McKinsey&Company

Climate Change Special Initiative

The US Low Carbon Economics Tool

A suite of models for estimating the economic implications of energy and climate policies for the United States of America

Preface

Over the past 4 years, McKinsey & Company has worked with leading institutions and experts to develop a framework and fact base to model the costs and potential of different options for reducing greenhouse gas (GHG) emissions. We first tackled this work at a global level, and subsequently conducted country-specific analyses for major GHG-emitting nations and regions. To date, we have published reports on abatement options for more than 20 countries.[1]

In April 2009, we began creating an analytic tool that would allow interested parties to examine the overall economic implications for the U.S. of various climate and energy policies. This effort complements our previous work in three significant ways. First, while our previous efforts focused on quantifying the direct costs and potential of different abatement measures, this new tool includes indirect and induced effects as well. For example, where our previous work calculated only the direct consumer costs and benefits of implementing a particular efficiency measure (such as installing a more efficient refrigerator), this work also calculates the impact on employment among appliance manufacturers and electric utilities, the effect on electricity prices, and so on. Tracing economic impacts across the economy allows us to quantify the economic implications at the industry, state, and national level. Second, we saw a critical need in the public policy arena for a tool based on a common analytical approach and fact base that different stakeholders could customize and use to run their own analyses. Third, this effort responds to requests from many of our corporate clients for help in planning their energy-related asset portfolios in light of potential legislation.

We are now making the custom modeling tool we developed as a result of this work—which we call the U.S. low carbon economics tool—available for others to use. While we are publishing this white paper outlining the technical specifications of the model, we want to be clear that McKinsey does not take positions on specific policy choices. Any policy conclusions from the use of the model are the responsibility of the users themselves.

During this effort, the team conducted more than 100 interviews with representatives of government agencies, public and private companies, academic institutions, research foundations, and non-governmental organizations, as well as many independent experts. They helped our team gain access to data, acted as thought partners while we developed and refined our tool, and encouraged and challenged us at each stage. These individuals, corporations and NGOs have given generously of their time and knowledge and deserve our warmest thanks. We would like to especially acknowledge Deutsche Bank, Duke Energy, DuPont, PG&E, Shell, ClimateWorks, the Energy Foundation, the Natural Resources Defense Council, the United Nations Foundation, and the World Resources Institute.

While our work has benefited enormously from these contributions, **the methodology underlying our tool is solely the responsibility of McKinsey & Company.** This paper does not necessarily reflect the views of any of our reviewers or contributors.

Chapter 1 provides a brief overview of the tool and the types of questions it can answer, while the remaining sections address more technical issues and are aimed at economic experts and others who will actually use the tool. Chapter 2 provides a technical description of the overall model architecture and the linkages among the parts of the model. Chapter 3 explains how we quantified the options for GHG reduction across the U.S. economy and calculated the abatement levers for each sector. Chapter 4 discusses the energy pricing models. Chapter 5 details the interface between our tool and the Policy Insight (PI+) tool created by

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[1] See, for example, *Costs and Potentials of Greenhouse Gas Abatement in the Czech Republic, An Australian Cost Curve for Greenhouse Gas Reduction, Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost, Japan GHG Abatement Cost Curve,* and *Costs and Potential of Greenhouse Gas Abatement in Germany.* These and other country reports can be found at http://www.mckinsey.com/clientservice/ccsi/costcurves.asp.

Regional Economic Models, Inc. (REMI), which we used to generate likely outcomes for the 48 continental states and 165 private-industry sectors.

A number of public and private organizations are currently using the model. We welcome any feedback on the model and its potential applications. Please direct your comments to USLCEtoolkit@mckinsey.com

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McKinsey & Company

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1. Overview of the U.S. Low Carbon Economics Tool

The U.S. low carbon economics tool is a set of multiple interlinked models that calculates the potential economic impacts of a wide range of potential energy and climate policies – including both cap-and-trade and uncapped policy frameworks – for the 48 continental United States and 165 industry sectors. For users that do not require that level of granularity, the tool allows analyses at a nationwide level, for 10 regional subsets, or for a smaller number of aggregated industry sectors. Users can define the type of policy to model (e.g., efficiency mandates combined with a clean energy standard but without a cap, or a cap-and-trade system with efficiency mandates and subsidies for clean energy) and a number of background assumptions (e.g., learning rates for clean technologies), and the tool generates an overview of the policy's impact on GDP, jobs, and prices at the state and industry level by year through 2030.

This chapter highlights what makes this tool distinctive, explains how the tool works in lay terms, gives examples of the types of questions it can answer, and outlines its limitations.

What's distinctive about this tool?

While there are many excellent tools that estimate the impact of potential energy and climate policies on the U.S. economy[2] we believe that our approach offers several unique strengths.

First, it draws upon McKinsey & Company's proprietary intellectual property—specifically, five pieces of work:

1. The GHG abatement curve models for the U.S. developed as part of two McKinsey publications on this topic. [3] These models provide year-by-year estimates of the costs and the GHG abatement potential of hundreds of possible measures across all sectors of the U.S. economy.

2. The granular database of U.S. energy-efficiency opportunities that was used as the basis for McKinsey's July 2009 report, ***Unlocking Energy Efficiency in the U.S. Economy.*** [4] This database quantifies the costs and energy savings of 675 energy-efficiency measures in building and industrial sectors (e.g., LED lighting, high-efficiency refrigerators). All results are available broken down by region and customer segment—for example, for low-income families living in rented houses in New England in which the owner pays the utility bill.

3. A multi-regional power price model for the U.S. that couples an hour-by-hour dispatch and transmission model with appropriate pricing logic for regulated and deregulated regions.

4. Technology learning curves developed during the course of multiple engagements with traditional energy and clean-tech companies.

5. An international offset supply model based upon McKinsey's Global GHG Abatement Curve v2.0 and plausible scenarios for the supply and demand of international offsets.

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[2] For example, the Energy Information Administration's National Energy Modeling System (NEMS), the Environmental Protection Agency's ADAGE, IGEM, and IPM, and the "G-Cubed" general equilibrium model used by the Brookings Institute.

[3] *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?* and *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve.*

[4] http://www.mckinsey.com/clientservice/electricpowernaturalgas/US_energy_efficiency/

Second, the results are provided at a high level of granularity, with all key results available for the 48 continental states and 165 industry sectors (plus private households and government) on an annual basis from 2010 to 2030. [5]

Third, the tool embodies a comprehensive approach, considering several components that are not always included in other publicly available analyses. Examples include the detailed implications of spending changes as new policies are put in place (e.g., reduced consumer spending on electricity and gas compensated by increased spending on clothing, restaurants, and other discretionary items), interactions between potential U.S. and international carbon markets, and the implications of different uses of carbon revenue if it exists.

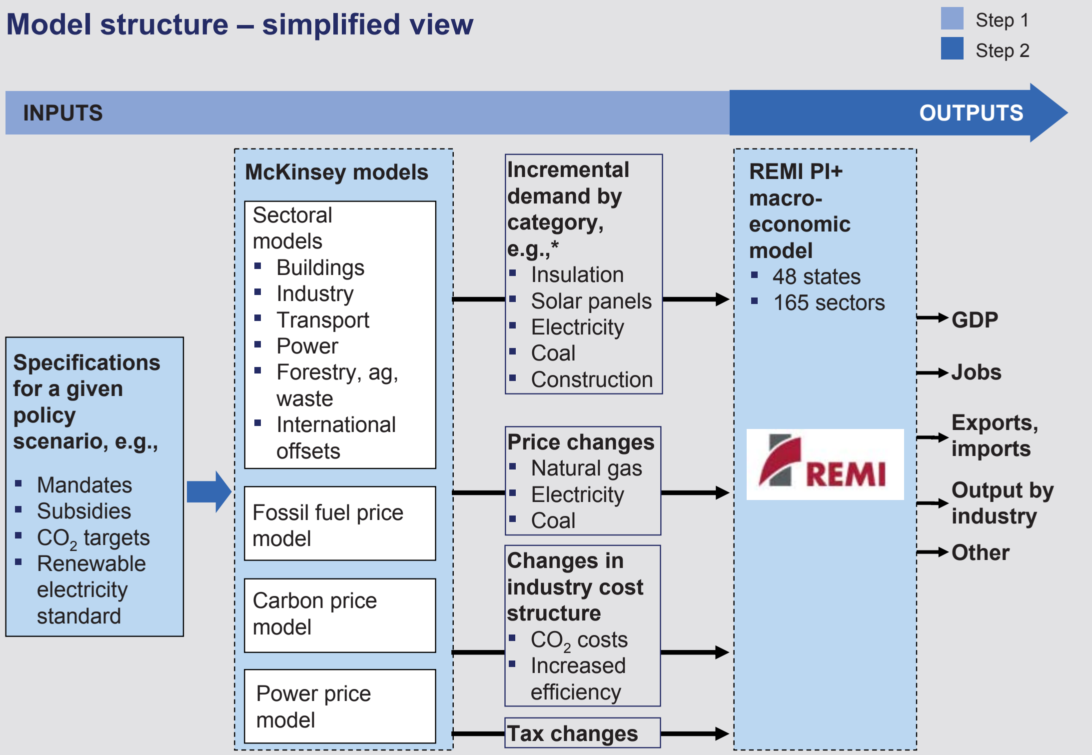
Finally, and most importantly, our modeling approach has significant built-in flexibility that lets users analyze and compare multiple policy variations, helping to clarify what is (and is not) at stake in key decisions.

How does the tool work?

Exhibit 1 provides a schematic overview of the tool. Users define the policy under consideration by

Exhibit 1

Model structure – simplified view



* Additional processing by McKinsey models distributes raw demand numbers across appropriate REMI industries

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[5] See Appendix for the list of industries.

selecting multiple parameters from hundreds of items, such as annual emissions targets, level of loan guarantees for clean power, and yearly mileage standards for light duty vehicles. This is an involved process that requires a significant time investment by both the user and McKinsey. The tool then follows a two-step process to calculate how these policies affect the U.S. economy.

Step 1 calculates the four primary direct effects of the policy:

- **Changes in demand.** Any policy change can trigger substantial demand changes across the economy, and a typical set of policies affects hundreds of spending categories. The result, for example, might be greater demand for solar panels, insulation, or LED lighting, or reduced demand for electricity and fossil fuels. Increased spending in one area will generally be offset by decreased spending in another. For example, if government mandates require more expensive higher-efficiency appliances, consumers may well reduce other types of spending to fund this outlay.[6] Our tool combines McKinsey's abatement curves with models of consumer, investor, and business behavior to quantify the expected size of these demand shifts in each year through 2030. Chapters 2-6 provide additional detail.

- **Changes in energy prices.** Energy price changes may be triggered in multiple ways, including reduced or increased reliance on expensive peak-capacity electricity as demand changes, lower marginal coal production costs if demand falls, and, in the case of policies with carbon pricing, higher carbon costs for electric generators, carbon revenue rebates to electric generators and consumers, and potential changes in pricing mechanisms (e.g., increases in the "coal floor" for natural gas prices when carbon prices rise). Our tool models these and other factors to calculate potential deflections from business-as-usual pricing levels.

- **Changes in industry cost structure.** Some industries will see increased costs (along with some potential reductions) from energy price changes, the direct and indirect effects of carbon prices (if applicable), and carbon revenue refunds (e.g., free allocations of emissions permits under a cap-and-trade system). The tool captures this effect by assigning to each industry the cost changes that are appropriate to its energy consumption and (if necessary) covered GHG emissions. Under some policy scenarios, some industries lower their operating costs through capital investments that increase efficiency. The impact of these factors is calculated based on the industrial and commercial abatement curves discussed in Chapter 3.

- **Changes in taxes.** Policies that increase government spending (e.g., subsidies for renewables) will eventually have an impact on taxes. We model this by assuming that incremental spending is financed at prevailing rates for 30-year government bonds and increase taxes by the amount required to service this debt. Indirect tax consequences (e.g., reduced corporate tax payments if profits fall) are handled within the macroeconomic model.

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[6] Note that the demand impacts from a single change in purchase will typically be spread over multiple years. Two effects are tracked in our model. First, changes in capital expenses that have long-lived effects on operating expenses. If consumers are required to buy more expensive, high-efficiency appliances in year 1, for example, they will have less money to spend on other items in year 1 but more money in subsequent years as the energy savings accrue. Second is financing. If increased capital costs are funded through borrowing, the reductions in spending that pay for them will be spread over several years. We assume that incremental capital expenses will be funded by borrowing at a national level—a reasonable approximation of what has happened historically.

Step 2 aggregates these changes into the appropriate sectors and feeds them into a macroeconomic model of the U.S. economy created by Regional Economic Models, Inc. (REMI). This dynamic, general equilibrium model calculates the overall economic implications of the policy as the U.S. adapts to new levels of demand, prices, costs, and taxation. Multiple effects are taken into account, including supply chain impacts when demand for an industry's product changes, revenue reductions for industries if increased costs reduce demand for their products or make them less competitive internationally, and shifts of workers and capital into industries and regions with higher returns.

At the end of this two-step process, the tool provides multiple outputs for analyzing the impact of the given policy—for example, electricity prices by year and region; GDP and job increases or decreases by year, state, and industry; and incremental spending on clean technologies; and, when applicable, carbon prices by year. These outputs can be used to address a wide range of questions that are relevant to policy makers, business leaders, investors, and consumers. The following section illustrates the kinds of questions that the tool is designed to answer.

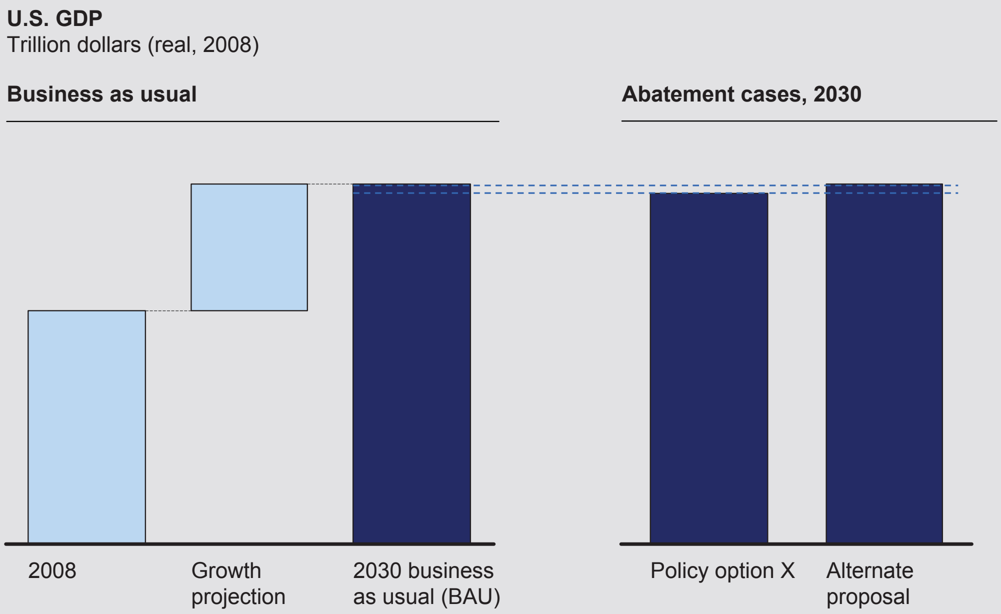
What questions can this tool address?

