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ECONOMIC CONSULTING

Impacts of Greenhouse Gas Regulations On the Industrial Sector

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The opinions expressed herein are those of the authors and do not necessarily represent the views of NERA Economic Consulting or any other NERA consultants.

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LIST OF ACRONYMS

ACCF CPR	American Council for Capital Formation Center for Policy Research
AEO	Annual Energy Outlook
AGR	Agriculture
ALU	Aluminum
BAU	Baseline (Business as Usual)
BOF	Basic Oxygen Furnace
CAA	Clean Air Act
CAFE	Corporate Average Fuel Economy
CES	Constant Elasticity of Substitution
CHM	Bulk Chemicals
CHP	Combined Heat and Power
CMP	Computer and Electronic Products
CMT	Cement
CNS	Construction
CO_2	Carbon Dioxide
COL	Coal
CPP	Clean Power Plan
CRU	Crude Oil
DG	Distributed Generation
DRI	Direct Reduced Iron
DSM	Demand-Side Management
EAF	Electric Arc Furnace
EIA	U.S. Energy Information Administration
ELE	Electric Sector
ELQ	Electrical Equipment
EPA	U.S. Environmental Protection Agency
FAB	Fabricated Metal Products

FICA	Federal Insurance Contributions Act
FOO	Food Products
G8	Group of Eight
GAS	Natural Gas
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GLS	Glass and Glass Products
HFC	Hydrofluorocarbons
IND	Manufacturing Sectors
I_S	Iron and Steel
LDV	Light Duty Vehicle
LULUCF	Land Use, Land Use Change and Forestry
M_V	Motor Vehicle Manufacturing
MAC	Machinery
MECS	Manufacturing Energy Consumption Survey
MIN	Mining
MY	Model Year
NAICS	North American Industry Classification System
NBER	National Bureau of Economic Research
NDC	Nationally Determined Contributions
NHTSA	National Highway Traffic Safety Administration
NT	No Trading
OEM	Other Energy-Intensive Manufacturing
OIL	Petroleum Refinery
OMA	Balance of Other Manufacturing
ONM	Other Non-Energy-Intensive Manufacturing
OTH	Other Sectors
PAP	Paper and Allied Products

PLA	Plastic and Rubber Products
RPS	Renewable Portfolio Standard
SAM	Social Accounting Matrices
SEDS	State Energy Data System
SIP	State Implementation Plan
SRV	Commercial
TRK	Trucking
TRN	Commercial Transportation (Sea, Air, and Rail)
TRQ	Transportation Equipment
U.S.	United States
USMCS	United States Mid-Century Strategy for Deep Decarbonization
USSBR	2016 Second Biennial Report of the United States of America
WOO	Wood Products

EXECUTIVE SUMMARY

NERA Economic Consulting was commissioned by the American Council for Capital Formation Center for Policy Research (ACCF CPR) to perform a comprehensive assessment of impacts on the overall U.S. economy in general, and on the industrial sector in particular, from regulating greenhouse gas (GHG) emissions under existing and potential future regulations.

President Obama announced the Climate Action Plan (CAP) to address climate change through executive action in 2013. In addition to other initiatives not requiring new legislation, it directed the U.S. Environmental Protection Agency (EPA) to establish the first ever restriction on carbon dioxide emissions from the electric sector. The EPA issued new rules to reduce GHG emissions from the electric sector through the "Clean Power Plan" (CPP), claiming under authorities granted in sections 111(b) and 111(d) of the Clean Air Act (CAA).

In addition to issuing new regulations to implement its CAP, the Obama Administration participated in meetings in Paris at the end of 2015 that created a new framework to reduce GHG emissions, based on voluntary "Nationally Determined Contributions" (NDC) from each country. The U.S. pledged in its initial NDC to reduce emissions more rapidly and further than the CPP alone would do, and in its *2016 Second Biennial Report of the United States of America*[1] (USSBR 2016) submitted to the United Nations (UN), it described in broad terms what additional regulations would be required to achieve those goals. The USSBR 2016 provides some options to achieve the 2025 NDC target to reduce net GHG emissions by 26 to 28% relative to 2005 levels. The U.S. NDC from the Paris Agreement is consistent with a straight-line emissions reduction pathway to economy-wide emission reductions of 80% or more by 2050. These long term goals of reducing emissions are detailed in the U.S.'s mid-century strategy (USMCS 2016)[2] that envisions a deep decarbonization of the U.S. economy to 80% below 2005 emissions by 2050.

It is widely agreed that the total potential emissions reductions from existing policies together with planned policies announced by the Obama Administration are insufficient to achieve the NDC pledge and would fall dramatically short of the 2050 goal. While the projected size of the NDC emissions "gap" varies somewhat among various analyses, it is clear that such a gap cannot be filled without contributions from the industrial sector. Accordingly, this study aims to estimate the costs and impacts of closing the Paris NDC gap under a number of different scenarios.

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[1] 2016 Second Biennial Report of the United States of America under the UNFCCC, The U.S. Department of State, 2016.

[2] United States Mid-Century Strategy for Deep Decarbonization, The White House, November 2016. http://unfccc.int/files/focus/long-term_strategies/application/pdf/us_mid_century_strategy.pdf

To address the study objectives, we develop a slate of scenarios to bracket the potential economic impacts on the industrial sectors and the economy as a whole from the U.S. reducing its GHG emissions as specified in its NDC. The scenarios employ a combination of market-based and direct measures to restrict GHG emissions. The core scenarios are constructed so that the U.S. as a whole ultimately meets its NDC emission target. Since the Obama Administration has taken the course of implementing its CAP through direct sectoral regulations, rather than broader market-based (i.e. cap-and-trade or carbon tax) measures that would require legislative action, we design some scenarios to illuminate the impacts of feasible direct measures. In light of suggestions that EPA could base its climate policies on Section 115 of the CAA, titled "International Air Pollution," we design a nationwide cap and trade program and overlay it with regulatory programs to meet the U.S. NDC target

All the programs to be analyzed are assumed to utilize available Land Use, Land Use Change and Forestry (LULUCF) offsets to meet the emissions target. The USSBR 2016 report on actions to reduce GHG emissions includes high and low estimates for sequestration of GHGs due to changes in land use and forestry that are uncertain and difficult to estimate. Based on these estimates, we estimate two different offset potentials (average and high) that are counted toward emission reduction targets in the study. Since this study deals only with regulations to reduce carbon dioxide (CO_2) emissions from fuel combustion, it excludes the costs of these measures to increase sequestration and reduce other GHGs. Costs of reducing non-CO_2 emissions in the assumed amounts and of increased sequestration would be additional to the study's cost estimated to reduce CO_2 emissions. For the core scenario assuming availability of the average level of offsets, the overall manufacturing sector will have to reduce its emissions by about 38% from its 2005 levels for the U.S. to meet its NDC target in 2025.

To conduct this study, we used NERA's N_{ew}ERA integrated model, which consists of a top-down general equilibrium macroeconomic model of the U.S. economy and a detailed capacity-planning and dispatch model of the North American electricity system. The N_{ew}ERA modeling framework captures interactions among all parts of the economy and transmits the effects of sectoral policies throughout the economy. The model's flexibility allows it to incorporate many different types of policies, such as those involving industrial, energy, environmental, financial, labor, and tax matters. The model represents five U.S. regions (four manufacturing based states and the rest of the U.S.) and captures manufacturing at a subsector level. The model includes 16 industrial sub-sectors, of which five are energy-related sectors and 11 are non-energy sectors. Of the 11 non-energy sectors reflected in the model, eight are manufacturing sectors and the other three represent the non-manufacturing subsectors. The model is run from 2016 through 2040 in three-year time steps.

We highlight below some key findings of our study for the core scenario that sets emissions caps without trading for each of the four broad sectors – Industrial, Electric, Transportation, and rest of other sectors – at levels to meet the overall U.S. 2025 NDC target and continue on a path of 80% reduction in emissions by 2050.

Key Findings of the Study[3]

Summary of some key impacts relative to the baseline

	2025	2040	2025	2040
	Average Sequestration		High Sequestration	
Percentage Change in Gross Domestic Product (%)	-1%	-9%	-1%	-8%
Change in Gross Domestic Product (2015$ Bil.)	-$250	-$2,900	-$180	-$2,500
Change in Income per Average U.S. Household (2015$/Household)*	-$160	-$7,000	-$60	-$5,900
Change in Manufacturing Sector Jobs (Thousands)	-440	-3,100	-280	-2,800
Change in Total Industrial Sector Jobs (Thousands)	-1,060	-6,500	-760	-5,800
Change in Total Economywide Jobs (Thousands)	-2,700	-31,600	-1,900	-27,900
Percentage Change in Industrial Sector Output (%)				
Paper and Allied Products	-4%	-12%	-3%	-10%
Cement	-21%	-23%	-13%	-21%
Bulk Chemicals	-5%	-12%	-3%	-10%
Iron and Steel	-19%	-38%	-12%	-35%
Coal	-20%	-86%	-18%	-82%
Natural Gas	-11%	-31%	-8%	-29%
Petroleum Products	-11%	-45%	-7%	-41%
Percentage Change in Emissions Relative to 2005 Levels (MMTCO$_2$)				
Industry	-38%	-61%	-27%	-56%
Transportation	-13%	-55%	-13%	-53%
Other	-1%	-53%	-1%	-51%
Electric	-31%	-57%	-31%	-55%
Industrial Process and other CO_2	-33%	-60%	-19%	-54%
Non-CO_2	-17%	-56%	-17%	-54%
Sequestration	30%	-12%	49%	38%

* Change in income per average U.S. household is expressed as a dollar value relative to current average income levels.

The U.S. economy could lose about $250 billion in 2025[4]

As the broadest measure of economic impact, the reductions in GDP due to costs of future GHG regulation are notable in each of the scenarios. In the core scenario, U.S. GDP loss could be about $250 billion in 2025 increasing to about $420 billion per year on average and a cumulative

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[3] The study results only reflect the least cost approach to meet emission reduction targets. It does not take into account potential benefits from avoided emissions. The study results are not a benefit-cost analysis of climate change. The long run, year 2040, impacts which are representative of the Obama Administration's long term emissions goal of an 80% reduction by 2050 are subject to a great deal of uncertainties about the future. The model does not take into consideration yet to be developed technologies that might influence the long term cost. The impacts estimated are based on current technology costs and availability assumed in our model.

[4] The values are denominated in 2015 dollar unless mentioned otherwise.

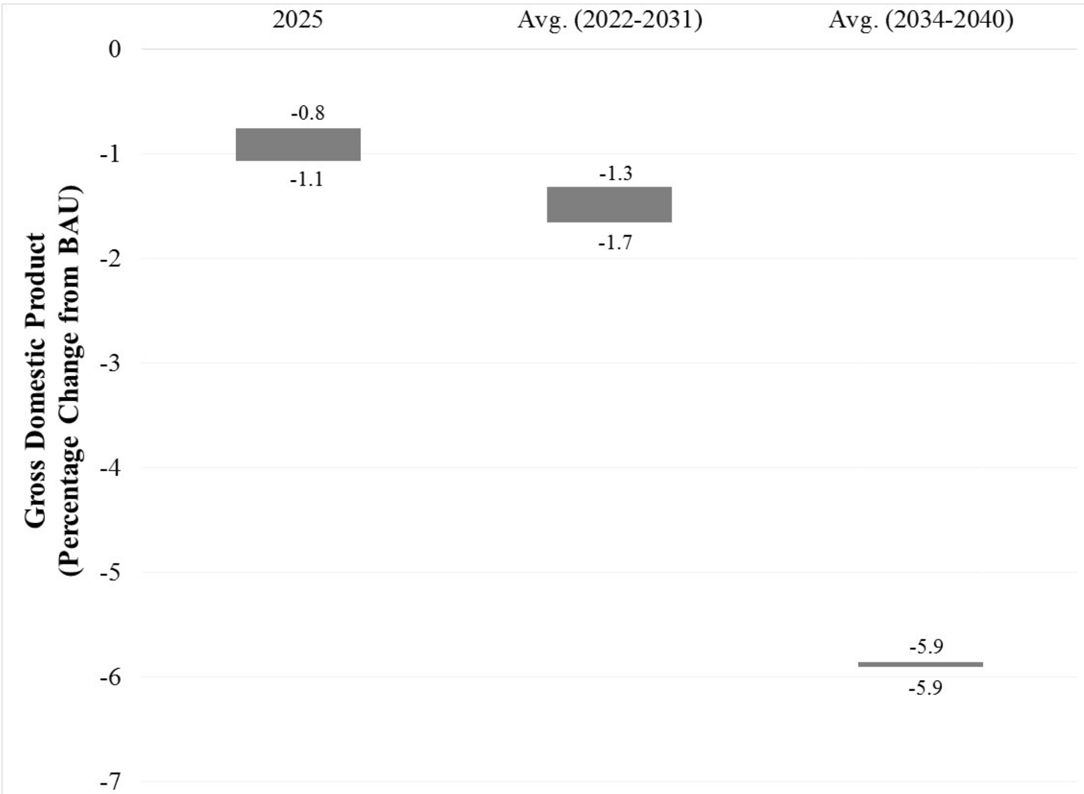
loss of about $4 trillion between 2022 and 2031. The losses become larger in the long run as the "mid-term" deep decarbonization target constrains the economy significantly. The U.S. economy could lose about 6% of its GDP on average between 2034 and 2040 amounting to a loss of greater than $2 trillion annually and a cumulative loss of $14 trillion.[5]

Availability of additional free offsets mitigate the overall impacts on the economy

Overall impact on the U.S. economy is mitigated by assumed free LULULCF offsets. Cumulative GDP loss is reduced from about 1.1% to about 0.8% if high estimates for sequestration of GHGs due to changes in land use and forestry are available. Having additional offsets reduces the impacts on GDP by about 30% in 2025, and 20% in the medium to long term, respectively. The impact even with high offsets amounts to about $180 billion in 2025, $330 billion in the medium term and $1.8 trillion in the long term. The range of GDP impact under the different sequestration levels is shown in the figure below with the height of the bars representing the range of impacts from high to low sequestration.

[5] The average impacts are represented as simple averages between years 2022 and 2031 and years 2034 and 2040 to represent a short/medium and long term impacts of the policy, respectively. All impacts are estimated relative to the baseline which is absent of the GHG policy.

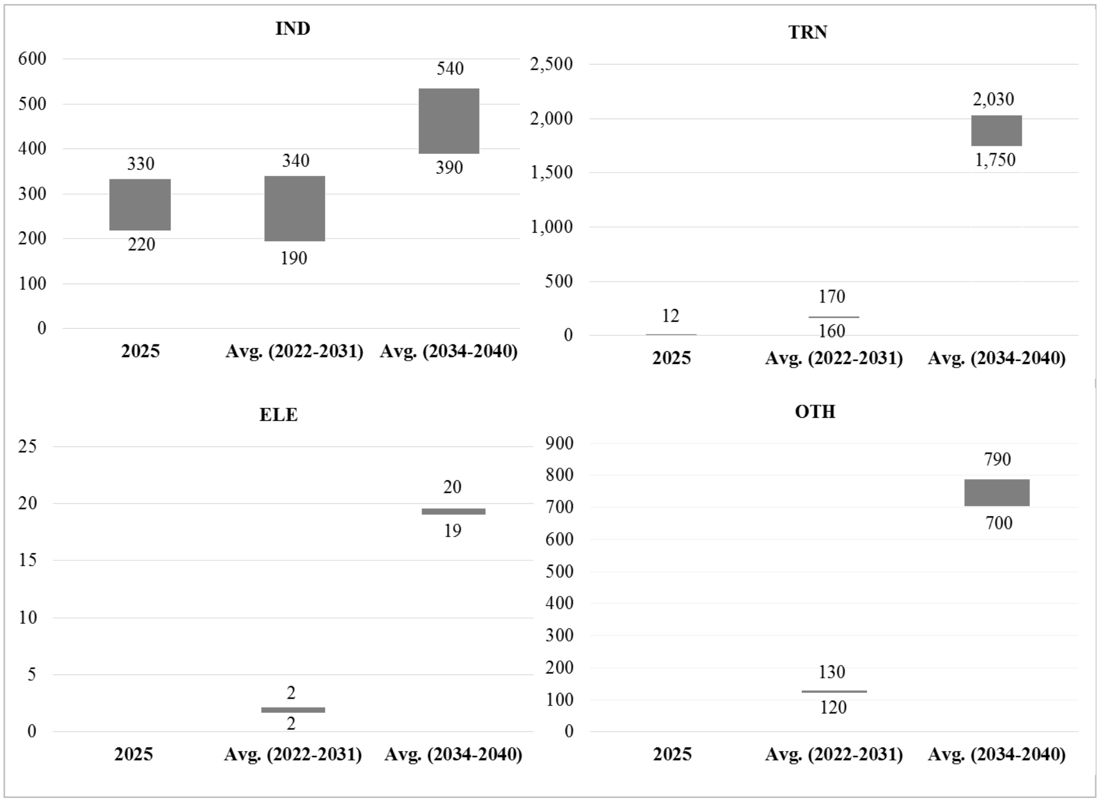
Percentage Change in Gross Domestic Product (%)



Marginal costs of reducing carbon varies across sectors

By representing subsectoral regulations as a cap on the entire industrial sector that includes all the targeted subsectors, we implicitly assume that regulators succeed in identifying the least cost mitigation options for all firms within each broad sector. Since the caps for each sector are set separately and no trading is allowed across the four broad sectors – Industry, Transportation, Electric Power, and Other— there will be a suboptimal allocation of effort across these sectors. The carbon price shows that the power sector experiences the lowest price to meet its targets. The industrial sector faces a carbon price of $200 per metric ton[6] of CO_2 (TCO_2) in 2025 and rises over time to about $400/$TCO_2$ in the long run. The other two broad sectors (Transportation and Other) face no carbon price until year 2028 since their emissions caps are non-binding until that time. The ranges of carbon prices for the four broad sectors for the different levels of sequestration in the model are shown below.

Carbon Price (2015$ per metric ton of CO_2) [7]



Energy-intensive sectors experience the greatest impacts

The most energy and carbon intensive sectors experience the greatest impacts. As a result of the GHG policy, these sectors face high costs and become globally uncompetitive leading to lower demand for their goods. Production of iron and steel, refined petroleum products, and cement sectors are the most impacted. Under the core scenarios, their 2025 output declines by about 19%, 11%, and 21%, respectively, and their 2040 output declines by about 38%, 45%, and 23% respectively. Bulk chemicals and paper and allied products output decline by about 5% relative to the baseline in 2025 and by 12% in 2040.

The motor vehicle sector sees an increase because a large amount of capital investment is directed to this sector to produce more fuel efficient and alternative fuel vehicles. Since the regulatory program represented by a carbon price has a direct impact on the cost of using fossil fuels, fuel demand is reduced and production of natural gas and crude oil declines by about 10%. The production of natural gas declines by 31% and crude oil by 45% by 2040. Coal production declines by 20% relative to the baseline production in 2025 and by 86% in 2040. The figure

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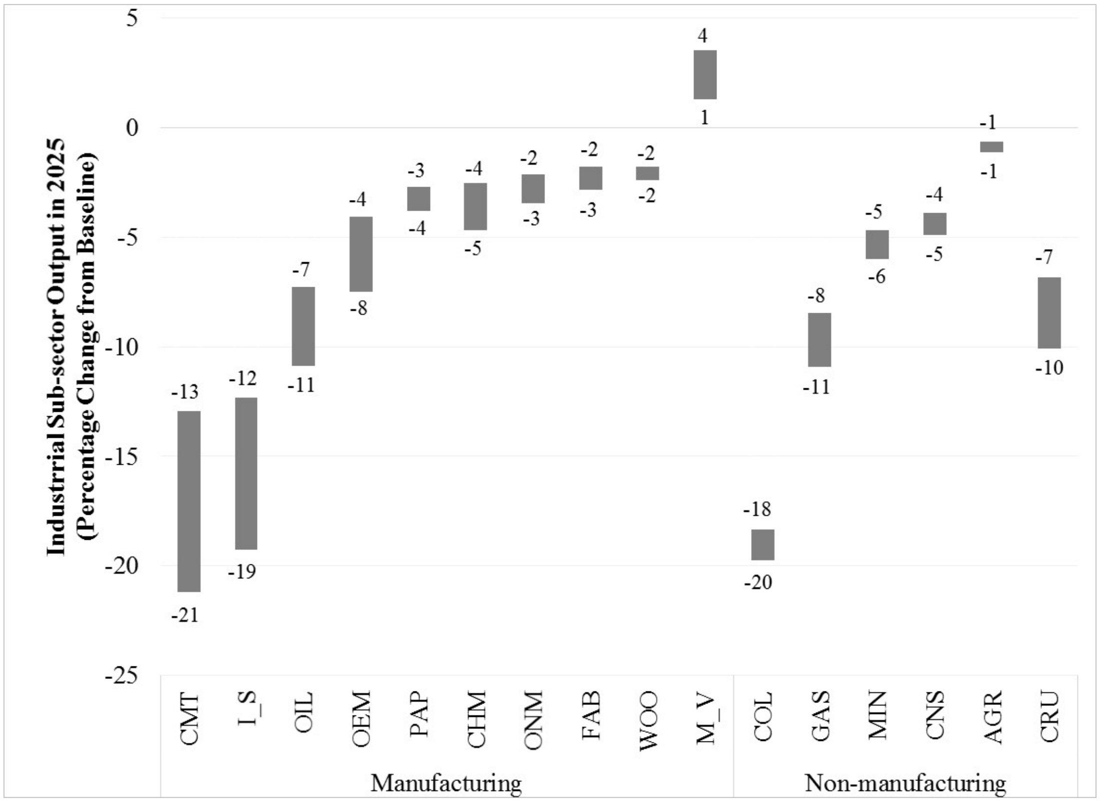
[6] Throughout the remainder of this report, CO_2 is reported in metric tons and for brevity referred to as tons.

[7] IND - Manufacturing sectors, TRN - Transportation sector, ELE - Electric sector, and OTH - Rest of the economic sectors, see Section III.

below shows the change in output of all of the industrial sub-sectors modeled in the study with the ranges shown corresponding to the levels of sequestration modeled.

Percentage Change in Industrial Sub-Sector Output (%) [8]



Leakage in emissions defeats the objective of reducing emissions from a global perspective

Leakage in emissions occurs when reductions in a region employing a policy are offset by an increase in emissions in another region. In particular for this study, U.S. emission reductions are offset by increases in emissions in the rest of the world, which undertakes no GHG reduction

[8] I_S – Iron and Steel, OIL – Refining, CMT – Cement, OEM – Other Energy Intensive Manufacturing, PAP – Paper and Allied Products, CHM – Bulk Chemicals, FAB – Fabricated Metal Products, WOO – Wood Products, M_V - Motor Vehicle Manufacturing, COL – Coal, Gas – Natural Gas, MIN – Mining, CNS – Construction, AGR – Agriculture, CRU – Crude Oil.

policy[9] beyond the programs that are already incorporated in the baseline.[10] Leakage defeats a large share of the emission reductions from the most energy-intensive and heavily impacted sectors. For every ton of CO_2 emissions reduced in the U.S., 0.3 tons of CO_2 emissions increase elsewhere from energy-intensive sectors. Hence, from a global perspective the overall effectiveness of the U.S. policy is undermined by leakage. Moreover, the high costs borne by especially the energy-intensive sectors produce even less emission reduction when viewed from a global basis.

