Macroeconomic and Employment Impacts of Achieving Net-Zero Emissions in the U.S. by 2050

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"Greenhouse gas emissions keep growing. Global temperatures keep rising. And our planet is fast approaching tipping points that will make climate chaos irreversible. We are on a highway to climate hell with our foot on the accelerator."

António Guterres, Secretary-General of the UN (2022)[1]

Abstract *The above quote highlights the urgency of addressing climate change. Success in this endeavor hinges particularly on the actions of the two largest emitters: the U.S. and China. Policymakers and researchers have proposed a variety of decarbonization strategies to reduce GHG emissions in the U.S. A important question is: "What will be the economic impacts of these strategies, and how will they affect households and business?"*

In this study, the Inforum macroeconomic interindustry model LIFT was coupled to the ENERGYpathways model produced by Evolved Energy Research to analyze the macroeconomic and employment impacts of a set of decarbonization strategies that may enable the U.S. to achieve net-zero emissions by 2050.

Two complementary assessments are analyzed. The first focuses on the direct employment impacts associated with the up-front investments in energy facilities and equipment, as well as employment impacts associated with the operation and maintenance of these facilities. The second analysis uses the Inforum LIFT model, and takes a broader perspective than the first by estimating the economy-wide economic impacts associated with reaching the net-zero by 2050 goal. As such, it was designed specifically to capture the spillover effects not accounted for in the direct employment impacts assessment. These spillover effects reflect a number of economic dynamics that affect industries and households across the broader economy. These include impacts up the supply chain from directly impacted industries as well as impacts for industries that produce goods purchased by workers in affected industries. The economy-wide assessment also reflects how changes in prices affect consumer spending patterns and how changes in investment affect productivity over time and the associated implications for output, employment, and income.

Background

The 26th Conference of the Parties (COP26) of the United Nations Framework Convention on Climate Change stimulated many research efforts to investigate the possible attainment of reduction of GHG emissions to "net zero" by 2050. In particular, the International Energy Agency (IEA) pursued a research program which led to a major publication exploring scenarios that could achieve net zero globally.[2] COP27, from which the headline quote is taken, led to further refinements in these analyses.

This paper explores the economic implications of a possible implementation of net zero strategies and policies, that would significantly reduce greenhouse gas emissions in the U.S., which is one of the two

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[1] See the quotes from the COP27 at https://cop27.eg.

[2] International Energy Agency (2021) *Net Zero by 2050: A Roadmap for the Global Energy Sector*.

largest contributors to GHG emissions, along with China. Net zero in the U.S. in these strategies is achieved through a combination of increased efficiency, electrification, substitution away from emitting industries, along with advanced technologies that produce low carbon fuels. Within the electric power sector, a significant realignment of generation technologies is envisioned, both to reduce reliance on fossil fuels and to reduce emissions arising from those fuels.

These strategies rely on policies to accelerate technology development and deployment, as well as to provide incentives to households, businesses and governments. These policies and technology adoption in combination may be able to reduce CO2 emissions by 80 percent by 2050. Additional GHG mitigation is achieved by reduction of other gases, and carbon removal.

1 Introduction

To mitigate the ongoing changes in climate that have resulted from anthropogenic emissions of greenhouse gases (GHGs), policymakers at multiple levels of government have begun to pursue or consider a variety of decarbonization strategies. These strategies often involve achieving broad-based GHG reductions across multiple sectors of the economy. For example, Colorado's Climate Action Plan, enacted in May 2019, commits the state to achieve a 26 percent GHG reduction relative to 2005 levels by 2025, a 50 percent reduction by 2030, and a 90 percent reduction by 2050. Similarly, New York's Climate Leadership and Community Protection Act (CLCPA) requires New York to reduce economy-wide GHG emissions by 40 percent by 2030 relative to 1990 levels and by 85 percent by 2050; the CLCPA includes even more ambitious reduction targets for the power sector.

As policymakers consider decarbonization efforts such as these at the national scale, there is likely to be significant interest in the effects of such initiatives on the economy, in particular the employment impacts of these policies. Key questions posed by policymakers and other stakeholders in this context include:

- Will decarbonization lead to a net increase in employment?
- What sectors face the greatest opportunities for job growth?
- How will job opportunities change over the coming decades?

To address these important questions, this paper presents an assessment of the employment impacts associated with a series of technology and policy pathways to achieve net-zero GHG emissions in the U.S. by 2050. By "net-zero", we mean that GHG emissions are reduced significantly and that all remaining GHG emissions released from human populations are counterbalanced by removing GHGs from the atmosphere, for example through forest restoration or direct air capture.

The paper presents two complementary assessments of the economic impacts of the net-zero by 2050 scenario. The first focuses on the direct employment impacts associated with the up-front investments in energy facilities and equipment to help achieve the net-zero target, as well as employment impacts associated with the operation and maintenance (O&M) of these facilities. Thus, this first analysis does not capture spillover impacts associated with complex supply chain interactions or workers spending their wages. This focus on direct impacts will help policymakers and the public understand the employment effects of the net-zero by 2050 target in those industries most closely involved in achieving this objective.

The second analysis takes a broader perspective than the first and estimates the economy-wide economic impacts associated with achieving net-zero by 2050. Rather than focusing narrowly on those industries directly affected by efforts to achieve the net-zero target, this analysis captures spillover effects to other industries. These spillover effects reflect a number of economic dynamics that affect industries and households across the broader economy. These include impacts up the supply chain from directly impacted industries as well as impacts for industries that produce goods purchased by workers in affected industries. The economy-wide assessment also reflects how changes in prices affect consumer spending patterns and how changes in investment affect productivity over time and the associated implications for output, employment, and income.

In the sections that follow, we outline the net-zero by 2050 technology and policy pathway in more detail and describe both the direct employment impact analysis and the assessment of economy-wide impacts.

The GHG emissions in the U.S. are intimately associated with production and consumption patterns, as well as the structure of international trade. GHG emissions can be linked to combustion of fossil fuels, manufacturing processes, agriculture (particularly livestock) and a few other minor sources. Energy use and emissions are also related closely to the technology embodied in equipment that is used to satisfy certain functional end uses. One way to describe these relationships is in an economic model that focuses on end uses (such as cooking or space heating), the capital (buildings and equipment) used to satisfy them, and the energy requirements of that capital. The EnergyPATHWAYS model adopted by Evolved Energy Research was used to pinpoint many specific changes in technology embodied in capital that enabled efficiency increases, substitution from fossil fuels, or both, necessary to achieve significant GHG reductions by 2050. This model was coupled with the Inforum LIFT model, which can incorporate outputs from the EnergyPATHWAYS model as assumptions, embodied within a consistent interindustry macroeconomic framework[3].

2. Net Zero by 2050

The net-zero technology and policy pathway examined in this paper is based on Decarb America's Sectoral Policies Scenario, with the addition of supplemental measures to reach net-zero. The Sectoral Policies Scenario contains a package of commonly discussed, sector-based decarbonization policies widely understood to be needed to realize deep decarbonization[4]. It combines a zero-emission vehicle standard, zero-carbon fuel standard (for diesel, gasoline, jet fuel, and hydrogen), electrification and efficiency standards for buildings, a clean energy standard for the power sector (100 percent clean electricity by 2050), and policies to reduce emissions of methane and ozone-depleting substances. Together, these policies are estimated to reduce overall U.S. emissions by 70 percent relative to current emissions, while reducing energy and industrial CO2 emissions by 80 percent.

This is a substantial reduction, but additional policies would be needed to achieve the net-zero-by-2050 goal. Reaching the net-zero goal in this scenario thus requires further reductions in non-CO2 greenhouse gases as well as additional CO2 reductions from carbon removal (including land-based sequestration, direct air capture, and carbon capture and storage) and further emissions mitigation in the areas of bioenergy, industrial heat, and off-road transportation. Comparing model results from the Sectoral Policies and High Renewables/High Efficiency scenarios indicates how these additional reductions might be achieved.

Based on the elements of the net-zero by 2050 pathway described above, we organize our analysis according to four broad categories, defined as follows:

> ***Power Infrastructure:*** The net-zero by 2050 technology and policy pathway involves significant increases in renewable generation capacity, battery storage installations (due to the intermittent nature of some renewables), and investment in transmission and distribution infrastructure (to integrate new renewable facilities into the grid and to accommodate increased electricity load requirements associated with electrification). In conjunction with these changes, the net-zero by 2050 pathway involves less investment in and reliance upon fossil fuel-based generating capacity. Table 1 shows the specific technologies included in the power infrastructure category and in other technology categories included in the net-zero by 2050 pathway.

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[3] See Steckley et al. for a similar coupling between LIFT and the MARKAL model.

[4] https://decarbamerica.org/scenarios/. This paper focuses on the High Renewables/High Electrification Scenario.

Table 1. Technologies Analyzed for Net Zero by 2050 Scenario

CATEGORY	TECHNOLOGIES	
Power Infrastructure	• Advanced nuclear energy • Conventional nuclear energy[3] • Coal generation[3] • Gas power with CCS • Gas power without CCS • Onshore wind • Offshore wind	• Utility-scale solar • Rooftop solar • Transmission & Distribution • Battery Storage
Fuels[1]	• Hydrogen produced from steam methane reformation (SMR) with CCS • Hydrogen produced from SMR without CCS • Electrolytic hydrogen[4] • BECCS hydrogen • Power-to-gas • Power-to-liquids • Biofuel: cellulosic ethanol • Biofuel: biomass to SNG	• Biofuel: biomass Fischer-Tropsch (with CCS) • Biofuel: biomass Fischer-Tropsch (without CCS) • Biofuel: biomass pyrolysis • Ammonia • Biomass
Energy Efficiency[2]	• Agriculture • Commercial • Residential	• Electric vehicles (EVs) • EV chargers • Other manufacturing
CO_2 Removal and Transportation	• CO2 Pipelines	• Direct air capture

Notes

1. Some of the fuels technologies listed here, such as BECCS and SMR hydrogen with CCS, could be considered forms of CO_2 removal. They are classified as fuels rather than as CO_2 removal in this analysis due to their similarities to the other fuels examined.
2. Each of the technologies shown for energy efficiency include more technologies than is practicable to present here. See Appendix B for more detail.
3. The net-zero technology and policy pathway does not include additional investment in coal-fired or nuclear generating capacity, but they do project less reliance on these technologies over time, which has implications for ongoing employment at these facilities for operation and maintenance.
4. For the purposes of this analysis, electricity used for electrolysis is taken from the grid.

- ***Fuels:*** To reduce GHG emissions from fuel consumption, the net-zero pathway includes increased reliance on various forms of low- and zero-carbon fuels. These fuels include SMR hydrogen (with and without CCS), electrolytic hydrogen, hydrogen produced via bioenergy carbon capture and storage (BECCS), power-to-gas, power-to-liquids, ethanol and other biofuels, ammonia, and biomass feedstocks.
- ***Energy Efficiency:*** In addition to reducing the GHG footprint of energy produced and/or consumed in the U.S., the net-zero pathway includes various investments to improve energy efficiency across the economy. These investments in energy efficiency include energy efficiency

in the agricultural, commercial, residential, and manufacturing sectors. In addition, because vehicle electrification increases the efficiency of light-duty and heavy-duty vehicles, we include electric vehicles and charging infrastructure in the energy efficiency category.

- ***CO_2 Removal and Transportation:*** Finally, the net-zero by 2050 pathway involves increased reliance on technologies to capture CO_2 from the atmosphere and transport it to storage sites.

The ENERGYPathways Model

The detailed implementation of changes in these four categories was first done in the ENERGYPathways model.[5] The EnergyPATHWAYS model is a comprehensive energy accounting and analysis framework specifically designed to examine large-scale energy system transformations. It accounts for the costs and emissions associated with producing, transforming, delivering, and consuming energy in the US economy. Its strengths in infrastructure accounting and the electric power sector distinguish it from other energy models. It is well-suited for calculating the impacts of energy system decisions on infrastructure investment, emissions, and costs to energy consumers.

The model projects energy demand and costs in subsectors based on user-decisions about technology (i.e. electric vehicle adoption) and activity levels (i.e. reduced vehicle miles traveled). These projections of energy demand across energy carriers are then sent to the supply-side of the model, which calculates upstream energy flows, primary energy usage, infrastructure requirements, emissions, and costs of supplying energy. These supply-side outputs are then combined with the demand-side outputs to calculate the total energy flows, emissions, and costs of the modeled energy system.

End uses are accounted for at a high level of detail, made possible by the availability of numerous high-quality data sources for the US energy economy. Demand by end use is calculated by relating it to combinations of technology stock, service demand and energy demand. Energy technology investments on the supply side are also tracked at a detailed level, and provide for explicit descriptions of introduction of new technologies. The wear-out pattern, levelized costs, and operations cost of capital are all modeled.

There are two categories of greenhouse gas emissions in the model. First, there are physical emissions. These are traditional emissions associated with the combustion of fuels, and they represent the greenhouse gas emissions embodied in a unit of energy. Physical emissions are accounted for on the supply-side in the supply nodes where fuels are consumed, which can occur in primary, product, delivery, and conversion nodes. Emissions, or consumption, coefficients, that is the units of fuel consumed can be a subset of energy coefficients. The second type of emissions are accounting emissions. These are not associated with the consumption of energy products elsewhere in the energy system. Instead, these are a function of energy production in a node. Accounting emissions rates are commonly associated with carbon capture and sequestration supply nodes or with biomass.

The database of the United States energy economy used in the model has high geographical resolution on technology stocks; technology cost and performance; built infrastructure and resource potential as well as high temporal resolution on electricity loads by end-use as well as renewable generation profiles. EnergyPATHWAYS leverages many of the same input files used to populate the National Energy Modeling System (NEMS) used by the United States Energy Information Administration (EIA) to forecast their Annual Energy Outlook.

The U.S. energy economy is separated into 65 energy-using demand subsectors. Subsectors, like residential space heating, represent energy-use associated with the performance of an energy-service. On the supply-

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[5] See Evolved Energy Research (2016, 2020) for more detailed documentation of this model.

side, the model is separated into interconnected nodes, which are associated with the production, transformation, and delivery of energy to demand subsectors.

On the demand side, residential uses such as water heating, clothes drying, dishwashing, refrigeration, freezing, cooking, heating and lighting are modeled. Detail for the commercial sector includes water heating, ventilation, space heating, commercial lighting, commercial cooking and commercial refrigeration, among others. Demand for detailed transportation and industrial sectors are also identified.

For this study, a scenario of investments was used in the model that implemented the technologies listed above in Table 1. The investment assumptions generated a spending stream for both new investment and operations and maintenance, as well as calculated changes in energy consumption for the transportation, industrial, commercial, residential and government sectors.

3. Direct Employment Impacts

The calculation of direct employment impacts provides insights related to those industries most closely involved in attaining the net-zero by 2050 target. To assess the direct employment impacts associated with the net-zero technology and policy pathway, we applied economic multipliers from the IMPLAN[6] input-output model to the projected expenditures associated with each pathway. The IMPLAN model is a well-established framework for assessing the employment impacts associated with a change in expenditures for one or several industries. Although the model can capture spillover effects to other industries, this analysis focuses on direct employment impacts only, as noted above. The direct employment multipliers that we apply from IMPLAN represent the number of jobs per million dollars of output, by industry. Using these multipliers, we estimate employment impacts associated with the upfront investments made pursuant to each technology and policy pathway (e.g., jobs related to the manufacture and installation of wind turbines) and, separately, the employment impacts related to ongoing operational activities stemming from those investments (e.g., operations and maintenance jobs for offshore wind facilities). Capturing investment- and production-related employment impacts separately is important for the overall accuracy of the results. Because the specific industries involved in designing and constructing facilities differ from those involved in operations, different IMPLAN data must be used for the analysis of investment impacts than for the assessment of operational impacts.