Overall economic outcomes

- What is the expected national GDP and jobs impact of a given policy proposal? How would changing different aspects of the policy affect overall economic outcomes? Exhibit 2 shows a sample result

Exhibit 2

Sample result – overall GDP impacts of abatement



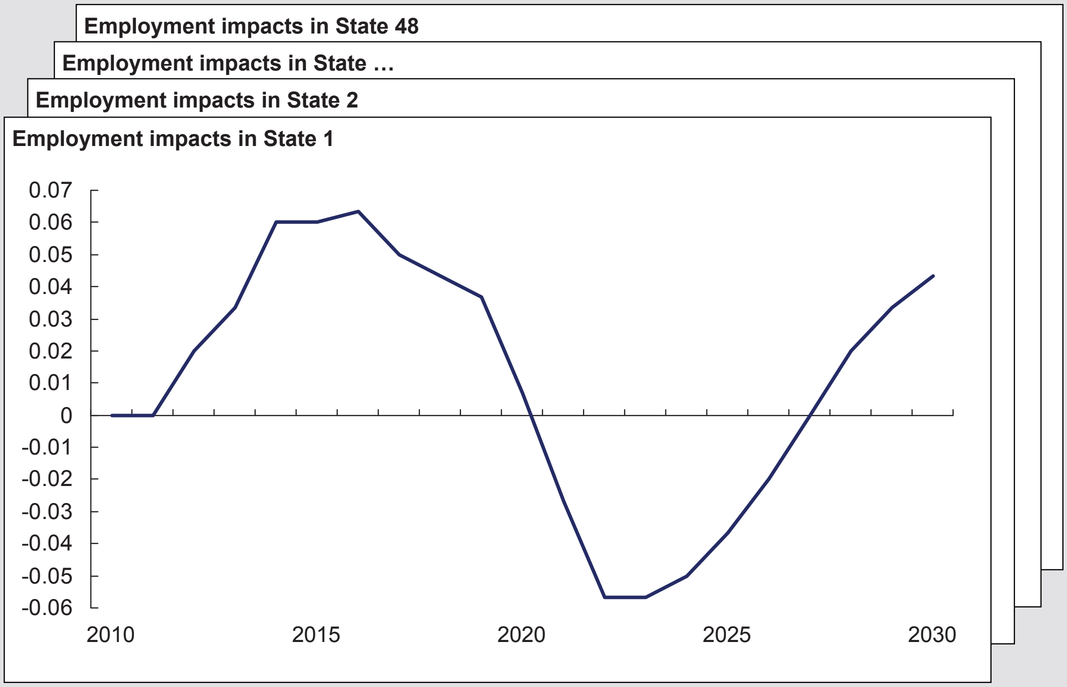
from an analysis of this type, in which the 2030 US GDP in the case of two different policy options is compared with the projected business-as-usual (BAU) GDP, which shows strong growth between today and 2030.

- What are state-level GDP and jobs impacts of a given policy proposal? Exhibit 3 shows how employment in the lower 48 states would compare with BAU growth in a hypothetical scenario.

Exhibit 3

Sample result – policy scenario X could differentially affect employment relative to BAU growth in individual states

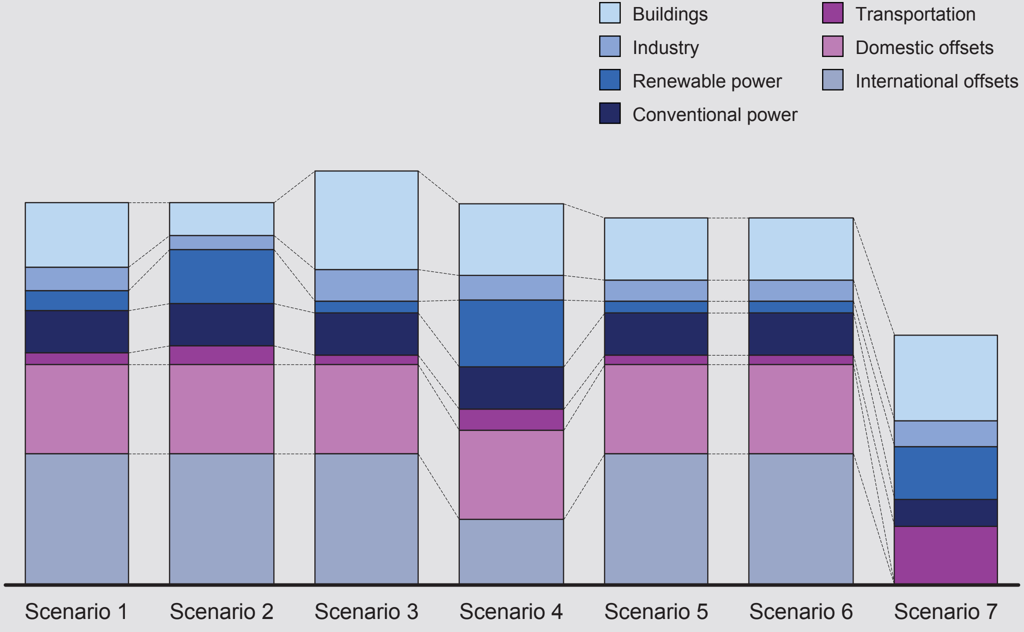
% change relative to BAU



Emissions reduction

- What are the potential sources of abatement under various policy scenarios? From which sectors does abatement come? How does the existence of a cap affect emissions? Exhibit 4 illustrates how the tool would answer this question.

Exhibit 4



Sample result – abatement could come from a mix of different sectors depending on policy scenario

Abatement by sector, 2030

Carbon prices

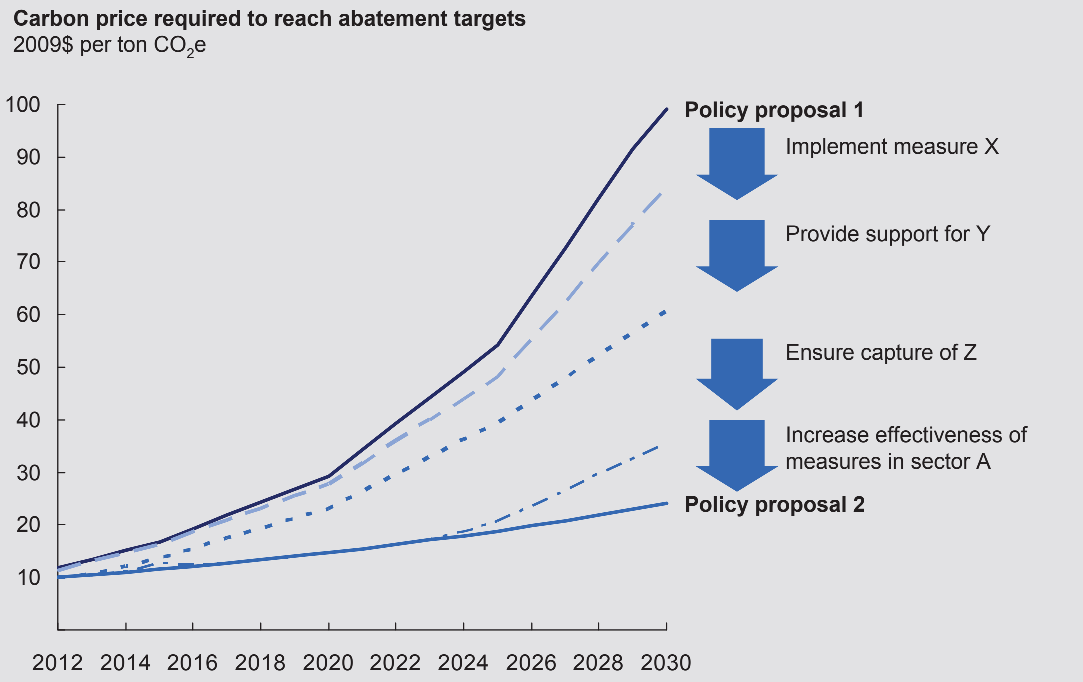
- If a cap-and-trade system were in place, what range of carbon prices would we expect to see through 2030?

- If in place, how would carbon prices be affected by potential complementary policies such as stricter fuel economy standards, buildings efficiency measures, or renewables subsidies? Exhibit 5 presents a sample output from this type of analysis. As the figure suggests, these policies can have a significant impact on carbon prices if they compel actions that would not otherwise be selected by the market, and if these reductions apply against the cap.

- What is the impact of different carbon pricing mechanisms, e.g., cap-and-trade versus sector-specific policies with no cap-and-trade system?

Exhibit 5

Sample result – policy choices affect carbon prices



- How are carbon prices and GDP impacts affected by price collars, different levels of domestic and international offsets, and other policies?

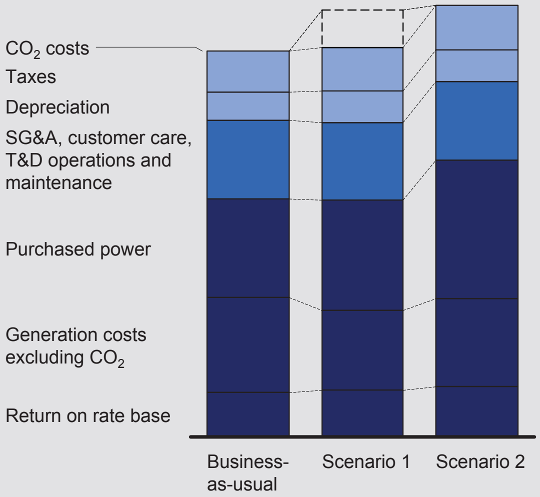
Power generation

- How are power prices affected by different deployment scenarios for nuclear power, coal with carbon capture and sequestration (CCS), and renewables?
- What impact do policy scenarios have on retail electricity prices (Exhibit 6)? What would this imply for GDP and jobs?
- What impact would different energy-efficiency and clean power legislation have on the power sector generation mix—and, in particular, on the coal and natural gas power generation sectors? Exhibit 7 presents a sample result for this type of analysis.
- How do different policies (e.g., low-cost loans vs. subsidies vs. renewable portfolio standards) affect energy asset-investment decisions? How does the outcome change for different fossil fuel prices?
- What are the future market sizes for various clean technologies under different policy scenarios?

Exhibit 6

Sample result – policy scenarios affect retail electricity prices and their components to varying degrees

Components of US average retail electricity price in 2030



Explanation of trend

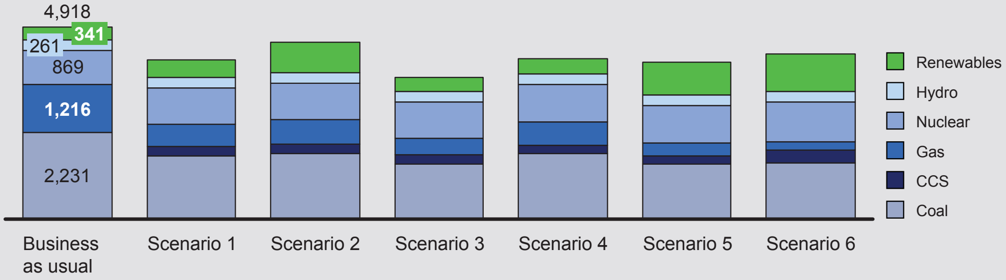
- Scenarios with a cap and carbon pricing impose CO_2 costs
- Slightly higher taxes and depreciation from larger rate-base when renewables are deployed
- Minimal impact on overhead
- Wholesale prices increase in cap-and-trade scenarios due to direct cost of allowances but in general can move in either direction
- Quantities of purchased power increase due to PPAs with renewables providers
- Generation costs decrease in abatement scenarios from reduced fossil fuel consumption
- Ratebase increases in abatement scenarios due to higher capex for renewables and need to allocate existing ratebase over fewer units sold

Exhibit 7

Sample result – power generation mix would depend on policy scenario and abatement required from power sector

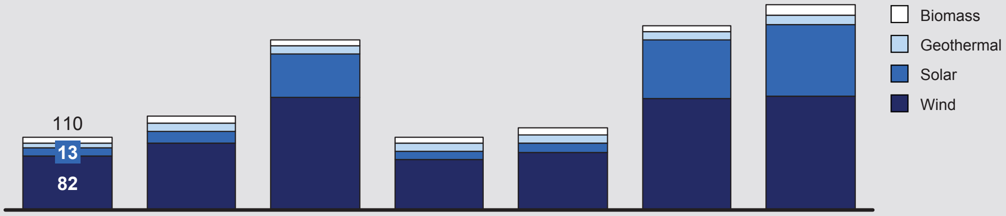
Generation mix by type

TWh, 2030



Renewables installed capacity by type

GW installed, 2030

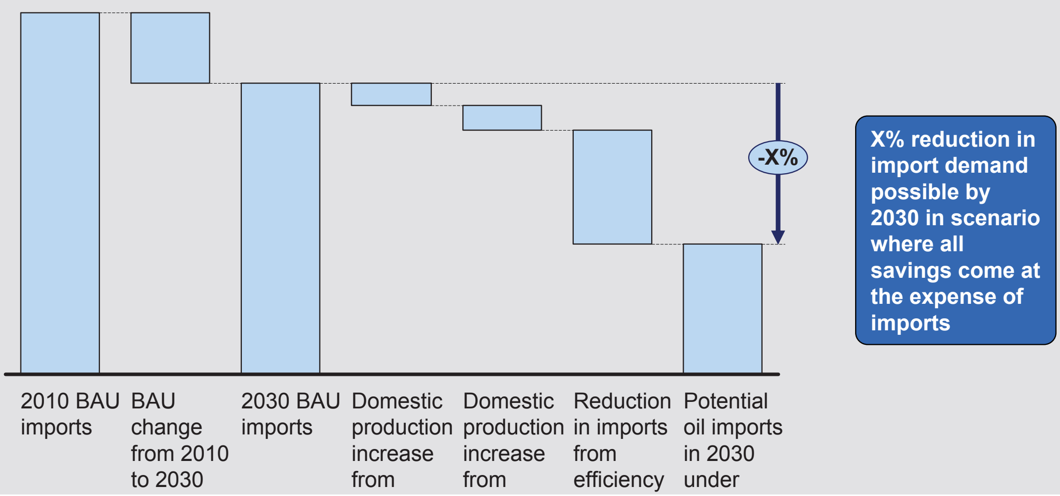


Transport

- What are the energy security implications of different types of transport legislation? Exhibit 8 gives a sample analysis of this question.

Exhibit 8

Sample result – policies A, B, and C could significantly reduce U.S. oil imports by 2030



X% reduction in import demand possible by 2030 in scenario where all savings come at the expense of imports

- How would potential transport policies (e.g., subsidies for biofuels, standards and incentives for more efficient vehicles) affect GDP and jobs?

Energy efficiency

- What are the GDP costs and benefits to the United States of capturing differing amounts of energy-efficiency potential? How does this vary by state? Exhibit 9 illustrates one type of output the model can produce to address this question.

- What would be the costs, consumer savings, and job creation from specific efficiency legislation—for example, a national program to retrofit buildings?

Allocations

- In a cap-and-trade system or carbon tax system, how would different uses of carbon revenue (e.g., free allowances, consumer rebates) affect industries and states? What sort of reallocation would be needed to keep the GDP impact on a given industry/state at less than X%? Exhibit 10 shows the kind of result that the tool can generate.

Exhibit 9

Sample result – specified package of energy efficiency measures could result in significant savings across the U.S.