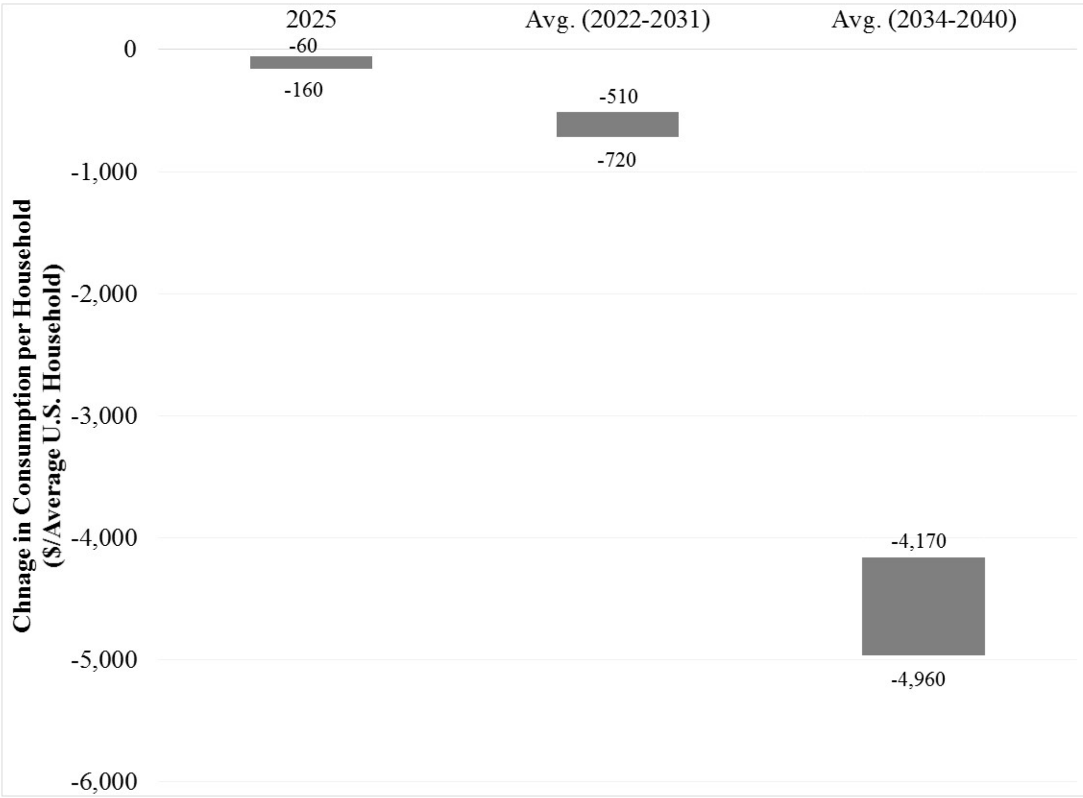
GHG policy leads to lower household income and consumption

Costs of compliance with CAP regulations and higher costs of using energy lead directly to reductions in household purchasing power. On average in 2025, a typical U.S. household's real annual income declines by $160 relative to today's income level. The average annual loss in income increases to about $710 per household between 2022 and 2031. The losses become significant and could reach about $5,000 per household between 2034 and 2040. The consumption or income impacts per average U.S. household are shown in the figure below.

[9] Since the intensity pledge of China, a major contributor of global emissions, does not deviate significantly from the current outlook (http://www.energyxxi.org/china%E2%80%99s-indc-significant-effort-or-business-usual), we omitted potential effects of other regions taking on their respective NDCs in this study.

[10] The leakage rate would be mitigated if other regions of the world also undertook policies to reduce carbon emissions.

Consumption per Household



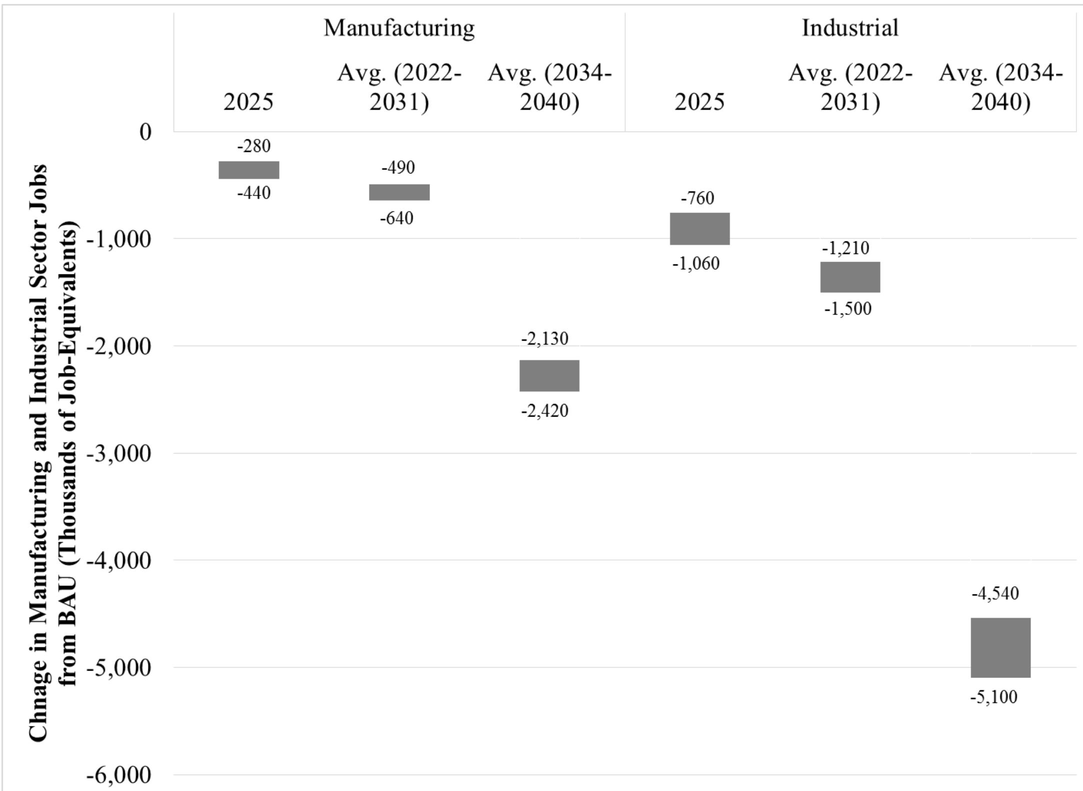
Manufacturing sector could lose about 440,000 jobs in 2025

Energy costs make up a large share of the total cost of production of manufacturing goods. A restriction in carbon emissions means that the total cost of fossil fuel increases leading to higher costs of production. This cost increase leads to the closing of facilities that cannot compete on a cost basis. The increasing stringency of the GHG policy leads to more closure of manufacturing sectors over time leading to fewer manufacturing jobs. In 2025, the manufacturing sector alone could potentially lose 440,000 job-equivalents relative to the baseline jobs and about 3.1 million in 2040.[11] Taking into account the loss in employment in other non-manufacturing sectors, the job-equivalents impact for the overall industrial sector could be about 1.1 million job-equivalents in 2025 and 6.5 million in 2040. A large share of this job loss occurs in the construction sector

[11] We represent jobs impacts are as "job-equivalents." The number of job-equivalents equals total labor income change divided by the average annual income per job. This does not represent a projection of the numbers of workers that may need to change jobs and/or be unemployed, as some or all of the loss in labor income could take the form of lower wages and be spread across workers who remain employed.

which employs a significant portion of the overall industrial labor force. Total economy-wide employment losses amount to about 2.7 million in 2025.

Change in Manufacturing and Total Industrial Sector Jobs (Thousands)



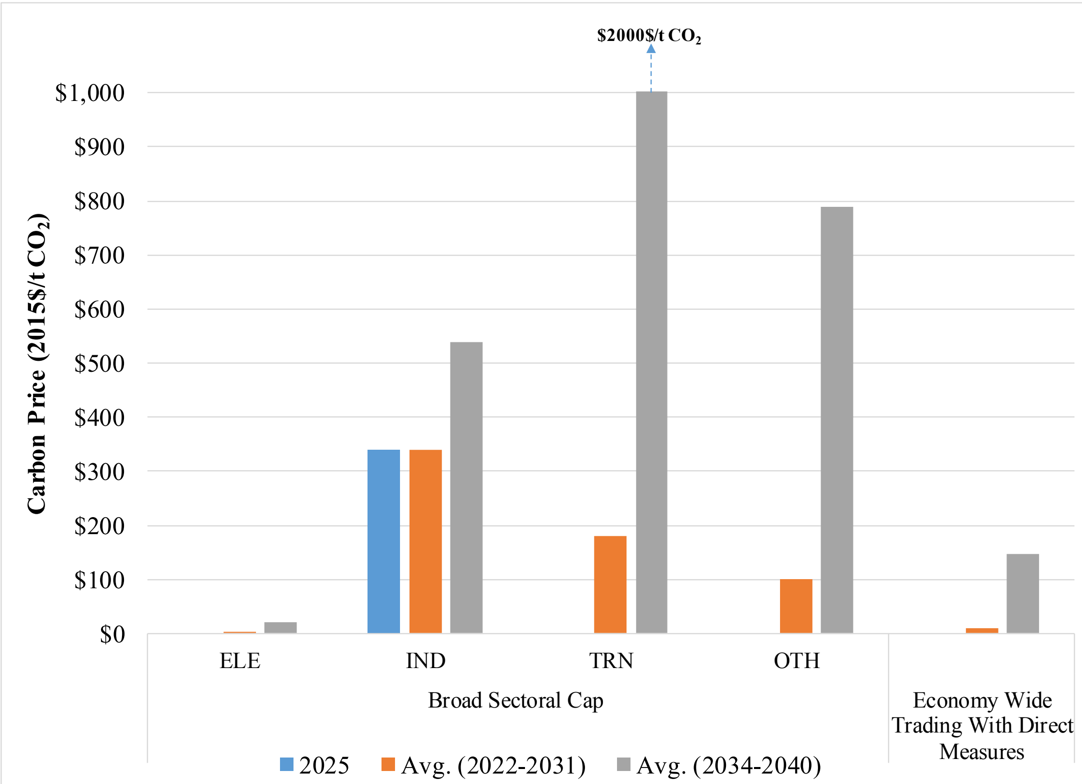
The overall costs of achieving the NDC targets depends upon the policy design

Implementing regulatory system through direct measures that requires no shutting down of existing facilities is insufficient to achieve the targets. Furthermore, the use of direct rather than broad market based measures is an inefficient way to achieve climate goals. The analyses from the study show policies that allow more flexibility achieve the same or greater emission reductions at lower, but still at a significant cost to the U.S. economy. The set of scenarios highlight the variation in costs estimates under scenarios using narrow based sectoral measures and economy-wide market-based measures. In particular, under a nationwide cap and trade program that allows trading across all sectors of the economy ensures that the marginal cost of reducing emissions are equalized across all sectors.[12] The overall cost of achieving the NDC

[12] This scenario assumes that EPA will depart from its existing authorities under CAA and claims broad authority to create an economy-wide cap and trade program. While the legality of whether EPA has such authority is still up

target would decrease by about 11% in a present value basis with an economy-wide trading regime with direct measures compared to the broad sectoral cap.

Carbon Prices for Different Trading Regimes (2015$ per metric ton of CO_2)



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for debate, numerous stakeholders have suggested than an argument for such authority could be made under CAA Section 115. If EPA were to attempt to do so, it is likely that they would be required to instruct states to include GHGs in State Implementation Plans (SIP).

I. INTRODUCTION

A. Background

In 2009, eight industrialized nations, including the United States (U.S.) referred as the Group of Eight (G8) - France, Germany, Italy, the United Kingdom, Japan, the U.S., Canada, and Russia – discussed cutting global emissions by 50% by 2050, with the highly industrialized nations to cut their emissions by 80%. President Obama in 2013 announced the Climate Action Plan (CAP) to address climate change. Under this plan, the administration has already used its existing authorities by issuing CAA standards to tighten fuel economy standards for cars and trucks, other efficiency standards, and requirements for use of renewable fuels in transportation. The CAP further directs the EPA to establish the first ever restriction on carbon dioxide emissions from the electric sector. The EPA issued new rules to reduce GHG emissions from the electric sector relying on sections 111(b) and 111(d) of the CAA. The electric sector's "Clean Power Plan" (CPP) was stayed by the U.S. Supreme Court, and its implementation will depend upon the resolution of legal challenges.

In addition to issuing new regulations to implement its CAP, the Obama Administration participated in meetings in Paris at the end of 2015 to address global GHG emissions. As a result of these talks, many countries agreed to reduce their emissions. These reductions are referred to as Nationally Determined Contributions (NDC). The U.S. pledged as part of its NDC to reduce emissions more rapidly and further than the CPP alone would do, and in its USSBR 2016 submitted to the UN in 2016 described in broad terms what additional regulations would be issued to achieve those goals. The USSBR 2016 provides a blueprint to achieve the 2025 target of a 26 to 28% reduction in emissions relative to the 2005 levels. The U.S. NDC is consistent with a straight-line emissions reduction pathway to economy-wide emission reductions of 80% or more by 2050 as presented in the mid-century strategy (MCS) that envisions a deep decarbonization of the U.S. economy of 80% below 2005 levels by 2050.

The U.S.'s NDC contains no specific targets for reduction of emissions in any sector (including industrial emissions), but it is widely acknowledged that industrial sector emissions would have to be reduced in order to achieve the NDC. Consistent with this, a recent EPA's budget proposal requested funding to begin considering new GHG regulations on the refining, paper and allied products, iron and steel, livestock, and cement sectors.[13] The Obama Administration also expects reductions in emissions from existing automobile efficiency standards and new standards for heavy trucks, new appliance efficiency standards, regulations on methane emissions from oil

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[13] United States Environmental Protection Agency, Fiscal Year 2015, Justification of Appropriation Estimates for the Committee on Appropriations, EPA-190-R-14-002, pg. 2013.

and gas operations, tighter appliance efficiency standards, voluntary measures to reduce hydrofluorocarbons under EPA's Significant New Alternatives Policy program, programs to enhance carbon sinks through land use management,[14] and many other such regulations that would directly or indirectly impact the industrial sector. Whether or not the current stay on implementation of the EPA's CPP, a centerpiece of the Obama Administration's proposed regulation to limit GHG emissions, is sustained, substantial emission reductions from the industrial sector would be required to meet the U.S.'s NDC and the overall emissions reduction goal for the U.S. reflected in the Paris Agreement.

B. Objectives of the Study

NERA Economic Consulting was asked by the American Council for Capital Formation (ACCF) to conduct a comprehensive assessment of impacts on the manufacturing sectors in particular and on the overall economy in general from the 2025 target and the long term goal of 80% reduction under different regulatory approaches and program flexibility to understand the potential range of economic impacts on the industrial sector.

C. How the Study Was Conducted

We use NERA's N_{ew}ERA model for this study. N_{ew}ERA model is a dynamic computable general equilibrium of the U.S. economy and is well suited to estimate impacts of policy, regulatory, and economic factors on the industrial sectors, energy sectors, and the economy. The N_{ew}ERA model combines a macroeconomic model with all sectors of the economy with a detailed electric sector model that represents electricity production. The model specification captures the effects of reduction in GHG reduction as they ripple through all sectors of the economy and the associated feedback effects.

CO_2 emissions from fuel combustion are directly represented in N_{ew}ERA, so that only the required emission reduction needs to be specified. Industrial process emissions of CO_2 are important in some industrial sectors such as cement. We assume reduction in process emissions to be proportional to reduction in the industrial fossil fuel CO_2 emissions.[15] The current carbon capture and storage (CCS) costs suggest that industrial CCS is not viable commercially, and we assume it will not be available during the period analyzed.

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[14] As per the NDC, the US intends to include all categories of emissions by sources and removals by sinks, and all pools and gases, as reported in the Inventory of United States Greenhouse Gas Emissions and Sinks. In the model we will assume exogenously removal from by sinks.

[15] Based on the 2005 ratio of process emissions to industrial energy, an industrial process emission is about 24% of the total industrial fossil fuel combustion emissions.

We do not explicitly model the cost of reducing other GHG emissions that the Obama Administration intends to regulate. We assume that methane, hydrofluorocarbons (HFCs), and other non-CO_2 GHGs will be reduced in line with USSBR 2016 projections which are based on current proposals, and count these reductions toward the emission reduction targets assumed in our scenarios. Thus any of our cost estimates will underestimate the cost to achieve emission targets related to all GHGs because we assume reductions of non-CO_2 GHGs can be achieved at no cost.

The USSBR 2016 on actions to reduce GHG emissions also includes high and low estimates for sequestration of GHGs due to changes in land use and forestry. These estimates are also counted toward emission reduction targets in the study. Since this study deals only with regulations to reduce CO_2 emissions from fuel combustion and CO_2 process emissions, it excludes the costs of these measures to increase sequestration and reduce other GHGs. Costs of reducing non-CO_2 emissions in the assumed amounts and of increased sequestration would be additional to the costs estimated to reduce CO_2 emissions.

The model baseline is calibrated to the Energy Information Administration's Annual Energy Outlook 2016 (AEO 2016). The model represents 5 U.S. regions (Missouri, Michigan, Pennsylvania, Ohio, and Rest of the U.S.) and includes detailed industrial sectors (10 manufacturing sectors and three non-manufacturing sectors), the other four energy sectors (coal, crude oil, natural gas, and electricity), residential, commercial, and commercial transportation and trucking sectors. The model is solved to 2040 starting in 2016 in three-year time steps.

D. Organization of the Report

The next section, Section II, provides a brief overview of the topic manufacturing sub-sectors. Section III provides a short summary of the NewERA model and the baseline assumptions. Section IV describes the scenarios followed by detailed discussion of the national and sectoral impacts in Section V. Section VI highlights macroeconomic impacts on the four states (Missouri, Michigan, Pennsylvania, and Ohio) that were analyzed for the study. Section VII concludes with insights drawn from the study.

II. OVERVIEW OF THE TOPIC INDUSTRIAL SUB-SECTORS

A. Bulk Chemicals

In 2015, the U.S. bulk chemicals manufacturing sector which incorporates both commodity and agricultural chemicals generated nearly $350 billion in product shipments, or nearly 6% of the total value of product shipments of the U.S. manufacturing sector as a whole with the product shipment values staying flat in comparison to 2014 values.[16] The sector employed around 286,000 people in 2015 up from around 284,000 people in 2014. In 2015, imports for the sector amounted to around $190 billion in product shipment value while exports amounted to $220 billion.[17]

Commodity chemicals are typically produced in large volumes and are characterized by chemical composition specifications that are homogenous in nature. In 2015, the product shipment value from commodity chemicals amounted to nearly $310 billion with nearly half of this value coming from bulk petrochemicals and intermediates.[18] Examples of commodity chemicals include inorganic chemicals, bulk petrochemicals, organic chemical intermediates, plastic resins, synthetic rubber, manufactured fibers, dyes and pigments, and printing inks.

The primary markets for commodity chemicals include other chemicals and chemical products, other manufactured goods such as textile products, automobiles, appliances and furniture where they are incorporated into the final product or may be used to aid in processing in other industries such as paper and allied products and oil refining. The production of commodity chemicals is typically both capital and energy intensive, large in scale with prices being highly co-related with capacity utilization levels and raw material costs. Also key to the production process is access to raw materials and plant size. These factors when coupled with potential environmental concerns create high barriers to entry in the market.

Agricultural chemicals while closely related to commodity chemicals are distinguished by having one very dominant end-use customer namely the farming sector. The business incorporates two major segments – fertilizers and crop production. Apart from farming, a few other businesses such as construction and utilities as well as a few institutional segments use agricultural chemicals. In 2015, the product shipment value from agricultural chemicals amounted to around $40 billion.[18]

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[16] Annual Energy Outlook 2016, Reference Case without Clean Power Plan, U.S. EIA, May 2016

[17] Value of Exports, General Imports and Imports by Country by 3-digit NAICS, U.S. International Trade Statistics, United States Census Bureau, July 2016.

[18] 2016 Guide to the Business of Chemistry, American Chemistry Council, June 2016.

B. Cement

Cement is a globally traded commodity. Cement is manufactured using a closely controlled chemical combination of calcium, silicon, aluminum, iron, and other ingredients. Common materials used to manufacture cement include limestone, shells, and chalk or marl combined with shale, clay, slate, blast furnace slag, silica sand, and iron ore. These ingredients, when heated at high temperatures form a rock-like substance that are ground into the fine powder that we commonly think of as cement.

In 2015, the U.S. cement manufacturing sector generated around $14 billion in product shipments or around 0.2% of the total value of product shipments of the U.S. manufacturing sector as a whole.[19] The sector employed around 25,000 people in 2015 up from 24,000 in 2014.[19] Historically, it has been one of the most energy intensive sectors with its energy intensity nearly ten times that of the average intensity of all sectors.[20]

The domestic production of cement increased slightly from 2014 levels to about 80.4 million tons of portland cement and 2.4 million tons of masonry cement.[21] Production, however, continued to be well below the record level of 99 million tons in 2005 reflecting full-time idle status at a few plants, underutilized capacity, and plant closures in recent years.[21] Total shipments to final customers including exports amounted to nearly 93 million tons with imports of hydraulic cement and clinker for consumption at nearly 11 million tons. [21]

The U.S. cement industry is made up of plants that produce clinker and grind it to make finished cement and clinker grinding plants that inter-grind clinker that was obtained elsewhere, with various additives. Clinker production is the most energy intensive stage in cement production and accounts for over 90% of total energy use and almost all of the sector's fuel use.[22] Electricity needed for the crushing and grinding of raw materials and finishing represent another source of energy demand. Proven technical options with the potential to enable reductions in energy use and CO_2 emissions include improvements in energy efficiency, use of alternative raw materials and fuels, and reduction in clinker content using alternative cement blends.

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[19] Annual Energy Outlook 2016, Reference Case without Clean Power Plan, U.S. EIA, May 2016. The cement industry keeps its own employment statistics that are compiled and published by the Portland Cement Association. In the interest of consistency across sectors, this report relies on the cited data from the U.S. EIA.

[20] The cement industry is the most energy intensive of all manufacturing industries, Today in Energy, U.S EIA, July 2013. Available: http://www.eia.gov/todayinenergy/detail.cfm?id=11911

[21] U.S. Geological Survey, Mineral Commodity Summaries, January 2016. Available: http://minerals.usgs.gov/minerals/pubs/commodity/cement/mcs-2016-cemen.pdf

[22] Energy Efficiency Improvement and Cost Saving Opportunities for Cement Making, Ernst Worell and Christina Galitsky, Ernest Orlando Lawrence Berkeley National Laboratory, March 2008.

