STUDIES AGREE 80 PERCENT CLEAN ELECTRICITY BY 2030 WOULD SAVE LIVES AND CREATE JOBS AT MINIMAL COST

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SUMMARY

This report highlights key findings from a meta-analysis of 11 studies released since 2020 and led by researchers at prominent universities, think tanks, nonprofits, and energy consultancies. All 11 studies model clean energy policy packages and converge on the immense benefits and feasibility of achieving approximately 80 percent clean electricity by 2030 in the United States. The studies capture the latest renewable technology cost declines, which are largely responsible for models finding that such a goal is achievable at minimal cost—a conclusion not reached by older studies.

These 11 studies collectively affirm that achieving 80 percent clean electricity by 2030 is feasible, affordable, critical to meeting national climate goals, and deeply beneficial to the economy and public health—all without compromising power system reliability.

[i] This report is an update from a previous version released in July 2021. It includes four additional studies and context around the proposed Clean Electricity Payment Program. The original version can be found here: https://energyinnovation.org/wp-content/uploads/2021/07/Studies-Converge-on-Benefits-of-a-Rapid-Clean-Energy-Transition.pdf.

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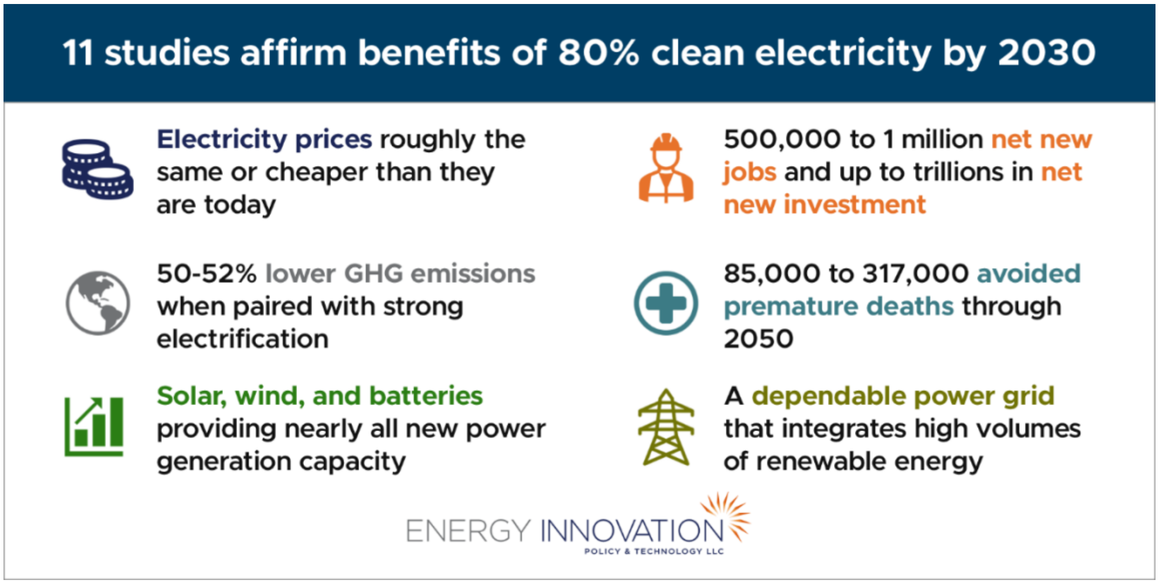
This meta-analysis is intended to help policymakers understand the economic and health benefits of a federal budgetary package that includes a Clean Electricity Payment Program (CEPP).

- **Affordability:** Three studies find wholesale electricity costs—which represent roughly a third of customer electricity bills—in a high clean electricity future would range from 4 percent lower to 3 percent higher in 2030 relative to today's prices. Three other studies find customer electricity bills would rise by less than 4 percent by 2030 and that federal tax credit extensions would put downward pressure on any cost increases.
- **Jobs and investments:** Five studies collectively find that ambitious clean electricity policies would drive a net increase of 500,000 to 1 million new jobs annually and hundreds of billions to trillions of dollars in new clean energy investment.
- **Climate:** All studies provide evidence that achieving roughly 70 to 80 percent clean electricity *and* ambitiously electrifying other sectors are required to achieve the Biden administration's greenhouse gas (GHG) emissions reduction target of 50 percent to 52 percent below 2005 levels by 2030—a level necessary to keep the U.S. on the path to a safer climate future.[1] Given that clean electricity deployment amplifies electrification-based emissions reductions in other sectors, higher levels of clean electricity may be economically and socially preferable to lower levels for meeting this goal.
- **Public health:** Eight studies collectively find that strong federal clean electricity policies would avoid 14,500 to 50,000 premature deaths through 2030 or 2035 and 85,000 to 317,000 premature deaths through 2050; the policies would also avoid combined health and climate damages of $150 billion to $705 billion through 2030 or 2035 and $1 trillion to $3 trillion through 2050. These benefits far outweigh any study's observed energy cost increases.
- **Feasibility:** All studies find the least cost pathway to achieving high penetration of clean electricity runs almost exclusively through new wind, solar, and battery storage—rather than new nuclear, incremental hydropower, geothermal, biomass, carbon capture and storage (CCS), hydrogen, and even natural gas (where partial crediting is allowed). Broadly, the models show achieving approximately 80 to 90 percent clean electricity in the 2030 to 2035 timeline requires building approximately 50 gigawatts (GW) to 100 GW per year of new wind and solar as well as up to 23 GW per year of new battery storage. This is roughly two to three times the U.S. record of 31 GW of wind and solar deployment set in 2020—a challenging but feasible pace of development.
- **Reliability:** All studies collectively suggest a 70 to 90 percent clean electricity system would be dependable (e.g., able to match supply and demand), including five studies that provide rigorous reliability checks of the grid under stressful weather and demand conditions.