Reduction in annual household electricity bills

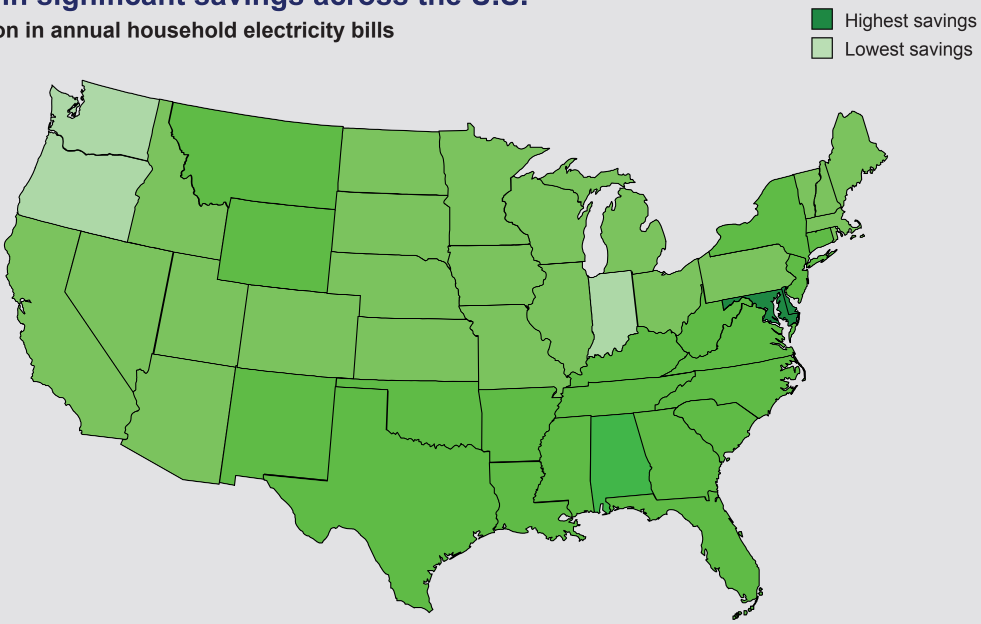
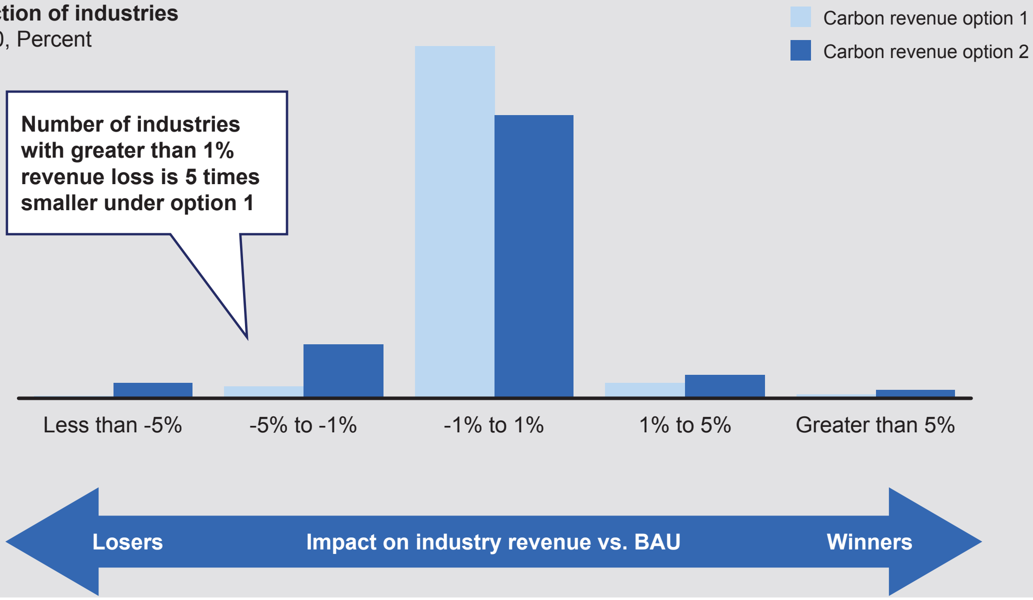


Exhibit 10

Sample result – alternate use of carbon revenue could significantly reduce the number of industries that are negatively affected by energy / climate policies

Fraction of industries
2020, Percent



What are the tool's limitations?

While the U.S. low carbon economics tool can address a wide range of questions, like all models it has its limitations, including the following.

1. It does not try to follow business cycles or to predict unexpected events such as the current recession. Future values for GDP, jobs, etc., will certainly depart from the projections in the model. The goal is not to forecast the future, but to clarify how policy X or policy Y will affect future outcomes relative to what would occur in the absence of a new policy.

2. Outputs will be only as good as the inputs. The user can set a wide range of input assumptions, including the effectiveness of various policies, technology learning rates, the maximum rate of nuclear deployment, elasticities of demand, and so on. The true values of these variables are uncertain. Estimates of policy impacts reflect our understanding of how market forces might play out in user-defined scenarios for these variables; they are not predictions.

3. In keeping with our abatement curve work, the tool assumes no changes in consumer behavior or preferences, does not attempt to model technologies beyond those currently under development, and does not extend beyond 2030.

4. We do not model secondary carbon markets but only abatement cost curves. Our "carbon prices" are actually marginal abatement costs. For a commodity-like "product" such as carbon abatement, market prices and marginal costs will often but not always be the same.

5. We do not fully capture the economic costs of some choices (e.g., increased road congestion, potential damages from climate change).

6. The REMI macroeconomic model has a number of limitations that are discussed more fully in Chapter 5. These include an incomplete treatment of capital markets, taxes, profits, and money supply; an undifferentiated labor pool that assumes workers can instantly be trained for new jobs; and no modeling of income distribution. In addition, REMI assumes backward-looking decision-making on the part of economic actors, rather than rational expectations—an assumption that is often but not always defensible. Finally, because our abatement modeling is done outside of REMI, some economic feedback loops are not automatically implemented. For example, if a policy causes GDP to shrink relative to business-as-usual, our abatement model will not automatically incorporate the resulting small decrease in the power sector abatement opportunity due to the reduction in electricity demand from lower economic activity. These feedback loops often have a small enough effect to be safely neglected, but in some cases they can mandate additional modeling iterations to reach high accuracy outputs. We are able to partly overcome these shortcomings in our external modeling. For example, we use additional iterations to capture critical feedback effects, and we calculate power sector investment decisions outside of REMI from a forward-looking perspective of either a public utility commission (PUC) or an investor, depending on the region. For most users, we believe that REMI's shortcomings will be more than offset by its ability to provide a very granular view of differing policy impacts. In some specialized circumstances, however, these limitations might necessitate using a tool other than REMI for the analysis.

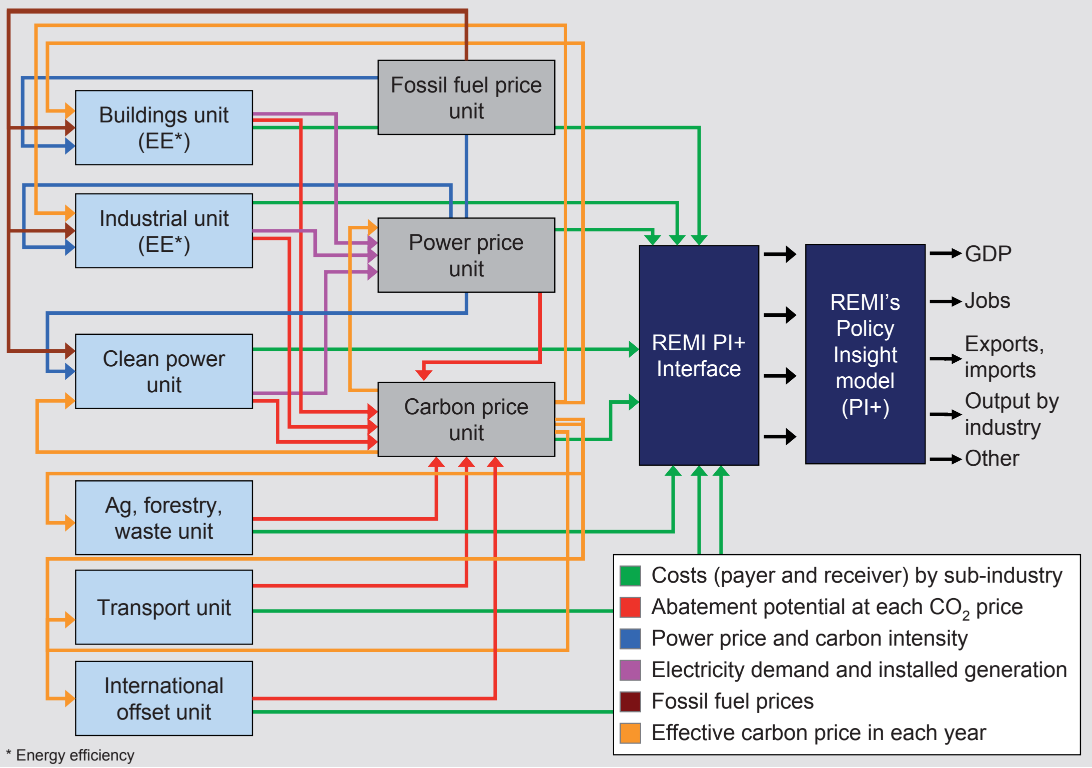
2. Technical overview of model architecture

This chapter provides a brief technical overview of the model architecture and the linkages among the various parts of the models. The subsequent sections of this paper explain each of these parts in greater detail.

Exhibit 11 shows each of the primary modeling units within the tool and the linkages between them. Working from left to right in the exhibit, there are three types of modeling units: first are six sectoral units; then three pricing units; and lastly the REMI interface and the REMI Policy Insights tool (PI+) itself.

Exhibit 11

Model structure



* Energy efficiency

Through the six sectoral units we estimate the spending changes and level of abatement that would be achieved in each year through 2030 given the policy measures and price signals that are in place. For example, the clean power unit estimates the extent to which project developers will deploy wind farms (or other clean technology) in each state each year given local power prices, local resource quality, and any available financial incentives. The output of each unit includes the level of GHG reduction that would be achieved each year along with an estimate of the associated capital and operating costs broken down by category.

The three pricing units calculate fossil fuel prices, carbon prices (if applicable), and electricity prices each year based on the predicted evolution of each sector, current abatement levels, and the policies being modeled.

The REMI interface aggregates information from each of the modeling units and translates it into a format REMI PI+ can understand. REMI PI+ then calculates the implied macroeconomic effects.

Multiple linkages connect these separate modeling units, in order to maintain logical consistency. Following are a few of the many examples of these linkages:

- Operating costs or savings from measures in the buildings and industrial sectors are affected by the prevailing fossil fuel and electricity prices, which usually have different values in abatement scenarios than in the business-as-usual scenario.
- Fossil fuel and electricity prices are in turn affected by the level of demand implied by decisions in the buildings and industrial sectors.
- Capital decisions in the power sector are influenced by (1) the overall level of electricity demand from buildings and industry and (2) the hour-by-hour marginal generation costs calculated by the dispatch model in each region in each scenario (in addition to other factors discussed below).
- Across all units, decisions on whether to deploy various abatement levers are influenced by the estimated carbon prices (if any) in each year—although the level of influence can be quite low for some levers, such as buildings efficiency measures, where price is not the main barrier to action.

Chapters 3 and 4 discuss the sector abatement curves and energy pricing models in greater detail.

3. Abatement levers

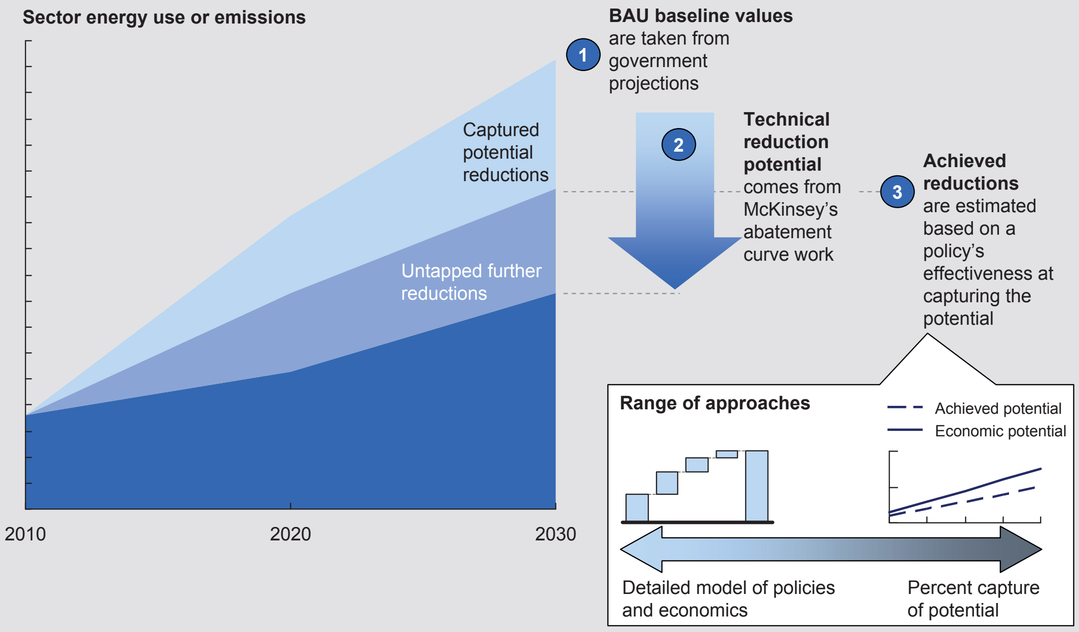
This chapter describes the approach we took to quantify the options the U.S. has for changing its patterns of energy use and (potentially) reducing its GHG. emissions. In keeping with McKinsey's previous work on this topic, we refer to each of these options as an "abatement lever"—but this does not imply that abatement is necessarily the motivation for implementing the lever. For example, increased usage of biofuels could be mandated by an energy bill whose goal is to increase the energy security of the U.S. The terms "abatement lever" or "abatement opportunity" should be read as a shorthand for any potential action the U.S. could take that would result in a change in its energy use and (potentially) GHG emissions.

Overall approach

Exhibit 12 illustrates our overall approach. We began by constructing a business-as-usual (BAU) reference case drawing on publicly available U.S. government data. This case represents our baseline view of U.S. GHG emissions in the absence of new policies. We then assembled existing McKinsey work on abatement opportunities into a database of the costs and abatement potential of hundreds of possible GHG reduction measures across all sectors of the U.S. economy. Finally, we used models of consumer, business, and investor behavior to estimate the extent to which each abatement measure would be triggered if a given set of policies were put in place.

Exhibit 12

We estimate achieved abatement starting with BAU and McKinsey's abatement cost curves



Business-as-usual (BAU) reference case

The BAU reference case represents what would occur under present trends and with all government policies and regulations in place as of 2009 (for example, state renewable electricity standards), but with no additional efforts made to address climate change. To create this reference case, the research team reconciled data sources from the Environmental Protection Agency, the Department of Agriculture, and the Department of Energy, as well as REMI's own internal baseline. In cases where additional detail was needed, we used the Energy Information Administration's April 2009 *Annual Energy Outlook* as the foundation.

The reference case forecast from that report integrates emissions and absorption of greenhouse gases across five sectors of the U.S. economy: power generation, buildings, industry, transportation, and forestry/agriculture/waste. It includes emissions of six greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxides (NO_x), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). To ensure comparability across sectors and sources, all greenhouse gas emissions and sinks were converted to a common metric CO_2 equivalents (CO_2e) measured in metric tons.

Emissions estimates were constructed in a bottom-up manner, assessing demand growth regionally through census divisions, for example. This approach accounts for regional variations such as climate, population growth, and carbon intensity of electric power generation portfolios.