Clinker may either be produced using a "wet" or "dry" process. In a wet rotary kiln, the feed blend typically contains about 36% moisture. This necessitates the use of a long kiln for purposes of evaporation of the moisture. Fuel use in a wet kiln can vary between 5.3 and 7.1 gigajoules per tonne (GJ/tonne) of clinker.[22] In a dry rotary kiln, feed material with much lower moisture content typically around 0.5% is used, thereby reducing kiln length. Later developments have included multi-stage suspension preheaters and kilns equipped with preheater/pre-calciner stages. Fuel use in a dry kiln is typically lower with the fuel consumption varying between 3.2 and 3.5 GJ/tonne clinker for a dry kiln with a 4 or 5 stage pre-heating.[22] The vast majority (96%) of the cement produced in the U.S. is through the "dry" process.

C. Iron and Steel

Steel production involves numerous steps which can be organized into various combinations depending on the product mix, the available raw materials, energy supply, and investment capital. Primary production involves the use of a blast furnace to produce molten iron from iron ore, coking coal and limestone. The molten iron produced is then subsequently converted to steel in a basic oxygen furnace (BOF). This route can be particularly energy intensive due to the inclusion of the coke making and sintering process. The secondary production of steel typically employs an electric arc furnace (EAF), where scrap steel is the primary input. The scrap steel is then melted using electricity. Natural gas may be used as a supplemental source of energy.

In 2015, the U.S. Iron and Steel sector generated nearly $116 billion in product shipments, or around 2% of the total value of product shipments of the U.S. manufacturing sector as a whole.[23] The sector employed around 154,000 people directly in 2015 up from around 152,000 people in 2014.[23] In 2015, steel shipments totaled 87 million tons, with finished imports amounting to 31 million tons and exports amounting to 10 million tons.[24]

In 2015, the steel industry accounted for about 1.5% of all industrial shipments and 6.1% of industrial delivered energy consumption.[25] According to EIA's AEO 2016 Reference Case, energy use in the steel industry is forecasted to increase by about 11% over 2015-40 while the energy intensity is projected to fall by 27%, compared to a decrease of 18% in overall industrial energy intensity. The overall energy intensity of the EAF route is significantly lower than that of the BOF route and the shift from one to the other has contributed to a substantial reduction in the energy intensity for the iron and steel manufacturing sector. The decrease in energy intensity can

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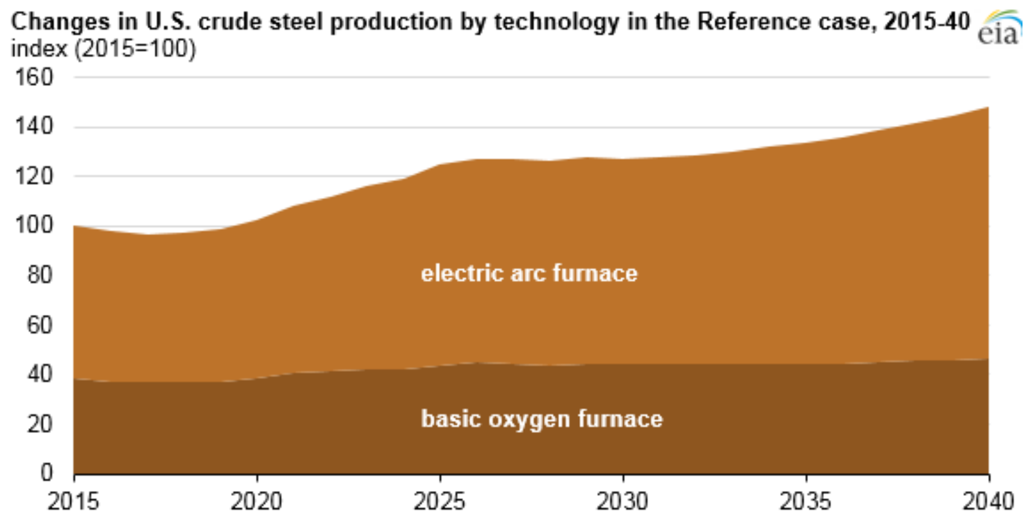
[23] Annual Energy Outlook 2016, Reference Case without Clean Power Plan, U.S. EIA, May 2016.

[24] 2016 Steel Industry Profile, American Iron and Steel Institute, July 2016. Available at https://steel.org/~/media/Files/AISI/Reports/2016-AISI-Profile.pdf

[25] Steel Industry Energy Consumption: Sensitivity to Technology Choice, Fuel Prices, and Carbon Prices in the AEO 2016 Industrial Demand Module, July 2016. Available at https://www.eia.gov/forecasts/aeo/section_issues.cfm#steel_industry

be attributed to omitting the need for ore preparation as well as coke making and iron making. According to data from the Manufacturing Energy Consumption Survey and the World Steel Yearbook, from 1991 to 2010, the share of U.S. steel production using electric arc furnaces increased from 38% to 61%, while the energy intensity of crude steel production decreased by 37%. In the AEO 2016 Reference Case, the electric arc furnace share of crude steel production is forecasted to increase to 69% by 2040 as seen in Figure 1.

Figure 1: U.S Crude Steel production by Technology Type



Direct reduced iron (DRI) production, a newer technology which is now commercially available and growing, accounted for about 8 million tons of iron production in 2015. This process involves the direct conversion of iron ore using a reducing agent which is usually natural gas. The resulting sponge iron is then used as a feedstock in the EAF process. This process is able to convert iron ore to iron using less energy and lower capital cost when compared to the BOF route. It can also take advantage of the relatively lower natural gas prices in the U.S.

D. Paper and Allied Products

The paper and allied products manufacturing sector converts fibrous raw materials into pulp, paper, and paperboard products. Market pulp mills produce only pulp which is then sold and transported to paper and paperboard mills. Paper and paperboard mills may purchase pulp or choose to manufacture their own pulp. In the latter case, the units are referred to as integrated mills. The major processes employed in the paper and allied products industry include raw materials preparation, pulping, bleaching, chemical recovery, pulp drying, and paper making. Certain paper and allied products mills also include converting operations such as coating or box making but these operations are usually carried out at separate facilities.

In 2015, the U.S. paper and allied products sector generated nearly $160 billion in product shipments, or nearly 3% of the total value of product shipments of the U.S. manufacturing sector as a whole.[26] Shipments declined from around $163 billion in 2014. This sector employed around 366,000 people in 2015 down from 370,000 people in 2014. In 2015, imports for the paper and allied products sector amounted to around $21 billion in product shipment value while exports amounted to around $24 billion.[27]

Paper and allied products manufacturing processes primarily differ in the pulping process employed. During this process, wood chips are separated into individual cellulose fibers by removing the lignin from the wood. There are four main types of pulping processes: chemical, mechanical, semi-chemical, and recycle. The chemical process (kraft or sulfite) involves digestion of the wood chips using aqueous chemical solutions and elevated temperature and pressure to extract the fibers. The Kraft process uses an alkaline cooking liquor of sodium hydroxide and sodium sulfide to digest the wood while the Sulfite process uses an acidic mixture of sulfurous acid and bisulfite ion. The use of sulfite pulping has declined in comparison to kraft pulping over time since sulfite pulps have less color in comparison to Kraft pulps and can be bleached more easily but are not as strong. In mechanical pulping, the pulp fibers are separated from the wood by physical energy such as grinding or shredding. Semi-chemical pulping uses a combination of chemical and mechanical energy to extract the fibers. In the recycle pulping process, pulp fiber is recovered from previously manufactured products such as cardboard and office paper through hydration and agitation.

Kraft pulping is the most extensively used chemical pulping process, accounting for about 80% of the paper and allied products manufacturing processes in the U.S.[28] This process requires more heat energy and has lower fiber yield than other pulping types. However, Kraft mills are able to meet almost all of their energy needs from by-products such as black liquor and can even be a net exporter of energy. It has also been demonstrated that the application of combined heat and power (CHP) can significantly enhance the energy efficiency of the paper and allied products industry with typical fuel savings of about 10-20% and energy savings of 30% compared to traditional technologies.

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[26] Annual Energy Outlook 2016, Reference Case without Clean Power Plan, U.S. EIA, May 2016.

[27] Value of Exports, General Imports and Imports by Country by 3-digit NAICS, U.S. International Trade Statistics. United States Census Bureau, July 2016.

[28] Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Pulp and Paper Manufacturing Industry, U.S. EPA, October 2010. Available: https://www.epa.gov/sites/production/files/2015-12/documents/pulpandpaper.pdf

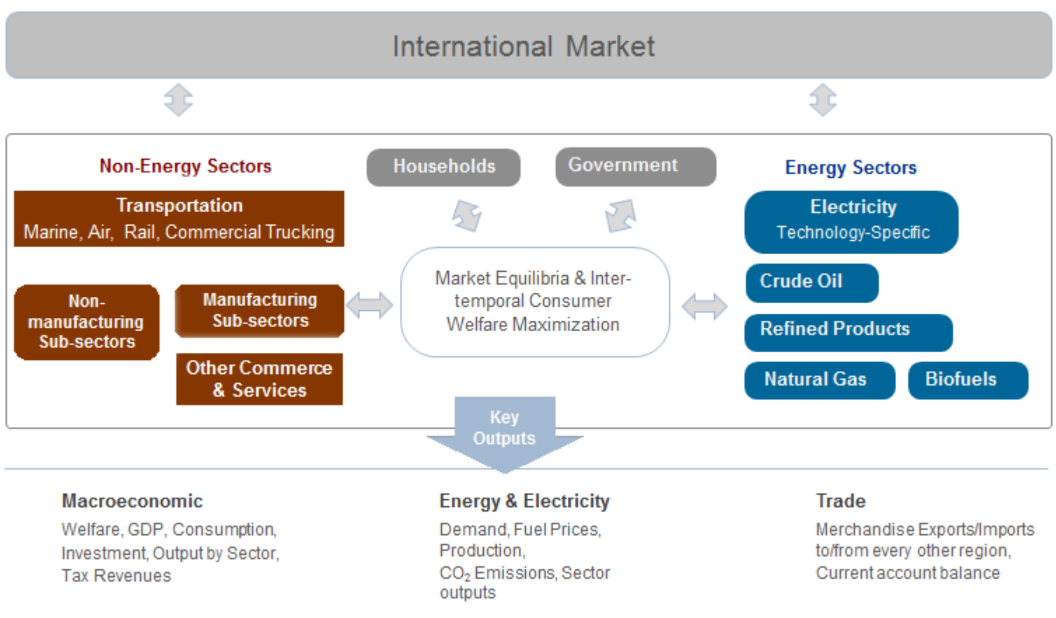
III. NERA METHODOLOGY AND BASELINE ASSUMPTIONS

A. Overview of the N_{ew}ERA Model and NERA Methodology

1. The N_{ew}ERA Model

To conduct this study, we used NERA's N_{ew}ERA integrated model, which consists of a top-down, general equilibrium macroeconomic model (Macro model) of the U.S. economy and a detailed bottom-up model of the North American electricity system (Ele Model). The NewERA model is used to estimate impacts of command and control regulations and market based policies on the U.S. economy as a whole and at a disaggregate sectors. In evaluating policies that have significant impacts on the entire economy, one needs to use a model that captures the effects as they ripple through all sectors of the economy and the associated feedback effects. The NewERA modeling framework takes into account these interactions between all parts of the economy and the effects of sectoral responses to the policies are transmitted throughout the economy. The model's flexibility allows it to incorporate many different types of policies, such as those affecting the industrial, energy, environmental, financial, labor, and tax matters. Figure 2 shows a high level overview of the NewERA modeling system.

Figure 2: NewERA Modeling Framework



a) U.S. General Equilibrium Model (Macro Model)

The Macro model is a forward-looking dynamic computable general equilibrium model of the United States. The model simulates all economic interactions in the U.S. economy, including those among industries, households, and the government. Industries and households maximize profits and utility assuming perfect foresight over the model horizon. The theoretical construct behind the model is based on the circular flow of goods, services, and payments in the economy. That is, every economic transaction has a buyer and a seller whereby goods/service go from a seller to a buyer and payment goes from the buyer to the seller. The model includes a representative household in each region, which characterizes the behavior of an average consumer, and 17 industrial sectors, including resource producing sectors, which represent the production sectors of the economy. Since the impacts on the industrial sector is a key objective of the study, we disaggregate the industrial sector into 10 manufacturing sub-sectors consistent with the Manufacturing Sector Energy Consumption Survey (MECS) sectors (Bulk Chemical, Cement, Fabricated Metal Products, Motor Vehicle Manufacturing, Iron and Steel, Other Energy-intensive Manufacturing, Other Non-Energy-Intensive Manufacturing, Pulp and Allied Products, and Refining), four other energy sectors (coal, natural gas, crude oil, and electricity), three non-manufacturing sectors (Agriculture, Construction, and Mining), see the following section for a description of the model sector and details of each of the industrial sectors represented in the model. In the model, the government collects tax revenues and returns it back to the consumers on a lump-sum basis.[29] The U.S. economy is linked to the rest of the world through trade in goods and services. Changes in the international prices of goods and services relative to the U.S. prices affect the exports and imports of goods and services. These changes enable the model to compute global competitiveness of the U.S. industries.[30]

Households provide labor and capital to businesses, taxes to the government, and savings to financial markets, while also consuming goods and services and receiving government subsidies. Industries produce goods and services using labor and capital and pay taxes to the government. Industries are both consumers and producers of capital that is augmented to the current capital stock through investment. Within the circular flow, equilibrium is found whereby demand for goods and services is equal to their supply, and investments are optimized for the long term. Thus, supply equals demand in all markets.

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[29] However, tax revenues collected through an equivalent ad valorem tax under the alternative scenarios are spent in funding wasteful activities. The tax revenues are not returned to the government that could have been used to support government expenditures on goods and services and thus avoid raising labor and capital tax rates to balance the government's budget.

[30] We simulate similar policies using NERA Global N_{ew}ERA model that models explicitly world regions and able to capture international prices and trade positions endogenously which are linked the U.S. N_{ew}ERA model.

The N_{ew}ERA model is based on a unique set of databases that we constructed for the benchmark year of 2015 by updating the economic data from the IMPLAN 2008[31] database and combining with the energy data from EIA's AEO 2016.

b) Electricity Model (Ele Model)

The bottom-up electricity sector model simulates the electricity markets in the U.S. and parts of Canada. The model includes more than 17,000 electric generating units and capacity planning, and dispatch decisions are represented simultaneously. The model dispatches electricity to load duration curves. The model determines investments to undertake and unit dispatch by solving a dynamic, non-linear program with an objective function that minimizes the present value of total incremental system costs, while complying with all constraints, such as demand, peak demand, emissions limits and transmission limits, and other environmental and electric specific policy mandates. The details in the electricity model allow us to analyze the CPP, which limits emissions from the power sector, in a consistent way for the study.

The integrated nature of the N_{ew}ERA model enables it to provide impacts on the electricity price consistent with a realistic electric system representation; while being able to compute macro-economic impacts. For this study, we model to year 2040 starting in 2016 in three-year time steps.

2. Sectoral Scope of the Model

In order to capture manufacturing at a subsector level and to have large heterogeneity in the factors of production, we modeled the manufacturing sector in detail. We created 16 industrial sectors, of which five are energy-related sectors and 11 are non-energy sectors. Industrial sectors in the N_{ew}ERA model are aggregated up from the IMPLAN database, which includes 440 sectors. Of the 11 non-energy sectors that we modeled, 8 are manufacturing sectors and the other 3 represent non-manufacturing subsectors. The subsectors within manufacturing are created in the model based on three North American Industry Classification System (NAICS)[32] entities and consistent with the sectors that are the focus of the MECS conducted by EIA.[33] The

[31] See www.implan.com.

[32] "The North American Industry Classification System (NAICS) is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy." http://www.census.gov/eos/www/naics.

[33] "The Manufacturing Energy Consumption Survey provides statistics on the consumption of electricity and other types of fuel. It also provides data on the capability of manufacturers to substitute alternative fuels for those actually consumed, end uses, the extent to which energy-related technologies are being used by manufacturers and other related topics." http://www.census.gov/econ/overview/ma0400.html.

manufacturing sector as a whole is represented by industrial entities contained in NAICS 31, NAICS 32, and NAICS 33. These three NAICS sectors consist of all manufacturing establishments engaged in the mechanical, physical, or chemical transformation of materials, substances, or components into new products. The manufacturing sectors represented in the model are briefly described below.

Petroleum Refinery (OIL): The petroleum refinery subsector represents industrial entities based on NAICS 3241. The subsector transforms crude petroleum and coal into useable products. It is the third largest subsector among the manufacturing subsectors.

Paper and Allied Products (PAP): The paper manufacturing subsector (NAICS 322) makes pulp, paper or converted paper products.

Bulk Chemicals (CHM): In the chemical manufacturing subsector (NAICS 325), the EIA has identified industries that manufacture bulk chemicals as energy-intensive. These include inorganic (NAICS 32512-32518), organic (NAICS 32511, 32519), resin (NAICS 3252) and agricultural (NAICS 3253) chemical manufacturing.

Cement (CMT): The cement product manufacturing industries (NAICS 32731) transforms mined or quarried nonmetallic minerals, such as sand, gravel, stone, clay, and refractory materials, into intermediate or final products.

Iron and Steel (I_S): The iron and steel mills and steel product manufacturing subsector (NAICS 3311-3312) smelt and/or refine ferrous metals from ore, pig or scrap, using electrometallurgical and other metallurgical techniques.

Fabricated Metal Products (FAB): The fabricated metal product manufacturing subsector (NAICS 332) transforms metal into intermediate or end products or treats metals and metal formed products with processes like forging, stamping, bending, forming, machining, welding and assembling.

Wood Products (WOO): The wood product manufacturing subsector (NAICS 321) manufactures wood products such as lumber, plywood, veneers, wood containers, wood flooring, wood trusses and mobile homes, and prefabricated wood buildings.

Other Energy-Intensive Manufacturing (OEM): Aluminum (ALU) represents the industrial entities based on NAICS 3313. Glass and glass products (GLS) represent the industrial entities based on NAICS 3272.

Other Non-Energy-Intensive Manufacturing (ONM): This sector includes the following other MECS sectors:

Food Products (FOO): The food manufacturing subsector (NAICS 311) transforms livestock and agricultural products into food products.

Computer and Electronic Products (CMP): The computer and electronic product manufacturing subsector (NAICS 334) manufactures computers, computer peripherals, communications equipment, and similar electronic products or components for such products.

Machinery (MAC): Industries in machinery manufacturing subsector (NAICS 333) create end products that apply mechanical force to perform work.

Electrical Equipment (ELQ): Industries in the electrical equipment, appliance and component manufacturing subsector (NAICS 335) manufacture products that generate, distribute and use electrical power. Products in this subsector include lighting equipment, household appliances, electric motors, generators, batteries, and wiring devices.

Transportation Equipment (TRQ): The transportation equipment manufacturing subsector (NAICS 336) produces motor vehicles, body, trailer and parts of motor vehicles, aerospace products and parts, railroad rolling stock, and ships and boats among others. The TRQ sector only includes transportation parts production but excludes personal motor vehicle production.

Plastic and Rubber Products (PLA): The plastics and rubber products manufacturing subsector (NAICS 326) makes goods by processing plastic materials and raw rubber.

Balance of Other Manufacturing (OMA): All remaining manufacturing subsectors are grouped into the category "Balance of Other Manufacturing". This category includes industries like furniture manufacturing (NAICS 337), fine chemical manufacturing (NAICS 3254 – 3256, 3259), beverage and tobacco product manufacturing (NAICS 312), textile and textile product mills (NAICS 313-314), apparel manufacturing (NAICS 315), and printing and paper manufacturing (NAICS 322-323).

The other sectors in the model are Residential, Commercial, and the Transportation sectors. The transportation sector in the model is represented by two types of transportation services: Commercial transportation which includes air, rail, and water borne transportation services and the Trucking sector. The detailed sectors in the model are classified into four broad sectors. The manufacturing sectors, transportation sector, other sector, and the power sector are referenced as IND, TRN, OTH, and ELE, respectively. Table 1 below provides the sectoral composition details.

Table 1: Sectoral Composition

Manufacturing Sectors: IND	Transportation: TRN	Other Sectors: OTH	Electric Sector: ELE
• Paper and Allied Products (PAP) • Bulk Chemicals (CHM) • Cement (CMT) • Iron and Steel (I_S) • Refining (OIL) • Motor Vehicle Manufacturing (M_V) • Fabricated Metal Products (FAB) • Wood Products (WOO) • Other Energy-Intensive Manufacturing (OEM) Aluminium Glass and Glass Products • Other Non-Energy Intensive Manufacturing (ONM) Food Products Computer and Electronic Products Electrical Equipment Machinery Transportation Equipment Plastic and Rubber Products Balance of Manufacturing	• Personal Transportation • Commercial Transportation (Sea, Air and Rail) (TRN) • Trucking (TRK)	• Residential • Commercial (SRV) • Agriculture (AGR) • Construction (CNS) • Mining (MIN) • Coal (COL) • Natural Gas (GAS) • Crude Oil (CRU)	• Electricity

3. Model Baseline

For the scenarios, all impacts are measured against our baseline, which is primarily calibrated to the EIA's AEO 2016 Reference Case without the CPP.[34] This scenario includes a set of rules and regulations that are on the books as of late 2015. Thus, our baseline incorporates the specific

[34] We omit the CPP in the baseline because the U.S. Supreme Court granted a stay on February 9, 2016 halting the implementation of the EPA's CPP pending the resolution of legal challenges.

measures explicitly or implicitly. In particular, all current state-level RPS programs and the California AB 32 policy are represented in the electric sector. The transportation sector baseline includes current CAFE regulations, national program for heavy-duty vehicle, GHG emissions, and fuel efficiency standards, lower biofuel targets consistent with what appears achievable given recent EPA waivers and adjustments to the statutory targets. The baseline for the Other sector includes appliance, equipment, and lighting energy efficiency standards, building energy codes, landfill air regulations (energy production), and federal energy management program. Industrial sector incorporates new source performance standards for petroleum refineries and federal air standards for oil and natural gas sectors.

a) Economy-wide Baseline Emissions Projection

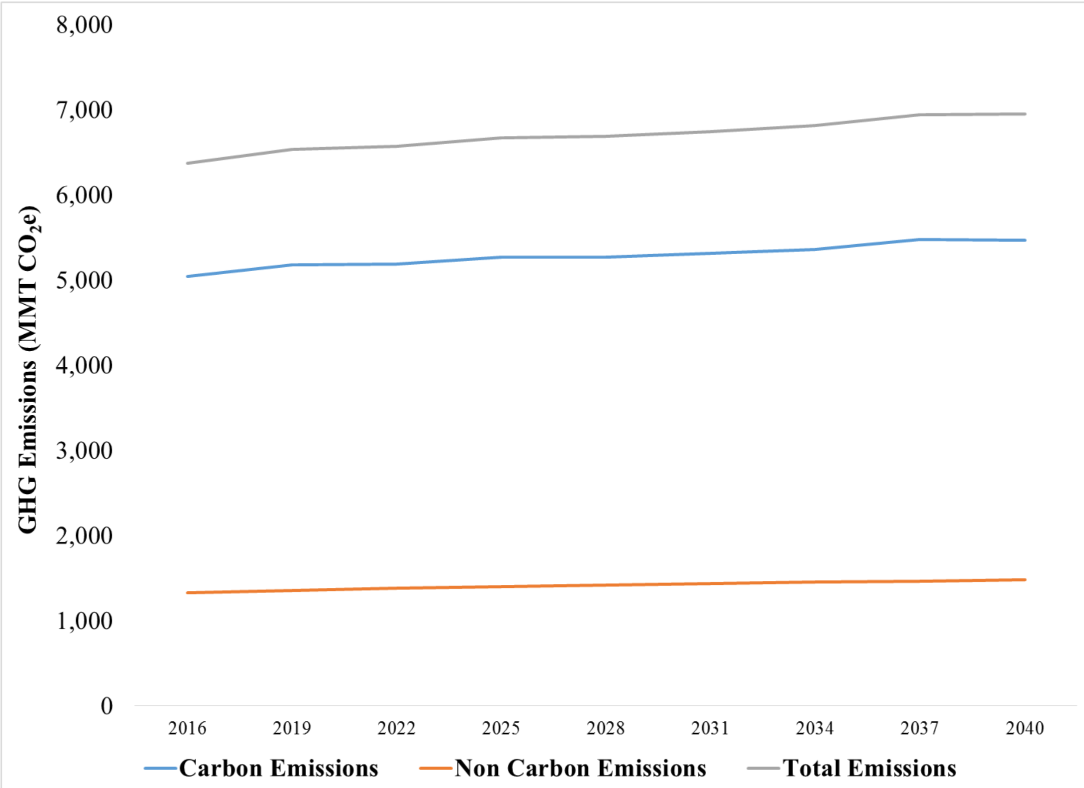
The economic impacts on the industrial sector of a GHG policy depend critically on the difference between the emissions that would arise without the policy and the level of emission reductions required by the measures. The baseline describes how GHG emissions would evolve in the industrial sector under current law. That is, the baseline reflects how the level of emissions changes over time in the absence of any GHG abatement measures.

