ELECTRICITY OVERVIEW

Generation, transmission, and distribution of electricity are responsible for 25% of GHG emissions in the U.S.[1] Conventional electricity-generating technologies such as coal, oil, and natural gas-fired power plants emit large quantities of carbon dioxide as well as small quantities of methane and nitrous oxide. All are heat-trapping gases that contribute to global warming. Many strategies are available to reduce/eliminate these sources of emissions (a set of practices that is called "decarbonization"), including:

- Increasing the efficiency of fossil fuel energy production by substituting less carbon-intensive fossil fuels and adopting efficiency measures like combined heat and power generation;
- Substituting renewable and other low-emissions energy for fossil fuel energy;
- Increasing end-use efficiency though advanced technologies (e.g., like many of those reviewed in "Buildings and Homes") or decreasing end-use demand (e.g., through time-variant electric pricing); and
- Implementing carbon capture and storage practices, in which carbon dioxide is captured before being emitted into the atmosphere, and stored securely underground (see "Sequestration").

The volume of GHG emissions produced by the electricity sector in the U.S. is already on its way down, from a peak of 2,466 million metric tons CO_2e in 2007 to 1,648 million tons CO_2e in 2019.[2] However, to reach a zero-emissions target on a timeline that climate experts believe is necessary to keep global warming within a manageable 1.5 degrees C, the rate of decline in electricity emissions must be dramatically increased as soon as possible.[3]

A net-zero economy will not just require decarbonization of the electric generation and distribution system, but will also require electrification of many functions that were previously not electrified, such as transportation and heating. Because there is no zero-emissions fuel that can power cars and trucks or heat homes and businesses directly, as oil, natural gas, and even coal have done for more than a century, decarbonizing these functions requires them to first be made electric, so that they can then be supplied with clean electricity from a renewable or zero-emissions source. In a full electrification scenario, demand for electricity is expected to increase by 38% by the year 2050.[4] Thus, plans and policies for the electricity sector must take into account the electricity needs of tomorrow as well as today.

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[1] EPA. "Sources of greenhouse gas emissions." https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

[2] EPA. "Greenhouse gas inventory explorer." https://cfpub.epa.gov/ghgdata/inventoryexplorer/#electricitygeneration/entiresector/allgas/category/all

[3] Plumer, Brad and Popovich, Nadja (October 25, 2021). "Yes, there has been progress on climate. No, it's not nearly enough." *New York Times.* https://www.nytimes.com/interactive/2021/10/25/climate/world-climate-pledges-cop26.html

[4] NREL (July 9, 2018). "NREL analysis explores demand-side impacts of a highly electrified future."

Solutions in the electricity sector include renewable energy (e.g., solar, wind, geothermal, hydropower, ocean power, and biomass), non-renewable zero-emissions energy (i.e., nuclear), and energy production methods that emit GHGs, but *fewer* GHGs than the current energy portfolio (e.g, biomass, landfill methane capture, methane digesters, combined heat and power). Some of these technologies are deployable as distributed energy resources (DER; e.g., micro wind turbines, solar PV panels, geothermal energy, small hydro), while others are deployable at utility scale (e.g., utility-scale wind and solar).

Since many renewable energy sources (e.g., sun and wind) are intermittent, scaling up energy storage is a vital step to enabling full decarbonization of the electric sector. Transmission and distribution improvements are also needed to convert grid systems that were designed for centralized electricity production into grids that combine both DER and utility-scale energy while responding in real time to fluctuations in supply and demand across multiple geographic scales.

A comprehensive, landscape-scale approach to solving climate change in the electricity sector could, in theory, start by taking stock of total potential capacity for generation of renewable and zero-emissions technologies in the U.S., and then measuring the gap between current capacity and potential capacity to understand where opportunities lie. In practice, this is difficult to do at a national level because of differences in methodologies, reporting units, and assumptions across regions and technologies.[5] Furthermore, many factors interact to shape the potential contribution of various technologies to the energy portfolio, including:

- Resource potential, which is function of physical constraints, physical potential, and the energy content of the energy resource (i.e., fossil fuels, sun, wind, geothermal resource, waterways for hydropower, etc.).
- Technical potential, which is a function of topographical constraints, land use constraints, and system performance.
- Economic potential, which is a function of projected technology costs and projected fuel costs.
- Market potential, which is a function of policy implementation and impacts, regulatory limits, investor response, and regional competition with other energy sources.[6]

A rough indication of the relative production potential of the top ten renewable energy technologies in the U.S. can be found in
Table 1. This table displays technical energy potential in two forms: capacity and generation. Capacity (often called "nameplate capacity") is the maximum output of electricity that a generation source can produce under ideal conditions, and it is measured in watts. Generation is the amount of energy that is produced over a certain amount of time, and it is measured in

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[5] DOE Office of Energy Efficiency and Renewable Energy (EERE). (October 2006, updated January 2011). "Report to Congress on Renewable Energy Resource Assessment Information for the United States." January 2011 (EPACT) Prepared by the National Renewable Energy Laboratory.