Abatement potential and costs

TTo determine the overall abatement potential in the U.S. economy, we drew heavily on existing McKinsey analyses, including Version 2 of the Global Greenhouse Gas Abatement Cost Curve (January 2009), the U.S. GHG Abatement Mapping Initiative (summarized in the December 2007 report, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?)*, and *Unlocking Energy Efficiency in the U.S. Economy* (July 2009), which highlighted opportunities in residential and commercial buildings and industry. When required, we updated prior estimates to reflect revised baselines, fossil fuel prices, capital costs, and so on. In keeping with McKinsey's prior work, we limited the abatement measures considered as follows:

1. No major technological breakthroughs or transformation of energy infrastructure were assumed. Instead, we relied on the likely evolution of existing technologies, typically with modest assumptions around penetrations and learning rates. Technologies in the pilot phase (e.g., carbon capture and sequestration, or CCS) were included in the analysis; those yet to be demonstrated (e.g., geoengineering) were not.

2. We assumed no evolution of consumer preferences. Options such as increased use of public transport, lower thermostat settings, and the like are not treated here, although they can make a meaningful contribution to overall abatement.

When assigning costs to individual measures, we generally took the decision maker's perspective, including all upfront capital costs and lifecycle savings or expenses. For example, utility decisions on whether to deploy solar are based on a discounted cash flow calculation of whether the investment would earn back its cost of capital given the electricity market structure in place. We did not attempt to include transaction costs, regulatory/enforcement costs, or communication/information costs since these are difficult to quantify. We do acknowledge the role that these costs play in impeding capture of the full abatement opportunity, and take them into account when estimating the achievable abatement.

Capture of abatement potential and implications

As a final step, we estimated the extent to which various policies would trigger each abatement measure and the impact this would have on demand.

Multiple factors affect whether an abatement measure will be captured. For example, decision makers are unlikely to implement NPV-negative abatement measures unless they are required to do so. Even NPV-positive abatement measures might not be implemented, however, if the decision maker does not know they exist, cannot pull together the financing required to cover upfront costs, has no incentive to act (e.g., a landlord with no incentive to weather-seal a drafty rental house), is frustrated by high transaction costs, does not have the right supporting infrastructure (e.g., transmission lines), and so on. Each model estimates the extent to which a given set of policies would overcome these barriers and lead to abatement action. The tool gives users significant flexibility to change the logic in this phase if desired.

Once the set of triggered abatement measures has been calculated, each model calculates the implied changes in demand for each of the 165 private-sector industries in the REMI PI+ macroeconomic model. For example, if consumers save electricity by purchasing more efficient (and expensive) air conditioners, the model would allocate increased revenue to appliance manufacturers and retailers and reduced revenue to electric utilities. [7] Chapter 5 explains how we calculate the effects of these demand changes.

This remainder of this section provides more detail on our abatement modeling in power generation, residential and commercial buildings, industry, transport, and domestic and international “offset” sectors such as forestry, agriculture, and waste.

Power generation

As analyzed in the McKinsey U.S. GHG report, the power sector offers nearly 900 megatons of potential abatement, 90% of which could be obtained at a cost of less then $50 per ton. Abatement in the power sector comes from changes in the mix of power generation as the sector moves from carbon-intensive sources (fossil fuels) to less carbon-intensive sources (switching of power generation from coal to gas, CCS) or zero-carbon sources (nuclear, renewables). The tool models the capture of all of these sources of abatement either directly (renewables, nuclear, CCS) or indirectly via the power dispatch model (switching of power generation from coal to gas).

As illustrated in Exhibit 13, the power sector model combines models of existing infrastructure and renewables potential to estimate future build-out, and then uses hour-by-hour demand and supply matching to estimate future power prices.

Renewable power

We model the build-out (capacity and expected energy generation) of all major renewable generation technologies, including wind, solar (utility-scale and rooftop photovoltaics and solar thermal), biomass, biomass co-firing, onshore wind classes 3-7, offshore wind, and geothermal, for each year between 2010 and 2030.

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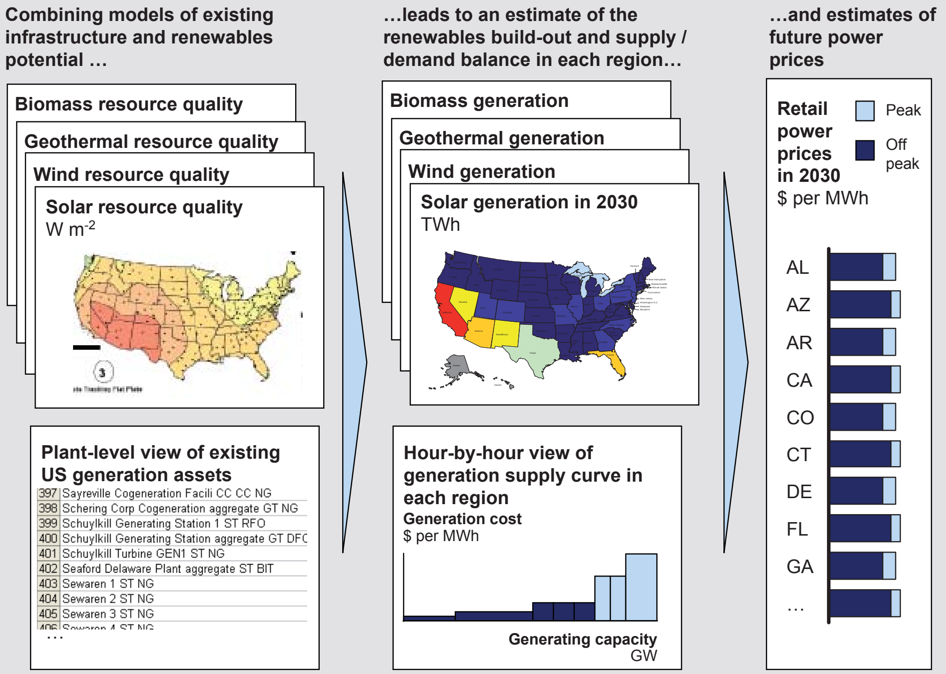
[7] As discussed later, the actual calculation of impacts is more complicated than this simplified sentence suggests. In some cases, for example, policy incentives or regulatory structures can cause electricity savings to be either revenue-neutral or revenue-positive for electric utilities. To illustrate, efficiency measures could involve capital outlays that substantially increase the utility’s rate base.

Exhibit 13

The power sector model estimates future capacity and prices



Combining models of existing infrastructure and renewables potential …

Biomass resource quality

Geothermal resource quality

Wind resource quality

Solar resource quality
W m^{-2}

Plant-level view of existing US generation assets

397 Sayreville Cogeneration Facili CC CC NG
398 Schering Corp Cogeneration aggregate GT NG
399 Schuylkill Generating Station 1 ST RFO
400 Schuylkill Generating Station aggregate GT DFC
401 Schuylkill Turbine GEN1 ST NG
402 Seaford Delaware Plant aggregate ST BIT
403 Sewaren 1 ST NG
404 Sewaren 2 ST NG
405 Sewaren 3 ST NG
406 Sewaren 4 ST NG
…

…leads to an estimate of the renewables build-out and supply / demand balance in each region…

Biomass generation

Geothermal generation

Wind generation

Solar generation in 2030
TWh

Hour-by-hour view of generation supply curve in each region
Generation cost
$ per MWh

Generating capacity
GW

…and estimates of future power prices

Retail power prices in 2030
$ per MWh

The renewables build-out is modeled by taking the perspective of the relevant decision maker (e.g., investor or PUC, depending on location) and determining which technologies will be selected in different regions and different years. Investment decisions are based on estimates of wholesale prices and marginal generation costs in each region in each time period, which we calculate via the dispatch model described below. In deregulated areas, investors are assumed to be willing to build a given technology if it would meet their threshold return on capital given projected wholesale prices and any incentives, including direct subsidies for capacity buildup, investment tax credits, and production tax credits. In regulated areas, PUCs are assumed to allow new builds of a clean technology if it is mandated by policy (e.g., renewable energy standards) or if the levelized cost of the new technology (less incentives) is less than the avoided costs of the power it displaces, which is mostly composed of avoided fossil fuel burning plus avoided fossil generation capital expenditure in situations where demand is growing.

The levelized cost of building a renewable generation technology depends on the capital cost of building a unit of capacity, the quality of the renewable resource, the expected utilization of the capacity, and any additional transmission, interconnect, and backing capacity costs. We use the capital costs specified in McKinsey's GHG Abatement Curve v2.0, which assume that costs fall over time based on various technology learning curves. State-level data on renewable resource quality comes from the National Renewable Energy Laboratory (NREL). The expected utilization is based on real hour-by-hour data on the variation in the resource quality (e.g., how strongly the sun was shining in Arizona on a particular hour and day). Other additional transmission, interconnect, and backing costs are derived from various sources. [8] When relevant, as in the case of wind power, we model the increase in these costs as penetration rises and the lowest-cost sites are occupied.

Conventional power

The "conventional" sources of abatement in the power sector are nuclear and carbon capture and sequestration (CCS). These are treated separately from renewables since decisions to build these technologies are not driven purely by economics.

In the case of nuclear, significant regulatory and political concerns come into play, as well as supply chain and know-how issues. Long construction lead times and severe bottlenecks in permitting, engineering, materials (e.g., nuclear-grade nickel alloys), equipment (e.g., nuclear-grade large-ring forgings), and construction have driven up the long-term cost of nuclear plant construction to $3,500 to $5,500 per kilowatt of capacity (net of financing cost) and may impede the buildup of this subsector in the future.

CCS, on the other hand, is at the moment an expensive, early-stage technology that has yet to be proven at commercial scale for baseload power generation. A number of emerging approaches are expected to enable carbon capture. Each of these technologies may provide tangible benefits and be better suited for specific coal types or installations. The development of CCS will depend in large part on the level of public and private support for research, development, and deployment.

In a typical scenario, we therefore base our expected nuclear and CCS build-out not on economics but on a combination of existing construction pipeline, expert estimates, and political and regulatory assumptions. These assumptions can be adjusted by users as desired.

Coal-to-gas substitution

Coal-to-gas substitution is an important near-term abatement option, as electric utilities can switch generation away from carbon-intense coal to less carbon-intense gas. The decision to dispatch gas or coal is made on economic grounds, taking into account start-up costs, fuel costs, emissions costs, and other plant operating costs. In normal operation, coal-to-gas substitution is triggered only if the marginal cost of gas generation is cheaper than that of coal generation in a given power dispatch region. The carbon price required to trigger this substitution depends on mix of plants in a region and the relative cost of natural gas and coal, as shown in Exhibit 14.

As carbon prices increase, the level of substitution will increase as well. At first, only the most efficient CCGT plants will be turned on and/or the highest-cost coal plants will be shut down; substantial substitution will not occur until higher carbon prices make it economical to substitute among plants with more typical heat rates and fuel costs. At a mid-range gas price of $6/mmbtu, the most efficient combined cycle gas turbine (CCGT) plants begin to displace the least efficient coal plants at $15/ton, while the bulk of substitution does not occur until $20-50/ton. The carbon price required to trigger substitution depends on the price of gas; at a low gas price of $4/mmbtu, some substitution could occur at a carbon price of less than $10/ton, while substitution might not begin until carbon prices reach $50/ton if gas costs $10/mmbtu.

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[8] See, for example, 20% Wind Energy by 2030, Department of Energy (2008) or the online documentation for NREL's Renewable Energy Deployment System.

Exhibit 14

Range of carbon prices which trigger coal displacement depends on price of gas

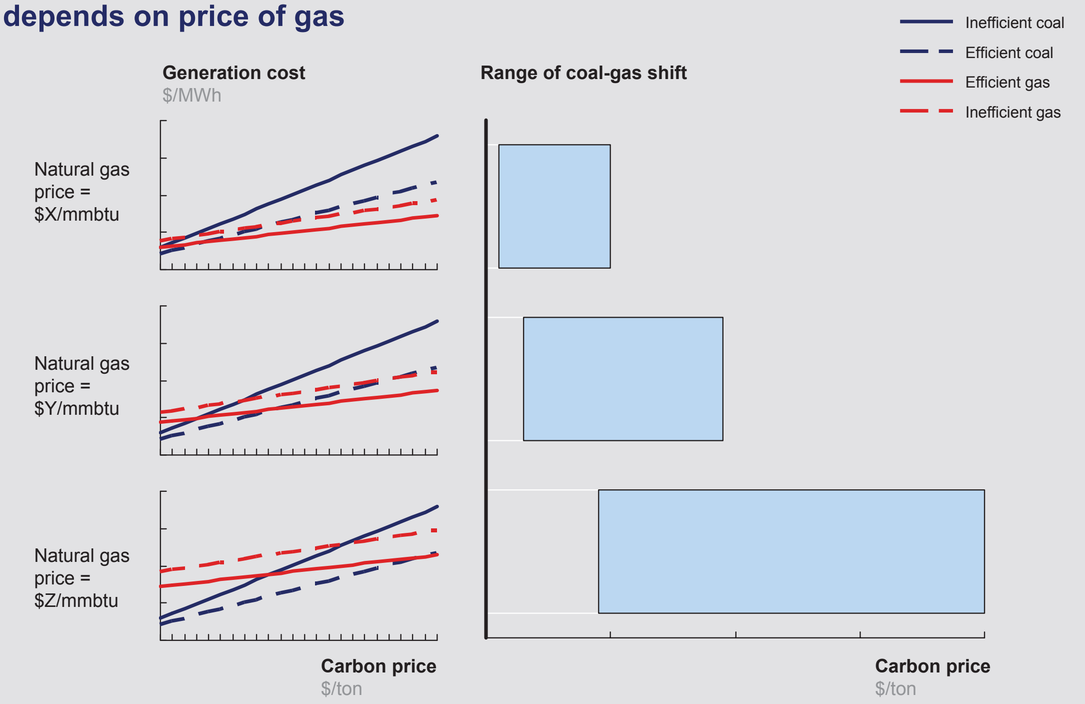

Exhibit 15 provides a detailed example of coal-to-gas switching in one of the grid sub-regions as the carbon price increases from $0/ton to $45/ton. On the left, the power generation supply stack in this region is shown for three carbon prices of $0/ton, $15/ton, and $45/ton. As carbon costs (orange) increase, coal generation (light blue) becomes more expensive relative to gas generation (dark blue), and coal increasingly shifts to the right on the power generation stack. On the right, the implications of these changes are shown. Because coal generation is increasingly on the margin, coal is increasingly displaced relative to gas as carbon costs rise. If desired, we have the ability to model specific policies that could induce or accelerate coal-to-gas switching (e.g., incentives for early retirement, coal-specific taxes, mandated coal-fired plant retirements).

Residential and commercial buildings

A large fraction of the total abatement potential comes from energy-efficiency measures in residential and commercial buildings. Building on our cost curve work, a recent McKinsey report detailed thousands of efficiency opportunities in the U.S. across various end uses, demographic categories, and regions.[9] Starting with this rich data set, we estimated the degree to which the efficiency opportunities might be captured based on various policies and economic factors, and then computed changes in energy demand and spending patterns by consumers and businesses due to the deployment of energy-efficient technologies.

