for the municipal climate resolution:

1. Zero Carbon,
2. Net Zero, and
3. 100% Renewable

While the three options are similar in terms of reducing fossil fuel energy use and GHG emissions, each have differing costs, benefits, and implications to the sources of energy the municipal government purchases and generates. First, we will define and explain the three options.

Zero Carbon:
Simply put, zero carbon means 100% of the energy used for space heating, lighting, and transportation is obtained from carbon-free sources. Specifically, it requires that the consumption or use of the energy does not release carbon dioxide into the atmosphere. The primary sources of zero carbon energy available today are wind, solar, hydropower, and geothermal (all renewable sources), and nuclear energy. Although nuclear energy is carbon free, it is not considered renewable because the energy is derived from uranium extracted from the ground and is therefore not a renewable resource. Although uranium is found in rocks all over the world, nuclear power plants usually use a very rare type of uranium, U-235. There are other environmental concerns related to nuclear power (see below). Although hydropower is both carbon free and renewable, there are other environmental concerns related to hydropower (see below).
Pros: Addresses GHG emissions, the root causes of climate change; accelerates the transition to a goal of carbon-free energy; the Levelized Cost of Energy (LCOE) for carbon-free energy (especially wind and solar PV) is projected to decline[2] over the next two decades (see Appendix Tables).
Cons: The LCOE of some carbon-free energy today is higher than natural gas, but with substantial variability (see Appendix Tables)[3]; there are practical constraints and it is somewhat difficult to achieve zero carbon in the short-term (<10 yrs.); nuclear and hydropower have their own environmental and societal impacts.

Net Zero:
The concept of net zero is most commonly used to describe buildings that generate an equivalent amount of on-site renewable energy consumed in the building. As a community goal, net zero (sometimes referred to as carbon neutral) refers to "balancing" a measured amount of carbon dioxide released with an equal amount of carbon offsets. A very simple example would be

[1] https://en.wikipedia.org/wiki/Cost_of_electricity_by_source
[2] Annual Energy Outlook 2020 with projections to 2050 (https://www.eia.gov/aeo)
[3] Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020 (https//www.eia.gov/aeo

offsetting X metric tons of carbon dioxide from burning natural gas with the generation of electricity from a wind turbine that generates the energy equal to X metric tons of carbon dioxide. Other means of achieving a net zero carbon goal is to purchase carbon offsets in "carbon markets" that sell renewable energy credits or carbon sequestration projects like reforestation projects. However, in order to achieve zero carbon, any increase in the amount of energy used from fossil fuel sources must be "balanced" by a corresponding increase in carbon-free sources or offsets, and requires accurate and detailed tracking of emissions from all fossil fuel sources and the equivalent carbon offsets. In addition, because net zero could allow continued use of some fossil fuels, a net zero goal would extent the amount of time necessary to reach a fully zero-carbon goal.

Pros: Net zero goal could allow a mix of carbon and non-carbon energy, so allows more flexibility to achieve progress; it targets creation and removal of carbon emissions; the LCOE for carbon-free energy (especially wind and solar PV) is projected to decline [4] over the next two decades (see Appendix Tables)

Cons: In the short-term, the LCOE of some carbon-free energy is higher than natural gas, but with substantial variability (see Appendix Tables)[5]; demand for carbon offsets is expected to rise, which is expected to increase the market price and costs; there are practical constraints and it is somewhat difficult to achieve zero carbon in the short-term (<10 yrs.); nuclear and hydropower have their own environmental and societal impacts; transfers the root problems (GHG emissions) from one resource/entity to another; allows continued investment in long-lived fossil fuel infrastructure (e.g., gas pipelines, heating systems); because new fossil fuel infrastructure is difficult/costly to replace with non-carbon energy, it can extend the time frame needed to achieve a fully, carbon-free energy goal.

100% Renewable:

100% renewable means all of the energy used by the municipal government is obtained from renewable sources. Renewable energy includes zero carbon (i.e., wind, solar, hydropower, and geothermal) and carbon emitting sources (i.e., biomass). See below for more information about renewable energy.

Pros: Addresses GHG emissions, the root causes of climate change; accelerates the transition to carbon-free, environmentally-sustainable, zero-carbon power supply; the LCOE for renewable energy sector is projected to decline substantially[6] over the next two decades (see Appendix Tables).