[6] NREL. 2012. *U.S. renewable energy technical potentials: A GIS-based analysis.* https://www.nrel.gov/docs/fy12osti/51946.pdf

watt-hours (a measure of electrical energy equivalent to a power consumption of one watt for one hour) per unit time.[7] The "capacity factor" of a generation source is equal to the source's capacity divided by its generation, and it is an indication of the percentage of time that the power source is actually producing energy.[8] Figure 1 compares capacity factors for renewable and conventional energy technologies.

Although technical potential offers a rough indication of the relative scalability of different energy technologies, many other factors determine what is actually feasible or most cost effective, including allocation of available land among technologies, availability of existing or planned transmission infrastructure, relative reliability of time-of-productions of power, costs associated with developing power at any location, the present of local, state, or national policies that could encourage or discourage development, and the location and magnitude of current and potential electricity loads.[9] Prices of many renewable energy technologies are dropping rapidly, but others, like geothermal and hydropower, are rising in costs because they have targeted the best locations first and their expansion can only take place in locations that are more costly to develop (see Figure 2).

Many electricity solutions have lifecycle impacts that are important to consider and address when evaluating their fishery friendliness and climate change-solving capacity. Lifecycle impacts include not only those that occur during operation, but also upstream impacts (e.g., resource extraction, material manufacturing, component manufacturing, and construction) and downstream (e.g., dismantling, decommissioning, disposal, and recycling). Nuclear energy is a well-known example of a zero-emissions technology that is hampered by concerns about the sourcing of materials (e.g, uranium) and disposal of radioactive waste (which can remain dangerous for up to a million years[10]), but nuclear is not the only electricity solution with lifecycle impacts: *all* energy technologies have *some* lifecycle impacts. Even in the fishery-friendliest possible energy portfolio possible, some degree of impacts to ecosystems and natural resources will be inevitable, and minimizing these impacts is a matter of evaluating tradeoffs and choosing among the best alternatives, not of eliminating impacts altogether.

All electricity solutions have some lifecycle GHG emissions, even those that produce no emissions during electricity generation. These emissions can take place during manufacturing, transportation, installation, operation, and decommissioning. Table 2. Median published life cycle emissions factors for electricity generation technologies. Source: NREL 2021.and Figure 3 present comparisons of lifecycle emissions for various renewable generation and storage technologies alongside conventional energy generation technologies. As these data show, even

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[7] DOE (August 7, 2017). "What's the difference between installed capacity and electricity generation?" https://www.energy.gov/eere/articles/whats-difference-between-installed-capacity-and-electricity-generation

[8] Wikipedia. "Capacity factor." https://en.wikipedia.org/wiki/Capacity_factor

[9] NREL. 2012. *U.S. renewable energy technical potentials: A GIS-based analysis.* https://www.nrel.gov/docs/fy12osti/51946.pdf

[10] Ro, Christine. (November 26, 2019). "The staggering timeline of nuclear waste disposal." https://www.forbes.com/sites/christinero/2019/11/26/the-staggering-timescales-of-nuclear-waste-disposal/?sh=e68987729cf5

the renewable and storage technologies with the highest lifecycle emissions emit far fewer GHG emissions than oil, coal, and even natural gas.

Some renewable energy solutions, like utility solar arrays and onshore and offshore wind farms, require a lot of space. Figure 4 shows the "surface power density" of various renewable and conventional energy technologies. Depending on where and how these developments are sited, they have the potential to compete with other activities and alter land and water use, with attendant impacts to ecosystems, natural resources, and dependent communities. These should be considered carefully when evaluating the fishery friendliness of these climate solutions.