A key input to our analysis is the estimated increase in capital expenditures associated with the expanded adoption of each technology under the net-zero by 2050 scenario, relative to baseline. As described in section 1, estimates of these expenditures were generated by Evolved Energy Research, using its ENERGYPathways model of the U.S. energy system. Evolved Energy Research also generated estimates of biofuel production that serve as inputs into our assessment of operation-related employment.

In the sections that follow, we describe the methods applied for the estimation of investment- and operation-related employment impacts. For investment-related impacts, we followed two separate but related approaches: one drawing from the National Renewable Energy Laboratory's (NREL's) IMPLAN-based Jobs and Economic Development Impact (JEDI[7]) models for specific power sector technologies and a second based on IMPLAN data and technology-specific information from the literature. Similarly, we applied two separate approaches for operation-related employment impacts: one approach for electric power facilities and another approach for all other technologies, except for energy efficiency. Because energy efficiency investments generally involve the replacement of reference case equipment with more efficient equipment, we assume that the amount of labor required to operate this equipment remains

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[6] See https://www.implan.com for documentation and description of the IMPLAN model

[7] Described and downloadable from https://www.nrel.gov/analysis/jedi/.

unchanged in the net-zero by 2050 scenario relative to baseline. Also, much of this equipment is used/operated by households that do not hire labor for use of the equipment.

Estimation of Investment-Related Employment Impacts with JEDI For Select Power Sector Technologies

Our analysis of investment-related employment impacts for gas-fired power plants (both with and without CCS), onshore wind, offshore wind, utility-scale solar, rooftop solar, and transmission and distribution infrastructure is based, in part, on data from NREL's JEDI suite of models. Designed by NREL as user-friendly tools for the assessment of economic impacts associated with constructing and operating different types of energy facilities, JEDI includes detailed information on the composition of spending for several types of electricity generation technologies. Using this information, JEDI estimates the employment impacts associated with constructing and operating a new facility in the state where it is located. For the purposes of this analysis, however, we use the data in JEDI to estimate the total U.S. employment impacts associated with building new power facilities, in the states where these facilities are located and in other states, the latter of which is not captured in JEDI. Our approach involves the following steps:

1. *Estimate the percentage of investment expenditures that are sourced within the U.S.* The magnitude of employment impacts associated with the design, manufacture, and installation of power technologies depends on the degree to which such technologies are sourced from U.S. suppliers. Therefore, as an initial step in estimating employment impacts, we specify the fraction of investment expenditures, by technology, directed to U.S.-based suppliers. Table 2 presents this value for each of the power system technologies for which we rely on data from JEDI. As indicated in the exhibit, most of these values were derived from domestic production data from the U.S. Economic Census and imports and export data from USA Trade (U.S Census Bureau 2017a; 2017b). For wind, however, the sectoral definitions in these data were too aggregated to apply. We therefore used data from NREL's JEDI model instead.

Table 2. Percent of Investment Expenditures Spent in U.S.

TECHNOLOGY	PERCENT DOMESTIC
Onshore Wind	58%
Offshore Wind	91%
Solar (utility-scale and rooftop)	56%
Gas-fired power plants	65%
Transmission and distribution infrastructure	74%

2. *Distribute expenditures across states:* To support the estimation of employment impacts at the state level, we allocated those expenditures that remain in the U.S. to individual states. Although the investment expenditure estimates generated by Evolved Energy Research's energy system modeling are at the state level, these data reflect where technologies are deployed. Many of the jobs associated with power system technologies are located where systems are designed and manufactured. We therefore developed a distribution distinct from the spatial distribution of deployment, following a two-step approach. First, for each technology type, JEDI includes an estimate of the percentage of project expenditures made in the state where a project is located; we applied these values in our analysis. We allocated the remaining portion of domestic expenditures based on the concept of economic gravity, a concept often used to characterize trade flows between countries and within large countries such as the U.S. The gravity concept posits that the economically larger two locations are and the closer they are

to one another, the more likely they are to trade with one another. For the purposes of this analysis, we operationalize this concept using the standard economic gravity equation as follows:

$$E_{ns} = \frac{F_{ns} D_{np}}{d_{sp}} \quad (1)$$

Where:

E_{ns} = Expenditures on technology n allocated to supplying state s;

$F_{n,s}$ = Labor force for technology n in supplying state s[8];

D_{np} = Demand for technology n in purchasing state p (i.e., expenditures for deployment in state p, as indicated in the Evolved Energy Research energy system model results);

d_{sp} = Distance between supplying state s and purchasing state p (based on the centroids of each state).

Because the standard gravity approach represented in Equation 1 does not constrain the values of E_{ns} such that total expenditures summed across individual states equals total expenditures remaining in the U.S. (excluding the portion remaining in the state where a project is located), we normalized E_{ns} to derive an estimate of the percentage of expenditures associated with an individual state:

$$F_{ns} = \frac{E_{ns}}{\sum_s E_{ns}} \quad (2)$$

where F_{ns} is the fraction of expenditures for technology n allocated to state s. The estimated values for F_{ns} are applied to the total investment expenditures remaining in the U.S. for a given technology, excluding expenditures already allocated to the states where projects are located.

3. *Allocate expenditures across components of the value chain:* As an intermediate step in estimating the employment impacts of an energy project, JEDI distributes investment expenditures for the project across 14 broad value chain components (see Table 3). The distribution across value chain components varies between project types (e.g., utility-scale solar versus onshore wind). Consistent with the approach in JEDI, we allocate investment expenditures to each of these value chain components for each technology, with the exception of transmission and distribution infrastructure. Because the investment in transmission and distribution infrastructure is focused heavily on distribution, we developed a customized distribution across value chain components based on project-specific information on the cost of upgrading a local distribution system grid to accommodate increased electrification of home heating. Table 3 shows the distribution across value chain components for each technology.
4. *Apply IMPLAN Employment Multipliers:* As a final step, we apply IMPLAN employment multipliers specific to each value chain component and state to the corresponding expenditures (estimated based on the steps above). For each value chain component, these multipliers represent a composite of the multipliers for relevant industries.

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[8] Labor force for each technology is based on employment data by NAICS code from U.S. Census Bureau (2017a).

Table 3. Distribution of Investment Spending Across Value Chain Components

VALUE CHAIN COMPONENT	ONSHORE WIND	OFFSHORE WIND	SOLAR (ROOFTOP AND UTILITY-SCALE)	GAS-FIRED POWER PLANTS	TRANSMISSION AND DISTRIBUTION INFRASTRUCTURE[2]
Agriculture	0%	0%	0%	0%	0%
Mining	0%	0%	0%	0%	0%
Construction	58%	1%	43%	58%	60%
Manufacturing	8%	1%	12%	0%	40%
Fabricated Metals	0%	0%	12%	0%	0%
Machinery	0%	0%	3%	3%	0%
Electrical Equipment	0%	15%	2%	0%	0%
Transportation, Communication, and Public Utilities	0%	41%	0%	2%	0%
Wholesale Trade	0%	0%	0%	0%	0%
Retail Trade	4%	0%	0%	0%	0%
Finance, Insurance, and Real Estate	0%	0%	0%	17%	0%
Misc. Services	4%	1%	0%	0%	0%
Professional Services	2%	31%	15%	0%	0%
Government	23%	9%	13%	19%	0%
Total	100%	100%	100%	100%	100%

Notes:

1. Coal-fired generation is not included here because the modeling from Evolved Energy Research shows no new investment in coal generation under the reference case or under the Net-Zero by 2050 scenario.

Sources:

1. Unless otherwise noted, National Renewable Energy Labs. 2016-2018. Jobs and Economic Development Impact Models. https://www.nrel.gov/analysis/jedi/models.html
2. City of Palo Alto (2020).

Estimation of Investment-Related Employment for All Other Technologies

To estimate the employment impacts associated with investment in the other technologies included in this analysis, we applied an approach based on IMPLAN multipliers and technology-specific information obtained from the literature. We applied this approach to battery storage, all forms of fuels included in the analysis, energy efficiency investments, and investments in technologies related to CO2 sequestration and removal. The elements of this approach are as follows:

- *Allocate investment expenditures between equipment and installation/ construction:* Because the sectors involved in the manufacturing of equipment may differ from those involved with the installation and construction of that equipment, we estimated the distribution between equipment costs and installation/construction costs for each technology based on technology-specific information identified in the literature, as summarized in Table A-1[9] for each technology. The exception to this is investments in energy efficiency. Because most of the energy efficiency investments included in this analysis do not involve the construction of new facilities or production systems (e.g., rather, they involve, for example, retrofitting homes with more efficient lighting), our analysis for energy efficiency improvements focuses on the employment impacts of producing more energy efficient goods and equipment.[10]
- *Estimate the percentage of equipment investment expenditures that stay within the U.S.:* Similar to the approach outlined above for various forms of power infrastructure, we also estimate the fraction of equipment expenditures directed to U.S. based suppliers. Because expenditures flowing to suppliers outside the U.S. do not result in employment impacts for the U.S., accounting for the allocation between U.S. and non-U.S. suppliers is important for generating accurate employment impact estimates. The last column of Table A-1 shows the U.S. percentage, by technology.
- *Identify IMPLAN sectors associated with equipment for each technology:* To enable estimation of the employment impacts associated with equipment manufacturing, we identified the specific IMPLAN sectors associated with the equipment necessary for each technology/facility type. We made these determinations based on the specific types of equipment identified in the techno-economic literature for each technology. The IMPLAN sectors chosen are shown in Table A-2. The exception to this analytic step is advanced nuclear energy, as we directly estimated employment per million dollars of expenditures based on sample project data for an AP1000 reactor.
- *Calculate equipment-related employment impacts:* After identifying the sectors related to each type of equipment, we calculated the employment impacts associated with the production of that equipment by multiplying equipment expenditures (by year) by the fraction of equipment purchases domestically sourced and the employment multipliers obtained from IMPLAN.
- *Allocate equipment-related impacts to the state level:* After estimating equipment-related impacts at the national level, we allocated impacts to individual states based on the spatial distribution of activity for individual industries. To perform this allocation, we relied on the spatial distribution of industry activity represented by NAICS-level employment data as reported by the U.S. Economic Census (U.S. Census Bureau 2017a). We followed this approach rather than the gravity-based method specified

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[9] Large tables have been relegated to Appendix A.

[10] To the extent that some energy efficiency investments reflect installation costs, these are reflected in the expenditure values included in Evolved Energy Research's energy system modeling outputs. The analysis presented here, in effect, treats such installation expenditures as equipment expenditures.

above for power-system investments because the specialized nature of several of these technologies would complicate applying the more detailed, precise gravity-based approach.[11]

- *Identify IMPLAN sectors associated with installation/construction:* Similar to the approach for equipment manufacturing, we also identified the IMPLAN sectors associated with installation and construction for each technology/facility type, based on information in the techno-economic literature. The IMPLAN sectors chosen are shown in Exhibit 5.[12]
- *Estimate portion of installation costs associated with labor (where possible):* For some technologies, the techno-economic studies containing information on the cost of installation/construction specify the portion of installation costs related to labor. In such cases, we applied labor's share of installation costs, as derived from these studies, to our estimates of total investment costs associated with a given technology.
- *Calculate installation-related employment impacts:* To generate estimates of installation-related employment impacts, we multiplied installation expenditures by the employment multipliers obtained from IMPLAN. For the technologies for which we were able to estimate installation labor costs directly (see previous bullet), we calculated employment impacts by dividing installation labor costs by the average labor cost per worker, as derived from IMPLAN.
- *Allocate installation-related impacts to the state level:* The energy modeling outputs provided by Evolved Energy Research for this analysis specify investments in each technology at the state level. To spatially allocate installation-related impacts for a given technology, we assume that such impacts are distributed across states in proportion to investments for that technology.
- *Sum equipment-related employment and installation-related employment:* As a final step, we calculated total investment-related employment by summing our estimates of equipment-related employment impacts and installation-related employment impacts.

Estimation of O&M-Related Employment Impacts In The Electric Power Sector

Complementing our estimates of investment-related power sector employment impacts, we also estimate the employment impacts associated with the operation of power sector facilities. These include employment gains for the operation of power generation technologies relied upon more under the net-zero by 2050 scenario and employment losses related to generation technologies relied upon less under this scenario. To develop these estimates, we followed a two-step process. First, for a given year, we estimated the total change in installed capacity (relative to the reference case) by power generation technology based on the energy system modeling performed by Evolved Energy Research. We then multiplied these values by technology-specific estimates of full-time equivalent employees per megawatt of capacity (see Exhibit 6) to estimate the change in employment by technology type and year.

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[11] The exception to this approach was advanced nuclear energy. We used the gravity-based approach for this technology to be consistent with the other power system investments described in the discussion above.

[12] Consistent with the approach described above for equipment, advanced nuclear energy is the exception to this approach. Rather than relying on IMPLAN data, we estimated employment per million dollars of expenditures directly for advanced nuclear energy based on sample project data for an AP1000 reactor.

Table 4. Full-Time Equivalents Per MW of Capacity

GENERATION TECHNOLOGY	FTE PER MW OF CAPACITY
Coal-based power[1]	0.2
Gas-based power (no CCS)[1]	0.065
Gas-based power (with CCS)[2]	0.214
Onshore wind[3]	0.06
Offshore wind[4]	0.1
Rooftop solar[5]	0.5
Utility-scale solar[6]	0.026
Conventional nuclear energy[1]	0.55
Advanced nuclear energy[7]	0.364

Sources:
1. National Commission on Energy Policy (2009).
2. Derived from Regional Carbon Capture Deployment Initiative (2020).
3. Keyser and Tegen (2019).
4. Borges et al. (2017).
5. Kuldeep et al. (2017)
6. SunPower (2016).
7. U.S. Department of Energy (undated)

Estimation of O&M-Related Employment Impacts for All Other Technologies

For O&M-related employment impacts outside the power sector, we follow an approach based on published information regarding the operation and maintenance costs associated with each technology and labor cost information from IMPLAN. The individual steps of this approach are as follows:

- ***Estimate annual O&M costs based on published techno-economic data:*** As an initial step in estimating O&M-related employment for each technology, we generate technology-specific estimates of O&M costs, by year. For several technologies, we develop these estimates based on published data on O&M costs per unit of output for each technology and the level of output by technology as included in the energy modeling outputs from Evolved Energy Research. For example, to estimate annual O&M costs for ammonia, we apply a unit O&M cost of $358 per metric ton to the annual ammonia production estimates included in Evolved Energy Research's model outputs.13,14 In addition to ammonia, IEc applied this approach (using different O&M cost parameters) for direct air capture, ethanol and biofuels, power-to-gas, power-to-liquids, and transmission & distribution infrastructure. Exhibit 7 shows the O&M cost parameters for each of these technologies.

  For battery storage, CO_2 pipelines, SMR hydrogen, electrolytic hydrogen, and BECCS, we estimated annual O&M costs based on published data characterizing the annual O&M costs for each technology as a fraction of cumulative capital investments. Thus, if annual O&M is 5 percent of cumulative investment for a given technology and $1.0 billion of capital is installed in year 1, $1.4 billion in year 2, and $1.6 billion in year 3, O&M costs in year 3 are $200 million (5 percent of $4 billion in

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[13] The unit O&M cost for ammonia production was derived from International Energy Agency, Techno-Economic Evaluation of HYCO Plant Integrated to Ammonia/Urea or Methanol Production with CCS, IEAGHG Technical Report 2017-03, February 2017.

