Investing in US Energy Efficiency and Infrastructure Creates More Nationally-Distributed Jobs while Saving Money and Protecting the Climate

John A. "Skip" Laitner
Economic and Human Dimensions Research Associates
Tucson Arizona

Written in Collaboration with
Dr. Stephen O. Andersen*
Dr. Gabrielle B. Dreyfus*
Kristen N. Taddonio*

*** The Institute for Governance & Sustainable Development (IGSD)**
Washington DC and Paris

March, 2021

ECONOMIC & HUMAN DIMENSIONS RESEARCH ASSOCIATES
GREATER PROSPERITY THROUGH RESOURCE PRODUCTIVITY

IGSD

A Brief Overview of the Report

Why a fresh look at energy-related employment when building back better from the COVID-19 recession?

This paper explains in detail how investing in energy efficiency increases net employment, including as a result of the money saved by energy efficiency improvements being spent locally in support of household and community development. This higher efficiency also allows a sustained improvement in the quality of life with cleaner air, better health, less damage from climate change, and less spent on health care and recovery from climate disasters. Low income and otherwise disadvantaged communities in areas despoiled by fossil fuel extraction and combustion for energy and industry all benefit from clean renewable energy (solar, wind, hydroelectric, geothermal) and more affordable appliance operating costs.

What is new in this economic narrative?

The authors present new and more comprehensive estimates of the likely direct, indirect, and induced jobs, health, and climate benefits of public and private investment in energy efficiency and infrastructure upgrades required to recover from the COrona Virus Disease (COVID)-19 recession and to strengthen United States (US) global competitiveness and full employment with new jobs distributed nationally over a wide range of job skills and wage rates in growth industries with high upward mobility.

What sectors are covered in the report?

The report broadly covers the aggregate residential, commercial, industrial, transportation and energy production sectors of the United States economy.

Who is the audience for this report?

The audience is local, state, and national authorities and their constituents seeking clear advice on investment in electricity supply and energy efficiency that will build a more productive, robust, and sustainable economy over the short- and long-term. The report is a model for analysis that can be applied in other jurisdictions using appropriate data sets and as a case study for economics students training to support sustainable development.

What methodology was used?

Evidence and analysis include: 1) economic and energy data for the United States extrapolated through 2040 for *Business as Usual* (BAU) and *Energy Innovation* Scenarios, 2) a sophisticated energy-economic input-output model to estimate the additional economic benefits of the *Energy Innovation* Scenario, and 3) interviews, analytical critiques, and literature reviews that validate the assessment..

Who are the authors?

The report is authored by a team from Economic and Human Dimensions Research Associates (EHDRA) in partnership with the Institute for Governance & Sustainable Development (IGSD) with assistance of its many collaborators. John A. "Skip" Laitner (EHDRA) provided the economic modeling and resulting assessment and Dr. Gabrielle B. Dreyfus, Dr. Stephen O. Andersen, Kristen N. Taddonio integrated that into the global investment framework under the Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol).[1]

Suggested Citation

Laitner, John A. "Skip", Stephen O. Andersen, Gabrielle B. Dreyfus, and Kristen N. Taddonio. 2021. *Investing in US Energy Efficiency and Infrastructure Creates More Nationally-Distributed Jobs while Saving Money and Protecting the Climate*. Washington DC and Paris, France: The Institute for Governance & Sustainable Development (IGSD); and Tucson, AZ: Economic and Human Dimensions Research Associates. https://theresourceimperative.com/wp-content/uploads/2021/03/Energy-Efficiency-Upgrades-Protecting-the-Climate-Creating-Jobs.pdf

[1] Any opinions expressed in this report are those of the authors and do not necessarily represent the views of EHDRA and IGSD. For questions or further information, contact John A. "Skip" Laitner at EconSkip@gmail.com.

Contents

Executive Summary

The United States (US) economy needs a reboot for the 21st century—one that simultaneously addresses its social, economic, and environmental health, as well as its long-term resilience. Recovery from the COVID-19 recession offers an opportunity to "build back better" by investing in both people and infrastructure such that the US economy's overall performance is decidedly more energy and resource productive, as well as more sustainable and resilient. The 20th century economy (and before) depended heavily on resource extraction and manufacturing, and while these remain important activities within the marketplace, it is the high-level performance of all sectors of the economy—whether they produce goods or services—that will contribute to the larger social well-being of the entire nation.

The US economy is slowly eroding. The nation's real Gross Domestic Product (GDP) per capita has slipped to 1.0 percent growth rate between 2007 and 2019, compared to 2.1 percent annually over the years 1970 to 2007. This erosion has occurred at the same time as US oil production has more than doubled and gas production increased by 150 percent.[2] Projections suggest the economy might rebound to a 1.3 or 1.4 percent annual growth rate through 2050, which implies an economy that may be 20 percent smaller in 2050 compared to the historical growth rate of the earlier decades. That, in turn, implies millions of fewer jobs than we might otherwise like to see, or anticipate.

The economy is slowly eroding for three reasons: (i) an aging and a less productive infrastructure; (ii) an insufficiently trained workforce with skills that do not yet match critical tasks within the unfolding information economy; inadequate upgrades in clean energy supply and energy efficient technologies; and most critically, (iii) the inefficient use of capital, fossil fuels, and other natural resources. These inefficiencies also increase the nation's air pollution and greenhouse gas emissions, and contribute to a less healthy population and the growing economic burden of climate change.

Fortunately, there is good news in all of this. Stimulating investments in the upgrade of the workforce and US infrastructure that increase resource productivity will build new opportunities for millions of new jobs and careers over the next two decades. This paper estimates the job creation that can be stimulated by new investments in end-use energy efficiency, decarbonization, and clean renewable energy systems compared to new investments in traditional fossil fuel technologies using a comprehensive methodology.

The analysis that follows identifies a number of critical steps which promote greater employment prospects as each of those many steps support a series of *direct jobs* from on-site activities and *indirect jobs* from the off-site supply of goods and services which support those direct jobs. And as the wages and earnings are spent within American communities, they sustain further *induced jobs* which support a range of community activities such as education, entertainment, food, health, and a quality of life. Investments in energy efficiency and clean renewable energy technologies have far lower social, economic and environmental costs, while increasing the disposable incomes of families. This is in part due to the fact that the delivered cost of electricity from new wind, solar, and other clean renewable energy systems is less expensive than from fossil fuel technologies. Energy efficiency and solar, in particular, can be ubiquitously built or sited at individual homes and businesses or neighborhoods. In short, these

[2] According to EIA, US monthly crude oil production grew from 5 million barrels per day in 2007 to about 13 million barrels per day in 2019 (2.6x), and natural gas production grew from about 70 billion cubic feet per day in 2007 to over 110 in 2019 (1.5x). (https://www.eia.gov/todayinenergy/detail.php?id=46476)

investments contribute to improving community prosperity while avoiding the human health and productivity costs, and agricultural and ecosystem damages associated with the consumption of fossil fuels.

This study does two things. First, it characterizes the job and the scale of economic benefits of a 40 percent savings in the cost of the nation's retail electricity bills. Second, it draws on the subsequent insights from that detailed assessment and then asks the question: What if we imagine a much larger opportunity if we were to transform the nation's entire energy structure. The main analysis found that mobilizing a cumulative investment of $1.2 trillion over the years 2021 through 2040 can reduce electricity end-use costs by 40 percent[3] in the year 2040. This stimulates an average net employment benefit of 2.8 million new jobs per year even as the nation's GDP might increase more than $580 billion (in constant 2012 dollars) by the year 2040. The resulting reduction of greenhouse gas emissions and air pollution would result in an average annual benefit of a further $112 billion in avoided air pollution and health costs (expressed in 2020 dollars). The cumulative benefit of this economic reboot would be on the order of $2.1 trillion through 2040 (also in constant 2020 dollars).[4]

Should business leaders and policy makers agree to reduce costs by 40 percent across the stream of the nation's entire energy expenditures—including all agricultural, industrial, building and transportation energy uses—that economic reboot would generate an average of 8.7 million net new jobs per year through the year 2040. Further, a complete 100 percent transformation of the overall energy system within the United States away from conventional fossil fuels and nuclear energy power plants to clean renewable energy would result in an average of 20 million new net jobs per year by 2040.

The job growth in induced jobs from investments in clean renewable energy and energy efficiency is far larger than the more conspicuous direct and indirect jobs. More critically, these induced jobs, as well as the many other benefits of the productive investments, are more equitably distributed geographically among the population and with higher employment over a wider range of skill levels and wages. Thus, the high rates of return on clean renewable energy and energy efficiency can accrue to the citizen taxpayers making the investment possible, and the avoided environmental and social costs of fossil fuel exploitation can similarly benefit all citizens, but particularly in lower income communities that would otherwise be located near fossil fuel extraction, combustion, and waste management activities.

The bigger lesson is that the economy is not any one isolated element, or even an array of investments and expenditures; rather the economy is a system of many highly interdependent connections. We can begin to understand the many possible interactions by exploring, in Table ES-1 below, seven different interactive drivers that can positively or negatively shape the nation's long-term social and economic well-being, as well as the nation's future job markets. Each of these drivers has unique direct, indirect, and induced jobs per stream of expenditures. How they both scale and converge to a more energy and

[3] A reduction in electricity costs can be achieved through energy efficiency, or by switching to a more productive means of electricity generation and distribution; for example, switching from fossil-fuel based to clean renewable forms of electricity generation and reducing losses that occur in the generation and transmission process. Thus a 40% reduction in electricity costs does not necessarily mean that consumers or businesses consume 40% less electricity at their homes or businesses. Rather, that 40% reduction in electricity costs could be achieved through a combination of factors, including more efficient and less wasteful production, generation, transmission, distribution and consumption of energy.

[4] While the investment magnitudes were first provided in 2020 dollars, the economic projections in the reference case of the *Annual Energy Outlook 2021*, op cit., were provided in constant 2012 dollars. Hence, the reference to different base-year dollars provided in this supplemental analysis.

resource productive economy can have a significant impact on the total number of good paying jobs available to communities.

Table ES-1. The Seven Major Drivers of Employment and Economic Benefits

Driver	Primary Impact
Intensity Shift	Moving away from capital-intensive to labor-intensive activities
Supply Chain Build Up	Building up greater local production and local services
Energy Cost Reduction	Both unit cost and total cost savings for efficiency and non-efficiency
Productivity Boost	Expanding non-energy benefits
Managing Volatility	Smoothing out price shocks
Minimizing Disruption	Avoiding the inconvenient interruption of supply
Innovating Plus	Cost and services breakthroughs in the delivery of energy and other services

Source: John A. "Skip" Laitner as described and discussed in the main text of the manuscript.

Not all investments deliver the same scale or the same set of social and economic benefits. A resilient and productive 21St century American economy invests in infrastructure and programs that leverage these drivers to:

- Move from capital/resource-intensive extraction and energy-production sectors to more labor-intensive but still-cost effective activities within the construction, manufacturing and service industries;
- Build up local production and service capacity as greater home weatherization and improvement services as well as a greater range of technical skills within all communities;
- Improve energy efficiency and reduce energy generation costs with low-cost solar, wind, and other clean renewable systems, which allows consumers to spend more on nutrition, education, and community development while enjoying the same or greater level of energy services;
- Increase overall capital, material, and water productivity across all sectors through investments in better information management and storage systems;
- Manage both cost and price volatility through smart demand response and other real-time management tools;
- Increase resilience through the enhanced use of energy resources, and with smart management systems which can minimize supply disruptions; and
- Grow the overall social and environmental benefits as set out in Appendix A of the main narrative.

The key to reaching a higher level of performance is not simply to focus on more supply, but to invest in people, systems and infrastructure to deliver an optimal mix of goods and services which simultaneously strengthen the economy while addressing the social, economic, environmental, health, and resilience needs of the country in the face of climate change. Investing in energy efficiency, alongside the transition to clean energy resources, saves people and businesses money. Savings which are respent locally, and which can more easily benefit all parts of the United States today and in the many years to come.

1.0 Introduction

The new administration of US President Joseph R. Biden has pledged to simultaneously address economic recovery from the COVID-19 pandemic, rapidly protect the climate, and improve social and environmental equity and justice (Biden Campaign 2020). This paper documents a critical strategic approach—that the shift from fossil fuels to clean energy resources, together with greater levels of overall energy efficiency, increases consumer wealth through potentially large savings in energy costs. The savings tend to be spent locally and create more jobs than are displaced, with broad geographical benefits.

In the one-year period from December 2019 to December 2020 total nonfarm employment dropped by 9.4 million jobs (BLS 2021). Wildfires, violent storms, and excess heat events worsened by climate change caused economic losses of at least $100 billion in 2020, with even greater climate damage predicted in the near future (Cappucci and Samenow 2020; see also Rich 2018; and Smith 2021).

With limited time to achieve significant reductions in the emissions of short-lived climate pollutants (SLCPs)[5] and carbon dioxide (CO_2) (see Plumer 2020; IPCC 2018; Ripple et al. 2019; and IGSD 2021), the evidence suggests that the economy is showing signs of erosion and a less resilient infrastructure. The reasons are three-fold: (i) a lagging and a less productive infrastructure (ACSE 2016; Corfee-Morlot et al. 2016; ACSE 2020a; and ACSE 2020b) (ii) an insufficiently trained workforce with a set of skills which do not yet match critical tasks or upgrades in clean energy supply and energy efficiency (Muro et al. 2019) as well as the need for workforce education and retraining more broadly (Adecco 2016; Giffi and Wellener et al. 2018; and UAW 2020);[6] and (iii) the inefficient use of fossil fuels and other natural resources (Ayres and Warr 2009; Kümmel 2011; Kümmel 2013; and Laitner 2015).

Conventional economic forecasts project that normal investment in energy efficiency and clean energy will move the US rapidly ahead in the next three decades or so. For example, the US Energy Information Administration's (EIA) *Annual Energy Outlook 2021* (EIA 2021a) indicates that the nation's economy is likely to increase from a GDP of $18.2 trillion in 2020, to about $34.4 trillion by the year 2050 (with the two values expressed in constant 2012 dollars). This is a projected 89 percent expansion over that 30-year period. Moreover, the EIA projects an increase of 42 million new jobs in non-farm employment by 2050.

However, these conventional projections ignore the growing financial and existential risks from climate change. Failure to protect the United States from the growing burden of climate change will weaken both financial markets and the larger economy (Brainard 2019; and Cohen 2020). A business-as-usual (BAU) scenario that overlooks the need to reduce greenhouse gas emissions significantly will increase the US climate burden by as much as ~$500 billion by mid-century.[7] Likewise, a recent assessment by climate research scientists at the Scripps Institution of Oceanography, Stanford University and elsewhere estimate that expected economic damages from CO_2 emissions will range from $177 to $805 per metric ton of CO_2, with a median value of $417. The social cost of carbon (SCC) at $417/metric ton adds $3.71 to the

[5] Short-lived climate pollutants (SLCPs) include hydrofluorocarbons (HFCs), methane, tropospheric ozone, and black carbon (soot).
[6] In fact, Giffi and Wellener et al. (2018) concluded that a persistent shortage of key work skills could risk the United States losing $2.5 trillion in economic output over the next decade.
[7] The scale of climate damages are discussed further in Section 5.2 of this narrative. In 2018, total gross US greenhouse gas emissions were 6,677 million metric tons of carbon dioxide equivalent (MMT $CO_{2\text{-eq}}$). Net emissions (including sinks) were 5,903 MMT $CO_{2\text{-eq}}$ Energy-related CO_2 emissions, that are the focus of discussions on this report, were 5,032 MMT CO_2 (or 75% of gross emissions). The remaining emissions included other sources of CO_2, methane (CH_4) 635 MMT $_{CO2\text{-eq}}$, nitrous oxide (N_2O) 435 MMT $CO_{2\text{-eq}}$, and the so-called fluorinated gases (including HFCs, PFCs, SF_6, NF3) which total emitted 183 MMT CO_{2eq} while land-use change and forestry (LULUCF) absorbed and offset 800 MMT CO_2 of gross emissions (EPA 2020 Table ES-2).

cost per gallon from the health, climate and other economic damages of the CO_2 emitted by burning a gallon of gasoline (Ricke et al. 2018).[8]

US infrastructure has in many places exceeded its design life and needs replacement, both to be more resilient to the growing climate-related impacts, as well as to more proactively support a 21st century economy. Failure to rebuild eroding public and private infrastructure can contribute to lagging economic productivity which weakens both employment prospects and our economic well-being (ACSE 2016; Corfee-Morlot et al. 2016; McGrattan and Schmitz 1999; and Pollin, Heintz and Garrett-Peltier 2009).

While there are a growing number of climate and economic imperatives (Ripple et al. 2019; Keith, Meerow, and Wagner et al. 2020; and Watts et al. 2021), there are also many opportunities to invest in an infrastructure that enables the more productive use of resources, including capital, materials, water, food and especially energy while avoiding the burdens of fossil fuels (Laitner et al. 2012; Hawken 2017; Grubler et al. 2018; Kutscher et al. 2020) – all of which, in turn, will enable a greater number of jobs bolstered by a more robust social and economic well-being.

This analytical narrative explores how the transition to the more productive use of electricity—and by extension all other energy and resources—will allow a more robust and sustainable economy which supports an even greater number of jobs within the United States compared to almost any BAU scenario. The analysis explores these employment benefits in five separate ways. Section 2.0 is a high-level overview of energy consumption and how that impacts our economy. Section 3.0 explains the critical link between greater energy productivity and social-economic well-being.

Section 4.0 elaborates one of the more complete analytical frameworks which can help identify those immediate investments, and also their returns, which provide the highest consumer benefits and the largest scale of new jobs. This analysis draws on other engineering and economic assessments to reinforce why upfront investments in energy efficiency can both save money and stimulate a very large number of new jobs. Section 5.0 reviews the climate and air pollution benefits of clean low-carbon electricity and greater energy efficiency. Section 6.0 provides a brief overview of the key policy implications of these findings.

2.0 Overview of US Energy Consumption

In 2020, the 330 million people living within the US spent an estimated $985 billion for energy services (EIA 2021a).[9] That is equivalent to an economy-wide energy bill of about $3,000 per person per year.

Although the US economy has historically derived important direct benefits from fossil fuel energy purchases, the inefficient use of energy from these resources has created an array of productivity, health, and climate costs that burden our economy. For example, the combustion of fossil fuels releases pollutants that damage health, crops and natural ecosystems; decrease worker productivity and quality of life; and increase private and public health care costs. The current mix of energy resources used to support worldwide economic activity causes more than $100 billion of health and environmental damages annually within the United States (Harvey 2016; Shindell 2020; and Watts et al. 2021). The US Energy Information Administration (EIA) estimates that current energy consumption patterns emitted 4.6 billion tons of CO_2

[8] It should be noted that the Ricke et al. (2018) values are based on constant 2005 dollars. Adjusting for the inflation rate between 2005 and 2020 would increase the social cost of carbon to ~$563 per tonne of CO_2, or $5.00 per gallon of gasoline equivalent in 2020 dollars. For other key studies on the effect of pollution and health see, Dedoussi et al. (2020) and Price et al. (2020).

[9] EIA 2021a. Op. Cit. See Table 3 of the Annual Energy Outlook 2021, "Energy Prices by Sector and Source." As a further note, the base year of the many dollar values reported in this assessment vary considerably.

in 2020 (EIA 2021a). A 2014 report published by the International Energy Agency (IEA) found that the inefficient use of energy imposes social and environmental costs which weaken economic well-being and constrain job creation (Campbell, Ryan et al. 2014; EPA 2011a; and EPA 2018). However, the historic price advantage of energy from fossil fuel has been eliminated in most applications by lower cost clean energy from geothermal, hydroelectric, solar and wind (Lazard 2020) and without the social cost of air, land, and water pollution.

A variety of other recent studies estimate that the global economy may be less than 20 percent energy efficient (Laitner 2020, based on Ayres and Warr 2009; Laitner 2015; Voudouris and Ayres et al. 2015; and Blok et al. 2015). These studies suggest that a greater level of energy productivity, or aggregate efficiency, may be a primary driver of social and technological progress.

The more productive use of energy and resources will *take purposeful effort, guided by smart policies and programs, to drive the necessary activities and investments to achieve optimal, large-scale benefits* (Laitner et al. 2018; Lebot and Weiland 2020).[10] This narrative focuses on *the compelling logic* of how transformation of America's existing infrastructure will ensure a more robust social well-being and job creation process within the American economy. Equally important to that success is the scale of the policies and programs which are required to support that transition. The narrative also explores the employment and other economic benefits that will result from the more productive investments in the nation's appliances, equipment, and infrastructure.