We incorporate many of these measures into the baseline by calibrating the growth in sectoral GHG emissions and energy use to that of AEO 2016 Reference case without CPP and develop baseline non-CO_2 GHGs based on the USSBR 2016.

The emissions trajectories for the economy wide baseline shown in Figure 3 are calculated as the sum of economy-wide CO_2 emissions from fossil fuel combustion, industrial process emissions, and non-CO_2 emissions. The CO_2 emissions represented in the baseline equal the sum of the energy-related CO_2 emissions from the residential, commercial, industrial, and the transportation sectors. These include emissions from both the burning of fossil fuels and purchased electricity as well industrial process CO_2 emissions.[35] Emissions associated with feedstock, especially for the Chemicals and Iron and Steel sector are excluded from the baseline CO_2 emissions. In the baseline economy wide GHG emissions are seen to rise from around 6,374 million metric tons carbon dioxide equivalents (MMTCO_2e) in 2016 to around 6,955 MMTCO_2e in 2040 at an annual average growth rate of 0.36% per year. CO_2 emissions and non-CO_2 emissions are seen to grow at 0.34% and 0.46%, respectively.

[35] 2016 Second Biennial Report of the United States of America under the UNFCCC, 2016.

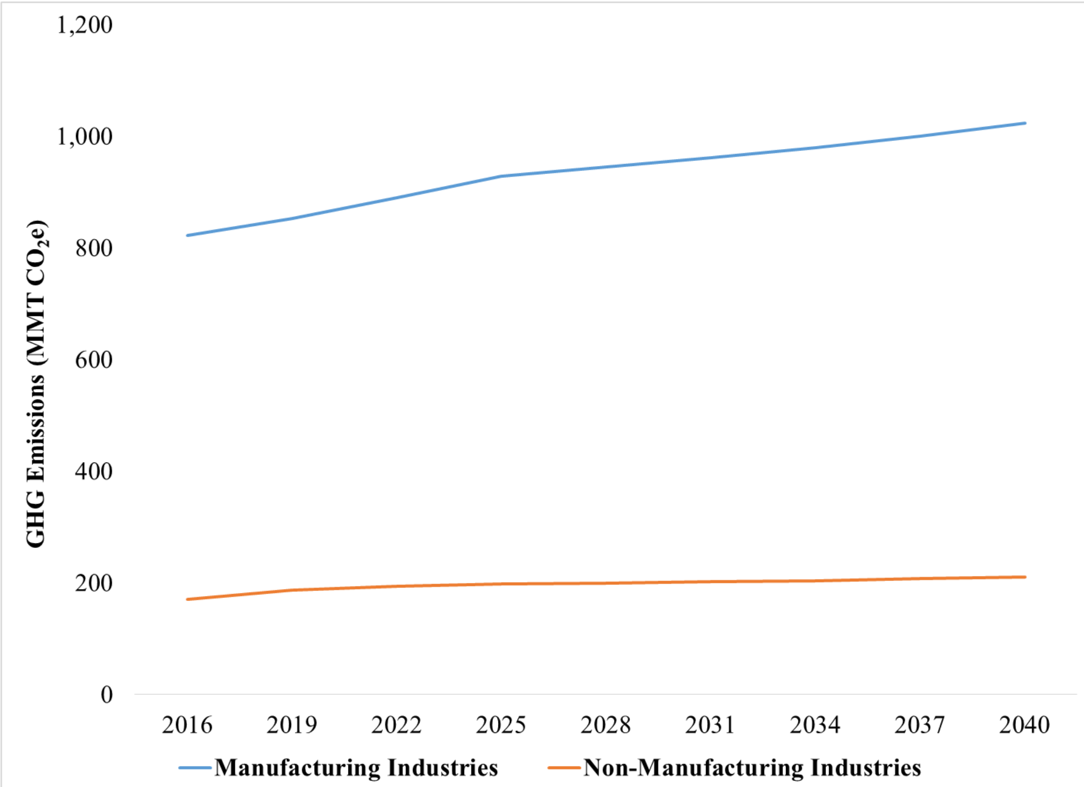
Figure 3: Trajectory of Economy-Wide Baseline GHG Emissions



With respect to the industrial sectors, baseline CO_2 emissions from the non-manufacturing industries increase from around 171 $MMTCO_2e$ in 2016 to around 210 $MMTCO_2e$ in 2040 at an average annual growth rate of 0.86% per year. The largest contributor to the emissions is the mining sector accounting for nearly 42 of the total emissions in 2040 while emissions from the construction sector is seen to have the highest growth rate at 1.74% per year from 2016 to 2040.

CO_2 emissions from the manufacturing industries grow from 822 $MMTCO_2e$ in 2016 to nearly 1,234 $MMTCO_2e$ in 2030 at an average annual growth rate of 0.92% per year. The largest contributor to the emissions is the bulk refining sector accounting for nearly 21% of the total emissions in 2040. Of the various sub-sectors, the ONM sub-sector comprised primarily of non-energy intensive manufacturing exhibited the highest growth rate of 1.82% per year from 2016 to 2040. The CO_2 emissions trajectory for the two industry categories are shown in Figure 4.

Figure 4: Trajectory of Baseline CO_2 Emissions by Industrial Sector Category



b) Industrial sector 2005 fossil fuel combustion emissions and forecast till 2040

To compute the baseline CO_2 emissions from fossil fuel combustion in 2005 for the industrial sub sectors, we take the aggregate 2005 CO_2 emissions for the aggregate industrial sector from the EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks as our starting point.[36] We distribute the aggregate industrial emissions using the energy consumption shares for the industrial sub-sector based on the last year (AEO 2008 Reference case) for which EIA produced industrial sub-sector energy consumption data for 2005. These shares are then used to distribute the aggregate CO_2 emissions among the various sectors. According to the U.S. GHG Inventory report, the CO_2 emissions from fossil fuel combustion in 2005 were 828 $MMTCO_2$ while from the AEO's 2008 Reference Case, the total industrial sector emissions from fossil fuel combustion were reported to be 1,010 $MMTCO_2$. The estimates for CO_2 emissions for the various industrial sector categories by fossil fuel are outlined in Table 2.

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[36] We devise this approach to estimate carbon emissions by fossil fuels for each industrial sector consistent with the aggregate AEO totals in the absence of detailed projections by sector.

Table 2: Baseline CO_2 Emissions in 2005 from Fossil Fuel Combustion by Industrial Sector and Fuel Type ($MMTCO_2$)

	AGR	CNS	MIN	OIL	PAP	CHM	CMT	I_S	WOO	FAB	M_V	OEM	ONM
Total	58.6	63.7	46.5	224.7	60.0	141.6	35.1	99.9	3.7	13.3	11.3	23.2	228.1
Petroleum	53.6	57.1	3.6	160.6	11.1	30.4	5.5	10.0	0.9	0.9	0.5	4.2	28.2
Natural Gas	5.0	6.6	42.0	57.1	24.1	86.3	1.0	31.0	2.7	11.7	10.4	15.5	138.3
Coal	0.0	0.0	0.9	7.0	24.8	24.9	28.6	58.9	0.1	0.7	0.4	3.5	61.6

We use a similar approach to estimate the projected CO_2 emissions from fossil fuel combustion for the industrial sector. We use the AEO 2016's Reference Case without CPP outlook. The baseline emissions from fossil fuel combustion are shown in Table 3. We use the energy consumption by the industrial sector and fuel source from AEO 2016's Reference Case without CPP to calculate the projected share of energy consumption for each sector by year. These shares are then used to distribute the aggregate industrial CO_2 emissions among the various sectors by year. From the CO_2 emissions calculated for each sector; the emissions by fuel type for each sector are calculated by multiplying the sectoral emissions by the ratio of the energy consumption for the fuel type to the total energy consumption for the sector. Based on our approach, the CO_2 emission estimates obtained for the various industrial sector categories are shown in Appendix-C. We also estimate baseline carbon intensities for each of the topic industries and provide a short description of it in Appendix-C. Table 3 outlines the projected economy wide CO_2 emissions by fossil fuel type.

Table 3 : Projected CO_2 Emissions from Fossil Fuel Combustion and Fuel Type ($MMTCO_2$)

	2016	2019	2022	2025	2028	2031	2034	2037	2040
Total	**992.8**	**1039.1**	**1083.3**	**1127.2**	**1144.3**	**1162.9**	**1183.8**	**1207.1**	**1234.2**
Petroleum	323.9	344.7	357.1	369.4	369.1	370.4	371.2	373.4	378.3
Natural Gas	513.5	539.6	567.7	590.7	606.2	623.5	644.6	666.4	688.3
Coal	155.5	154.8	158.5	167.0	169.0	169.0	167.9	167.3	167.6

IV. DESCRIPTION OF SCENARIO DESIGN

A. Introduction

The following slate of scenarios is designed to bracket the potential economic impacts on the industrial sectors and the economy as a whole from the U.S. reducing its GHG emissions. The basic scenarios are constructed such that the U.S. as a whole ultimately meets its NDC emission target. Since the Obama Administration has taken the course of implementing its CAP through direct sectoral regulations, rather than through broader market-based (i.e. cap-and-trade or carbon tax) measures, we designed one of our scenarios to illuminate the impacts of those types of measures. Also, to help understand the feasibility and the costs of various proposed emission reduction measures, we constructed scenarios that impose these emission reduction measures without a requirement that U.S. emissions meet its NDC targets with and without trading across specific and broad sectors in the model. Some commenters have suggested that Section 115 of the CAA, titled "International Air Pollution" provides a basis to achieve climate change goals.[37] It is claimed that EPA could create a nationwide cap and trade program under this section of the CAA, because it gives EPA broad authority in dealing with pollution that crosses international boundaries and for which other countries have agreed to reciprocal action. It's also been suggested that EPA can also incorporate existing rules and any future regulations to limit GHG reduction in a system established under Section 115. To address this option, we have designed a scenario with a nationwide cap and trade program based on the US NDC target in addition to specified regulatory programs. The following sections describe how we estimated the NDC targets for each scenario.

A. Sectoral Emission Targets Derived from NDC

The U.S. NDC calls for economy-wide GHG reductions of 26% to 28% below 2005 levels by 2025. The scenarios analyzed are intended to study a range of reasonable paths through which the Executive Branch may seek to meet the NDC. For example, the U.S. could take the percentage reduction in emissions promised in the U.S. NDC to compute an overall emission target for the economy as a whole, including the industrial sector. Under this approach, a mass-based goal for the industrial sector would be set to achieve the same percentage reduction as the mid-range of the overall U.S. NDC target (27%). The NDC target calls for reductions to begin immediately; therefore, emissions from the industrial sector would experience a sharp decline by 2019. In setting these targets we include only emissions from combustion of fossil fuels. Changes in process emissions are accounted for separately on an aggregate basis.

The 2005 emission levels for the electric, transportation, industrial, residential and commercial sectors are derived from EIA's Monthly Energy Review. [38] Emissions from the electric sector amount to 2,416 $MMTCO_2$. Total direct emissions from the industrial sector amount to 1,006 $MMTCO_2$. We distribute the total emissions among the manufacturing and non-manufacturing industrial sectors based on the shares of the emissions from these industry categories reported in EIA's AEO 2008 Reference Case. This yields emissions of 841 $MMTCO_2$ and 165 $MMTCO_2$ for the manufacturing and non-manufacturing industry categories, respectively. For the transportation sector, direct emissions for 2005 amount to 1,981MMT CO_2. We subtract emissions from the use of international bunker fuels equal to 114MMT CO_2 obtained from the USSBR 2016 U.S.to get emissions of 1,897MMT CO_2. For the residential and commercial sectors, the total direct emissions equal 592MMT CO_2.

Non-CO_2 emissions for 2005 are obtained from EPA's GHG inventory. Emissions from methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride amount to 717 $MMTCO_2$, 398 $MMTCO_2$, 120 $MMTCO_2$, 7 $MMTCO_2$ and 14 $MMTCO_2$ respectively. Sequestration levels for 2005 are obtained from EPA's GHG Inventory and equal 698 $MMTCO_2$ which represent the net sum of all emissions from the LULUCF sector (sources) plus removals of CO_2 from the atmosphere.

We calculate the overall emission targets for sectors other than electric power that would be required nationwide to achieve the NDC goal in each year from 2019 onwards. In this calculation, we credit the electric power sector with only the emission reductions estimated for the CPP. [39] The CPP is a nationwide regulation under Section 111(d) of the CAA that regulates existing electricity generating units, specifically fossil fuel-fired steam units and combined-cycle combustion turbines. The rule provides two compliance structures, one based on meeting state-specific emission rate in pounds of CO_2 per megawatt-hours (lbs/MWh) and the other based on a CO_2 cap for total emissions from the regulated generators in each state ("mass cap"). Each state's mass cap is based on EPA's assessment of the emissions that would be equivalent to complying with the state's rate-based limit. The limits, rate- or mass-based, are phased in from 2020 through 2030. The rule also allows state to trade with other states that elect the same generic regulatory option. According to EPA's estimates, the CPP will result in U.S. power sector CO_2 emissions in 2030 that will be 32% below their level in 2005. We assume trading across all states and an emissions cap of 1,800 $MMTCO_2$ in 2020 decreasing to 1,583 $MMTCO_2$ by 2030. Beyond

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[38] Monthly Energy Review, U.S. EIA, October 2016. Available: http://www.eia.gov/totalenergy/data/monthly/archive/00351610.pdf

[39] This scenario does not assume that the stringency of the CPP would be increased. Thus all the burden of complying with the INDC would be undertaken by the industrial sector.

2030, we lower the target linearly till 2040 so that it follows the trajectory of a linear decline to 80% below 2005 levels by 2050.

For the transportation sector, we assume that Phase 2 Standards are put into effect. The proposed Phase 2 standards issued by the EPA and the National Highway Traffic Safety Administration (NHTSA) in July 2015 addresses specific vehicle categories including combination tractors, trailers, heavy-duty pickup trucks, vans and vocational vehicles.[40] The proposed Phase 2 rulemaking establishes a second round of standards for GHG emissions and fuel consumption by medium- and heavy-duty trucks. The proposed Phase 2 standards take effect in Model Year (MY) 2021 (or MY 2018 for trailers) and increase in stringency through MY 2027.Under the Phase 2 standards, average fuel economy increases for all new vehicles covered by the standards. For the scenario, we assume the transportation sector's emission trajectory consistent with EIA's AEO 2016 Phase 2 standards side case. We assume EIA's emissions pathway till 2025 and then post-2025, the emissions trajectory follows a linear path so as to achieve the target of 80% below 2005 levels by 2050.

For the rest of the other economic sectors – residential, commercial and non-manufacturing sectors - represented by the "Other" sector (OTH), we assume that these sectors will not be under any emissions programs until 2025. Hence we assume that the emissions to remain at the baseline levels until 2025. Post 2025, these sectors also share the same burden as other sectors and hence follow a similar trajectory to achieve the target of 80% below 2005 levels by 2050.

The target for the industrial sector emissions from fossil fuel combustion in 2025 is set to achieve the overall emission reductions required to meet the overall NDC target, after taking into account the estimated effect of reductions in process emissions, mitigation of emissions of other GHGs, and sequestration.

CO_2-industrial processes and other CO_2 emissions, excluding non-energy use of fuels, are assumed to be decline in proportion to reduction in the overall industrial emissions from fossil fuels. We use the ratio of process to industrial fossil fuel emissions in 2005 and apply this ratio to forecasted industrial emissions from fossil fuels to arrive at the trajectory of industrial process CO_2 emissions.[41] With the exception of HFCs, the emissions targets for all non-CO_2 gases use

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[40] U.S. Environmental Protection Agency and National Highway Traffic Safety Administration, "Greenhouse Gas Emissions and Fuel Efficiency Standards for Medium- and Heavy-Duty Engines and Vehicles – Phase 2" (Washington, DC: June 19, 2015), http://www.nhtsa.gov/fuel-economy.

[41] This assumption is conservative in regards to the cost to abate emissions. Based on our discussions with industry experts, process emissions per unit of output are fixed in all industrial sectors, so that only combustion emissions can be reduced to meet targets without reducing output. That is, fossil fuel emissions can decline faster than output

the 2013 emissions outlined in EPA's GHG inventory as our starting point. We then use inter-temporal growth rates of non-CO_2 emissions based on the USSBR 2016 to calculate emission targets till the last reported year of 2030.[42] Beyond 2030, we assume that non-CO_2 emissions also decline linearly to meet 2050 reduction target. We assume the reduction target for HFCs to be consistent with the reduction target proposed during the Kigali climate talks held in October 2016. We compute the target based on a reduction of about 15% of 2012 levels by 2036.[43] Post 2036, we hold the HFC emission level constant until 2040.

Emissions from LULULCF are challenging to estimate and highly uncertain. A particular challenge in estimating LULUCF is that government estimates of future and even current LULUCF offsets have varied widely over the past few years. According to EPA's U.S. Greenhouse Gas Inventory, LULUCF activities in 2005 resulted in net sequestration of 698 $MMTCO_2e$. We use the growth rates for the high and the low sequestration projection ranges reported in the USSBR 2016 to project 2005 EPA's sequestration level till 2030. Beyond 2030, we assume the net sequestration to remain constant at the 2030 level. Based on these ranges, we construct an average sequestration projection by averaging the high and low net LULUCF levels. For the study we used the high and the average level of net sequestration to reflect uncertainties in LULUCF.[44] Table 4 presents the average and high net sequestration levels that we use to calculate emission targets.

Table 4: Range of Emission Reductions from Sequestration (MMTCO2e)

	2015	2020	2025	2030
Average sequestration	793	963	908	774
High sequestration	801	1,028	1,037	964

Based on the modeling assumptions about the emissions reduction from different sectors of the economy, the industrial sector is responsible for reducing its CO_2 emissions from fossil fuel combustion relative to its 2005 level in 2025 by 38% and 27% if average and high net sequestration assumptions are used respectively.

through substitution of lower emitting energy sources (e.g., electricity) for higher emitting sources (e.g., coal) so allowing process emissions to be reduced faster lowers the cost of abatement. .

[42] 2016 Second Biennial Report of the United States of America under the UNFCCC, 2016.

[43] http://www.nytimes.com/2016/10/15/world/africa/kigali-deal-hfc-air-conditioners.html?_r=0

[44] We do not include low sequestration reported in the USSBR 2016 for the study, which would imply a larger gap and a much more stringent target for the industrial sector.

Table 5 below summarizes the baseline emissions, NDC emissions target in 2025, and targets in 2040 and 2050 to meet the deep decarbonization target of 80% reduction for two different net sequestration assumptions.

The emissions reduction targets can be meet through either market based approaches or command-and-control regulatory measure approaches. For this study, we design different scenarios to reflect different ways in which reduction programs might be implemented or regulated. We model five scenarios of which three scenarios are market based approaches, one scenario is designed to reflect regulatory measures approach, and a final scenario that combines layers regulatory measures on top of a cap-and-trade approach, a hybrid approach. We include flexibility in the policy by allowing trading across the sectors and also provide range of impact estimated for two different levels of sequestration for the cap-and-trade scenarios.

Table 5. Emission Targets by Major Sector ($MMTCO_2e$)

	2005	Baseline		Average Sequestration			High Sequestration		
		2025	2040	2025	2040	2050	2025	2040	2050
Total CO_2 from Energy (Less Bunkers)	5,880	5,251	5,340	4,577	2,564	1,683	4,674	2,715	1,835
Power Sector	2,416	1,909	1,959	1,677	1,046	691	1,677	1,092	753
Industrial (Manufacturing)	841	929	1,024	521	328	241	618	369	262
Transportation	1,867	1,667	1,599	1,633	835	534	1,633	880	582
Other (Res, Com, Non-Manufacturing)	756	745	757	745	355	217	745	374	237
Industrial (Process and Other CO_2)	237	277	316	159	95	68	192	108	74
Non-CO_2	1,256	1,403	1,486	1,043	550	359	1,043	579	392
Methane	717	765	792	620	319	205	620	336	224
Nitrous Oxides	398	381	377	318	172	114	318	181	124
Hydro-fluorocarbons	120	244	290	93	26	26	93	26	26
Perfluorocarbons	7	5	13	4	3	2	4	3	2
Sulfur Hexafluoride	14	9	13	8	5	4	8	6	4
Total Gross GHGs	7,373	6,931	7,141	5,779	3,210	2,110	5,912	3,404	2,299
Sequestration	(698)	(908)	(563)	(908)	(774)	(774)	(1,037)	(964)	(964)
Total Net GHGs	6,674	6,023	6,578	4,871	2,436	1,336	4,875	2,440	1,335
Reduction vs. 2005 Net GHG Levels				-27%	-64%	-80%	-27%	-63%	-80%

Source: EIA AEO 2016, 2016 Second Biennial Report of the United States of America, U.S. GHG Inventory 2016 and NERA Estimates

B. Scenarios for Policies to Achieve Targets

In every scenario, we assume that sequestration and controls on emissions of non-CO_2 GHGs contribute to achieving the overall target, but we assign no cost to these measures. Therefore, the actual cost of sequestration and control of non-CO_2 GHGs are in addition to the costs estimated in this study. Table 6 provides a summary of the scenarios and the following sections describe the scenarios in more detail.