[14] The Evolved Energy Research results report ammonia production in terms of its energy value instead of its mass. We converted energy to mass based on an energy content of 5.17 MWh per metric ton.

cumulative investment costs). Exhibit 4 presents annual O&M as a percentage of cumulative investment for each of the technologies to which this approach was applied.

- ***Estimate labor cost component of O&M costs, where possible:*** For several of the technologies examined, the cost information in the available techno-economic studies indicates labor's share of O&M costs. These values are presented in the right-hand column of Table A-3. Applying these percentages to the O&M cost estimates generated in the previous step, we estimated the O&M labor costs associated with these technologies.
- ***Apply IMPLAN data to costs to calculate employment impacts:*** As a final step in estimating O&M labor, we applied data from IMPLAN to the cost values generated in the previous steps to estimate the number of O&M-related jobs for a given year. For technologies for which we estimated labor-related O&M costs, we divided these costs by the average labor costs per worker as indicated by IMPLAN data for the relevant industries. For those technologies for which we estimate O&M costs overall but not labor costs, we relied on IMPLAN employment multipliers.[15]

Results

Following the approach outlined above, we estimated the direct employment impacts associated with the various technologies included in the net-zero by 2050 pathway. Figure 1 shows the projected trajectory of direct employment effects for each of the four technology categories described above. As the figure shows, annual employment associated with the net-zero by 2050 pathway grows steadily over time from approximately 140,000 jobs in 2023 to nearly 2.4 million jobs in 2050. Through the 2020s, energy efficiency investments account for the largest share of employment gains, with more than 100,000 jobs in 2023 related to energy efficiency alone (relative to 140,000 jobs in total). Although employment related to energy efficiency is projected to grow over time (390,800 jobs by 2050), projected job growth for the other technology categories is more rapid, particularly power infrastructure. By the early to mid-2030s, we project that jobs related to power infrastructure will overtake energy efficiency as the largest source of employment among the four categories. By 2040, the nearly 678,000 jobs associated with power infrastructure will account for half of estimated employment gains. Figure 1 also shows that jobs related to CO2 removal and transportation account for a small fraction of new employment relative to the other technology categories, particularly over the first two decades projected. However, the analysis projects jobs associated with CO2 removal and transportation will grow significantly between 2040 and 2050, from 87,500 jobs in 2040 to 352,000 jobs in 2050.

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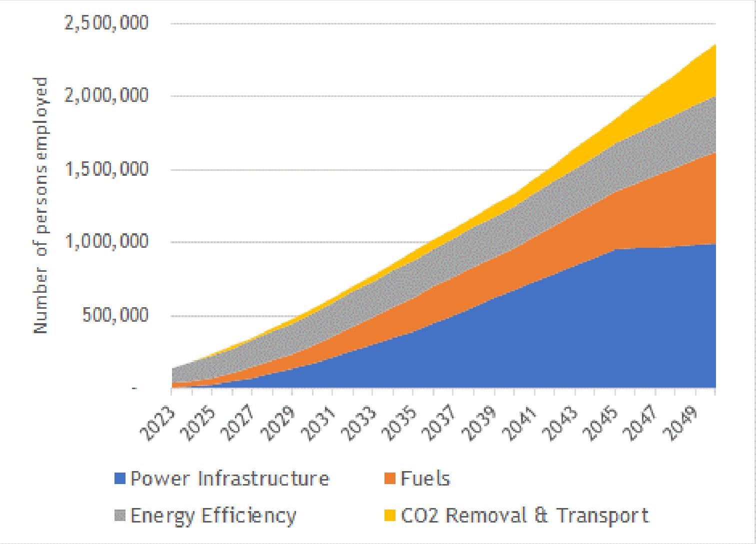
[15] Because direct employment per million dollars of O&M spending is typically less than employment per million dollars of output, we likely underestimate O&M-related employment impacts for these industries.

Figure 1. Direct Employment by Category: 2023-2050



For additional detail on the projected employment associated with achieving net-zero GHG emissions, Table A-4 presents employment by individual technology and year. Impacts are shown for each year between 2023 and 2030 and every fifth year thereafter. Note that for ease of exposition, some technologies have been combined (e.g., onshore wind and offshore wind are presented as a single category for wind). The technology-specific detail in the exhibit highlights several key insights from the analysis:

- *Energy efficiency in the residential, commercial, and manufacturing sectors is an early driver of employment related to the clean energy transition:* Table A-4 shows that efficiency investments in the residential building, commercial building, and manufacturing sectors account for the vast majority of projected employment impacts through the 2020s. Combined, energy efficiency investments in these sectors make up more than 95,000 jobs in 2023, which is more than two-thirds of total employment related to the clean energy transition across all technologies that year. Efficiency investments in these sectors continue to account for a significant portion of employment impacts through 2030, making up more than half of employment impacts in 2025 and more than one-third of job impacts in 2030. The investments that drive these efficiency-related employment impacts are largely related to existing technologies that are widely available today. Moreover, unlike utility-scale renewable energy projects or other large capital-intensive investments, which may take years to develop, the energy efficiency technologies for these sectors require minimal time to put in place, which is one of the main reasons why they account for such a large portion of employment impacts in the early years of the analysis.
- *Blue hydrogen is an important early driver of fuels jobs, but over time biofuels and biomass feedstocks show the greatest job gains:* Within the fuels category, employment impacts in the early to mid-2020s are dominated by SMR hydrogen. Between 2023 and 2030, SMR hydrogen accounts for between 40 and 55 percent of fuels employment impacts. By the 2040s, however, SMR hydrogen makes up no more than 15 percent of employment impacts related to fuels, as employment in biofuels and biomass feedstock production grows significantly during this period. Between 2035 and 2050, employment related to biofuels and biomass feedstocks grows from 63,900 jobs to 402,000 jobs.
- *Over time, transmission and distribution investment is the biggest generator of jobs among all the technologies examined:* Although employment gains related to transmission and distribution (T&D) investments are relatively low through the 2020s, by 2035 it becomes the most significant technology in terms of annual employment impacts, accounting for 170,000 jobs that year, or 18 percent of total employment impacts. In 2050, T&D is expected to account for nearly 560,000 jobs, or 24 percent of

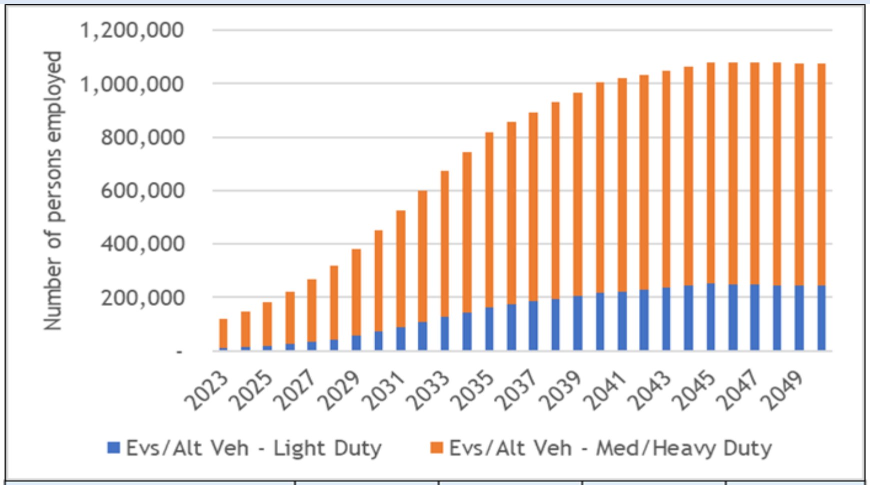
total impacts. The growth in T&D employment impacts (and investment) post-2030 reflects the increased need for T&D infrastructure to accommodate renewables during this time, as well as electrification of transportation and heating.

- *Renewable electricity jobs grow steadily over most of the study period, surpassing 135,000 in 2030 and 400,000 jobs in 2045 before declining to 365,000 jobs in 2050.* While the early years see more employment in solar energy, starting in the mid-2020s, wind energy jobs become more prevalent and increase at a faster pace. Notably, looking more broadly at power supply jobs, the growth in renewable energy jobs exceeds job losses at natural gas- and coal-fired power plants.[16]

ADDITIONAL DETAIL ON ELECTRIC VEHICLE EMPLOYMENT IMPACTS

The employment impacts for energy efficiency shown in Exhibit 9 reflect the ***net*** spending by technology. Thus, for EVs and other alternative vehicles the impact estimates reflect net spending on vehicles overall. To provide insights into employment specifically associated with EVs and other alternative vehicles, we performed a supplemental analysis estimating employment impacts associated with ***gross*** expenditures on these vehicles under the net-zero by 2050 scenario (i.e., not net of the baseline). For this supplemental analysis, we also captured indirect employment impacts, given vehicle manufacturers extensive reliance on outside suppliers. The results of this analysis are presented in the graph and table below. As shown, we estimate more than 180,000 direct and indirect jobs related to alternative vehicles in 2025 and nearly 1.1 million jobs in 2050. Most of these jobs are related to medium- and heavy-duty vehicles. Although spending on light duty alternative vehicles is projected to be much higher than on medium- and heavy-duty alternative vehicles, a larger portion of medium- and heavy-duty vehicles are produced in the U.S. and the direct and indirect employment multipliers are also higher for these vehicles than for light duty vehicles.

DIRECT AND INDIRECT EMPLOYMENT ASSOCIATED WITH PROJECTED EXPENDITURES ON ALTERNATIVE VEHICLES UNDER THE NET ZERO BY 2050 SCENARIO



	2025	2030	2040	2050
Evs/Alt Veh - Light Duty	18,800	71,300	216,400	243,000
Evs/Alt Veh - Med/Heavy Duty	162,100	380,500	788,600	834,100
Total	**180,900**	**451,800**	**1,005,000**	**1,077,100**

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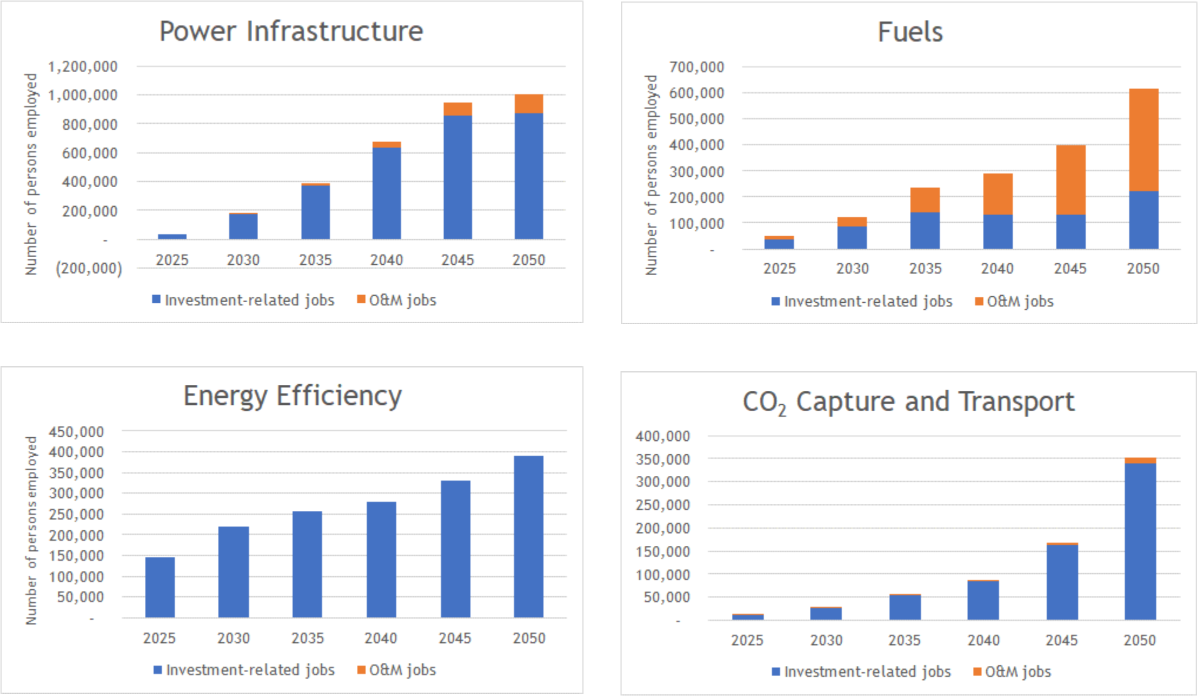
[16] Also related to renewables, Table A-4 shows slightly negative employment impacts for wind power in 2023. This reflects a relatively small amount of substitution between solar and wind that year.

The results in Table A-4 also show growth in employment related to clean transportation (EVs and chargers) over time, with total employment impacts for vehicles and chargers exceeding 25,000 jobs in 2050. For vehicles alone, we project a reduction in employment in the 2040s and in 2050. This reflects efficiencies in battery manufacturing under the net-zero by 2050 scenario relative to baseline that reduce the costs of EVs and the labor required to produce them.

Employment impacts related to natural gas-fired generation vary between positive and negative over the time horizon of the analysis. The increase shown in Table A-4 in the early to mid-2020s reflects investments in gas-fired generating capacity displacing investments in coal-fired capacity. As investment in renewables increases more significantly in the late 2020s and early 2030s, investment in and employment associated with natural gas-based power generation declines.

As noted above, the employment impacts associated with achieving net-zero by 2050 include impacts associated with investment expenditures on various technologies and impacts associated with operating these technologies. Exhibit 10 shows the distribution between these two types of effects. As shown in the exhibit, investment-related job impacts account for most of the total for power infrastructure, CO2 removal & transportation, and energy efficiency. Over time, however, operation-related impacts account for a larger share of impacts for power infrastructure and fuels. This reflects the cumulative effect of expanding capacity of individual technologies over time; as more capacity is installed, more labor is required to operate that capacity. For energy efficiency, however, Exhibit 10 show no O&M-related employment impacts. This reflects the assumption stated above that the labor required to operate more energy efficient equipment (e.g., more efficient heating and cooling systems in commercial buildings) is similar to that associated with equipment used under baseline conditions. In addition, in contrast to the other technology categories, Exhibit 10 shows that O&M job impacts outpace investment-related job impacts for fuels. In large part, this reflects the jobs associated with biomass feedstock production.

Figure 2. Distribution Between Investment-Related Employment Impacts and O&M-Related Employment Impacts



Power Infrastructure

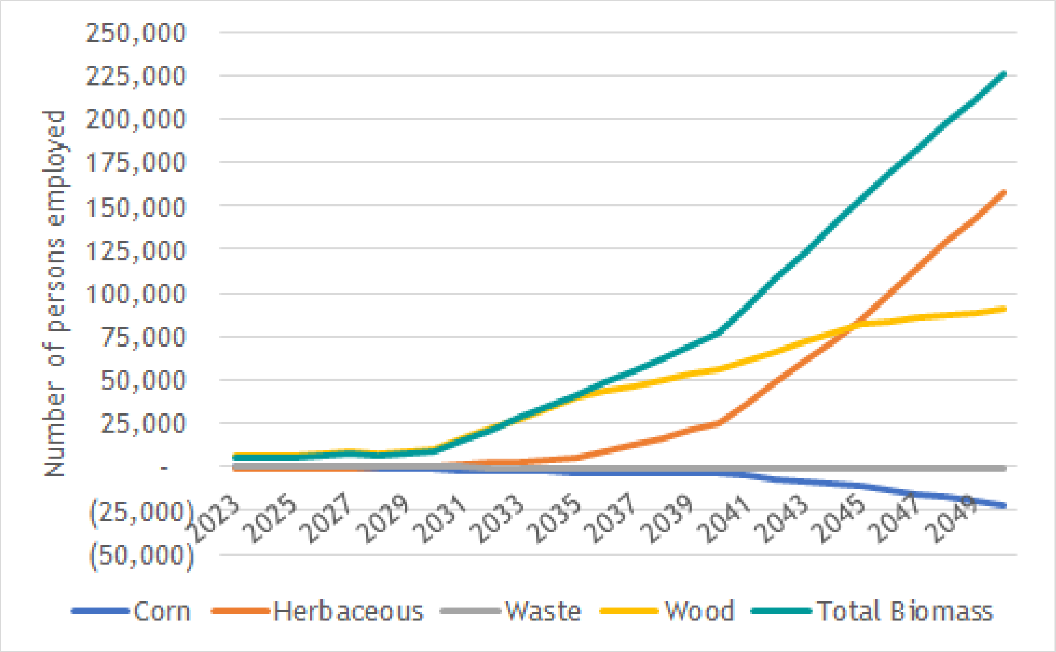
Fuels

Energy Efficiency

CO_2 Capture and Transport

The employment impacts presented below for biomass feedstocks reflect impacts for four different types of feedstocks: corn, herbaceous biomass, waste, and woody biomass. Figure 3 shows the job impact trajectory for each of these biomass types, as well as for all four combined. As highlighted in the exhibit, the employment impacts related to biomass are driven largely by woody biomass and herbaceous biomass, with the former accounting for almost all biomass-related employment impacts through 2040. The figure also shows that employment impacts related to both corn and, to a lesser extent, waste decline over time under the net-zero by 2050 scenario. The decrease projected for corn reflects reduced liquid fuel demand for the transportation sector over time.