Variation in results across these studies is due primarily to differences in assumptions such as technology costs, fuel prices, electricity demand, subsidies (e.g., federal clean energy tax credits), policy design features (e.g., stringency and timing of targets, definition of "clean" energy, alternative compliance mechanisms), and policy scope (e.g., single policies, sectoral policy packages, multi- or cross-sector policy packages). Results also depend on researchers' choice of modeling tools. Despite this variation, the studies collectively find broad agreement on the widespread benefits of a rapid transition to clean electricity.



CONTEXT

This meta-analysis of recent clean energy modeling studies is intended to help policymakers understand what experts have forecasted would occur should legislators enact federal policy to accelerate the clean electricity transition.

As of September 2021, Congress is deliberating a $3.5 trillion budgetary package that includes a CEPP provision that uses financial incentives and penalties to encourage electric utilities to increase their shares of clean electricity generation over time such that the U.S. achieves 80 percent clean electricity *on average* by 2030. Under this design, utilities that make sufficient progress toward their clean electricity goals would receive federal payments to reduce the consumer costs of investments in clean energy.

Notably, the studies in this meta-analysis do not explicitly analyze a CEPP design, which itself is a moving target. Instead, many of these studies explore federal clean electricity standard (CES) designs, which require (rather than incentivize) utilities to meet clean electricity targets over time, similar to existing state programs. Key elements of CES policies include the following:

- Utilities must procure clean energy “credits” from qualifying power plants (or generate their own clean power) to meet their obligations; these credits can typically be traded among utilities as well to keep costs low (e.g., if a utility procures too many credits, it can sell some to another utility that fell short).
- “Clean energy” is typically defined as including any resource that does not emit GHGs, such as wind, solar, geothermal, nuclear, biomass, and hydropower. Some policies award partial credit to natural gas or CCS, with the amount of credit benchmarked to a pre-set emissions rate (i.e., a lower emissions rate translates to a higher credit value).
- Some policies allow utilities to make an alternative compliance payment (ACP) for each credit they fail to procure; ACPs act as a cost ceiling for a given policy.
- Some policies allow utilities to over-procure credits for a given year and “bank” them for use in a later year, providing the option to trade higher near-term emissions reductions for lenience down the road.

The CEPP was designed to achieve the outcome of a CES while taking a purely budgetary (incentives- and penalties-based) approach. While the studies in this meta-analysis examine CES designs, their findings represent the best available proxy for how the CEPP would affect customer bills, the economy, utilities, GHG emissions, public health, and the reliability of the power system.

The key difference between a CES and the CEPP is that while a CES requires electricity customers to cover the cost of compliance, the CEPP is designed to shift the cost burden of the clean electricity transition to the federal taxpayer, insulating lower- and middle-income groups from possible bill increases. All else equal, this should reduce the consumer cost of a CES relative to the results modeled in this meta-analysis. However, computer models also must make simplifying assumptions to ascertain the impacts of a rapid electricity transition on the complex, institutionally diverse U.S. electricity system. Utilities, states, and regions will implement the CEPP with varying degrees of success, due in large measure to the competence of utilities and their regulators. Inevitably, some jurisdictions will find more success than others in unlocking benefits for their electric customers. These results, while highly convergent, represent a high-level national picture.

This paper refers to policy outcomes under a CES (as well as broader power- and cross-sectoral decarbonization policy outcomes) rather than the CEPP in order to relay the results of these studies as accurately as possible.[ii]

[ii] For more information on the CEPP design, see the following August 2021 explainer from Clean Air Task Force: https://www.catf.us/wp-content/uploads/2021/08/CATF_CEPP_2Pager_08.05.21.pdf.

METHODOLOGY

This meta-analysis reviewed six studies that model clean electricity standards (“Tier 1”), one study that models other power sector decarbonization policies (“Tier 2”), and four studies that model economy-wide decarbonization policy pathways (“Tier 3”). The studies vary widely in their institutional authorship (e.g., universities, think tanks, nonprofits, energy consultancies), models and datasets employed, cases and sensitivities tested, and metrics reported, but they all demonstrate widespread benefits of ambitious federal clean electricity policy.

The meta-analysis primarily draws from the studies’ policy scenarios, which are cases that test policies (such as a CES) but use industry-standard assumptions around electricity demand, fuel prices, financing costs, and renewable energy technology costs. Some studies also report results from “sensitivities,” which apply the same policies as a given policy scenario but flex one or more underlying assumptions to test their impact on the outputs. For example, a sensitivity might assume much higher renewable energy technology costs or lower fuel prices to see how this affects the cost of electricity. We report the results of these sensitivities in footnotes where applicable throughout the meta-analysis.