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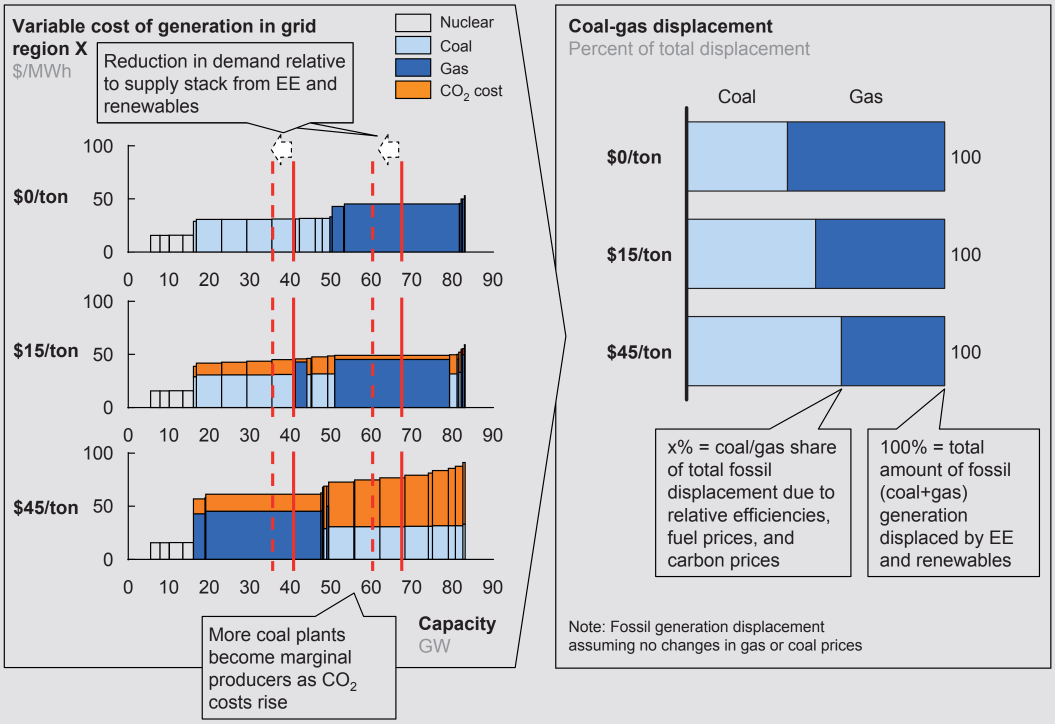
[9] *Unlocking Energy Efficiency in the U.S. Economy*, McKinsey & Company, July 2009.

Exhibit 15

As CO_2 costs rise, gas generation becomes increasingly cheap compared to coal if delivered fuel prices remain constant



Reduction in demand relative to supply stack from EE and renewables

More coal plants become marginal producers as CO_2 costs rise

x% = coal/gas share of total fossil displacement due to relative efficiencies, fuel prices, and carbon prices

100% = total amount of fossil (coal+gas) generation displaced by EE and renewables

Note: Fossil generation displacement assuming no changes in gas or coal prices

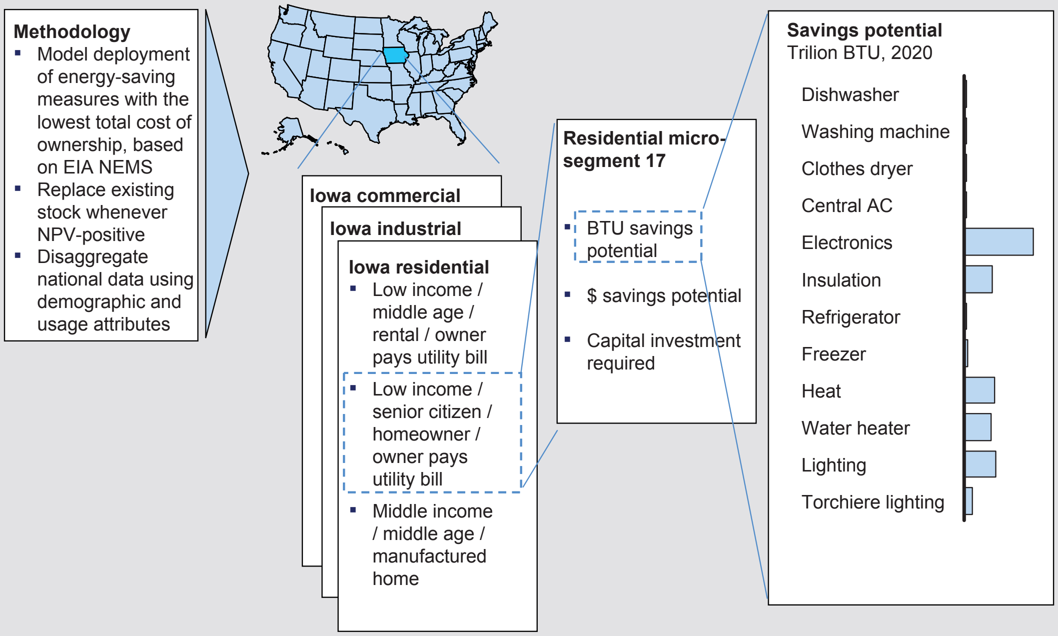
The report detailed economic (NPV-positive) energy-efficiency opportunities available in the U.S. residential, commercial, and industrial sectors. It used the Energy Information Administration's National Energy Modeling System (NEMS) as a foundation to develop a set of business-as-usual choices for end-use technology, by region and building type. Then, 675 energy-saving technology alternatives were modeled and those with the lowest total cost of ownership were selected. The most cost-effective alternatives replaced the BAU technology whenever doing so was NPV-positive, resulting in the most NPV-positive energy-efficiency technology mix. Only existing technologies or those forecast by NEMS as highly likely to be adopted were among the alternatives.

In all cases, national data on energy use were disaggregated using some 60 demographic and usage attributes, creating roughly 20,000 consumption micro-segments across which energy-efficiency potential could be analyzed. Exhibit 16 illustrates the high degree of granularity captured by the energy-efficiency data. For example, we have estimates for the savings represented by more efficient dishwashers in homes in Iowa rented by low-income seniors where the owner pays the utility bill. Our database contains both the potential energy savings and the capital cost of each optimal technology. The capital costs include only the direct cost of the technology and the direct labor associated with installing it, and do not include transaction, marketing, administrative, or other costs.

The report found that the total economic abatement potential in buildings efficiency is 720 megatons CO_2e in 2020, split evenly between residential and commercial buildings. Key opportunities include retrofitting

Exhibit 16

Abatement opportunity is modeled in detail by region, demographic segment, and end use



Methodology
- Model deployment of energy-saving measures with the lowest total cost of ownership, based on EIA NEMS
- Replace existing stock whenever NPV-positive
- Disaggregate national data using demographic and usage attributes

Iowa commercial

Iowa industrial

Iowa residential
- Low income / middle age / rental / owner pays utility bill
- Low income / senior citizen / homeowner / owner pays utility bill
- Middle income / middle age / manufactured home

Residential micro-segment 17
- BTU savings potential
- $ savings potential
- Capital investment required

Savings potential
Trilion BTU, 2020

building shells and HVAC systems (270 megatons), using more energy-efficient consumer electronics (200 megatons) and lighting (100 megatons), and installing optimal equipment in new buildings (70 megatons).

While the approach described above gives an estimate of the theoretical NPV-positive potential from energy-efficiency measures, the actual realized potential under any policy scenario is likely to be far lower due to persistent barriers at both the individual opportunity level and the overall system level. Energy-efficiency measures typically require a substantial upfront investment in exchange for savings that accrue over the lifetime of the deployed measures. In addition, efficiency potential is highly fragmented, spread across more than 100 million locations and billions of devices. This dispersion ensures that efficiency is the highest priority for almost no one. Finally, measuring and verifying energy not consumed is difficult, leading to investor uncertainty. Beyond these fundamental attributes of energy efficiency, there are three specific barriers that must be overcome to capture the theoretical efficiency opportunity:

- **Structural barriers.** These impede the alignment of interests and pricing signals necessary to drive the capture of energy-efficiency gains. For example, an agency barrier exists when the energy bill payer is different from the investment decision maker; there are ownership transfer barriers when the owner of an efficiency investment expects to divest it before payback time; transaction barriers add to the cost of deployment; and regulatory, tax, or other distortions can obscure price signals that might otherwise drive desired behavior.

- **Behavioral barriers.** These include risk and uncertainty regarding the ability to capture the benefit of an efficiency investment; lack of awareness and information about product efficiency and one's own behavior; and habits that prevent the full capture of potential (e.g., not using efficient power settings on electronics).

- **Availability.** As mentioned earlier, most efficiency investments require a significant upfront capital outlay, and lack of access to capital can impede capture of the potential. Similarly, lack of access to, or lack of a market for, appropriate efficient products can also reduce the capture rate.

A spectrum of approaches exists for estimating the actual level of energy-efficiency gains that a given set of policies would achieve. At one end of the spectrum, one could estimate in detail the specific impacts of a wide range of policy measures, including standards and mandates, financial incentives, and information programs, based on a combination of the historical performance of similar programs (energy saved per dollar spent) and data on compliance rates, etc. At the other end of the spectrum, one could simply assume that a given fraction of the overall potential is captured, and determine the implications of that assumption for the rest of the economy. This approach can be coupled with a discussion of reasonable policy measures to achieve the assumed energy-efficiency capture, given past experience in the U.S. or elsewhere and likely future outcomes.

Once the achieved efficiency potential has been estimated, the buildings model generates two classes of output data: (1) changes in electricity, natural gas, and fuel oil demand in commercial and residential buildings relative to the business-as-usual scenario, and (2) shifts in spending patterns of consumers and businesses as they spend more on energy-efficient technology and less on energy relative to BAU. The change in electricity demand drives change in power prices, and the spending shifts drive changes in the macroeconomic models calculated by the REMI PI+ model.

Industry

The industrial model determines the abatement curve from five energy-intensive sectors: manufacturing, chemicals, petroleum and gas, cement, and iron and steel. These five were chosen because they make up ~88% of U.S. industrial GHG emissions and would be capped under the currently proposed legislation. Other industrial sectors that contribute significantly to U.S. GHG emissions and corresponding abatement potential (e.g., waste) are treated separately, with the potential abatement made available in the form of offsets.

The total technical potential in the industrial sector is significant, reaching 14% of BAU emissions by 2020 and 23% of BAU by 2030 for carbon prices up to $100/ton (Exhibit 17). However, over half of the potential is NPV-positive only if the carbon price is above zero.

Within the five modeled sectors are a set of highly fragmented abatement opportunities for six GHGs (CO_2, CH_4, SF_6, HFCs, PFCs, and NO_x) across industries, processes, and energy-related applications that could be triggered through stronger carbon price signals or direct regulation. Although the opportunity is fragmented across levers, there are a few large, carbon-intense industries in which the abatement potential is up to 25% in 2020 and 40% in 2030.

The fragmented abatement opportunities can be grouped broadly into five areas, which together account for roughly 75% of the potential in this sector. As Exhibit 18 shows, these include (1) recovering and/or destroying non-CO_2 greenhouse gases, (2) increasing combined heat and power (CHP) capacity, (3) improving energy efficiency, (4) innovating process and product, and (5) capturing and storing CO_2.

Exhibit 17

McKinsey's GHG abatement curve v2.0 estimates that there is significant technical potential for industrial emissions

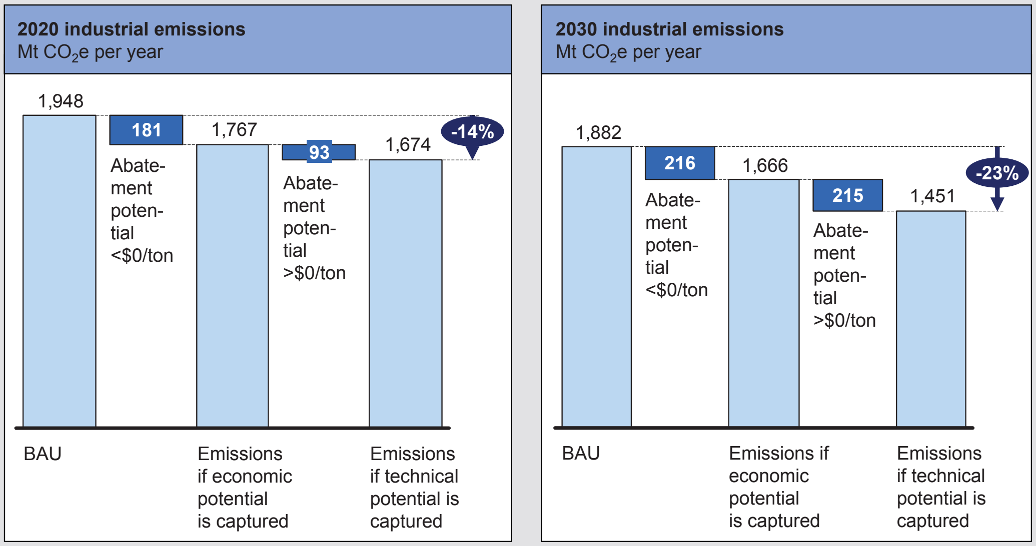
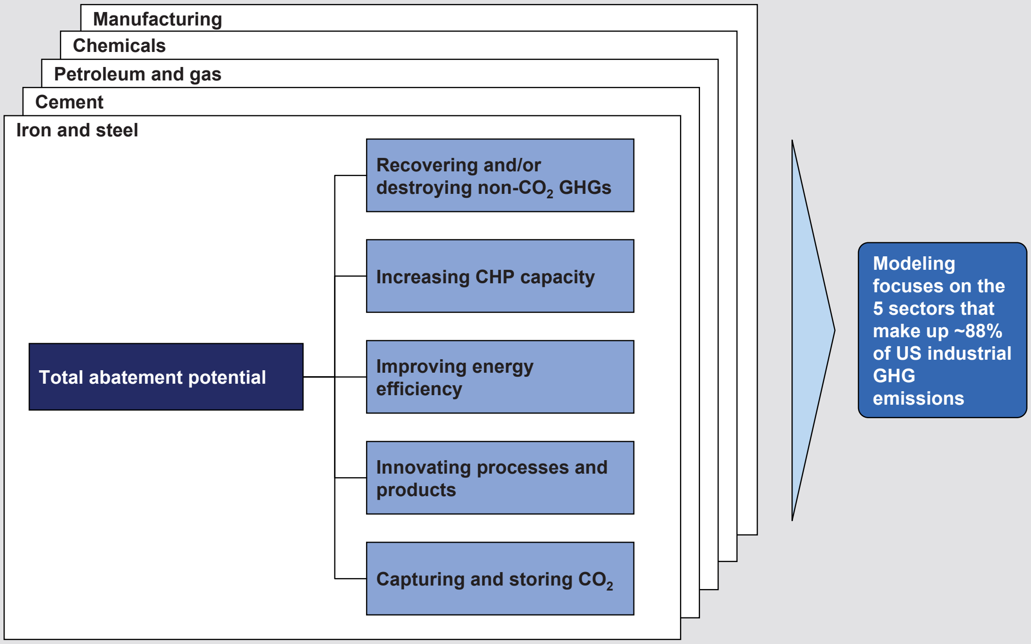


Exhibit 18

In each major industrial sector, we estimated the total efficiency and abatement opportunity by studying the potential in 5 key areas



The largest area is **recovery and/or destruction of industrial non-CO_2 GHGs**. This includes methane management in the natural gas and petroleum sector, HFCs/PFCs in manufacturing processes, and nitrous oxide in chemical processes. Specific actions to abate non-CO_2 GHGs vary across industries and include, for example, abating HFCs/PFCs in the manufacturing industry by repairing leaks, improving capture and recovery systems, eliminating thermal oxidation, and cleaning remotely.