Figure 3. Employment Impacts Related to Biomass Production



For perspective on the spatial distribution of the employment impacts associated with achieving net-zero by 2050, Figures 4A to 4D present impacts by state for the years 2025, 2030, 2040, and 2050. To normalize for population, these impacts are presented on a per-capita basis, accounting for projected population growth in each state.[17] As shown in the four maps included in Table A-4, employment impacts per capita are projected to grow over time, which implies that employment associated with achieving net-zero by 2050 is likely to grow more rapidly than population. Across all four years shown, employment per capita is projected to be higher in the central and northern plains than in other states. The drivers of these impacts vary between states and over time. In 2025, investments in energy efficiency and power infrastructure account for the largest share of employment impacts in most of these states. By 2050, however, employment related to fuels accounts for the largest share of employment impacts in many states (e.g., Iowa and Kansas). By 2050, employment impacts per capita in the northern Rockies and northern New England are also projected to be high relative to impacts in other states.

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[17] State-level population projections are those associated with the Integrated Climate and Land-Use Scenarios (ICLUS) available from the U.S. EPA at https://www.epa.gov/gcx/about-iclus.

Figure 4-A. Direct Employment Impacts of Net-Zero by 2050 per 1,000 residents - 2025

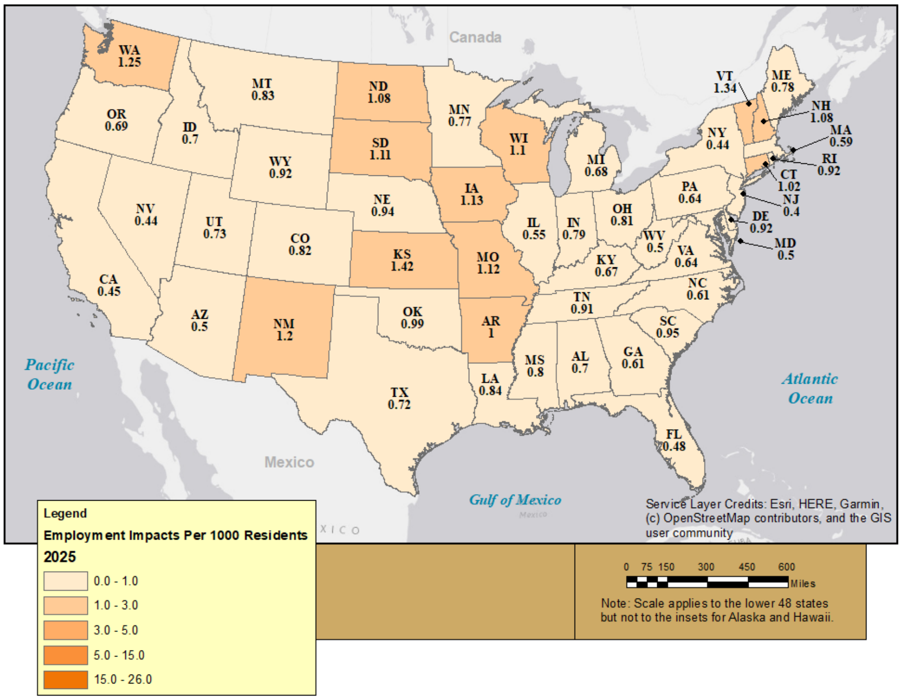


Figure 4-B. Direct Employment Impacts of Net-Zero by 2050 per 1,000 residents - 2030

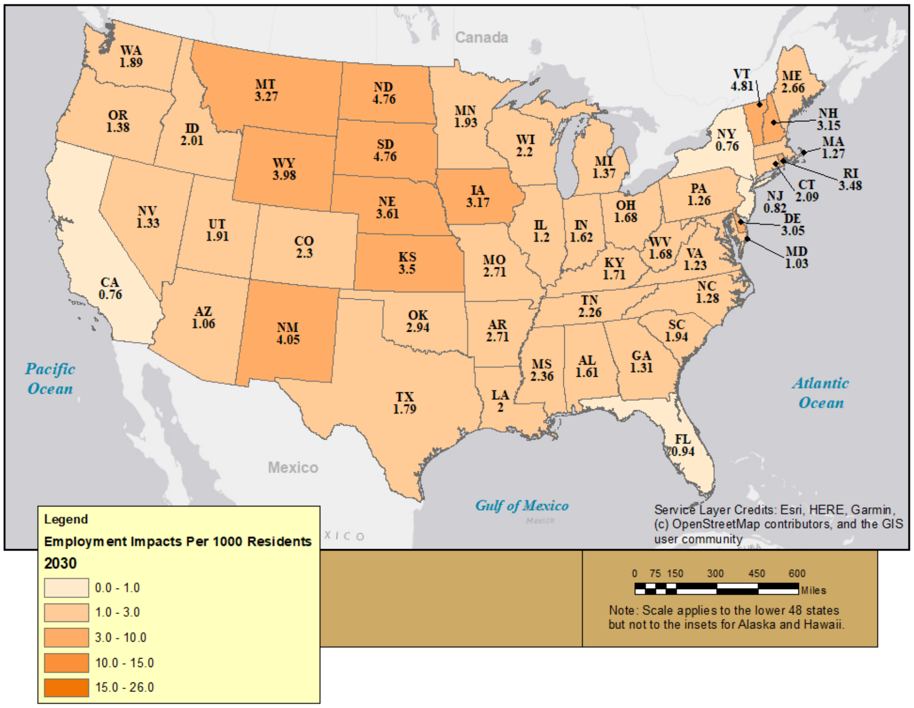


FIGURE 4-C. Direct Employment Impacts Of Net-Zero By 2050 Per 1,000 Residents - 2040

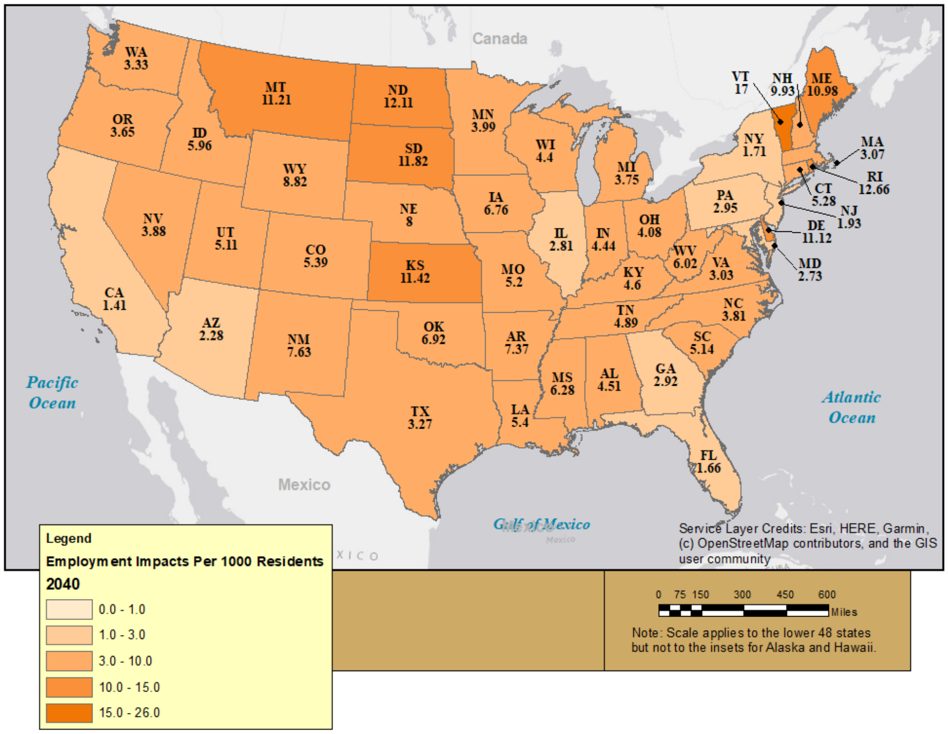
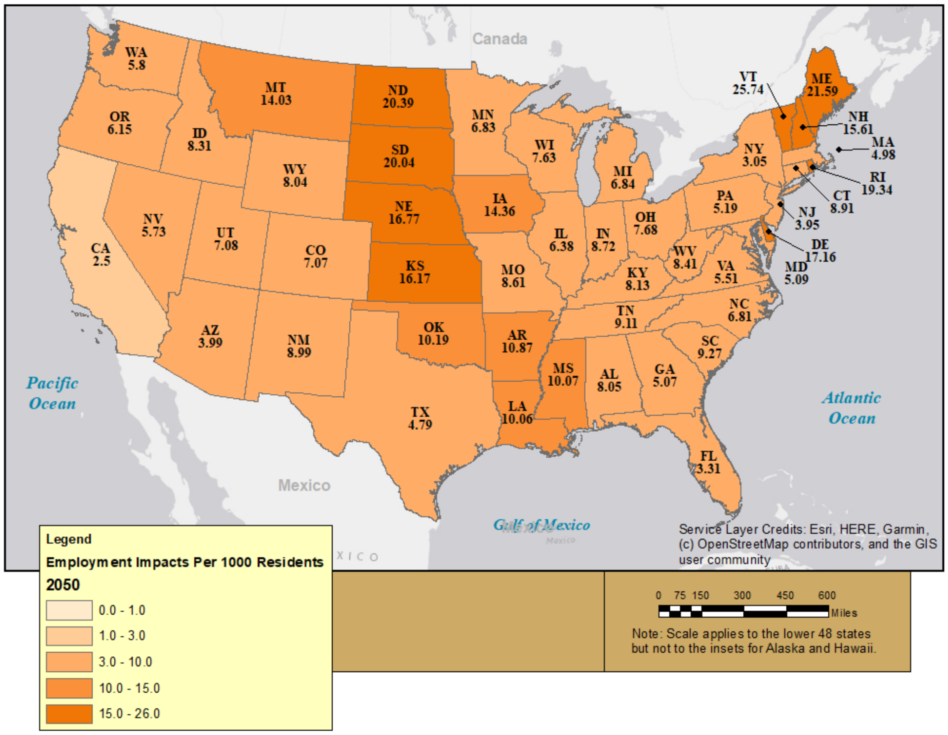


FIGURE 4-D. Direct Employment Impacts Of Net-Zero By 2050 Per 1,000 Residents – 2050



4. Economy-Wide Impacts

The analysis presented in the previous section provides useful insights into the employment impacts associated with manufacturing, installing, and operating technologies that can enable the achievement of net-zero GHG emissions by 2050. While informative, this analysis provides only a partial view of the employment impacts associated with achieving net-zero emissions, as it does not capture the myriad spillover effects across the broader economy. To assess employment impacts more comprehensively, we conducted an economy-wide assessment of these impacts that captures the various indirect pathways through which achieving net-zero GHG emissions may affect employment. Because the energy sector and other industries expected to make significant investments under the Net-Zero by 2050 scenario are closely linked with so many sectors of the economy, capturing these indirect effects is important for developing a full understanding of employment impacts. The economy-wide analysis captures not only direct employment impacts, but also (among other effects) employment impacts through the supply chain, impacts associated with reduced demand for fossil fuels (as reliance on renewables increases), and the extent to which employment related to investments in net-zero emissions crowds out employment for other activities.

Approach

To capture the full range of employment impacts associated with Net-Zero by 2050, we applied the LIFT macro-econometric model of the U.S. economy. LIFT is a macroeconomic input-output (IO) model of the U.S. economy, with 121 commodity sectors (for final demand, output and commodity prices) and 71 industry sectors (for employment, investment and value added).[18] The model combines an IO formulation with extensive use of regression analysis to employ a "bottom-up" approach to macroeconomic modeling. That is, the model works like the actual economy, building macroeconomic totals from details of industry and commodity activity, rather than distributing predetermined macroeconomic quantities among industries. LIFT also captures interactions between industries across the economy, enabling the model to gauge how changes in prices, investment, or productivity in one industry cascade across the economy. In the context of the policies considered here, this is an important feature for understanding the demand side and supply side impacts of the proposed investments, the changes in electric power generation mix, and changes in the consumption of energy by type in the agriculture, industrial, commercial, transportation, and residential sectors.

In the sections that follow, we present additional details on *LIFT*, the baseline data incorporated into *LIFT* for this analysis, and our approach for incorporating scenario-specific data inputs into *LIFT*.

The LIFT Model

The LIFT model used for this analysis is unique among large-scale models of the U.S. economy in that it is based on an IO core and builds macroeconomic forecasts from the bottom up. Investments are made in individual firms in response to market conditions in the industries in which those firms produce and compete. Aggregate investment is simply the sum of these industry investment purchases. Decisions to hire and fire workers are made jointly with investment decisions with a view to the outlook for product demand in each industry. The net result of these hiring and firing

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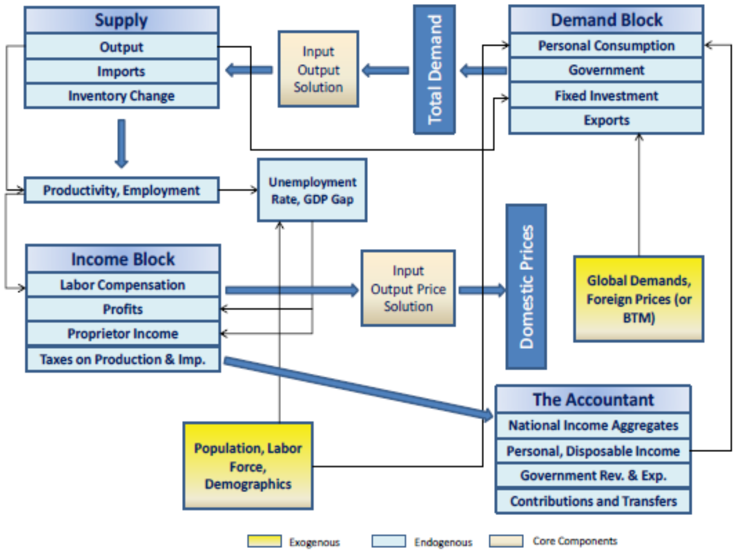
[18] See Meade (2020), McCarthy (1991). For general information on interindustry macro models developed by Inforum, see Grassini (1997) and Meade (2014). Previous studies done with the LIFT model related to the current paper include Steckley et al. (2010), Meade, Werling and Wescott (2009) and Meade and Price (2015).

decisions across all industries determines total employment, and hence the unemployment rate. The general structure of LIFT is shown in Figure 5.