3.0 The Imperative of a More Resource Productive Economy

Over the period 1970-2007 real per-capita GDP—a useful proxy of economy-wide productivity—grew at a rate of 2.1 percent per year. Over the next 12-year period through 2019, however, the growth of per capita GDP weakened significantly, dropping to 1.0 percent per year. This erosion has occurred at the same time as US oil production has more than doubled and gas production increased by 150 percent.[11] Recent projections indicate the growth rate might rebound to 1.3 percent over the period 2019 through 2050 (Woods and Poole 2020). The difference between a 2.1 percent rate of improvement compared a 1.3 percent implies an economy that may be 20 percent smaller than otherwise expected by the year 2050. A weaker economy means lower incomes and higher unemployment with less tax revenue for education, healthcare, environmental protection, and investment that can support future infrastructure improvements.[12]

Figure 1 brings to light the importance of energy productivity as it moves our economy ahead compared to the immediate consumption of coal, oil, natural gas or electricity. Data made available by the US EIA (2021b) shows that the American economy grew from $2,290 billion in 1950 to $18,409 billion by 2020 (that is, GDP as measured in constant 2012 dollars). In effect, the US economy was 8.04 times bigger by

---

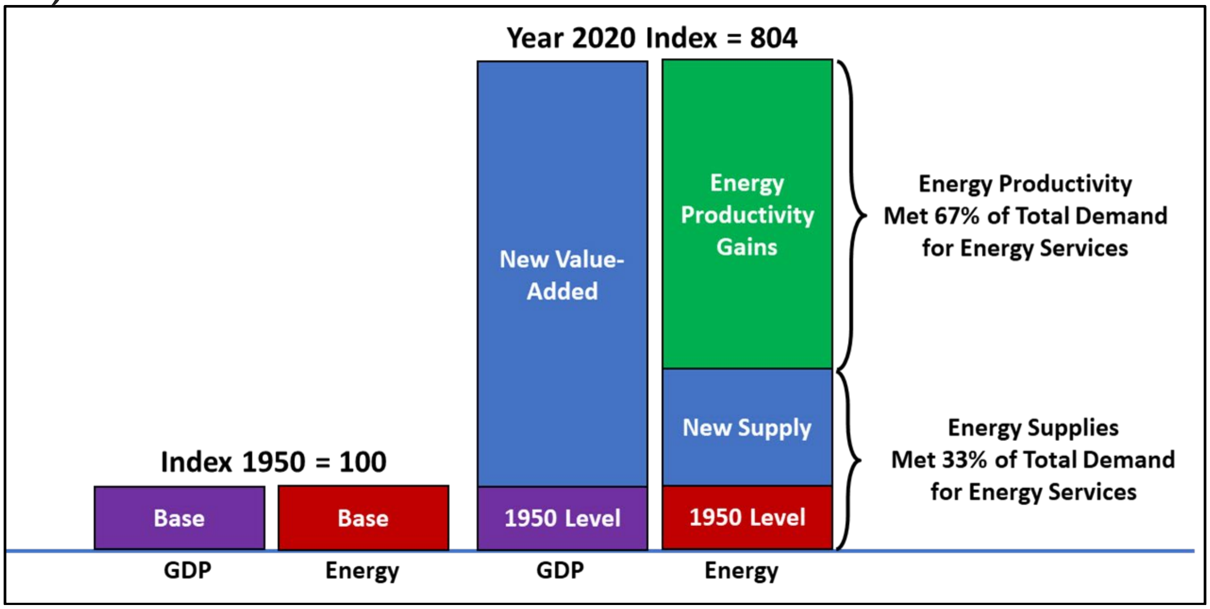
[10] Examples of both international and U.S. scenarios which achieve that scale of reduction can be found in European Climate Foundation (ECF 2010), Laitner et al. (2012), Teske et al. (2015), Metropolitan Region of Rotterdam and Den Haag (2017), Haley et al. (2019), RMI (2020), and SDSN (2020). It might be worth noting that, as an update to an earlier study (Laitner et al. 2012), Nadel (2016) and Nadel and Ungar (2019) found a large number of specific measures in the United States, if pursued aggressively, would reduce 2050 energy use by 50 percent relative to currently predicted levels.

[11] According to EIA, US monthly crude oil production grew from 5 million barrels per day in 2007 to about 13 million barrels per day in 2019 (2.6x), and natural gas production grew from about 70 billion cubic feet per day in 2007 to over 110 in 2019 (1.5x). (https://www.eia.gov/todayinenergy/detail.php?id=46476)

[12] New population, employment and economic projections from Woods and Poole are due in May 2021. It is likely that the 2019, 2020 and 2050 projections are likely to change in absolute value. However, the larger economic trends are likely to remain on a similar trajectory to those reported here.

2020 compared to 1950. Converting these values to an index in which 1950 is 100, the 2020 index is then 804.

Figure 1. Magnitude of US Energy Productivity Gains & Energy Supply (1970 to 2020)



Source: Author calculations based Energy Information Administration data as described within the text (EIA 2021).

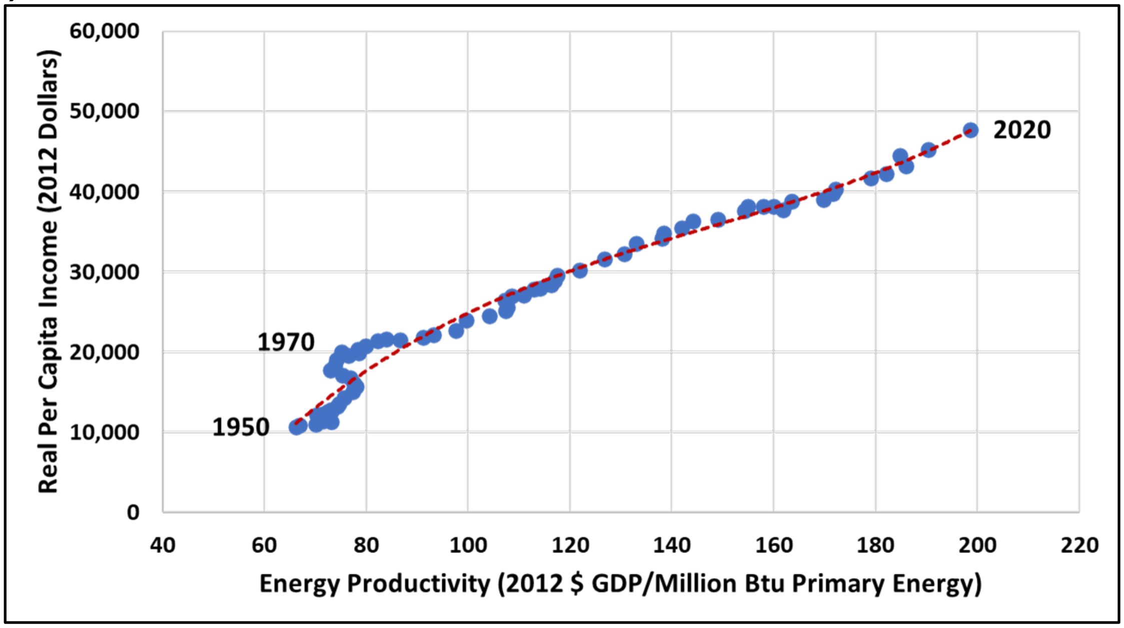
The use of energy within the American economy is measured in quadrillion (10^{15}) British thermal units (Btus), or quads (EIA 2021). One quad, on average, is sufficient to meet today's energy needs of about 5.9 million homes or power about 17.2 million cars, both for one year. In 1950, total primary energy consumption in the US was 34.6 quads. As of 2020, the use of energy grew to only 92.7 quads. Thus, while the economy expanded by a factor of 8, total energy demand grew only 2.7 times.

If we think of GDP as a demand for overall energy services, rather than simply a demand for energy—whether those services are provided by a variety of physical energy assets, or greater levels of energy productivity—the physical resources accounted for only 33 percent of the demands for energy services since 1950. In effect, energy resources provided about three times as much GDP in 2020 than in 1950, with the more productive use of energy providing 67 percent of the total demand for such services. Thus, greater economic prosperity is not as much from new energy supplies as it is from new energy efficiency and clean energy investments. Figure 2 which follows, confirms the positive relationship between aggregate efficiency and economic well-being.

In 1950, the consumption of one million Btus (MBtu) of total energy supported only $66 of economic activity (or GDP expressed in constant 2012 dollars).[13] That scale of productivity enabled an average income of about $10,700 in 1950 (also expressed in 2012 dollars). Although the economic transition that followed World War II was accomplished with a somewhat variable ratio of GDP per MBtu, the economic transitions in the 1980s were accomplished with stable and predictable improvements in GDP/MBtu. By 2020 each one million Btus of energy consumed in the US supported $199 of GDP, a level of economic productivity which also supported an average personal income of nearly $47,800 per year.

[13] The Energy Information Administration calculates that one million Btus is currently equal to about 8.6 gallons of gasoline or about 293 kilowatt-hours of electricity.

Figure 2. Trends in US Energy Productivity as it tracks Per Capita Income (1950-2020)



Source: Calculations by John A. "Skip" Laitner using EIA and BEA data for the United States (February 2021).

The rate of improvement for both income and energy productivity has generally declined in the last few years and particularly as a consequence of the COVID-19 pandemic. Two supplemental but critical perspectives emerge as we examine the data in more detail, however. First, while the pandemic closed down the economy by about 3.5 percent in 2020, energy productivity actually increased by 4.3 percent in that same year. Second, it was the transition to a knowledge-based and more service-oriented economy which helped drive up per capita incomes even as those services were considerably less energy intensive, as opposed to the loss of manufacturing jobs which tend to be more energy intensive.

As "Energy Productivity" is defined here—again, the level of real GDP supported by an average one million Btus—three primary categories of work are responsible for the improvement in US energy productivity since the 1950s:

> The first is energy efficiency improvements at the end-use level. This includes more efficient lighting, heating and air-conditioning, appliances, vehicles and other equipment within homes and businesses. It also includes the more efficient industrial processes.
>
> The second is improving the efficiency of electricity generation. Clean and renewable energy systems including geothermal, hydroelectric, solar, and wind systems require far less primary energy per kilowatt-hour (kWh) generated and produce electricity at lower cost per kWh and no social cost from pollution. The shift that is now underway to produce electricity through wind and solar resources could eliminate as much as 23 quadrillion Btus of energy (or Quads), on average, or about 23 percent of both current and future energy requirements through the year 2050.
>
> The third category is the more productive use of capital, materials, chemicals, water and food. By reducing aggregate waste in all of these categories, less energy is necessary to transform such resources into the desired goods and services, and then distribute them in ways that support social and economic well-being.

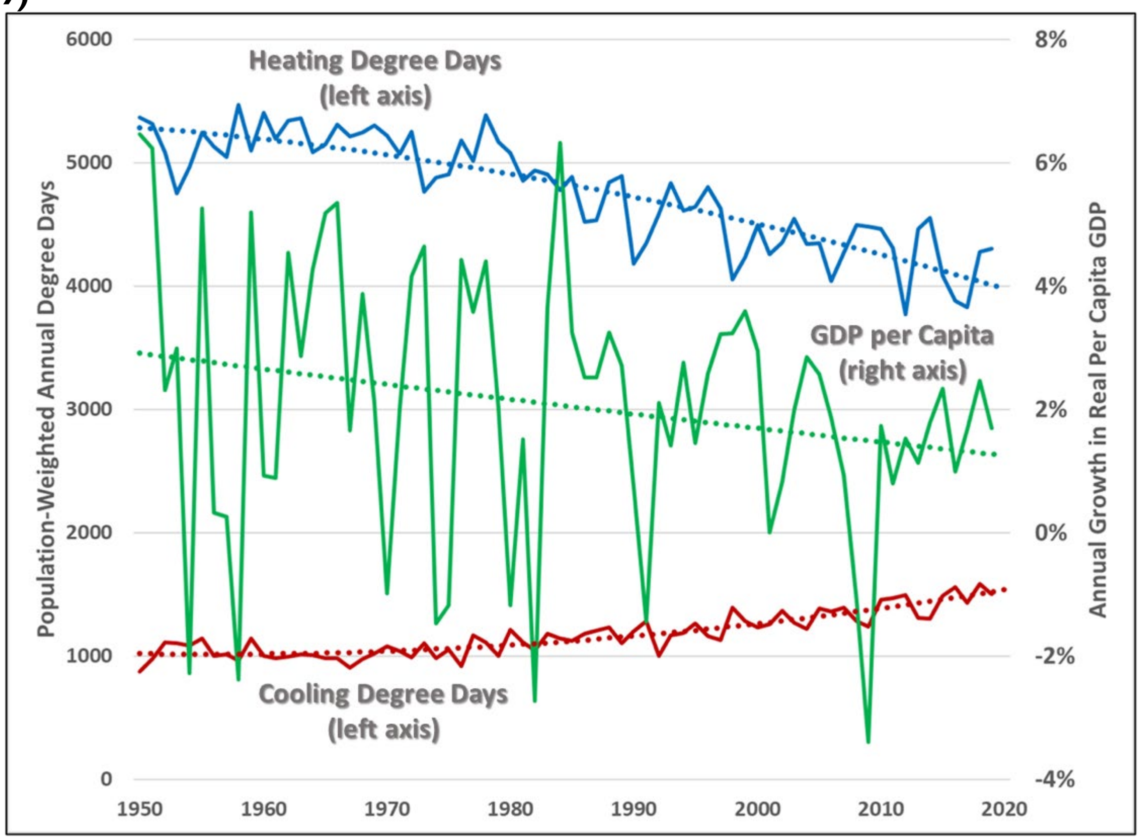
Adding up all of these three elements—(i) higher end-use energy efficiency, (ii) greater deployment of clean renewable energy; and (iii) reduced waste in the use of all other resources—can significantly lower total energy needs even as the nation's economy can become more robust and more resilient.

Figure 3 describes the ***Blue-Green-Red Resource Squeeze*** on the American economy. To elaborate on the implications of this "squeeze", data is drawn from the EIA (2021b) to map and evaluate two key trends: the ***economic squeeze*** and the ***climate squeeze***. The green data points represent the ***economic squeeze*** of a weakening trend in real GDP per capita over time, within the United States. The blue and red data points track the ***climate squeeze*** from the growing burden of climate.

3.1 The Squeeze on the Nation's Per Capita GDP

Most projections of GDP over the period 2019 through 2050 point to a long-term attrition in both the US and the global economies—with per capita GDP over the next 30 years estimated at about 0.8 percent less improvement than the historic average. The data all point to a US economy that may be as much as $9 trillion smaller in 2050 compared to one that might have expanded at the larger historical rates of growth. That means fewer jobs and a less certain level of income.

Figure 3. Trends in US Heating/Cooling Degree Days and Per Capita GDP (1950-2019)



Source: John A. "Skip" Laitner using data from the US Energy Information Administration, January 2021.

3.2 The Trend in Degree Days and Rising Annual Temperatures

Heating degree days (HDD) and cooling degree days (CDD) quantify the energy needed to heat or cool a building to the desired temperature. They are derived from measurements of outside air temperature. In the United States, the accepted reference temperature is 65° Fahrenheit (F). The colder the integrated outside temperature, the higher the number of HDDs. The more extreme the integrated summer heat, the higher the number of CDDs. A high number of cooling and heating degree days generally results in higher levels of energy use.

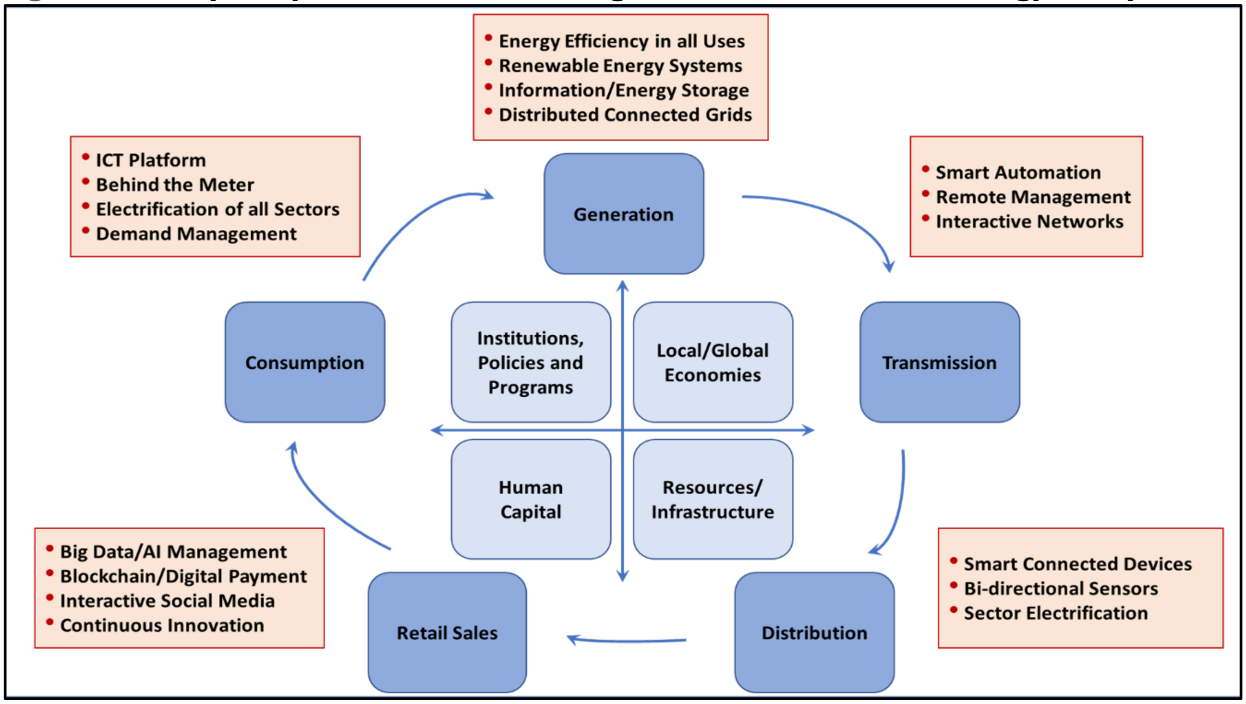
The winters are getting warmer (fewer HHDs) and the summers are getting colder (more CDDs). Other indicators of a rapidly warming planet include global ice melting, seal level rise, wildfires and the surge in tropical storms and hurricanes. For example, a day with an average outside temperature of 40°F degrees means there are 25 HDD in that 24-hour period. On the other hand, a day with a 75°F average temperature implies a total of 10 CDD. Because the winters tend to be longer in the US, with a greater difference between the winter average temperatures compared to the 65°F benchmark, there are many more heating degree days than cooling degree days in any given year. It is especially worrisome to see that there were six times the number of HDD in 1950 but by 2019 that ratio dropped to less and three times the number of HDD compared to CDD.

According to data released by the National Oceanic and Atmospheric Administration (NOAA) (Smith 2021) the US weather and climate costs in the 1980s averaged ~$18 billion per year. In the last three years (2018 to 2019) that grew to ~$78 billion per year with 2020 at ~$95 billion. A simple extrapolation suggests the total could reach ~$500 billion by mid-century without any further action (with all dollars CPI-adjusted).

3.3 The Driver *and* the Solution?

The warming trend, as well as the slow erosion of the economy, are driven by the inefficient use of resources (Ekins and Hughes, et al. 2017; Laitner 2018; Laitner and Weiland 2018). The scale of conventional use of energy and the associated waste of all resources can be seen as a common causation of both a weakening economy and the growing burden of climate. The solution? A much greater emphasis on the productive use of clean renewable energy and ***all other resources***.

Figure 4. Array of Systems and Technologies to Transform the Energy Ecosystem



Source: Graphic Illustration adapted from the World Bank by John A. "Skip" Laitner (February 2021).

4.0 Critical Building Blocks and Jobs

Interviews and discussions with more than 100 people since August 2018,[14] as well as a detailed review of several major assessments (Laitner et al. 2012, and 2018; Jadun et al. 2018; IRENA 2019; Kutscher, Logan, and Coburn 2020; and Griffith and Calisch 2020)[15] determined that simultaneously enhancing energy productivity and transitioning to clean renewable energy will require a substantial upgrade in existing, but also new capital stock and infrastructure, to enable greater economic productivity. Underpinning that transition, as highlighted in Figure 4, is an array of information and communication technologies which will be necessary to support a highly productive electrification of the economy.

4.1 Build Back Better for a More Productive Infrastructure

The United States is the largest global economy with an annual GDP in 2019 of $19.1 trillion per year (in constant 2012 US dollars). What may be less appreciated, however, is that the scale of the nation's existing capital stock (including fixed assets and consumer durables) is on the order of $60 trillion (Bureau of Economic Analysis 2021). This is about 3.1 times the size of annual economic activity. If we are to think about an improved overall economic performance, we necessarily must also think about an infrastructure, together with all of its many buildings and other components, that is three times the scale of our annual economic activity. Most would agree that is a very tall order.

[14] The many interviews began as part of an invitation to help lead a three-day deep dive, "Rethinking Energy Demand," initiated by colleagues with a European team from the International Institute of Applied Systems Analysis (IIASA) and the Japanese-based Research Institute for Innovative Technologies for the Earth (RITE). This was convened September 2018 with literally dozens of interviews and discussions since that gathering.

