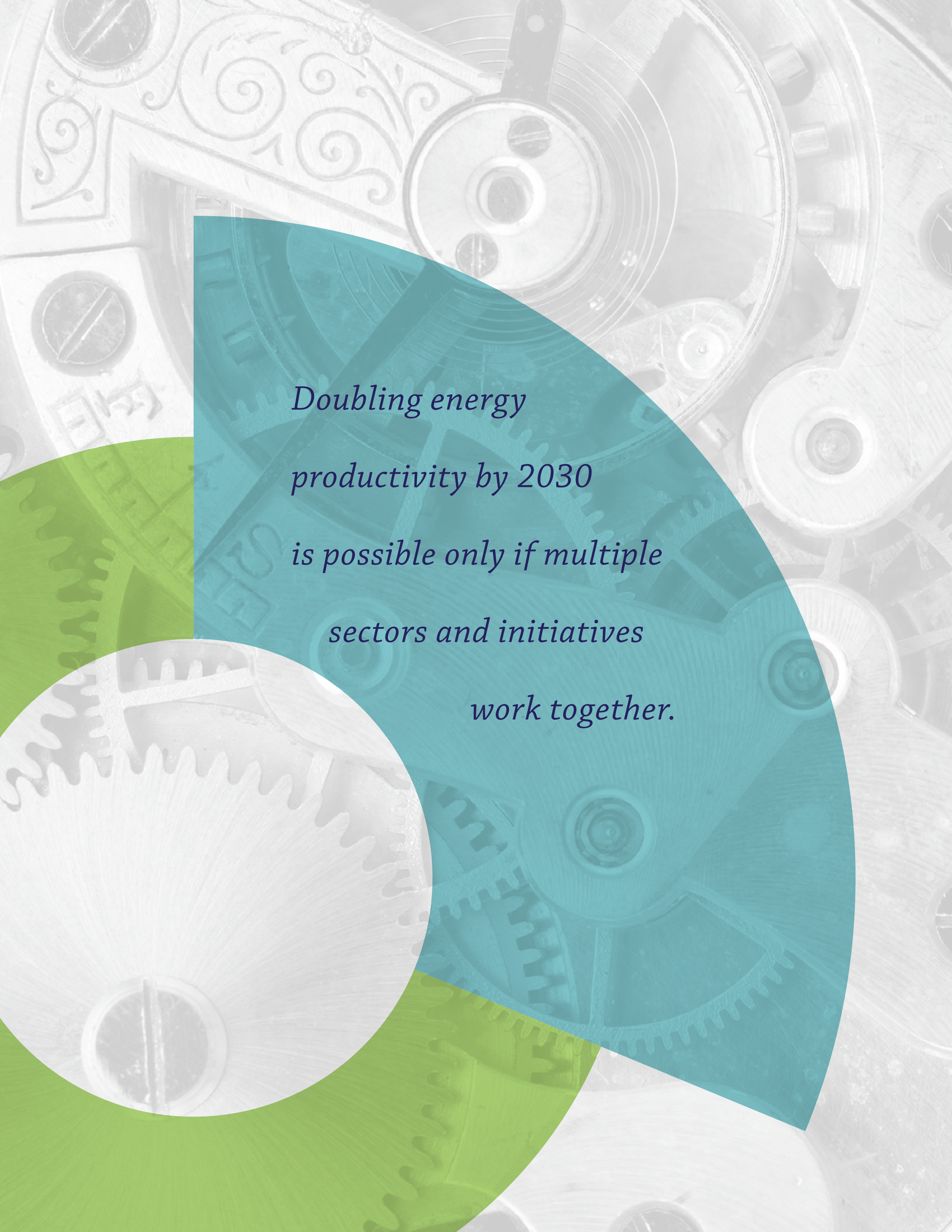

Doubling energy productivity by 2030 is possible only if multiple sectors and initiatives work together.