Figure 5. Flow Diagram of the Inforum LIFT Model



Unlike typical IO frameworks, the LIFT model is dynamic, modeling changes in investment, capital stock, productivity, and prices year by year. Like other IO models, it captures spillover (indirect and induced) effects of direct expenditures. However, since LIFT is also a macroeconomic model, it adheres to budget constraints of consumers and firms, and explicitly models the federal and state and local government accounts. It also models constraints in the employment and capital markets, that may lead to “crowding-out” effects of increased investments.

Despite its IO basis, LIFT is a full macroeconomic model with more than 1,200 macroeconomic variables determined either by econometric equation, exogenously or by identity. Certain macrovariables provide important levers for studying the effects of government policy. Examples include the monetary base and the personal tax rate. Other macroeconomic variables, such as potential GDP and the associated GDP gap, provide a framework for perceiving tightness or slack in the economy.

The extensive simultaneity in LIFT requires an iterative solution for each year. At the beginning of each year’s solution, first guesses are made for some important endogenous variables, such as output and prices by industry, import shares, and many macro variables. Assumptions for exogenous variables are also established. Then the model loop runs until outputs and other variables converge.

The key steps in the model loop include determining real final demand expenditures; solving the input-output (IO) equations jointly for output, imports, and inventory change; computing employment; and finally computing prices. Final demand expenditures include personal consumption, government expenditures, exports, equipment investment, and construction investment. Personal consumption of individual products is modeled in the consumer demand system known as the Perhaps Adequate Demand System (PADS)[19]. This system allows for the

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[19] See Almon (1998) for a description of PADS.

classification of consumption goods into related expenditure groups, such as food, transportation or medical care. In the demand system, electricity prices affect the demand for natural gas since electricity and natural gas are substitutes in many cases. The demand system's parameters are estimated from historical consumption data. It is possible, however, to guide the level of consumption for individual products within the model. For example, if more efficient electric heat pumps are expected to come online, the amount of electricity consumed can be reduced accordingly.

With respect to supply, the IO equations in LIFT are determined by the IO coefficients, which represent the quantity of an input per unit output of a product and are specified to change over time. Individual coefficients can also be modified, to model changes in price or technology.

Jobs in the LIFT model are calculated at the industry level. There are 66 private industries and 5 government industries in the model. In the private sector, jobs are derived as a combination of real output and labor productivity projections by industry. Output is a function of final and intermediate demand by industry. Labor productivity is projected using an equation that combines a time-trend and a cyclical component. Total jobs in the economy are equal to the sum of jobs by industry and public sector jobs.

For the purposes of assessing the employment and other macroeconomic impacts associated with an economic shock, LIFT was designed to track a long-term growth path such as potential GDP, and to return to a normal rate of unemployment after a shock. The model is not constrained to immediately return to the baseline growth path, as would perhaps be true of an equilibrium or classical model. However, the model is also not Keynesian, in that eventually the model crowds out certain sectors in response to additional stimulus, and the economy starts to return to the growth path again after a response to a negative shock. In short, the goal was to design the model to be Keynesian, or demand-responsive, in the short- to medium-term, but approaching classical response in the long run.

Reference Case

As a starting point for analysis, the baseline forecast in LIFT was calibrated to the Energy Information Administration's 2021 Annual Energy Outlook (AEO) baseline for the years 2021 through 2050. This calibration was done in two stages. In the first stage, industry variables, macroeconomic variables, and IO coefficients were modified to produce a macroeconomic forecast consistent with the AEO. In the second stage, imports, exports, personal consumption expenditures and IO coefficients were modified to calibrate to energy and carbon projections from the AEO. The current forecasting horizon of both AEO 2021 and LIFT is 2050.

The goal of the macroeconomic calibration is to produce a LIFT reference case that has the same overall GDP growth and composition as that of the AEO reference case. Although LIFT has detailed equations for the components of personal consumption, equipment investment, construction, and imports and exports, controls can be imposed on the model that bring the totals of these final demand categories into alignment with the AEO. The standard Inforum reference case also has a different projection of population, labor force, labor productivity, and total employment than the AEO. These demographic and employment variables are also modified so as to be consistent with AEO. Labor productivity by industry is modified to obtain the employment projection calibration.

This AEO baseline was then modified to be consistent with the baseline of the Evolved Energy Research ENERGYPathways model. Because the employment impacts of decarbonization depend on the extent to which the economy is (or is not) decarbonized already, calibrating to the same baseline as used in the ENERGYPathways modeling is important for generating accurate estimates of employment impacts. To that end, the AEO-derived baseline in LIFT was modified to reflect Evolved Energy Research's baseline projections of energy consumption by sector by type, electric power generation by type of generation and in total, and carbon emission ratios associated with production and energy use by sector. Other than these changes, our reference case is largely based on the AEO 2021 reference case.

Figure 6 shows a summary of the baseline energy consumption values by sector and energy type, in quadrillions of Btus. The consumption of energy by sector by type is related to LIFT energy flows. The industrial and commercial sectors are defined according to LIFT industries, and commercial includes government. Residential energy consumption includes energy use associated with housing services. Transportation includes consumption by the transportation sectors in LIFT, consumption by the auto leasing sector, and personal consumption of gasoline and diesel fuel. Input-output coefficients are adjusted in the model to calibrate to the totals from Evolved Energy research.

In the case of the household sector, the personal consumption equations for electricity, gas, and transportation fuels are left to operate normally, responding to income and price changes, but are adjusted multiplicatively to be consistent with the baseline specified by Evolved Energy Research. The same adjustments remain in the Net-Zero by 2050 scenario, so the equations still respond to income and price effects.

Table 5. Baseline Energy Consumption by Sector (quadrillion btus)

SECTOR	2025	2030	2035	2040	2045	2050
Industrial	30.0	31.3	32.4	33.5	34.7	36.0
Commercial	17.8	18.6	19.7	20.6	21.6	22.6
Transportation	24.5	21.5	18.6	15.9	13.8	12.6
Residential	19.4	19.4	19.5	20.0	20.5	21.1
Total	**91.6**	**90.5**	**90.1**	**89.9**	**90.6**	**92.6**

Table 6 presents the baseline projections of primary energy production, which are consistent with the energy consumption by sector and the exports and imports of primary energy exogenously specified from the Evolved Energy Research model. For example, in *LIFT*, the output of crude petroleum is derived from demand for crude petroleum exports less crude petroleum imports, plus domestic demand which is largely based on production of refined petroleum-based fuels, but also for other petroleum derived products such as asphalt, tar and petrochemicals.

Table 6. Baseline Output of Primary Energy (Billion 2018$)

ENERGY SECTOR	2025	2030	2035	2040	2045	2050
Crude petroleum	$445.8	$451.8	$472.6	$471.3	$398.0	$305.8
Natural gas extraction	$117.5	$145.5	$159.1	$175.6	$191.3	$207.2
Coal	$21.0	$18.4	$17.6	$17.3	$17.3	$17.1
Petroleum refining	$702.6	$695.4	$699.4	$704.9	$709.5	$714.8

Table 7 shows the baseline projections of electricity production by technology/fuel type. Due to differences in the labor intensity of different power generation technologies and differences in the supply chain across technologies (e.g., primary fuel used), specifying a baseline generation mix in *LIFT* that is consistent with that in the Evolved Energy Research modeling is important for accurately capturing the employment implications related to changes in the electricity generation mix. As indicated in Table 7, the baseline projections show a decline in fossil fuel-based generation over time and an increase in renewables.

Table 7. Baseline Electricity Production (billion kWh)

TECHNOLOGY/FUEL	2025	2030	2035	2040	2045	2050
Total	**4,332.9**	**4,393.4**	**4,525.3**	**4,637.1**	**5,038.4**	**5,078.8**
Coal	475.5	301.4	238.8	186.5	186.3	172.9
Gas	2,203.3	2,279.8	2,309.7	2,103.0	2,084.1	1,715.1
Oil	3.4	3.1	2.4	2.4	2.4	1.3
Nuclear	802.9	803.1	791.6	791.8	774.5	691.1
Hydro	265.7	269.6	271.7	261.6	283.9	282.1
Wind	324.5	437.1	540.6	854.3	1,096.8	1,458.0
Solar	272.5	324.0	398.7	464.8	638.4	782.7
Other	7.1	2.8	1.9	1.9	1.9	1.8

The development of the Net-Zero by 2050 scenario involved incorporating a variety of data into *LIFT* to reflect the investments and other changes to the U.S. energy system reflected in this scenario. Rather than incorporate these data into *LIFT* at once, we introduced these data into the model one variable at a time to ensure that the model used each data element correctly. These data, based on Evolved Energy Research's ENERGYPathways modeling, are as follows:[20]

- ***Industrial Efficiency Investments*** – Efficiency investments for agriculture crops and other agriculture, as well as investments for 14 manufacturing sectors and the construction industry were specified through 2050. These were matched to the *LIFT* investment sectors and specified as increases in plant and equipment investment in those sectors. These investments reach a total of $132.5 billion by 2050.
- ***Commercial Efficiency Investments:*** As listed in Table B-1, these include investments for cooking, HVAC, lighting, refrigeration, water heating, and other. These were modeled as efficiency investments by the *LIFT* sectors that purchase these types of equipment. Investments for refrigeration and cooking were directed to Food and Beverages, Wholesale Trade, Food and Beverage stores, Accommodation, and Food Services. Investments in HVAC, lighting, and water heating were distributed according to existing investment patterns of the assets used for these investments in the commercial sector. Overall, incremental commercial sector efficiency investments reach a total of $41.3 billion by 2050.
- ***Residential Efficiency Investments:*** Also listed in Exhibit B-1, these include many investments in residential buildings themselves, as well as home appliances. These investments were distributed to the Residential Additions and Alterations industry in *LIFT*, and personal consumption of home appliances. The total investments by 2050 are $51.9 billion.
- ***Electric Vehicle Costs and Charging Stations:*** Electric vehicle investments were distinguished by investments in heavy vehicles (heavy- and medium-duty trucks, and transit buses), and light vehicles (light-duty autos and light-duty trucks). Heavy duty electric vehicle investments were distributed to Construction, Wholesale trade, Truck transportation, and Transit and Ground Passenger Transportation. Light vehicle

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[20] Note that all dollar figures found in this section are in constant 2018$, incremental to baseline investment.

investments were distributed to Retail trade and Rental and Leasing Services, as well as Personal Consumption of Autos and Light Trucks. Additional net investments in electric vehicles start off positive but are at net -$13.3 billion relative to the reference case by 2050, due to cost reductions for battery technology. Charging station investments reach $59.2 billion by 2050 and are modeled as state and local investment purchases of Other Electrical Equipment and Components.

- ***Biomass Feedstocks Investment:*** This investment was modeled as spending on the Agricultural Services sector. These investments reach $22.1 billion by 2050.
- ***Expenditures for CO_2 Pipelines:*** Approximately 60 percent of these expenditures were directed to construction investment by the Other Power sector, and the balance was allocated to equipment investment spending by Pipeline Transportation. Total investments are $32.5 billion by 2050.
- ***Electric Power Transmission and Distribution Investment:*** This is one of the largest expenditures in the Net-Zero scenario and represents upgrading of substations and other elements of the transmission and distribution network, as well as modernizing of existing infrastructure. Total investment by 2050 reaches about $158.3 billion. This is modeled as incremental investment in the Electric Power sector.
- ***Electric Power Generation Investments:*** This represents a panoply of investments in various types of electric power generation, including onshore and offshore wind, energy storage, nuclear energy, hydro, utility-scale and rooftop solar, as well as the more traditional coal, oil and gas generation. Total investments reach a peak of $155.5 billion in 2045 and are a net $105.6 billion in 2050.
- ***Investments in Low Carbon Fuels and Direct Air Capture:*** This category includes investment in 15 low carbon fuel technologies, including SMR hydrogen, electrolytic hydrogen, hydrogen produced via bioenergy carbon capture and storage (BECCS), power-to-gas, power-to-liquids, ethanol and other biofuels, and ammonia. These are modeled as investments in the Chemicals sector. Investments in direct air capture were also modeled with these expenditures. Total investments reach $90.6 billion by 2050.
- ***Changes in Energy Efficiency and Consumption by Fuel:*** The *LIFT* model shows use of energy by 6 energy sectors by 112 industries comprising the private sector. *LIFT* also shows personal consumption of energy by sector, government consumption, and exports and imports. These energy flows in the *LIFT* model are related to categories in the EIA National Energy Modeling System (NEMS) at a level of industrial, commercial, residential, transportation and electric power. The *LIFT* model is calibrated to the Annual Energy Outlook by relating intersectoral flows of energy to the aggregates in NEMS. As mentioned above, a first calibration of *LIFT* was made to AEO 2021. This was then modified slightly to match growth rates of energy by sector by type specified by Evolved Energy Research. To implement these changes in the model, groups of input-output coefficients are modified over time. For example, reductions in the use of natural gas in the commercial sector are modeled by reducing the IO coefficients for gas in some 40 commercial sectors.[21]

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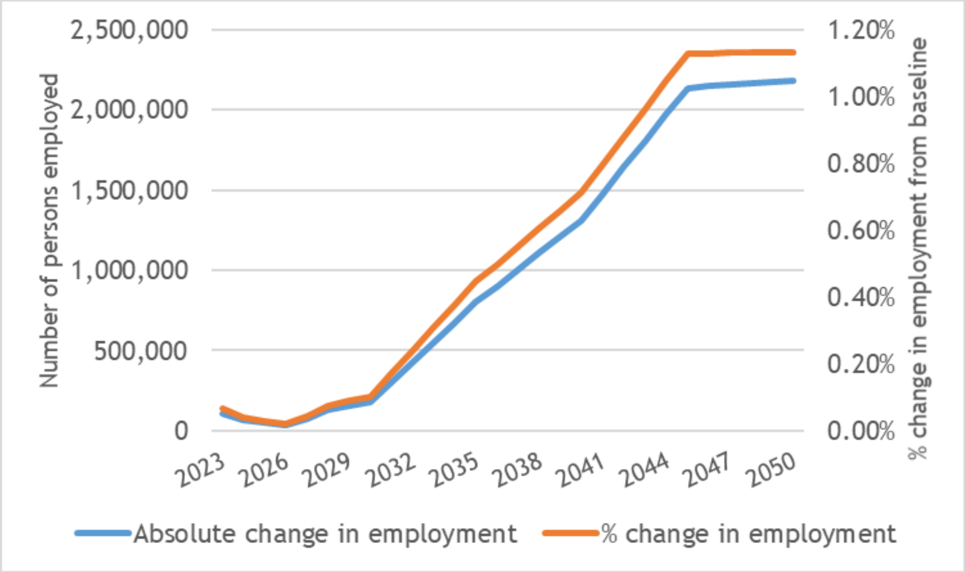
[21] Expressed in TBtus, the projections of energy use by major sector in *LIFT* are quite close to those specified by Evolved. However, AEO and *LIFT* estimate the "usage" of electricity implied by electricity losses. In Btu terms, these can often be larger than the total delivered electricity in a sector. Primarily for this reason, the Btu totals in *LIFT* are larger than those in the Evolved ENERGYPathways model.