Wind, solar, and energy storage (as well as electric vehicles, which represent the electrification of transportation) depend on inputs of minerals. Key minerals for renewable energy and storage technologies include the following:[11]

- Lithium-ion batteries: cobalt, lithium, nickel, manganese
- Electric vehicles (EVs): rare earths (neodymium and dysprosium)
- Solar PV: cadmium, indium, gallium, selenium, silver, tellurium
- Wind power: rare earths (neodymium and dysprosium)
- Aluminum and copper are used in all technologies

Figure 5 shows how various types of energy generation (renewable and conventional) stack up in their use of these minerals. Many of these minerals are difficult or impossible to substitute, as they have key properties that enable renewable energy and energy storage technologies to function at scale. Some, like copper, are recyclable, but others, like lithium, silver, and rare earths are difficult to recycle with current technologies.[12] As these renewable energy and energy storage technologies are deployed at greater scales, observers note that it will be necessary to assure that the sourcing of such minerals is done in an environmentally and socially responsible manner and that once they have served their useful life, these materials are reused or recycled so as to avoid creating waste, while reducing the need for additional primary sourcing of minerals that are either rare or limited by environmental, social, or geopolitical constraints.[13]

Many policy tools are available to help achieve broader deployment of electricity sector climate solutions, including:

- Net metering: Forty states have enacted policies that enable net metering, which allows utility customers producing DER to deliver excess electricity into the grid in exchange for

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[11] Institute for Sustainable Futures. 2019. *Responsible minerals sourcing for renewable energy.* Prepared for Earthworks. https://earthworks.org/assets/uploads/2019/04/MCEC_UTS_Report_lowres-1.pdf

[12] Institute for Sustainable Futures. 2019. *Responsible minerals sourcing for renewable energy.* https://earthworks.org/assets/uploads/2019/04/MCEC_UTS_Report_lowres-1.pdf

[13] Institute for Sustainable Futures. 2019. *Responsible minerals sourcing for renewable energy.* https://earthworks.org/assets/uploads/2019/04/MCEC_UTS_Report_lowres-1.pdf

credits against their electric bills.[14] In addition, some states allow for “virtual net metering,” in which consumers can earn credit for a share in a DER system that they own that produces electricity offsite (including community solar, in which individuals purchase a share of a utility-scale project and receive credits for their “share” of production).

- Standard offer contracts / feed-in tariffs: Standard offer contracts (SOCs), which include feed-in tariffs, operate by offering a certain value (either through credit or payment) for the generation and delivery of DER energy to the grid. SOCs can be tailored for wholesale producers or customer generators.[15] Seven states have policies that enable feed-in tariffs,[16] a type of SOC that allows utility customers with DER to sell the electricity produced from these systems to their local utility at a fixed cost. Customers who use less electricity than they sell can come make a net profit.
- Interconnection standards: To make it easier for ratepayers who install DER to interconnect with (i.e., “plug into”) the grid, 36 states and D.C. have adopted interconnection standards that lay out a clear and straightforward interconnection process.[17]
- Tax incentives: Many state and federal programs provide tax incentives, usually in the form of investment or production-based tax credits, to individuals and businesses that adopt clean electricity production or energy efficiency practices.
- Grants: Some state and federal programs provide grants to businesses, farmers, and homeowners to defray the costs of installing energy efficiency and renewable energy systems.
- Financing mechanisms: There are a number of financing programs available to businesses and individuals to help them overcome the up-front investment costs associated with installing energy efficiency and DER systems. These include loans, bonds, and on-bill financing (also called on-bill repayment, in which a utility or a third-party private entity pays for a customer’s DER or energy efficiency project, and then bills the customer for repayment through their utility bills).[18] Twelve states have implemented on-bill financing/repayment legislatively, and 19 states have done so through utility programs approved by state Public Utilities Commissions.[19]
- Standards: Ten states have a Renewable Portfolio Standard (RPS), a policy prescribing that a certain percentage of the state’s electricity use must be supplied by renewable

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[14] Center for the New Energy Economy. 2019. “Net metering and aggregate net metering.” https://spotforcleanenergy.org/wp-content/uploads/2021/06/8469d28617f5c88ef3634ea6b0200894.pdf

[15] Center for the New Energy Economy. 2017. “Renewable standard offer.” https://spotforcleanenergy.org/wp-content/uploads/2017/05/48598afcc9a3d4a497e5f285c9c70b16.pdf

[16] Energy Sage. “Feed-in tariffs: A primer on feed-in tariffs for solar.” https://news.energysage.com/feed-in-tariffs-a-primer-on-feed-in-tariffs-for-solar/

[17] Center for the New Energy Economy. 2019. “Interconnection standards.” https://spotforcleanenergy.org/wp-content/uploads/2016/05/184511ff9ae2c70a7b8be09492a70533.pdf

[18] Center for the New Energy Economy. 2016. “On-bill repayment and on-bill financing.” https://spotforcleanenergy.org/wp-content/uploads/2016/03/9b01946799e4b5aa2ad36382efb3d1e4.pdf

[19] Center for the New Energy Economy. 2016. “On-bill repayment and on-bill financing.” https://spotforcleanenergy.org/wp-content/uploads/2016/03/9b01946799e4b5aa2ad36382efb3d1e4.pdf

energy by a certain date.[20] Thirty states have a Clean Energy Standard (CES), a policy prescribing that a certain percentage of the state's electricity use must be supplied by clean energy by a certain date.[21] Although these standards are similar, they differ in what kinds of electricity qualifies to meet the quota: nuclear power would qualify under a CES but not an RPS, while biomass would qualify under an RPS but not a CES.