The table below summarizes these 11 studies. Wherever possible, we highlight assumptions and metrics for 2030, given the year’s relevance to current federal policy discussions about incentivizing a transition to 80 percent clean electricity by 2030. The brief summarizes the key findings, although much more detailed information by study is available in an accompanying public Google Sheet.[2]

Tier	Study	Authors	Date	Summary of Relevant Cases
1	Evaluation of Power Sector Emissions Reduction Pathways[3]	Resources for the Future, REBA Institute	Jul. 2021	**80 percent by 2030 CES;** no partial crediting for gas
1	An 80x30 Clean Electricity Standard: Carbon, Costs, and Health Benefits[4]	Clean Energy Futures (Syracuse University, Harvard University, Georgia Institute of Technology, Resources for the Future, Southern University of Science and Technology)	Jul. 2021	100 percent by 2040 CES **(achieving 83 percent clean electricity by 2030);** partial crediting for natural gas until 2040; banking allowed through 2050
1	2030 Report[5]	UC Berkeley, GridLab, Energy Innovation	Apr. 2021	**80 percent by 2030 CES** with high electrification of other sectors; no partial crediting for gas; all coal forced to retire by 2030; model not permitted to build new gas-fired power plants

Tier	Study	Authors	Date	Summary of Relevant Cases
1	Robust Decarbonization of the U.S. Power Sector: Policy Options[6]	Harvard University	Apr. 2021	Three 100 percent by 2035 CES policies **(with 80 percent by 2030 interim CES targets)** allowing partial crediting for gas; one 90 percent by 2035 CES policy **(with a 70 percent by 2030 interim CES target)** with no partial crediting for gas
1	2035 Report[7]	UC Berkeley, GridLab, PaulosAnalysis	Jun. 2020	90 percent by 2035 CES **(with a 70 percent by 2030 interim CES target);** no partial crediting for gas; all coal forced to retire by 2035; model not permitted to build new gas-fired power plants
1	Two Key Design Parameters in Clean Electricity Standards[8]	Resources for the Future	Mar. 2020	Four 100 percent by 2050 CES policies differing on partial crediting for gas and target escalation rates **(achieving 58 to 70 percent clean electricity by 2035)**
2	Federal Clean Energy Tax Credits: A Vital Building Block for Advancing Clean Electricity[9]	Union of Concerned Scientists	Apr. 2021	Clean Energy for America Act (2019), which would extend technology-neutral tax credits at full value, phasing down in the mid-2030s **(achieving 62 percent clean electricity by 2035)**
3	Decarb America Research Initiative[10]	Decarb America (Bipartisan Policy Center, Clean Air Task Force, Third Way)	TBD	Economy-wide decarbonization pathways that include five 100 percent by 2050 CES scenarios and a 100 percent by 2035 CES scenario **(achieving 84 percent clean electricity by 2030);** most scenarios allow partial crediting for gas
3	A Transformative Climate Action Framework: Putting People at the Center of Our Nation's Clean Energy Transition[11]	Union of Concerned Scientists (in collaboration with an Expert Advisory Committee)	Jul. 2021	Two scenarios achieving net economy-wide GHG emissions reductions of 50 percent below 2005 levels by 2030 (and net-zero by 2050), power sector emissions reductions of 80 percent below 2005 levels by 2030, and high levels of investment in energy efficiency and electrification in other sectors; main scenario **achieves 74 percent clean electricity by 2030**
3	The Biden Administration Must Swiftly Commit to Cutting Climate Pollution At Least 50 Percent by 2030[12]	Natural Resources Defense Council, Evolved Energy Research	Mar. 2021	Scenario that reduces net economy-wide GHG emissions 53 percent below 2005 levels by 2030 **(achieving 80 percent clean electricity by 2030)**
3	Net-Zero America[13]	Princeton University	Dec. 2020	Five pathways to achieving net-zero economy-wide GHG emissions by 2050 **(achieving 70 to 85 percent clean electricity by 2030)**

FINDINGS

AFFORDABILITY

Rapid cost declines for wind, solar, and battery storage have made a transition to at least 80 percent clean electricity by 2030 possible at a modest cost to electricity customers. The reviewed studies vary in the metrics used to assess affordability, making "apples-to-apples" comparisons challenging. Yet, as a group, the studies converge on the possibility of achieving rapid electricity sector decarbonization at relatively low incremental cost—generally ranging from bill savings to small cost increases.

Electricity cost projections do *not* factor in the avoided public health and climate damages realized by a rapid transition from fossil to clean energy. Substantial reductions in harmful air pollution and climate-related economic costs drive enormous benefits across all reviewed studies, vastly exceeding the incremental cost of a CES and making such a transition a "no regrets" policy target.

Three studies report affordability metrics in terms of changes to wholesale electricity costs, which typically make up roughly a third of customers' electricity bills. The studies suggest that **high penetration of clean electricity may result in 2030 wholesale electricity costs that are 4 percent lower to 3 percent higher than today's prices—that is, plus or minus 1 percent of customer electricity bills.**

- UC Berkeley's 2030 Report modeling an 80 percent by 2030 CES (with high electrification of other sectors) finds wholesale electricity costs[iii] would be the same in 2030 as in 2020.[iv]
- UC Berkeley's 2035 Report modeling a 90 percent by 2035 CES (achieving 70 percent clean electricity by 2030) finds wholesale electricity costs would be 4 percent lower in 2030 relative to today.[v]

[iii] In the UC Berkeley studies, "wholesale electricity costs" include total capital and operational costs of power plants, plus incremental transmission costs (which the studies report as 5.1 cents per kilowatt-hour on average in the U.S. in 2020). They do not consider existing transmission or existing and new distribution system costs.

[iv] Sensitivities range from costs being 8 percent lower to 4 percent higher in 2030 relative to 2020.

[v] Sensitivities range from costs being 10 percent lower to 12 percent higher in 2030 relative to 2020. Numbers estimated from the 2035 Report's accompanying Data Explorer.