- ***Changes in the Electric Power Generation Mix:*** An extremely important sector in *LIFT* is the electric power sector. Although the IO tables on which the *LIFT* model is based only have one sector for electric power, we have divided it into 8 types of generation: coal, natural gas, hydro, nuclear energy, oil, wind, solar, and geothermal and other. The original IO column for electric power has been split so that the fossil fuel generation types create demand for that fossil fuel input (coal, gas, petroleum). We have calibrated the projected electric power generation mix to be generally consistent with that specified by Evolved Energy Research, although the Evolved ENERGYPathways model shows electric power generation at a much finer level of detail.
- ***Changes in Primary Energy Exports:*** An important component of the modeling is the assumptions about energy exports. The Net-zero case shows natural gas and coal exports dwindling considerably towards the end of the scenario. We have exogenously modified exports of these sectors to match the Evolved model projections.

Results

Applying LIFT as described above, we estimated the economy-wide employment impacts of the Net-Zero by 2050 scenario over the years 2023 through 2050. Figure 6 summarizes these impacts, both in absolute terms and as a percentage of baseline employment. As shown in the exhibit, annual economy-wide employment impacts vary between 40,000 jobs and 160,000 jobs during the 2020s before increasing more steadily after 2030 and reaching a high of approximately 2.2 million jobs in the late 2040s. In proportional terms, these gains represent an increase of employment of less than 0.1 percent relative to baseline in the 2020s and gains of more than 1.1 percent in the late 2040s.

Figure 6. Estimated Economy-Wide Employment Impacts for the Net-Zero by 2050 Scenario



The results in Figure 6 show that the employment gains related to the Net-Zero by 2050 Scenario are flat or somewhat declining from the early 2020s to the mid-2020s. This reflects how the Net-Zero by 2050 scenario is implemented in the early years of the analytic time horizon. As described in Chapter 2, energy efficiency investments are the dominant GHG reduction strategy at that time.

Based on the Pathways modeling conducted by Evolved Energy Research, these investments increase at a moderate pace during this period, from $65 billion in 2023 to $140 billion by 2030. While this increase in investment has a positive impact on employment, the corresponding reduction in energy consumption puts downward pressure on employment in fossil fuel industries and the industries that support them. This fuel consumption effect is also cumulative, which is why employment gains trend somewhat downward in the early to mid-2020s. That is, the reduction in fuel consumption (and fuel-related employment) in a given year reflects efficiency investments made that year as well as in prior years. In contrast, the employment gains from efficiency investments are largely limited to the year in which those investments are made. By the mid- to late-2020s, other elements of the Net-Zero by 2050 scenario (the increase in power infrastructure investments) more than offset this effect, leading to the steeper upward trend in employment impacts shown in Figure 6.

For additional detail, Table A-5 presents the estimated economy-wide employment impacts by industry. Although *LIFT* estimates employment for 71 distinct industries (66 private industries and 5 government categories), we consolidate these to 29 industry sectors here for ease of presentation. As shown in Exhibit 15, the largest employment gains are projected for the other services sector, which includes (but is not limited to) healthcare, education, entertainment, and childcare. The employment gains for these industries reflect the expenditures of workers involved in the various investments included in the Net-Zero by 2050 scenario. Because households spend a sizable portion of their income on these services and because these services are relatively labor-intensive, the employment gains related to these services are larger than for any other industry. The employment gains for retail trade and housing services, while smaller than those for other services, reflect the same consumer expenditure effect. Note that job gains would have been larger if not for the presence of crowding out effects. The additional demand spurred by the investments in these scenarios generates price increases that cut off demand in equipment and structures investment, personal consumption, and net exports.

The results in Table A-5 also show large gains for the construction, electrical equipment, heating/venting/air conditioning, other machinery, and all other manufacturing sectors. These gains in large part reflect investments directly associated with the Net-Zero by 2050 scenario. The investments related to power infrastructure, fuels, energy efficiency, and CO_2 removal/transport all involve the production of equipment by one or more of these sectors.

Near the end of the analytic time horizon, the results in Table A-5 highlight employment gains for farms, forestry, fishing, and related activities. The significant growth in employment for this sector in the 2040s reflects increased reliance on biomass feedstocks under the Net-Zero by 2050 scenario.

Table A-5 also shows job losses across several sectors, partially offsetting the gains in other sectors. Among these are losses are in fossil fuel extraction industries (i.e., oil, natural gas, and coal extraction). These losses reflect the significant reductions in fuel consumption arising from energy efficiency improvements and increased reliance on renewables under the Net-Zero by 2050 scenario. The downstream job losses in petroleum & coal products and gas utilities reflect these same effects. Electric utilities, however, follow a slightly different pattern, with small job losses in the 2020s followed by significant gains. This pattern reflects reduced electricity consumption in the 2020s due to investments in end use energy efficiency followed by increased electrification of buildings and vehicles.

The results in Table A-5 also suggest significant job losses in professional services. These losses largely result from reduced output among fuel producers, which rely on professional services firms to support a number of activities, such as engineering and permitting assistance. As fuel production declines, fuel producers' need for outside professional services will also decline. The job losses estimated for finance, information, and insurance reflect the same dynamic.

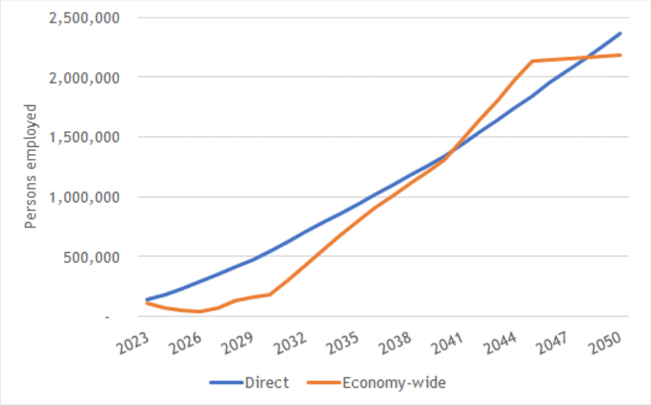
An important caveat to the estimated job losses in fossil fuel extraction and professional services is that they reflect an assumption of a steep downward trajectory in U.S. fossil fuel exports under the Net-Zero by 2050 scenario. Although these significant reductions in exports are not necessary for achieving the net-zero goal, the energy system modeling conducted by Evolved Energy Research in support of this analysis assumed reduced demand for U.S. fossil fuel exports under the core Net-Zero scenario. To the extent that exports would not decline as steeply as assumed, we may overestimate job losses in fossil fuel industries and professional services. Over the time horizon of this analysis, potential changes in global oil markets are uncertain, particularly in the context of geopolitics involving major oil producers and consumers.

As an alternative perspective on industry-specific employment impacts, Table A-6 presents employment impacts by industry as a percentage of baseline employment. In proportional terms, the job gains associated with the Net-Zero by 2050 scenario are most significant for the ventilation/heating/air conditioning equipment industry and the electrical equipment industry. Fossil fuel extraction industries and gas utilities are projected to experience the most significant declines in employment relative to the baseline projection.

Comparison With Direct Employment Impacts

Figure 7 compares the results of the economy-wide employment impact assessment against the results presented above in the direct employment impact analysis. As shown in the exhibit, the projected economy-wide employment impacts are less than direct employment impacts until 2040. The gap between the two, however, narrows during the 2030s until economy-wide employment impacts surpass direct employment impacts in 2040. This pattern likely reflects the change in the composition of the Net-Zero by 2050 investments over time. As described above, in the early years of the time horizon, energy efficiency represents the most significant of the investments associated with the Net-Zero by 2050 scenario. Due to the resulting efficiency gains, demand for fossil fuels decreases, causing employment in fossil fuel production and related support industries to decline. This effect builds year-over-year, as the efficiency gains and reduction in fuel consumption for a given year reflect efficiency investments made that year and in prior years. This effect is captured in the economy-wide analysis but not in the assessment of direct employment impacts. Starting around 2030, the composition of the Net-Zero by 2050 investments changes, as investments in power system infrastructure start to increase more significantly. The increase in labor demand among manufacturers of this equipment is captured in the direct and economy-wide analyses, but only the latter captures spillover effects to parts suppliers and service providers that support these manufacturers as well as spillover effects associated with workers spending their wages. Therefore the increase in employment post-2030 is more rapid in the economy-wide analysis than in the direct impact assessment.

Figure 7. Comparison of Direct Employment Impacts and Economy-wide Employment Impacts



5. Summary and Conclusions

This study performs in-depth analyses of pathways to obtaining net-zero GHG emissions in the U.S. by 2050. Three different models are applied to these analyses: the ENERGYPathways model, the IMPLAN/JEDI model, and the Inforum LIFT model. ENERGYPathways is used to spell out the detailed investments by sector (Transportation, Industrial, Commercial, Electric Power, Residential and Government), as well as the operations and maintenance (O&M) cost over time stemming from those initial investments. This model also derives calculations of changes in energy consumption by type in each sector resulting from those investments. The spending on investment and O&M is then allocated to spending by industry and passed to the IMPLAN model, to derive direct impacts on domestic output and jobs. The outputs from ENERGYPathways are used by LIFT in a more comprehensive coupling. The LIFT model, first calibrated to the Annual Energy Outlook 2021, is then calibrated to incorporate investments and O&M spending, as well as changes in energy consumption by detailed industrial sector. The changing mix of electric power generation by type modeled in ENERGYPathways is also reflected in the LIFT scenario. Power generation by type is directly related to the consumption (and emissions from) fossil fuels such as coal and natural gas in LIFT, and therefore LIFT tracks output and jobs in these fossil energy sectors as well. Jobs in LIFT reflect the direct impacts of the investment and O&M spending, as well as the changes in the output mix of industries across the economy, and the changing interrelationships between them, spurred by the new investments.

This study does not highlight the implications of the net-zero policies and investments on federal and state and local government expenditures and revenue, and also does not highlight the impacts on trade patterns. In previous studies using LIFT[22], explicit assumptions were made for the costs of tax credits and other incentives, as well as the revenue impact of possible carbon taxes. In the latter case, the form of revenue "recycling" was also important, i.e., how much was earmarked for energy efficiency investments and R&D, and how much was returned to businesses and consumers in the form of tax cuts or other tax incentives. These revenue implications of any given set of policies to achieve net zero are an important part of the overall picture.

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[22] See Meade (2009, 2010), and Meade, Werling and Wescott (2009).

Finally, all studies of this kind are subject to the inherent uncertainty in projecting the rate at which the costs of new technologies decline, such as production of hydrogen, CCS, and enhanced biofuels. The rates of adoption in our scenario are premised on declining cost curves, as well as government incentives that make investment in GHG-reducing technologies economically sensible. If these costs don't decline as rapidly as assumed, the feasible date for net-zero must also be pushed back.

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Appendix A. Derivation of Assumptions, and Selected Tables of Results

Table A-1. Equipment and Installation Information For Selected Technologies

CATEGORY	TECHNOLOGY	BASIS FOR SPLIT BETWEEN EQUIPMENT AND INSTALLATION	EQUIPMENT/ INSTALLATION SPLIT	% OF EQUIPMENT PURCHASED FROM U.S. SUPPLIERS[1]
Power Infrastructure	Battery Storage	Detailed battery storage cost data published by the National Renewable Energy Laboratory (Feldman et al. 2021).	Equipment: 85% Installation: 15%	68%
	Advanced Nuclear	Breakout as provided for an AP1000 reactor, as reported in Rothwell (2020).	Equipment: 71% Installation: 29%	90%[2]
Fuels	Blue Hydrogen with CCS	Detailed SMR hydrogen facility cost data published by the International Energy Agency (IEA 2017b)	Equipment: 53% Installation: 47%	77%
	Blue Hydrogen without CCS		Equipment: 53% Installation: 47%	77%
	Green Hydrogen	Detailed electrolytic hydrogen facility cost data published by the Hydrohub Innovation Program for a 1 GW electrolysis plant (Van't Noordende and Ripson 2020)	Equipment: 68% Installation: 32%	80%
	BECCS Hydrogen	Detailed BECCS hydrogen cost data in Hamedani et al. (2016) and DOE (2021) and CCS system cost data in Klein et al. (2011)	Equipment: 79% Installation: 21%	76%
	Power-to-Gas	Detailed cost data for power-to-gas facility from Gorre and van Leeuwen (2019).	Equipment: 83% Installation: 17%	75%
	Power-to-Liquids	Derived from power-to-liquid cost data presented in Albrecht et al. (2016).	Equipment: 78% Installation: 22%	96%
	Biofuel: Cellulosic Ethanol[3]	Split between equipment and installation reflects detailed cost information for cellulosic ethanol projects as reported in NREL's Jobs & Economic Development Impact (JEDI) model for cellulosic ethanol (NREL 2017).	Equipment: 36% Installation: 45%	68%
	Biofuel: Biomass to SNG (with CCS)[4]	Split between equipment and installation reflects detailed cost information for biomass-to-SNG projects in Worley and Yale (2012) and for CCS systems in Klein et al. (2011).	Equipment: 64% Installation: 18%	68% for biomass-to-SNG equipment 81% for CCS equipment
	Biofuel: Biomass Fischer-Tropsch (without CCS)	The techno-economic analysis of Fischer-Tropsch in Zhu et al. (2011) includes detailed information on the costs of individual equipment components for these facilities and the costs of installation, inclusive of indirect costs (e.g., engineering and legal).	Equipment: 27% Installation: 73%	75%
	Biofuel: Biomass Fischer-Tropsch (with CCS)		Equipment: 27% Installation:73%	75% for Fischer-Tropsch equipment 81% for CCS equipment

CATEGORY	TECHNOLOGY	BASIS FOR SPLIT BETWEEN EQUIPMENT AND INSTALLATION	EQUIPMENT/ INSTALLATION SPLIT	% OF EQUIPMENT PURCHASED FROM U.S. SUPPLIERS[1]
	Biofuel: Biomass Pyrolysis (without CCS)	NREL's techno-economic assessment presents broad information on the costs of equipment versus the costs of installation for pyrolysis systems (Wright et al. 2010).	Equipment: 33% Installation: 67%	70%
	Biofuel: Biomass Pyrolysis (with CCS)		Equipment: 33% Installation: 67%	70% for pyrolysis equipment 81% for CCS equipment
	Ammonia	Assumed that composition similar to that of major cost components for SMR hydrogen as reported in IEA (2017b).[5]	Equipment: 49% Installation: 51%	69%
	Biomass production	Installation/construction relevant to corn biomass only. Production of corn-based biomass involves equipment purchase. Other forms of biomass examined (herbaceous, wood, and waste) are residues and do not involve capital investments for production.		Equipment for corn biomass: 84%
Energy Efficiency[6]	Agriculture	Energy efficiency investments analyzed as equipment purchases. While installation is involved with some of this equipment, many of these installations simply displace installations of less efficient conventional equipment.		70%
	Commercial			74%
	Residential			59%
	Electric Vehicles			Light Duty: 55% Heavy Duty: 81%
	Chargers			16%
	Other Manufacturing			64%
CO2 Removal and Transportation	CO2 Pipelines[7]	Cost inputs for analysis of multiple CO2 pipeline scenarios documented in Dubois et al. (2017).	Equipment: 24% Installation: 60%	94%
	Direct Air Capture (DAC)	Derived from techno-economic assessment of DAC system presented in Keith et al. (2018).	Equipment: 82% Installation: 18%	80%

Notes:

1. Unless otherwise noted, values derived from sector level data from IMPLAN.
2. Nuclear Energy Agency & International Atomic Energy Agency (2018).
3. The equipment and installation values for cellulosic ethanol sum to less than 100% because the installation figure reflects installation labor only, as reported in the NREL (2017) data source.
4. The equipment and installation values for biomass to SNG sum to less than 100% because the installation figure reflects installation labor only, as reported in Worley and Yale (2012).
5. The allocation between equipment and installation for ammonia differs slightly from that for SMR hydrogen because the "Other Costs" category from the IEA (2017b) report was excluded when calculating the percentages for ammonia.
6. The values reported for categories related to energy efficiency reflect weighted averages across the various types of equipment included in each category. For example, the value for residential reflects clothes dryers, lighting, dishwashers, etc. Domestic producers' share of the market for each type of equipment was derived from U.S. Census Bureau (2017a, 2017b)
7. The equipment and installation values for CO2 pipelines do not sum to 100% because a portion of costs is for land acquisition.