- Utility green power option: Thirteen states require electricity providers to offer green power options to customers, and 47 states have voluntary green pricing programs. Green power options enable customers to opt to purchase their power from renewable energy sources such as wind or solar rather than from conventional fossil fuel sources.[22] In one form of green power option, the community choice aggregation (CCA) model, a community can aggregate their load and purchase energy from a supplier other than the default utility; customers in the community who do not wish to participate can opt out.[23]
- Cap-and-trade and carbon pricing: Rather than prescribing or supporting specific technologies, carbon pricing and cap-and-trade programs are economy-wide approaches that focus on bringing down GHG emissions through market-based mechanisms. These policies make renewable and zero-emission energy more competitive in the marketplace relative to fossil fuel energy, and they let the market decide on the precise mix of energy and efficiency solutions that are employed as a result. Eleven Northeast states from Virginia to Maine are participants in the Regional Greenhouse Gas Initiative (RGGI), a cap-and-trade program established in 2005 to cap and reduce emissions from the electricity sector. The program issues a certain number of annual emissions allowances to utilities, which they may then trade amongst themselves so that those who reduce their emissions most quickly profit the most. The number of allowances issued decreases over time so that total emissions come down for the region as a whole. California has had a cap-and-trade program in place since 2013. Another way to put a price on carbon is through a carbon fee ($/ton), combined with a border adjustment to ensure that a flood of cheaper imported goods does not undermine emissions reductions or harm domestic production. Five carbon pricing bills were introduced in the 117th session of Congress, and ten carbon pricing bills were introduced in the previous session.[24]

More information:

- [NREL: Net metering]

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[20] National Conference of State Legislatures (NCSL; August 31, 2021). "State renewable portfolio standards and goals." https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx

[21] National Conference of State Legislatures (NCSL; August 31, 2021). "State renewable portfolio standards and goals." https://www.ncsl.org/research/energy/renewable-portfolio-standards.aspx

[22] Center for the New Energy Economy. 2019. "Utility green power option." https://spotforcleanenergy.org/wp-content/uploads/2021/07/b8babdc1c1835445e5a80ae94352e001.pdf

[23] Center for the New Energy Economy. 2019. "Utility green power option." https://spotforcleanenergy.org/wp-content/uploads/2021/07/b8babdc1c1835445e5a80ae94352e001.pdf

[24] RFF (June 21, 2021). "Carbon pricing tracker." https://www.rff.org/publications/data-tools/carbon-pricing-bill-tracker/

- Energy Sage: Feed-in tariffs – A primer on feed-in tariffs for solar
- DOE: Funding and financing
- Resources for the future (RFF): Clean energy standards
- National Conference of State Legislatures (NCSL): State renewable portfolio standards and goals
- C2ES: U.S. state carbon pricing policies
- C2ES: Regional Greenhouse Gas Initiative (RGGI)
- C2ES: California cap-and-trade
- RFF: Carbon pricing tracker
- State Policy Opportunity Tracker (SPOT) for Clean Energy: net metering, renewable standard offer, Interconnection standards, on-bill financing / on-bill repayment, utility green power option, Renewable Portfolio Standard
- Database of State Incentives for Renewables and Efficiency (DSIRE)
- Institute for Sustainable Futures. 2019. *Responsible minerals sourcing for renewable energy.*
- Roberts, David (February 7, 2022). "Here are the minerals we need for batteries, solar, and other clean energy tech." *Canary Media.*

Table 1. Total estimated U.S. technical potential in annual generation and installed capacity, for various renewable and low-carbon technologies. For this analysis, "renewable energy technical potential" is defined as "the achievable energy generation of a particular technology given system performance, topographic limitations, environmental, and land-use constraints." Source: NREL 2012.[25]

Technology	Generation Potential (TWh)	Capacity Potential (GW)
Urban utility-scale PV	2,200	1,200
Rural utility-scale PV	280,600	153,000
Rooftop PV	800	664
Concentrating solar power	116,100	38,000
Onshore wind power	32,700	11,000
Offshore wind power	17,000	4,200
Biopower	500	62
Hydrothermal power systems	300	38
Enhanced geothermal systems	31,300	4,000
Hydropower	300	60