- Harvard University's study modeling four 90 to 100 percent by 2035 CES policies (achieving 70 to 80 percent clean electricity by 2030) finds wholesale electricity costs[vi] would range from 3 percent lower to 3 percent higher in 2030 relative to today.[vii]

Three other studies report affordability metrics in terms of how retail electricity prices (i.e., the entire customer electricity bill) would change relative to a "business-as-usual" case wherein no new policies are adopted. The studies find that **high penetration of clean electricity should raise electricity bills by less than 4 percent by 2030, and that an extension of federal tax credits would put downward pressure on any cost increases.**

- The Resources for the Future and REBA Institute study modeling an 80 percent by 2030 CES finds retail electricity prices would be 3.7 percent higher in 2030 relative to a business-as-usual case.[viii]
- The Resources for the Future study modeling four 100 percent by 2050 CES policies (achieving 58 to 70 percent clean electricity by 2035) finds retail electricity prices would be just 1 to 3 percent higher in 2035 relative to a business-as-usual case.[ix]
- The Union of Concerned Scientists' study modeling different federal tax credit policies finds that each would result in "slightly lower electricity bills for households and businesses" (all else equal) while achieving up to 62 percent clean electricity by 2035, shifting some of the upfront costs of a clean energy transition to the federal government.

Finally, two other studies that model economy-wide decarbonization policy packages report macro-level affordability metrics. Each suggests **unlocking the enormous benefits of addressing climate change requires relatively modest spending.**

- The Natural Resources Defense Council's study modeling a 53 percent reduction in net economy-wide GHG emissions by 2030 (relative to 2005 levels) finds the policy package would require investments equivalent to a mere 0.4 percent of forecast U.S. gross domestic product in 2030.[x]

[vi] In the Harvard University study, "wholesale electricity costs" are calculated as annualized capital costs plus annual fuel and operations and maintenance costs divided by annual load. The study reports such costs as approximately 3.6 cents per kilowatt-hour on average in the U.S. in 2020.

[vii] Sensitivities range from costs being 19 percent lower to 17 percent higher than today's costs by 2030. Numbers estimated from Figure 2 of the Harvard University study.

[viii] The study reports that this cost increase is conservative due to several artificial constraints that—if relieved—would lower costs (e.g., electricity demand not being affected by electricity prices, Canadian generation not being allowed to earn clean energy credits). Additionally, the study does not assume future clean energy tax credits, which would mitigate any upward pressure that a CES may exert on electricity bills. The study also notes that costs would fall if the West and Southeast adopted competitive electricity markets and if the U.S. built more high voltage transmission lines.

[ix] Numbers estimated from Figure 7 of the Resources for the Future study; 2030 data were not reported.

[x] These investments represent the costs of deploying new clean energy technologies minus the savings of reduced fossil-fuel-related expenses, above those investments forecasted under a business-as-usual case.

- Princeton University's study modeling five pathways that each achieve net-zero economy-wide GHG emissions by 2050 finds each pathway would require total U.S. energy expenditures to increase by less than 3 percent through 2030.

JOBS AND INVESTMENTS

Five studies directly modeled and reported jobs impacts or clean energy investment, collectively finding that **ambitious clean energy policy would drive a net increase of 500,000 to 1 million jobs annually and hundreds of billions to trillions of dollars in clean energy investment.**

- UC Berkeley's 2035 Report shows a 90 percent by 2035 CES would support a net increase of 530,000 jobs annually[xi] and drive $1.6 trillion in clean energy investments and $100 billion in new transmission capital investments from 2019 to 2035.[xii]
- UC Berkeley's 2030 Report shows an 80 percent by 2030 CES would drive $1.5 trillion in new clean energy investments and $100 billion in new transmission capital investments from 2020 to 2030.[xiii]
- The Union of Concerned Scientists' study modeling an expanded, long-term federal tax credit extension shows this policy alone would drive an additional $177 billion in wind and solar investments from 2020 to 2035 (i.e., above those funds projected to be disbursed under existing federal tax credit policies), at a cost to the U.S. Treasury of only $63 billion.[xiv]
- Decarb America's study finds achieving net-zero economy-wide GHG emissions by 2050 (including a 100 percent by 2050 CES and strong cross-sectoral electrification policies) would drive incremental investment of $285 billion in power infrastructure through 2030 and

  $4.2 trillion in power infrastructure[xv] between 2031 and 2050—above business-as-usual investments.[xvi] This policy pathway would also support an average net increase of 130,000 direct jobs in the power sector annually through 2030.[xvii]

[xi] Calculated from the 2035 Report's accompanying Data Explorer tool.
[xii] "Clean energy investments" include new capacity costs and refurbishment; "transmission capital investments" include spurline transmission, bulk transmission, and substation costs. Data are from an email conversation with the study authors.
[xiii] "Clean energy investments" include new capacity costs and refurbishment; "transmission capital investments" include spurline transmission, bulk transmission, and substation costs.
[xiv] The Union of Concerned Scientists' study reports these investment and cost values in 2020 dollars, applying a 7 percent discount rate.
[xv] "Power infrastructure" includes new power generation and energy storage capacity, transmission, and distribution.
[xvi] Specifically, this case does not artificially constrain the rate of renewables deployment, relying on "assumptions common to other net-zero analyses in terms of achieving high levels of electrification and renewable energy deployment." Statements are derived from an email conversation with the study authors.
[xvii] This definition of jobs (direct) does not include indirect and induced jobs.