Table 6: Scenario descriptions and policies applied to each broad sector

Scenario No.	Scenario Description	Regulation	Industry (IND)	Electric (ELE)	Trans-portation (TRN)	Other (OTH)	Trading among broad sectors	Trading among industrial sub-sectors	Sequestra tion
0	Baseline	Consistent with AEO 2016's Reference Case without CPP							
1	Broad Sectoral Cap	Broad sector specific cap to meet NDC target	NDC	CPP	NDC	NDC	No	Yes	Average and High
2	IND Sector Cap Only	NDC cap on the industrial sector	NDC	None	None	None	No	Yes	Average
3	Maximum Direct Measures	Command and Control	Energy Intensity Improve ments	Extended CPP	CAFE Standards and Efficiency Improvem ents	Building Energy Efficiency	N/A	No	None
4	Sector Specific Cap	NDC sector specific cap to meet the NDC target	NDC by Sub-Sector	CPP	NDC	NDC	No	No	Average
5	Cap & Trade Approach with regulatory programs	Cap and Trade + Command and Control	Energy Intensity Improve ments	Extended CPP	CAFE Standards and Efficiency Improvem ents	Building Energy Efficiency	Yes	Yes	Average

1. Scenario 1 - Broad Sectoral Cap

Emissions caps are set for each of the four broad sectors – IND, ELE, TRN, and OTH - at levels specified in Table 5 above. By applying the cap to a broad industrial sector that includes all the targeted subsectors, we assume that the regulators succeed in identifying the least cost mitigation options for all firms within each broad sector. Since the caps for each sector are set separately and no trading (NT) is allowed among the broad Industry, Transportation, Electric Power, and Other sectors, there will be a suboptimal allocation of effort across the four broad sectors. We assume that there is trading between the industrial sub-sectors. These caps are for all CO_2 emissions from the sector; therefore indirect emissions from generating electricity used by the industrial sector will be excluded from its emissions. This scenario captures both the direct effect of regulating industrial sector emissions as well as the indirect effects of regulating emissions from the other sectors (e.g., higher electricity prices seen in the industrial sector from capping electric sector emissions under CPP).

2. Scenario 2 - Industrial Sector Only

In order to isolate the cost of industrial sector emission reductions, we impose only the Scenario 1 Industry cap and impose no additional regulations from those in the baseline on all other sectors including electric power. This scenario compared to Scenario 1 highlights the effect of having a broader cap and its effect on the trade-off between manufacturing goods demand. As with Scenario 1, we allow trading between the industrial sub-sectors.

3. Scenario 3 - Direct Measures

Direct measures, regulatory measure, listed below are applied to all sectors to the extent deemed feasible based on EIA's estimates using the AEO's side cases. These direct measures were constructed to design a regulatory approach system. The direct measures could be quite costly, but direct measures that would automatically force a shut down in production are excluded (e.g., direct measure that mandate reductions beyond what is technologically achievable). The scenario applies specific direct measures to each subsector. In particular, we impose regulatory measure that requires the process industries to improve its energy intensity, fuel economy standard for light duty vehicles and heavy duty trucks, increase CPP stringency, a more stringent renewable portfolio standard on the electric sector, and reduction in building sector energy consumption. The details of these direct measures are described in detailed in Appendix-D.

4. Scenario 4 - Subsector-Specific Regulation

In light of the results of Scenario 3, we find that identifiable direct measures are insufficient to achieve the required reduction in emissions for the industrial sector and for the economy overall to meet the NDC target. In Scenario 4, we represent the unknown additional direct measures to achieve the NDC targets through a cap on each of the industrial subsectors – fabricated metal products (FAB), wood products (WOO): petroleum refining (OIL), chemicals (CHM), iron and steel (I_S), cement (CMT), paper (PAP), other energy intensive manufacturing (OEM), and other non-energy intensive manufacturing (ONM) – at levels that would achieve the required percentage reductions in each year. Each subsector of industry is assigned the same percentage reduction that is applied to the industrial sector as a whole in Scenario 1, and each broad sector (TRN, OTH, and ELE) is assigned the same percentage reduction that Scenario 1 assigns. This scenario forbids trading across subsectors. We believe that this subsector specific scenario captures as realistically as possible the nature of regulations that EPA would issue under Section 111(d) if EPA were to follow a Clean Power Plan-like approach to regulation.

5. Scenario 5 - Economy-Wide Trading with Direct Measures

This scenario assumes that EPA will depart from its existing authorities under CAA and claims broad authority to create an economy-wide cap and trade program. While the legality of whether EPA has such authority is still up for debate, numerous stakeholders have suggested than an argument for such authority could be made under CAA Section 115. If EPA were to attempt to do so, it is likely that they would be required to instruct states to include GHGs in State Implementation Plans (SIP). .

In this scenario, we assume that all states and sectors trade carbon allowances in a single nationwide market while meeting the direct measures identified in Scenario 3. Each state is assigned a cap in 2025 equal to 27% of its 2005 emissions, declining linearly from there to 80% below by 2050. To be consistent with the timing and carbon prices of the regulatory scenarios, we assume no banking is allowed. We also assume that all the direct measures included in Scenario 3 would be maintained in force.

V. NATIONAL STUDY RESULTS

This section discusses in detail the national impacts across all six scenarios analyzed in this study. The changes in impacts are reported relative to the baseline that is absent of the policy. We first discuss the impacts estimated for the core scenario, Scenario 1. We highlight impacts on the CO_2 emissions changes and carbon prices by sector; changes in fuel consumption by sector, changes in electricity generation mix, changes in income (or consumption) per average household, gross domestic product (national), changes in industrial output, changes in cost of production by industry, employment impacts (by sector), changes in imports and exports, international competitiveness of domestic industries, and international emissions leakage.

In the absence of a uniform economy-wide program, comparing Scenario 1 to the baseline gives a lower bound on the cost to meet the central range of the nationwide NDC target of 27% relative to 2005 level in 2025. The section on Scenario 1 results, discussed below, highlights the relationship among the different macroeconomic metrics as well as the relationship of these metrics to the sectoral results. Since these relative relationships are similar across Scenarios 1 and 2 and for the two different levels of sequestration, these detailed results are reported only for Scenario 1 under the average sequestration assumption.

Comparing Scenario 2 to the baseline gives an estimate of the cost of industrial sector regulations taken as a standalone package. Comparing the standalone cost of industrial regulations to the cost of economy wide regulation of broad sectors in Scenario 1 provides a sense of how much of the cost of including all sectors of the economy comes about from regulating emissions in the industrial sector.

Comparing the emission reductions in Scenario 3 to the 27% NDC target in 2025 indicates the feasibility of meeting that target through direct measures that do not require shutdown of establishments or industries.

Comparing Scenario 4 to the baseline gives an estimate of the cost of meeting the NDC targets with regulations sufficient to bring each subsector into compliance with its sectoral NDC targets on its own. We believe this is still an underestimate of the true cost of a fully regulatory approach that purports to regulate at a facility level because scenario 4 assumes perfect trading among establishments within the subsector and no other costs arising from distorted incentives created by regulations. Furthermore, this scenario still applies emissions targets at a broad sub-sector level.

Comparing Scenario 5 to the baseline provides estimates of the minimum cost that might be achieved with a full economy-wide cap and trade system in conjunction with Scenario 3 regulatory measures that impose a cap and trade system. We offer no opinions on the legality of such an approach, but note that working through SIPs poses a significant risk of introducing barriers to trading and inefficiencies into the system.

Last, by comparing the results of scenario 1 under the average and high sequestration levels, we evaluate the impact of allowing larger amounts of sequestration or offsets to be used.

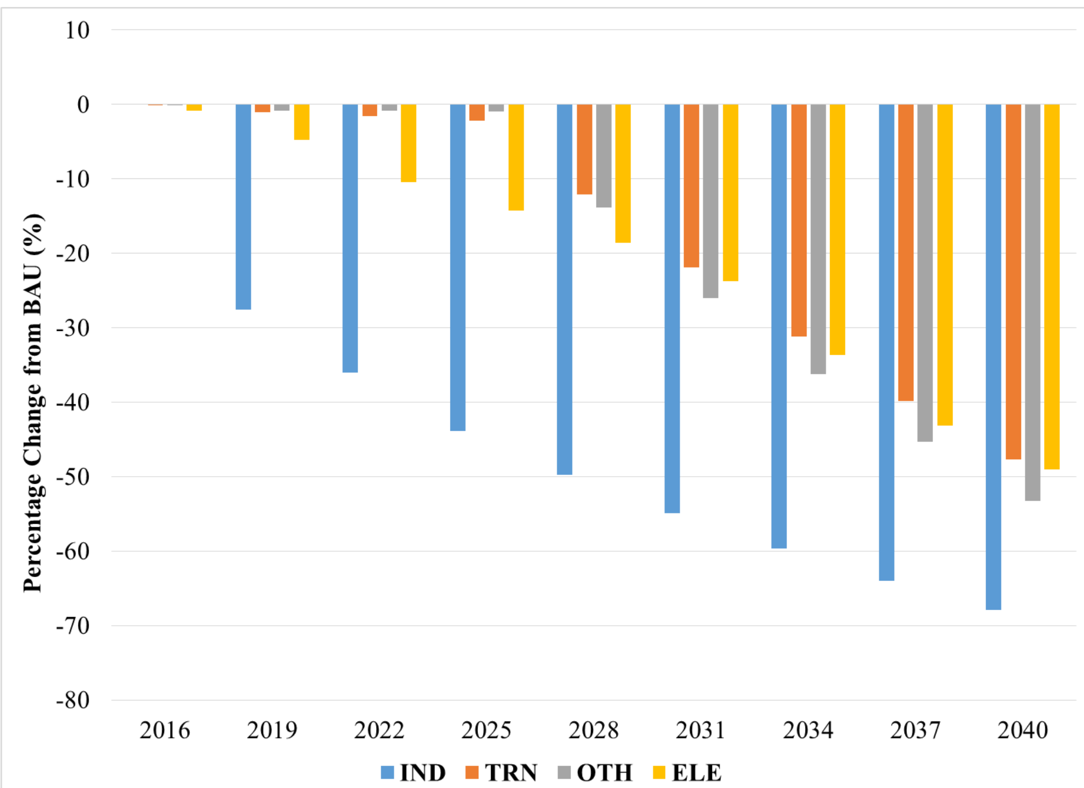
A. National Results

1. CO_2 Emissions and Implicit Carbon Prices

The cost and burden of reducing emissions to a specified percentage below 2005 levels will differ across sectors depending on their baseline growth in emissions, intensity of energy usage, and opportunities for reducing emissions.

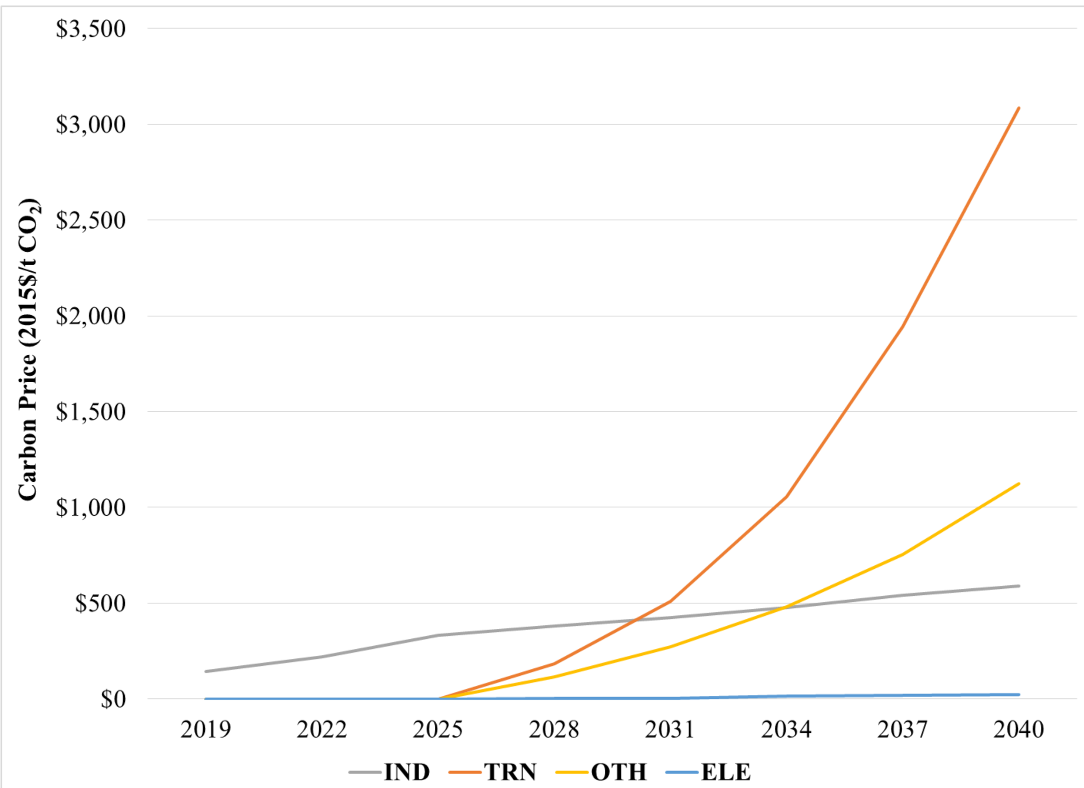
The percentage reduction in emissions relative to the current policy baseline (BAU) is shown in Figure 5 for each of the four broad sectors. This chart reveals that the industrial sector has the highest baseline emissions growth, and therefore must make the greatest reductions to achieve the NDC targets. In 2025, the reduction for the industrial sector is about 44 percent relative to the baseline, which is about a 38% reduction from the 2005 levels.

Figure 5: Emission Reductions for Broad Sectors



Although the scenarios are intended to represent the outcomes of a regulatory approach to climate policies, we can use sectoral carbon prices that results from sector specific carbon cap as proxies for the cost to reduce emissions under regulatory scenarios. When we represent the goal of a regulatory program as a specific limit on emissions in each sector, we can estimate the marginal cost of achieving that target with no cap-and-trade policy in place across the broad sectors but with trading among the industrial subsectors. The resulting implicit carbon prices serve as indicators of the relative difficulty of achieving the specified caps in different sectors. Figure 6 reveals that the specified targets for the four sectors become a challenge for some sectors long before others. The NDC target for the electric sector can be met at relatively low cost because of opportunities to switch from high emitting coal-fired generation to lower emitting gas-fired and renewable generation. Gas-fired generation becomes much less expensive when other sectors are regulated because they predominantly use natural gas in the baseline, so regulating these sectors reduces demand for natural gas and hence the price of natural gas.

Figure 6: Carbon Price by Broad Sector



The transportation sector will over achieve the NDC target until 2028 because of current transportation regulations (e.g., CAFE and diesel truck regulations) in the baseline. But achieving further reductions from these programs becomes quite costly as seen by the rapid rise in allowance prices after 2028. The high allowance prices also suggest that there are large hidden costs with the current regulations. Emission reductions in the transportation sector come for less cost from personal vehicles than trucking. Emissions from trucking decline little from 2015 levels compared to the percentage reduction in emissions from light duty vehicles (LDV).

Existing efficiency standards and lower demand for services keep emissions from the OTH sector below its cap through 2025. By 2028 though, the current (and proposed) standards are insufficient, leading to a binding carbon cap from this point onward. Reducing emissions becomes costly, but less so than in the TRN sector because of its relatively lower energy intensity.

The IND sector, which could face regulation in the future, will have the most difficulty achieving the targets, which will be binding immediately and become more and more costly while other sectors need make little or no additional effort to achieve the targets in the near term. The carbon price in 2019 starts at \$140/TCO_2 and reaches \$330/TCO_2 by 2025. It gradually ramps up to exceed \$500/TCO_2 in the out years.[45]

2. Energy Consumption

Demand for energy, especially fossil fuels, declines in all sectors of the economy. Since coal is highly carbon intensive, the cost of using coal increases significantly as the targets decline resulting in switching away from coal to other sources of energy in all sectors of the economy. Overall, economy-wide coal consumption declines by about 20% of which a large part of the reduction in coal demand comes from the electric sector (80 percent) because the power sector switches from coal to relatively cheap natural gas. Petroleum products which are the second most carbon intensive decline by about 5% while natural gas demand declines by about 10% in

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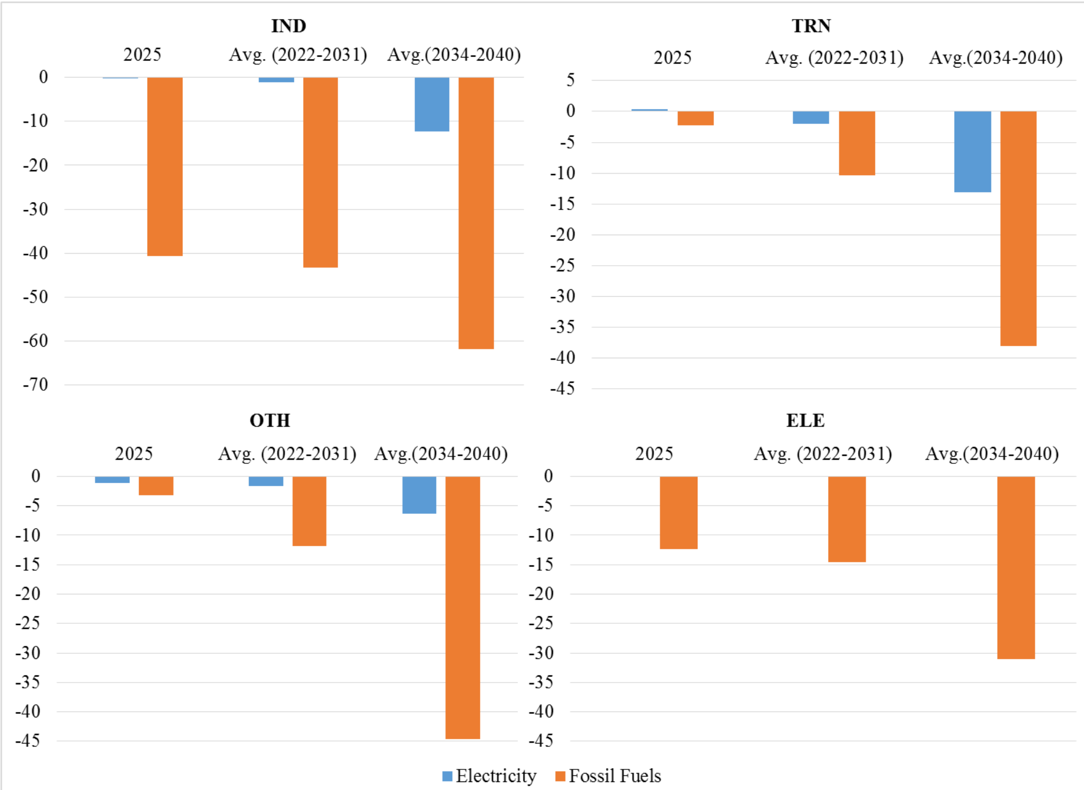
[45] To the best of our knowledge, we are unaware of other studies that have estimated sectoral carbon prices for such deep decarbonization scenarios conducted in this study. However, there are several model comparison exercises that have estimate carbon prices for an economy-wide 80% reduction type of scenario. These include: (i) Elmar Kriegler & John P. Weyant & Geoffrey J. Blanford & Volker Krey & Leon Clarke & Jae Edmonds & Allen Fawcett & Gunnar Luderer & Keywan Riahi & Richard Richels & Steven K. Rose & Massimo Tavoni & Detlef P. van Vuuren, "The role of technology for achieving climate policy objectives: overview of the EMF 27 study on global technology and climate policy strategies," Climatic Change, 123(3-4):353-367 · April 2014 found 2050 carbon price to range from \$100 to \$940 per ton of CO2; (ii) Clarke, L., A. Fawcett, J. McFarland, J. Weyant, Y. Zhou, 2014. Technology and U.S. Emissions Reductions Goals: Results of the EMF 24 Modeling Exercise. The Energy Journal. Vol. 35, No. SI1found that 2050 range from \$65 to \$1460 per ton of CO_2; and (iii) Riahi K., E. Kriegler, N. Johnson, C. Bertram, M. Den Elzen, J. Eom, M. Schaeffer, J. Edmonds, and et al. (2015). Locked into Copenhagen Pledges - Implications of short-term emission targets for the cost and feasibility of long-term climate goals. Technological Forecasting & Social Change 90: 8–23 showed that modeled carbon prices for the 450 ppm scenario for some of the models exceeded \$1500 per ton of CO_2.

2025. Petroleum products demand declines by less than natural gas because the carbon restriction only becomes constrained in 2028 and beyond hence the transportation sector need not reduce demand for petroleum products to comply with the pre-2028 targets. As the carbon cost rises significantly in the transportation, demand for petroleum products decreases significantly. Overall, petroleum products demand declines by about 40% on average relative to the baseline between 2034 and 2040. Overall economy wide natural gas demand decreases by about 11% in 2025. Since the industrial sector is the only broad sector that is carbon constrained in 2025, a large part of the natural gas demand reduction comes from the lower demand from this sector. In 2025, only 5% of the total demand for natural gas comes from the electric sector while the remaining 95% of the demand reduction comes from the non-electric sector.

In the long run natural gas becomes more favorable to the electric sector with modest carbon prices hence natural gas demand in the electric sector increases on average by about 10% but the natural gas demand in the non-electric sector, especially the industrial declines significantly. Overall demand for natural gas in the economy declines by about 30% on average between 2034 and 2040. As an aggregate, final fossil energy sectors, coal, natural gas, and refined petroleum products, decline the most with the order of decline directly correlated with carbon intensity in the long run.

Since the increase in the cost of electricity much smaller than the increase in the cost of fossil fuel use for the industrial sector, the industrial sector in particular undertake some fuel switching from fossil fuels to electricity. This switching mitigates the drop in electricity demand caused by lower output and economic contraction. Total electricity demand loss in 2025 is about 3 percent; and in the long run, the loss in demand is about 10 percent, a much smaller loss compared to the other fossil fuel demand. Figure 7 shows change in energy consumption by the four broad sectors represented in the model.

Figure 7: Energy Consumption (Percentage Change from Baseline)



3. Energy Prices

The carbon prices required to meet the NDC target for each sector increase the delivered cost of fossil fuels to the end user. In 2025, the average U.S. gasoline price could increase by about 11% due to the cap on transportation sector emissions. Reduction of demand for natural gas from the industrial sector in the short run leads to lower Henry Hub prices and hence a lower delivered price of natural gas to the households that are not subject to regulations or an emission cap until after 2025. Delivered cost of natural gas to households declines by about 5% in 2025. However, as all sectors come under caps after 2025, the delivered cost of fossil fuel also rises for all sectors after 2025. Between 2022 and 2031 the delivered price of gasoline and natural gas to households increase on average by about 58% and 31 percent, respectively. The cost of gasoline and natural gas would have to increase by several orders of magnitude by 2040 to achieve the deep decarbonization targets. Overall, changes in electricity prices are only marginally affected since the additional cost of reducing emissions in the electricity sector is small once the CPP drives out coal.