Table A-2. IMPLAN Sectors for Estimating Direct Employment Impacts Associated with Equipment Manufacturing and Installation

CATEGORY	TECHNOLOGY	BASIS FOR SECTORAL ALLOCATIONS FOR EQUIPMENT AND INSTALLATION	IMPLAN SECTORS FOR EQUIPMENT	IMPLAN SECTORS FOR INSTALLATION
Power Infrastructure	Advanced Nuclear	Not applicable. Advanced nuclear energy employment per million dollars of expenditures estimated based on a combined equipment and construction cost of $2.56 billion for a Westinghouse AP1000 advanced nuclear plant, supporting 7000 jobs over a period of 1.5 years (Georgia Power 2021; Winters and Corletti 2001).		
	Battery Storage	Feldman et al. (2020) includes a breakdown of costs for batteries; electronic components; structural components; labor & equipment for construction; engineering, procurement, and construction services; and development.	• Storage battery manufacturing • All other miscellaneous electrical equipment and component manufacturing • Construction of new power and communications structures	• Construction of new power and communications structures • Architectural, engineering, and related services
Fuels	Blue Hydrogen with CCS	IEA (2017b) includes detailed cost information for the hydrogen plant, CO2 capture, CO2 compression, power island, and utilities & balance of plant. Costs for each of these are broken down between direct material; construction; other costs; engineering, procurement, and construction services; and contingency.	• Fabricated structural metal manufacturing • All other industrial machinery manufacturing • Air conditioning, refrigeration, and warm air heating equipment manufacturing • Relay and industrial control manufacturing • All other miscellaneous electrical equipment and component manufacturing	• Wholesale trade • Miscellaneous nonmetallic mineral products manufacturing • Architectural, engineering, and related services • Management of companies and enterprises • Office administrative services • Construction of new power and communication structures
	Blue Hydrogen without CCS	Assumed same as SMR hydrogen with CCS	Assumed same as SMR hydrogen with CCS	Assumed same as SMR hydrogen with CCS
	Green Hydrogen	Van't Noordende and Ripson (2020) present detailed information on electrolytic hydrogen facility costs, with detail on balance of plant (compressors, gas treatment, heating/cooling, gas/liquid separators, and piping), utilities (process automation, piping, cooling towers, and demineralized water plant), power supply and electronics, stacks (catalyst-coated membranes, power-to-liquid, frame, and	• Air and gas compressor manufacturing • Industrial gas manufacturing • Air conditioning, refrigeration, and warm air heating equipment manufacturing • All other industrial machinery manufacturing • Fabricated pipe and pipe fitting manufacturing	• Architectural, engineering, and related services • Construction of new power and communication structures

CATEGORY	TECHNOLOGY	BASIS FOR SECTORAL ALLOCATIONS FOR EQUIPMENT AND INSTALLATION	IMPLAN SECTORS FOR EQUIPMENT	IMPLAN SECTORS FOR INSTALLATION
		plates), engineering, construction, owner's costs, and civil/ structural/ architectural costs.	• Industrial process variable instruments manufacturing • Concrete pipe manufacturing • Pump and pumping equipment manufacturing • Other electronic component manufacturing • Plastics material and resin manufacturing • Other fabricated metal manufacturing • Nonferrous metal, except copper and aluminum, shaping • Plate work manufacturing	
	BECCS Hydrogen	Hamedani et al. (2016) provide detailed cost breakdown for the gasifier (membranes, piping, machinery, and heating), portable purification unit, carbon capture (membranes, piping, machinery, compressor), engineering and design, and purchasing and construction.	• Plastics and material resin manufacturing • Fabricated pipe and pipe fitting manufacturing • All other industrial machinery manufacturing • Heating equipment manufacturing • Air and gas compressor manufacturing • Plastics material and resin manufacturing • Fabricated pipe and pipe fitting manufacturing	• Architectural, engineering, and related services • Construction of new power and communication structures
	Power-to-Gas	Gorre et al. (2019) provide a production cost breakdown for a power-to-gas plant which includes the costs associated with equipment (electrolyzer, methanation system, hydrogen, CO2 and SNG storage, CO2 compressor, and gas grid injection system) as well as installation, design, and planning.	• Plastics and material resin manufacturing • Industrial gas manufacturing • Pipeline transportation • Metal tank (heavy gauge) manufacturing • Air and gas compressor manufacturing • Oil and gas field machinery and equipment manufacturing	• Industrial gas manufacturing • Other miscellaneous chemical product manufacturing
	Power-to-Liquids	Albrecht et al. (2016) identify the following equipment components that were mapped to IMPLAN sectors: autothermal reformer,	• Power boiler and heat exchanger manufacturing	• Petrochemical manufacturing • Other miscellaneous chemical product manufacturing

CATEGORY	TECHNOLOGY	BASIS FOR SECTORAL ALLOCATIONS FOR EQUIPMENT AND INSTALLATION	IMPLAN SECTORS FOR EQUIPMENT	IMPLAN SECTORS FOR INSTALLATION
		Fischer-Tropsch synthesis reactor, gas turbine cycle, gas/liquid separator, hydrocracker, selexol unit, solid-oxide-cell unit, steam turbine cycle. Albrecht et al. also provide a breakdown of the equipment installation costs associated with a power-to-liquid plant.	• Turbine and turbine generator set units manufacturing • All other industrial machinery manufacturing • Oil and gas field machinery and equipment manufacturing • Industrial gas manufacturing	
	Biofuel: Cellulosic Ethanol	The equipment/installation allocation is based on the National Renewable Energy Laboratory's (NREL) Jobs and Economic Development (JEDI) model for cellulosic ethanol production. NREL estimates project costs for the following equipment: feed handling, pretreatment, neutralization/conditioning, saccharification & fermentation, distillation and solids recovery, wastewater treatment, storage, and boiler/turbogenerator.	• Pump and pumping equipment manufacturing • Scales, balances, and miscellaneous general purpose machinery manufacturing • Metal tank (heavy gauge) manufacturing • Power boiler and heat exchanger manufacturing • All other industrial machinery manufacturing • Air conditioning, refrigeration, and warm air heating equipment manufacturing	• Architectural, engineering, and related services • Management of companies and enterprises • Office administrative services • Construction of new power and communication structures
	Biofuel: Biomass Pyrolysis (without CCS)	Wright et al. (2010) provide a breakdown of the total equipment and installed costs for fast pyrolysis and bio-oil upgrading with hydrogen production.	• Conveyor and conveying equipment manufacturing • All other industrial machinery manufacturing • Automatic environmental control manufacturing • Power boiler and heat exchanger manufacturing • Industrial process furnace and oven manufacturing • Air conditioning, refrigeration, and warm air heating equipment manufacturing • Motor and generator manufacturing	• Architectural, engineering, and related services • Management of companies and enterprises • Office administrative services • Construction of new power and communication structures

CATEGORY	TECHNOLOGY	BASIS FOR SECTORAL ALLOCATIONS FOR EQUIPMENT AND INSTALLATION	IMPLAN SECTORS FOR EQUIPMENT	IMPLAN SECTORS FOR INSTALLATION
	Biofuel: Biomass Pyrolysis (with CCS)	Klein et al. (2011) provides a breakdown of investment and O&M costs for bio-IGCC both with and without CCS. The ratio of these costs serves as the basis for adjusting biomass pyrolysis equipment and installation costs to account for CCS. CCS equipment includes membranes, piping, machinery, and compressors.	Non-CCS Equipment: • Assumed same as Biofuel: Biomass Pyrolysis (without CCS). CCS Equipment: • Plastics material and resin manufacturing • Fabricated pipe and pipe fitting manufacturing • All other industrial machinery manufacturing • Heating equipment (except warm air furnaces) manufacturing	• Assumed same as Biomass Pyrolysis (without CCS).
	Biofuel: Biomass Fischer-Tropsch (without CCS)	Zhu et al. (2011) identify the following equipment components for Fisher-Tropsch facilities that were mapped to IMPLAN sectors: air separation units, feed prep and drying, gasification with tar reforming and heat recovery, syngas cleanup and steam reforming, Fisher-Tropsch synthesis, hydrocracking and product separation, steam system and power generation, and remainder offsite battery limits	• Power boiler and heat exchanger manufacturing • Support activities for oil and gas operations • All other industrial machinery manufacturing	• Construction of new power and communication structures • Architectural, engineering, and related services • Management of companies and enterprises • Office administrative services
	Biofuel: Biomass Fisher-Tropsch (with CCS)	Same as Fischer-Tropsch without CCS.	Non-CCS Equipment: • Assumed same as Biomass Fisher-Tropsch (without CCS) CCS Equipment: • Plastics material and resin manufacturing • Fabricated pipe and pipe fitting manufacturing • All other industrial machinery manufacturing • Heating equipment (except warm air furnaces) manufacturing	• Assumed same as Biomass Fischer-Tropsch (without CCS).
	Biofuel: Biomass to SNG (with CCS)	Worley and Yale (2012) provide a breakdown between direct (equipment, buildings, instrumentation, etc.) and	Non-CCS Equipment: • Air and gas compressor manufacturing	• Construction of new power and communication structures

CATEGORY	TECHNOLOGY	BASIS FOR SECTORAL ALLOCATIONS FOR EQUIPMENT AND INSTALLATION	IMPLAN SECTORS FOR EQUIPMENT	IMPLAN SECTORS FOR INSTALLATION
		indirect costs (e.g., engineering services, pre-project costs) for a biomass gasification plant.	• Power boiler and heat exchanger manufacturing • All other industrial machinery manufacturing • Air purification and ventilation equipment manufacturing • Automatic environmental control manufacturing CCS Equipment: • Plastics material and resin manufacturing • Fabricated pipe and pipe fitting manufacturing • All other industrial machinery manufacturing • Heating equipment (except warm air furnaces) manufacturing	• Architectural, engineering, and related services • Management of companies and enterprises • Office administrative services
	Ammonia	Equipment/installation allocation assumed same as Blue Hydrogen (IEA 2017b)	Assumed same as Blue Hydrogen.	• Construction of new power and communication structures • Architectural, engineering, and related services • Management of companies and enterprises • Office administrative services
	Biomass production	Based on crop budget for corn published by Iowa State University (Plastina 2021)	• For corn biomass: Farm machinery and equipment manufacturing. Other biomass types examined are residues and do not involve new capital investment.	
Energy Efficiency	Agriculture	Not applicable. Equipment/installation distinction not incorporated into analysis of energy efficiency investments.	IMPLAN sectors chosen based on the subsector names included in the energy efficiency investment estimates provided by Evolved Energy Research.	
	Commercial			
	Residential			
	Electric Vehicles			
	Chargers			
	Other Manufacturing			

CATEGORY	TECHNOLOGY	BASIS FOR SECTORAL ALLOCATIONS FOR EQUIPMENT AND INSTALLATION	IMPLAN SECTORS FOR EQUIPMENT	IMPLAN SECTORS FOR INSTALLATION
CO_2 Removal and Transport	CO_2 Pipelines	Dubois et al. (2017) includes a breakdown of pipeline costs across the following components: material, CO_2 surge tanks, pipeline control systems, pumps, construction labor, and miscellaneous.	• Iron, steel pipe and tube manufacturing from purchased steel • Metal tank manufacturing • Pump and pumping equipment manufacturing	• Construction of new manufacturing structures
	Direct Air Capture	Detailed cost distribution for equipment obtained from Keith et al. (2018) includes costs related to air contactor, pellet reactor, calciner-slaker, air separation unit, CO_2 compressor, steam turbine, power plant, fines filter, other equipment, buildings, and transformer. Because Keith et al. (2018) do not provide similar detail for installation costs, we apply the same IMPLAN sectors to installation as applied for equipment. As noted in Exhibit 4, installation accounts for just 18% of expenditures for DAC.	• Automatic environmental control manufacturing • Power boiler and heat exchanger manufacturing • Industrial process furnace and oven manufacturing • Support activities for oil and gas operations • Air and gas compressor manufacturing • Turbine and turbine generator set units manufacturing • Power, distribution, and specialty transformer manufacturing • Industrial and commercial fan and blower and air purification equipment manufacturing • Engineering services	• Automatic environmental control manufacturing • Power boiler and heat exchanger manufacturing • Industrial process furnace and oven manufacturing • Support activities for oil and gas operations • Air and gas compressor manufacturing • Turbine and turbine generator set units manufacturing • Power, distribution, and specialty transformer manufacturing • Industrial and commercial fan and blower and air purification equipment manufacturing • Engineering services

Table A-3. O&M Cost Parameters

TECHNOLOGY		UNIT O&M COST	O&M AS % OF CUMULATIVE INVESTMENT	LABOR SHARE OF O&M COSTS (%)
Transmission and Distribution[1]			1%	2%
Battery Storage[2]			11%	NA
Blue Hydrogen with CCS[3]			2%	NA
Blue Hydrogen without CCS[3]			5%	NA
Green Hydrogen[4]			5%	NA
BECCS Hydrogen[5]			10%	NA
Power-to-Gas[6]			11%	12%
Power-to-Liquids[7]		$80,800 per GWh		7%
Biofuel: Cellulosic Ethanol[8]		$17.85 per MMBtu		12%
Biofuel: Biomass to SNG (with CCS)[9]		$96,500 per GWh		51%
Biofuel: Fischer-Tropsch (without CCS)[10]		$17,900 per GWh		18%
Biofuel: Fischer-Tropsch (with CCS)[10]		$25,600 per GWh		18% for biofuel production; 27% for CCS
Biofuel: Biomass Pyrolysis (without CCS)[11]		$49,800 per GWh		27%
Biofuel: Biomass Pyrolysis (with CCS)[11]		$71,400 per GWh		27% for biofuel production 27% for CCS
Ammonia[12]		$358 per metric ton of ammonia		9%
Biomass production	Corn biomass[13]	50% of total expenditures		7%
	Herbaceous biomass, woody biomass, and waste[14]	$9,478 per GWh for transport for herbaceous and woody biomass. Remainder of expenditures for handling.		Transportation of biomass: 26% Biomass handling: 43% for herbaceous & woody; 37% for waste.
CO_2 Pipelines[15]		20% (labor)		NA
Direct Air Capture[16]		$32 per metric ton of CO_2		8%

Note: Unless otherwise indicated below, labor share of O&M costs derived from IMPLAN data.

Sources

1. Transmission and distribution based on NREL (2016) for unit O&M cost and labor share of O&M.

2. Battery storage based on Cole & Frazier (2019) and Feldman et al. (2021).
3. Blue hydrogen based on IEA (2017b).
4. Green hydrogen based on Jovan (2020).
5. BECCS based on DOE (2021).
6. Power-to-gas based on Gorre et al. (2019).
7. Power-to-Liquids based on Albrecht et al. (2016).
8. Cellulosic ethanol based on NREL (2017) for both unit O&M cost and labor share of O&M.
9. Biomass to SNG based on Thunman et al. (2019) for both unit O&M cost and labor share of O&M.
10. Biomass Fischer-Tropsch (with and without CCS) based on Bressanin et al. (2020) and Brown et al. (2020). The CCS component is based on Klein et. al (2011), under the assumption that Fischer-Tropsch would be similar to a bio-integrated gasification combined cycle facility.
11. Pyrolysis (with and without CCS) based on Badger et al. (2011) and Wright et al. (2010) for both unit O&M cost and labor share of O&M. CCS component is based on Klein et. al (2011), under the assumption that it would be similar to a bio-integrated gasification combined cycle facility.
12. Ammonia based on IEA (2017a) and Brown (2017) for both unit O&M costs and labor share of O&M.
13. For corn biomass, both percentages based on Plastina (2021). O&M components include seed, chemicals, other materials, land (e.g., imputed rent), and labor. Percentages shown applied to total expenditures on corn biomass.
14. For herbaceous, wood, and waste biomass, unit O&M costs provided by Ben Haley of Evolved Energy Research.
15. CO_2 pipelines based on input provided by Ben Haley of Evolved Energy Research, 2021.
16. Direct air capture based on Keith et al. (2018), McQueen et al. (2020), and NASEM (2019) for both unit O&M cost and labor share of O&M.