[15] A variety of other critical assessments of future opportunities again might include Blok et al. (2015), Teske et al. (2015), Zuckerman et al. (2016), Hawken (2017), Ekins and Hughes et al. (2017); Jacobson et al. (2017), MRDH (2017), Grubler et al. (2018), Jacobson et al. (2019), SDSN (2020), and RMI (2020).

The International Renewable Energy Agency (IRENA 2019) suggests a total expenditure of 60 percent of one year's GDP to achieve a 40% reduction in fossil fuel energy use. That is, $10 to $12 trillion expended over the next several decades. As suggested by IRENA, higher energy efficiency and conversion to as much as 86 percent clean renewable electricity can lower total energy demand in 2050 to as little as 65 quads of primary energy with between $3 and $7 in savings for every dollar invested through 2050 and an estimated increase in overall GDP by up to 2.5 percent. Thus, the US economy can use 40 percent less energy, but in ways that boost economic activity by an additional ~$859 billion relative to the 2050 Reference Case published by the Energy Information Administration (2021) (again, in constant 2012 dollars). If we are to imagine 100 percent a carbon pollution-free electricity sector by 2035, as suggested by President Biden,[16] that points to a greater level of investment. And as policies and market strategies find ways to lower the cost of that transition, both the economy and employment can be enhanced even further.

4.2 Exploring the Jobs Creation Benefits

With a current oil and gas industry supporting about 10.3 million jobs in the United States,[17] the question becomes which combination of clean energy and energy efficiency investments might best support the largest number net gain of permanent jobs?[18] The data in Figure 5 shows what might be possible as a function of both policies and investments.

Figure 5 draws on the 2019 IMPLAN (IMpact Analysis for PLANning) US national-level data sets, which rely on public data made available through a variety of agencies and institutions. The graph presents what are called sector-based "total job coefficients" (IMPLAN 2021). A subsequent discussion will identify what are called the direct, the indirect, and the induced jobs which add up to the total gain of employment for each one million dollars spent within a given sector of the national economy. From the summary graphic in Figure 5, and as we scale to jobs per billion dollars within the very large US economy, it can be seen that the electric utility industry, with total retail sales of $381 billion within the US economy, supported an estimated 10,800 total jobs for each one billion dollars of revenues received from its many customers. That compares to a somewhat larger 14,700 total jobs per billion dollars of manufactured goods which might be purchased, as well 19,900 jobs in the construction industry and 20,800 jobs within the various government enterprises.[19]

---

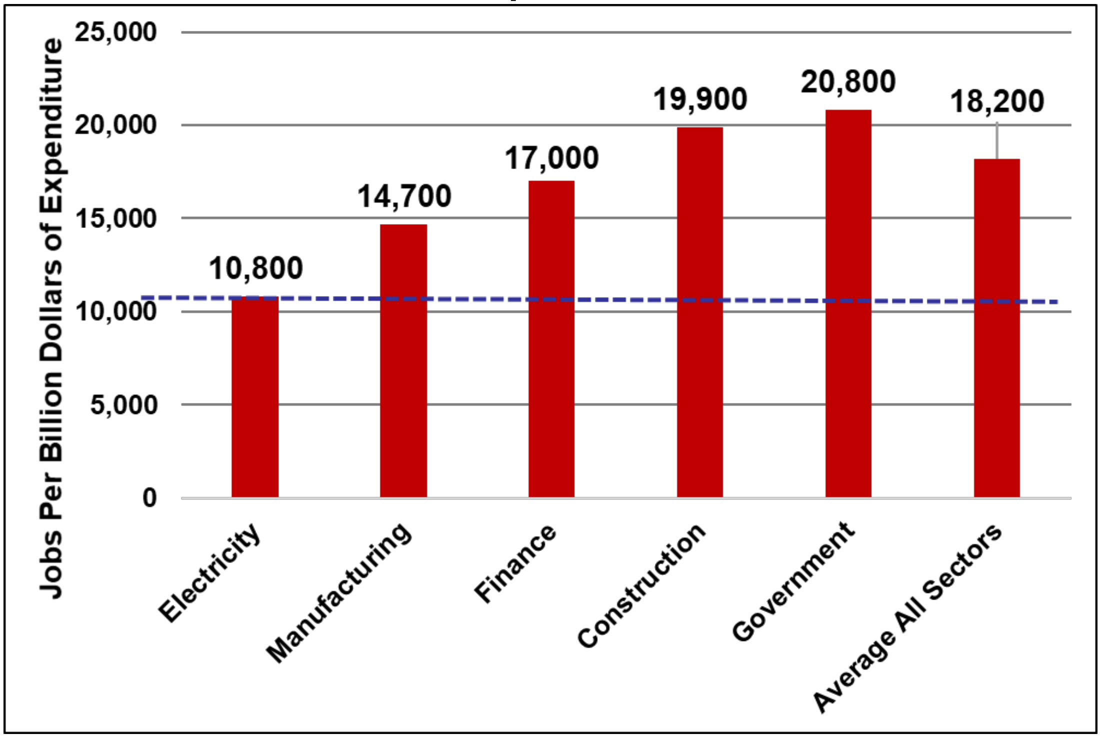
[16] See, Executive Order on Tackling the Climate Crisis at Home and Abroad, January 27, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

[17] See, for example, "Execs' Open Letter to 2020 Candidates Promotes Oil & Natural Gas 2/24/2020." As explained in subsections 4.2.2 of this narrative, the 10.3 million jobs cited here reflects not simply the direct jobs in the oil and gas industry, but also the indirect and induced jobs also supported by larger industry. See, https://www.westernenergyalliance.org/pressreleases/execs-open-letter-to-2020-candidates-promotes-oil-natural-gas. Yet, to place this into a more complete context we should note that, depending on a final accounting of total employment following the pandemic, there are on the order of 200 million people employed in various ways within the United States as of 2020 (Woods and Poole 2020).

[18] Critical to the explanation that follows is understanding that aggregate efficiency is the result of 3 key drivers, as explained in the discussion reviewing Figure 2 of this report, including: (i) greater end-use energy efficiency, (ii) the move to clean renewable energy technologies which eliminates the need for significant magnitudes of primary energy otherwise lost in the conventional combustion process, and (iii) an improved use of capital, materials, water, and food—further reducing energy needs as part of the production process.

[19] The combined federal, state and local government activities account for about 12% of total jobs within the US in 2019 with the private sector accounting 88% of the total jobs (Woods and Poole 2020).

Figure 5. Total Labor Intensities for Key Sectors within the United States Economy



Source: John A. "Skip" Laitner, using IMPLAN 2019 Data for the United States (January 2021).

For every one billion dollars spent on average for all goods and serves within a given year, the nation's economy supports an average of 18,200 total jobs (IMPLAN 2021).[20] Hence, **for every one billion dollars of electricity bill savings today, from cost-effective energy efficiency improvements and investments in cost-effective clean renewable energy technologies—whether they benefit households or businesses—the national economy will gain a net increase of 7,400 new jobs, as long as those savings are spent within the country.**[21]

As described next, the full job creation potential within the United States depends on what we can call: (i) the seven economic drivers; together with (ii) the three job effects; (iii) the four changeover impacts; and finally, (iv) three key deployment variables of job creation. Table 1 helps open a discussion around the list of at least seven key drivers that are likely to enable a more robust economy as a result of *any given Innovation Scenario*.

4.2.1 *Understanding the Major Drivers of Employment and Economic Benefits*

The economy is not any one isolated element or even an array of investments and expenditures; rather it is a system of many highly interdependent connections. We can begin to understand the scale of the many possible interactions by exploring, in Table 1, at least seven different interactive drivers which can positively or negatively shape the nation's long-term social and economic well-being, as well as the nation's future job markets.

[20] IMPLAN is an industry-standard macroeconomic model. Users of the input-output economic data and analytical tools include academia, federal, state, and local governments, and the private sector.

[21] That calculation would be [(18.2/$million less 10.8/$million) * $1,000 million (or $1 billion)] = 7,400 jobs.

Table 1. The Seven Major Drivers of Employment and Economic Benefits

Driver	Primary Impact
Intensity Shift	Moving away from capital-intensive to labor-intensive activities
Supply Chain Build Up	Building up greater local production and local services
Energy Cost Reduction	Both unit cost and total cost savings for efficiency and non-efficiency
Productivity Boost	Expanding non-energy benefits
Managing Volatility	Smoothing out price shocks
Minimizing Disruption	Avoiding the inconvenient interruption of supply
Innovating Plus	Cost and services breakthroughs in the delivery of energy and other services

Source: John A. "Skip" Laitner as described and discussed in the text of the manuscript.

(1) Intensity Shift: Just as some energy resources are more carbon-intensive than others—for example natural gas combustion produces less CO_2 per million Btus of energy than does coal,[22] while clean renewable energy resources produce de minimis CO_2 emissions compared to any form of fossil fuels—different sectors of the economy have different income and employment intensities. As already reviewed in the Figure 5 discussion, one billion dollars' worth of expenditures in various economic sectors supports different levels of employment. Although not explored in detail here, these data demonstrate the idea that the more capital-intensive energy sources support fewer jobs than almost all other sectors within the US economy.[23]

(2) Supply Chain Build Up: The United States generates a large rate of value-added from the intermediate goods and services that it produces or purchases (IMPLAN 2021). To the extent that the nation is able to increase its local production capacity for key goods and services, this will increase both the resilience and vitality of the nation's economy. Fostering the local supply of energy efficiency, clean renewable energy, and infrastructure equipment and materials, further enhances local economic development.[24]

(3) Energy Cost Reduction: Investments in energy efficiency and clean renewable energy now cost far less than fossil fuel or nuclear energy (see, for example, Nadel and Ungar 2019; and Lazard 2020). For the majority of coal plants in the country, it would be cheaper to replace them with clean renewable energy than to keep paying the fuel and maintenance costs.[25] Additionally, reduced demand for energy as a consequence of increased energy efficiency can likewise put a downward pressure on the price of

---

[22] It should be noted that leakage in the extraction and transport of natural gas can offset this carbon-intensity advantage (Wigley 2011).

[23] In economics, an input–output model is a quantitative method that represents the interdependencies between different sectors of a national economy or different regional economies, see Miller and Blair (2009).

[24] We can illustrate how building up greater local supply capacity can increase the robustness of the US economy by adapting the idea of the Keynesian multiplier. In this case we substitute the use of domestic resources (DOM) in place of the marginal propensity to consume (MPC). Hence the formula, OUTPUT = [1 / (1 – DOM)]. For example, if 48% of a given sector's total output is the value-added component (including profit and labor income), and if the economy imports 13% of its needed resources, then 39% of its output recipe is the initial domestic or local use of resources. In that case, the formula of [1 / (1 – 0.39)] suggests a base economic multiplier of 1.64 for each dollar spent by local businesses and consumers. But if that sector reduced its economy-wide imports, and if it increased the domestic purchase coefficient from 39% to 45%, then the base multiplier increases to 1.82. For example, instead of a $100 consumer purchase that supports $164 of overall economic activity, a more internally resilient sector might support $182 of activity, without any other additional costs to the market. The number of job opportunities will increase at roughly the same rate.

[25] Iulia Gheorghiu. 2019. Majority of coal plants are uneconomic to nearby wind, solar, report finds. https://www.utilitydive.com/news/majority-of-coal-plants-are-uneconomic-to-nearby-wind-solar-report-finds/551187/ reporting on: Eric Gimon, Mike O'boyle, Christopher T.M. Clack, and Sarah Mckee. 2019. The Coal Cost Crossover: Economic Viability of Existing Coal Compared to New Local Wind and Solar Resources. https://energyinnovation.org/wp-content/uploads/2019/04/Coal-Cost-Crossover_Energy-Innovation_VCE_FINAL2.pdf.

traditional energy, spreading the cost benefits of clean energy nationwide. This is often referenced as the "Demand Reduction Induced Price Effects—DRIPE" (Taylor, Hedman and Goldberg 2015).

For example, if energy demand in 2050 is 70 percent of the projected level, then average energy prices might be 25 percent lower than would otherwise be the case (EIA 2021a). The nationally lower cost of energy will translate into cost reductions in the purchase of other goods and services—whether food and household appliances or business equipment and industrial feedstocks. The direct energy savings and savings from less-costly goods and services are redeployed to more labor-intensive activities within the economy, which creates even more new jobs.

(4) Productivity Boost: Investments in efficiency and clean renewable energy impact broader economic productivity as well. For instance, upgrades in industrial processes can reduce energy demand and more energy-efficient industrial processes also lower requirements for chemical feedstocks and water, even as overall operating and maintenance costs decrease (Worrell et al. 2003; Abt Associates 2005; and Wagner et al. 2020). Thus, the non-energy benefits of investment in energy efficiency and clean renewable energy can have an important catalytic effect on job growth and prosperity.

The Bureau of Labor Statistics (BLS) estimates that the United States generated a 2019 total economic output of $34.0 trillion as measured in 2012 constant dollars (as distinguished from the value-added components of the $19.4 trillion of GDP. Total wage and salary employment that year was recorded at 163 million jobs (BLS 2020a). This implies that each one million dollars of economic activity supported 4.78 jobs within the 2019 economy. Had the nation's economic productivity been just 0.5 percent higher over the period 2009 through 2019, total output would have been $1.7 trillion larger (in 2019). Despite normal growth in labor productivity (as opposed to productivity gains in energy or capital), that extra $1.7 trillion might have supported an additional 8.2 million more jobs in that year. This underscores the importance of the productive use of all resources—whether capital, labor, materials, water, and especially energy.

(5) Managing Price Volatility and (6) Minimizing Supply Disruption: These benefits include reducing the disruption in the availability of energy and other resources, while also minimizing the negative impacts of unexpected price volatility. A more productive economy that uses fewer and less-costly energy and other resources will enjoy a reduced exposure to unexpected market risks and price volatilities.

(7) Innovation Plus: The seventh major driver summarized in Table 1 is the greater employment and economic benefits that result from a productivity-anchored energy transition which stimulates the prospects for continuous learning and the encouragement of new innovations. This is explored more fully within Appendix A of this report, *Further Insights on Energy Productivity and the Economy*.

4.2.2 *The Three Effects of Job Creation*

Each of the economic drivers described in the preceding section has three separate, but interconnected, job coefficients which are described next. While the IMPLAN database has as many as 544 sectors, Table 2 reports the direct, indirect, induced effects for 6 aggregated sectors within the entire US economy for 2019, the base year of this analysis.[26]

[26] In effect, all of IMPLAN's 544 sectors have been aggregated using a weighted average of each sector's output. Construction, for example, has 13 different subsectors combined into the single sector characterized here, and manufacturing has about 329 different subsectors which are averaged into the single sector shown in Table 2.

Table 2. Jobs Per One Billion 2019 Dollars for Key Sectors of the US Economy

Key Sectors	Direct Jobs	Indirect Jobs	Induced Jobs	Total Jobs	Average Gains in Labor Productivity/Year
Construction	6,700	3,100	10,200	19,900	0.91%
Manufacturing	2,100	4,100	8,500	14,700	1.89%
Electric Utilities	800	1,900	8,100	10,800	2.62%
Finance	3,000	4,000	10,000	17,000	1.32%
Government	8,800	500	11,500	20,800	0.91%
All Sectors	5,300	3,200	9,700	18,200	1.47%

Source: IMPLAN US 2019 data and BLS 2020 estimates of labor productivity improvements (January 2021). Note: totals may not add because of rounding.

The three separate effects, supported by an economy in 2019 that generated a value-added, or GDP, of $21,433 billion, include the:

Direct Effect: These are the on-site jobs created by any given investment. In the case of building a clean renewable energy system, the direct effect would be the on-site jobs of the construction contractors and subcontractors. For each $1 billion dollars spent building a new utility-scale clean renewable energy system, a total of 6,700 people are on average employed. For Manufacturing it would be 2,100 jobs while for the electric utility industry as a whole, it would be about 800 direct jobs.

Indirect Effect: These are the off-site jobs created by the direct investment, which includes jobs such as the staff of vendors who supply and deliver equipment, bankers who finances a project, an accountant who keeps the books for the vendor, component and materials manufacturers, and wholesale suppliers who provide other goods and services. For the construction sector these indirect jobs add up to 3,100 jobs per billion dollars received.

Induced Effect: These are the jobs created when people who are directly and indirectly employed by the project spend their income within their communities. Hence, they are said to "induce" other economic activity. This refers to money received by the grocer, for instance, who hires people to work in his or her store. Or it may include revenue received by schools, hospitals, movie theatres and department stores. For the construction sector these induced jobs add up to 10,200 jobs for each billion dollars spent.

The sum of these three effects within construction yields a Total Effect of 19,900 jobs supported by an aggregate construction expenditure of $1 billion. A final category of impact is the anticipated rate of sector labor productivity as drawn from the BLS (2020a) data.[27] The analysis is still incomplete since it only accounts for the direct, indirect and induced job effects of the investment upgrade itself. The "changeover impacts" are considered next.

[27] As explained more fully in Appendix B, about the DEEPER modeling system, labor productivity means that while in the average sectors of the economy there are 5.3 direct jobs per million dollars in the 2019 IMPLAN base-year, by 2040, at an annual rate of productivity improvement of 1.47% per year, there may be only 3.9 jobs per million dollars. The critical element is whether information technologies, greater energy productivity and productive infrastructure investments can stimulate the economy at a greater rate than gains in labor productivity. The data currently suggests that employment can be greater than under more conventional patterns of investments.

4.2.3 *The Four Changeover Impacts of Job Creation*

There is a third category of four "changeover impacts" that determine how total employment can be affected by large-scale transition to energy efficiency and clean energy. The first is project implementation such as installing new commercial building upgrades or building a new photovoltaic energy system; the second are changes in energy spending patterns that result from the change or turnover in energy systems. The implementation component includes both the impact of construction and the purchase of new manufactured technologies as well as the influence of programs, policies, and other practices (whether done by the private or the public sectors) to enable a desired set of upgrades to actually happen. Implementation can have both a positive and negative aspect of the transition.

The second changeover impact is the energy expenditure component. This includes changes in the type of energy saved or used as they affect overall consumer costs. This incorporates both changed patterns of commodity purchases (e.g., clean renewable energy compared to natural gas combustion generation), as well as the influence of lower unit costs of the energy services. Both components, in turn, are affected by linkages to other sectors, the capacity to deliver local versus imported goods and services, and an array of non-energy benefits that might also follow. This can also have a positive and negative aspect.

This section begins with an analytical review of how an input-output analysis explores the impact on different economic sectors of a nation which invests an assumed $1 billion dollars in some form of a technology upgrade. For example, suppose that a series of utility-scale photovoltaic (PV) systems are installed at a cost of $1 billion. Drawing on data from Lazard (2020) and assuming that the PV installation has a 10-year payback over a 20-year lifetime, the *unsubsidized* utility-scale PV systems are now averaging $29 to $42/megawatt-hour (MWh), while conventional generation technologies may have a cost of $65/MWh, or more (Lazard 2020). In some US states, such as Colorado, utility-scale wind and solar projects are now being constructed for well below $20 per megawatt-hour, or $0.02 per kWh (Svaldi, 2018). Even with the more conservative comparison, it is possible to save about $100 million year in lower wholesale electricity costs, including a range of lower fixed and variable costs, which are then passed onto businesses and household consumers. Analysts at Morgan Stanley and Moody's Investors Service expect that more electric utilities will accelerate their transition away from coal, with billions in financial benefits for ratepayers and shareholders. In a research report released at the end of 2019 titled "The Second Wave of Clean Energy," analysts at Morgan Stanley noted that "the surprisingly low cost of renewables" will drive utilities to close most of the remaining U.S. coal plants over the next decade. Furthermore, Morgan Stanley believes that replacing coal with cheaper renewable energy could save electricity customers as much as $8 billion each year:

> *"We conducted an in-depth, asset-by-asset assessment of the coal fleet in the US and found that >70 GWs of coal capacity will become economically at risk through the course of the next decade (excluding 24 GWs already scheduled to retire), resulting in coal-fired electricity declining from 27% of total US power in 2018 to just 8% by 2030e. The nationwide benefit to customers from replacing coal-fired power with renewables could be as high as $3-8b/year, we estimate, while at the same time we see a total renewables investment opportunity for utilities of $93-184b.*" (Sweeney 2019; Smyth 2020).

The first set of job impacts occur when the utility pays a construction firm to purchase and install the new system as part of the utility's generation assets. The construction firm, in turn, may buy PV equipment from an array of manufacturing industries. Those working in both the direct and indirect categories then spend their incomes which induces even more employment benefits. Pulling information from Figure 5 in our example, then each $1 billion of investment in the PV system supports a total of 19,900 construction-related jobs during the construction phase. Again, this is the sum of interconnected direct, indirect and induced effects made possible by the system upgrade. Consumer spending on local goods and services for each chunk of $100 million (or $0.1 billion) savings (made possible by the variety of lower energy costs) might support a total of 1,820 jobs. At the same time, each $100 million (again $0.1 billion) in lower energy revenues might also reduce total electricity sector employment by 1,080 jobs.