4. Sectoral Output

At the four broad sectors represented in the model, sectoral output declines by less than 5% before 20205. Since the industrial sector, which represents the manufacturing subsectors, is the only sector that is carbon constrained the output decline is the greatest among the four broad economic sectors. In 2025, output from the industrial and the electric sector declines by about 5 and 4% relative to the baseline, respectively. The transportation sector decline is also small because the sector is not carbon constrained while the other sectoral output declines the least– 1% – since this sector is relatively non-energy and carbon intensive. Over time, the broad sectors are impact quite differently.

The least energy intensive sectors such as services, represented in the other sector (OTH) definition, experience the smallest loss in output. Even by 2040, output from this sector declines by less than 5%. Electricity sector output is affected far less because the electric sector can more easily decarbonize and in the near-term its target is easy to meet. While in the long run its output is also impacted as a result of contraction of the U.S. economy, fuel switching towards electricity from fossil fuels in the industrial sector in particular mitigates the output reduction in electricity. The transportation sector experiences large losses because baseline direct measures limit opportunities to further increase fuel efficiency and limit opportunities to switch fuels.46 The transportation sector output declines as the carbon price ramps up after 2031. Furthermore, demand for transportation services decreases as the economy shrinks. In the long run, the loss in transportation sector output could be about 25%. Figure 8 shows the losses in output from the four broad sectors.

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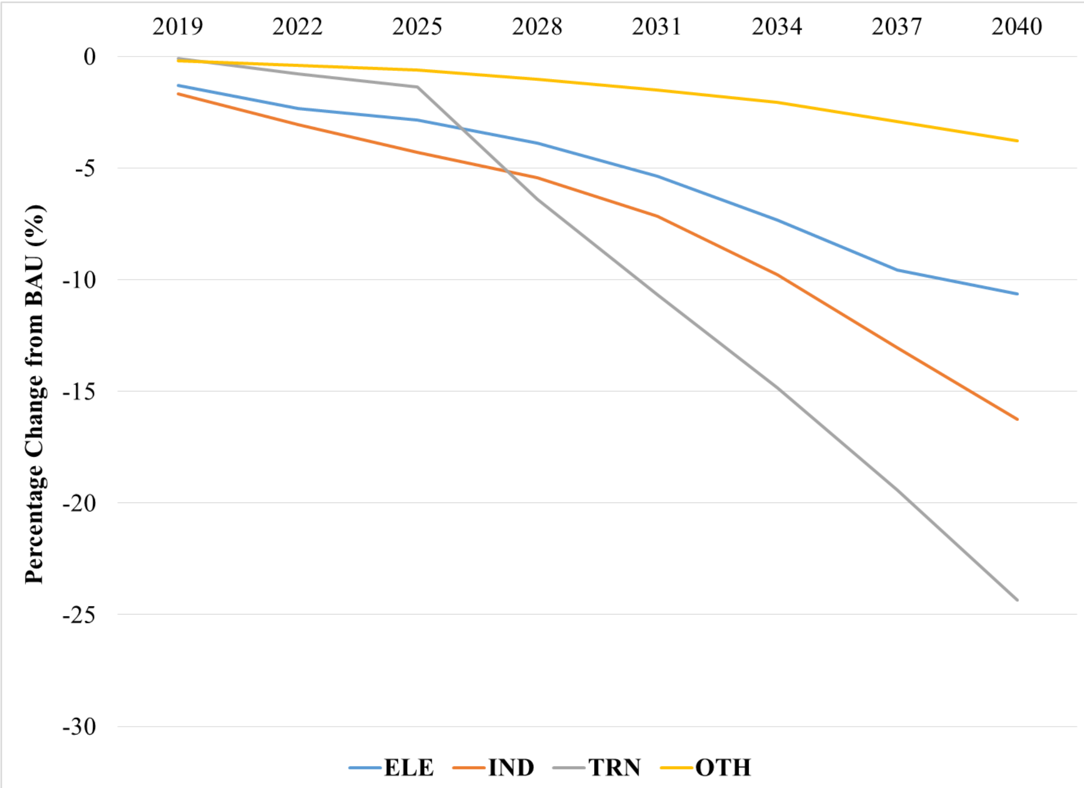
[46] The model does not allow alternative fuels to come online beyond the baseline levels. In addition, for the study we did not also allow provision for alternative vehicles, e.g., electric vehicles.

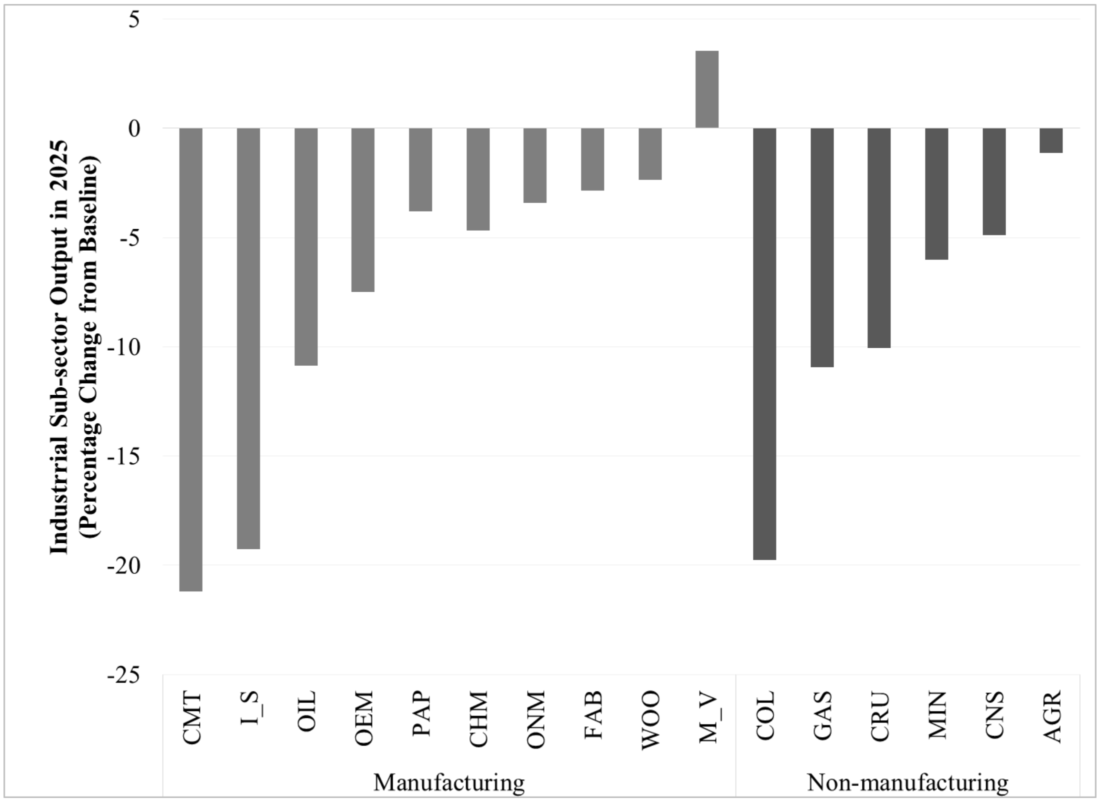
Figure 8: Broad Sectoral Output



The impacts across the industrial subsectors vary with the carbon intensity of the subsector and the opportunities available to the subsectors to switch from their current mix of fuels to a less carbon intensive mix, and their ability to reduce their overall energy intensity. In 2025, iron and steel, refinery, and cement sectors experience the most negative impacts. Iron and steel and cement output declines by about 20 percent; while the loss in refinery output could be about 10%. Other energy-intensive manufacturing which includes aluminum and glass product manufacturing output could see a loss of about 8% relative to the baseline. Other relatively less energy and carbon intensive sectors, e.g., paper, fabricated metals, and wood products loss experience less than a 5% loss. The motor vehicle sector gains since high gasoline prices induce consumers to switch toward demanding more fuel efficient vehicles in the model in 2025. On the non-manufacturing sector side, coal (20 percent), natural gas (10 percent), and crude oil (10 percent) production declines since the economy demands less fossil fuel.

Figure 9 shows sectoral output loss by manufacturing and non-manufacturing sub-sector.

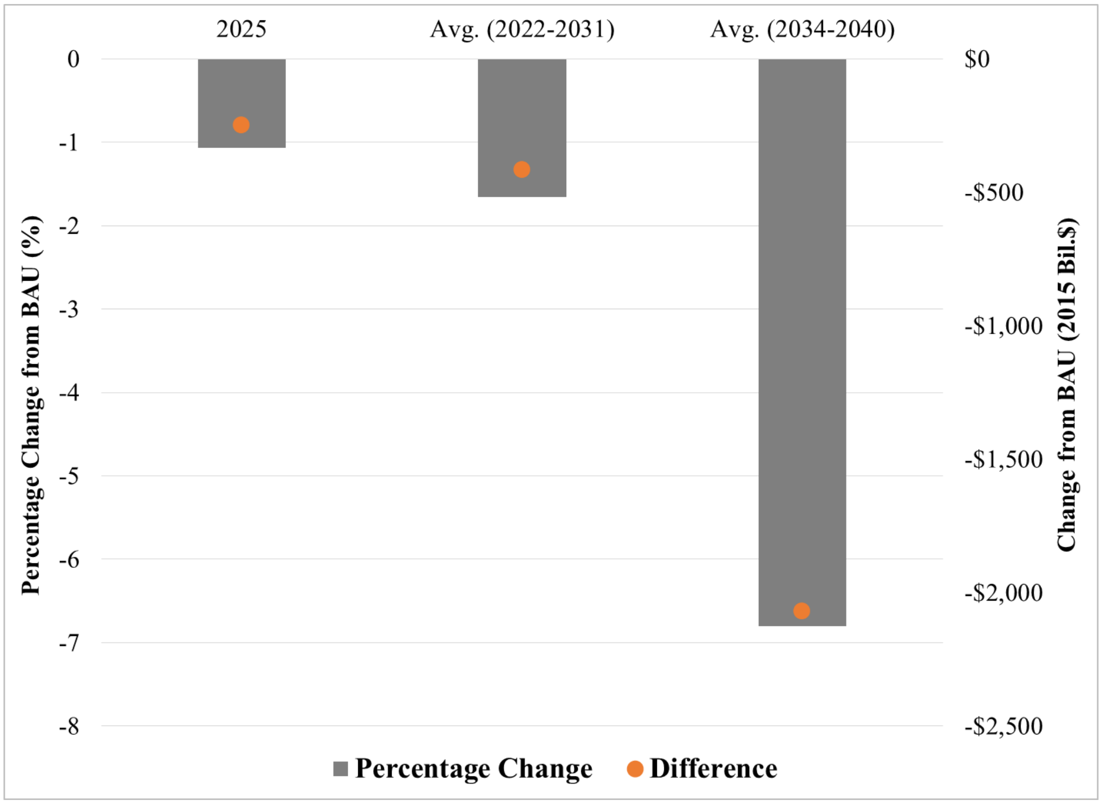
Figure 9: Sub-Sectoral Industrial Output



5. Gross Domestic Product

The loss in economic output translates to a loss in the nation's GDP as the reduction in output leads to less income for households because of lost wages, and the drop in output means a drop in investment. Aggregate investment declines by about 6 to 7% on average relative to the baseline in the medium term while in the long run with less economic activity investment drops by about 18% on average. Lower aggregate consumption along with lower investment coupled with lower exports of domestic goods and services leads to lower GDP. The U.S. GDP drops by about 1.1% in 2025 which amounts to a loss of $250 billion relative to the baseline. The decline in GDP accelerates over time as the targets become much more difficult to comply with and the targets start to constrain output in all sectors. Loss in GDP exceeds $1 trillion by 2034 and reaches a loss of nearly $3 trillion by 2040. Figure 10 shows the loss in GDP in 2025 and the average annual GDP loss in the medium and long run.

Figure 10: Change in GDP

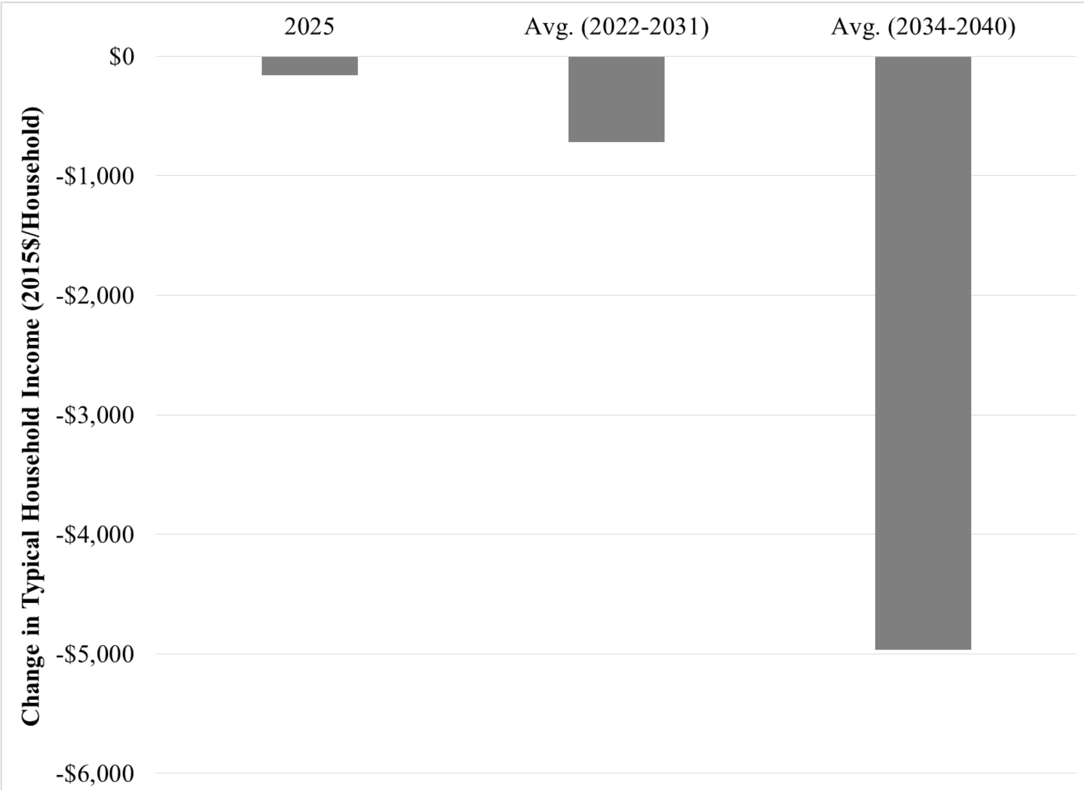


6. Income (or Consumption) per Average Household[47]

The high cost of energy to the household along with lower overall economic activity reduces the overall income and purchasing power of the U.S. households. Figure 11 shows changes in the cost of living for an average household. The regulations would have the net effect of reducing real consumption expenditures by $160 in 2025 and rising steeply thereafter to $7,000 by 2040. On average between 2022 and 2031, a typical U.S. households' average annual income relative to current income could drop by about $720; while in the long run the loss in income could be as large as $4,900 per household. The rapid increase in transportation costs in the long run has a direct effect on real household income.

[47] In this study, reduced income per average U.S. household is expressed as a dollar value relative to current average income levels to make it easier for readers to put these estimates into context with current household income.

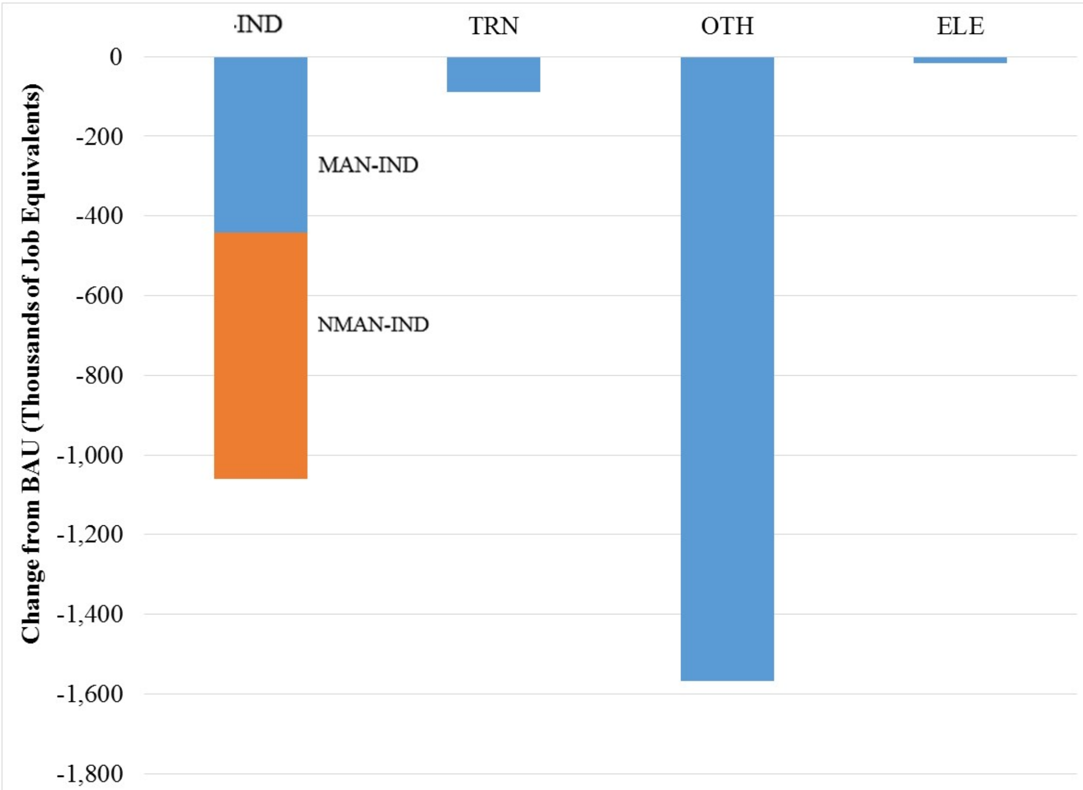
Figure 11: Change in Cost per Household



7. Employment Impacts

The decrease in the sectoral output results in a loss in employment. The industrial sector job loss could exceed 1 million in 2025 relative to the baseline total industrial employment of 24 million. The manufacturing sector alone could see a reduction of about 440,000 jobs in 2025 relative to the baseline employment of about 12 million. The loss in jobs in the non-manufacturing sector is mainly dominated by a loss in construction jobs as a result of a reduction in investment and contraction of the economy. Total economy-wide employment losses amount to about 2.7 million jobs in 2025. Figure 12 outlines job losses in 2025 for the four broad sectors of the economy. Employment impact for the topic industries are discussed in the following section.

Figure 12: Employment Impacts by Sector in 2025

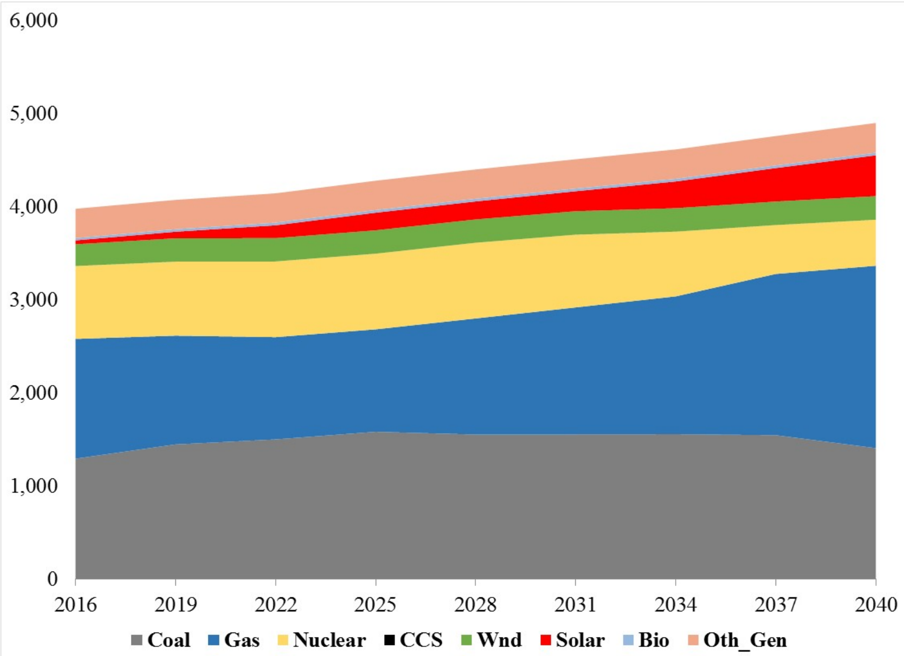


8. Changes in electricity generation mix

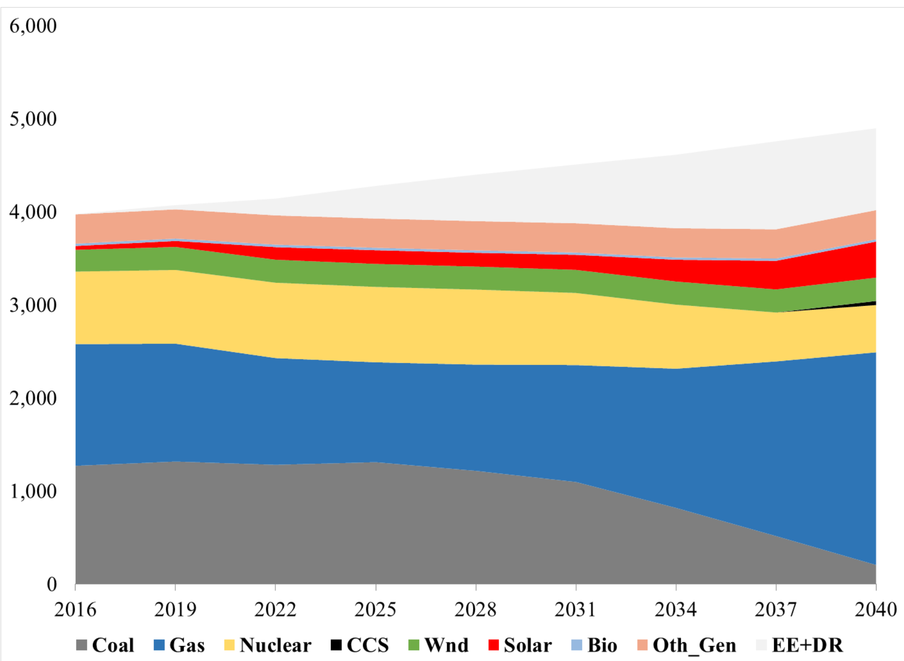
By 2040, the electricity sector still consumes some fossil fuel. Over time, gas-fired generation pushes out more and more coal-fired generation and by 2040 coal is almost completely eliminated because in large part the reduction in gas prices brought about by the drop in the wellhead price of gas, which is caused by the drop in industrial sector's demand for natural gas. The higher carbon prices also contribute to the decline in the demand for coal. In the near-term, coal-fired generation stays fairly constant as a share because the drop in gas prices is not large enough to induce fuel switching and the electricity sector does not face a carbon price until 2028 because the CPP is barely binding. The reduction in generation mainly comes from natural gas primarily displacing coal and solar generation. The supply of other resources in the generation mix remains at the same level between the baseline and the scenario. Figure 13 below shows the generation mix for the baseline and for the scenario, which includes demand response represented as EE+DR.