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[25] NREL. 2012. *U.S. renewable energy technical potentials: A GIS-based analysis.* https://www.nrel.gov/docs/fy12osti/51946.pdf

Table 2. Median published life cycle emissions factors for electricity generation technologies. Source: NREL 2021.[26]

	Technology	**Lifecycle emissions** (grams CO_2e per kWh)	**Sources** For complete references, refer to NREL 2021.[27]
Renewable	Biomass	52	EPRI 2013 Renewable Electricity Futures Study 2012
	Solar PV (thin film and crystalline silicon)	43	Kim et al. 2012 Hsu et al. 2012 NREL 2012
	Concentrating solar power (tower and trough)	28	Burkhardt et al. 2012
	Geothermal	37	Eberle et al. 2017
	Hydropower	21	DOE 2016
	Ocean power	8	IPCC 2011 DOE 2015
	Wind power (onshore and offshore)	13	DOE 2016
Storage	Pumped storage hydro	7.4	Nicholson et al. 2021
	Lithium-ion battery	33	Khan et al. 2005
	Hydrogen fuel cell	38	Warner and Heath 2012 O' Donoughue et al. 2013
Nonrenewable	Nuclear (light-water reactor only)	13	IPCC 2011 Whitaker et al. 2012
	Natural gas	486	EPRI 2013 Renewable Electricity Futures Study 2012
	Oil	840	Kim et al. 2012 Hsu et al. 2012 NREL 2012
	Coal	1001	Burkhardt et al. 2012

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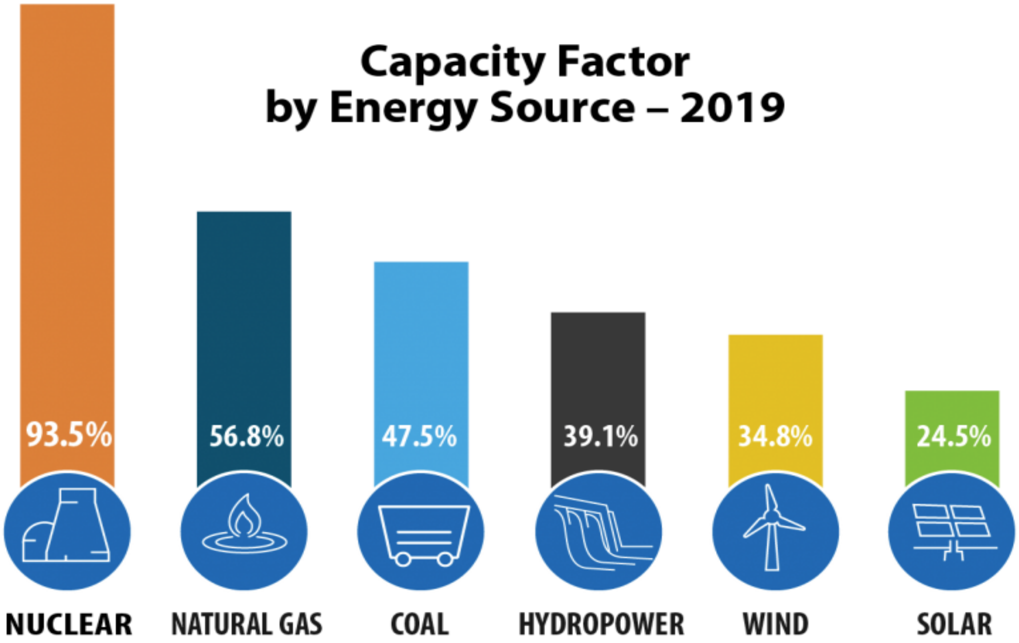
[26] NREL. 2021. "Life cycle greenhouse gas emissions from electricity generation: Update." https://www.nrel.gov/docs/fy21osti/80580.pdf

[27] NREL. 2021. "Life cycle greenhouse gas emissions from electricity generation: Update." https://www.nrel.gov/docs/fy21osti/80580.pdf

Figure 1. Capacity factor (the percentage of time that a power source is generating power). Source: DOE 2020.[28]