Cons: In the short-term, the LCOE of some renewable energy is higher than natural gas, but with substantial variability (see Appendix Tables)[7]; there are practical constraints and it is somewhat difficult to achieve in the short-term (<10 yrs.); renewable energy has lower power density compared to nuclear and fossil fuel energy (i.e., large area requirements); wind and solar energy is intermittent/non-dispatchable without energy storage capacity.

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[4] Annual Energy Outlook 2020 with projections to 2050 (https://www.eia.gov/aeo)

[5] Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020 (https//www.eia.gov/aeo

[6] Annual Energy Outlook 2020 with projections to 2050 (https://www.eia.gov/aeo)

[7] Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2020 (https//www.eia.gov/aeo

Energy Source Overview

Renewable Energy:

According to the Department of Energy, Energy Information Administration (EIA), renewable energy is energy from sources that are naturally replenishing but flow-limited; renewable resources are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time.[8] The EIA projects renewable energy to expand and replace most fossil fuels, and the costs are projected to decline by 2050[9].

The major types of renewable energy sources are:

- Biomass: Biomass is organic material that comes from plants and animals, and is a renewable source of energy. Plants absorb the sun's energy and atmospheric carbon in a process called photosynthesis. Biomass can be burned directly or converted to liquid biofuels or biogas that can be burned as fuels.
  Although biomass is considered renewable, it is a carbon energy source and when burned the carbon dioxide is released into the atmosphere. Although most of the embodied carbon in biomass was extracted from the atmosphere by plants through photosynthesis, there are concerns that the energy used in the processing of biomass fuel, and in some cases growing the crops used in the feedstock, can substantially increase emissions of GHGs. Biomass can release other air pollutants that are known to cause smog, ozone, and respiratory disease. Other concerns with biomass energy are that the land and resources it uses can compete with food crops, causing food shortages and higher consumer prices. Biomass production for energy can also increase the amount of chemicals used, including pesticides and fertilizers. Biomass energy can include:

  Wood and wood waste–Wood pellets are manufactured wood products that can involve substantial energy use and emissions in production and transportation.

  Municipal solid waste– Municipal solid waste (MSW) or garbage, is used to produce energy at waste-to-energy plants and at landfills. MSW includes plant or animal products, materials such as paper, cardboard, food waste, and wood. MSW also includes non-biomass combustible materials such as plastics and other synthetic materials made from petroleum and non-combustible materials such as glass and metals. Waste-to-energy plants can "scrub" some pollutants after combustion, but are known to emit carbon dioxide, dioxin, lead, and mercury. In addition, they generally consume more energy and are more costly compared to recycling and composting the materials.

  Landfill gas and biogas– Biogas is produced from biomass through the process of anaerobic decomposition. Anaerobic bacteria digest biomass and produce biogas. Biogas is composed mostly of methane and carbon dioxide. Biogas forms in, and can be collected from, municipal-solid-waste landfills and livestock manure holding ponds. Biogas can be used as a fuel similar to natural gas, and like other biomass sources carbon dioxide is released during the combustion process.

  Ethanol–Ethanol is a clear, colorless alcohol made from a variety of biomass materials called feedstocks (the raw materials used to make a product). Fuel ethanol feedstocks

[8] https://www.eia.gov/energyexplained/renewable-sources/

[9] Annual Energy Outlook 2020 with projections to 2050 (https://www.eia.gov/aeo)

include grains and crops with high starch and sugar content such as corn, sorghum, barley, sugar cane, and sugar beets. Ethanol can also be made from grasses, trees, and agricultural and forestry residues such as corn cobs and stocks, rice straw, sawdust, and wood chips. Carbon dioxide is released during the combustion of ethanol.

Biodiesel– Biomass-based diesel fuels is used in transportation and heating fuels. Biodiesel is made from biomass or materials derived from biomass, and can be made from nearly any feedstock (raw material) that contains adequate free fatty acids (e.g., raw vegetable oils, used cooking oils, and animal fats). Biodiesel is typically blended with petroleum distillate/diesel in ratios of 2%-20%.