Once the new system is installed, businesses and consumers will be able to spend about $100 million ($0.1 billion) in electricity price savings each year for other goods, equipment and services. While that $100 million ($0.1 billion) of savings benefits the local economy, the energy company may lose some part of its revenues which represents a loss to the overall economic activity. At this point, the analysis has identified four separate changeover impacts in normal purchase patterns. Two are positive and two are negative.

Investment Impact: This is the outlay for a potential system upgrade, including both equipment and labor costs as well as related services necessary to carry out the construction effort. In the case just described, it is the $1 billion cost of the PV system—regardless of how it might be financed.

Revenue Impact: This refers to the transfer of funds from one place to another which must be recorded as a loss in the overall set of transactions. In the system upgrade described here, while the construction firm receives $1 billion, the energy company might defer or delay other investments or expenditures to enable building of the new systems. For this example, imagine the deferral of $0.6 billion (or $600 million) that might have been spent elsewhere.

Substitution Impact: With the PV system now installed, the improvements are effectively "substituted" for some amount of conventional energy use. If that amount generates a net savings, the result is increased local spending equal to some portion of the energy savings. In this example, the wholesale energy costs, benefiting from a 10-year payback, is reduced by $0.1 billion per year as the new system begins to generate electricity. Those savings are spent by business and residential consumers on other goods and services with recirculation in the local economy.

Displacement Impact: Any money saved by the lower wholesale cost of electricity will be a loss of income for the fossil fuel energy provider but will also reduce health care costs, increase agricultural productivity, and avoid costly reclamation from coal, petroleum, and natural gas extraction as well as avoid the consequences of climate change. Consider also that the reduced cost of electricity from clean renewable sources may actually increase the employment in the local electric utility.

A complete multiplier analysis captures the direct, indirect and induced effects of each major changeover in local expenditure patterns. There are two major tasks in completing an employment analysis of this type. The first is to understand just how the expenditure patterns affect each sector of the economy. The second is to identify and calibrate an appropriate economic model to reflect the total impacts of those four spending changes, both positive and negative.

The job impact for the first year in which the PV system is built and operated are shown next (in billions of dollars with jobs shown in rounded terms):

(1) Investment Impact = + $1 Billion PV System * 19,900 Construction = + 19,900 Job Gains during construction period

(2) Revenue Impact = - $1 Billion PV System * 0.6 Interim Deferral * 10,800 Electricity = - 6,480 Job Losses

(3) Substitution Impact = + $0.1 Billion Lower Energy Costs * 18,200 Other Sectors = + 1,820 Job Gains

(4) Displacement Impact = - $0. 1 Billion Energy Revenue Loss * 10,800 Electricity = - 1,080 Job Losses

Net Impact = 14,160 net employment gain in year one; and as calculated below, with an ongoing 740 net employment benefits in subsequent years.

In this example, overall employment will be strengthened by a net gain of about 14,160 jobs compared to current fossil fuel electricity production. This includes the direct, indirect and induced effects of all four sets of expenditures. Similar calculations also can be done for net value-added, or net GDP contributions to the economy.

At the same time, if the PV system is up and running one year with a continued savings for the electricity that is generated over the 20-year life of the system, the benefit to the economy is calculated by equations 3 and 4 with ongoing net employment benefit of 740 jobs.

If a second PV system or equivalent were installed in year 2, then the economy would again benefit by a net gain of 14,160 jobs PLUS the 740 jobs from the year 1 investment, or for a net total of 14,900 jobs in year 2. And should new PV systems continue to be constructed at the same scale over a 20-year period, by the year 20 the net employment gain would be 28,220 total jobs. Essentially, a national *Energy Productivity Transformation* can open the door for billions of dollars of profitable investment creating hundreds of thousands, even millions of net new jobs and avoiding trillions of dollars of climate and air pollution damage.[28]

4.2.4. *Three Key Deployment Variables of Job Creation*

Notwithstanding the many factors and calculations explained to this point, there are still at least three more angles to the story. They include: (i) an accounting of policy and program costs to achieve an optimal or at least a more desirable scale and resource mix, (ii) how the investment will be paid for or financed, and (iii) the actual payback and/or expected returns on the anticipated investments.

Policy and Program Costs: As the old adage suggests, "It takes money to make money." In this case it takes policy and program efforts to achieve the required scale of investment and the optimal mix of resources necessary to ensure the desired outcome (Laitner et al. 2018; and Hoffman et al. 2018). Early in any large investment project policy and program costs might require about 20 percent of needed investment and falling to about 8 percent once experience is gained and institutions are streamlined (Lebot and Weiland 2020). Of course, once market transformation is complete there is no overhead because investments are part of normal business operations. In an assessment of a Clean Power Plan that would reduce CO_2 emissions by 32 percent below 2005 levels by the year 2030, Buonocore and Lambert et al. (2016) estimated administrative costs at 18 percent of total funding while the actual technology investments would entail 82 percent of the capital requirements. Long-time designer and implementer of community energy programs George Burmeister reported that in May 2020 a one-megawatt (MW) photovoltaics farm costing about $1 million to build and install had costs to the convening local

[28] In laying out this analytical framework, there is one important caveat as it relates to the pattern of spending within each of the four changeovers. On the one hand, for example, the revenue impact may affect only the electric utility in which case there may be a loss of 10,800 jobs per billion dollars of net change in spending. On the other hand, it may be a combination of both the utility and a construction firm in which case the spending may impact for 10,800 jobs and/or 19,900 jobs—or some combination of both. Or the substitution effect may impact only a manufacturing complex, or a limited set of households within a community. The example here is intended only to lay out the pattern of revenue changes rather than a precise estimate of a given set of spending changes.

government of about $200,000, or 20 percent of the required investment. Burmeister predicted that replication of the investment would have local government costs of 10 percent in years 2 and 3, and zero government costs for replicated investments over the next two decades.[29] Of course, these program costs are labor intensive with almost all expenditures for wages.

Financial Costs: A significant level of investment will have to be provided through some form of public or private funding or borrowing, which adds to the overall cost of any investment. For example, if investment funds are borrowed, over a 20-year period, at an interest rate of 4.36 percent within that time-span, this will effectively increase the cost by approximately 50 percent compared to funds with a zero interest rate or through some other form of out-of-pocket expenditures. And if the interest rate rises to as high as 7.75 percent over that same 20 years, it will effectively double the cost of investment. By way of comparison, current home interest rates are within the 3 to 8 percent range, depending on levels of down payment that might be made, credit scores and other variables.[30] As it turns out, investor-owned utilities are allowed to earn a return on equity (ROE), which is typically around 9 to 10 percent per year.[31] Given the scale of impact likely supported by the financial community, a financial cost variable, including interest or borrowing rates, should be included in any jobs assessment. Of course, profits from investment are passed onto stockholders who spend the money locally, which creates more jobs.

Energy Cost Savings: From an investment self-interest standpoint with no consideration of environmental or social externalities , whether a household consumer or an established business enterprise, the reduction in energy costs should outweigh the combination of both program and policy costs as well as the cost of financing the upgrades. For example, a 2012 study by the American Council for an Energy-Efficient Economy-ACEEE (Laitner et al. 2012) found that to cost-effectively reduce energy costs by 42 to 59 percent compared to business-as-usual projections for the year 2050, that annual investments would need simple energy savings paybacks on the order of 6-8 years. A $100 investment should lower overall energy and operating & maintenance costs on the order of $12.5 to $16.7 per year. In effect, some form of cost-effectiveness of any investment portfolio should become part of the employment analytics.

4.3 Laying Out a Representative Analytical Framework

Garrett-Peltier (2017) provided a thoughtful review that compared the employment impacts of energy efficiency, clean renewable energy, and fossil fuels using US Bureau of Economic Analysis input-output tables to create a model that compared conventional fossil fuel (FF) and energy efficiency and renewable energy (EERE) expenditures. She analyzed the job impact of shifting $1 billion out of fossil fuel subsidies into public EERE technologies. Her model found that there are only 2.65 direct and indirect jobs/$Million for conventional fossil fuel subsidies while EERE expenditures supported 7.72 direct and indirect jobs/$Million. Thus moving $1 billion from fossil fuel subsidies cause a loss of 2,650 total jobs but reinvestment in EERE adds 7,720 jobs for a net employment increase of 5,070 total jobs throughout the full economy.

While the Garrett-Peltier model provides a useful first approximation, it is an incomplete assessment. It does not include the induced effects of employment, nor does it include the job benefits of lower energy costs over a 20-year period. Moreover, it does not include the added jobs from program management and financing, the expected gains in labor productivity, and other benefits described in section 4.2 above.

[29] Memo and personal communication from George Burmeister, President of the Colorado Energy Group. May 21, 2020.

[30] When accessed on January 15, 2021, a typical range of home mortgage interest rates of ~3-8 percent can be found at: https://www.valuepenguin.com/mortgages/average-mortgage-rates

[31] https://newenglandcleanenergy.com/energymiser/2018/02/22/how-electric-utilities-make-money/

4.3.1. *A More Complete Assessment*

In providing a more complete assessment of the job benefits which might be driven by a given "Innovation Scenario", one can imagine a large number of variables that will impact any estimate of the absolute number of jobs created for a given year. In the illustration and tables that follow, the impacts are demonstrated using five critical variables using an employment assessment tool was developed for this exercise. The tool is a modified "lite" version of what is called Dynamic Energy Efficiency Policy Evaluation Routine (DEEPER) modeling system.[32] The core of that tool consists of five critical components. The first is a set of annual energy efficiency investments. The second is a policy and program stimulus that is equivalent to 20 percent of the technology investment in the year 2021, but which drops to 8 percent by the year 2040 as both experience and economies of scale are gained.

Net consumer benefits and net gains in jobs are calculated within a benefit-cost range of from 1.2 to 3.2. The above tables provide the reader with an overview of three different sets of economic impacts over the years 2021 through 2040: (i) Table 3A shows the range of benefit-cost ratios—if we assume a discount rate of 5 percent over the same 20-year time horizon; (ii) Table 3B highlights the average annual net consumer savings in millions of 2019 dollars for the 20-year timeframe; and (iii) Table 3C details the average of net jobs which might be gained annually.[33] The tables show how each set of the three impacts might be affected under an array of assumed interest rates (ranging from 3 to 7 percent) and assumed payback periods (ranging from 5 to 9 years).

As the assumed interest rates rise from 3 percent to 7 percent, the benefit-cost ratio presented in Table 3A declines significantly; the benefit-cost ratio also declines if there is a longer payback period. For example, a 3 percent interest rate with a 5-year payback shows a discounted benefit-cost ratio over the 20-year period of 3.14. If the payback is 9 years, the benefit-cost ratio changes to a significantly lower value of 1.75. Similarly, if we assume a 7 percent interest rate and a 9-year payback then the benefit-cost ratio drops to below 1.31.

The job coefficients for construction and manufacturing are significantly larger than the job coefficients for conventional electricity services. And while the larger financial payments associated with borrowing weaken other consumer spending somewhat, the job coefficients associated with the financial sector are still larger than for electricity services. The end result of a larger stimulus, even if mildly reduced by the cost of financial services, both of these catalysts tend to increase employment opportunities so that a 9-year payback, together with 7 percent borrowing propel a net gain of 2.95 million jobs (rounded) as shown in Table 3C.

---

[32] The DEEPER modeling system is consistent with the idea of "aggregate efficiency" referenced in footnote 18, and as discussed more completely within Appendix B of this manuscript. In short, here "Energy Efficiency" means all three forms of aggregate efficiency highlighted in the discussion as part of Figure 2: (i) end-use energy efficiency, (ii) the transition to clean renewable energy, and (iii) the productive upgrade to the nation's infrastructure in a more circular economy. Following the spirit of inquiry framed by Huntington et al. (1982), here we are modeling for insight, not precision. Indeed, depending on the uniqueness of any given innovation scenario, there may be many other variables which also affect the job benefits which may be reported here—both negatively and positively.

[33] See Appendix C of this report, *Framework for an Electricity Innovation Scenario*, for a more detailed review of the economic framework which underpins the findings in Tables 3A, 3B, and 3C as well as the main scenario used to explain the scale of the job creation in more detail. As a further note, while the AEO 2021 (EIA 2021a) reports energy expenditures in constant 2020 dollars, the base-year of the model is tied to 2019 job coefficients. Hence, a small one-year downward adjustment is created to maintain the 2019 dollars in the DEEPER Lite tool.

The net employment benefits remain roughly the same magnitude regardless of payback periods and interest rates. As shown again in Table 3C, the less costly scenario generates a low of 2.58 million jobs compared to the more costly (but still cost-effective) scenario which supports the 2.95 million jobs previously cited.

Table 3. Annual Average Net Benefits from a 40% Electricity Savings by 2040

Table 3A. Benefit-Cost Ratio (BCR)

The Key Assumptions (Payback/Interest Rates)		20-Year Loan Interest Rate		
		3%	5%	7%
Simple Payback (in Years)	5	3.14	2.71	2.35
	7	2.25	1.93	1.68
	9	1.75	1.50	1.31

Table 3B. Net Annual Energy Savings (Billion 2019 $)

The Key Assumptions (Payback/Interest Rates)		20-Year Loan Interest Rate		
		3%	5%	7%
Simple Payback (in Years)	5	$78.4	$72.5	$66.1
	7	$64.1	$55.9	$46.9
	9	$49.9	$39.3	$27.7

Table 3C. Net Average Annual Job Increases (Millions)

The Key Assumptions (Payback/Interest Rates)		20-Year Loan Interest Rate		
		3%	5%	7%
Simple Payback (in Years)	5	2.583	2.577	2.569
	7	2.780	2.770	2.760
	9	2.976	2.964	2.951

Source: Results from the DEEPER Lite Employment Assessment Tool as described in the narrative.

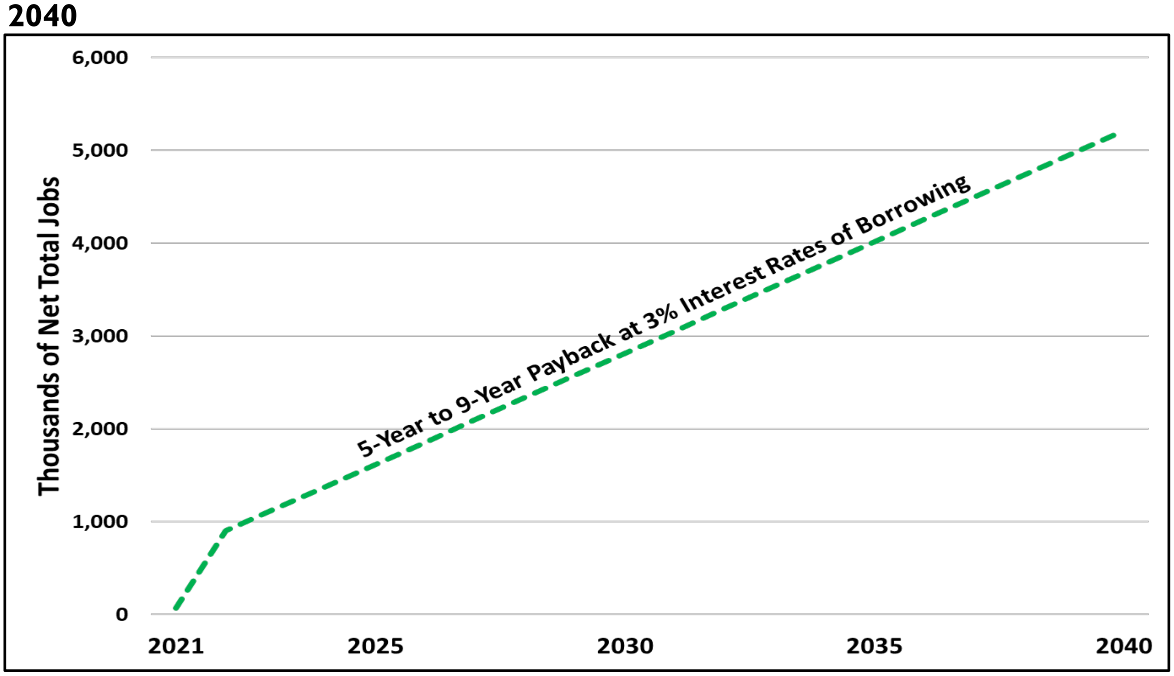
4.3.2. *Evaluating the Economy-Wide Net Job Benefits*

The economy-wide job benefits are estimated next for a single innovation scenario to illustrate the scale and other details of net job benefits over time. The basic assumptions of this specific exercise are four-fold. First, assuming quick action by utilities, and the various state, local and federal agencies, an expanded set of policies and programs are presumed to encourage a 40 percent savings by 2040. The first such expenditures are introduced in 2021 and then grow over time. Second, the initial set of efficiency investments are made in 2022 and in each subsequent year through 2040. Efficiency savings begin at 2.2 percent in 2020, and they rise annually at that rate to reach a 40 percent reduction in retail electricity expenditures by 2040.

The consumer savings include lower energy costs in any given year as they accumulate over time. They include an array of non-energy or ancillary benefits equal to 40 percent of the aggregate energy savings. A third supposition is that a one-year savings of $1 billion requires a $5 billion investment in 2022 (reflecting the lesser 5-year payback early in the timeline), but which then slowly rises to $9 billion by 2040 (again reflecting a 9-year payback in that year). Including policy and program costs, as well as loan payments as they all driven the energy and non-energy benefits of this main scenario.

The last hypothesis is that the benefit-cost ratio of these expenditures and savings is 2.59, well within the range shown in Table 3A. The four hypotheses for this scenario are documented in Appendix C, previously mentioned in footnote 33. The appendix highlights all of the premises which underpin Tables 3A, 3B, and 3C as well as the main innovation scenario. Given these economic conventions, Figure 6 lays out the annual trend of net jobs which might be driven by a much greater emphasis on overall energy efficiency within all key end-use sectors of the economy.

Figure 6. Prospective Trend in US Net Job Creation from a 40% Electricity Savings by 2040



Source: Results from the DEEPER Lite Employment Assessment Tool as described in the narrative.

4.3.3. *The Scale and Categories of Employment Benefits and Opportunities*

The DEEPER Lite Employment Assessment Tool indicates a small but immediate response as the early 60,000 jobs are driven by policies and programs of both the public and private about midway through 2021. And as the first upgrade investments are made in 2022, slowly building each year through 2040, the net employment benefits continue to grow. As shown in Table 4 which highlights key metrics for selected years, in 2022 the net job gains rise to 898,000; by 2030 they reach 2.7 million; and by 2040 which is the last year of this analysis, new employment opportunities (and hopefully new careers) have grown to just over 5.2 million net jobs in that last year.

Table 4. Key Results of 40% Electricity Savings for Selected Years of the US Economy

Expenditures (Billion 2019 $)	2022	2025	2030	2035	2040	Average /Year
Policy and Program Costs	$3.1	$8.9	$8.2	$7.5	$7.9	$7.0
Investment	$47.6	$52.3	$61.0	$71.2	$98.2	$61.4
Loan Payment	$3.2	$13.4	$32.7	$55.2	$82.5	$37.0
Energy & Non-Energy Benefits	$0.0	$40.0	$106.7	$173.4	$240.0	$117.6
Net Consumer Savings	($6.3)	$17.7	$65.8	$110.7	$149.7	$70.0
Benefit Cost Ratio						2.59
Employment Benefits (thousands)						
Net Jobs	898	1,595	2,722	3,836	5,214	2,803

Source: Results from the DEEPER Lite Employment Assessment Tool as described in the narrative.

All of the jobs are supported by public and private sector policy and program expenditures which average $7 billion dollars per year, but especially driven by annual investments averaging $61.4 billion per year. As those investments are translated into annual reimbursements with a 3 percent borrowing interest rate, the loan payments average $37 billion annually. All of these outlays continue to drive an average of energy savings or benefits that slowly rise over time from zero in 2022 to $240 billion per year by 2040. The net consumer savings are the benefits which remain after the policy and program expenditures and the loan repayments are made in any given year. All of these outflows and savings combine in various ways to drive the net job gains within any given year.

Table 5. Job Catalysts – Stimulus, Transition, and Enhanced Economy (2021-2040)

Catalysts of Job Creation	Key Sectors of the Economy	Net Job Creation (Actual)	Average 20-Year Share
Stimulus: Policy/Program Jobs	Government, Education, Technical Services, Consulting	58,337	2.1%
Stimulus: Investment/Finance Jobs	Construction, Manufacturing, Technical Services, Finance	505,225	18.0%
Transition: Redirected Energy Spending Jobs	All Sectors Supporting Households, Businesses, Government	581,947	20.8%
Transition: Energy Jobs	Mining, Production, Processing, and Utilities	-125,851	-4.5%
Enhanced Economy: Induced Jobs	All Sectors Supporting Households, Businesses, Government	1,783,416	63.6%
Totals		**2,803,073**	**100.0%**

Source: Results from the DEEPER Lite Employment Assessment Tool as described in the narrative.