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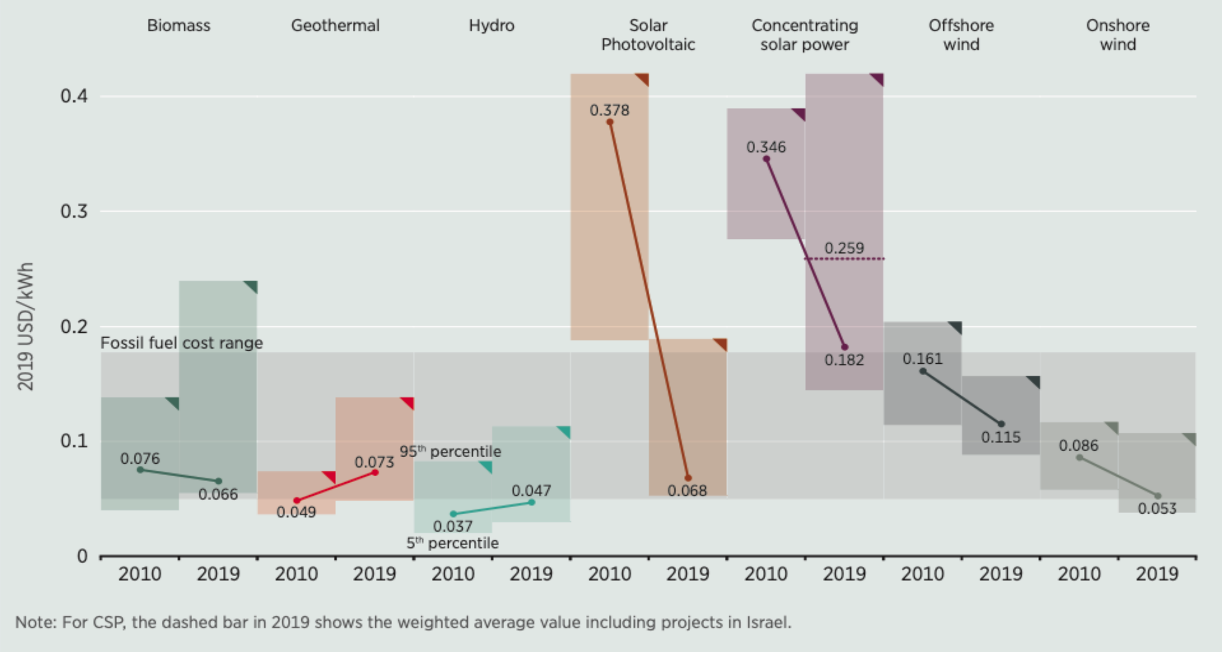
[28] DOE (May 1, 2020). "What is generation capacity?" https://www.energy.gov/ne/articles/what-generation-capacity

Figure 2. Global weighted average levelized cost of electricity from utility-scale renewable power generation technologies, 2010 and 2019. Costs reflect the weighted average of plants commissioned in each year. For comparison, the thick gray band represents the range of costs typical of fossil fuel power generation. The bands for each renewable generation technology represent the 5th and 95th percentiles. Source: IRENA 2020.[29]



Note: For CSP, the dashed bar in 2019 shows the weighted average value including projects in Israel.