Increasing CHP capacity is another significant area. Medium-sized and large projects can be realized at near negative cost, whereas small projects have less favorable economics. Distribution of potential CHP capacity varies widely across industrial subsectors. About 90% of small CHP applications are in food and other smaller-site manufacturing sectors; 70% of large CHP applications are concentrated in large industrial areas such as refining, chemicals, and cement. Moreover, the economics of CHP are heavily region-specific, driven by local construction costs and electricity prices. Our analysis assumed that natural gas would be the fuel of choice for additional CHP.

Improving energy efficiency could reduce both direct emissions associated with reduced fuel and or feedstock consumption (75% of the opportunity) as well as efficiency measures to reduce electricity consumption (25%). Options for direct emissions abatement include industry-specific energy-efficiency measures such as increasing the efficiency of fired and steam systems, using advanced process controls, and performing preventative maintenance within energy-intensive sectors.

There are a large range of **process and product innovations** in the chemicals, iron and steel, and cement industries. Adopting new processes and technologies, such as moving to electric arc furnaces for steelmaking, would effectively reduce the carbon intensity of the industrial sector.

The addition of **CCS technology** to manufacturing sites is another opportunity, although it typically poses higher costs than alternative opportunities.

More than 80 individual abatement levers fall within these groups/industries. We took the overall abatement potential for each from McKinsey's Global GHG Abatement Curve v2.0 and applied a small scaling to make the potential consistent with the EIA's 2009 AEO forecast for each sector. The capital expenses and operating costs associated with each lever are taken from the same source.

While many of the abatement opportunities in the industrial sector are formally NPV-positive, especially under scenarios involving higher carbon prices, there are barriers to implementation in the absence of direct regulation. These barriers include the following:

- **A lack of focus on energy efficiency** resulting from a lack of awareness among industrial sector participants. Because energy typically represents a relatively small fraction of operating costs (less than 5%), senior management tends not to pay much attention to it.

- **High investment hurdles and tight budgets.** Industrial companies typically focus on quarterly targets at the expense of projects with longer payback periods. This difficulty is compounded by the separation of plant operations budgets and capital improvement budgets, which means that energy-efficiency projects appear as a cost in one budget while the savings reside in another.

- **Procurement and distributor availability and price volatility constraints.** These add risk to pursuing natural gas, particularly in an unstable environment.

- **High transaction costs associated with implementing abatement projects.** These costs relate to issues such as space constraints, invested resource time, process disruptions, and potential effects on product quality.

The degree to which these barriers are overcome can be modeled at varying levels of detail according to the user's preference.

Once this process has identified the abatement levers that will be triggered each year by a given set of policies, the model calculates the nationwide incremental capital and operating expenditure by type (e.g., increased spending on efficient motors, reduced spending on electricity) for each industry in each year. It then distributes the incremental spending across states in proportion to the industry's value-added in each state.

Transport

The transport sector consists of four subsectors: road, sea, air, and rail. Our transport model covers road and air transport, which together generate nearly 90% of emissions from this sector. Road is the largest subsector (accounting for ~75 percent of GHG emissions in 2006), and is treated in a detailed bottom-up analysis. The air sector is also treated here in a top-down approach.

Within the **road sector** we modeled the stock and flow of three vehicle segments: light-duty vehicles (LDVs), which include passenger cars and light trucks; medium-duty vehicles (MDVs; classes 2B-6); and heavy-duty vehicles (HDVs; classes 7-8). LDVs are largely privately owned, while MDVs and HDVs are usually owned by commercial enterprises. Vehicles from all segments potentially can use different fuel types, such as gasoline, diesel, biofuels, or electricity, or mixes of various fuels, and we model biofuel penetration.

Our transport model abatement curve is based on four sources of potential abatement in road vehicles, as illustrated in Exhibit 19.

1. **Efficiency improvements in traditional internal combustion engines (ICEs).** Technical enhancements to powertrain and non-powertrain systems can significantly enhance the fuel efficiency of conventional engines. Examples of powertrain enhancements for gasoline LDVs include variable valve control, engine downsizing, engine friction reduction, and homogenous direct injection. Non-powertrain measures include low-rolling-resistance tires, air conditioning modification, and pump and steering electrification. Diesel ICE measures are similar. The individual efficiency improvements are grouped into bundles that take into account some cross-measure cannibalization.

   The bundles for MDVs and HDVs are defined in a similar manner. However, commercial vehicles are further along on reducing fuel consumption and therefore the relative improvement potential is lower.

2. **Adoption of hybrid vehicles.** These range from simple start-stop systems to full electrical drive systems packaged in parallel to the ICE drive systems and calibrated to run when conditions best suit electric-powered driving. Hybrids can be recharged while driving or by tapping into external sources of power, as in the case of "plug-in hybrids."

3. **Adoption of electric vehicles.** These currently have very low market penetration but are gathering

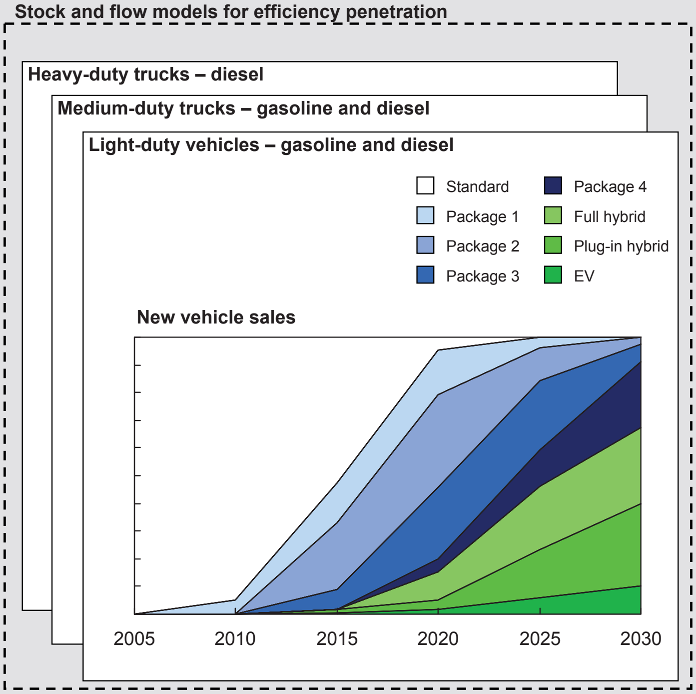
significant momentum as battery technology evolves. The abatement potential for electric vehicles depends on the CO_2 intensity of the electricity drawn from the grid.

4. **Replacement of fossil fuels with biofuels.** Our analysis includes both first-generation biofuels, such as bioethanol, and second-generation biofuels based on lignocellulosic biomass. The abatement potential varies depending on the biomass used for biofuel production and on the treatment of changes in emissions associated with increased crop production.

The model calculates overall abatement potential and costs from these four sources using both a stock and flow model of penetration of vehicle measures into the fleet and a model of biofuels penetration into the fuel mix.

Exhibit 19

Transport abatement is based on four levers



Sources of abatement

1. Efficiency improvements in internal combustion vehicles (packages 1-4)
- E.g., low rolling resistance tires, variable valve timing, reducing weight)

2. Hybrid vehicles (Full and plug-in hybrids)
- Vehicles with both electric and internal combustion engines (e.g., Toyota's Prius)
- Hybrid vehicles that can be plugged into the grid to recharge

3. Electric vehicles (EV)
- Fully electric vehicles

4. Replacement of fossil fuel with biofuels (not shown on chart)

Inputs to the stock and flow model include scheduled mileage-per-gallon targets for new vehicles, penetration rates for a portfolio of air and vehicle efficiency packages, and adoption rates for various biofuels. From these inputs, and with assumptions of vehicle sales forecasts and lifespan from the EIA's AEO 2009, the model calculates the penetration of abatement measures into U.S. consumer and commercial LDV, MDV, and HDV fleets. Then, based on EIA forecasts of vehicle miles traveled, the model calculates each fleet's fuel demand and determines the associated CO_2 emissions from energy intensities provided by petroleum and gas manufacturers and fuel carbon intensities from the McKinsey Global GHG Abatement Curve v2.0. The model compares these CO_2 emissions with those calculated using inputs from the EIA's AEO 2009 baseline scenario to find the incremental abatement due to the policy scenario.

Beyond the four abatement sources described above, there are several other opportunities that we are not considering. These include consumer behavioral changes; commercial transport improvements (e.g., increased vehicle capacity, modal shifts); and traffic-system improvements, including intelligent transportation systems, road design, and regulatory levers such as lower speed limits and introduction of congestion charges.

As in the industry sector, many of the abatement opportunities in the transport sector are formally NPV-positive, especially under scenarios involving higher carbon prices. However, in the absence of direct regulation, the barriers to implementation include the following:

- **Consumer preferences and non-rational economics**, which influence the decision to buy a new car. Fuel consumption is only one dimension for consumers comparing vehicles. In addition, consumers usually do not thoroughly calculate and compare the economics of different vehicles; or, if they do so, they typically overestimate the upfront investment compared with the lifetime savings.

- **Disconnect between the expectations of LDV original equipment manufacturers (OEMs) and rational consumer behavior.** It is not clear to OEMs that consumers would be willing to pay the extra price for fuel-saving bundles, even when they would benefit. Therefore, these fuel-saving options may not be implemented or offered.

- **Current technology limitations**, which restrict the range and speed of vehicles running on batteries and electric motors. Battery capacity and cost are the key factors limiting broad use of hybrid and electric vehicles.

The abatement potential in the air sector comes from three areas:

1. **Technology solutions, which include the use of alternative fuels.** Technology measures include aerodynamic improvements, engine retrofit and upgrades, accelerated fleet replacement, and reduced speed design. For alternative fuels, we considered biofuels, gas to liquid, and, to a lesser extent, hydrogen. These measures come at medium to high cost and account for about 50% of the total sector potential.

2. **Improvements in operations efficiency.** These can be achieved at low to medium cost and include better fuel management.

3. **Improvements in infrastructure and air-traffic management.** Redesigned airspace, flexible use of military airspace, and improved flight tracks are net-profit positive or low cost.

Once the investment costs and ongoing operating costs associated with the air and vehicle transport efficiency and biofuels are calculated, the model distributes the incremental spending and fuel savings across states for both consumer and commercial vehicles. Consumer spending is distributed based on the percentage of total vehicles registered in each state using data from the U.S. Department of Transportation, with additional scaling for specific technologies (e.g., urban density for electric vehicles). Commercial spending is distributed across industries based on their transportation intensity and across states based on the output size of each industry.

Domestic and international "offset" sectors

The model includes both domestic and international offsets based on the specifications for a given policy scenario.

Domestic offsets

Domestic offsets typically result from measures in the forestry, agriculture, and waste sectors, areas that are not covered under the many proposed caps.

The key abatement levers within these three sectors are as follows:

1. **Forestry.** Opportunities include reduced deforestation, reduced intensive agriculture conversion, pasture and cropland afforestation, and improved forest management (e.g., restoration of degraded forests).
2. **Agriculture.** GHG emissions from agriculture are primarily in the form of NO_x and methane, and there is an additional potential for GHG abatement through carbon sequestration. Key sources of emissions can be grouped into five categories: agricultural soils, livestock enteric fermentation, rice cultivation, livestock manure management, and other agricultural practices.
3. **The waste sector** plays a critical role in non-CO_2 GHG abatement, primarily from methane from landfills. Abatement measures would expand the number of landfills at which methane is recovered and improve the capture methods at others. Once captured, the methane can be used in industrial processes or in electricity generation, or flared rather than vented, converting the methane into CO_2, which has considerably less warming potential. Other abatement levers include direct use of landfill gas, recycling new waste, and composting new waste.

The supply curve for offsets in these sectors is based on McKinsey's Global GHG Abatement Cost Curve v2.0, which uses the EPA's June 2006 *Global Mitigation of Non-CO_2 Greenhouse Gases* report to define the baseline scenario through 2030. The total available offset volume is the potential U.S. abatement beyond the reference case emissions, excluding sources included under the cap.

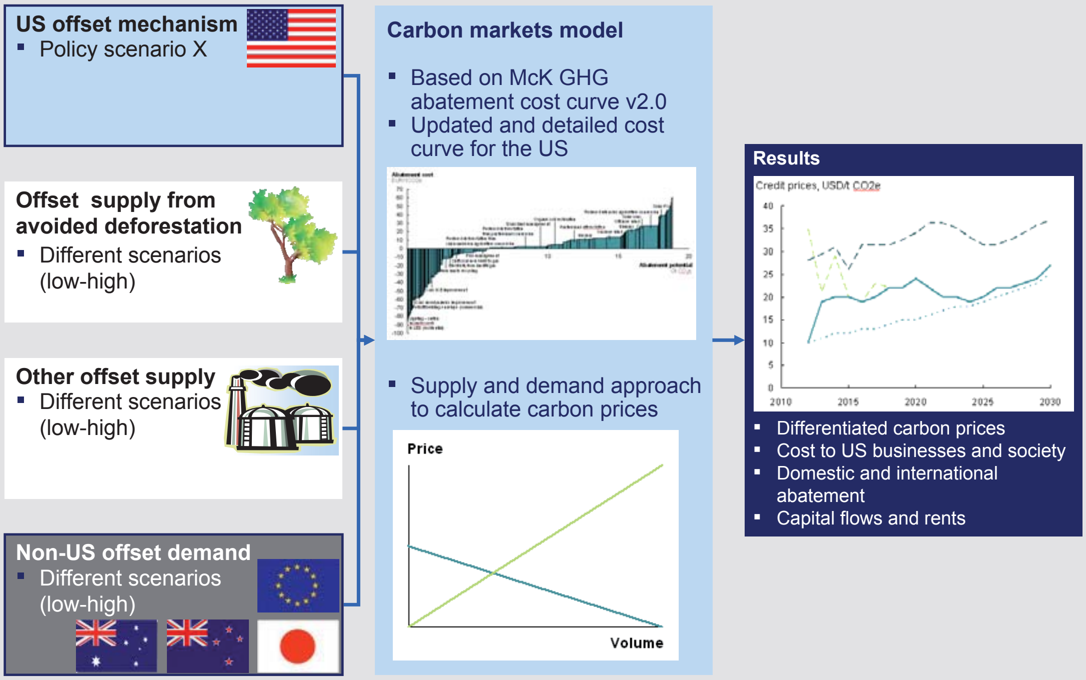
International offsets

International offsets can come from multiple sources, including avoided deforestation, increased afforestation, and a host of measures in the power, industrial, waste, buildings, and transport sectors. Our international carbon markets model takes as its starting point the abatement potential in each of these sectors identified in McKinsey's Global GHG Abatement Curve v2.0. These curves cover the abatement levers discussed above for each of 21 regions worldwide. Users can set the supply of international offsets by adjusting the rules governing availability of different types of offsets (e.g., which countries and sectors are allowed to supply offsets, how quickly offset mechanisms can be scaled up). Similarly, they can set the demand for offsets in each of the non-U.S. markets. The balance between supply and demand determines prices (Exhibit 20).

While we take no position on the likely future development of international offset markets and supporting institutions, users can take default values for international offset supply and demand from one of several pre-defined scenarios. These scenarios are designed to span the range of potential outcomes on the supply and demand side:

Exhibit 20

McKinsey's carbon markets model was used to assess the offset market under different scenarios



US offset mechanism
- Policy scenario X

Offset supply from avoided deforestation
- Different scenarios (low-high)

Other offset supply
- Different scenarios (low-high)

Non-US offset demand
- Different scenarios (low-high)

Carbon markets model
- Based on McK GHG abatement cost curve v2.0
- Updated and detailed cost curve for the US
- Supply and demand approach to calculate carbon prices

Results

- Differentiated carbon prices
- Cost to US businesses and society
- Domestic and international abatement
- Capital flows and rents

- **Supply side.** At one end of the spectrum, a tight offset market could develop if only few countries participate (e.g., China, Brazil, India, Mexico) in a limited number of sectors (e.g., industry and power) with a low rate of supply to market. At the other end, an offset glut could be possible if additional countries participate (e.g., Russia, Ukraine, Middle East, South Africa, rest of Eastern Europe), if more sectors are allowed (e.g., transportation, buildings), and mechanisms are developed that bring offsets to market at a high rate.