- Hydropower: Hydropower is created by the force of water flowing in streams and rivers to produce mechanical energy. Hydropower was one of the first sources of energy used for electricity generation and until 2019, hydropower was the largest source of total annual U.S. renewable electricity generation. Hydropower plants uses water flowing through a pipe, or penstock, then pushes against and turns blades in a turbine to spin a generator to produce electricity. Conventional hydroelectric facilities include run-of-the-river systems, where the force of the river's current applies pressure on a turbine, and storage systems, where water accumulates in reservoirs created by dams on streams and rivers and is released through hydro turbines as needed to generate electricity. Most U.S. hydropower facilities have dams and storage reservoirs.

  Although hydropower is a zero-carbon energy source, hydropower facilities can have a major impact on aquatic ecosystems, both upstream, on-site, and downstream of the dammed reservoir and facility. Reservoir water is usually more stagnant than normal river water. As a result, the reservoir will have lower oxygen levels and higher than normal amounts of sediments and nutrients, which can cultivate an excess of algae and other aquatic weeds. These weeds can crowd out other river animal and plant-life. In addition, if too much water is stored behind the reservoir, segments of the river downstream from the reservoir can dry out. Older dams, especially in New England, can have substantial maintenance costs and liabilities[10]. Hydropower dams, with either inefficient or nonexistent fish bypass structures, restricts the movement of fish and invertebrates in rivers and streams. Damming of rivers and streams has been a major cause of the population decline of U.S. Atlantic salmon, and other diadromous species including alewife, blueback herring, American shad, and American eel in New England and Canada.

- Geothermal: Geothermal energy is heat within the earth and is a renewable energy source because heat is continuously produced inside the earth. In New England, geothermal energy is typically extracted using buried pipes that are drilled several meters underground and using geothermal heat pumps. Although geothermal "fuel" is free and geothermal heat pumps are extremely energy efficient, they require energy to operate the associated pumps, compressors, and fans.

[10] https://stories.usatodaynetwork.com/climatechange/aging-dams/; https://patch.com/massachusetts/marlborough/unsafe-local-dam-one-39-mass-documents-show

- Wind: Wind is a renewable energy that is caused by uneven heating of the earth's surface by the sun. The wind is extracted as mechanical energy to generate electricity. Wind energy “fuel” is free and is a zero-carbon energy source.

- Solar: Solar energy can be extracted as thermal energy to heat water for use in buildings for space and water heating, or at high temperatures in solar thermal power plants. Solar photovoltaic (PV) devices, or solar cells, change sunlight directly into electricity. Arrangements of many solar cells in PV panels and arrangements of multiple PV panels in PV arrays can produce electricity for an entire building. Commercial PV power plants can involve large arrays that cover many acres to produce electricity for thousands of homes. Using solar energy has three main benefits: solar energy is free, the systems do not produce air pollutants or carbon dioxide, and it has minimal effects on the environment. The two primary limitations of solar energy is the amount of sunlight that arrives at the earth's surface is not constant, and varies depending on location, time of day, season of the year, and weather conditions, and the amount of light reaching a square foot of the earth's surface is relatively small, so a large surface area is necessary to absorb or collect a useful amount of energy. According to the EIA, solar PV has the lowest estimated levelized cost of energy (LCOE) of any other utility-scale electricity source (see Appendix Tables)[11]

Nuclear Power

As discussed above, nuclear power is zero carbon, but is not a renewable energy source. Nuclear power uses nuclear reactions that release energy to generate heat, which most frequently is then used in steam turbines to produce electricity in a nuclear power plant. Nuclear power can be obtained from nuclear fission, nuclear decay and nuclear fusion reactions. Presently, the vast majority of electricity from nuclear power is produced by nuclear fission of uranium and plutonium. Nuclear decay processes are used in niche applications such as radioisotope thermoelectric generators. Generating electricity from fusion power remains at the focus of international research.