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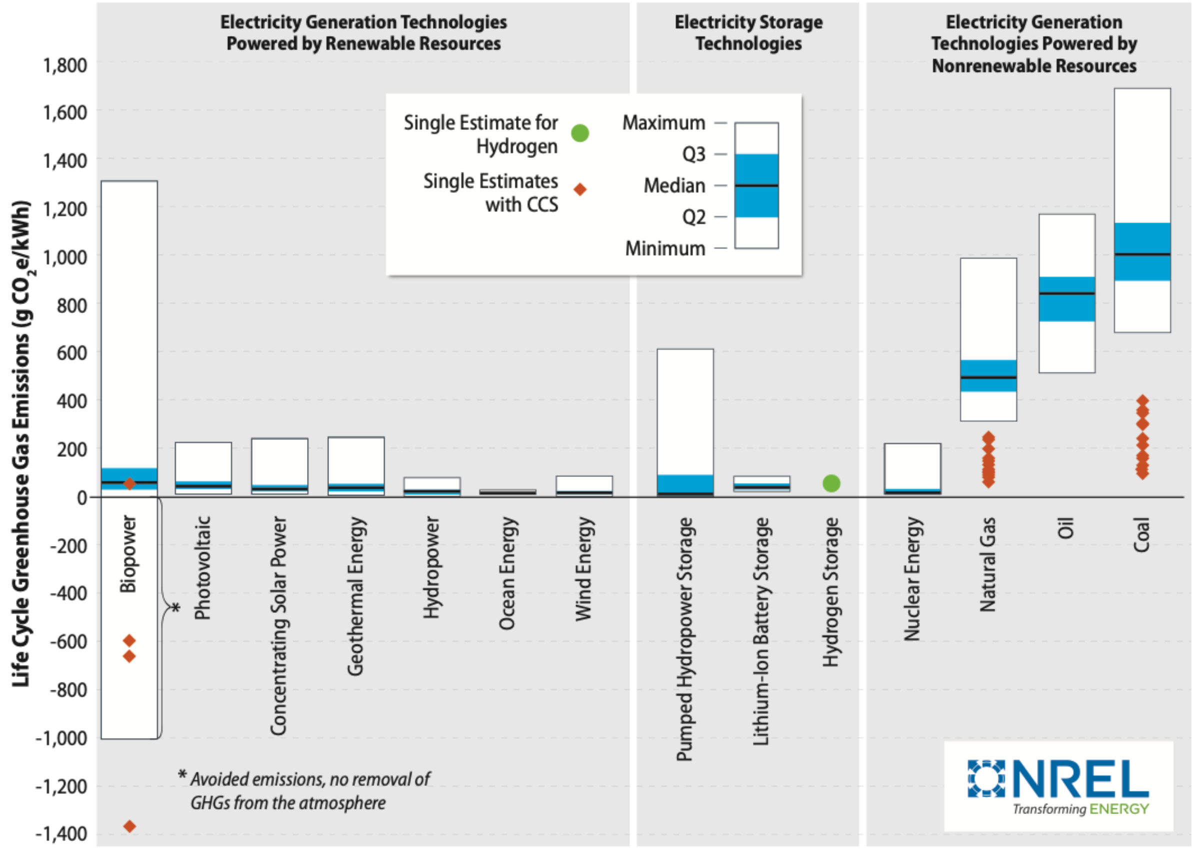
[29] IRENA. 2020. *Renewable power generation costs in 2019.* https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Power_Generation_Costs_2019.pdf

Figure 3. Life cycle GHG emission estimates for selected electricity generation and storage technologies, and some technologies integrated with carbon capture and storage. Source: NREL 2021.[30]



	Biopower	Photovoltaic	Concentrating Solar Power	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Pumped Hydropower Storage	Lithium-Ion Battery Storage	Hydrogen Storage	Nuclear Energy	Natural Gas	Oil	Coal
Estimates	276 (+4)	46	36	35	149	10	186	16	29	1	99	80 (+13)	24	164 (+11)
References	57 (+2)	17	10	15	22	5	69	4	3	1	27	47 (+11)	10	53 (+9)

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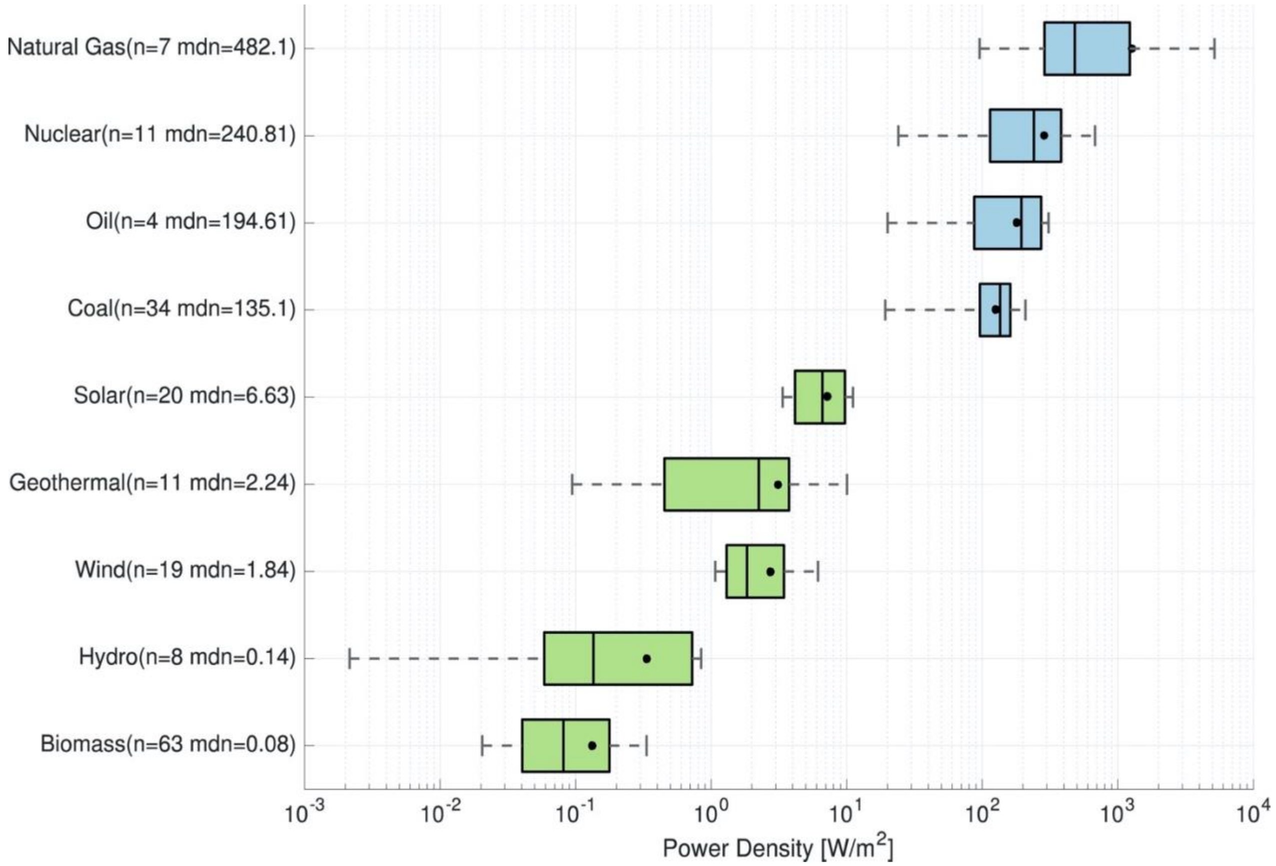
[30] NREL. 2021. "Life cycle greenhouse gas emissions from electricity generation: Update." https://www.nrel.gov/docs/fy21osti/80580.pdf