- Princeton University's study finds five policy pathways to net-zero economy-wide GHG emissions by 2050 would support a net increase of 500,000 to 1 million energy supply jobs annually through 2030; it also reveals that the pathways would deploy on the order of $1 trillion to 10 trillion from 2020 to 2050 in energy supply-side capital (depending on the scenario, timeline, and sectors considered).[xviii]

CLIMATE

Curtailing power sector emissions is essential to meeting President Biden's goal of reducing economy-wide GHG emissions 50 to 52 percent by 2030 relative to 2005 levels. While there is not firm agreement on precisely how much clean electricity the U.S. needs to meet this goal, higher penetrations of clean electricity make it easier to decarbonize other sectors, with more emissions curtailed per item electrified (e.g., electric vehicles, electric water heaters, heat pumps). Conversely, slower electricity decarbonization will require greater reliance on other, more speculative technologies to meet the 2030 target.

Accounting for these qualifications, the reviewed studies suggest **roughly 70 to 80 percent clean electricity or 80 to 85 percent reductions in power sector emissions is foundational for the U.S. to meet President Biden's 2030 climate goal.** Given that clean electricity deployment amplifies electrification-based emissions reductions in other sectors, the upper end of this range may be economically and socially preferable relative to the lower end for meeting this goal.

- UC Berkeley's 2030 Report pairs an 80 percent by 2030 CES with ambitious electrification policies in the transport, buildings, and industry sectors. The study finds this policy package would cut power sector carbon dioxide (CO_2) emissions 84 percent and economy-wide GHG emissions 50 percent by 2030 relative to 2005 levels.
- The Union of Concerned Scientists' study modeling a 50 percent reduction in net economy-wide GHG emissions by 2030 (relative to 2005 levels) and an 80 percent reduction in power sector CO_2 emissions by 2030 (relative to 2005 levels) finds such targets are possible with just 74 percent clean electricity if the U.S. employs relatively aggressive decarbonization policies across other sectors, such as strong energy efficiency measures and ambitious electrification of transport, buildings, and industry.
- The Natural Resources Defense Council's study modeling a 53 percent reduction in net economy-wide GHG emissions by 2030 (relative to 2005 levels) projects approximately 80 percent clean electricity by 2030.

[xviii] "Energy supply" includes power generation, transmission, distribution, fuels conversion, and CO_2 transport and storage.

- Princeton University's study modeling five pathways that each achieve net-zero economy-wide GHG emissions by 2050 results in all pathways eliminating coal and achieving 70 to 85 percent clean electricity by 2030. The study scenario with the lowest clean energy share in 2030 requires the greatest use of carbon sequestration technologies in the post-2030 period to make up lost ground, whereas scaling proven renewable technologies in the 2020s reduces reliance on these more speculative measures.

The reviewed studies also show **reaching approximately 80 percent clean electricity by 2030 would reduce power sector emissions by 78 to 84 percent below 2005 level.** Variation is due to the share of coal in the remaining electricity supply, whether natural gas and CCS partially qualify as "clean" electricity, and whether utilities can "bank" clean energy credits in earlier years to use in later years.

- The Resources for the Future and REBA Institute study finds an 80 percent by 2030 CES would cut power sector CO_2 emissions 78 percent by 2030 relative to 2005 levels. This study's CES policy allows CCS to qualify in part as "clean" and permits the development of new natural gas-fired power plants.[xix]
- Clean Energy Futures' study finds a 100 percent by 2040 CES (achieving 83 percent clean electricity by 2030) would cut power sector CO_2 emissions 78 percent by 2030 relative to 2005 levels. In this study, while natural gas can earn partial "clean" credit through 2040, utilities can also "bank" clean energy credits through 2050; in other words, they can over-achieve in early years to make complying with the 100 percent CES easier in the 2040 to 2050 period.
- The Union of Concerned Scientists' study modeling an 80 percent reduction in power sector CO_2 emissions by 2030 relative to 2005 levels (as part of a broader economy-wide decarbonization scenario) results in a system with 74 percent clean electricity and 26 percent natural gas by 2030.
- UC Berkeley's 2030 Report finds an 80 percent by 2030 CES would cut power sector CO_2 emissions 84 percent by 2030 relative to 2005 levels. Notably, the policy design requires all coal-fired power plants to retire by 2030 and it forbids the development of new natural gas-fired power plants; however, it does allow natural gas with CCS to qualify as "clean."

Conversely, studies modeling delayed clean electricity targets, loosening restrictions for meeting targets (e.g., setting a relatively low alternative compliance payment), or relying strictly on tax credit extensions fall short of the deeper reductions necessary to safeguard the climate.

[xix] Values are from an email conversation with the study authors.

- UC Berkeley's 2035 Report finds a 90 percent by 2035 CES would achieve approximately 72 percent clean electricity by 2030 but cut power sector CO_2 emissions just 71 percent by 2030 relative to 2005 levels.[xx]
- The Resources for the Future study modeling four 100 percent by 2050 CES policies (achieving 58 to 70 percent clean electricity by 2030) finds they would cut power sector CO_2 emissions approximately 50 to 61 percent by 2035 relative to 2005 levels.[xxi]
- Harvard University's study modeling four 90 to 100 percent by 2035 policies (achieving 70 to 80 percent clean electricity by 2030) finds they would cut power sector CO_2 emissions approximately 63 to 66 percent by 2030 relative to 2005 levels; these relatively low emissions cuts for the 100 percent by 2035 policies are due in part to allowing partial credit for natural gas and permitting utilities to fall short of their targets by making alternative compliance payments at rates of $20-40/ton CO_2 (in 2020 dollars, rising at 3 percent per year).[xxii]
- Decarb America's study finds a range of different 100 percent by 2050 CES designs would cut power sector CO_2 emissions approximately 47 to 53 percent by 2030 relative to 2005 levels. The study also finds a 100 percent by 2035 CES (achieving 84 percent clean electricity by 2030) would cut power sector CO_2 emissions 72 percent by 2030 relative to 2005 levels. Notably, most scenarios (including the 100 percent by 2035 CES) allow natural gas generation to qualify for partial credit.[xxiii]
- The Union of Concerned Scientists' study modeling an expanded, long-term federal tax credit extension finds the policy would cut power sector CO_2 emissions approximately 60 percent by 2030 relative to 2005 levels.

PUBLIC HEALTH

The public health benefits of deep power sector decarbonization are enormous and widely dispersed across the U.S. As coal- and natural gas-fired power plants operate less often and retire,

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[xx] The 2035 Report does not analyze multi-sectoral electrification policies. Data were taken or estimated from the report's accompanying Data Explorer tool.

[xxi] Numbers estimated from Figure 6 of the Resources for the Future study; 2030 data were not reported.

[xxii] Numbers estimated from Figure 1 of the Harvard University study, referring only to the Reference Cases (approximating from the mid-point between low and high demand). Notably, looking to 2035, two of the four CES policy designs achieved power sector CO_2 emissions cuts of at least 80 percent relative to 2005 levels across all 10 tested sensitivities (e.g., flexing fuel price and renewable energy technology cost trajectories), including reaching as high as a 95 percent reduction. One such policy modeled a 100 percent by 2035 CES with partial crediting for natural gas and a $40/ton penalty for undercompliance; the other modeled the same policy but included federal tax credit extensions.

[xxiii] Values are from an email conversation with the study authors.

particulate matter ($PM_{2.5}$), nitrogen oxides (NO_x), and sulfur dioxide (SO_2) emissions fall accordingly, and the frequency with which people fall sick or die early from air pollution declines apace.

Viewed in the aggregate, the studies show **strong federal clean energy policy would avoid 14,500 to 50,000 premature deaths through 2030 to 2035 and 85,000 to 317,000 premature deaths through 2050.** These estimates of avoided premature deaths result from air pollution; they do not account for climate change-related deaths, such as from more frequent and intense storms, floods, and heat waves.

- The Resources for the Future and REBA Institute study finds an 80 percent by 2030 CES would avoid more than 14,500 premature deaths through 2030.[xxiv]
- Clean Energy Futures' study finds a 100 percent by 2040 CES (achieving 83 percent clean electricity by 2030) would avoid 50,000 and 317,000 premature deaths through 2030 and 2050, respectively, and prevent 2.2 million and 11.8 million asthma attacks annually in 2030 and 2050, respectively.
- UC Berkeley's studies modeling a 90 percent by 2035 CES and an 80 percent by 2030 CES find that, respectively, they would avoid 85,000 to 93,000 premature deaths through 2050.[xxv] Further, strong transportation electrification policies (as modeled in the 2030 Report) would avoid an additional 150,000 premature deaths through 2050.
- The Resources for the Future study modeling four 100 percent by 2050 CES policies finds the reductions in NO_x and SO_2 emissions would avoid 24,500 to 31,500 premature deaths through 2035.[xxvi]
- The Union of Concerned Scientists' study modeling an expanded, long-term federal tax credit extension finds the policy would avoid 7,000 premature deaths through 2035.
- Princeton University's study modeling five pathways that each achieve net-zero economy-wide GHG emissions by 2050 finds they would avoid 40,000 premature deaths through 2030 across the power and transportation sectors alone. They would also avoid 200,000 to 300,000 premature deaths through 2050.

These data are also often reported in economic terms of avoided health and climate-related damages, with values derived from applying estimates for a "statistical life" for the former and a "social cost of carbon" for the latter. Some estimates may also include monetization of avoided illnesses (such as asthma attacks) and other inputs to the social cost of carbon.[14] Collectively, the

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[xxiv] Values are from an email conversation with the study authors.
[xxv] The 80 percent by 2030 CES scenario retires all coal-fired generation by 2030, while the 90 percent by 2035 CES scenario retires all coal-fired generation five years later in 2035.
[xxvi] Numbers estimated from Figure 8 of the Resources for the Future study.

studies show **strong federal clean energy policy would avoid combined health and climate damages of $150 billion to $705 billion through 2030 to 2035 and $1 trillion to $3 trillion through 2050.**

- Clean Energy Futures' study finds a 100 percent by 2040 CES (achieving 83 percent clean electricity by 2030) would avoid $1.13 trillion in health damages and $637 billion in climate damages from 2020 to 2050.[xxvii]
- UC Berkeley's studies modeling a 90 percent by 2035 CES and an 80 percent by 2030 CES find that, respectively, they would avoid $1.2 trillion and $1.7 trillion in combined health and climate damages from 2020 to 2050. Further, strong transportation electrification policies (as modeled in the 2030 Report) would avoid an additional $1.3 trillion in health and climate damages from 2020 to 2050.
- The Resources for the Future study modeling four 100 percent by 2050 CES policies finds they would avoid roughly $630 billion to $705 billion in combined health and climate damages from 2022 to 2035.[xxviii]
- The Union of Concerned Scientists' study modeling an expanded, long-term federal tax credit extension finds the policy would avoid $255 billion in combined health and climate damages from 2020 to 2035.[xxix]
- The Natural Resources Defense Council's study modeling a 53 percent reduction in net economy-wide GHG emissions by 2030 (relative to 2005 levels) finds such a cross-sectoral policy package would avoid $150 billion in combined health and climate damages from the power sector alone through 2030.
- Princeton University's study modeling five pathways that each achieve net-zero economy-wide GHG emissions by 2050 finds they would avoid $400 billion in health damages through 2030 across the power and transportation sectors alone. They would also avoid $2 trillion to $3 trillion in health damages through 2050.

FEASIBILITY

All reviewed studies find **the least-cost pathway to achieving high penetration of clean electricity is through almost exclusively new wind, solar, and battery storage.** While these models were allowed to select other new zero- or low-emissions technologies—such as nuclear, incremental hydropower, geothermal, biomass, CCS, hydrogen, and even natural gas (where partial crediting is

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[xxvii] This value uses a 5 percent discount rate and is reported in 2019 dollars. The study's monetized health benefits are conservative as they do not account for potential benefits from reduced NO_2 exposure and decreases in climate impacts.
[xxviii] Numbers estimated from Figure 9 of the Resources for the Future study, applying a cumulative inflation rate of 11.10 percent from 2013 to 2020.
[xxix] This value uses a 7 percent discount rate and is reported in 2020 dollars.

allowed)—the models generally do not build any of these or deploy a marginal quantity through 2030.

Broadly, the models show **achieving approximately 80 to 90 percent clean electricity in the 2030 to 2035 timeline requires building approximately 50 GW to 100 GW per year of new wind and solar as well as up to 23 GW per year of new battery storage. This is roughly two to three times the U.S. record of 31 GW of wind and solar deployment set in 2020.** The differences—detailed below—largely owe to the stringency of the targets, innovation and technology cost curve assumptions, and the level of electrification assumed for other sectors.[xxx]

For battery storage in particular, the wide range in deployment rates is due in part to the amount of dispatchable generation (e.g., natural gas, hydrogen, CCS) available to help integrate variable renewable energy; lower amounts of this dispatchable generation generally require higher penetrations of battery storage to maintain system reliability.

- The Resources for the Future and REBA Institute study projects an 80 percent by 2030 CES would spur annual averages of 94 GW of new wind and solar and 11.4 GW of new battery storage from 2021 to 2030. Nuclear generation would remain about the same as today (with some planned new units replacing units set to retire). New natural gas, CCS, and hydrogen represent less than 2 percent of unplanned newly built capacity.[xxxi]
- Clean Energy Futures' study finds a 100 percent by 2040 CES (achieving 83 percent clean electricity by 2030) would drive large increases in solar and wind generation, an elimination of coal generation, and little change in generation from nuclear, hydropower, and other sources such as biomass by 2030.
- UC Berkeley's study modeling an 80 percent by 2030 CES (including strong electrification measures) projects this target would spur annual averages of 95 GW of new wind and solar and 22.7 GW of new battery storage from 2021 to 2030. The study retires all coal by 2030 and does not build any other technology.
- UC Berkeley's study modeling a 90 percent by 2035 CES projects this target would spur annual averages of 69 GW of new wind and solar and 14.2 GW of new battery storage from 2020 to 2035. The study retires all coal by 2035 and does not build any other technology.
- The Union of Concerned Scientists' study modeling an expanded, long-term federal tax credit extension (achieving 62 percent clean electricity by 2035) projects that the policy would spur annual averages of 17.7 GW of new wind and solar and 0.6 GW of new battery storage above

[xxx] Notably, the models generally did not assume high levels of energy efficiency, greater reliance on demand response (including vehicle-to-grid integration), or the development of longer-duration energy storage—all of which would reduce the capacity buildout required in these transitions.
[xxxi] Statement is based on an email conversation with the study authors. The model was not allowed to build biomass.

business-as-usual conditions from 2021 to 2035. The model does not build any other zero- or low-emissions technologies despite their qualifying for tax credits.

- Decarb America's study projects a 100 percent by 2035 CES (achieving 84 percent clean electricity by 2030) would spur annual averages of 69 GW of wind and solar, 3.6 GW of other resources defined as being clean (CCS, hydropower, nuclear, and biomass), and 0.5 GW of energy storage from 2020 to 2030.[xxxii]
- The Union of Concerned Scientists' study modeling a 50 percent reduction in net economy-wide GHG emissions by 2030 relative to 2005 levels (achieving 74 percent clean electricity by 2030) and net-zero GHG emissions by 2050 would spur annual averages of 58 GW of new wind and solar from 2021 to 2030. The policies would also essentially phase out coal by 2030, maintain most nuclear generation through 2050, and add negligible amounts of new nuclear or power sector CCS through 2050.[xxxiii]
- Princeton University's study modeling five pathways that each achieve net-zero economy-wide GHG emissions by 2050 (and achieve 70 to 85 percent clean electricity by 2030) finds they would spur annual averages of 53 to 65 GW of new wind and solar and 1 to 2 GW of new battery storage from 2021 to 2030. Four of the five pathways would only build wind and solar over this period. In the fifth pathway, wind and solar deployment rates are artificially capped at the maximum U.S. historical build rate—forcing significant geothermal and other zero- and low-emissions technologies to make up the difference. However, wind and solar developers already exceeded these rates in 2020, and there is little evidence suggesting they cannot continue to do so.

These deployment rates will be challenging to meet. Yet, they rely almost exclusively on technologies that have robust supply chains and are commercially available today, rather than speculative technologies like CCS. U.S. developers have consistently broken domestic deployment records as technology costs have plummeted, and these rates are not unprecedented globally—for example, China added 120 GW of new wind and solar capacity in 2020.

U.S. developers already had 462 GW of solar, 209 GW of wind, and 200 GW of energy storage capacity in transmission interconnection queues across the country at the end of 2020.[15] Historically, most projects in interconnection queues do not reach commercial operations due to a variety of financial and regulatory barriers. However, with the right supplemental policy support (such as federal action to address permitting and siting challenges, build new bulk transmission, and ease other constraints in the interconnection process), developers could raise the odds of success of projects currently in the interconnection queue and achieve the deployment rates studies forecast are needed to reach 80 percent clean electricity by 2030.

[xxxii] Values are from an email conversation with the study authors.
[xxxiii] Values are from an email conversation with the study authors.

RELIABILITY

All studies demonstrated **the U.S. power system would be dependable with high clean energy penetration** across a range of models (PLEXOS,[xxxiv] RIO,[xxxv] E4ST,[xxxvi]). These modeling exercises vary in their fidelity; for example, the two UC Berkeley studies test the grid in every hour of multiple weather-years (PLEXOS), the four Tier 3 studies test the grid over multiple sample days (RIO), and the Resources for the Future and REBA Institute study tests the grid against the most challenging hours of a three-year historical period (E4ST).

On one hand, the literature would benefit from more robust analyses to further demonstrate the reliability of a grid supplied predominantly by renewable energy. Recent research from the National Renewable Energy Laboratory shows with higher fidelity the reliability of the electricity system with approximately 60 percent wind and solar energy, or roughly what is required to reach 80 percent clean electricity if existing nuclear and hydro generation is held constant.[16] Federal funding to enhance scientific understanding of reliable grid operations with high renewable energy penetration—and to develop technologies such as grid-forming inverters—would complement an ambitious federal CES or CEPP.

On the other hand, the Tiers 1 and 2 studies generally do not account for reliability-enhancing measures like demand response, emerging technologies (e.g., long-duration energy storage and grid-forming inverters), and cross-sectoral uses for otherwise-curtailed renewable energy (e.g., generating green hydrogen for use in industrial applications).[xxxvii] Researchers and practitioners should continue to study reliability, but this meta-analysis did not reveal any challenges that should prevent immediate action on rapidly deploying clean energy.

POLICY RECOMMENDATIONS

This meta-analysis reveals important considerations for designing U.S. energy policy.

[xxxiv] The PLEXOS Integrated Energy Model (PLEXOS) is a production-cost model developed by Energy Exemplar.

[xxxv] The Regional Investment and Operations (RIO) Platform is a supply-side cost optimization model developed by Evolved Energy Research.

[xxxvi] The Engineering, Economic, and Environmental Electricity Simulation Tool (E4ST) is a power sector simulation model developed by Resources for the Future.

[xxxvii] Tier 3 studies generally included some demand-side flexibility and cross-sectoral uses of renewable electricity (e.g., green hydrogen production for use in industry). These measures boost the cost-effectiveness of a highly renewable grid; however, deployment of such measures tends to be negligible prior to 2030.

THE IMPORTANCE OF A HOLISTIC CLEAN ELECTRICITY PLAN

All studies show that a strong CES is one of the best ways to achieve deep decarbonization of the power sector. The recently proposed Clean Electricity Payment Program is designed to achieve the goals of a CES through a system of payments to electric utilities for rapidly decarbonizing their power supplies, and it can be passed under the constraints of budget reconciliation. **Achieving 80 percent clean electricity on average by 2030 can put the U.S. on a path to meeting its GHG emissions reduction goals,** while tax credit extensions alone—though helpful—would fall short.

These studies also suggest that allowing natural gas to qualify for partial credit under a CEPP would lead to more gas consumption, exacerbating upstream methane emissions and other fuel cycle impacts from natural gas production and distribution, with questionable impacts on emissions. To the extent this results in new gas plants being built, it is incompatible with a low-cost path to 100 percent clean electricity by 2035, locking in unneeded infrastructure investments. Furthermore, any cost savings from greater reliance on gas are not substantial enough to be felt by customers and are swallowed by greater uncertainties such as the future costs of natural gas, established renewable technologies, and emerging alternatives.

COMPLEMENTARY POLICIES

The success of a CEPP will depend on the pace of construction of new wind, solar, and battery storage systems. Achieving a sufficiently rapid deployment rate—and capturing the immense net benefits—may in turn depend on a few important complementary policies, some of which exist in the Bipartisan Infrastructure Deal[17] or are expected to be financed as part of the Senate budget resolution:[18]

- Congress should establish and fund a Grid Deployment Authority at the U.S. Department of Energy to support the building of new bulk transmission that can reduce congestion and speed deployment and interconnection of high-quality wind and solar resources.
- Congress should reaffirm the Federal Energy Regulatory Commission’s authority to reform grid operators’ interconnection processes, developing means to allocate the costs of new transmission among all beneficiaries (rather than forcing one project to build infrastructure from which a subsequent set of projects would freely benefit) and requiring a quicker timeline for interconnection studies (to prevent years of project delays).
- Congress should extend the federal clean energy tax credits for at least their current values through at least 2030, convert them to “direct pay” mechanisms (i.e., grants) to reduce soft costs associated with securing tax equity financing, and allow all clean energy and energy storage technologies to qualify. Doing so would provide greater business certainty, shift the cost burden of the clean energy transition from ratepayers (regressive) to taxpayers (progressive), remove barriers to utility participation, and unlock additional emissions reduction potential.

Energy Innovation's Rewiring the U.S. for Economic Recovery report includes other policy design considerations to accelerate the clean energy transition.[19] Collectively, this policy package—led by a strong CEPP—can facilitate a transition to a reliable and affordable clean electricity future, bringing with it enormous economic, public health, and climate benefits.

NOTES

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