Table 5 presents the total net job creation process from three different perspectives. The first is as a stimulus to economy. The second as a transition away from a purely conventional electricity supply to consumer bill savings made possible by a greater level of energy efficiency upgrades. And a third is an enhanced economy enabled by greater consumer spending for other goods and services catalyzed by the direct and indirect jobs created by the stimulus and the transition together.

Table 5 shows the relatively large impact of the Enhanced Economy, which supports an estimated 63.6 percent, or almost 1.8 million of the total net annual jobs over the period 2021 through 2040. These employment opportunities refer to the induced jobs sustained by the combined direct and indirect employment incomes supported by the Stimulus and the Transition jobs. Although the Enhanced Economy jobs are large in scale, *none of those jobs would be possible without the Stimulus jobs made possible by the programs and policies, and especially the investment upgrades in the nation's electricity infrastructure*.

The key sectors for the stimulus jobs are the Government, Education, Technical Services, and Consulting, which support policies and programs and the Construction, Manufacturing, Technical Services, and Finance sectors which enable the investment upgrades to actually occur. These direct and indirect jobs provide a solid foundation for the Transition jobs which slowly begin to displace employment within the conventional fossil fuel electricity service sectors. As net consumer savings grow, from lower costs of clean renewable energy and the use of more efficient appliances, those savings are spent on typical goods and services such as food, healthcare, education, and entertainment supporting Households, Businesses, and Government. The job losses occur within the Mining, Production, Processing, and Utility industries. One important note, however, is that as the current pattern of energy-related industries adapt to the new investment and spending patterns, their own business models will likely begin to merge with energy efficiency and clean renewable energy industries and services so that their jobs are not necessarily lost, but only transitioned into new occupations within the existing companies or sectors.

4.3.4. *Impact of Various Occupations*

The primary focus of this assessment is to explore how an investment stimulus, together with the resulting improvement in aggregate efficiency and greater resource productivity, can increase the social and economic well-being within the many sectors of the economy. Yet, each sector may require hundreds of different occupations or categories of jobs to support the larger activities of the economy. As but one example, what we call the "utility sector"—requiring an estimated 549,000 jobs in 2019 to maintain electricity, natural gas and water services within the United States—is actually composed of more than 200 different occupations. And the 7.5 million jobs found within the various construction sectors also require an estimated 200 or more separate occupations to provide its many different categories of services. The occupational categories range from operation managers, human resource specialists, and clerical support to software developers, architecture and engineering professionals and a long list of production workers. Indeed, the Occupational Employment Statistics (OES) program of the Bureau of Labor Statistics produces employment and wage estimates annually for nearly 800 occupations.[34]

While the tendency is to focus on the many jobs within specific sectors, the outcome is actually the combination of productive labor (given its many occupational enterprises), capital (including an array of appliances, equipment, machines together with the new infrastructure), and the more productive use of clean energy resources that animate both labor and capital. One recent study by the Brookings Institution (2019), identified 320 unique occupations needed to fully promote a productive combination of clean

[34] For more details on the many occupational and industry aggregations, see generally, https://www.bls.gov/oes/. See also BLS (2020b) on the fastest growing occupations.

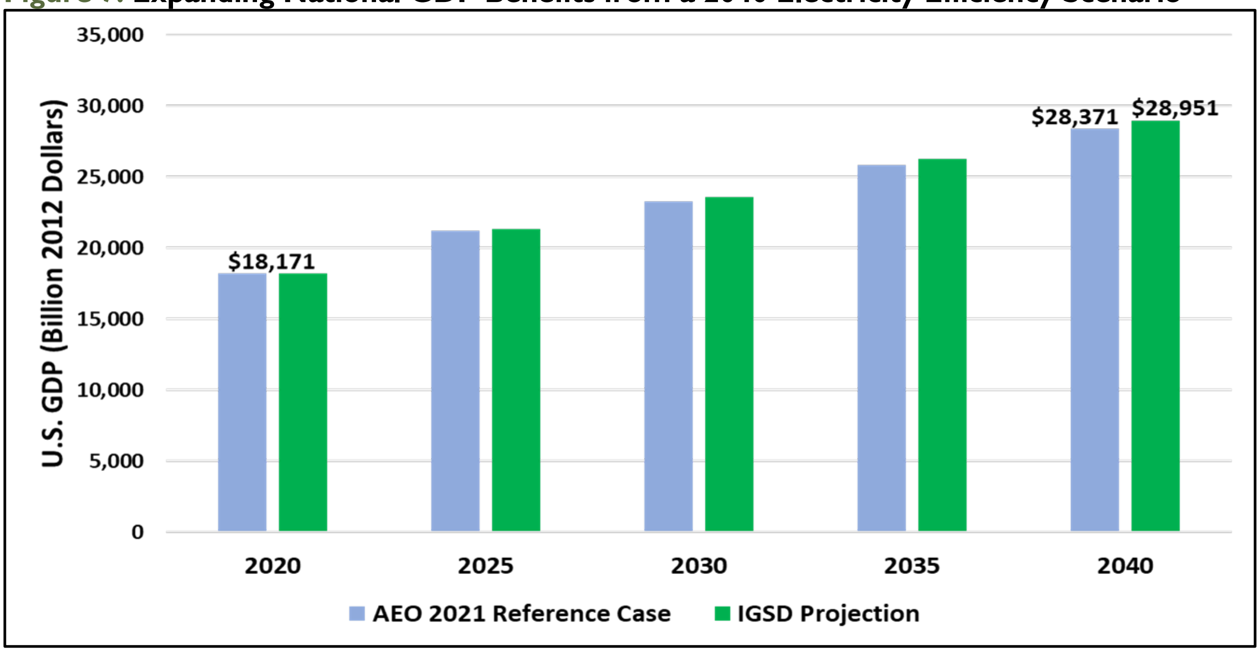
energy production, energy efficiency, and environmental management. The study notes that most of these jobs will require "both vocational and professional training in design, engineering, and mechanical knowledge."

The Brookings study found that hourly wages in these "new green jobs" exceed the national average by 8 to 19 percent with low-income workers earning $5 to $10 more per hour than in comparable jobs in the old economy. The Brookings study also found that because much of the existing infrastructure workforce is nearing retirement age there will be even higher labor demand in the new green jobs. State, municipal, and county governments are just now beginning to establish what has been called "infrastructure academies" that can both retrain the existing workforce and also prepare a younger generation for the new infrastructure jobs.

4.3.5. *Translating Employment into GDP Impacts*

The DEEPER Lite Employment Assessment Tool can provide some useful metrics on the scale of the potential GDP benefits in a more robust and resilient economy. Figure 7 illustrates the results of this step in the analysis.

Figure 7. Expanding National GDP Benefits from a 2040 Electricity Efficiency Scenario



Source: Author calculations based on the narrative described within the text (February 2021).

The Annual Energy Outlook 2021 (EIA 2021a) underpins a significant portion of the energy and economic projections used in this part of the assessment. The COVID-19 pandemic eroding the nation's economic vitality with GDP dropping 3.5 percent in 2020 down to $18,171 billion (EIA 2021b), but is predicted to increase to $28,371 billion by the year 2040 (EIA 2021a, in constant 2012 dollars).[35] As already indicated, that scale of change implies a growth rate of 2.3 percent per year. Analytics from Woods and Poole Economics (2020) estimate that GDP activity supported by each job within the US economy will grow from $96,484 in 2021 to $111,292 in GDP outcomes by 2040 (still in 2012 constant dollars). That is a net increase of 5.2 million jobs by 2040, those gains to the employment figures could boost GDP by about $580 billion dollars compared to a "reference case" forecast for that year. That would bump up the

[35] See "Table 20. Macroeconomic Indicators" in the AEO 2021 (EIA 2021a).

nation's GDP in 2040 to $28,951 billion. That extra bump in GDP would mean that the annual growth rate would increase from 2.3 percent, to a somewhat higher 2.4 percent increase per year.[36]

4.3.6. *Exploring the Scale of Both Energy Savings and the Employment Opportunity*

This analysis was limited to exploring a possible 40 percent *electricity* bill savings by 2040 yielding an average net gain of 2.8 million jobs over the 20-year time horizon, with as many as 5.2 million net new jobs by the year 2040 itself. And the nation's economy might be boosted by as much as $580 billion dollars, also by 2040 (Figure 7)—even as households and businesses might enjoy a net average savings of $70 billion per year (Table 4).

If we assume a 40 percent savings of *total energy*, the average employment benefit might increase from 2.8 million to about 8.7 million annual net jobs. And if we assume a complete 100 percent transformation of the overall energy system away from conventional fossil fuels and nuclear energy power plants, then net jobs might exceed 20 million per year. If that scale of energy productivity benefits were to accrue, that might come close to achieving near zero greenhouse gas emissions within the next two or three decades.

At the same time, however, the scale of borrowing, together with a different mix of overall costs and benefits, would likely change the scenario in significant ways. The larger scope of a remaking of the economy might somewhat lower these last estimates of employment benefits. Nonetheless, the thought experiment underscores the potential for an even greater net benefit should the nation find the wherewithal and the stimulus to achieve a very larger scale of a performance upgrade in the U.S. economy. Griffith and Calisch (2020), for example, suggest that a complete *Rewiring of America,* drawing CO_2 emissions down to near zero, could provide as many as "25 million peak new jobs, tapering off to about 5 million sustained new jobs, in addition to the current jobs supported by the energy industry" (page 2). They also note that despite the scale of this *Maximum Feasible Transition* (as they refer to it), the average household might still save $1,000 to $2,000 per year.[37] So, as pioneering physicist John Wheeler once commented, "We shape the world by the questions we ask." And in that same spirit, we should clearly be asking bigger and better questions about the economy as well as the climate and health benefits.

5.0 Climate and Air Pollution Benefits

In addition to significant job creation of clean renewable energy and energy efficiency, there are other social, economic, health, and environmental benefits that will improve the nation's economy. As one example, a Stanford University study assessed the economic benefits as cities transition to a 100 percent clean renewable energy strategy. The analysts found that the cleaner air resulting from the full mix of clean energy technologies might avoid health costs generally the equivalent of 1.83 percent of America's GDP by the year 2050 (Jacobson et al. 2019).

---

[36] It is worth noting that the scale of macroeconomic benefits reported here are broadly consistent with other recognized assessments completed by the Economic Policy Institute (Bivens 2017) and the Business Roundtable (BRT 2019). Bivens (2017) notes, for example, that "each $100 spent on infrastructure boosts private-sector output by $13 (median) and $17 (average) in the long run." Meanwhile, the BRT comments that "every additional $1 invested creates $3.70 in economic growth over 20 years." It is also worth noting that the Energy Efficiency upgrade strategy similarly drives more employment and economic well-being, but in ways that also increase aggregate efficiency, and dramatically reduces both greenhouse gas emissions and air pollution. The overall benefit-cost ratio this scenario described in Table 4 is a rather conservative 2.59. In other words, each dollar of cost generates a benefit of $2.59 over the 20-year period of analysis (assuming a 5 percent discount rate).

[37] Although the report by Griffith and Calisch (2020) use a less complete job assessment methodology than characterized here, their analysis nicely lays out the likely scale of the opportunity for the US economy. The authors detail this and other analyses in an upcoming book, *Electrify Everything* (to be published with MIT Press in 2021). A summary handbook is now available in the interim at https://www.rewiringamerica.org/. In full disclosure, the lead author of this narrative (Laitner) also contributed to the employment methodology summarized in the Griffith-Calisch report.

The Stanford methodology applied to the anticipated 40 percent reduction in fossil fuel use and emissions avoids at least $500 billion in air quality health effects and global climate-change in the year 2040 alone (in constant 2012 dollars). The sections that follow focus on the avoided costs of air pollution (clean air benefits) and the avoided costs of climate change.

5.1 Evaluating the Clean Air Benefits

The annual labor income losses from lost productivity and premature retirement and mortality due to air pollution exposure totaled nearly US$179 billion globally in 2015. This was an increase of about US$47 billion, or 36 percent in real terms, since 1995 (in constant 2014 dollars). For North America, the annual labor income losses were estimated to be US$21 billion in 2015, a US$5 billion or 30 percent increase since 1995 (Lange et al. 2018). The International Renewable Energy Agency (IRENA) estimates global fossil fuel externality costs at $5.7 trillion to $7.7 trillion per year (IRENA 2019). The IEA estimates that fossil fuel dependence in the United States—including costs for health impacts of fossil fuel combustion, macroeconomic costs, and military costs for securing fossil fuel supplies—range from $450 to $900 billion per year (IEA 2011).

The range of cost estimates vary widely.[38] When converted from other units to dollars per Million Btu ($/MBtu), and then weighted to the same mix of fossil fuel consumption and the same year currency (expressed in 2020 dollars), the air pollution externality calculated by the US Environmental Protection Agency (EPA 2019) is around $3.80/MBtu with a range of $1 to $8 per MBtu. The IMF cost appears to be $10.60/MBtu with a range of $2.90 to as high as $20.50 per MBtu (again in 2020 dollars). The central estimate for the Stanford University study is $6.50/MBtu. Some reasonably central appraisals, derived from a series of European assessments, are reported in the Cairo Egypt Regional Center for Renewable Energy and Energy Efficiency (RCREEE 2013). Adjusted again to 2020 dollars, they estimate externality costs of $2.02, $6.42, and $7.01 per MBtu for natural gas, coal, and oil respectively. Given the current pattern of fossil fuel consumption in the United States, the fuel-weighted average is $4.75 per MBtu. This compares to a current primary energy price for the US of $10.61/MBtu.

For purposes of this assessment, rather than costs per MBtu or kWh, the SCC is applied – including both air pollution and climate impacts – as highlighted by Ricke et al. (2018). As noted earlier, their median value of $417 per metric ton of CO_2 in 2005 dollars missions. As adjusted for the inflation rate between 2005 and 2020, that increases the social cost of carbon to $563 per tonne of CO_2, or about $5.00 per gallon of gasoline equivalent in 2020 dollars.

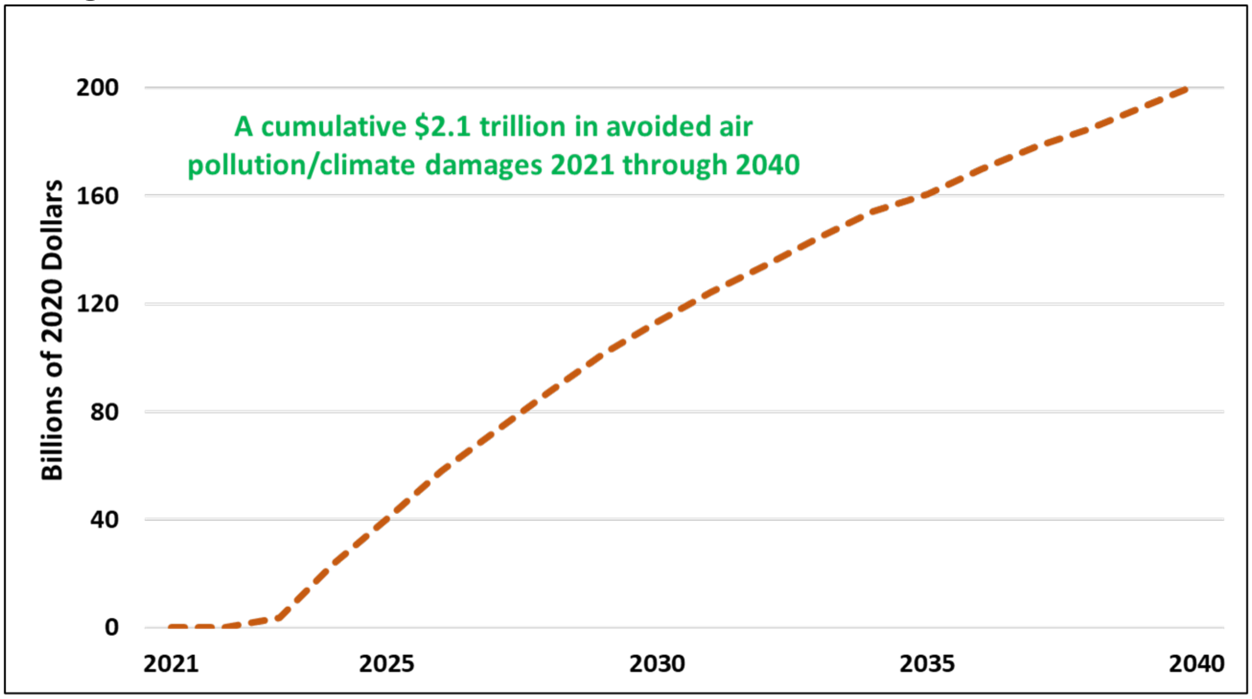
If that externality cost is applied to a growing electricity efficiency improvement that reaches 40 percent savings within the United States by 2040, but also adjusting for decreasing energy intensities and improved electric generation efficiencies over time, Figure 8 highlights the avoided air pollution, health costs annually, and climate damages over the period 2021 through 2040.[39] By 2025 the benefits have grown to more than $40 billion in that year, rising steadily to $200 billion by 2040. The cumulative value of avoided air pollution over that 20-year period, as summarized in Figure 8, is about $2.1 trillion.[40]

[38] Comparisons of the various estimates of externality costs is complicated by different metrics, base years, time intervals, currencies and assumptions. For example, an IMF study (Parry et al. 2014) evaluated the externalities for coal and natural gas expressed in $/gigajoule, but they used $/liter for both gasoline and diesel fuel all reported in 2010 US dollars. In contrast, US Environmental Protection Agency (EPA 2019) estimated per kilowatt-hour externalities reported in 2017 US dollars. The Stanford University report (2019) of a 100 percent clean renewable energy scenario estimates the avoided health and climate externality costs of fossil fuel phaseout by 2050 using $/kWh as reported in 2013 US dollars.

[39] The key assumption in this scenario is that policy and program actions are undertaken in the year 2021 and 2022, but first savings and impacts do not begin until 2022 and reach the desired goal of 40 percent electricity savings by 2040.

[40] Because of the large variability in unit externality costs, coupled with many uncertainties on energy intensities and pollution control technologies, and other variables over time, there likely is a wide variation in potential outcomes. With time and resources, we could run a series of Monte Carlo simulations to integrate more variables and a wider range of those variables to see what that central tendency would be. Yet, this is an indicative result which is highly consistent with many other study outcomes.

Figure 8. Potential Scale of Air Pollution/Climate Benefits from a 40% Electricity Savings



Source: Author calculations as described in the narrative (February 2021).

5.2 Understanding Climate Opportunities

December 2020 marked the 424th consecutive month in which nominal temperatures were above the 20th century average. The average temperature in 2019, across both global land and ocean surfaces, was 1.71°F (0.95°C) above the twentieth-century average of 57.0°F (13.9°C), which makes 2019 the second-warmest year on record. The global annual temperature increased at an average rate of 0.07°C (0.13°F) per decade since 1880, but over twice that rate (+0.18°C / +0.32°F) since 1981.[41] Table 6 provides us with a close look at the potential economic impacts of climate change if left unmitigated.

Table 6. Period Comparisons of United States Climate Disasters Statistics

Time Period	Deaths/Year	Cost/Year (Billion 2020 $)
1980s (1980-1989)	287	18
1990s (1990-1999)	305	27
2000s (2000-2009)	309	52
2010s (2010-2019)	522	81
Last Year (2020)	262	95
By the Year 2040?	~750+	~500+

Source: Data from NOAA (March 2021)[42] with a projection out to the year 2040 as described in the text

[41] More information is available from NOAA's Climate.gov website. At https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature.

[42] https://www.ncdc.noaa.gov/billions/summary-stats. Statistics valid as of March 3, 2020.

Fossil fuel combustion releases greenhouses gases that heat the atmosphere while also emitting particulate matter that compromises human health,[43] making people more susceptible to the coronavirus.[44] This last subsection of the narrative is focused more closely on the climate burden that is growing in real time, and get a sense of how large that impact might be if continued unmitigated. The investigation begins with some useful insights shown in Table 6 (above) from NOAA.

The climate impacts from wildfires, droughts, flooding and severe storms are growing (Table 6). The climate-related disasters cost of $18 billion per year in the 1980s (with 287 deaths per year), jumping to $81 billion per year by the 2010s (522 deaths per year), and in the last year rising to $95 billion per year (262 deaths). Using a simple statistical trending technique, by the year 2040 the cost could grow to $500 billion per year or more, with an estimated 750 deaths or more in that year. Over the period 2020 through 2040, the cumulative impact of each of those years could be $4 trillion in costs (2020 $), with 8,000 or more unnecessary deaths.

The question then becomes, how to compare a $342 billion impact in 2040 with magnitudes reported from other studies? First recall the $700 billion (also referenced in 2020 dollars) estimate from the Stanford University study mentioned in the introduction to this subsection. In 2017, Nobel Prize economist William Nordhaus published a seminal paper in the *Proceedings of the National Academy of Sciences of the United States of America* (PNAS), entitled "Revisiting the Social Cost of Carbon" (Nordhaus 2017), which estimated that warming 1°C above the twentieth-century average (where the economy is roughly now) to 2°C above (where the economy could be by 2040) may weaken the economy by $727 billion (also in 2020 dollars). This comparable to the adjusted costs estimated by the Stanford University assessment. Extrapolation of these costs imply a cumulative climate cost of about $5.5 trillion over the period 2020 through 2040 (expressed in 2020 dollars). Rather than hunker down until the seeming threats pass away, or "tweaking current practices to provide the appearance of attending to disruptive forces", as one observer commented (Colburn 2021), there are several unsettling dynamics which are likely to converge in a very large, and potentially negative impact on the US economy if action is not taken immediately within the framework of an Energy Innovation Strategy.

5.3 A Graphic Summary of the Estimated Benefits

As elaborated in Section 4.3 of this report, and summarized in the figure below, an investment stimulus in the upgrade of the nation's electricity end-use technologies can deliver a large benefit to the nation's economy – both in terms of a larger return on GDP and also a greater number of jobs. Mobilizing a cumulative investment of $1.2 trillion over the years 2021 through 2040 to reduce electricity end-use cost by 40 percent[45] in the year 2040 would lead to an average annual employment increase of 2.8 million net

---

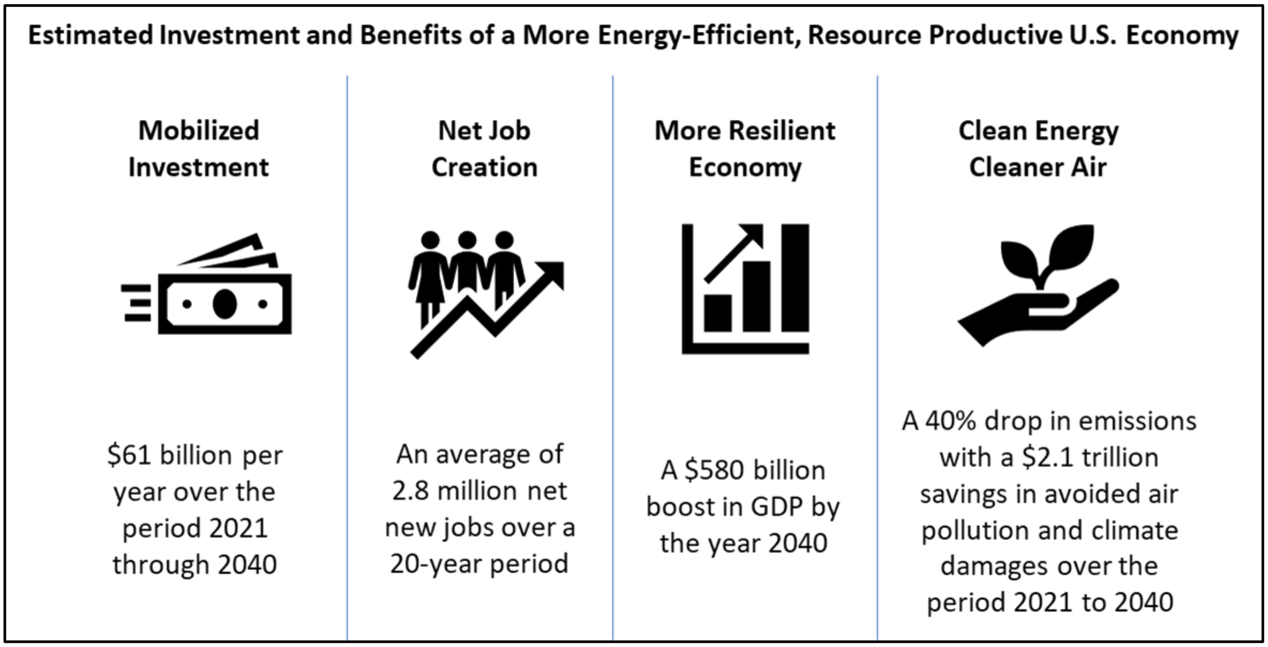
[43] Vohra K., Vodonos A., Schwartz J., Marais E.A., Sulprizio M.P., & Mickley L.J. (2021) *Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem*, Environmental Research 110754. Accessed at https://www.sciencedirect.com/science/article/pii/S0013935121000487. ("We estimate a global total of 10.2 (95% CI: -47.1 to 17.0) million premature deaths annually attributable to the fossil-fuel component of $PM_{2.5}$. The greatest mortality impact is estimated over regions with substantial fossil fuel related $PM_{2.5}$, notably China (3.9 million), India (2.5 million) and parts of eastern US, Europe and Southeast Asia.").

[44] Pozzer A., Dominici F., Haines A., Witt C., Münzel T., & Lelieveld J. (2020) *Regional and global contributions of air pollution to risk of death from COVID-19*, Cardiovascular Research. Accessed at http://academic.oup.com/cardiovascres/advance-article/doi/10.1093/cvr/cvaa288/5940460. ("The degree to which air pollution influences COVID-19 mortality was derived from epidemiological data in the USA and China. We estimate that particulate air pollution contributed ~15% (95% confidence interval 7–33%) to COVID-19 mortality worldwide, 27% (13 – 46%) in East Asia, 19% (8–41%) in Europe, and 17% (6–39%) in North America. Globally, ~50–60% of the attributable, anthropogenic fraction is related to fossil fuel use, up to 70–80% in Europe, West Asia, and North America.").

[45] A reduction in electricity costs can be achieved through energy efficiency, or by switching to a more productive means of electricity generation and distribution; for example, switching from fossil-fuel based to clean renewable forms of electricity generation and reducing losses that occur in the generation and transmission process. Thus a 40% reduction in electricity costs does not necessarily mean that consumers or businesses consume 40% less electricity at their homes or businesses. Rather, that 40% reduction in electricity costs could be achieved through a combination of factors, including more efficient and less wasteful production, generation, transmission, distribution and consumption of energy.

new jobs even as the nation's GDP might increase more than $580 billion (in constant 2012 dollars) by the year 2040.

Figure 9. Estimated Cost and Benefits of a 40% Reduction in Electricity Costs



Source: As summarized here, and Sections 4.0 and 5.0 of the main narrative for the years 2021 through 2040.

In annual terms, over the period 2021 through 2040, the cumulative $1.2 trillion investment begins with an initial $48 billion in 2021 with increments that reach $98 billion by 2020. The average over that period is $61 billion annually (with all values expressed in 2019 dollars, the base year of the model). Although the full inquiry reviews a range of 9 different sensitivity scenarios (Tables 3A, 3B, and 3C), for the purposes of this assessment the focus is on the main scenario in which employment quickly increases by 68,000 jobs in 2021. By the year 2040 this grows to a total of 5.2 million new jobs (Table 4). In effect, the resulting work that must be undertaken, together with other benefits which also boost employment, is estimated to drive an average net gain of 2.8 million new jobs over the 20-year period.

Given the increased productivity of each job, total GDP in the year 2040 is projected to grow by $580 billion (expressed here in constant 2012 dollars). At the same time, both greenhouse gas emissions and the array of fossil fuel air pollutants from electricity generation are expected to drop somewhere close to 40 percent by 2040. That could result in an average annual benefit of a further $112 billion in avoided air pollution and health costs (also expressed in 2020 dollars). That adds up to a cumulative benefit on the order of $2.1 trillion also through 2040 (with these last costs reported in constant 2020 dollars).[46]

6.0 Policy Implications

The evidence is compelling. The US economy needs a reboot for the 21st century—one that simultaneously addresses its social, economic, and environmental health, as well as its long-term resilience. Depending on the scale, and the cost-effectiveness of the stimulus, the net job creation potential might grow from 2.8 million net new jobs per year, to 8.7 million, or as many as 20 million or more jobs annually (highlighted in the section 4.3.6 discussion). How we understand and view the underlying economics of generating a more energy and resource productive economy that robust, resilient, and sustainable is key

[46] While the investment magnitudes were first provided in 2020 dollars, the economic projections in the reference case of the *Annual Energy Outlook 2021*, op cit., were provided in constant 2012 dollars. Hence, the reference to different base-year dollars provided in this supplemental analysis.

to driving this change. In short, as business leaders and policy makers shift their focus away from a cost or spending problem, and if they begin to think instead of the reboot as an investment with very big and very important returns, there is a possibility of actually making this happen. There is neither a law of physics, nor a purely economic constraint, which limits any possible outcome. Rather there is an economic imperative and very real opportunity do so, if we choose to make it happen.

One significant finding is that the induced jobs from investments in clean renewable energy and energy efficiency, what are referred to as enhanced economy jobs in Table 5, are far larger than the more conspicuous direct and indirect jobs. More critically, these induced jobs, as well as the many other benefits of the productive investments, are more equitably distributed geographically among the population and with higher employment over a wider range of skill levels and wages. Thus, the high rates of return on clean renewable energy and energy efficiency can accrue to the citizen taxpayers making the investment possible, and the avoided environmental and social costs of fossil fuel exploitation can similarly benefit all citizens, but particularly to lower income communities that would otherwise be located near fossil fuel extraction, combustion, and waste.

A growing number of studies (e.g., Smith 2012; Muro et al. 2019; E4TheFuture 2019; and EESI 2019; and UAW 2020) identify a large number of programs and strategies which can enable a more skilled and more productive set of occupations. For example, there is interest in establishing green academic apprenticeships in the 50 states—a Green Corps, a Conservation Corps, a Climate Corps, an Infrastructure Corps—that will provide "a living wage" and technical and professional certification and/or clinical learning credits toward academic degrees upon completion of service, allowing a younger generation of Americans to advance careers in the emerging green economy. These academic apprenticeships should be universally available, but they should also prioritize student engagement in the most disadvantaged communities.

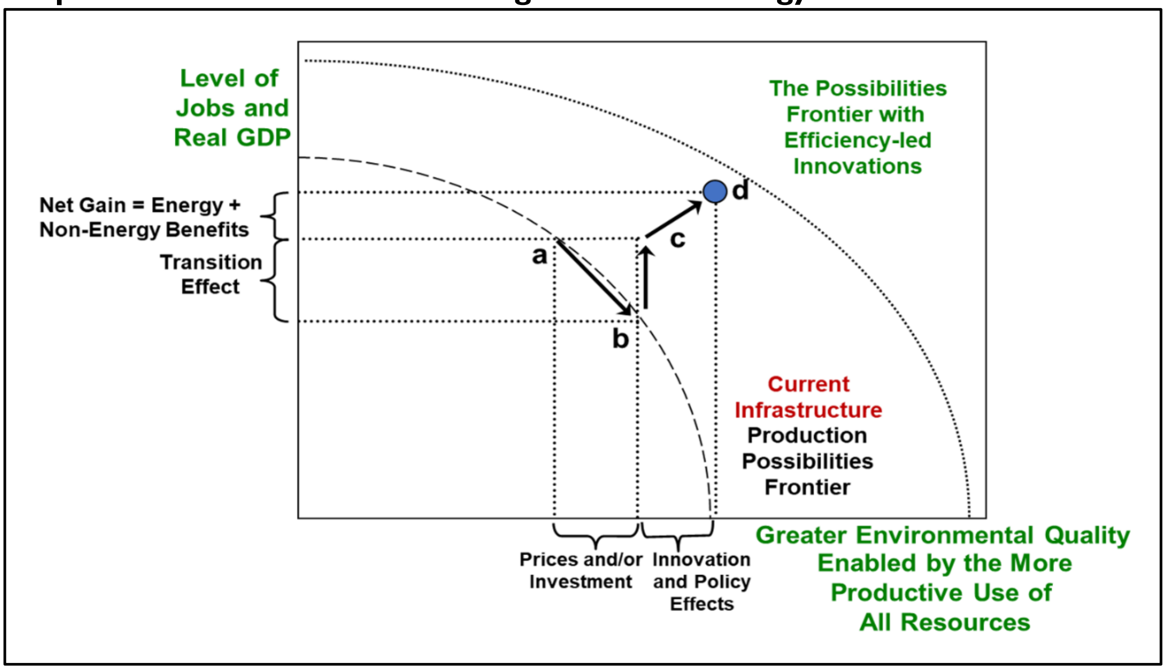
There is ample precedent for these initiatives in the US. The Peace Corps, VISTA, and AmeriCorps have proved invaluable in encouraging public service and providing opportunities for young people to learn new skills, which have helped them find career paths and employment. Universities, trade schools, unions, and local governments across the US will play an important role in partnering with the various service corps in preparing the new green workforce of the twenty-first century.

Granting paid apprenticeships, technical and professional certification, and clinical learning credits toward academic degrees to millions of young people will provide the coming generation with the talent and skills to engage in trade, technical, and professional employment in a climate change economy increasingly focused on new resilient business models and accompanying careers. These proposed clinical learning agencies at the state, county, and local level will also be among the first responders in climate events and disaster relief and recovery missions that will increasingly be a constant reality rather than a rare anomaly.

Appendix A. Further Insights on Aggregate Efficiency and the Economy

Table I in Section 4.2 of the main report lays out the seven major economic and employment drivers, which fully understood can help promote a more robust and sustainable economy. We can conceptually summarize all elements in Table I as the graphical illustration shown the diagram below which helps pull the key ideas of any likely energy productivity "Innovation Scenario" into a useful perspective. Although the scale of detectable responses to the complete set of economic stimuli is not known at this time, a positive overall explanation of how multiple benefits are likely to emerge through the implementation of a collaborative and productivity-led investment strategy.

Conceptual Framework for Evaluating the Global Energy Transformation



Source: John A. "Skip" Laitner, adapted to illustrate the equivalent of an Energy Productivity Transition as cited in the narrative.

Assuming that current energy consumption and production patterns continue indefinitely would imply that the US economy is already optimized on what is called a production frontier at point "a" in the above diagram. If all resources are, indeed, optimally arrayed and utilized, the country faces a tradeoff whereby increasing economic growth can only come at a cost to the environment (e.g., through the increased consumption of fossil fuels) and vice versa (i.e., that improving environmental quality means a reduction in our social and economic well-being). Any change to satisfy a demand for greater efficiencies, or the demand for large reduction in greenhouse gas emissions, will likely result in a move down and to the right to a point like "b." Although the US might achieve some mix of isolated productivity improvements, and there might be some reduction in greenhouse gas emissions, conventional wisdom suggests that this must surely come at the cost of a reduction in jobs and GDP.

Alternatively, a shift to increased deployment of energy efficiency and clean renewable energy may instead allow the economy to shift to a point like "c." The transition toward cleaner and more efficient energy systems can improve the environment while also spurring increased local economic growth. The result is an improvement in overall aggregate efficiency, especially with the more productive use of clean energy resources, even as the economy remains at a relatively stable level of GDP.

At some point, however, the various energy and non-energy benefits that result from an array of incentives and policy initiatives can boost the performance of the economy to a higher than expected level of performance. Although the figure in this appendix is not drawn to scale, the migration from point "a" to the eventual point "d" might represent an eventual doubling of energy productivity that drives a concomitant increase in economic activity or per capita GDP. Hence, a net 40 percent electricity savings should rouse a significant boost in net jobs, career opportunities and GDP—as indeed summarized in Table 4 of the main narrative. Equally critical, a clean energy transition can become a way to catalyze the seventh benefit of such strategies—outlined in Table 1, an enhanced or further push of the production frontier so that future technologies and markets are encouraged, developed, and implemented to the long-term benefit of jobs and the economy.

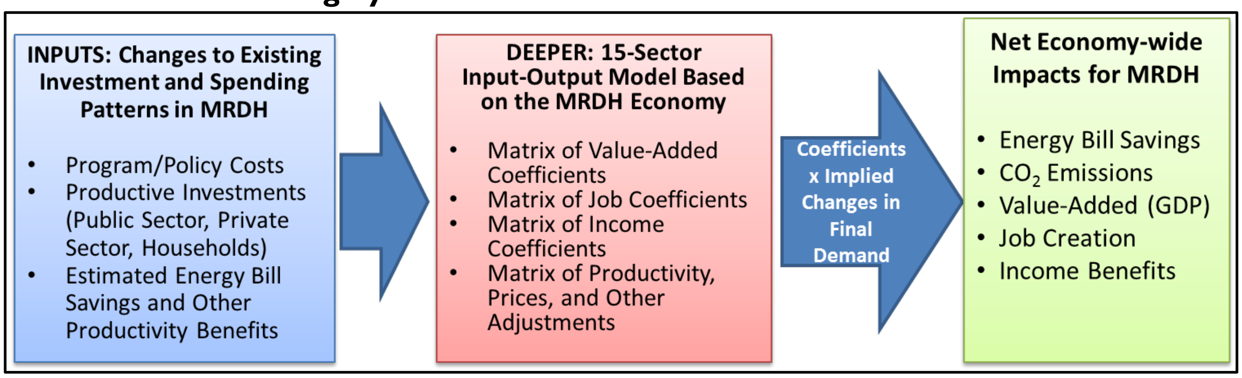
Appendix B. The DEEPER Modeling System

This analysis used the modeling system known as the ***D**ynamic **E**nergy **E**fficiency **P**olicy **E**valuation **R**outine* (DEEPER). The model, developed by John A. "Skip" Laitner in early 1992, is a compact 15-sector dynamic input-output model of a given regional or national economy.

The DEEPER model has a 29-year history of development and application by entities including earlier versions applied on behalf of the Arizona Energy Office and the Nebraska Energy Office in the mid-1980s. An early version of the modeling elements can be found in Laitner et al. (1998). It was used in 2017 to assess the potential outcomes and economic benefits of the Third Industrial Revolution in the Metropolitan Region of Rotterdam and Den Haag, an industrial region 2.3 million people in South Holland. The DEEPER model is also frequently used by the American Council for an Energy-Efficient Economy in a variety of policy assessments and white papers (see Ungar et al. 2020 as one recent example).

As it was implemented for this analysis, the model takes into account the change in spending and investment patterns as the result of a 20 percent Aggregate Efficiency improvement within the electricity sector, based on a variety of data made available by IMPLAN LLC (2021), Woods and Poole Economics (2020), the Bureau of Labor Statistics (2020), and the US Energy Information Administration (2020). The Figure below provides a diagrammatic view of the DEEPER modeling system.

The DEEPER Modeling System



Note: As discussed within this Appendix.

Although the DEEPER model is not a general equilibrium model, it does provide sufficient accounting detail to match import-adjusted changes in investments and expenditures within one sector of the economy and balance them against changes in other sectors.[47]

One critical assumption that underpins the core result of the DEEPER analysis is that any productive investment or spending—whether in energy efficiency, clean renewable energy, and/or a more dynamic infrastructure that pays for itself over a reasonably short period of time—will generate a net reduction in the cost of energy services (as well as a lower cost of other resources which are needed to maintain the material well-being of the nation's economy). That net reduction of energy and resource expenditures will be spent for the purchase of other goods and services.[48]

---

[47] When both equilibrium and dynamic input-output models use the same technology, investment, and cost assumptions, both sets of models should generate a reasonably comparable set of outcomes. For a diagnostic assessment of this conclusion, see, "Tripling the Nation's Clean Energy Technologies: A Case Study in Evaluating the Performance of Energy Policy Models," Donald A. Hanson and John A. "Skip" Laitner, Proceedings of the 2005 ACEEE Summer Study on Energy Efficiency in Industry, American Council for an Energy Efficient Economy, Washington, DC, July 2005.

[48] Note that unlike many policy models, DEEPER also captures trends in labor productivity. That means the number of jobs needed per million dollars of revenue will decline over time. For example, from Table 2, if we assume a 0.91 percent labor productivity improvement over the 21-year period from 2019 (the base year of the model) through 2040, 19.9 construction jobs supported by spending of $1 million within the United States today may support only 16.5 jobs by the year 2040. The calculation is $19.9 / 1.0091^{(2040-2019)} = 16.5$ jobs (rounded to the nearest tenth).

Once the mix of positive and negative changes in spending and investments has been established for the Energy Innovation Scenario, the net spending changes in each year of the model are converted into sector-specific changes in final demand. The DEEPER modeling system is a dynamic input-output analysis according to the following predictive model:

$X = (I-A)^{-1} * Y$

where:

X = total industry output by a given sector of the economy

I = an identity matrix consisting of a series of 0's and 1's in a row and column format for each sector (with the 1's organized along the diagonal of the matrix)

A = the matrix of production coefficients for each row and column within the matrix (in effect, how each column buys products from other sectors and how each row sells products to all other sectors)

Y = final demand, which is a column of net changes in spending by each sector as that spending pattern is affected by the policy case assumptions (changes in energy prices, energy consumption, investments, etc.)

This set of relationships can also be interpreted as $\Delta X = (I-A)^{-1} * \Delta Y$.

A change in total sector output equals the expression $(I-A)^{-1}$ times a change in final demand for each sector.[49] Employment quantities are adjusted annually according to exogenous assumptions about labor productivity. From a more operational standpoint, the macroeconomic module of the DEEPER model traces how each set of changes in spending will work or ripple its way through the regional economy in each year of the assessment period. The end result is a net change in jobs, income, and GDP (or value-added).

For a review of how an Input--Output framework might be integrated into other kinds of modeling activities, see Hanson and Laitner (2009). While the DEEPER model is not an equilibrium model, as explained previously, some key concepts of mapping technology representation for DEEPER are borrowed that use the general scheme outlined in Hanson and Laitner (2009).[50] This includes an economic accounting to ensure resources are sufficiently available to meet the expected consumer and other final demands reflected in different policy scenarios.

[49] Perhaps one way to understand the notation $(I-A)^{-1}$ is to think of this as the positive or negative impact multiplier depending on whether the change in spending is positive or negative for a given sector within a given year.

[50] "Input-Output Equations Embedded within Climate and Energy Policy Analysis Models," by Donald A. Hanson and John A. "Skip" Laitner, in Sangwon Suh, Editor, *Input-Output Economics for Industrial Ecology*. Dordrecht, Netherlands: Springer, 2009. See also, "A Pragmatic CGE Model for Assessing the Influence of Model Structure and Assumptions in Climate Change Policy Analysis," by Stephen Bernow, Alexandr Rudkevich, Michael Ruth, and Irene Peters. Boston, MA: Tellus Institute, 1998.

Appendix C. Framework for an Electricity Innovation Scenario

This report is designed to document scale of potential employment benefits through much greater increases in energy efficiency and improvements in overall energy productivity, rather than to assess the economics of a technology-based scenario. Laitner et al. (2012), for example, determined that the deployment of dozens of specific technologies in all of the major end-use sectors should cost-effectively reduce U.S. energy demands by 40 to 60 percent by the year 2050. Moreover, their analysis found that the combination of investments together with a large net energy bill savings would stimulate between 1.3 and 1.9 million net new jobs within the United States. And although that analysis documented key details such as the sector job coefficients and changes in labor productivity, it did not identify the many ways that jobs would be created as laid out in Sector 4 of this narrative. Yet, the many jobs which might be generated required a set of investment and savings to drive that employment benefit.

Here we focus, not on specific technologies, but on the underpinnings of an overall economic framework. That is, we illustrate the magnitude of job creation which might be possible from the stimulus of productive investment as it might favorably impact the nation's electric utility services. The absence of specific technologies requires a set of major drivers as if those technologies might be deployed. That includes the scale of possible electricity bill savings, a reasonable complement of non-energy benefits which likely follows the efficiency improvements, the effectiveness of the investments as they might be defined by payback periods, and the different rates of interest necessary to borrow money over a 20-year period. As all of these variables might impact a range of benefit-cost ratios. These key assumptions are described next.

The Scale of Energy Efficiency Improvements

Thinking through the scale of energy efficiency improvements is perhaps the first and most difficult set of estimates to help frame this particular analysis. As already alluded to above, in 2012 the American Council for an Energy-Efficient Economy made a first estimate of energy efficiency opportunities out to the year 2050, finding that a variety of energy efficiency improvements could reduce projected 2050 US energy use by 40 to 60 percent (Laitner et al. 2012). Amory Lovins and his team found a similar magnitude of potential energy efficiency savings in an analysis released by the Rocky Mountain Institute (Lovins 2011). More recently Nadel and Ungar (2019) concluded that sufficient efficiency opportunities "will be available by 2040 to put the United States on a path to reducing projected 2050 energy use by 50%."

More broadly, a Stanford University study of 143 countries of the world, looking at the year 2050, determined that a 100 percent "clean, renewable wind-water-solar (WWS) energy, efficiency, and storage" scenario would lead to a small end-use efficiency improvement of about 7 percent for the United States, but a total energy productivity benefit of 59 percent improvement. That would, in turn, reduce total energy costs of about $600 per person within the United States (Jacobson et al. 2019). This was an update of an earlier study of 139 countries, including the United States (Jacobson et al. 2017). On the other hand, Grubler et al. (2018) determined that global final energy demand, enabled by a much greater scale of energy efficiency improvements, though still cost-effective, might reduce 2050 demands of projected energy use to around 40 percent lower than today—despite increases in population, income and activity. At the same time, because this framework focuses on energy efficiency improvements within the electricity sector alone – more by way of illustrating the potential for job creation than focusing on a single pathway – we chose to focus on the recent *2020 Utility Energy Efficiency Scorecard* published by the American Council for an Energy-Efficient Economy (Relf, et al. 2020). In that 2020 assessment the top ten utilities showed a weighted average of a 2.02 percent annual savings. If extended out to 2040 that implies an eventual 43 percent energy efficiency improvement which, in this study, is rounded to 40 percent savings by the year 2040.

The Scale of Non-Energy Benefits.

A systematic literature review by Rasmussen (2017) found over 200 papers, reports and articles reviewing the returns of non-energy benefits, co-benefits, or ancillary benefits which accompanied the more conventional energy efficiency upgrades in a wide variety of assessments. More recently, Cooremans (2021) reviewed a new three-year European Union project to study the full range of the additional benefits from energy Efficiency. As one of many examples, the renovation of a large office building in Switzerland, with a negative return based on energy savings only, rose to an annual 11 percent return on investment when both energy and non-energy benefits included in the analysis. Such upgrades included the improved use of space, the reduction in maintenance costs, and a much higher employee productivity. See also Campbell and Ryan (2014), EPA (2018), and Karlsson et al. (2019).

In Worrell et al. (2003), a review of 52 industrial energy efficiency upgrades found that investments would pay for themselves over a period of 4.2 years on average when examined only from an energy savings perspective. When a full array of non-energy benefits were included with the energy savings, that payback fell to 1.9 years. In other words, the ancillary benefits amplified the energy bill savings by about 2.2 times. Returning to a review of benefits and costs specifically from electricity efficiency renovations, a supplementary review of 31 utilities, found again in Relf et al. (2020), suggested the weighted average of a total resource cost test (i.e., a benefit-cost ratio, or BCR) of 2.22. In other words, for every dollar of cost, the combination of the discounted utility and customer savings was $2.22. The range ran from a low of 1.20 to a high of 4.59.

In this assessment we determined that a reasonable range of benefit-cost ratios might run from a high of 3.2 to a low of only 1.2. Hence, if we conservatively assumed another 40 percent of ancillary or non-energy benefits, that would push weighted TRC of 2.22 to just above 3.1. As we then varied both the payback periods as well as the borrowing interest rates (discussed in the two subsections below), and assuming a 5 percent discount rate over the period 2021 through 2040, we found a range of benefit-cost ratios which ran from a high of 3.14 to a low of 1.31. These are summarized in Table 3A found within the main narrative of this report.

The Payback Period and the Interest Rates

The central target of this energy efficiency or energy productivity employment assessment was the anticipated 40 percent savings of a projected set of retail electricity expenditures. According to the newly released *Annual Energy Outlook 2021* (EIA 2021a) the total 2040 energy expenditures for the U.S. economy were pegged at $1,345.4 billion while total retail electricity expenditures were $432.9 billion in that same year, with both values reported in 2020 constant dollars. To stay within the anticipated 1.31 to 3.14 range of benefit-cost ratios we found a combination of simple payback periods of 5 years to 9 years, together with borrowing rates that varied between 3 percent and 7 percent would meet that objective. If, as an example, a 5-year average payback period were assumed, that would imply a required investment of $432.9 billion times 40 percent, times 5 years, or a total of $865.8 billion would be needed to drive the savings by the year 2040. If the payback period were 9 years, instead, they a total of 1,558.4 billion of investment would be required to achieve a 40 percent savings by 2040.

The cost of borrowing money further adds to the overall cost the energy efficiency improvements. For example, a 3 percent borrowing rate for a $1 million loan, paid over a 20-year period, would require a total payment of $1.34 million dollars. Said differently, a 3 percent loan increases the consumer cost by about 34 percent. Similarly, a 4.22 percent interest rate over a 20-year period would increase the consumer cost by 50 percent while a 7.75 percent loan would effectively double the consumer cost of energy efficiency upgrades.

The Full Convergence

Tables 3B and 3C document the array of average annual net consumer savings and net job creation as a function of the range of payback periods and assumed rates of borrowing money. To explain in more detail the impact of a 40 percent electricity savings, the main scenario in this report assumed an initial 5-year payback period for investments made in 2022, but which rose to a 9-year payback by the year 2040. The array of investments assumed a 3 percent borrowing rate over a 20-year period. Including the annual loan payments together with a set of policy and program costs necessary to drive the desired outcome, and assuming a 5 percent discount rate over the years 2021 through 2040, the main scenario showed a benefit-cost ratio of 2.59. The array of expenditures and savings over that time period supported an average of 2.8 million net jobs, rising from an initial set of 898,000 net jobs in 2022 (the first year of the efficiency upgrades) to a high of 5.2 million net jobs by 2040.

Select Acronyms

ACEEE	American Council for an Energy-Efficient Economy
BAU	Business-as-usual
BLS	Bureau of Labor Statistics
Btu	British thermal units
CDD	Cooling degree days
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
COVID	Corona Virus Disease
DEEPER	Dynamic Energy Efficiency Policy Evaluation Routine
EERE	Energy efficiency and renewable energy
EHDRA	Economic and Human Dimensions Research Associates
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FF	Fossil fuel
GDP	Gross domestic product
HDD	Heating degree days
IEA	International Energy Agency
IGSD	Institute for Governance & Sustainable Development
IIASA	International Institute of Applied Systems Analysis
IMPLAN	Impact Analysis for Planning
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
MMT	Million metric tons
MPC	Marginal propensity to consume
NOAA	National Oceanic and Atmospheric Administration
OES	Occupational Employment Statistics
PV	Photovoltaic
Quad	Quadrillion Btus
RCREEE	Regional Center for Renewable Energy and Energy Efficiency
RITE	Research Institute for Innovative Technologies for the Earth
ROE	Return on equity
SCC	Social cost of carbon
SLCP	Short-lived climate pollutant
US	United States
WWS	Wind-water-solar

References

Adecco. 2016. *The American Skills Gap is Real*. The Adecco Group. https://www.adeccousa.com/employers/resources/skills-gap-in-the-american-workforce/

ASCE. 2016. *Failure to Act: Closing the Infrastructure Investment Gap for America's Economic Future.* Washington, DC: American Society of Civil Engineers. https://www.infrastructurereportcard.org/wp-content/uploads/2016/05/2016-FTA-Report-Close-the-Gap.pdf

ASCE. 2020a. *Failure to Act: Electric Infrastructure Investment Gaps in a Rapidly Changing Environment*. Washington, DC: American Society of Civil Engineers. https://www.asce.org/electricity_report/

ASCE. 2020b. *The Economic Benefits of Investing in Water Infrastructure: How a Failure to Act Would Affect the US Economic Recovery*. Washington, DC: American Society of Civil Engineers. https://www.asce.org/water_and_wastewater_report/.

ASES. 2007. "Tackling Climate Change in the US" Boulder, CO: American Solar Energy Society. https://www.ases.org/wp-content/uploads/2019/01/Tackling_Climate_Change_A.pdf.

Ayres, Robert U. and Benjamin Warr. 2009. *The Economic Growth Engine: How Energy and Work Drive Material Prosperity*. Northampton, MA, Edward Elgar Publishing, Inc. https://www.e-elgar.com/shop/the-economic-growth-engine?

Biden Campaign. 2020. "The Biden Plan to Build a Modern, Sustainable Infrastructure and an Equitable Clean Energy Future." Joe Biden Clean Energy. 2020. https://joebiden.com/clean-energy/.

Bivens, Josh. 2017. The potential macroeconomic benefits from increasing infrastructure investment. Washington, DC: Economic Policy Institute. https://www.epi.org/files/pdf/130111.pdf.

Blok, Kornelis, Paul Hofheinz, and John Kerkhoven. 2015. The 2015 Energy Productivity and Economic Prosperity Index: How Efficiency Will Drive Growth, Create Jobs and Spread Wellbeing Throughout Society. Utrecht, Netherlands: Ecofys Group, also The Lisbon Council, and Quintel Intelligence B.V. https://www.ctc-n.org/resources/2015-energy-productivity-and-economic-prosperity-index-how-efficiency-will-drive-growth-0.

BLS. 2020a. "Industry Output and Employment Projections 2019 to 2029." Washington, DC: U.S. Bureau of Labor Statistics. 2020. https://www.bls.gov/emp/data/industry-out-and-emp.htm

BLS. 2020b. "Fastest Growing Occupations." Washington, DC: U.S. Bureau of Labor Statistics. 2020. https://www.bls.gov/emp/tables/fastest-growing-occupations.htm.

BLS. 2021. Total nonfarm, seasonally adjusted jobs. Washington, DC: US Bureau of Labor Statistics. Current Employment Statistics. Comparing December 2020 and December 2019. Accessed January 16, 2021 (9:51:40 AM). https://data.bls.gov/cgi-bin/surveymost

Brainard, Lael. 2019. "Why Climate Change Matters for Monetary Policy and Financial Stability." Remarks at the research conference, "The Economics of Climate Change", sponsored by the Federal Reserve Bank of San Francisco. November.
https://www.federalreserve.gov/newsevents/speech/brainard20191108a.htm

BRT 2019. Delivering for America: The macroeconomic impacts of reinvesting in America's infrastructure systems. Washington, DC: Business Roundtable.
https://s3.amazonaws.com/brt.org/BRT-InfrastructureReport12052018.pdf

B**uonocore, Jonathan J., Kathleen F. Lambert, Dallas Burtraw, Samantha Sekar, Charles T. Driscoll. 2016.** An Analysis of Costs and Health Co-Benefits for a US Power Plant Carbon Standard. PLOS ONE 11(6).
https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0156308.

Bureau of Economic Analysis (BEA). 2020. BEA Data. A variety of tables. Washington, DC: US Department of Commerce. https://www.bea.gov/data/.

Campbell, Nancy, Lisa Ryan, Vida Rozite, Eoin Lees, and Grayson Heffner. 2014. Capturing the Multiple Benefits of Energy Efficiency. Paris, France, International Energy Agency. https://webstore.iea.org/download/direct/375.

Cappucci, Matthew and Jason Samenow. 2020. "From ferocious fires to a historic hurricane season, 2020 took weather to new extremes." *The Washington Post*. Dec. 29. https://www.washingtonpost.com/weather/2020/12/29/extreme-weather-2020-fires-hurricanes/.

Cohen, Ariel. 2020. "Federal Reserve Warns Of Climate Risks, In Historic First." *Forbes*. November 11. https://www.forbes.com/sites/arielcohen/2020/11/11/us-fed-report-acknowledges-climate-change-risks-in-historic-first/.

Cohen, Judah, Xiangdong Zhang, Jennifer Francis, Monica Ionita, Marlene Kretschmer, Frédéric Laliberté, S. Lee, Hans W. Linderholm, Wieslaw Maslowski, Yannick Peings, K. Pfeiffer, Ignatius Rigor, Tido Semmler, J.C. Stroeve, Patrick C. Taylor, S. J. Vavrus, Timo Vihma, Shih-Yu Simon Wang, Manfred Wendisch, Y. Wu, and Jin-Ho Yoon. 2020. Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather *Nature Climate Change*, Vol: 10, Issue: 1, Pages: 20-29. https://doi.org/10.1038/s41558-019-0662-y.

Colburn, Kenneth A. 2021. Personal communication on related topics, July 5. Bar Harbor, Maine.
Symbiotic Strategies LLC.

Cooremans, Catherine. 2021. "Beyond Energy Savings: Quantifying the Additional Benefits from Energy Efficiency." Multiple Benefits Project hosted by the Fraunhofer Institute for Systems and Innovation Research. https://www.mbenefits.eu/static/media/uploads/site-6/library/Cases%20and%20examples/ccooremans_better_buildings_webinar_mbenefits_12.01.2021.pdf.

Corfee-Morlot, Jan, Ipek Gençsü, James Rydge, Helen Mountboard, Ferzina Banaji and Joel Jaeger. 2016. The Sustainable Infrastructure Imperative: Financing for Better Growth

and Development. Washington, DC: New Climate Economy.
http://newclimateeconomy.report/2016/wp-content/uploads/sites/4/2014/08/NCE_2016Report.pdf.

Dedoussi, Irene C., Sebastian D. Eastham, Erwan Monier and Steven R. H. Barrett. 2020. "Premature mortality related to United States cross-state air pollution." *Nature* **volume 578**, pages 261–265. https://www.nature.com/articles/s41586-020-1983-8.

E4TheFuture. 2019. "Energy Efficiency Jobs in America 2019." E4TheFuture and E2. https://www.e2.org/wp-content/uploads/2019/09/Energy-Efficiency-Jobs-in-America-2019-Full-Report.pdf.

EESI. 2019. "Fact Sheet - Jobs in Renewable Energy, Energy Efficiency, and Resilience." Washington, DC: Environmental and Energy Study Institute. 2019. https://www.eesi.org/papers/view/fact-sheet-jobs-in-renewable-energy-energy-efficiency-and-resilience-2019.

EIA. 2021a. *The Annual Energy Outlook 2021 with Projections to 2050*. Washington, DC: United States Energy Information Administration. https://www.eia.gov/outlooks/aeo/

EIA. 2021b. *The Annual Energy Review*. Washington, DC: United States Energy Information Administration. https://www.eia.gov/totalenergy/data/annual/

Ekins, Paul, Nick Hughes, Stefan Bringezu, Charles Arden Clarke, Marina Fischer-Kowalski, Thomas Graedel, Maarten Hajer, Seiji Hashimoto, Steve Hatfield-Dodds, Petr Havlik, Edgar Hertwich, John Ingram, Katja Kruit, Ben Milligan, Yuichi Moriguchi, Nabil Nasr, David Newth, Michael Obersteiner, Anu Ramaswami, Heinz Schandl, Sangwon Suh, Mark Swilling, Ester van der Voet, Brian Walsh, Jim West and Henk Westhoek. 2017. *Resource Efficiency: Potential and Economic Implications. A report of the International Resource Panel*. United Nations Environment Program. http://www.resourcepanel.org/reports/resource-efficiency.

EPA. 2011. *Assessing the Multiple Benefits of Clean Energy: A Resource for States*. EPA-430-R-11-014. EPA-430-R-11-014. Washington, DC: US Environmental Protection Agency, Climate Protection. https://www.epa.gov/sites/production/files/2015-08/documents/accessing_the_benefits_of_clean_energy.pdf.

EPA. 2018. *Quantifying the Multiple Benefits of Energy Efficiency and Renewable Energy A Guide for State and Local Governments*. Washington, DC: Environmental Protection Agency. https://www.epa.gov/sites/production/files/2018-07/documents/epa_slb_multiple_benefits_508.pdf.

EPA. 2019. *Public Health Benefits per kWh of Energy Efficiency and Renewable Energy in the United States: A Technical Report*. Washington, DC: Environmental Protection Agency. https://www.epa.gov/sites/production/files/2019-07/documents/bpk-report-final-508.pdf.

EPA. 2020. Data Highlights Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2018. Washington, DC: US Environmental Protection Agency.

https://www.epa.gov/sites/production/files/2020-04/documents/us-ghg-inventory-2020-main-text.pdf.
ECF. 2010. Roadmap 2050: A Practical Guide to a Prosperous, Low-Carbon Europe. A Technical Summary. European Climate Foundation.
https://www.roadmap2050.eu/attachments/files/Volume1_ExecutiveSummary.pdf

Garrett-Peltier, Heidi. 2017. Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model. *Economic Modelling* 61 (2017) 439–447. http://dx.doi.org/10.1016/j.econmod.2016.11.012.

Giffi, Craig, Paul Wellener, Ben Dollar, Heather Ashton Manolian, Luke Monck and Chad Moutray. 2018. *The Manufacturing Institute Skills Gap and Future of Work Study*. Deloitte & Touche LLP. https://www2.deloitte.com/us/en/pages/manufacturing/articles/future-of-manufacturing-skills-gap-study.html

Griffith, Saul and Sam Calisch. 2020. "Mobilizing for a zero carbon America: Jobs, jobs, jobs, and more jobs." Rewiring America. https://www.rewiringamerica.org/jobs-report.

Grubler, Arnulf, Charlie Wilson, and Nuno Bento, Benigna Boza-Kiss, Volker Krey, David L. McCollum, Narasimha D. Rao, Keywan Riahi, Joeri Rogelj, Simon De Stercke, Jonathan Cullen, Stefan Frank, Oliver Fricko, Fei Guo, Matt Gidden, Petr Havlík, Daniel Huppmann, Gregor Kiesewetter, Peter Rafaj, Wolfgang Schoepp and Hugo Valin. 2018. "A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies." *Nature Energy*, Vol 3, pages, pages 515–527 (June). https://doi.org/10.1038/s41560-018-0172-6.

Haley, Ben, Ryan Jones, Gabe Kwok, Jeremy Hargreaves, Jamil Farbes, and James H. Williams. 2019. *350 PPM Pathways for the United States*. US Deep Decarbonization Pathways Project. Sustainable Development Solutions Network. https://irp-cdn.multiscreensite.com/be6d1d56/files/uploaded/350PPMPathwaysfortheUnitedStates.pdf.