ANALYSIS & RESULTS

The previous section of the *Roadmap* describes a number of strategies to achieve significant improvements to U.S. energy productivity. In this section of the *Roadmap*, DOE models the impacts of six combinations of productivity improvement strategies, referred to as wedges, to identify the most effective pathway forward. Fully analyzing the effect of those wedges on energy productivity requires a model of interaction between the U.S. economy's use of energy and its GDP. Based on a review of the existing literature on energy productivity and GDP, DOE developed a modeling framework that dynamically relates changes in energy use and investment to changes in GDP.

The model improves upon previous analyses conducted by DOE because it combines robust estimates of the relationships between various sectors of the economy using historical data and because it dynamically estimates the future effects of changes to the economy using those historical relationships. More broadly, the model estimates the net effects of changes to energy use and investments on GDP, capturing any GDP feedback effects caused by energy efficiency investments. Consequently, the model is capable of directly estimating how future changes in both energy use and investments may affect energy productivity. For instance, the model can predict what level of national effort, in terms of investment and energy reduction, is required to meet the energy productivity goal.

3.1 Synthesis of Strategies into Energy Productivity Wedges

The energy productivity strategies presented in the *Roadmap* often involve multiple economic sectors and levels of government. To capture the collective potential impacts of those strategies, DOE has developed six productivity wedges. A summary description of each wedge, including associated investment and energy savings used in the analysis, is provided below. Model inputs for each wedge were developed using assumptions and results from published studies, as summarized in Table 2. The results of these studies were generated using models and assumptions that are separate from the model and analysis developed for the *Roadmap*, and do not represent impacts of specific strategies and actions identified in the *Roadmap*. The results from these studies, however, are assumed to be illustrative of the types of energy and economic changes that would be expected to result from following the *Roadmap* and are appropriate to use as inputs to the energy productivity model. The published studies are best described as prospective analyses that estimate potential energy savings (in Btu and dollars) for a particular economic sector, given a certain level of investment. However, not all sources included estimates of associated investment levels or energy savings in dollars. Where sources did not include dollar energy savings, estimates of these savings were generated using AEO 2014 fuel price projections and estimated energy savings. Note that successful implementation of energy productivity wedges are likely to affect future energy commodity prices. Where a source report did not include energy savings estimates, such as for the Smart Manufacturing wedge, assumptions from the report were used to develop energy savings estimates from AEO 2014 data.

Table 2 presents the productivity wedges and summarizes their connections to the strategies discussed earlier in the *Roadmap*. Note that there are overlaps and interactions between wedges and individual strategies that may be part of several wedges. Energy productivity wedges are entered into the model as changes in overall investment and total energy use. The model does not differentiate between the types of investments and energy savings by sector. More specifically, the model assumes that an increase in investment of $1.00 has the same effect regardless of what sector of the economy the investment occurs. Likewise, the model assumes that a 1 Btu change in energy use has the same effect regardless of the economic sector and the energy carrier. The model does report GDP impacts by three separate sectors: goods, services, and natural resources and utilities. The model does account for energy used to produce the additional goods and services that result from increased investments. This results in a net energy impact that is less than the sum of energy savings of each individual wedge.

Table 2. Summary of Model Analysis Sources and Inputs by Energy Productivity Wedge[158]