Nuclear power is a safe energy source in terms of fatalities per unit of energy generated compared to other energy sources. Coal, petroleum, natural gas and hydroelectricity each have caused more fatalities per unit of energy due to air pollution and accidents. Because there are no emissions from operation, nuclear power has prevented about 1.84 million air pollution-related deaths and the emission of about 64 billion tons of carbon dioxide equivalent that would have otherwise resulted from the burning of fossil fuels since commercialization in the 1970s.[12]

However, accidents in nuclear power plants have occurred, including the Chernobyl disaster in the Soviet Union in 1986, the Fukushima Daiichi nuclear disaster in Japan in 2011, and the more contained Three Mile Island accident in the United States in 1979. In addition to concerns of accidents or terrorist acts at nuclear power plants, disposal of nuclear waste is often considered the most politically divisive aspect in the lifecycle of a nuclear power facility. Because there is no current U.S. plan for disposing of nuclear waste at central depositories, all plants will be required to keep the waste on the plant premises indefinitely.[13]

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[11] Annual Energy Outlook 2020 with projections to 2050 (https://www.eia.gov/aeo)
[12] https://en.wikipedia.org/wiki/Nuclear_power
[13] Ibid

There is a debate about nuclear power as strategy for addressing the climate change crisis. Proponents, such as the World Nuclear Association and Environmentalists for Nuclear Energy, contend that nuclear power is a safe, sustainable energy source that reduces carbon emissions. Nuclear power opponents, such as Greenpeace, the World Information Service on Energy, and the Nuclear Information and Resource Service, contend that nuclear power poses many threats to people and the environment.

The economics of new nuclear power plants is a controversial subject, and there are diverging views on the topic. Nuclear power plants typically have high capital costs for building the plant, but low fuel costs. The US Energy Information Administration estimated that for new nuclear plants going online in 2025, capital costs are higher than fossil-fuel power plants and all renewable energy plants except offshore wind.[14] An analysis by Lazard in 2019 found the global LCOE for nuclear was $118-192/MWh, compared to $28-54/MWh for onshore wind and $32-42/MWh for utility-scale solar.[15] The EIA reported similar LCOE values.[16]

Although nuclear power's future is not bright, it could experience a revival as countries address climate change more seriously and seek to increase non-carbon sources. However, in January 2020 the EIA projected a 19% decline in nuclear electric generating capacity from 98 GW in 2019 to 79 GW in 2050, and no new plant additions occurring after 2022. Projected nuclear retirements are driven by declining revenues that result from low growth in electricity load and from increasing competition from low-cost natural gas and declining cost of renewables.[17]

Summary

According to the EIA's 2020 Energy Outlook Report, the LCOE for carbon emitting and non-renewable energy was projected to be higher for both the short-term (2025) and long-term (2040) compared to non-carbon and renewable energy. The primary cost factor differential in these technologies is fuel costs (included in the column for levelized variable O&M). Solar and wind have no fuel costs for generation and relatively small operation and maintenance costs, so their LCOE is mostly determined by capital and financing costs. For generators that consume fuels such as coal and natural gas, both fuel costs and capital cost significantly increase their LCOEs.

The levelized capital cost of non-carbon and renewable energy sources are generally higher on average than carbon and non-renewable sources. In the year 2025, for example, combined cycle and combustion turbine natural gas plants have levelized capital costs of 8.40 and 16.17 MWH, respectively, while solar PV and onshore wind have levelized capital costs are 26.14 and 29.63 MWH, respectively. Offshore wind has the highest levelized capital cost of any of the compared energy sources (90.95 MWH) because it is relatively new technology and higher costs associated with working in marine environments. However, the levelized capital costs for non-carbon and renewable energy sources are projected to decline by the year 2040 and beyond. For example, offshore wind levelized capital costs in 2040 are nearly half the costs in 2025.[18]

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[14] Annual Energy Outlook 2020 with projections to 2050 (https://www.eia.gov/aeo)
[15] https://www.lazard.com/perspective/lcoe2019/
[16] Annual Energy Outlook 2020 with projections to 2050 (https://www.eia.gov/aeo)
[17] https://www.eia.gov/outlooks/aeo/
[18] Annual Energy Outlook 2020 with projections to 2050 (https://www.eia.gov/aeo)

Summary of Three Options for the Municipal Climate Resolution

Each option will require energy conservation and efficiency as a complementary initiative, as well as targeted incentives and restrictions to achieve the goal. Note the costs ($) are current technology costs, while the projections (red, black or green triangles are future years (2025-2040) (see Appendix for details).