Figure 4. Median surface power density (electrical power produced per horizontal m^2 of surface area) of renewable and conventional energy sources. Source: van Zalk and Behrens 2018.[31]



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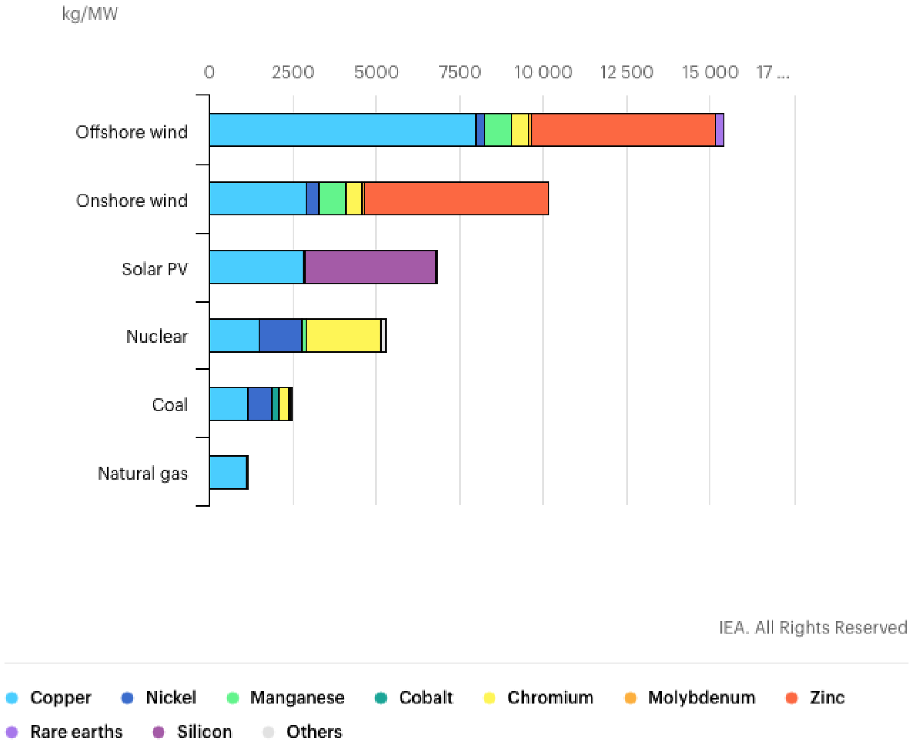
[31] van Zalk, John and Behrens, Paul. 2018. The spatial extent of renewable and non-renewable power generation: A review and meta-analysis of power densities and their application in the U.S. *Energy Policy* 123: 83-91. https://doi.org/10.1016/j.enpol.2018.08.023.

Figure 5. Minerals used in clean energy technologies compared to fossil fuel power generation sources. Source: IEA 2021.[32]



Continue reading at https://fisheryfriendlyclimateaction.org/solutions

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[32] IEA. 2021. *The role of critical minerals in clean energy transitions.* https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf