INL/RPT-22-68535-Revision-0

Global Energy Policy to Achieve the United States Nationally Determined Contributions: Potential Pathway

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Prepared for the
U.S. Department of Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Global Energy Policy to Achieve the United States' Nationally Determined Contributions: Potential Pathway

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Date: August 5th 2022

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Abstract

In 2021, the United States declared its Nationally Determined Contribution (NDC) in preparation for the COP26 climate summit, setting goals to achieve zero emission electricity by 2035, and reducing net emissions by 50–52% compared to 2005 levels. The current U.S. energy policies were found to not be adequate to meet these goals, thus it is necessary to draft a pathway to achieving these goals through policy changes. This study focused on foreign energy policies to analyze the most effective policies in a host of sectors. By identifying the most ambitious and effective policies from around the world in each sector, this study was able to suggest a policy pathway that can potentially achieve both of goals set in the NDC. In guiding the development of the proposed policy pathway, this study analyzed policies from Australia, Canada, California, China, Denmark, France, Germany, Japan, Russia, South Korea, Sweden, the United Kingdom, and the United States. This study found that the most drastic CO_2 reductions came from low-carbon electricity policy, but contributions were also made from carbon capture, reforestation, hydrogen, energy efficiency, and climate smart agriculture.

I. INTRODUCTION

In 2021, the United States announced its Nationally Determined Contribution (NDC) in preparation for the COP26 climate summit. The NDC set targets for the U.S. to achieve 50–52% reductions in emissions by 2030 compared to 2005 levels, as well as achieve zero emissions from electricity by 2035[1]. Current U.S. policies do not support these ambitions—the Energy Information Administration (EIA) projects the U.S. barely breaking 50% electricity from low-carbon sources in 2035. As a result, it is necessary to investigate what policies could be adopted to create a pathway to achieving the U.S. NDC. This paper focuses on drawing from existing foreign policy that has seen success, with a priority on the utilization of nuclear power and hydrogen. As seen in Figure 1, the countries analyzed have collectively made progress in emissions reductions in all sectors. By combining the most ambitious policies from around the world in each sector, a pathway to meet the NDC goals can be developed.

FIG. 1. Cumulative changes in emissions reductions in selected countries from 2005 to 2018 in various sectors[2].

II. EFFICIENCY

One of the key methods to reduce emissions is to look at more efficient processes. Energy efficiency policy can impact the industry, transportation, and building sectors.

A. Buildings

While the U.S. has made progress in building energy efficiency, more ambitious progress is achievable. As seen in Figure 2, several other nations have achieved larger heating efficiency improvements. Additionally, while individual appliances have improved in the U.S., these improvements are outpaced by increased electrification leading to an overall increase in energy intensity of appliances.

FIG. 2. Average percent reduction per year in energy intensities of various countries in the appliance and space heating sectors[3, 4, 5, 6, 7, 8, 9].

A few key policy changes drawn from other countries can further improve U.S. energy efficiency. Japan is a global leader in appliance efficiency due to their “Top Runner” program, which sets efficiency standards equal to the top 10% most efficient appliances in a category[4]. Conversely, the U.S. ENERGYSTAR program only mandates efficiency improvements for the least-efficient performers. Strengthening the efficiency requirements like Japan does can lead to meaningful improvements.

The U.S. heating efficiency programs can expand by using examples from other countries. France and Sweden give a 30% credit for expenditures for efficiency improvements, while the U.S. only gives 10%. France, Sweden, and Germany also all have mandatory building codes, while the U.S. only publishes an optional federal building code. Increasing funding for heating efficiency improvements and mandating the federal building code can increase the levels of improvement in the U.S. energy intensity[8, 9, 10, 11, 12, 13, 14].

It is estimated that these improvements would in total drive a reduction of 27 $MtCO_2$ and 31 TWh of electricity by 2030, assuming constant rates of change and reductions in fossil fuel use proportional to the overall use in buildings. For a full breakdown of assumptions for all policies, see Appendix A.

B. Transportation

1. *Fuel economy*

Energy intensity in the U.S. also has room to grow. As seen in Figure 3, passenger transportation has been declining in the U.S., largely as a result of less carpooling and public transport use.

FIG. 3. Average percent reduction per year in energy intensities of various countries the freight and road transport sectors[2, 3, 4, 5, 6, 7, 8, 10, 11, 14, 15].

Like appliances, the U.S. could also take steps to simply increase fuel standards. Japan's Top Runner program applies to vehicles and sets standards nearly twice as high as the U.S. Despite this, top U.S. vehicles are more efficient than Japan's requirements[16], indicating that the technology is available in the U.S. to keep up with higher fuel standards. More ambitious standards in the U.S. can help to make a cleaner fleet.

2. *Electric vehicles*

In addition to fuel burning vehicles, electric vehicles (EV) can play a major role in reducing transportation emissions. Currently, the U.S. has a goal to reach 50% EV sales penetration by 2030[17]. Despite the U.S. offering subsidies on par with and even higher than some countries, the rate of EV adoption in the U.S. has not seen as much growth as in other areas, as shown in Figures 4 and 5.

FIG. 4. Electric vehicle sales as a percent of total annual vehicle sales in selected countries over time[19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46].

FIG. 5. Maximum available electric vehicle subsidies in selected countries over time[2, 3, 4, 5, 6, 8, 10, 11, 14, 25, 47].

One key hurdle to EV adoption in the U.S. is that the current subsidy is limited to 200,000 vehicles per manufacturer. This means that the largest providers of EV are no longer eligible for subsidies; 78% of EV sold in the U.S. in 2021 were ineligible[48]. Reopening the subsidy to all manufacturers will enable the U.S. to see EV penetration at much higher levels, even if rates are reduced. Sweden has also seen progress by offering subsidies for private chargers, which could also be effective in the U.S. China has also put pressure on manufacturers by mandating them to develop a certain percent of vehicles as EV each year. This allowed them to achieve growth in EV sales while scaling down subsidies[49]. Using a mandate model could potentially be an option as to help the U.S. achieve its more ambitious goal of 50% penetration by 2030.

It is estimated that these policies could reduce emissions by 101.7 $MtCO_2$ per year by 2030 but increase electricity demand 139.9 TWh per year, with cumulative spending of $66.7 billion. Key assumptions include constant total sales each year, with fuel standards increasing twice and EV penetration growing annually.

C. Manufacturing

The U.S. has made the most progress in manufacturing efficiency of the countries analyzed, shown in Figure 6. While its policies are effective, it is important to still consider further changes that can be made, as improvements become more challenging as efficiency increases.

FIG. 6. Absolute energy intensity in 2018 and average percent change in energy intensity per year in the manufacturing industry of selected countries[2, 3, 4, 5, 6, 8, 10, 11, 14].

The U.S. currently offers rebates for small and medium businesses to receive energy audits. These audits can help identify energy savings that can reduce costs for the company[11]. Expanding the rebate to larger companies or mandating a form of energy audit for large companies as is done in Denmark and Japan, which can allow the U.S. to maintain improvements as the country's energy intensity continues to fall[4, 6].

It is estimated that this change would limit emissions growth to 36 $MtCO_2$ and electricity growth to 27.4 TWh per year by 2030. Although energy intensity will continue to decrease, projected rates of growth in manufacturing are so high that it is estimated to outpace energy intensity reductions, thus an overall increase in energy usage.

III. ELECTRICITY

To meet the target of 100% low-carbon electricity, it was necessary to establish goals of capacity from different sources. These goals were established by utilizing the global energy supply laid out in the International Energy Agency's Net Zero Emissions pathway[50]. This composition was altered to account for higher nuclear share and more diverse renewables reflective of resources available in the U.S. Final targets for capacity changes by 2035 are shown in Table 1. The targets are not representative of any fixed needs or predictions for capacity, but rather give a general goal for this study to achieve which can realistically meet the U.S. electricity needs. Further details on assumptions can be found in Appendix A.

Table 1. Capacity Targets by 2035.

Energy source	Capacity Targets by 2035 (GW)	Current Capacity in 2021 (GW)
Solar	800	61
Wind	500	132.4
Hydropower	6	80
Biofuel	7.1	12.7
Concentrating Solar-Thermal Power	8.3	1.8
Geothermal	10	2.6
Nuclear	40	95
Coal	-207	210
Coal with Carbon Capture	3	0
Natural Gas	-397	491
Natural Gas with Carbon Capture	93.8	0

A. Nuclear

Only a few selected developed countries have aimed to continue development of nuclear power. Of those analyzed, only three have been able to achieve meaningful progress recently in commercial nuclear development, the U.S. not included, as seen in Figure 7.

FIG. 7. Percent change in annual electricity generation from nuclear power from 2010 to 2020, nuclear plants under construction as a percent of current capacity, and current nuclear power generation as a percent of total power generation in selected countries[18, 51].

In the U.S., nuclear support has been given in the form of loan guarantees. This has largely failed to attract investment, as there is only one project in construction resulting from this policy. Nuclear investment is inherently high due to its major capital costs, which loan guarantees failed to effectively mitigate. Direct financing of capital has been shown to be more effective in drawing investment. China offers nuclear developers low interest loans[52], while Russia gives direct funding for nuclear[53]. The UK has given long term subsidies to recoup capital costs, but future developers are looking for more up-front support[54]. In order to revive nuclear development in the U.S., capital investment is needed. Low interest loans are likely the most viable option.

The U.S. also has a history of delays and overruns in nuclear development. Certain steps need to be taken to ensure rapid and efficient development of nuclear.

1. **Maintain vested interest in success.** Several utilities in regulated sectors in the U.S. have canceled nuclear construction after billions of dollars have been spent. Legislation allowed these utilities to pass the full cost to ratepayers while also collecting a portion of the spent money as profit[55]. Government-financed projects need to explicitly prevent developing any profits from failed projects.
2. **Increase standardization.** First-of-a-kind (FOAK) costs significantly increase the cost and duration of construction. This can be lowered by minimizing design changes during construction, which can cause meaningful delays[56]. Additionally, further savings can be achieved when using the same plant design as well as experienced construction managers[57]. Current developmental goals should prioritize the use of technology commercially available in 2022 to prevent continued design changes from increasing costs. Expansion of existing sites can facilitate these improvements[58].
3. **Decrease regulatory approvals, especially for minor changes.** When approvals are needed for design changes, the delays caused are exacerbated. In addition to initial siting approvals, this can make regulation a substantial part of the construction timeline. Streamlined regulatory processes will help increase the rate of expansion.
4. **Improve construction techniques.** By using more effective techniques, costs from all aspects of production can be saved. Automation can reduce labor needed. Additionally, factory fabrication of certain parts can experience faster economies-of-scale and reduce costs further[59]. To ensure the most cost-effective measures are taken, fabricators and construction experts should work with the design team prior to construction.

In addition to encouraging development of new plants, policy is needed to ensure existing plants can stay online. In the U.S., plants have been threatened by low natural gas and subsidized renewable prices, causing closures due to economic reasons. Some states have enacted policies supporting nuclear, allowing planned closures to be rescinded. A low-carbon portfolio standard that requires utilities to source a certain percent of electricity from clean sources can help keep existing nuclear afloat.

These policies are estimated to lead to 40 GW of added capacity by 2035 for $94.6 billion in loans, assuming 50% financing from loans and prices and rates based on MIT projections of AP1000 reactors.

In addition to nuclear power, renewable electricity is a vital low carbon source that must be expanded to meet the U.S. NDC.

A. Renewables

The U.S. has seen substantial renewable growth in the past decade, as seen in Figure 8, but even more ambitious growth is possible and necessary to reach decarbonized electricity by 2035.

FIG. 8. Percent growth in power generation from 2010 to 2020 and power generation as a percent of total electricity generated in the wind and solar photovoltaic sectors in selected countries[2, 3, 4, 5, 6, 8, 10, 11, 14, 60, 61, 62].

1. *Wind and solar*

Three major systems encourage renewable production. Renewable portfolio standards (RPS) require utilities to source a percent of their electricity from renewables. While they are effective in increasing renewable use, RPS often pool all resources into one source, as seen in solar growth in Japan and California. They also leave no room for nuclear or carbon capture to develop, making them suboptimal for long-term growth. Feed in tariffs (FIT) give a flat rate of subsidy for renewable energy production. FIT have been effective as they can be adjusted to give different sources appropriate subsidies, but they can also be quite costly. Germany and the UK have switched from FIT to auctions, which allow renewables to bid on the lowest subsidy needed to be viable. Renewable auctions have seen major decreases in cost while also increasing production[5, 14]. The U.S. could benefit by switching from FIT to renewable auctions for all the renewables.

It is estimated that with this change, the U.S. could develop 681 GW of solar and 605 GW of wind by 2035 spending a total of $98.5 on subsidies, assuming development growth rates based on the UK's wind and Germany's solar auction results.

2. *Hydropower and geothermal*

Hydropower in the U.S. is partly limited by the lengthy approval process to retrofit dams[63]. This process could be avoided by Federal Energy Regulatory Commission (FERC) preapproving dams for hydropower. Conversely, geothermal power is largely saturated in areas with optimal resources, and technological improvements are needed to use geothermal power in other areas. This would require more substantial funding to drive improvements[64].

It is estimated that using auctions, the U.S. could develop 6 GW of hydropower and 10 GW geothermal by 2035 spending a total of $5.4 billion, assuming that rates of growth are proportional to the total estimated resources available in the U.S.

3. *Concentrating solar-thermal power and biofuels*

Concentrated solar-thermal power (CSP) and biofuels are both sources that currently exist, but their technology has not developed enough to make them financially competitive with other sources. For this reason, their growth is expected to be more limited. It is estimated that 7.7 GW of CSP and 11.6 GW of biofuels could be developed by 2035 for a total cost of $8.05 billion in subsidies, assuming growth rates akin to biomass auctions in Germany.

In total, low-carbon sources under these policies are projected to achieve 1491 TWh per year in 2030 and 3508.4 TWh per year in 2035, not including production from carbon capture and hydrogen. Carbon capture and hydrogen account for an additional 242 TWh in 2030; their policies will be discussed in the following sections. In total, clean electricity drives major reductions in fossil fuel use, particularly coal, to achieve an estimated reduction of 1,073.6 MtCO$_2$ per year by 2030.

IV. TRANSMISSION

Countries such as China, Germany, and Australia, have seen major issues related to renewable growth without transmission to move energy across the country[2, 65, 66]. In Denmark, this is solved by having substantial capacity for interconnection between its two grids[67]. If the U.S. partially financed a series of ultra-high voltage lines, it would provide access to the grids to balance supply and demand with intermittency issues that arise from renewables. In exchange for this financing, utilities can be required to connect renewables to the grid, decreasing costs for small developers. Transmission upgrade are essential to facilitating a transition to clean electricity.

V. HYDROGEN

The U.S. has made a commitment to enabling hydrogen in the future, but its ambition for growth is not as mature as other hydrogen-pursuing countries, as shown in Figure 9.

FIG. 9. Current hydrogen production in relation to gross domestic product (GDP) and planned hydrogen production capacity additions per year in relation to GDP in select countries[68, 69, 70, 71, 72, 73].

There are two prevailing roadmaps for hydrogen strategy around the world. Japan and South Korea's focus on fuel cell development will allow cheap fuel cells to be used for heating and in vehicles. Production is ramped up overseas due to a lack of available renewable resources domestically[68, 69, 70]. As the U.S. will likely have abundant renewable resources to produce hydrogen, it might choose not to pursue this path. In Australia and Canada, the major focus is on hydrogen production and decreasing cost of fuel. Financing for carbon-free hydrogen aims to reduce the cost of hydrogen as a fuel source. Additionally, funds are allocated for pilot projects in the fuel cell, heavy transport, electricity production, and industry heat sectors. The goal is to ensure that when these demand-side technologies are ready for commercial use in 2030, hydrogen is affordable enough that it motivates industrial users to make the switch to hydrogen technology[71, 72]. The U.S. should follow this approach, allocating a majority of funding into hydrogen production. Hydrogen hubs are being developed in the U.S., which can help drive down costs by collocating supply and demand centers near each other. Hydrogen can also be immediately blended in natural gas pipelines to help demand keep up with the rapidly increasing supply. A National Renewable Energy Laboratory study has found that blending can be done up to 20% hydrogen without changes to current infrastructure[74].

This study estimates that hydrogen policy focused on hydrogen development can help reduce emissions by 120 $MtCO_2$ per year by 2030, assuming 20% natural gas blending and the rest in industrial uses mirroring reduction rates in Canada.

VI. CARBON CAPTURE

Of the parties committed to developing carbon capture in the future, the U.S. is one of only three which has already developed carbon capture at scale, as seen in Figure 10.

FIG. 10. Current carbon capture capacity and targeted carbon capture capacity in 2030 as a percent of carbon emissions in 2019 countries[75, 76, 77, 78, 79, 80, 81, 82].

In recent years, the U.S. has offered $\$65/tCO_2$ tax credits to companies for implementing carbon capture, utilization, and storage (CCUS) projects[83]. As a result of this, announced projects have reached over 100 $MtCO_2$ of capture, over 100% of what the U.S. can currently provide. However, this subsidy does not fully cover the costs of CCUS in some areas. Increasing the level of subsidy will even further increase investment into CCUS projects. The U.S. also limits this tax credit to major emitters. Allowing smaller companies to claim this credit will further the development of CCUS[83]. One issue is that the U.S. tax credit does not incentivize transmission as much, so it is harder for remote CCUS developers to properly store their captured carbon. The U.S. could implement a policy like the UK has, which offers funding to transmission developers to avoid FOAK funding costs. The UK then sets regulated rates for use of the transmission to avoid a monopolistic environment, allowing remote CCUS developers to deliver their captured CO_2 to an area with plentiful storage capabilities[84, 85, 86].

It is estimated that these additions to current policy will reduce emissions by 416 $MtCO_2$ per year by 2030, assuming projects at the same level of ambition set by the UK can be achieved.

VII. LAND USE, LAND USE CHANGES, AND FORESTRY

Land use, land use change, and forestry (LULUCF) is a major but often overlooked sector in climate policy. The U.S. accounts over 700 $MtCO_2$ in reductions from LULUCF, so it is important to consider what changes to LULUCF can contribute to further reductions.

B. Forestation

Forestation amongst different countries is very challenging to compare, as each measures emissions differently and the accuracy of reporting is often contested. Despite this, China has been found to have made substantial progress in incentivizing forestation. After switching from a mandate approach to an incentive approach that pays farmers to plant and maintain trees, China has seen a near doubling of forestland[87, 88].

The U.S. still uses a reforestation mandate, but only 1% of eligible land is reforested each year[89]. It is estimated that between 156 to 333 $MtCO_2$ can be reduced in the U.S. from forestation efforts[90, 91], but current policy does not fully support this target. Seedling producers currently cite labor, financial needs, and market instability as reasons why they choose not to scale up production[90]. If the U.S. gave subsidies for seedling production, planting, and post planting efforts, with subsidies scaling based on appraisal of capacity to capture emissions, substantial carbon reductions could be seen. It is estimated that these subsidies could enable reductions of 170 $MtCO_2$ per year by 2030, assuming forestation of 32 billion trees.

C. Climate smart agriculture

Climate smart agriculture (CSA) is a broad assortment of practices that improve on efficiency compared to conventional farming, with the bonus of helping to reduce emissions. The United States Department of Agriculture's (USDA's) plan to implement CSA is effective. By using a flexible approach, the most efficient practices can be determined at a local level. In this sector, effectiveness of practices varies greatly, so adaptability is key[92]. The researcher estimates that this policy can reduce emissions by 15 $MtCO_2$ per year by 2030, assuming the most efficient practices are rapidly deployed.

VIII. CONCLUSION

In totality, the suggested policy pathway proposed in this study are estimated to reduce emissions by 1887.1 $MtCO_2$ per year by 2030, representing a 50.3% reduction in emissions compared to 2005 levels. A summary of the foreign policy changes suggested, and their potential estimated impacts are shown below in Table 2.

Table 2. Foreign policies suggested for adoption in the US and their potential estimated impacts in the US

Policy sector	Policy description	Policy country of origin	Impact of policy in origin country	Estimated result of policy adoption in U.S.	U.S. recent status of result indicator

Appliances	Mandate appliance efficiency to top 10% of performers	Japan	Average of 1.11% reduction in energy intensity of appliances per year in past decade[2]	23.7 GJ/dwelling energy intensity of appliances in 2030	25.11 GJ/dwelling energy intensity of appliances in 2021
Space Heating	Mandatory federal building code, 30% rebate on investment in energy efficiency renovations	Germany, Sweden	2.1%, 2.69% average reductions in energy intensity of space heating per year in past decade, respectively9, 8	0.148 GJ/m^2 energy intensity of space heating in 2030	0.1784 GJ/m^2 energy intensity of space heating in 2021
Fuel standards	Mandate fuel standards to top 10% of vehicles	Japan	Average of 1.21% reduction in energy intensity of road transport per year in past decade[2]	In conjunction with higher EV use, 924.3 $MtCO_2$ emitted per year from light-duty vehicles by 2030	1,026 $MtCO_2$ emitted from light-duty vehicles in 2021
Electric vehicles	Nonrestrictive subsidies for EVs, starting at $5,000 and decreasing yearly. Mandatory percent of manufacturer sales must be EV	China	15% market penetration of EV in 2021[28]	50% EV market penetration by 2030	4% EV market penetration in 2021[19]
Nuclear	Low-interest loans provided for commercial plants	China	Addition of 50 GW of nuclear power capacity since 2001[57]	40 GW added nuclear power capacity by 2035	95 GW of nuclear power capacity in 2022
Renewables	Renewable subsidy auctions, individualized per source	Germany, UK	33.9%, 29.1% of total electricity generation from	1508.6 TWh renewable electricity generation per year by 2030	849.2 TWh renewable electricity in 2021

			renewables, respectively		
Hydrogen	Focused funding on green hydrogen production, supplemental funding to get demand use applications to commercial level by 2030	Canada	Target of 4 MtH_2 per year[72] production by 2030[102]	12.3 MtH_2 added green hydrogen production per year by 2030	10 MtH_2 produced in 2022, 5% green
Carbon capture	Provide funding and establish regulated rates of use for carbon transmission	UK	Target of 30 $MtCO_2$ in capture capacity by 2030[85]	416 $MtCO_2$ per year in added capture capacity by 2030	40 $MtCO_2$ capture capacity in 2021
Forestation	Subsidize seedling production, planting measures, and post planting measures	China	Increased forest land area from 13% in 1981 to 22% in 2021[87]	170 $MtCO_2$ additional CO_2 removals from planting of 33 billion additional trees by 2030	1% of possible area reforested per year with target of planting 1.2 billion trees by 2030

FIG. 11. Estimated CO_2 emissions reductions per sector from 2021 to 2030 resulting from policies recommended in this study.

While electricity makes up the majority of carbon emissions by 2030, seen in Figure 11, the smaller shares in carbon capture, hydrogen, and efficiency represent the first steps in pivotal sectors that are necessary for achieving net zero emissions in the long term. By pulling from policies around the world, this study has shown that it is possible to not only generate a pathway to achieving both goals set out by the NDC, but also pave a path which can potentially achieve longer term clean energy goals in the U.S.

Appendix A: Assumptions for estimating impacts of policy recommendations

This appendix details the assumptions that were taken to determine carbon emissions reductions in each sector discussed in this study. These assumptions include, but are not limited to, assuming growth or success rates akin to other countries and constant rates of growth or development in sectors based on other reports.

Building Efficiency

In 2020 there were 122.3 million households[93], projected to reach 142.8 to 153.2 million by 2030[94]

Assume 0.6% growth rate per year in household quantity, 1% growth in commercial floor space per year[95]

Assume average home floor space increases by 0.3% each year

Assume constant rates of growth from 2020 to 2023 to account for unknown data points

Assume policy impacts begin 2023

123 million households in 2021, 129.8 million households in 2030

20.54 billion m^2 from households in 2021, 22.27 billion m^2 from households in 2030

9 billion m^2 commercial space in 2018 leads to 9.27 billion m^2 floor space from commercial sector in 2021, 10.14 billion m^2 floor space from commercial sector in 2030[96]

29.81 billion m^2 floor space in 2021 total, 32.41 billion m^2 in floor space total in 2030

Space heating intensity in 2016 is .1897 GJ/m^2

Assuming constant decrease at current U.S. rate of 1.19% reduction per year, space heating intensity in 2021 is .1784 GJ/m^2, down to .1739 GJ/m^2 by 2023

Appliance intensity is 23.63 GJ/dwelling in 2016, up to 25.11 GJ/dwelling in 2021 and 25.698 GJ/dwelling in 2023

Assume rate of change in water heating intensity remains constant at all time- in 2021 water heating intensity reaches 14.06 GJ/dwelling

Assume that at all times, 2/3 of heating is from natural gas, 1/6 is from oil, 1/6 is from electricity

Assume 117 pounds CO_2 emitted per MMBTU of natural gas, 161.3 pounds CO_2 emitted per MMBTU of oil[97]

In 2021, 5.318 billion GJ used for space heating, 1.73 billion GJ for water heating, total of 7.048 GJ used for heating

236 $MtCO_2$ produced from natural gas in 2021 for heating, 81.5 MtCO2 produced from oil for heating, 317.5 $MtCO_2$ total consumed for heating 2021

1.175 billion GJ electricity for heating, 3.0885 billion GJ electricity used for appliances, total of 4.2635 billion GJ electricity in 2021

From 2023 to 2030, assume rates of reduction in heating intensity equivalent to Germany's (2.1% reductions per year) and rates of reduction in appliance intensity equivalent to Japan's (1.11% reductions per year)

Space heating intensity in 2030 is .148 GJ/m^2

Appliance intensity in 2030 is 23.7 GJ/dwelling

Water heating intensity in 2030 is 12.72 GJ/dwelling

In 2030, 4.8 billion GJ from space heating, 1.65 billion GJ from water heating, 6.45 billion GJ total from heating

216 $MtCO_2$ produced from natural gas in 2030, 74.5 $MtCO_2$ produced from oil in 2030

290.5 $MtCO_2$ produced from heating in 2030 yields a 27 $MtCO_2$ reduction from 2021 to 2030

1.075 billion GJ electricity from heating in 2030, 3.0767 billion GJ electricity from appliances in 2030

4.1517 billion GJ total electricity in 2030 represents a decrease from 2021 of 111.8 million GJ or 31 TWh

Assuming constant rates of change, electricity demand is further reduced by 48 TWh from 2021 to 2035

Vehicles

Assume constant sales of 15 million cars per year, 3.3 million increases in fleet size per year, thus 11.7 million cars removed from circulation each year[98]

Assume cars are replaced every 12 years, so the average model is 6 years old, therefore assume current fleet fuel economy is the average of 2016 models, 25 mpg, and that all new cars sold until 2026 have a fuel economy of 36 mpg

Assume that from 2026 to 2028, fuel economy increases to 49 mpg for new cars, and from 2028 to 2030, new cars have a fuel economy of 55 mpg

Assume that emissions are directly proportional to gallons of gasoline consumed in combustion engine vehicles

Assume average miles driven per vehicle per year remains constant

Assume that EV sales are at the mandated level shown in the table below

Table 2. Recommended subsidy and EV mandatory sales values for changes to EV policy.

	2023	2024	2025	2026	2027	2028	2029	2030
Direct Subsidy ($)	5000	4200	3600	3000	2600	2200	1800	1500
Mandatory Sales %		9	12	18	24	32	40	50
Private Charging Subsidy (%, $ cap)	50, 1000	50, 1000	50, 800	50, 800	40, 600	40, 600	40, 400	40, 400

In 2021, 1,026 $MtCO_2$ emitted from light duty vehicles

By 2030, estimated 924.3 $MtCO_2$ emitted, representing a 101.7 $MtCO_2$ emissions reduction from 2021 to 2030

Assume average of 13,476 miles driven per year[99], with EV demand of 0.346 kWh per mile[100]

30 million EVs added by 2030 causes added 139.9 TWh electricity by 2030, increased to an added 419.7 TWh electricity by 2035, assuming ramping EV mandate reaches 100% in 2035

Manufacturing Efficiency

Assume a constant rate of reduction in manufacturing intensity equal to current rate (2.43% reduction per year)

Manufacturing industry worth $5,973.8 billion in 2020, projected to be worth $7,599.8 billion in 2030

Assuming constant rate of growth, $6,136.4 billion worth in 2021

5 MJ/$ in 2018 leads to 4.64 MJ/$ in 2021

28.5 trillion MJ used in manufacturing in 2021

Industry uses 34% petroleum, 40% natural gas, 9% renewables, 4% coal, 13% electricity

Assume that manufacturing has the same proportions of energy sources as overall industry

Expected 3.851 MJ/$ in 2030 leads to 29.26 trillion MJ used by manufacturing in 2030, 760 billion MJ increase

98.8 billion MJ increase equates to 27.4 TWh increase per year by 2030, assuming constant rates of change, increased to 42.6 TWh by 2035

Assume 215 pounds of CO_2 per MMBTU of coal, 161.3 pounds of CO_2 per MMBTU of petroleum, and 117 pounds of CO_2 per MMBTU of natural gas[97]

258.4 billion additional MJ petroleum causes 17.9 $MtCO_2$ per year added in 2030

304 billion additional MJ natural gas causes 15.3 $MtCO_2$ per year added in 2030

30.4 billion additional MJ coal causes 2.8 MtCO$_2$ per year added in 2030

Total of 36 MtCO$_2$ per year added in 2030

Efficiency Total Impacts

-92.7 MtCO$_2$ per year from 2021 to 2030

+136.3 TWh electricity needed per year from 2021 to 2030 (3.3% total increase)

+414.3 TWh electricity per year from 2021 to 2035

Nuclear

Through collaboration with existing managers, the researcher assumes that most FOAK costs can be avoided. Using MIT independent estimates, the researcher determines cost and time estimates for plant development[101]. These are increased by 20% for the next wave of development in the U.S. to account for imperfections in fully eliminating FOAK costs using less experienced managers. The MIT study outlines plans for the AP1000 design. While this may not be the most adopted design used, the researcher will assume its cost trends are similar to what would be produced.

Assume $5,160/kW and 6 years for first wave of reactors, $4,300 and 5 years for second wave of reactors

Assume U.S. gives loans for 50% of overnight cost

In recent years, the U.S. has seen 20 GW of projects proposed, with most being canceled before construction. The researcher assumes that a similar level of interest can be stimulated with U.S. backed low interest loans. With expedited approval, these projects can be approved by 2024, and completed in 6 years, by 2030. The researcher asserts that another similarly sized wave of production can be mobilized starting in 2029, with construction starting in 2030. These plants will adhere to the MIT estimates and be completed by 2035.

Assume 90% capacity factor.

Assume that no existing nuclear plants will close. Diablo canyon reactors in California were slated to close due to political pressure, but very recent legislation has opened up the possibility that they can remain active

By 2030, first wave of reactors will be complete, providing 157.7 TWh of electricity per year and costing $51.6 billion in loans. By 2035, a total of 315.4 TWh of electricity per year will be provided from new nuclear, costing the government a total of $94.6 billion in loans

Solar and Wind

NOTE: Prices discussed for all renewables are in terms of flat subsidies in order to simplify estimations. However, the true policy recommendation involves the use of CFD

Assume starting solar and onshore wind auction capacity are both 10% of current capacity. UK and Germany are closer to 1.5% for solar[102, 103, 104], but the researcher adjusted starting point up and growth rate down to decrease overall solar usage

Assume growth rates of 35% per year of solar auction capacity and 12% for onshore wind capacity. Solar is substantially lower than average German growth rate to account for higher starting auction

Assume auctions start in 2023, and projects from auctions are connected to the grid 2 years after auction.

Assume solar and onshore wind auctions follow cost trend of German solar auctions, 5.2% reduction in cost/kWh per year. Assume starting auctions prices slightly higher than current subsidies ($6.5/MWh for solar, up from $6/MWh. $16/MWh for wind, up from $15/MWh)

Assume offshore wind auction capacity starting at 800 MW, same as current planned increases. First 2 years assume 166% growth in offshore wind auction capacities, based on UK rates, followed by 47% growth rate for 2 years, before finally falling to 15% growth rates for the remaining years.

Assume that offshore wind subsidy starts at $24.3/MWh (difference between LCOE[105] and wholesale price[106]), rapidly falling to $10/MWh based off of UK auction price trends. Rates then fall based on German solar auctions to 5.2% price reduction per year.

Assume capacity factor of .161 for solar PV, .51 for offshore wind, .35 for onshore wind[50]

Total additions in 2030 and 2035 for all renewables are shown in the table below

Hydropower and geothermal

Hydropower is very limited, so assume that half of available dams are retrofitted with hydropower by 2035. Assume 0.66 GW added annually for 6 years followed by 0.4 GW added annually for 5 years. Assume that auction price is $21.3/MWh to account for difference between LCOE[107] and wholesale price[106], with no change in price over time because hydropower is a relatively matured technology.

Geothermal is also limited in the U.S., and technological advances are needed to fully utilize the resource. Thus, it will follow the model of offshore wind in the UK and emerging innovation auctions in Germany. The researcher assumes that auction capacities start at 100 MW, and run every other year for 7 years, increasing capacity at each auction by 400 MW. For the remaining years, assume auction capacity grows by 200 MW each year.

Assume that prices start at $16.3/MWh to reflect difference in LCOE[105] and wholesale cost of electricity[106]. Assume that prices then fall by 5.2% per year, modeled after German solar rates.

Assume a 0.371 hydropower capacity factor and a 0.723 capacity factor for geothermal[50]

CSP w/ storage and Biofuels

Assume growth in capacity in biofuel of 35% per year, which is much less than Germany's average biofuel auction growth of 72% per year.

Assume biofuel auctions start at 115 MW capacity. Assume biofuel auction prices start at $38.3/MWh to account for difference between LCOE[108] and wholesale price[106], then fall at a rate of 5.2% per year based on German solar prices[102]

Assume CSP auctions start at 14.3 MW and grow at a rate of 72% per year, modeled after German biofuel auctions.

Assume CSP auction prices start at $77.3/MWh to account for difference between LCOE[105] and wholesale price[106] and fall by 5.2% each year.

Assume a 0.539 capacity factor for biofuel and a 0.32 capacity factor for CSP[50]

Table 3. Predicted added generation, capacity, and subsidy spending by 2030 and 2035 from renewable sources due to recommended policies.

	Added capacity 2030 (GW)	Added Capacity 2035 (GW)	Added generation 2030 (TWh per year)	Added generation 2035 (TWh per year)	Cumulative cost by 2030 (billion USD)	Cumulative cost by 2035 (billion USD)
Wind (Offshore)	312.4 (44)	605 (156)	1019 (196.6)	2073.6 (697)	22.1 (5.58)	84.5 (26.7)
Solar PV	198.5	680.6	280	960	2.5	14

Hydropower	4	6	13	19.5	0.96	2.75
Geothermal	1.5	10	9.5	63.5	0.40	2.69
CSP w/ storage	0.5	7.7	1.4	21.5	0.20	2.69
Biofuels	2.2	11.6	10.4	54.9	0.96	5.36

Total Electricity Impacts

Net electricity needed is assumed to be 4,478.1 TWh per year in 2030, based on estimates from efficiency, hydrogen, and current electricity demand. The researcher assumes that nuclear helps to facilitate a major transition away from coal, and a smaller transition away from natural gas. A reduction of 800 TWh of coal and 600 TWh of natural gas per year leaves the U.S. with an estimated 4,489.5 TWh per year in 2030, after accounting for increased generation from renewables, hydrogen, nuclear, and carbon capture. These reductions lead to an 852.7 MtCO$_2$ reduction from coal use and a 221 MtCO$_2$ reduction from natural gas use per year by 2030.

Hydrogen

Assume planned addition of hydrogen comparable to Canada's (.0523 MtH$_2$/trillion USD GDP-year) equating to 12.3 MtH$_2$ per year by 2030.

Assume 75% of hydrogen is from electrolysers, with 16 TWh electricity required per MtH$_2$ produced with electrolysers. 147.6 TWh additional electricity required per year by 2030 for hydrogen.

Assume 30% of hydrogen produced is mixed in natural gas pipelines, resulting in under 20% blending. Assume 6.2 MtCO2 is saved per MtH$_2$ blended. Assume the rest of the hydrogen is used similarly to Canada, who anticipates 11.25 MtCO$_2$ are reduced for each MtH$_2$. In total, the researcher estimates 119.8 MtCO$_2$ are reduced per year by 2030 due to hydrogen policy.

Assume that there is 2 GW of hydrogen power production by 2030, contributing 12.6 TWh per year (not included in net electricity demand from hydrogen)

Carbon Capture

Assume same growth as UK strives for can be achieved (8.77% of 2019 CO2 emissions captured using CCUS in 2030, total of additional 416 MtCO2 captured using CCUS per year by 2030)

Assume 60% of capacity goal in 2035 is achieved by 2030, resulting in 4.7 TWh produced by coal w/ CCUS and 182 TWh produced by natural gas w/ CCUS per year by 2030.

Forestation

Assume value in between 2 reported estimates of potential emissions reductions that can be achieved through reforestation[109, 90] (156 MtCO2 and 180 MtCO$_2$. Choose to assume that 170 MtCO$_2$ can be reduced. Assume that maximum reforestation occurs by 2030.

CSA

Assume that rule 2 from International Food Research Policy Institute study applies, assuming ambitious adoption of CSA[110]. This would lead to global CO$_2$ reductions of 50 MtCO$_2$.

Assume that global emissions can be scaled down proportionately to the U.S. share of crop production[111] (30%) to yield 15 MtCO$_2$ reductions by 2030.

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