- **Demand side.** The extremes range from high demand driven by strong abatement targets in developed countries (the high range of countries' proposals) to low demand based on the low range of countries' proposals (including Russian and Ukrainian hot air banked in 2008-12).

Given a scenario for offset availability and external demand, and the U.S. carbon market rules (e.g., price containment mechanisms, type and level of allowed international offsets), the model estimates the overall supply curve of international offsets for the U.S. carbon market. This supply curve, along with the domestic supply curve, is used in the carbon pricing model described in the next chapter. As discussed there, the prices of international offsets can differ from the U.S. carbon price when limits are placed on the quantity of offsets that U.S. entities can purchase.

4. Pricing models

This chapter describes the iterative process the tool uses to estimate how a given policy would affect prices for fossil fuels, electricity, and carbon. These prices play a critical role in our abatement curve modeling, driving many of the investment decisions that lead to GHG reductions.

Fossil fuel prices

Climate and energy policies can cause fossil fuel prices to deviate from the values assumed under the business-as-usual (BAU) scenario. Our default model captures these deviations as follows; users can adjust these assumptions as desired. In all cases we estimate price deviations relative to BAU price levels rather than prices themselves. BAU price forecasts are taken from AEO 2009 for coal and oil and from NYMEX forwards and/or estimated reinvestment costs (~$6/mmbtu) for gas.

Coal: Coal prices come under pressure in any scenario where coal generators' variable costs approach those of CCGT plants. For BAU price levels of $6/mmbtu for gas and $2/mmbtu for coal, this begins to happen if carbon prices approach $15-20 per ton. Faced with the prospect of declining demand, coal mines and railroads would likely reduce margins in an effort to stay competitive with gas. Low-cost mines in the western U.S. (e.g., Powder River Basin) would likely continue to gain share. These two factors would allow coal to stay competitive with gas for carbon prices up to $40/ton. Beyond that point, the coal value chain would have little margin left to give, gas generation would begin to gain an advantage over coal, and variable cost pricing would prevail because there would be little need to incentivize new investments in a shrinking industry. Our price model captures this dynamic by leaving coal prices at BAU levels for carbon prices less than $15/ton, slowly reducing coal prices from BAU levels to zero-margin levels as CO_2 prices increase to $40/ton, and leaving coal prices at marginal cost levels beyond that point.

Gas: A similar dynamic would likely shape gas prices. As long as gas generation has higher variable costs than coal, long-term average gas prices should not deviate substantially from BAU levels. As discussed above, this situation holds for carbon prices up to roughly $40/ton. At higher carbon prices, gas will be able to gain substantial market share at the expense of coal. In this situation, traditional market dynamics would shift as heavy demand from utilities would trigger a shortage of gas. Gas producers would gain pricing power and gas prices would likely rise until gas generation was only marginally cheaper than coal generation (the "coal floor"). Our price model captures this dynamic by leaving gas prices at BAU levels for carbon prices below $40/ton and increasing prices to match the coal floor for higher carbon prices.

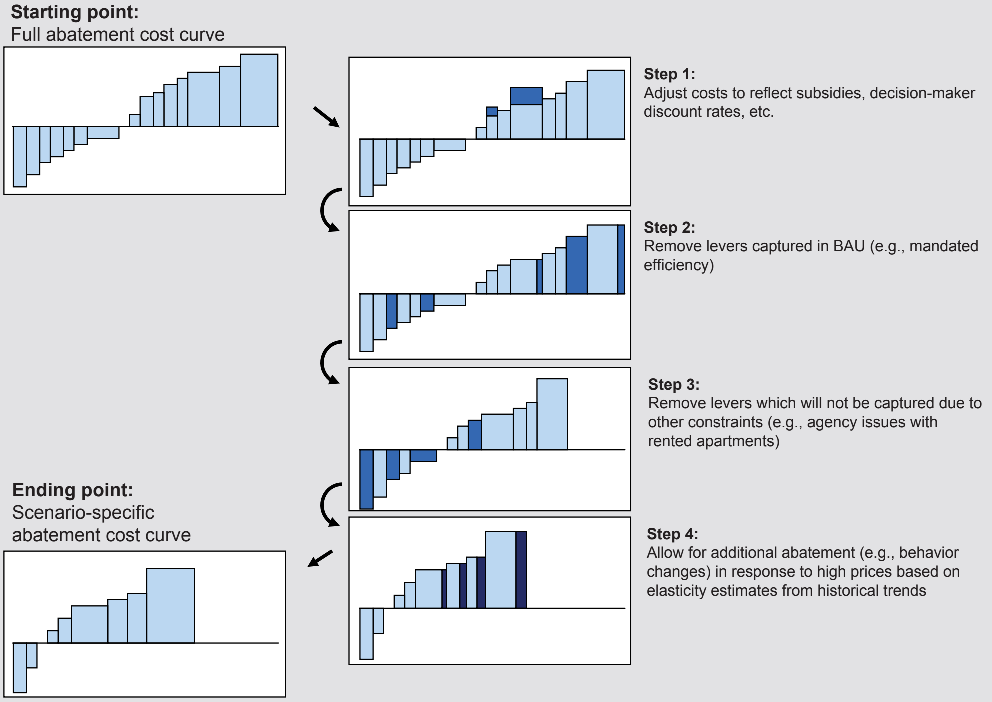
Oil: Typical policy scenarios do not reduce U.S. oil demand by enough to have a material impact on international oil prices. Prices are held at BAU levels in all but very exceptional scenarios.

Carbon prices

When modeling policies that include a cap-and-trade system, carbon prices must be estimated for each year the cap is in place. The model does this by constructing abatement supply curves and calculating the market-clearing price that achieves the required level of abatement. Realistic abatement supply curves are first calculated by narrowing down the list of technical abatement options to just those that could be activated given the technology and policy options in place. This process is illustrated in Exhibit 21. Marginal abatement costs are calculated by adjusting market-clearing prices as necessary to reflect price controls, banking, borrowing, etc. For the sake of simplicity, our model assumes that market carbon prices are equal to marginal abatement costs; we do not treat dynamics in the secondary carbon markets. The following paragraphs provide additional detail on each of these steps.

Exhibit 21

Abatement supply curves represent realistic expectations of achievable abatement with adjustments for capture rates



Starting point:
Full abatement cost curve

Step 1:
Adjust costs to reflect subsidies, decision-maker discount rates, etc.

Step 2:
Remove levers captured in BAU (e.g., mandated efficiency)

Step 3:
Remove levers which will not be captured due to other constraints (e.g., agency issues with rented apartments)

Step 4:
Allow for additional abatement (e.g., behavior changes) in response to high prices based on elasticity estimates from historical trends

Ending point:
Scenario-specific abatement cost curve

Marginal abatement curves are calculated by combining the realized abatement curves from each sector, for each year and each scenario, as shown in Exhibit 22, and adding in additional levels of abatement at each carbon price to reflect sector-specific short-term demand elasticity. As discussed above, the realized sectoral curves contain only the set of measures that would be triggered at each carbon price given the policies in place; they do not include measures unlikely to be triggered in the modeled scenario. For example, the realized abatement curve for the buildings sector would not include the potential from weatherizing rental houses unless the policy scenario contained credible measures to address the barriers to this opportunity.

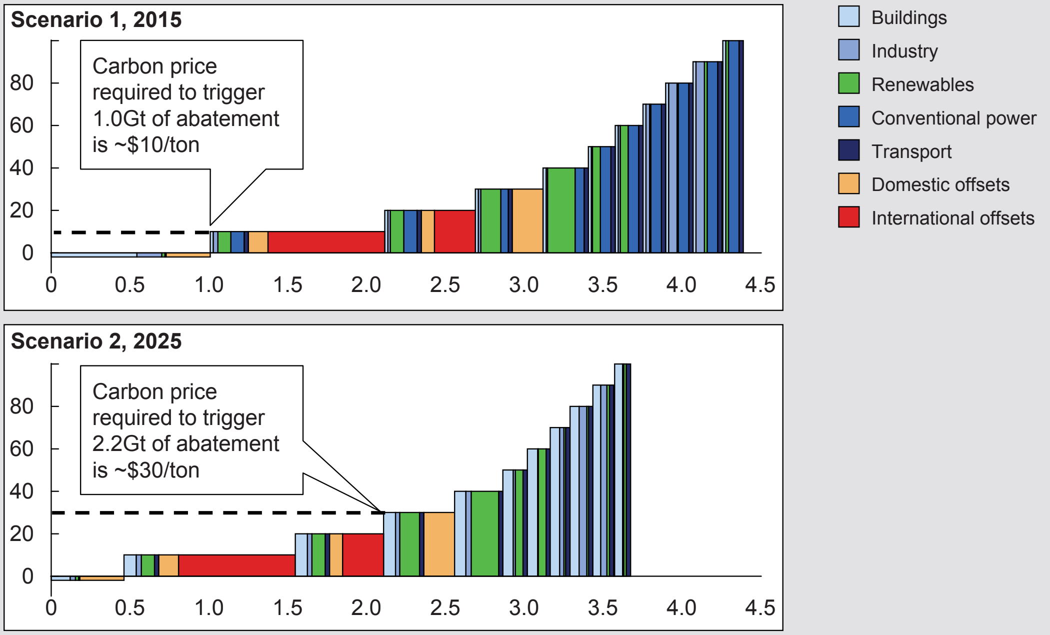
Because they can be subject to volume limits, domestic and international offsets may have prices that are lower than the market-clearing carbon price. When applicable, we trace the separate prices for offsets and allowances. We make two default assumptions in these cases: first, that offset providers are fragmented and have little pricing power, so that U.S. entities can purchase offsets at the international market-clearing price; second, that access to low-cost international offsets is divided among firms in proportion to their carbon emissions. These assumptions can be adjusted as desired.

After marginal prices have been calculated for each year, secondary processing can be applied as desired to model the impacts of banking, borrowing, price floors and ceilings, and so on. Modeling these measures requires some judgment (e.g., the value of the discount rate that investors would apply to banked emissions allowances, given expected regulatory uncertainty), and we can work with users to find the approach that

Exhibit 22

Required abatement is matched to combined cost curves which depend on scenario and year to produce CO_2 price

Abatement potential



makes the most sense in their circumstance. These measures may affect more than just carbon prices. For example, if a price floor is imposed that is higher than the market-clearing carbon price, some covered entities will likely choose to reduce emissions beyond the levels mandated in the cap. This is because many of them will find it cheaper to reduce their own emissions than to purchase an allowance at the (high) price floor. As a result, auctions will be undersubscribed and the U.S. will exceed its abatement target.

Electricity prices

Electricity prices are calculated using (1) an hour-by-hour power dispatch model, which calculates generation costs and marginal pricing, and (2) a retail price model, which computes the residential, commercial, and industrial retail price by state and year by allocating the wholesale price and all other relevant costs (transmission and distribution, SG&A, capital expenditure) across ratepayer segments in proportion to their peak demand, as appropriate for the local market structure (fully regulated, partly regulated, or deregulated).

Power dispatch model

McKinsey's proprietary power dispatch model is a deterministic, highly parameterized model that is broadly similar to both the Electicity Market Module of the National Energy Modeling System (NEMS) used by the Energy Information Administration and the Integrated Planning Model developed by ICF Consulting and used by the Environmental Protection Agency. However, our model differs in several respects, including the use of historically based hourly load curves and hourly renewables resource quality curves. It computes generation costs and marginal prices in each of 42 grid regions within the continental United States for each of about 50,000 sampled hours from 2009 through 2030 by solving for electricity market equilibrium within each region, taking into account the generation supply stack, interregional electricity trade, and emissions costs for CO_2, SO_2, and NO_x.

The composition of generating capacity is determined in three ways. First, based on the detailed modeling of renewables build-out projected by the renewables model, we input the expected renewable energy production into the dispatch model. The renewables build-out is in turn influenced by results from the dispatch model in an iterative process. Second, deregulated regions invest in new capacity based on technology capital costs and expected future cash flows, with investors selecting the option with the highest NPV per kW. Third, regulated regions invest in new capacity based on a PUC perspective, trading off the need for low levelized cost with the need for a balanced portfolio of generating technologies.

Plants are dispatched based on the minimization of short-run variable costs, subject to various operating constraints described below. Equilibrium in interregional power trading is defined as the level of trading necessary to equilibrate regional marginal generation costs net of transmission costs and power losses. In the BAU scenario, these interregional transactions are constrained by available interregional transmission capacity (first contingency) as reported by the North American Electric Reliability Council, the Western Electricity Coordinating Council, the Electric Reliability Council of Texas, and various independent systems operators. We include a short-term pipeline of capacity under construction and our internal long-term projections of transmission capacity expansion to de-bottleneck the system for renewable energy flows. Other scenarios for transmission capacity growth can also be modeled.

The model relies on a database of actual power generation plants (more than 1,700 power stations and collections of capacity by type, which includes key operating parameters for each plant). It takes a number of additional factors into account when deciding which units to dispatch, including start-up costs, plant performance, and fuel prices. All thermal, hydro, and renewable technologies are included. Technologies are modeled in detail, including hourly profile and variations for solar and wind, coal and CCGT load following at night, hydro reservoir dispatching to maximize profits, economics of combined heat and power, must-run nuclear and hydro run-of-river, and pumped storage hydro.

Retail electricity price model

The retail model computes end-user electricity prices by sector and state given the wholesale prices and generation costs calculated by the power dispatch model. A wide range of electricity market structures exist in the U.S. The model uses the following simplified logic to approximate the appropriate pricing logic in each region. In regions that are fully regulated, pricing is based on cost: rates are determined such that revenue from customers covers all operating costs and provides a predetermined return on equity to all owners of generation, transmission, and distribution assets. In regions that are fully deregulated, the transmission and distribution (T&D) component of bills continues to be cost-based as above, but the generating costs are determined based on wholesale electricity prices. Typical regions are modeled as a mix of these two approaches.

Costs taken into account include the following:

- *Return on ratebase:* The return on invested capital given to owners of T&D assets in all regions and to owners of generation assets in regulated regions. The model tracks the value of the ratebase in each region in each year, increasing it as capital is invested in new assets and in maintenance (e.g., turbine overhauls) and decreasing it as assets are depreciated or retired.

- *Production costs:* The fixed and variable costs of generating power (e.g., fuel, start-up costs, SO_2/NO_x/CO_2 allowances). This category accounts for the bulk of generation costs in traditionally regulated regions.
- *Purchased power:* The cost of power purchased from other entities (e.g., merchant generators). This category accounts for generation costs in deregulated regions.
- *Depreciation:* Annual depreciation costs, calculated from the value of rate-based generation, transmission, and distribution assets
- *T&D operating and maintenance costs.*
- *Local and federal taxes.*
- *SG&A, customer care, and additional costs from utility operations.*

After calculating utilities' total annual revenue requirements in each region by summing the above costs, the model calculates electricity rates for industrial, residential, and commercial segments by (1) allocating each region's total revenue requirement among its residential, commercial, and industrial segments in proportion to each segment's peak load, and (2) dividing each segment's revenue requirement by its annual electricity consumption to reach a cost per kilowatt hour.

While this logic does not capture the full complexity of various market structures (e.g., tiered pricing within various customer classes in California), it provides a reasonable base for examining state- and national-level price impacts of energy and climate policies.

5. The REMI PI+ macroeconomic model

The PI+ model is the latest version of the Policy Insight modeling tool created by Regional Economic Models, Inc. (REMI). Federal, state, and local government agencies, universities, nonprofit institutions, consulting firms, and utilities companies are the primary users of REMI's modeling tools. These tools have been used to simulate the economic effects of a wide range of policies, including development, transportation, energy, natural resource, and infrastructure programs.

We use the REMI PI+ model to project the economy-wide effects of changes in demand and prices due to low-carbon policy measures. Take, for example, an energy efficiency measure such as a stricture building standard. The stricter standard leads to higher short-term investment in efficient building technology and a long-lasting reduction in energy expenditure. The REMI PI+ model allows us to trace the effects of these changes through all aspects of the economy, including changes in consumer spending, reduction in demand for energy products, increase in demand for technology, and all of the resulting changes in industry output and employment.

The remainder of this chapter explains how the PI+ model works and then specifically describes how we translate outputs from the McKinsey models into the PI+ model.

How the PI+ model works

The PI+ model is a dynamic, general equilibrium model with an input-output framework at its core. The model also captures spatial aspects of the economy by modeling transportation costs, agglomeration effects, and other features in its economic geography equations. Thousands of simultaneous equations with parameters estimated using econometric methods govern the economic behavior of the model.

The model consists of five major blocks: (1) output and demand, (2) labor and capital demand, (3) population and labor supply, (4) compensation, prices, and costs, and (5) market shares. Within each block, users can adjust various economic levers such as exogenous final demand, production costs, fuel costs, personal taxes, and consumer spending.

Demand comes from consumption, government spending, intermediate inputs, and investment. Consumption depends on population, per capita income, relative prices, and income and price elasticities. The model classifies consumption goods as either luxuries or necessities and specifies marginal income and price elasticities for both types. [10] Changes in population and the size of the economy drive government spending.

A Cobb-Douglas production function determines the substitutability among labor, capital, and fuel production inputs. For labor, the occupation-specific elasticity of substitution comes from Weisbrod, Vary, and Treyz (2001). The input-output tables govern the inter-industry demand for intermediate inputs. The model treats fuel inputs as a value-added factor and therefore excludes fuel from the detailed intermediate industry transactions.

Residential and nonresidential investment follows the dynamic capital stock adjustment process modeled in Rickman, Shao, and Treyz (1993). The key parameter governing investment is the proportion of the gap closed each year between optimal and actual capital stock. Rickman and his colleagues estimate this speed of adjustment parameter using nonlinear least squares and a constructed regional investment data series based on regional construction industry value added reported by the Bureau of Economic Analysis and census building permit data.

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[10] Treyz and Petraglia (2001) contains an earlier version of the consumption equation

The model includes endogenous labor force participation rates (Treyz, Christopher, and Lou, 1996) and economic migration within the U.S. The economic migration equations are based upon a model incorporating both equilibrium and disequilibrium components whose parameters are estimated using an instrumental variables fixed-effects approach (Greenwood, Hunt, Rickman, and Treyz, 1991; Treyz, Rickman, Hunt, and Greenwood, 1993).

Market shares depend on various factors including local supply and demand, price elasticities, a distance decay parameter estimated in a gravity model, and relative costs of production. These relative costs of production depend on productivity that can differ across regions. The PI+ model incorporates economic geography through commodity and labor access indices that effectively capture the productivity advantages associated with having access to a wider variety of inputs. In addition, access to a wider variety of consumer goods factors into the economic migration decision. See Fan, Treyz, and Treyz (2000) for a more complete treatment of economic geography incorporated into the model.

REMI produces PI+ models for single-region, multi-region, or national simulations with varying levels of industry sector detail. We base our analysis on a multi-region national version of the PI+ model that disaggregates the national economy to the individual state level to allow for interstate trade flows and economic migration. This model version divides the private nonfarm sector of the economy into 165 private industry subsectors based on the North American Industry Classification System (NAICS) to allow detailed analysis across subsectors of the economy. Using the PI+ model to simulate various policy scenarios, our analysis focuses on the output in terms of national GDP, state GDP, the value added across industry sectors, and employment levels.

Translating McKinsey model outputs into PI+ model inputs

The REMI PI+ model provides various levers for policy analysis. The levers we use in our analysis directly affect firms, consumers, or the government. The levers affecting firms are exogenous final demand, production costs, and three types of fuel costs: electricity, natural gas, and residual (petroleum and coal) fuel. The levers affecting consumers and the government are total consumer spending, consumption reallocation (shifts in consumer spending patterns), consumer prices, dividends, personal taxes, and government spending. We translate the outputs from the various McKinsey models into dollar amount inputs for the various PI+ model levers.

Cap and trade

In order to model a potential cap-and-trade system, we assign carbon costs to the industries and consumers that would bear them, and assign carbon revenues to the industries and consumers that would receive them.

We assign carbon costs to covered industries based on their share of emissions after adjustment for whatever abatement measures they have taken. Carbon costs are modeled as increases to each industry's production cost. These carbon costs include the purchase of both allowance and domestic/international offsets. Consumers face carbon costs directly through higher prices for electricity, natural gas, gasoline, and oil, and indirectly through increased prices for other consumption goods caused by higher production costs.

Carbon revenues flow to industries and consumers in one of four ways. First, industries and consumers may be eligible for direct rebates. Depending on how the rebate policy is structured, this can be modeled as either a decrease in production costs (for output-based rebates) or as a lump-sum payment. Second, there are rebates that power producers are required to pass on to end-consumers. Examples include the free allocations given to power producers under recent policy proposals such as the American Clean Energy and Security Act. Depending on the policy, this can be modeled as a reduction in electricity prices, an effective reduction in tax rates, or in other ways. Third, some industries (e.g., agriculture) may be able to increase revenue by selling offsets. We model this as an increase in exogeneous final demand for the industry. Finally, there are the indirect impacts on costs to end-consumers implied by the first three effects. These are calculated by the PI+ model.

Indirect effects of cap-and-trade policies (e.g., greater demand for wind turbines, reduced demand for coal, higher power prices) are reflected as discussed below.

Energy-efficiency measures

To model energy-efficiency initiatives, we increase exogenous final demand for industries that provide the goods and services for these initiatives (e.g., manufacturers of LED lighting and insulation). Similarly, since efficiency measures reduce the demand for energy, we reduce the exogenous final demand for the appropriate fuel types. To capture the costs of undertaking these measures, we increase the production cost for industries to reflect capital expenditures. We model the operational savings from reduced fuel demand as a reduction in fuel costs for industries.

On the consumer side, we increase consumer spending for the categories of goods and services associated with implementing efficiency initiatives, such as household appliances. We model energy savings as a reduction in consumer spending on electricity, natural gas, gasoline, and oil. In order to keep the amount of consumer spending constant, if households spend more while implementing efficiency measures, we offset this with a reduction in consumption across all other categories while keeping the relative amounts constant. Likewise, when energy savings imply that consumers have more to spend on other goods and services, we increase consumption in other categories by this difference.

If we model the energy-efficiency initiatives with financing, we keep the demand-side drivers the same as before, but we spread the increase in production costs for firms and the reduction in non-energy consumption for individuals across the appropriate financing period. We account for interest payments by adding them to the overall increase in production costs for firms and the reduction in non-energy consumption for individuals.

Energy-efficiency initiatives can also affect the prices of fossil fuels and electricity. This effect is calculated in our pricing unit and is communicated to the PI+ model by changing consumer and industry spending levels in these areas.

Other policies

The impacts of other policies are managed in a similar manner. In each case, we calculate the implied impacts on demand, prices, and production costs.

Demand changes are always calculated in a two-step process. First, we calculate the direct impact of the spending by summing the implied demand changes for each of the triggered abatement measures to reach the change in demand for each of the 165 industries' products. Building a nuclear power plant, for example, will result in increases in incremental demand across many of the 165 REMI sectors (e.g., engineering services, pump and compressor manufacturing, boiler and tank manufacturing, metal ore mining) and decreases in demand for fossil fuels and traditional generating technologies. Each of these changes is communicated to PI+ by adjusting exogenous final demand for the relevant industries.

Second, spending in other areas may need to be decreased or increased to compensate. We use the PI+ model's consumption reallocation lever to capture the compensating changes in consumer spending and use increased production costs to trigger the required adjustments in industrial spending.

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Appendix – list of REMI PI+ industry sectors

Sector	NAICS Code
Forestry; Fishing, hunting, trapping	1131, 1132, 114
Logging	1133
Support activities for agriculture and forestry	115
Oil and gas extraction	211
Coal mining	2121
Metal ore mining	2122
Nonmetallic mineral mining and quarrying	2123
Support activities for mining	213
Electric power generation, transmission, and distribution	2211
Natural gas distribution	2212
Water, sewage, and other systems	2213
Construction	23
Sawmills and wood preservation	3211
Veneer, plywood, and engineered wood product manufacturing	3212
Other wood product manufacturing	3219
Clay product and refractory manufacturing	3271
Glass and glass product manufacturing	3272
Cement and concrete product manufacturing	3273
Lime, gypsum product manufacturing; Other nonmetallic mineral product manufacturing	3274, 3279
Iron and steel mills and ferroalloy manufacturing	3311
Steel product manufacturing from purchased steel	3312
Alumina and aluminum production and processing	3313
Nonferrous metal (except aluminum) production and processing	3314
Foundries	3315
Forging and stamping	3321
Cutlery and handtool manufacturing	3322
Architectural and structural metals manufacturing	3323
Boiler, tank, and shipping container manufacturing	3324
Hardware manufacturing	3325
Spring and wire product manufacturing	3326
Machine shops; turned product; and screw, nut, and bolt manufacturing	3327
Coating, engraving, heat treating, and allied activities	3328
Other fabricated metal product manufacturing	3329
Agriculture, construction, and mining machinery manufacturing	3331
Industrial machinery manufacturing	3332
Commercial and service industry machinery manufacturing	3333
Ventilation, heating, air-conditioning, and commercial refrigeration equipment manufacturing	3334
Metalworking machinery manufacturing	3335
Engine, turbine, power transmission equipment manufacturing	3336

Other general purpose machinery manufacturing	3339
Computer and peripheral equipment manufacturing	3341
Communications equipment manufacturing	3342
Audio and video equipment manufacturing	3343
Semiconductor and other electronic component manufacturing	3344
Navigational, measuring, electromedical, and control instruments manufacturing	3345
Manufacturing and reproducing magnetic and optical media	3346
Electric lighting equipment manufacturing	3351
Household appliance manufacturing	3352
Electrical equipment manufacturing	3353
Other electrical equipment and component manufacturing	3359
Motor vehicle manufacturing	3361
Motor vehicle body and trailer manufacturing	3362
Motor vehicle parts manufacturing	3363
Aerospace product and parts manufacturing	3364
Railroad rolling stock manufacturing	3365
Ship and boat building	3366
Other transportation equipment manufacturing	3369
Household and institutional furniture and kitchen cabinet manufacturing	3371
Office furniture (including fixtures) manufacturing	3372
Other furniture related product manufacturing	3379
Medical equipment and supplies manufacturing	3391
Other miscellaneous manufacturing	3399
Animal food manufacturing	3111
Grain and oilseed milling	3112
Sugar and confectionery product manufacturing	3113
Fruit and vegetable preserving and specialty food manufacturing	3114
Dairy product manufacturing	3115
Animal slaughtering and processing	3116
Seafood product preparation and packaging	3117
Bakeries and tortilla manufacturing	3118
Other food manufacturing	3119
Beverage manufacturing	3121
Tobacco manufacturing	3122
Fiber, yarn, and thread mills	3131
Fabric mills	3132
Textile and fabric finishing and fabric coating mills	3133
Textile furnishings mills	3141
Other textile product mills	3149
Apparel knitting mills	3151
Cut and sew apparel manufacturing	3152

Apparel accessories and other apparel manufacturing	3159
Leather, hide tanning, finishing; Other leather, allied product manufacturing	3161, 3169
Footwear manufacturing	3162
Pulp, paper, and paperboard mills	3221
Converted paper product manufacturing	3222
Printing and related support activities	323
Petroleum and coal products manufacturing	324
Basic chemical manufacturing	3251
Resin, synthetic rubber, and artificial synthetic fibers and filaments manufacturing	3252
Pesticide, fertilizer, and other agricultural chemical manufacturing	3253
Pharmaceutical and medicine manufacturing	3254
Paint, coating, and adhesive manufacturing	3255
Soap, cleaning compound, and toilet preparation manufacturing	3256
Other chemical product and preparation manufacturing	3259
Plastics product manufacturing	3261
Rubber product manufacturing	3262
Wholesale trade	42
Retail trade	44-45
Air transportation	481
Rail transportation	482
Water transportation	483
Truck transportation	484
Couriers and messengers	492
Transit and ground passenger transportation	485
Pipeline transportation	486
Scenic and sightseeing transportation and support activities for transportation	487, 488
Warehousing and storage	493
Newspaper, periodical, book, and directory publishers	5111
Software publishers	5112
Motion picture and sound recording industries	512
Internet and other information services	516, 518, 519
Broadcasting (except internet)	515
Telecommunications	517
Monetary authorities, credit intermediation	521, 522
Funds, trusts, and other financial vehicles	525
Securities, commodity contracts, and other financial investments and related activities	523
Insurance carriers	5241
Agencies, brokerages, and other insurance related activities	5242
Real estate	531
Automotive equipment rental and leasing	5321
Consumer goods rental and general rental centers	5322, 5323

Commercial and industrial machinery and equipment rental and leasing	5324
Lessors of nonfinancial intangible assets	533
Legal services	5411
Accounting, tax preparation, bookkeeping, and payroll services	5412
Architectural, engineering, and related services	5413
Specialized design services	5414
Computer systems design and related services	5415
Management, scientific, and technical consulting services	5416
Scientific research and development services; Other professional, scientific, and technical services	5417, 5419
Advertising and related services	5418
Management of companies and enterprises	55
Office administrative services; Facilities support services	5611, 5612
Employment services	5613
Business support services; Investigation and security services; Other support services	5614, 5616, 5619
Travel arrangement and reservation services	5615
Services to buildings and dwellings	5617
Waste collection; Waste treatment and disposal and waste management services	562
Elementary and secondary schools; Junior colleges, colleges, universities, and professional schools; Other educational services	61
Offices of health practitioners	6211-6213
Outpatient, laboratory, and other ambulatory care services	6214-6216
Home health care services	6219
Hospitals	622
Nursing care facilities	6231
Residential care facilities	6232, 6233, 6239
Individual, family, community, and vocational rehabilitation services	6241-6243
Child day care services	6244
Performing arts companies; Promoters of events, and agents and managers	7111, 7113, 7114
Spectator sports	7112
Independent artists, writers, and performers	7115
Museums, historical sites, and similar institutions	712
Amusement, gambling, and recreation industries	713
Accommodation	721
Food services and drinking places	722
Automotive repair and maintenance	8111
Electronic and precision equipment repair and maintenance	8112
Commercial and industrial equipment (except automotive and electronic) repair and maintenance	8113
Personal and household goods repair and maintenance	8114
Personal care services	8121
Death care services	8122

Drycleaning and laundry services	8123
Other personal services	8129
Religious organizations; Grantmaking and giving services, and social advocacy organizations	8131-8133
Civic, social, professional, and similar organizations	8134, 8139
Private households	814
State and Local Government	NA
Federal Civilian	NA
Federal Military	NA
Farm	111, 112

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