Wedge	Summary of Representative Energy Productivity Actions	Sources of Inputs	Inputs
Smart Energy Systems	Implementation of smart grid technologies in transmission and distribution systems and for consumers.	EPRI (Electric Power Research Institute). 2011. *Estimating the Costs and Benefits of the Smart Grid.* Palo Alto, CA: Electric Power Research Institute. EPRI. 2009. *The Potential to Reduce CO2 Emissions by Expanding End-Use Applications of Electricity.* Palo Alto, CA: Electric Power Research Institute.	$738 billion cumulative net cost savings to utilities and consumers; 70 Quadrillion Btu cumulative energy savings by 2030.
Technologies for Buildings Energy Productivity	High achievable potential for adoption of energy-efficient equipment.	EPRI. 2014. *U.S. Energy Efficiency Potential Through 2035*. Palo Alto, CA: Electric Power Research Institute.	5.4 Quadrillion Btu/year energy reduction by 2030; $331 billion cumulative investment costs by 2030; $409 billion cumulative cost savings by 2030.
Buildings Energy Productivity Financing	Building energy efficiency retrofits enabled by energy service agreements, property assessed clean energy, on-bill financing.	Rockefeller Foundation and DB Climate Change Advisors (2012). *United States Building Energy Efficiency Retrofits: Market Sizing and Financing Models.* Frankfurt: Deutsche Bank AG.	Cumulative investment of $279 billion with cumulative cost savings of $717 billion by 2030. 39 Quadrillion Btu cumulative energy savings by 2030.
Smart Manufacturing	ICT that enables energy efficiency in electrical equipment used in manufacturing processes and buildings. Recommendations for government (lead by example, R&D), public utilities, and ICT suppliers.	Rogers, Ethan A., R. Neal Elliott, Sameer Kwatra, Dan Trombley, and Vasanth Nadadur. 2013. *Intelligent Efficiency: Opportunities, Barriers, and Solutions.* Washington, DC: American Council for an Energy-Efficient Economy.	15 Quadrillion Btu cumulative reduction in energy use and $15 billion cost savings by 2030.
Transportation	Technical potential of energy efficiency improvements for light-duty vehicles; adoption of alternative fuel vehicles; reduction of vehicle miles traveled through trip reduction, land use change (e.g., higher densities, walkable neighborhoods), efficient driving, mode switching; and efficient technologies for freight modes.	DOE Office of Energy Efficiency and Renewable Energy, National Renewable Energy Laboratory, and Argonne National Laboratory. 2013. *Transportation Energy Futures* series. http://www.nrel.gov/analysis/transportation_futures/.	Cumulative energy reduction of 152 Quadrillion Btu and cost savings of $4,051 billion by 2030.
Water Infrastructure	Efficiency potential for pumps and other equipment in water supply and wastewater treatment utilities.	WRF (Water Research Foundation) and EPRI. 2013. *Electricity Use and Management in the Municipal Water Supply and Wastewater Utilities.* Denver, CO: Water Research Foundation, Palo Alto, CA: Electric Power Research Institute.	Cumulative energy reduction of 1 Quadrillion Btu and cost savings of $6 billion through 2030.

158 Care was taken to select a set of model inputs that would avoid double-counting investments and energy savings for each energy productivity wedge. However, it was not possible to quantify potential double-counting given the varying level of detail contained in the source reports. The buildings energy productivity technology and buildings finance wedges are the most likely to have some overlap, although this likely does not affect the conclusions drawn from results of the energy productivity analysis. The inputs for the buildings energy productivity-technology wedge were identified in the source report as part of a "high achievable" scenario, which includes barriers that limit adoption of energy efficiency measures. It is assumed that novel funding mechanisms represented by the buildings energy productivity-financing scenario overcome these barriers. As a result, the investments and energy savings are additional and not double-counted.

The published studies can be described as prospective analyses that estimate potential energy savings (in Btu and dollars) for a particular economic sector, given a certain level of investment. However, not all sources included estimates of associated investment levels or energy savings in dollars. Where sources did not include dollar energy savings, estimates of these savings were generated using AEO 2014 fuel price projections and estimated energy savings. Note that successful implementation of energy productivity wedges is likely to affect future prices of energy commodities. Where a source report did not include energy savings estimates, such as for the Smart Manufacturing wedge, assumptions from the report were used to develop energy savings estimates from AEO 2014 data.

Energy productivity wedges are entered into the model as changes in overall investment and total energy use. The model does not differentiate between the types of investments and energy savings by sector. In other words, the model assumes that an increase in investment of $1.00 has the same effect regardless of the economic sector in which the investment occurs. Likewise, the model assumes that a one-Btu change in energy use has the same effect regardless of the economic sector or the energy carrier. The model does report GDP impacts by three separate sectors: goods, services, and natural resources and utilities. The model does account for energy used to produce the additional goods and services that result from increased investments. This results in a net energy impact that is less than the sum of energy savings of each individual wedge.