Net Zero (Carbon-Neutral): As a community goal, carbon-neutral refers to "balancing" a measured amount of carbon dioxide emissions with an equal amount of credits or offsets. Carbon offsets can be either purchased or created. Demand for offsets is expected to rise, which will increase costs. For the Town, both options would likely involve purchasing carbon offsets from established vendors that aggregate funds for renewable energy and wetland/forest restoration projects.

Pros	Cons
Allows flexibility to achieve progress	Transfers (does not solve) many of the root problems
Targets creation and removal of emissions	Can encourage investments in long-lived, fossil fuel infrastructure (e.g., gas pipelines, heating systems)
	Can extend time frame to achieve carbon-free energy goal
Current Relative New Construction, O&M Costs & Projections: $ $ $ ▲	
Implementation Time: ⌛	

Carbon-Free (Zero Carbon): Simply put, zero carbon means all of the energy used for heating, lighting, and transportation is obtained from carbon-free sources. Specifically, it requires that the consumption or use of the energy does not release carbon dioxide into the atmosphere. The primary sources of zero carbon energy available today are wind, solar, hydropower, geothermal, and nuclear energy. Costs of nuclear and hydropower projected to remain constant and renewable energy costs will decline, resulting in a modest reduction in cost by 2040 (depending upon energy mix).

Pros	Cons
Targets the root causes	Difficult to achieve (practical constraints)
Accelerates transition to carbon-free energy goal	Some carbon-free energy sources have other environmental and societal impacts (i.e., nuclear and hydropower)
Current Relative New Construction, O&M Costs & Projections: $ $ ▶	
Implementation Time: ⌛ ⌛	

100% Renewable: 100% renewable means all of the energy used is obtained from renewable sources which includes both carbon (i.e., biomass) and carbon-free sources (e.g. wind, solar, hydropower, and geothermal). The cost of all renewable energy, particular offshore wind, is projected to decline significantly by 2040.

Pros	Cons
Environmentally sustainable, zero-carbon power supply	Difficult to achieve (practical constraints)
Targets the root causes	Low-power density (large area requirements)
Accelerates transition to sustainable, carbon-free energy goal	Intermittent/non-dispatchable and requires energy storage capacity
Current Relative New Construction, O&M Costs & Projections: $ $ $ $ ▼	
Implementation Time: ⌛ ⌛ ⌛	

Appendix

Table 1. Estimated levelized cost of electricity (LCOE, unweighted) for new generation resources entering service in 2025 (2019 dollars/MWH)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit[2]	Total LCOE including tax credit
Dispatchable technologies								
Ultra-supercritical coal	85	47.57	5.43	22.27	1.17	76.44	*NA*	76.44
Combined cycle	87	8.40	1.59	26.88	1.20	38.07	*NA*	38.07
Combustion turbine	30	16.17	2.65	44.33	3.47	66.62	*NA*	66.62
Advanced nuclear	90	56.12	15.36	9.06	1.10	81.65	-6.76	74.88
Geothermal	90	20.38	14.48	1.16	1.45	37.47	-2.04	35.43
Biomass	83	39.92	17.22	36.44	1.25	94.83	*NA*	94.83
Non-dispatchable technologies								
Wind, onshore	40	29.63	7.52	0.00	2.80	39.95	*NA*	39.95
Wind, offshore	44	90.95	28.65	0.00	2.65	122.25	*NA*	122.25
Solar photovoltaic[3]	29	26.14	6.00	0.00	3.59	35.74	-2.61	33.12
Hydroelectric[4,5]	59	37.28	10.57	3.07	1.87	52.79	*NA*	52.79

1 O&M = operations and maintenance.
2 The tax credit component is based on targeted federal tax credits such as the production tax credit (PTC) or investment tax credit (ITC) available for some technologies. It reflects tax credits available only for plants entering service in 2025 and the substantial phaseout of both the PTC and ITC as scheduled under current law. Technologies not eligible for PTC or ITC are indicated as *NA*, or not available. The results are based on a regional model, and state or local incentives are not included in LCOE calculations. See text box on page 2 for details on how the tax credits are represented in the model.
3 Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.
4 As modeled, EIA assumes that hydroelectric generation has seasonal storage so that it can be dispatched within a season, but overall operation is limited by resources available by site and season.
5 Costs are for 2023 online year. See page 6 for details on the exception.
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020*