Table A-4. Employment Impacts by Technology and Year

CATEGORY	TECHNOLOGY	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
Power Infrastructure	Nuclear Energy	-	-	-	-	-	-	-	1,000	1,500	11,700	60,900	55,400
	Coal Power Plants	-2,600	-3,200	-3,700	-3,900	-3,900	-3,700	-3,600	-3,600	-4,700	-6,700	-6,200	-5,900
	Gas Power Plants	4,500	4,600	2,500	-1,600	-7,900	-16,200	-21,400	-23,300	2,500	7,400	(42,700)	(28,200)
	Wind	-1,400	2,000	9,100	19,800	34,100	52,000	68,000	82,000	134,700	214,300	237,700	285,300
	Solar	4,400	8,400	14,100	21,600	30,800	39,500	47,700	55,500	83,400	110,600	162,400	79,500
	Transmission & Distribution	1,500	3,200	6,900	13,000	22,100	34,100	48,000	63,500	169,800	320,800	465,600	559,400
	Battery Storage	-	-	-	-	-	-	-	-	2,200	20,200	71,200	56,800
Fuels	SMR Hydrogen (with CCS)	12,700	17,200	21,700	29,300	37,100	45,000	53,200	61,500	83,400	39,600	23,900	21,900
	SMR Hydrogen (without CCS)	-	-	-	-	-	1,300	1,900	2,600	7,000	5,200	3,600	3,400
	Electrolytic Hydrogen	-	-	-	-	-	-	-	2,100	17,600	36,700	44,500	69,000
	BECCS Hydrogen	6,000	7,700	8,800	9,200	9,000	8,000	7,100	6,300	8,000	30,800	61,500	95,300
	Power-to-X	3,500	4,500	5,300	5,800	6,100	6,200	6,500	7,000	11,400	12,000	9,100	11,600
	Biofuels	-	-	-	-	-	-	1,300	2,600	22,600	62,500	81,800	176,200
	Ammonia	2,500	4,300	6,900	10,500	15,000	20,500	25,600	30,500	46,200	28,500	21,100	14,000
	Biomass Feedstocks	4,800	5,600	5,400	6,700	7,100	6,900	7,300	8,900	41,300	76,700	154,700	225,900
Energy Efficiency	Agriculture	1,800	1,900	1,900	2,000	2,100	2,100	2,100	2,200	2,400	2,700	4,000	5,800
	Commercial	19,300	24,200	30,900	39,200	48,500	58,000	66,900	74,400	92,700	100,700	118,300	140,700
	Residential	46,200	59,500	70,500	79,100	84,800	87,400	88,700	89,200	87,100	89,200	96,100	100,700
	Vehicles	4,500	5,600	6,500	6,800	6,400	5,200	3,900	2,600	-	(1,400)	(3,300)	(4,800)
	EV Chargers	1,400	2,200	3,300	4,600	6,200	8,200	10,500	13,000	25,800	31,900	33,700	31,300
	Other Manufacturing	30,400	31,700	33,000	34,400	35,800	37,000	38,200	39,400	46,900	57,200	80,900	117,100
CO2 Removal & Transport	CO2 Pipelines	1,100	5,800	10,500	15,200	19,900	24,600	26,500	28,400	56,500	87,500	155,700	263,500
	Direct Air Capture	-	-	-	-	-	-	-	-	-	-	13,300	88,500
	TOTAL	140,600	185,200	233,600	291,700	353,200	416,100	478,400	545,800	938,300	1,338,100	1,847,800	2,362,400

Table A-5. Economy-Wide Employment Impacts of the Net-Zero by 2050 Scenario, by Industry

INDUSTRY	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
1 Farms, Forestry, Fishing, Related Activities	7,100	8,500	10,200	10,700	7,500	6,900	3,500	1,900	-1,400	14,200	36,600	74,300
2 Crude Oil Extraction	-15,200	-22,600	-36,300	-46,700	-49,900	-54,900	-61,200	-68,900	-83,800	-92,000	-80,000	-59,700
3 Natural Gas Extraction	-3,900	-5,800	-6,300	-7,700	-9,800	-10,100	-12,100	-13,800	-15,300	-19,500	-29,300	-35,500
4 Coal Mining	-5,200	-6,900	-8,300	-9,700	-10,300	-10,500	-12,000	-13,000	-14,500	-16,700	-17,400	-17,300
5 Other Mining and Support Activities	-1,100	-2,800	-4,400	-7,300	-7,400	-7,700	-8,200	-10,500	-14,500	-7,200	-12,100	-9,200
6 Electric Utilities	0	-600	-900	-100	2,000	4,700	7,800	11,400	37,300	62,900	77,000	80,500
7 Gas Utilities	-1,200	-2,000	-2,900	-4,500	-6,200	-8,000	-10,100	-12,300	-24,000	-33,700	-39,000	-40,500
8 Water and Sanitation	-200	-400	-600	-1,000	-1,200	-1,300	-1,500	-1,700	-2,100	-2,200	-2,200	-1,900
9 Construction	61,000	74,200	88,700	100,300	99,500	98,900	103,300	103,200	100,900	113,700	124,900	177,100
10 Food, Beverage, and Tobacco Products	-400	-1,000	-1,500	-1,800	-1,800	-1,500	-1,100	-400	3,900	4,400	2,600	-6,100
11 Petroleum and Coal Products	-600	-900	-1,100	-1,800	-2,400	-3,700	-4,300	-5,900	-14,100	-22,900	-30,000	-33,600
12 Chemical Products	-200	-600	-1,300	-1,900	-1,900	-2,200	-2,600	-3,100	-1,700	-2,700	-1,900	-3,300
13 Ventilation, heating and air-conditioning equipment	5,900	9,300	14,100	20,300	26,600	33,500	35,900	38,300	37,700	30,900	25,900	20,300
14 Other machinery	15,300	15,200	15,000	15,600	19,400	36,000	25,200	27,400	47,000	50,900	50,600	42,200
15 Electrical Equipment	7,400	10,400	15,500	23,300	27,200	38,400	39,900	50,600	80,400	79,500	66,700	38,000
16 Motor Vehicles and Parts	7,800	10,000	11,500	12,600	13,300	12,400	11,100	7,000	8,000	4,700	-1,400	-12,700
17 All Other Manufacturing	39,400	34,800	32,200	33,100	43,500	37,700	57,700	43,200	117,800	197,000	673,900	467,900
18 Wholesale Trade	6,000	1,000	-2,200	-2,600	-1,700	300	1,000	-2,000	12,000	1,000	-15,900	-23,800
19 Retail Trade	34,700	45,600	55,600	65,000	73,200	79,700	85,600	87,600	91,100	79,700	84,200	77,400
20 Transportation, Warehousing, Storage	900	-4,600	-9,200	-12,400	-14,300	-14,400	-14,700	-16,700	2,000	9,600	17,500	22,200
21 Information	-5,000	-11,300	-16,000	-19,800	-22,900	-23,400	-24,300	-26,700	-18,500	-20,800	-29,300	-39,900
22 Finance	-7,100	-12,000	-15,100	-17,600	-18,600	-18,800	-20,000	-21,000	-6,800	-4,800	-13,300	-29,600
23 Insurance	-6,600	-8,700	-11,000	-13,400	-15,100	-16,600	-18,300	-19,200	-19,300	-26,200	-48,100	-63,400
24 Housing Services and Other Real Estate	-1,000	500	2,600	3,200	3,800	3,700	2,600	2,400	8,600	15,900	20,400	24,700
25 Rental Services	-2,900	-4,600	-5,800	-7,100	-7,900	-8,400	-9,600	-10,800	-9,700	-10,300	-12,000	-12,700
26 Professional Services	-30,200	-53,800	-75,200	-98,200	-108,600	-115,600	-130,400	-145,700	-125,100	-146,000	-189,200	-225,800
27 Management of Companies	-5,400	-11,300	-17,900	-23,700	-25,400	-27,100	-30,700	-35,100	-30,700	-34,300	-32,200	-28,900
28 Other Services	13,000	13,200	24,400	40,300	72,300	115,000	159,600	228,900	656,600	1,114,800	1,545,000	1,845,400
29 Government	-3,100	-4,900	-6,800	-9,100	-10,700	-12,600	-14,900	-17,000	-21,300	-27,700	-34,400	-39,600
TOTAL	**109,300**	**67,800**	**46,900**	**38,100**	**72,300**	**130,200**	**157,200**	**178,300**	**800,400**	**1,312,300**	**2,137,300**	**2,186,600**

Table A-6. Percent Change in Employment by industry Based on Economy-wide Modeling - Net-Zero by 2050 Scenario

INDUSTRY	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
1 Farms, Forestry, Fishing, Related Activities	0.3%	0.4%	0.4%	0.5%	0.3%	0.3%	0.2%	0.1%	-0.1%	0.7%	1.9%	4.2%
2 Crude Oil Extraction	-10.1%	-15.2%	-23.3%	-29.7%	-32.5%	-36.6%	-41.2%	-46.0%	-56.0%	-64.0%	-66.8%	-66.3%
3 Natural Gas Extraction	-17.0%	-23.2%	-25.3%	-29.0%	-35.0%	-36.2%	-41.9%	-47.5%	-50.5%	-60.4%	-84.5%	-96.4%
4 Coal Mining	-13.4%	-18.0%	-22.3%	-26.2%	-28.6%	-30.5%	-35.0%	-38.9%	-44.8%	-50.5%	-50.9%	-49.9%
5 Other Mining and Support Activities	-0.3%	-0.7%	-1.1%	-1.8%	-1.8%	-1.9%	-2.1%	-2.7%	-3.9%	-2.1%	-3.7%	-2.9%
6 Electric Utilities	0.0%	-0.2%	-0.2%	0.0%	0.6%	1.4%	2.3%	3.3%	11.3%	19.4%	24.1%	25.8%
7 Gas Utilities	-1.5%	-2.5%	-3.8%	-6.0%	-8.4%	-11.2%	-14.4%	-18.0%	-39.1%	-58.9%	-72.2%	-80.0%
8 Water and Sanitation	-0.4%	-0.7%	-1.1%	-1.7%	-2.1%	-2.4%	-2.8%	-3.1%	-4.1%	-4.4%	-4.7%	-4.3%
9 Construction	0.7%	0.8%	1.0%	1.1%	1.1%	1.1%	1.1%	1.1%	1.0%	1.0%	1.1%	1.4%
10 Food, Beverage, and Tobacco Products	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	0.0%	0.2%	0.3%	0.2%	-0.4%
11 Petroleum and Coal Products	-0.5%	-0.7%	-0.9%	-1.4%	-1.9%	-3.0%	-3.5%	-4.8%	-12.2%	-20.6%	-28.1%	-33.1%
12 Chemical Products	0.0%	-0.1%	-0.2%	-0.2%	-0.2%	-0.3%	-0.3%	-0.4%	-0.2%	-0.4%	-0.3%	-0.6%
13 Ventilation, heating and air-conditioning equipment	5.1%	7.8%	11.8%	17.1%	23.1%	30.1%	32.7%	35.6%	37.2%	32.7%	28.3%	22.2%
14 Other machinery	1.5%	1.4%	1.4%	1.5%	1.9%	3.6%	2.5%	2.8%	4.9%	5.5%	5.5%	4.5%
15 Electrical Equipment	1.9%	2.7%	4.0%	6.2%	7.5%	11.1%	11.9%	15.8%	29.0%	34.0%	34.6%	24.6%
16 Motor Vehicles and Parts	0.8%	1.0%	1.2%	1.3%	1.4%	1.4%	1.3%	0.8%	1.0%	0.6%	-0.2%	-2.1%
17 All Other Manufacturing	0.5%	0.5%	0.4%	0.5%	0.6%	0.6%	0.9%	0.7%	1.9%	3.3%	11.7%	8.2%
18 Wholesale Trade	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	-0.3%	-0.5%
19 Retail Trade	0.2%	0.3%	0.3%	0.4%	0.5%	0.5%	0.5%	0.5%	0.6%	0.5%	0.5%	0.5%
20 Transportation, Warehousing, Storage	0.0%	-0.1%	-0.1%	-0.2%	-0.2%	-0.2%	-0.2%	-0.3%	0.0%	0.2%	0.3%	0.3%
21 Information	-0.2%	-0.4%	-0.5%	-0.7%	-0.8%	-0.8%	-0.8%	-0.9%	-0.7%	-0.8%	-1.2%	-1.8%
22 Finance	-0.2%	-0.3%	-0.4%	-0.4%	-0.5%	-0.5%	-0.5%	-0.5%	-0.2%	-0.1%	-0.3%	-0.6%
23 Insurance	-0.2%	-0.3%	-0.4%	-0.4%	-0.5%	-0.6%	-0.6%	-0.6%	-0.6%	-0.9%	-1.5%	-2.0%
24 Housing Services and Other Real Estate	0.0%	0.0%	0.1%	0.2%	0.2%	0.2%	0.1%	0.1%	0.5%	0.9%	1.2%	1.5%
25 Rental Services	-0.5%	-0.7%	-0.9%	-1.1%	-1.3%	-1.3%	-1.5%	-1.7%	-1.6%	-1.8%	-2.1%	-2.3%
26 Professional Services	-0.3%	-0.5%	-0.6%	-0.8%	-0.9%	-1.0%	-1.1%	-1.2%	-1.0%	-1.2%	-1.5%	-1.9%
27 Management of Companies	-0.2%	-0.4%	-0.7%	-0.9%	-0.9%	-1.0%	-1.1%	-1.3%	-1.1%	-1.2%	-1.1%	-1.0%
28 Other Services	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.2%	0.3%	0.9%	1.4%	1.9%	2.1%
29 Government	0.0%	0.0%	0.0%	0.0%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%
TOTAL	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.4%	0.7%	1.1%	1.1%

Appendix B. Energy Efficiency Technologies Examined

TECHNOLOGY GROUPINGS	SPECIFIC TECHNOLOGIES
Agriculture	• Agriculture-crops • Agriculture-other
Commercial	• Commercial cooking • Commercial HVAC • Commercial lighting • Commercial other • Commercial refrigeration • Commercial water heating
Residential	• Residential building shell • Residential clothes drying • Residential clothes washing • Residential cooking • Residential dishwashing • Residential freezing • Residential HVAC • Residential lighting • Residential other uses • Residential refrigeration • Residential water heating
Electric vehicles	• Heavy duty trucks, medium duty trucks, transit buses (Vehicle Costs) • Light duty autos & light duty trucks (Vehicle Costs)
EV chargers	• Heavy duty trucks, medium duty trucks, transit buses (EV Charger Costs) • Light duty autos & light duty trucks (EV Charger Costs)
Other manufacturing	• Aluminum industry • Aviation • Computer and electronic products • Construction • Electrical equip., appliances, and components • Fabricated metal products • Food and kindred products • Glass and glass products • Machinery • Metal and other non-metallic mining • Paper and allied products • Plastic and rubber products • Transportation equipment • Wood products