- **Smart Energy Systems:** Energy systems, including those that participate in the generation and delivery of electricity, are sources and enables the backbone of improvements to U.S. energy productivity. Broad and deep transformations involving the effective integration of information and communications technologies are required to enable transitions to distributed energy resources, real-time energy pricing, smart appliances, and increased energy efficiency. The Smart Grid is estimated to produce cumulative benefits of $23.7 billion–$46.8 billion and 42 billion kWh–134 billion kWh of electricity savings by 2030.[159]
- **Technologies for Building Energy Productivity:** Improving R&D and increased focus on deployment is required to bring the next generation of energy productivity. Enabling technology and equipment for commercial and residential buildings requires both the widespread use of currently available energy-efficient technologies and practices, and the development of next generation technologies. Annual investment in the residential, commercial, and industrial sectors of $7 billion, $12 billion, and $74 million respectively are estimated to yield combined energy savings of 5.4 quads.[160]
- **Financing for Building Energy Productivity:** Significant changes to financing mechanisms are required to ensure that energy productivity-enabling technology is purchased by businesses and households. Strategies include

159 C. Gellings, *Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid* (Palo Alto, CA: Electric Power Research Institute, 2011), accessed July 2015, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001022519.

160 S. Mullen-Trento, *U.S. Energy Efficiency Potential Through 2035* (Palo Alto, CA: Electric Power Research Institute, 2014), accessed July 2015, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001025477.

on-bill financing, creating secondary markets for energy efficiency loans, and tailoring financing for the unique needs of small and medium enterprises. Building retrofits enabled by new financing mechanisms are assumed to result in a 10-year cumulative investment of $279 billion and 3.0 quads of annual energy savings in 10 years.

- **Smart Manufacturing:** Sensors and other ICT will allow industries better control over their processes, as well as improved energy management of their buildings. Based on analysis by the American Council for an Energy-Efficient Economy, annual energy savings are estimated to reach 2.1 quadrillion Btu by 2030.[161]
- **Transportation:** Increasing the energy productivity of moving goods and people relies on developing and deploying new technologies that increase vehicle efficiency; increasing options for mass transit; and better integrating transportation needs with the built environment. Model inputs for this wedge are net annual energy reduction of 16 quads/year by 2030 and investments of $531B/year by 2030.
- **Water Infrastructure:** The linkages between energy and water systems provide opportunities to increase energy productivity. Specifically, water and waste water treatment plants can improve energy efficiency and demand response, implement emerging technologies and processes, and deploy energy recovery and generation technologies. Improvements made in this wedge are assumed to result in an energy reduction of 0.14 quads/year by 2030 and investments of $800M/year by 2030.

Table 3. Energy Productivity Strategies Organized by Productivity Wedge

	Smart Energy Systems	Technologies for Buildings Energy Productivity	Buildings Energy Productivity Financing	Smart Manufacturing	Transportation	Water Infrastructure
FEDERAL GOVERNMENT						
Research and Development	X	X		X	X	X
Performance Information and Product Standards	X	X			X	X
Tax Policy	X	X	X		X	X
Workforce Training	X	X			X	
Demonstration and Leading by Example	X	X	X		X	X

161 Ethan A. Rogers, R. Neal Elliott, Sameer Kwatra, Daniel Trombley, and Vasanth Nadadur, *Intelligent Efficiency: Opportunities, Barriers, and Solutions, Research Report E13J* (Washington, D.C.: American Council for an Energy-Efficient Economy, 2013), accessed July 2015, http://aceee.org/research-report/e13j.

	Smart Energy Systems	Technologies for Buildings Energy Productivity	Buildings Energy Productivity Financing	Smart Manufacturing	Transportation	Water Infrastructure
STATE GOVERNMENT						
Energy Efficiency Portfolio Standards		X	X			
Energy Productivity Financing		X	X			
Combined Heat and Power		X	X			
Smart Regional Transportation Solutions						X
Building Codes		X				
LOCAL GOVERNMENT						
Local Ordinances to Facilitate Distributed Resources, where appropriate	X	X				X
Building Energy Dis-closure Ordinances	X	X	X			
Creating Advanced Manufacturing Ecosystems		X	X		X	X
Built Environ-ment-Transportation Nexus	X	X				X
COMMERCIAL BUSINESSES						
New Financing Models		X	X	X		
Workforce Training	X	X		X	X	
INDUSTRIAL BUSINESSES						
Public-Private Partnerships	X				X	X
Energy Management Certification		X			X	
Advanced Manufac-turing					X	X
Innovative Products to Enable Energy Savings	X	X		X	X	X

	Smart Energy Systems	Technologies for Buildings Energy Productivity	Buildings Energy Productivity Financing	Smart Manufacturing	Transportation	Water Infrastructure
ELECTRIC UTILITIES						
Grid Infrastructure Productivity	X					
New Business Models	X		X		X	X
Rate Design	X	X			X	X
WATER UTILITIES						
	X			X		
HIGHER EDUCATION INSTITUTIONS						
Workforce Training	X	X			X	X
Accelerating Energy Productivity from the Lab to the Real World	X	X			X	X
HOUSEHOLDS						
Energy Productivity at Home		X				X

3.2 Overview of Energy Productivity Analysis Framework

As described in the previous section, the strategies identified in the *Roadmap* are aggregated into six illustrative energy productivity wedges. These wedges are representative of the *Roadmap* strategies and illustrate the types of economic and energy changes that could be expected following implementation of the *Roadmap*. The investments and corresponding reductions in energy use for each wedge are described in Table 2 and serve as inputs to the modeling efforts.

In the abstract, diverting spending from one use (such as consumption) to another use (such as investments in energy-efficient technology) has ambiguous effects on GDP that depends on the relative GDP multipliers of the specific type of consumption and investment. (The GDP multiplier captures the direct and indirect effects of a change in direct spending patterns on GDP.) Thus DOE built a model to better understand how changes in direct spending, such as increases in energy efficiency investment as described by the wedges, would produce indirect effects on GDP. The combination of those direct and indirect effects represent the net effects of changes to energy use and investments on GDP, capturing any GDP feedback effects caused by energy efficiency investments.

Specifically, DOE employed a vector error correction model (VECM) to estimate the effect of the wedges on U.S. GDP. This approach is commonly used by economists as a forecasting tool because of its ability to robustly estimate historical relationships between various sectors of the economy and then use those historical relationships to dynamically predict economic growth in a way that incorporates interactions and feedback effects between economic sectors. The model improves upon previous analyses conducted by DOE. The model has three component parts, each with two periods: the estimation period when historical relationships between sectors are statistically estimated (1970 to 2013), and the forecast period (2014 to 2030).

The objective of the first set of VECM equations is to dynamically estimate GDP and energy use with feedback effects. The equations capture how energy expenditures interact with consumption and investment, two major components of GDP. The primary actors in all wedges are investors, privately held businesses, and households; this set of equations models the economic relationships between those actors and energy expenditures.

The objective of the second set of VECM equations is to estimate energy prices such that energy expenditures can be converted to the quantity of energy used. Energy expenditures were estimated in the first set of equations, which consist of prices for various energy commodities multiplied by the quantities of those energy commodities consumed. The second set of VECM equations captures feedback effects between prices, quantities and other macroeconomic variables including consumption, investment, and total energy expenditures.

The objective of the third set of VECM equations is to estimate the changes in activity for each modeled sector of the economy. The model decomposes GDP into three component sectors: goods, services, and natural resources combined with utilities. These sectors were chosen because they correspond well with the structure of the model, which focuses on GDP and energy. The goods sector contains agriculture, manufacturing, and construction. The natural resources and utilities sector contains mining and other extractive industries as well as utilities. The services sector contains all other industries, including sales, warehousing, transportation, information business services, leisure services, and other services. These equations rely on the variables estimated in the first two sets of equations, as well as other variables such as the size of the labor force, net exports, and industrial production.

Data for the model is drawn primarily from the Energy Information Administration (EIA) with sector-specific data pulled from the Bureau of Economic Analysis (BEA) and the World KLEMS Initiative.[162] Specifically, the VECM model relies on historical data between 1970 and 2013 and forecasts from 2014 to 2030, which is developed in EIA's AEO 2014. The model's baseline does not precisely match that of AEO 2014 because of different model structure and assumptions, although the two baselines are similar. Data that relate economic growth to the use of economic inputs are provided by the Bureau of Economic Analysis (BEA) and the World KLEMS Initiative. These data are widely used in productivity analysis to estimate how changes in the use of economic inputs affect changes in economic output.

Energy productivity wedges are entered into the model as increases in overall investment and reductions in total energy use. The model does not differentiate by sector between the types of investments and energy savings by sector. More specifically, an increase in investment of $1.00 is the same regardless of what sector of the economy the investment occurs. Likewise, the model assumes that a 1 Btu change in energy use is the same regardless of the economic sector and the energy consumer.

This modeling technique is not without limitations. Perhaps the most significant hurdle to successful implementation of the model is the large amount of historical detail required for each sector modeled. As the number of sectors increases, longer time series are necessary to find statistically significant relationships between industries. Other techniques that are often used for similar forecasting exercises, such as input-output (I-O) and computable general equilibrium (CGE) models, often have even more sector-level detail, yet rely on theoretical interactions between sectors rather than observed historical relationships. In addition, I-O models are described as static because they assume that prices, technology, and productivity remain unchanged over time. And although relative prices can change in a CGE model, CGE model results are dependent on what the modeler specifies, instead of historical relationships, with respect to the sensitivity of changes in energy consumption by each industry or households are to prices. Thus, the VECM model was attractive because it is a dynamic model that relies on historical data to identify relationships between sectors.

3.3 Energy Productivity Potential

Given the scenario outlined above for all six productivity wedges, the model shows that doubling energy productivity by 2030 is possible but only if multiple sectors and initiatives concurrently work together. By 2030, model results show that

162 KLEMS is an acronym for the five components of intermediate inputs used by industries: capital (K), labor (L), energy (E), materials (M), and services (S). These data are widely used in productivity analysis to estimate how changes in the use of economic inputs affect changes in economic output. See, for example: Douglas Koszerek, Karel Havik, Kieran McMorrow, Werner Röger, and FrankSchönborn, *An Overview of the EU KLEMS Growth and Productivity Accounts* (Brussels: European Commission Economic and Financial Affairs, 2007), accessed July 2015, http://ec.europa.eu/economy_finance/publications/publication9467_en.pdf and Era Dabla-Norris, Si Guo, Vikram Haksar, Minsuk Kim, Kalpana Kochhar, Kevin Wiseman, and Aleksandra Zdzienicka, *The New Normal: A Sector-Level Perspective on Productivity Trends in Advanced Economies* (Washington, D.C.: International Monetary Fund, 2015), accessed July 2015, http://www.imf.org/external/pubs/ft/sdn/2015/sdn1503.pdf.

GDP (2005$) increases to $22.5 trillion and primary energy use falls to 78 quads. In comparison, the Energy Information Administration's (EIA) *Annual Energy Outlook* (AEO) 2015 projections are $21.7 trillion and 103 quads Btu in 2030. Thus, in 2030, the Roadmap scenario achieves 3.6 percent higher GDP and 24 percent lower primary energy use than AEO 2015 projections. These results are equivalent to increasing energy productivity in 2030 to $287/MMBtu, which is more than double the modeled 2010 baseline of $134/MMBtu, as shown in Figure 7. From 2014 to 2030, energy productivity increases at an annual average rate of approximately 4.2 percent. This rate of improvement is slightly greater than the rate experienced from 1981 to 1983, the period of the largest multi-year energy productivity growth experienced between 1970 and 2010. The buildings- and transportation-related productivity wedges offer the greatest potential to drive energy productivity improvements. Although these wedges alone may result in significant progress, achieving the doubling goal requires many actors working together across all sectors of the economy.

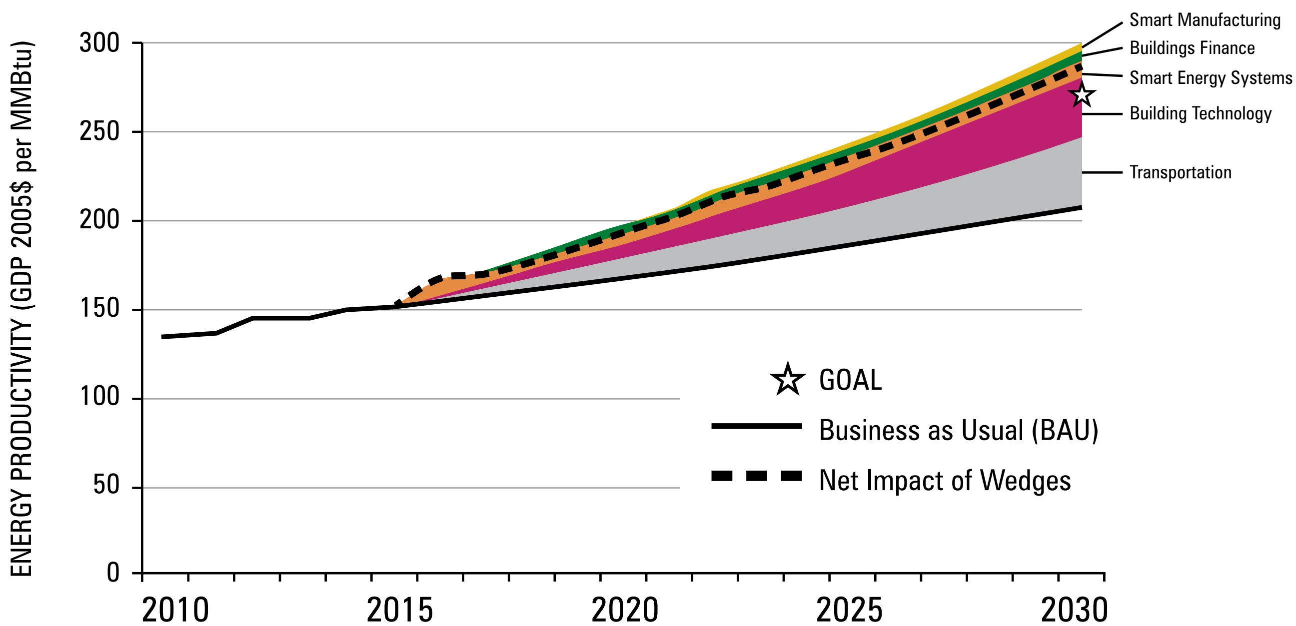

Figure 7. Projected Energy Productivity Benefits to 2030

The wedges in aggregate contribute to a net increase of $922 billion in U.S. GDP by 2030. This is primarily supported by an increase of $753 billion in household expenditures, although it is also driven by a $169 billion increase in investment.

Consumption and investment represent allocations of expenditures in an economy. These are not modeled as two different groups of consumers. One household, for example, could invest while also making personal consumption expenditures. The wedges analyzed involve changing these allocations and subsequently receiving returns on these investments in the form of savings from reduced energy expenditures. Investors are also the owners of businesses, so business investments also directly affect households. These capital expenditures must come from the population, and subsequent returns then accrue back to these investors. Put more simply, households are able to increase their purchases of other goods and services by making energy productivity investments that reduce their energy bills. By 2030, there is a 26-quad gross reduction in energy consumption compared to the baseline. Over the period of the analysis, the net total reduction is 23.7 quads. The model does account for energy used to produce the additional goods and services purchased by households. This results in net energy savings values that are approximately 14 percent smaller than the 26-quad gross reduction specified in the model inputs for each productivity wedge. The effect is shown in Figure 7 as the dashed line.

Producers of goods and services are also shown to benefit from increased economic activity spurred by energy productivity investments. As shown in Figure 8, the service industry exhibits the most significant growth, with a nearly $1.08 trillion increase in baseline by 2030. By 2030, goods-providing industries increase by approximately $51 billion over the model baseline. Declines in economic activity in the natural resources and utilities are due to decreases in energy expenditures and demand for production from utilities and their supply chain. By 2030, this decrease is $248 billion, or -1.6 percent of GDP, below baseline. Because the analysis focuses on investment and energy spending, these results do not capture other benefits that are likely to accrue to the natural resources and utilities sector, such as reduced economic losses from power outages (discussed in Section 2.3.1.)

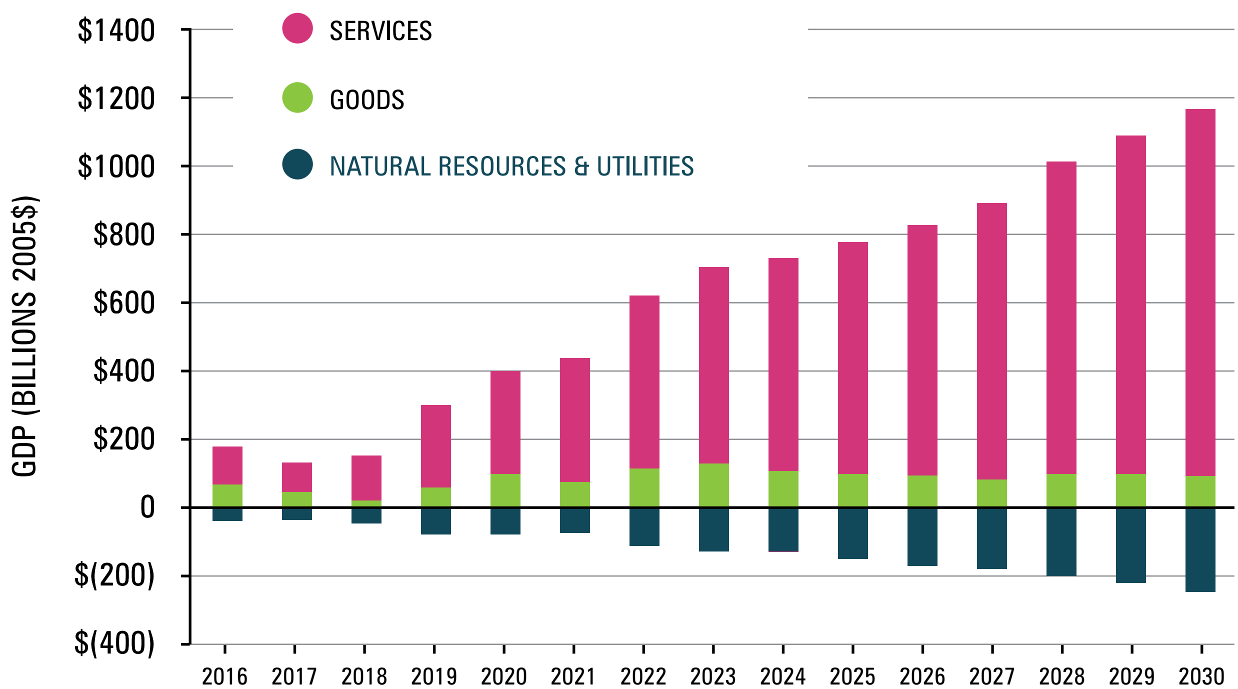

Figure 8. Projected Changes to GDP by Sector (Billions 2005$)