Table 2. Estimated levelized cost of electricity (LCOE, unweighted) for new generation resources entering service in 2040 (2019 dollars/MWH)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit[2]	Total LCOE including tax credit
Dispatchable technologies								
Ultra-supercritical coal	85	43.97	5.43	22.17	1.25	72.81	*NA*	72.81
Combined cycle	87	7.50	1.59	32.52	1.28	42.89	*NA*	42.89
Combustion turbine	30	13.89	2.65	52.15	3.70	72.39	*NA*	72.39
Advanced nuclear	90	48.21	15.36	9.47	1.18	74.22	-4.85	69.37
Geothermal	90	18.86	15.88	1.16	1.55	37.44	-1.89	35.56
Biomass	83	33.25	17.22	35.02	1.34	86.83	*NA*	86.83
Non-dispatchable technologies								
Wind, onshore	40	25.51	7.49	0.00	2.97	35.97	*NA*	35.97
Wind, offshore	44	53.85	28.83	0.00	2.85	85.53	*NA*	85.53
Solar photovoltaic[3]	29	19.86	6.00	0.00	3.83	29.70	-1.99	27.71
Hydroelectric[4]	70	40.98	9.22	1.39	2.00	53.58	*NA*	53.58

1 O&M = operations and maintenance.
2 The tax credit component is based on targeted federal tax credits such as the production tax credit (PTC) or investment tax credit (ITC) available for some technologies. It reflects tax credits available only for plants entering service in 2040 and the

substantial phaseout of both the PTC and ITC as scheduled under current law. Technologies not eligible for PTC or ITC are indicated as *NA*, or not available. The results are based on a regional model, and state or local incentives are not included in LCOE calculations. See text box on page 2 for details on how the tax credits are represented in the model.
3 Costs are expressed in terms of net AC (alternating current) power available to the grid for the installed capacity.
4 As modeled, EIA assumes that hydroelectric generation has seasonal storage so that it can be dispatched within a season, but overall operation is limited by resources available by site and season.
Source: U.S. Energy Information Administration, *Annual Energy Outlook 2020*

Table 3. Estimated levelized cost of electricity (LCOE, unweighted) by carbon and non-carbon sources for new generation resources entering service in 2025 (2019 dollars/MWH) (adapted from Table 1 above)

Plant type	**Capacity factor (%)**	**Levelized capital cost**	**Levelized fixed O&M[1]**	**Levelized variable O&M**	**Levelized transmission cost**	**Total system LCOE**	**Levelized tax credit[2]**	**Total LCOE including tax credit**
Carbon emitting technologies								
Ultra-supercritical coal	85	47.57	5.43	22.27	1.17	76.44	*NA*	76.44
Combined cycle	87	8.40	1.59	26.88	1.20	38.07	*NA*	38.07
Combustion turbine	30	16.17	2.65	44.33	3.47	66.62	*NA*	66.62
Biomass	83	39.92	17.22	36.44	1.25	94.83	*NA*	94.83
Mean		28.02	6.72	32.48	1.77	**68.99**		**68.99**
Non-carbon emitting technologies								
Wind, onshore	40	29.63	7.52	0.00	2.80	39.95	*NA*	39.95
Wind, offshore	44	90.95	28.65	0.00	2.65	122.25	*NA*	122.25
Solar photovoltaic[3]	29	26.14	6.00	0.00	3.59	35.74	-2.61	33.12
Hydroelectric[4,5]	59	37.28	10.57	3.07	1.87	52.79	*NA*	52.79
Advanced nuclear	90	56.12	15.36	9.06	1.10	81.65	-6.76	74.88
Geothermal	90	20.38	14.48	1.16	1.45	37.47	-2.04	35.43
Mean		43.42	13.76	2.22	2.24	**61.64**		**59.74**

Table 4. Estimated levelized cost of electricity (LCOE, unweighted) by carbon and non-carbon sources for new generation resources entering service in 2040 (2019 dollars/MWH) (adapted from Table 2 above)

Plant type	**Capacity factor (%)**	**Levelized capital cost**	**Levelized fixed O&M[1]**	**Levelized variable O&M**	**Levelized transmission cost**	**Total system LCOE**	**Levelized tax credit[2]**	**Total LCOE including tax credit**
Carbon emitting technologies								
Ultra-supercritical coal	85	43.97	5.43	22.17	1.25	72.81	*NA*	72.81
Combined cycle	87	7.50	1.59	32.52	1.28	42.89	*NA*	42.89
Combustion turbine	30	13.89	2.65	52.15	3.70	72.39	*NA*	72.39
Biomass	83	33.25	17.22	35.02	1.34	86.83	*NA*	86.83
Mean		24.65	6.72	35.47	1.89	**68.73**		**68.73**
Non-carbon emitting technologies								
Wind, onshore	40	25.51	7.49	0.00	2.97	35.97	*NA*	35.97
Wind, offshore	44	53.85	28.83	0.00	2.85	85.53	*NA*	85.53
Solar photovoltaic[3]	29	19.86	6.00	0.00	3.83	29.70	-1.99	27.71
Hydroelectric[4]	70	40.98	9.22	1.39	2.00	53.58	*NA*	53.58
Advanced nuclear	90	48.21	15.36	9.47	1.18	74.22	-4.85	69.37
Geothermal	90	18.86	15.88	1.16	1.55	37.44	-1.89	35.56
Mean		34.55	13.80	2.00	2.40	**52.74**		**51.29**

Table 5. Estimated levelized cost of electricity (LCOE, unweighted) by non-renewable and renewable sources for new generation resources entering service in 2025 (2019 dollars/MWH) (adapted from Table 1 above)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit[2]	Total LCOE including tax credit
Non-renewable technologies								
Ultra-supercritical coal	85	47.57	5.43	22.27	1.17	76.44	*NA*	76.44
Combined cycle	87	8.4	1.59	26.88	1.2	38.07	*NA*	38.07
Combustion turbine	30	16.17	2.65	44.33	3.47	66.62	*NA*	66.62
Advanced nuclear	90	56.12	15.36	9.06	1.1	81.65	-6.76	74.88
Mean		32.07	6.26	25.64	1.74	**65.70**		**64.00**
Renewable technologies								
Wind, onshore	40	29.63	7.52	0	2.8	39.95	*NA*	39.95
Wind, offshore	44	90.95	28.65	0	2.65	122.25	*NA*	122.25
Solar photovoltaic[3]	29	26.14	6	0	3.59	35.74	-2.61	33.12
Hydroelectric[4,5]	59	37.28	10.57	3.07	1.87	52.79	*NA*	52.79
Biomass	83	39.92	17.22	36.44	1.25	94.83	*NA*	94.83
Geothermal	90	20.38	14.48	1.16	1.45	37.47	-2.04	35.43
Mean		40.72	14.07	6.78	2.27	**63.84**		**63.06**

Table 6. Estimated levelized cost of electricity (LCOE, unweighted) by non-renewable and renewable sources for new generation resources entering service in 2040 (2019 dollars/MWH) (adapted from Table 2 above)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit[2]	Total LCOE including tax credit
Non-renewable technologies								
Ultra-supercritical coal	85	43.97	5.43	22.17	1.25	72.81	*NA*	72.81
Combined cycle	87	7.5	1.59	32.52	1.28	42.89	*NA*	42.89
Combustion turbine	30	13.89	2.65	52.15	3.7	72.39	*NA*	72.39
Advanced nuclear	90	48.21	15.36	9.47	1.18	74.22	-4.85	69.37
Mean		28.39	6.26	29.08	1.85	**65.58**		**64.37**
Renewable technologies								
Wind, onshore	40	25.51	7.49	0	2.97	35.97	*NA*	35.97
Wind, offshore	44	53.85	28.83	0	2.85	85.53	*NA*	85.53
Solar photovoltaic[3]	29	19.86	6	0	3.83	29.7	-1.99	27.71
Hydroelectric[4,5]	70	40.98	9.22	1.39	2	53.58	*NA*	53.58
Biomass	83	33.25	17.22	35.02	1.34	86.83	*NA*	86.83
Geothermal	90	18.86	15.88	1.16	1.55	37.44	-1.89	35.56
Mean		32.05	14.11	6.26	2.42	**54.84**		**54.20**