Harvey, Chelsea. 2016. The staggering economic cost of air pollution. *The Washington Post*. January 29. https://www.washingtonpost.com/news/energy-environment/wp/2016/01/29/the-staggering-economic-cost-of-air-pollution/.

Hawken, Paul (editor). 2017. *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*. Penguin Books. http://www.drawdown.org.

Hoffman, Ian, Charles A. Goldman, Sean Murphy, Natalie Mims, Greg Leventis and Lisa Schwartz. 2018. *The Cost of Saving Electricity Through Energy Efficiency Programs Funded by Utility Customers: 2009–2015*. Berkeley, CA: Lawrence Berkeley National Laboratory.
https://eta-publications.lbl.gov/sites/default/files/cose_final_report_20200429.pdf

Huntington, Hillard, John Weyant, and James Sweeney. 1982. Modeling for Insights, Not Numbers: The Experiences of the Energy Modeling Forum. *Omega: The International Journal of Management Science* 10(5): 449–462. **https://web.stanford.edu/group/emf-research/docs/planning_papers/PP6.5.pdf**
IMPLAN. 2021. Multi-Regional Input-Output (MRIO) Data and Analytical Capabilities. Huntersville, NC: IMPLAN, LLC. https://implan.com/.

IGSD. 2021. The Need for Fast Near-Term Climate Mitigation to Slow Feedbacks and Tipping Points: Background Note on the Critical Role of Short-lived Super Climate Pollutants in the Climate Emergency. Institute for Governance & Sustainable Development and Center for Human Rights and Environment**.** http://www.igsd.org/wp-content/uploads/2020/09/Science-Supporting-Need-for-Fast-Near-Term-Climate-Mitigation-Sept2020.pdf.

International Energy Agency (IEA). 2011. *Climate Change Adaptation, Damages and Fossil Fuel Dependence: An RETD Position Paper on the Costs of Inaction*. Prepared by Navigant Consulting for the International Energy Agency (IEA). July 15. http://iea-retd.org/wp-content/uploads/2011/11/SC6-Costs-of-Inaction-Final-Report.pdf.

IPCC 2018. Global Warming of 1.5°C: Special Report. International Panel on Climate Change. Geneva, Switzerland. https://www.ipcc.ch/sr15/.

IRENA 2019. *Global Energy Transformation: The REmap Transition Pathway.* International Renewable Energy Agency (IRENA), Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Apr/IRENA_GET_REmap_pathway_2019.pdf.

Jacobson, Mark Z., Mark A. Delucchi, Zack A.F. Bauer, Savannah C. Goodman, William E. Chapman, Mary A. Cameron, Cedric Bozonnat, Liat Chobadi, Hailey A. Clonts, Peter Enevoldsen, Jenny R. Erwin, Simone N. Fobi, Owen K. Goldstrom, Eleanor M. Hennessy, Jingyi Liu, Jonathan Lo, Clayton B. Meyer, Sean B. Morris, Kevin R. Moy, Patrick L. O'Neill, Ivalin Petkov, Stephanie Redfern, Robin Schucker, Michael A. Sontag, Jingfan Wang, Eric Weiner, and Alexander S. Yachanin. 2017. "100% Clean and Renewable Wind, Water, and Sunlight All-Sector Energy Roadmaps for 139 Countries of the World." *Joule* (2017), http://dx.doi.org/10.1016/j.joule.2017.07.005.

Jacobson, Mark Z., Mark A. Delucchi, Mary A. Cameron, Stephen J. Coughlin, Catherine A. Hay, Indu Priya Manogaran, Yanbo Shu, and Anna-Katharina von Krauland. 2019. "Impacts of Green New Deal Energy Plans on Grid Stability, Costs, Jobs, Health, and Climate in 143 Countries." *One Earth*, 4(1), 449-463. https://www.cell.com/one-earth/pdfExtended/S2590-3322(19)30225-8.

Jadun, Paige, Colin McMillan, Daniel Steinberg, Matteo Muratori, Laura Vimmerstedt, and Trieu Mai. 2017. Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-70485. https://www.nrel.gov/docs/fy18osti/70485.pdf.

Karlsson, Mikael, Eva Alfredsson and Nils Westling. 2019. "Climate policy co-benefits: a review." *Climate Policy*, 20:3, 292-316. https://doi.org/10.1080/14693062.2020.1724070.

Keith, Ladd, Sara Meerow and Tess Wagner. 2020. Planning for extreme heat: A review. Journal of Extreme Events. 6(3&4), 2050003. http://dx.doi.org/10.1142/S2345737620500037.

Kümmel, Reiner. 2011. *The Second Law of Economics: Energy, Entropy, and the Origins of Wealth*. New York, NY, Springer. http://www.springer.com/us/book/9781441993649.

Kümmel, Reiner. 2013. Why energy's economic weight is much larger than its cost share. *Environmental Innovation and Societal Transitions*, (9): 33-37. http://isiarticles.com/bundles/Article/pre/pdf/46005.pdf.

Kutscher, Charles F., Jeffrey S. Logan, and Timothy C. Coburn. 2020. *Accelerating the US Clean Energy Transformation: Challenges and Solutions by Sector*. Boulder, CO: Renewable and Sustainable Energy Institute. December. https://www.colorado.edu/rasei/sites/default/files/attached-files/accelerating_the_us_clean_energy_transformation_final.pdf.

Laitner, John A. "Skip." 2015. Linking Energy Efficiency to Economic Productivity: Recommendations for Improving the Robustness of the US Economy. *Wiley Interdisciplinary Reviews: Energy and Environment*, 2015. Volume 4: 235-52. http://onlinelibrary.wiley.com/doi/10.1002/wene.135/abstract.

Laitner, John A. "Skip." 2018. "The Growing Burden of Waste and the Need to Rethink Infrastructure Informed by Science," by John A. "Skip" Laitner, Washington, DC: National Counsel for Science and the Environment. 2018. https://www.ncseglobal.org/ncse-essays/growing-burden-waste-and-need-rethink-infrastructure-informed-science.

Laitner, John A. "Skip." 2020. Working Memorandum on Energy as Work: Estimating Exergy Efficiency for the United States and the Global Economy. Tucson, AZ: Economic and Human Dimensions Research Associates. https://theresourceimperative.com/wp-content/uploads/2021/03/Memorandum-on-Energy-as-Work.pdf

Laitner, Skip, Stephen Bernow and John DeCicco. 1998. "Employment and other macroeconomic benefits of an innovation-led climate strategy for the United States." *Energy Policy*, 26(5), 425–432. https://doi.org/10.1016/S0301-4215(97)00160-2

Laitner, John A. "Skip", Steven Nadel, Harvey Sachs, R. Neal Elliott, and Siddiq Khan. 2012. The Long-Term Energy Efficiency Potential: What the Evidence Suggests. ACEEE Research Report E104, Washington, DC: American Council for an Energy-Efficient Economy. http://aceee.org/research-report/e121.

Laitner, John A. "Skip" and Meagan Weiland. 2018. Let's Talk Trash. *The Environmental Forum*. Washington, DC: Environmental Law Institute. https://www.eli.org/the-environmental-forum/lets-talk-trash

Laitner, John A. "Skip", Benoît Lebot, Matthew McDonnell and Meagan Weiland. 2018. Smart Policies and Programs as Critical Drivers for Greater Energy Efficiency Investments. Paris, France: International Partnership for Energy Efficiency Cooperation (IPEEC). https://theresourceimperative.com/wp-content/uploads/2018/02/IPEEC-Smart-Policies-and-Programs-as-Critical-Drivers-of-Greater-Energy-Efficiency-Investments-Feb-2018.pdf.

Lange, Glenn-Marie, Wodon, Quentin and Carey, Kevin. 2018. *The Changing Wealth of Nations 2018 : Building a Sustainable Future*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/29001.

Lazard. 2020. "Lazard's Levelized Cost of Energy Analysis 2020 --Version 14.0." New York, NY: Lazard. https://www.lazard.com/media/451419/lazards-levelized-cost-of-energy-version-140.pdf.

Lebot, Benoît Lebot and Meagan Weiland. 2020. Policies and Programs Critical for Greater Energy Efficiency. Economic Policy, Vol. 15, No. 2 (April 2020), pp 148-167. http://ecpolicy.ru/images/stories/2020_2/008_lebot.pdf.

Lovins, Amory. 2011. *Reinventing Fire: Bold Business Solutions for the New Energy Era*. White River Junction, VT: Chelsea Green Publishing. https://www.barnesandnoble.com/w/reinventing-fire-amory-lovins/1100821351

McGrattan, Ellen R. and James A. Schmitz. 1999. Maintenance and Repair: Too Big to Ignore. Federal Reserve Bank Minneapolis *Quarterly Review*. Volume 23(4), pages 2-13. Fall. https://researchdatabase.minneapolisfed.org/downloads/8049g522d.

Metropolitan Region of Rotterdam and Den Haag (MRDH). 2017. Roadmap Next Economy. https://mrdh.nl/RNE.

Miller, Ronald and Peter Blair. 2009. *Input-Output Analysis: Foundations and Extensions*. Cambridge University Press. https://doi.org/10.1017/CBO9780511626982.

Muro, Mark, Adie Tomer, Ranjitha Shivaram, and Joseph Kane. 2019. "Advancing Inclusion Through Clean Energy Jobs." Washington, DC: Brookings Institution. https://www.brookings.edu/research/advancing-inclusion-through-clean-energy-jobs/.

Nadel, Steven. 2016. Pathway to Cutting Energy Use and Carbon Emissions in Half. ACEEE Working Paper. Washington, DC: American Council for an Energy-Efficient Economy. http://aceee.org/white-paper/pathways-cutting-energy-use.

Nadel, Steven and Lowell Ungar. 2019. Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050. ACEEE Working Paper. Washington, DC: American Council for an Energy-Efficient Economy. https://www.aceee.org/research-report/u1907.

Nordhaus, William D. 2017. "Revisiting the social cost of carbon." Proceedings of the National Academy of Sciences of the United States of America (PNAS). https://doi.org/10.1073/pnas.1609244114.

Ogen, Yaron. 2020. "Assessing Nitrogen Dioxide (NO2) Levels as a Contributing Factor to Coronavirus (COVID-19) Fatality." Science of The Total Environment 726 (July): 138605. https://doi.org/10.1016/j.scitotenv.2020.138605.

Parry, Ian, Dirk Heine, Eliza Lis, and Shanjun Li. 2014. *Getting Energy Prices Right: From Principle to Practice*. Washington, DC: International Monetary Fund. http://dx.doi.org/10.5089/9781484388570.071.

Plumer, Brad. 2020. "To Cut Emissions to Zero, US Needs to Make Big Changes in Next 10 Years." *The New York Times*. December 15, 2020. https://www.nytimes.com/2020/12/15/climate/america-next-decade-climate.html

Pollin, Robert, James Heintz, and Heidi Garrett-Peltier. 2009. *How Infrastructure Investments Support the US Economy: Employment, Productivity and Growth*. Amherst, MA: Political Economy Research Institute, University of Massachusetts-Amherst. https://ideas.repec.org/p/uma/perips/peri_infrastructure_investments.html.

Pozzer Andrea, Francesca Dominici, Andy Haines, Christian Witt, Thomas Münzel, and Jos Lelieveld. 2020. *Regional and global contributions of air pollution to risk of death from COVID-19*, Cardiovascular Research. http://academic.oup.com/cardiovascres/advance-article/doi/10.1093/cvr/cvaa288/5940460.

Price, Jason, Sahil Gulati, Jacob Lehr, and Stefani Penn. 2020. The Benefits and Costs of US Air Pollution Regulations. Prepared for Natural Resources Defense Council by Industrial Economics, Incorporated, Cambridge, MA. https://www.nrdc.org/sites/default/files/iec-benefits-costs-us-air-pollution-regulations-report.pdf.

Rasmussen, Josefine. 2017. The additional benefits of energy efficiency investments—a systematic literature review and a framework for categorization. *Energy Efficiency,* 10, 1401–1418. https://doi.org/10.1007/s12053-017-9528-1

RCREEE. 2013. "Environmental Externalities from Electric Power Generation." Cairo, Egypt: Regional Center for Renewable Energy and Energy Efficiency. https://rcreee.org/sites/default/files/rcreee_rs_environmentalexternalitiesfromelectricpowergeneration_2013_en.pdf.

Rich, Nathaniel. 2018. "Losing Earth: The decade we almost stopped climate change." *New York Times Magazine*, 8/1/2018. https://www.nytimes.com/interactive/2018/08/01/magazine/climate-change-losing-earth.html.

Ricke, Katharine, Laurent Drouet, Ken Caldeira, and Massimo Tavoni. 2018. "Country-Level Social Cost of Carbon." Nature Climate Change 8 (10): 895–900. https://doi.org/10.1038/s41558-018-0282-y.

Ripple, William J, Christopher Wolf, Thomas M Newsome, Phoebe Barnard, and William R Moomaw et al. (2019). "World Scientists' Warning of a Climate Emergency." *BioScience* November 5, 2019. https://academic.oup.com/bioscience/advance-article/doi/10.1093/biosci/biz088/5610806

RMI. 2020. "US Stimulus Strategy." Basalt, CO: Rocky Mountain Institute. 2020. https://rmi.org/insight/recommendations-for-a-zero-carbon-economic-recovery/.

SDSN. 2020. "America's Zero Carbon Action Plan." Sustainable Development Solutions Network. New York: SDSN. https://www.unsdsn.org/americas-zero-carbon-action-plan-zcap.

Shenot, John. 2013. Quantifying the Air Quality Impacts of Energy Efficiency Policies and Programs. Montpelier Vt: Regulatory Assistance Project. https://www.raponline.org/knowledge-center/quantifying-the-air-quality-impacts-of-energy-efficiency-policies-and-programs/.

Shindell, Drew. 2020. "Health and Economic Benefits of a 2°C Climate Policy." Testimony to the House Committee on Oversight and Reform Hearing on 'The Devastating Impacts of Climate Change on Health' Aug 5, 2020. Washington, DC. Durham, NC: Duke University, Nicholas School of the Environment. https://nicholas.duke.edu/sites/default/files/documents/Shindell_Testimony_July2020_final.pdf.

Smith, Heidi Jane. 2012. Mobilising Investments for urban Sustainability, Job Creation and Resilient Growth Issues Paper, OECD Roundtable of Mayors and Ministers, 8 March 2012, Chicago, Illinois, United States. https://www.academia.edu/2523934/Mobilising_Investments_for_urban_Sustainability_Job_Creation_and_Resilient_Growth_Issues_Paper_OECD_Roundtable_of_Mayors_and_Ministers_8_March_2012_Chicago_Illinois_United_States.

Smith, Adam B. 2021. "2020 US billion-dollar weather and climate disasters in historical context." Washington, DC: National Oceanic and Atmospheric Administration, Science & Information for a Climate-Smart Nation. https://www.climate.gov/news-features/blogs/beyond-data/2020-us-billion-dollar-weather-and-climate-disasters-historical. See also: https://www.ncdc.noaa.gov/billions/.

Smyth, Joe. 2020. "Financial analysts expect decarbonization will benefit utility ratepayers and shareholders: Replacing coal with renewable energy could save customers $8 billion each year." *Energy and Policy Institute.* January 9, 2020. https://www.energyandpolicy.org/financial-analysts-expect-decarbonization-will-benefit-utility-ratepayers-and-shareholders/

Sweeney, Darren. 2019. "Morgan Stanley: 'Second wave of renewables' to drive 70 GW of coal retirements." *S&P Global Market Intelligence*. December 20, 2019. https://www.spglobal.com/marketintelligence/en/news-insights/trending/n2V18rq_af4OBgqaW6CmkQ2

Svaldi, Aldo. 2018. "Xcel Energy receives shockingly low bids for Colorado energy from renewable sources." *Denver Post*, January 16, 2018. https://www.denverpost.com/2018/01/16/xcel-energy-low-bids-for-colorado-electricity/.

Teske, Sven, Steve Sawyer, Oliver Schäfer, Thomas Pregger, Sonja Simon, and Tobias Naegler. 2015. *Energy [r]evolution. A sustainable world energy outlook 2015: 100% Renewable Energy for All.* Greenpeace. http://www.greenpeace.org/international/Global/international/publications/climate/2015/Energy-Revolution-2015-Full.pdf.

UAW. 2020. Taking the High Road: Strategies for a Fair EV Future. Detroit, MI: United Auto Workers International. UAW Research. https://uaw.org/wp-content/uploads/2019/07/190416-EV-White-Paper-REVISED-January-2020-Final.pdf.

Ungar, Lowell, James Barrett, Steven Nadel, R. Neal Elliott, Edward Rightor, Jennifer Amann, Peter Huether, and Mike Specian. 2020. Growing a Greener Economy: Job and

Climate Impacts from Energy Efficiency Investments. Washington, DC: American Council for an Energy-Efficient Economy. https://www.aceee.org/sites/default/files/pdfs/efficiency-investments-analysis-sept-2020.pdf.

Vohra, Karn, Alina Vodonos, Joel Schwartz, Eloise A. Marais, Melissa P. Sulprizio, and Loretta J. Mickley. 2021. *Global mortality from outdoor fine particle pollution generated by fossil fuel combustion: Results from GEOS-Chem*, Environmental Research 110754. https://www.sciencedirect.com/science/article/pii/S0013935121000487.

Voudouris, Vlasios, Robert Ayres, Andre Cabrera Serrenho, and Daniil Kiose. 2015. "The economic growth enigma revisited: The EU-15 since the 1970s." *Energy Policy* 86 (2015), pages 812–832. http://www.sciencedirect.com/science/article/pii/S0301421515001779.

Wagner, Claas, Melissa Obermeyer and Richard Lüchinger. 2020. "A methodology for the assessment of multiple benefits of industrial energy efficiency measures. *SN Applied Sciences*, Volume 2 (270). https://link.springer.com/article/10.1007/s42452-020-2071-2.

Watts, Nick, Markus Amann, Nigel Arnell, and Sonja Ayeb-Karlsson, Jessica Beagley, Kristine Belesova, Maxwell Boykoff, Peter Byass, Wenjia Cai, Diarmid Campbell-Lendrum, Stuart Capstick, Jonathan Chambers, Samantha Coleman, Carole Dalin, Meaghan Daly, Niheer Dasandi, Shouro Dasgupta, Michael Davies, Claudia Di Napoli, Paula Dominguez-Salas, Paul Drummond, Prof Robert Dubrow, Kristie L Ebi, Matthew Eckelman, Paul Ekins, Luis E Escobar, Lucien Georgeson, Su Golder, Delia Grace, Hilary Graham, Paul Haggar, Ian Hamilton, Stella Hartinger, Jeremy Hess, Shih-Che Hsu, Nick Hughes, Slava Jankin Mikhaylov, Marcia P Jimenez, Ilan Kelman, Harry Kennard, Gregor Kiesewetter, Patrick L Kinney, Tord Kjellstrom, Dominic Kniveton, Pete Lampard, Bruno Lemke, Yang Liu, Zhao Liu, Melissa Lott, Rachel Lowe, Jaime Martinez-Urtaza, Mark Maslin, Lucy McAllister, Alice McGushin, Celia McMichael, James Milner, Maziar Moradi-Lakeh, Karyn Morrissey, Simon Munzert, Kris A Murray, Tara Neville, Maria Nilsson, Maquins Odhiambo Sewe, Tadj Oreszczyn, Matthias Otto, Fereidoon Owfi, Olivia Pearman, David Pencheon, Ruth Quinn, Mahnaz Rabbaniha, Elizabeth Robinson, Joacim Rocklöv, Marina Romanello, Jan C Semenza, Jodi Sherman, Liuhua Shi, Marco Springmann, Meisam Tabatabaei, Jonathon Taylor, Joaquin Triñanes, Joy Shumake-Guillemot, Bryan Vu, Paul Wilkinson, Matthew Winning, Peng Gong, Hugh Montgomery, and Anthony Costello. 2021. "The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises." *The Lancet*. Vol 397, 10269, pp 129-170. January 9. https://doi.org/10.1016/S0140-6736(20)32290-X.

Wigley, Tom M. L. 2011. "Coal to gas: the influence of methane leakage, *Climatic Change* 108(3): 601. Accessed at https://doi.org/10.1007/s10584-011-0217-3

Woods and Poole. 2020. US Data Pamphlet for the United States 1969-2050. Washington, DC: Woods and Poole Economics, Inc. https://www.woodsandpoole.com/.

Worrell, Ernst, John A. Laitner, Michael Ruth, and Hodayah Finman. 2003. "Productivity Benefits of Industrial Energy Efficiency Measures." *Energy* (2003), 28, 1081-98. https://doi.org/10.1016/S0360-5442(03)00091-4.

Zuckerman, Julia, Frejova, Jama, Granoff, Ilma, and Nelson, David (Climate Economy). 2016. *Investing at Least a Trillion Dollars a Year in Clean Energy*. Contributing paper for Seizing the Global Opportunity: Partnerships for Better Growth and a Better Climate. New Climate Economy, London and Washington, DC. Available at: http://newclimateeconomy.report/misc/working-papers.