Figure 13: Baseline and Scenario Electricity Generation over Time (TWh)

Baseline:



Scenario:



B. Detailed analysis of Industrial impacts

1. Bulk Chemicals

a) Overview

The main source of energy for the bulk chemicals sector is natural gas, providing about 75% of the sector's energy needs. Electricity provides more than half of the balance; while coal and petroleum provide a small share. The energy usage pattern is fairly consistent over time (see Table 7).

Table 7: Energy Use in the Bulk Chemicals Sector (Baseline)

	Energy Use (Quads)			Energy Use (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Coal	0.12	0.12	0.12	4%	4%	4%
Natural Gas	2.19	2.21	2.42	74%	74%	75%
Petroleum	0.22	0.22	0.20	8%	7%	6%
Electricity	0.41	0.42	0.47	14%	14%	15%
Total	2.95	2.97	3.21			

With the imposition of the GHG policy, fossil energy usage declines while the amount of electricity used remains the about the same through 2031 and then drops off by about 15% relative to the baseline in the long-term. Therefore, the mix of energy shifts toward electricity as its share of energy reaches 27% by 2040 under the GHG policy compared to only 15% in the baseline. Since natural gas is the cleanest burning of the three fossil fuels, the GHG policy does not induce much switching out of natural gas, but rather induces a reduction in coal, natural gas, and petroleum usage. With the greater increase in coal prices because of its higher carbon content, coal experiences the greatest percentage decline from the baseline at 75% (see Table 7 and Table 8). In modeling the bulk chemicals we allow for the natural gas and petroleum products feedstock to change with the sectoral output. Hence, the energy feedstock demanded by this sector also declines as production declines.

Table 8: Energy Use in the Bulk Chemicals Sector (Scenario 1 with Average Sequestration)

	Energy Use (Quads)			Energy Use (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Coal	0.03	0.03	0.03	2%	2%	2%
Natural Gas	1.33	1.29	0.97	69%	68%	63%
Petroleum	0.16	0.15	0.13	8%	8%	8%
Electricity	0.41	0.42	0.42	21%	22%	27%
Total	1.93	1.89	1.55			

To abate emissions, the chemicals sector becomes more energy efficient. Given that the chemicals sector uses primarily natural gas, the reduction in carbon intensity mirrors closely the reduction in energy intensity. To meet the needed emission reductions, the biggest changes are the drop in overall energy because of the drop in production and overall improvement in energy intensity (see Table 9).

Table 9: Energy and Carbon Intensity of the Bulk Chemicals Sector

	Energy Intensity (Th. Btu/ 2015$ of Output)			Carbon Intensity ($MMTCO_2$/2015 '000$ of Output)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Baseline	2.10	2.04	1.71	0.13	0.12	0.10
Scenario	1.33	1.25	0.78	0.08	0.07	0.05
% Change	-37%	-39%	-54%	-39%	-40%	-55%

b) Production, Imports and Exports

As a result of higher costs associated with using fossil energy and electricity, the global competitiveness of the U.S. chemicals sector erodes. The higher cost of production caused by policies to reduce GHG emissions leads to a drop in domestic and foreign demand for output from the U.S. chemicals sector. The U.S. price of chemicals relative to that of international chemicals increases by about 2.5% in 2025 and up to 4% by 2040. The chemicals sector does benefit from the lower prices on fossil fuel feedstocks. This reduction in the cost of non-energy inputs helps mitigate the increase in production costs associated with using fossil fuels for energy.

The small increases in price lead to a modest change in trade position. The higher U.S. production costs make exports less competitive, leading to a 15% to 27% drop in exports from 2028 onward (see Table 10). The significant improvement in energy and carbon intensity coupled with the lower feedstock costs allows the chemicals sector to avoid much of the direct cost of the GHG policy. Therefore, the percentage drop in output is far below the percentage drop in energy usage.

The drop in exports and increase in imports leads to a reduction in domestic production. But the decline in overall economic activity harms domestic production more as demand for chemicals declines over time.

Table 10: Change in Production, Imports, and Exports for the Bulk Chemicals Sector (Scenario 1 with Average Sequestration)

	Change in production, imports and exports (Bil. 2015$)			Change in production, imports and exports (% Change)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Production	-56.6	-61.6	-158.5	-5%	-5%	-10%
Imports	7.0	6.1	6.8	3%	2%	2%
Exports	-15.4	-15.1	-20.4	-15%	-15%	-27%

c) Employment

The reduction in the sectoral output of the chemicals sector has a direct impact on the number of jobs the sector employs. The sector is relatively employment intensive sector and is estimated to employ about 845 thousand in 2025. The chemicals sector sees a reduction of 25 thousand jobs in 2025 relative to the baseline jobs and rising overtime as the stringency of the GHG policy increases. On average the annual jobs reduction between 2022 and 2031 could be 35 thousand; while in the long run the sector could reduce total number of jobs relative to the baseline by 120 thousand or 16% from the baseline (see Table 11).

Table 11: Employment Impacts for the Bulk Chemicals Sector

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Difference (Thousands of Job Equivalents)	-25	-35	-120
Percentage Change from BAU	-3%	-4%	-16%

2. Cement

a) Overview

Energy usage in the cement sector is predominantly split among coal, petroleum, and electricity. Over time, we see the share of coal in the energy mix to decline slightly at the expense of petroleum whose share is found to increase. The share of natural gas and electricity remain fairly constant over time.[48] .

Table 12: Energy Use in the Cement Sector (Baseline)

	Energy Use (Quads)			Energy Use (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Coal	0.16	0.16	0.17	49%	48%	44%
Natural Gas	0.02	0.02	0.02	5%	5%	5%
Petroleum	0.09	0.10	0.13	27%	29%	34%
Electricity	0.06	0.06	0.07	18%	18%	17%
Total	0.33	0.34	0.39			

With the imposition of the GHG policy, we see a decline in the overall energy use in the cement sector brought on by a decline in the output. The share of electricity in the energy mix remains about the same as that in the baseline. The share of petroleum is found to decline slightly while that of coal and natural gas is found to increase slightly relative to baseline shares. (see Table 13).

Table 13: Energy Use in the Cement Sector (Scenario 1 with Average Sequestration)

	Energy Use (Quads)			Energy Use (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Coal	0.12	0.12	0.11	50%	49%	44%
Natural Gas	0.02	0.02	0.02	7%	7%	7%
Petroleum	0.06	0.06	0.08	25%	26%	33%
Electricity	0.04	0.05	0.04	19%	18%	17%
Total	0.24	0.25	0.26			

[48] The shares reported do not take into account energy use from biomass since our model only accounts for fossil fuels and electricity usages.

To meet the needed emission reductions, the biggest changes are in the drop in overall energy because of the drop in production and overall improvement in energy intensity. This drop in overall energy usage also leads to a reduction in carbon intensity (see Table 14).

Table 14: Energy and Carbon Intensity of the Cement Sector

	Energy Intensity (Th. Btu/ 2015$ of Output)			Carbon Intensity (TCO_2/2015 '000$ of Output)		
	2025	**Avg.(2022 -2031)**	**Avg.(2034 -2040)**	**2025**	**Avg.(2022 -2031)**	**Avg.(2034 -2040)**
Baseline	20.1	19.3	19.7	2.4	2.2	2.0
Scenario	18.1	17.2	16.4	2.1	2.0	1.7
% Change	-10%	-11%	-17%	-10%	-11%	-17%

b) Production, Imports and Exports

Improving energy efficiency and reducing carbon intensity significantly raise production costs. The U.S. price of cement relative to the international cement increases by about 20% in 2025 to over 40% by 2040. The cement sector is significantly more energy intensive compared to the other topic sectors analyzed and hence the GHG policy affects the cement sector more negatively and raises production costs to a greater degree when compared to the other sectors. These large cost increases coupled with the highly substitutable nature of cement (i.e., homogeneity of the product) leads to increases in imports of about 62% by the 2030 time period. Also, what little exports existed disappear by 2034 because U.S. produced cement is no longer competitive on the world market.

Table 15: Change in Production, Imports, and Exports for the Cement Sector (Scenario 1 with Average Sequestration)

	Change in production, imports and exports (Bil. 2015$)			Change in production, imports and exports (% Change)		
	2025	**Avg.(2022 -2031)**	**Avg.(2034 -2040)**	**2025**	**Avg.(2022 -2031)**	**Avg.(2034 -2040)**
Production	-2.9	-2.6	-3.4	-21%	-18%	-20%
Imports	1.5	1.5	0.8	69%	62%	24%
Exports	-0.04	-0.04	-0.01	-90%	-86%	-52%

The commodity nature of cement causes U.S. production to be quite vulnerable to imports. Therefore, small cost increases in domestic production costs compared to foreign production lead to large substitution of domestic produced cement for foreign produced cement. This easy substitution means the efficacy of the U.S.'s GHG policy is rather poor when it comes to regulating emissions of the cement industry. There is about a 25% leakage in 2025 and the leakage increases over time to over 30% by 2040. Thus, every ten tons of emissions reduced in the U.S. from the cement sector are offset by an increase of 2.5 to 3 tons of emissions overseas.[49]

c) Employment

The reduction in the sectoral output of the cement sector has a direct impact on the number of jobs the sector employs. The cement sector could see reduction of 5,000 jobs in 2025 relative to the baseline jobs and rising overtime as the stringency of the GHG policy increases. On average the annual jobs reduction between 2022 and 2031 could be 4,600; while in the long run the sector could reduce total number of jobs relative to the baseline by 7,500 or 27% from the baseline (see Table 16).

Table 16: Employment Impacts for the Cement Sector

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Difference (Thousands of Job Equivalents)	-5.0	-4.6	-7.5
Percentage Change from BAU	-18%	-16%	-27%

3. Iron and Steel

a) Overview

The iron and steel sector has a relatively balanced energy usage pattern among coal, natural gas, and electricity. Natural gas is the most dominant energy source accounting for nearly half of the energy consumed. Electricity and coal comprise most of the balance, leading to these fuels and natural gas accounting for about 90% of the energy consumed by the iron and steel sector (see

Table 17)

[49] There is an overall drop in cement demand. Lower domestic demand for cement is met by reduction in domestic production and increase in imports. Reduction in domestic production is not fully offset by increase in imports. Although the global emission from the cement industry decreases, the global emissions reduction is less than the emissions reduced by the U.S. cement sector.

Table 17: Energy Use in the Iron and Steel Sector (Baseline)

	Energy Use (Quads)			Energy Use (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Coal	0.27	0.26	0.25	27%	26%	23%
Natural Gas	0.46	0.45	0.48	45%	45%	45%
Petroleum	0.10	0.10	0.13	10%	10%	12%
Electricity	0.18	0.19	0.21	18%	19%	20%
Total	1.01	1.00	1.07			

With the imposition of the GHG policy, energy usage drops significantly. In the long-term, coal, natural gas, petroleum, and electricity usage are down by 80%, 67%, 55%, and 20%, respectively. Substitution occurs among fossil energy and electricity. The share of energy from electricity reaches 37% by 2040 under the GHG policy compared to only 20% in the baseline. Since the cost to the electric sector to comply with the CPP and future targets is relatively small, the share of energy used by source shifts toward electricity and away from fossil fuels. In addition, many substitution opportunities exist for electricity, coal, and natural gas to trade-off against each other. With the greater increase in coal prices because of its higher carbon content, this fuel sees the greatest percentage decline. Its share is cut in half in the long-term (see Table 18).

Table 18: Energy Use in the Iron and Steel Sector (Scenario 1 with Average Sequestration)

	Energy Use (Quads)			Energy Use (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Coal	0.08	0.08	0.05	14%	15%	11%
Natural Gas	0.27	0.25	0.16	47%	45%	37%
Petroleum	0.06	0.06	0.06	10%	10%	14%
Electricity	0.17	0.17	0.16	29%	30%	37%
Total	0.58	0.55	0.42			

To comply with the GHG reduction policy, the Iron and Steel sector greatly reduces its energy consumption and the carbon intensity of the energy it uses. There are many opportunities to switch from coal to gas and the model see in the baseline. It actually looks as if there is less switching in the scenario. On the demand side, the higher cost of iron and steel and lower economic growth would hold consumption down, by about 7% below BAU in order to reduce emissions without even larger reductions in output, the iron and steel industry would shift in a major way from coal-fired blast furnaces to electric arc processes.

Table 19: Energy and Carbon Intensity of the Iron and Steel Sector

	Energy Intensity (Th. Btu/ 2015$ of Output)			Carbon Intensity (TCO_2/2015 '000$ of Output)		
	2025	**Avg.(2022 -2031)**	**Avg.(2034 -2040)**	**2025**	**Avg.(2022 -2031)**	**Avg.(2034 -2040)**
Baseline	4.73	4.46	3.55	0.51	0.48	0.36
Scenario	2.90	2.66	1.64	0.28	0.26	0.15
% Change	-39%	-41%	-54%	-45%	-46%	-58%

a) Production, Imports and Exports

Overall the carbon and energy intensity decline dramatically for iron and steel, but this reduction comes at a cost. This cost causes iron and steel output to fall by 19% below baseline levels by 2025 under the GHG policy, and further by almost 33% by 2040.

As a result of higher costs associated with using fossil energy and electricity, the global competitiveness of the U.S. iron and steel sector erodes. The higher cost of production caused by policies to reduce GHG emissions leads to a drop in domestic and foreign demand for output from the U.S. iron and steel sector. The U.S. price of aggregate iron and steel relative to the international price increases by about 7% in 2025 up to 11% by 2040.

The increased costs harm U.S. production. Some of the reduction in output would be replaced by imports, which increase by almost 20% in 2025, staying at that level until 2040. Exports would drop more precipitously, and be down by almost 50% by 2025 and over 75% by 2040.The increases in the domestic price lead to changes in the trade position. The higher U.S. production costs make exports less competitive, leading to a 49% to 68% drop in exports from 2028 onward (see Table 20). The significant improvement in energy and carbon intensity allows the iron and steel sector to avoid some of the direct cost of the GHG policy. Therefore, the percentage drop in output is far below the percentage drop in energy usage.

The drop in exports and increase in imports leads to a reduction in domestic production. But the decline in overall economic activity harms domestic production more as demand for iron and steel falls by over $80 billion whereas net imports increases by about $10 billion in the long-run.

Table 20: Change in Production, Imports, and Exports for the Iron and Steel Sector (Scenario 1 with Average Sequestration)

	Change in production, imports and exports (Bil. 2015$)			Change in production, imports and exports (% Change)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Production	-33.7	-36.3	-79.7	-19%	-20%	-33%
Imports	7.4	7.3	10.2	13%	13%	14%
Exports	-10.4	-10.1	-11.8	-49%	-49%	-68%

On the demand side, the higher cost of iron and steel and lower economic growth would hold consumption down, by about 8% below BAU in 2025 and more than 24% below BAU in 2040. Thus even with imports replacing domestic production, total consumption falls.

The increase in imports that offsets the drop in domestic production represents leakage of the U.S.' GHG reduction efforts. The commodity nature of parts of the iron and steel sector causes U.S. production to be quite vulnerable to imports. Therefore, small cost increases in domestic production compared to foreign production lead to large substitution of domestic produced iron and steel for foreign produced products. This easy substitution compromises the efficacy of the U.S.'GHG policy when it comes to regulating emissions of the iron and steel industry as with other energy intensive sectors. There is about a 35% leakage in 2025 and the leakage levels off at about 30% in the long-term. So every ten tons of emissions reduced in the U.S. from the cement sector are offset by an increase of 3 to 3.5 tons of emissions overseas.

The results reported in this section are for the entire iron and steel sector. The impacts would likely be more severe for the upstream portion of this sector, which is more commodity based and hence more trade exposed. It is also more energy intensive and therefore must reduce emissions and energy usage much more. On the other hand, the impacts would likely be less severe for the downstream iron and steel sector which is more specialized and less energy intensive.

b) Employment

The reduction in the sectoral output of the iron and steel sector has a direct impact on the number of jobs the sector employs. This sector could see a reduction of 19 thousand jobs in 2025 relative to the baseline jobs and rising overtime as the stringency of the GHG policy increases. On average the annual jobs reduction between 2022 and 2031 could be 21 thousand; while in the long run the sector could reduce total number of jobs relative to the baseline by 38 thousand or 32% from the baseline.

Table 21: Employment Impacts for the Iron and Steel Sector

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Difference (Thousands)	-19	-21	-38
Percentage Change from BAU	-12%	-14%	-32%

4. Paper and Allied Products

a) Overview

The paper and allied products sector has a relatively balanced usage of energy among coal, gas, and electricity.[50] Therefore, this sector has a number of opportunities to substitute one energy source for another.

Table 22: Energy Use in the Paper and Allied Products Sector (Baseline)

	Energy Use (Quads)			Energy Use (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Coal	0.20	0.20	0.21	24%	23%	23%
Natural Gas	0.40	0.40	0.41	47%	47%	46%
Petroleum	0.02	0.02	0.02	3%	3%	3%
Electricity	0.22	0.23	0.26	26%	27%	29%
Total	0.84	0.85	0.90			

With the imposition of the GHG policy, substitution takes place among fossil fuels and electricity. The share of electricity in the total energy consumption reaches 50% by 2040 under the GHG policy compared to only 30% in the baseline. Since the cost to the electric sector to comply with the CPP and future targets is relatively small, the relative share between electricity and fossil shifts towards electricity. As a result, the end user share of energy shifts toward electricity and away from fossil fuels. In addition, many substitution opportunities exist for coal and gas to trade-off against each other. With the greater increase in coal prices because of its higher carbon content, there is switching from coal to gas. Over the 2022 to 2031 time frame, the share of coal in the energy mix drops by two-thirds from its baseline share, and by 2040 coal

[50] We include biomass as a fuel option based on EIA's energy consumption for the sector. We assume no penalty for biogenic CO_2 emissions consistent with UNFCC reporting guidelines.

use drops by over 85% with its share declining by over 70%. Natural gas and petroleum maintain their share (see Table 23).

Table 23: Energy Use in the Paper and Allied Products Sector (Scenario 1 with Average Sequestration)

	Energy Use (Quads)			Energy Use (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Coal	0.04	0.05	0.04	8%	8%	7%
Natural Gas	0.29	0.28	0.22	50%	49%	42%
Petroleum	0.03	0.03	0.03	5%	5%	5%
Electricity	0.22	0.22	0.24	38%	39%	46%
Total	0.58	0.58	0.51			

As seen above, the energy usage changes in two ways in response to the GHG policy. As output changes, the energy demand along with other goods and services decline, as well as substitution as the relative input prices change. Overall energy intensity drops by about one third in 2030 and 45% by 2040, by 40% in the near-term and 52% in the long-term (see Table 24).

Table 24: Energy and Carbon Intensity of the Paper and Allied Products Sector

	Energy Intensity (Th. Btu/ 2015$ of Output)			Carbon Intensity (TCO_2/2015 '000$ of Output)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Baseline	2.89	2.85	2.77	0.19	0.19	0.18
Scenario	1.76	1.71	1.34	0.10	0.10	0.08
% Change	-39%	-40%	-52%	-47%	-48%	-58%

As a result of the GHG policy the sector responds by introducing more efficient ways to improvement energy and carbon usage. These changes in energy mix and drop in energy intensity lead to a reduction in carbon intensity for the sector. But to meet the needed emission reductions, the biggest changes are in the drop in overall energy because of a drop in production and overall improvement in energy intensity. This drop in overall energy usage leads to a substantial reduction in carbon intensity.

b) Production, Imports and Exports

As a result of higher costs associated with using fossil energy and electricity, the global competitiveness of the U.S. paper and allied products industry erodes. In other words, the higher cost of production caused by policies to reduce GHG emissions leads to a drop in domestic and foreign demand for output from the U.S. paper and allied products sector. The U.S. price of paper and allied products relative to the international price increases by about 3% in 2025 up to 4.5% by 2040, leading to the change in U.S.-international trade position. The higher U.S. production costs make exports less competitive, leading to a 10% to 20% drop in exports from 2028 onward. The significant improvement in energy and carbon intensity allows the sector to avoid much of the direct cost of the GHG policy. Therefore, the percentage drop in output is far below the percentage drop in energy usage.

Much of the drop in production is caused by the overall decline in economic activity in the U.S. The imports drop in similar proportion to domestic production. This similarity is evidence of the fact that economic activity is a key driver in the reduction in output.

Table 25: Change in Production, Imports, and Exports for the Paper and Allied Products Sector (Scenario 1 with Average Sequestration)

	Change in production, imports and exports (Bil. 2015$)			Change in production, imports and exports (% Change)		
	2025	Avg.(2022-2031)	Avg.(2034-2040)	2025	Avg.(2022-2031)	Avg.(2034-2040)
Production	-8.1	-9.4	-21.9	-4%	-4%	-9%
Imports	-2.4	-3.2	-13.1	-3%	-3%	-7%
Exports	-0.2	-0.1	-0.1	-7%	-8%	-16%

The change in trade position leads to marginal changes in where and how paper and allied products are produced internationally. Our analysis suggests that this change has consequences on the emissions from the paper sector globally. For every ton of emissions reduced in 2025 from the U.S. paper and allied products sector as a result of the U.S. GHG policy, we see an increase of 0.05 tons of emissions elsewhere in the world – a leakage rate of 5%.

c) Employment

The reduction in the sectoral output of the paper and allied products sector has a direct impact on the number of people the sector employs. The sector could see a reduction of 12 thousand jobs in 2025 relative to the baseline jobs and rising overtime as the stringency of the GHG policy increases. On average the annual jobs reduction between 2022 and 2031 could be 18 thousand; while in the long run the sector could reduce the total number of jobs relative to the baseline by 59 thousand.

Table 26: Employment Impacts for the Paper and Allied Products Sector

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Difference (Thousands)	-12	-18	-59
Percentage Change from BAU	-3%	-5%	-17%

5. Wood Products

Consumption of fossil fuels and carbon emissions from the wood products sector are less than 1% of the total industrial energy consumption and carbon emissions. Given its output value, the sector is the least energy and carbon intensive of the entire manufacturing sub-sectors. However, with respect to the sector's energy sources, a relatively higher share comes from purchased electricity compared to fossil fuels. Based on its composition of fuels consumed, the sector is less affected by fossil fuel costs than policies that would lead to an increase in electricity prices. Therefore, imposition of the GHG policy has a modest impact on the wood products sector.

Production of wood products decreases by about 2.4% relative to the baseline in 2025. On average between 2022 and 2031 production declines by about 3% and in the long run due to contraction of the economy and demand for wood product, output loss could reach 10% on average between 2034 and 2040.

The reduction in the sectoral output of the wood products sector has a direct impact on the number of people the sector employs. The sector employs about 530 thousand in 2025 and is relatively labor intensive. The sector could see a reduction of 17 thousand jobs in 2025 relative to the baseline jobs and rising overtime as the stringency of the GHG policy increases. On average the annual jobs reduction between 2022 and 2031 could be 27 thousand; while in the long run the sector could reduce the total number of jobs relative to the baseline by 110 thousand.

C. Economy-wide Leakage

The above sections discussed leakage for individual sectors, but what matters is the overall leakage of the U.S. policy. The level of leakage depends upon how much of production shifts from the U.S. to other parts of the world that does not face any carbon constraint and then ship the commodity back to the U.S. In the short run since overall demand erosion is not as large in the long run until there is demand for imported goods and hence relatively more goods are produced overseas. However, as the economy contracts and wage income declines, the purchasing power for U.S. household erodes leading to less demand for imports overall. These impacts lead to relatively lower production and lower leakage rate in the long run as shown in Table 27.[51]

Table 27: Overall Leakage of the U.S. Policy (%)

	2019	2022	2025	2028	2031	2034	2037	2040
Leakage (%)	39	35	33	19	16	8	7	6

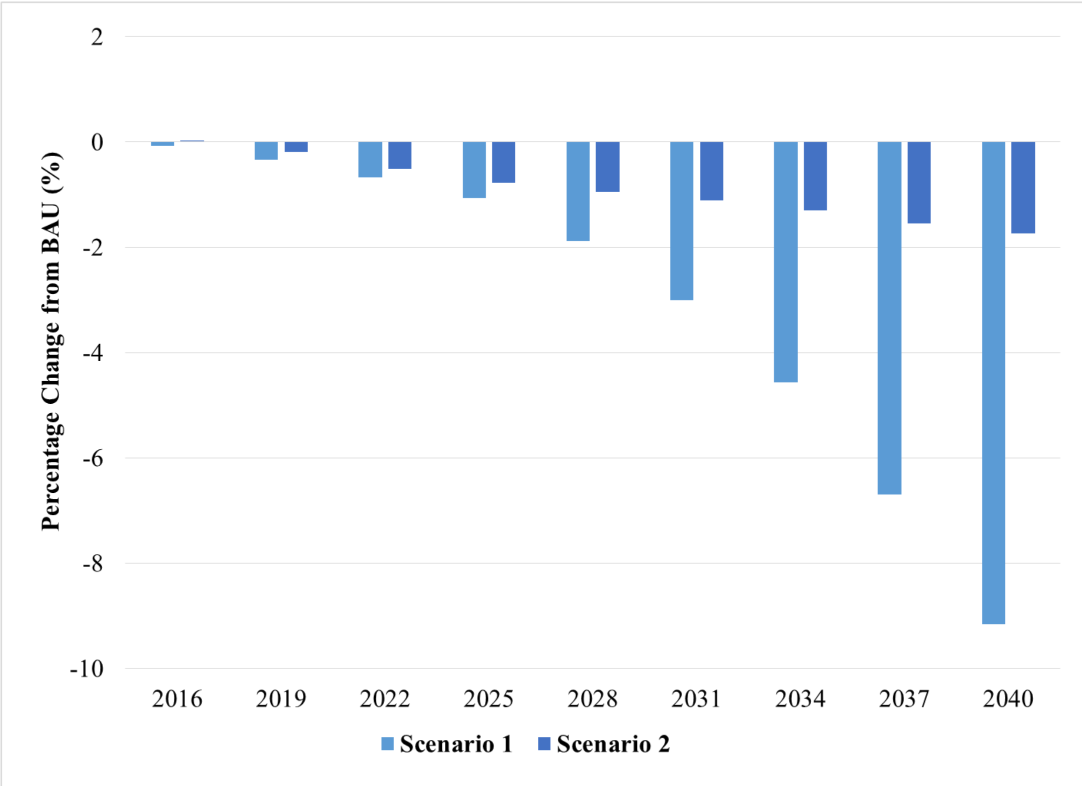
D. Lessons Learned from Alternate Scenarios

1. Scenario 2 – Industrial Sector Only

Scenario 2 imposes the same cap on the industrial sector as Scenario 1, but it imposes no caps or direct measures in addition to those in the baseline on any of the other three broad sectors. In the years up to 2025, GDP impacts of economy-wide regulation and regulation of the industrial sector alone are about the same. This reveals that most of the impacts on the economy as a whole through 2025arise from regulation of the industrial sector. The impacts begin to diverge after 2025 as policies to regulate GHG emissions in the non-industrial sectors are tightened. Though the impacts in the scenarios diverges more and more over time, the loss in GDP under Scenario 2 reaches about 2% by 2040 as seen in Figure 14.

[51] The leakage rate in the model is sensitive to the assumption about how easily the U.S. can substitute between domestic with imported goods and the relative carbon intensity of goods produced overseas.

Figure 14: Change in GDP from the Baseline under Scenarios 1 and 2

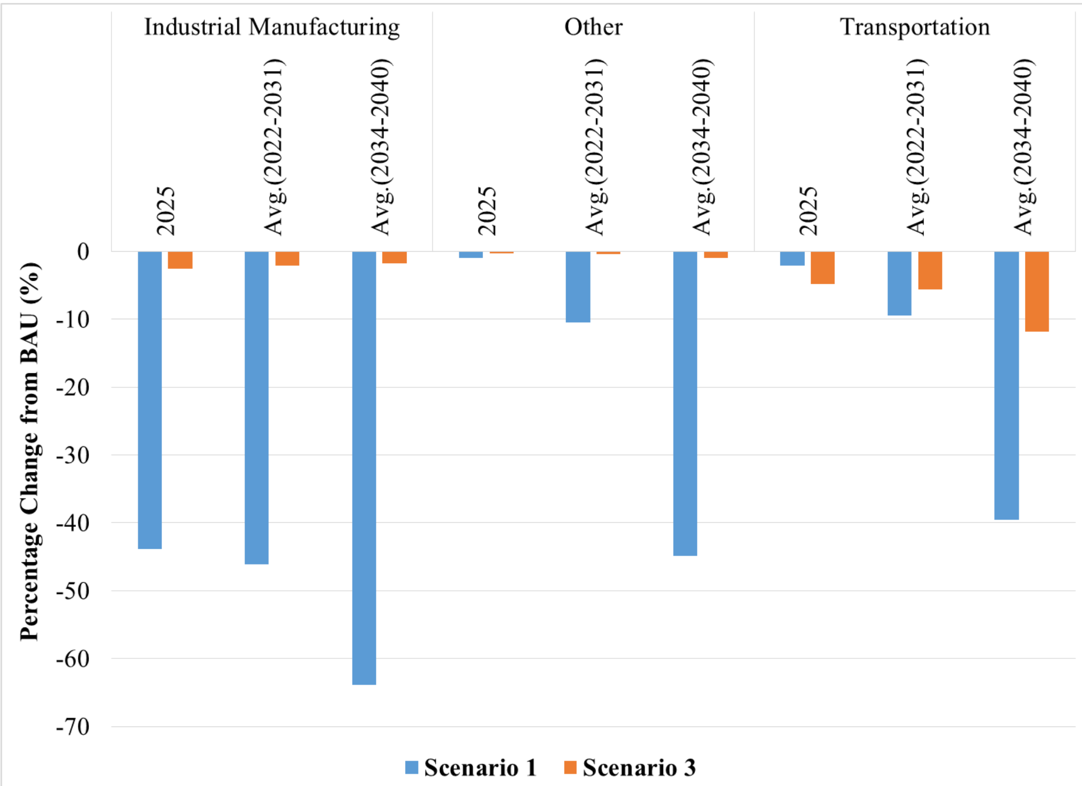


The IND Only policy also causes a loss in household consumption. The relationship of this loss under Scenario 2 to that of Scenario 1 is similar to that of the losses in GDP. In the near-term IND only scenario reduces household income by about the same amount as that Scenario 1. Over the 2034-2040 time period, the loss in household income is about 15% of the loss under the Scenario 1, showing how much of the loss in household income arises from targets on the industrial sector that cause reductions in industrial labor compensation and investment returns and increases in prices of manufactured goods.

2. Scenario 3 – Direct Measures

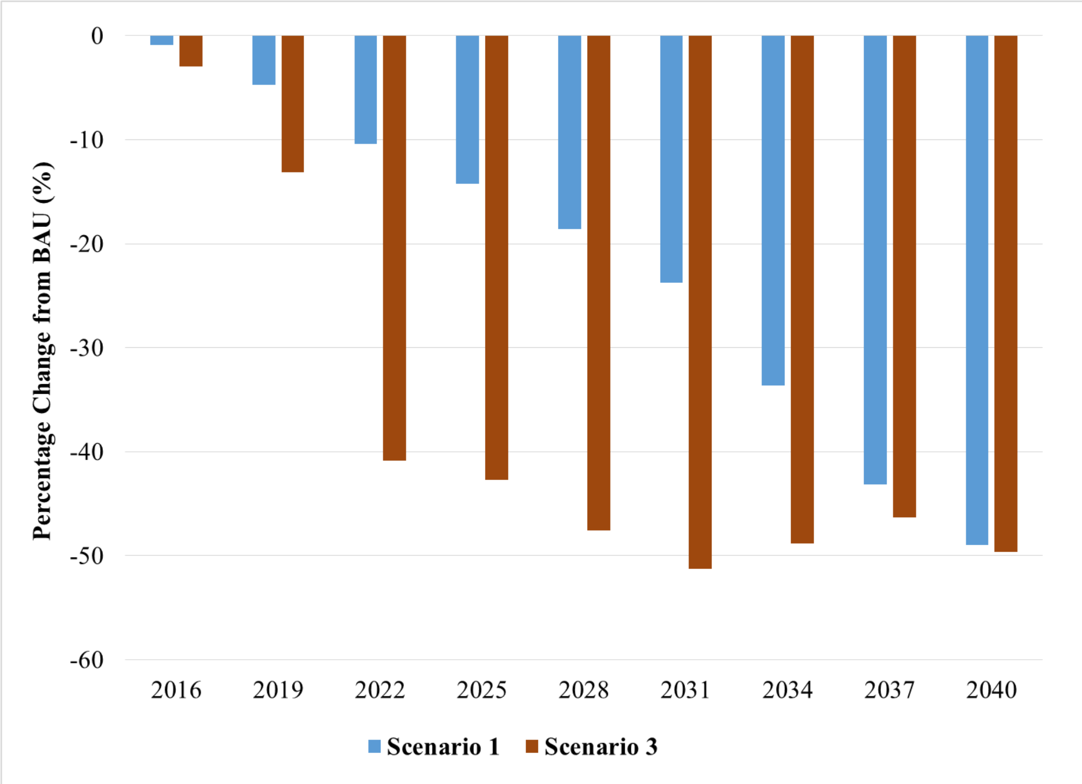
This section compares the results of Scenario 3 that imposed direct measures with Scenario 1 to understand how close implementing measures identified and designed in this study can come to achieving the NDC targets for the different broad based sectors. Figure 15 reports the change in emissions for the industrial, transportation, and other sectors under Scenarios 1 and 3. In the near-term, the direct measures for the transportation sector achieve about three percentage points more emission reductions than the reductions that occur under Scenario 1. Through 2025, the emission reductions under Scenario 3 differ greatly from those in Scenario 1, implying that the direct measures, as implemented, are clearly unable to achieve the NDC targets. For the aggregate industrial sector, the direct measures fail to come close to meeting even the 2025 NDC target since the measures primarily imposes feasible energy efficiency measures.

Figure 15: Change in Industrial, Transportation, and Other Sector emissions for Scenarios 1 and 3



The energy efficiency measures in the non-electric sectors and a stringent RPS imposed in the electricity sector in Scenario 3 leads to much larger reduction in electricity consumption and fossil fuel based generation compared to Scenario 1. Even though, the overall electricity demand is not that large between the two scenarios decreases of 12% in Scenario 3 and 8% in Scenario 1 in 2025, a large amount of natural gas and coal generation is displaced at the expense of biomass to meet the RPS in Scenario 3. This lead to relatively large reduction in emissions from the electricity sector in Scenario 3 compared to Scenario 1 as seen in Figure 16.

Figure 16: Emission Reduction in the Electric Sector under Scenarios 1 and 3



Not only do these direct measures fail to achieve the long-term emission reductions, but also they lead to greater economic harm in the short-run than the more market based scenario 1. Emission reductions of 930 $MMTCO_2$ are achieved at a consumption loss of $150 billion in Scenario 3 in 2025 suggesting an average consumption cost of $160/$TCO_2$. For Scenario 1, reductions of 720 $MMTCO_2$ are achieved at a consumption loss of $25 billion suggesting an average consumption cost of $35/$TCO_2$. This result suggests that on average the cost of reducing a ton of emission is much higher in Scenario 3 than under a market based mechanism as in Scenario 1. Mandates are an inefficient way to reduce emissions. The loss in consumption under the direct measures is significantly greater though 2025 and the equal in 2028. After which, the household loss is far greater under Scenario 1, which achieves much greater emission reductions.

Table 28: Change in Household Consumption (2015$/HH)

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Scenario 1	-162	-717	-4,964
Scenario 3	-965	-993	-1,414

3. Scenario 4 – Subsector-Specific Regulation

As direct regulations become more specific in how entities must reduce their emissions, the regulations provide businesses and households with less flexibility in how they choose to comply with the regulations. In other words, the more specific a regulatory measure, the smaller the set of compliance options and hence the more costly it is to comply because there are fewer options.

We constructed Scenario 4, which employs an emissions cap at the sectoral level for the industrial sectors. This scenario contrasts with Scenario 1, which employs one overarching policy for the entire industrial sector. Having individual policies for each industrial sector leads to distortions, which can be seen by the difference in the marginal cost of abatement across the industrial sectors. Under scenario 4, there is a wide range of abatement costs across sectors ranging from \$190/TCO_2 to \$740/T CO_2 in the medium-term and from \$290/TCO_2 to \$1,770/TCO_2 in the long-term. These marginal abatement costs compares to a uniform abatement cost across all industrial sectors of \$340/TCO_2 in the medium term and \$540/TCO_2 in the long term.

Table 29: Marginal Cost of Abatement under Scenarios 1 and 4 (2015 \$/TCO_2)

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Scenario 1	340	340	540
Scenario 4 (Min)	170	190	290
Scenario 4 (Max)	800	740	1,770

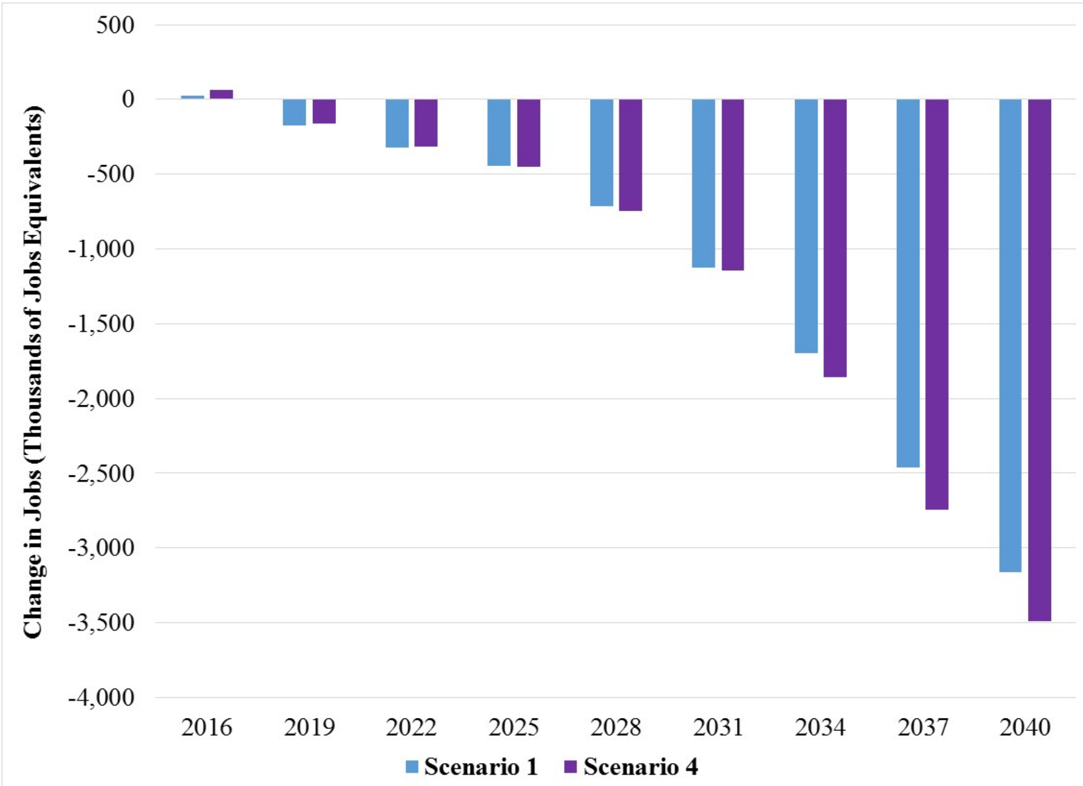
These additional distortions lead to slightly greater losses in consumption and GDP. Household consumption experiences greater harm as there are more jobs lost under Scenario 4 as seen in Table 30.

Figure 17 presents a comparison of the manufacturing sector employment impacts for Scenarios 1 and 4. Scenario 4 experiences greater loss compared to Scenario 1 because the manufacturing sub-sectors share a non-optimal burden leading to greater loss in consumption and output. These effects cause GDP to decline more under Scenario 4 than scenario 1.

Table 30: Percentage Change in GDP and Consumption from the Baseline for Scenarios 1 and 4

	Change in GDP (%)			Change in Consumption (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Scenario 1	-1.1	-1.7	-6.8	-0.14	-0.64	-4.4
Scenario 4	-1.2	-1.7	-6.9	-0.34	-0.8	-4.5

Figure 17: Manufacturing Sector Employment Impacts for Scenarios 1 and 4



Other sectors also suffer because of the greater impact on the industrial sector. In particular, since the industrial sectors are heavy users of electricity, the greater reduction in output from these sectors results in lower consumption and hence lower output from the electric sector (see Table 31).

Table 31: Change in Value of Output from the Electricity Sector (%)

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Scenario 1	-3%	-4%	-9%
Scenario 4	-4%	-5%	-10%

4. Scenario 5 – Economy-Wide Trading with Direct Measures

Scenario 5 allows trading across all sectors of the economy such that marginal costs of reducing emissions are equalized across all sectors. This means that emissions are reduced at the least cost manner in the economy leading to the lower carbon prices for the industrial sector. This equalization contrasts with Scenario 1, which has very disparate abatement costs for the major sectors (see Table 32).

Table 32: Sectoral Level Carbon Price for Scenarios 1 and 5 (2015 $/Ton CO_2)

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Scenario 1			
Electric Sector	0	2	20
Industry	330	340	540
Transportation	0	170	2,030
Other	0	130	790
Scenario 5[52]	0	10	150

In general, Scenario 5 lowers the abatement cost in the non-electric sectors and raises it in the electric sector. Therefore, the electric sector undertakes much greater reductions under the economy-wide cap than in Scenario 1 (see Table 33). In the long-run, emission reduction under Scenario 5 in the electric sector is about two times than in Scenario 1; while the other sectors are reduce their emissions by significantly lesser amounts because emissions reduction in the electric sector is relatively cheaper.

Table 33: Change in CO_2 Emissions by Sector under Scenarios 1 and 5 (Percentage Change from Baseline)

	Scenario 1 (%)			Scenario 5 (%)		
	2025	Avg.(2022 -2031)	Avg.(2034-2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Industry	-44%	-46%	-64%	-1%	-3%	-36%
Other	-1%	-10%	-45%	-0.3%	-1%	-17%
Transportation	-2%	-9%	-40%	-4%	-4%	-14%
Electric Sector	-14%	-17%	-42%	-44%	-52%	-86%

The differences between Scenarios 1 and 5 indicate how distortionary Scenario 1 is. The implications of the extra distortions in Scenario 1 have significant economic consequences. Moving from broad sector caps to one economy-wide cap lowers significantly the losses in consumption and GDP as the economic distortions are smaller. Although there is reduction in GDP relative to the baseline level, in both scenarios economy still grows over time, albeit at a

[52] The carbon price in 2025 is zero because the direct measures alone reduce carbon emissions more than the cap level.

much slower growth rate for Scenario 1 compared to Scenario 5. In the long-run, the losses in GDP and consumption are cut by about70% and60%, respectively (see Table 34).

Table 34: Change in GDP and Consumption for Scenarios 1 and 5 (Percentage Change from Baseline)

	Change in GDP (%)			Change in Consumption (%)		
	2025	Avg.(2022 -2031)	Avg.(2034 -2040)	2025	Avg.(2022 -2031)	Avg.(2034 -2040)
Scenario 1	-1.1%	-1.7%	-6.8%	-0.14%	-0.64%	-4.4%
Scenario 5	-0.5%	-0.7%	-2.2%	-1.1%	-1.1%	-1.7%

As the comparison of scenarios 5 and 1 show, broadening the cap reduces economic impacts relative to the baseline. Whereas the differences in impacts between scenarios 1 and 4 were relatively small, the differences in impacts between scenarios 1 and 5 are large. Thus, regulators can achieve the greatest benefit from broadening the cap when they include sectors with disparate emission reduction costs.

Alternative scenarios 4 and 5 meet the U.S. NDC target. Comparison of the results, see Table 35, shows that more flexibility under Scenario 5 to achieve the same or greater emission reductions results in lower economic cost. By allowing trading across all sectors, electric sector provides opportunity for relatively less expensive reductions than from the industrial sector. Hence, it would be much less costly to allow other sectors to purchase credits from the electric sector for emission reductions than to meet NDC targets on their own.

Table 35: Impact on Key Variables Relatives to Baseline for Scenario 4 and 5 for Average Sequestration

	Scenario 4		Scenario 5	
	2025	2040	2025	2040
Percentage Change in Gross Domestic Product (%)	-1.2%	-9.8%	-0.5%	-3.0%
Change in Gross Domestic Product (2015$ Bil.)	-$270	-$3,100	-$110	-$950
Change in Income per Average U.S. Household (2015$/Household)*	-$480	-$7,000	-$1,250	-$2,400
Change in Manufacturing Sector Jobs (Thousands)	-450	-3,500	-12	-430
Change in Total Industrial Sector Jobs (Thousands)	-1,100	-7,300	-200	-1,740
Change in Total Economy-wide Jobs (Thousands)	-3,400	-33,500	-2,300	-8,700

* Change in income per average U.S. household is expressed as a dollar value relative to current average income levels.

5. Impacts of Sequestration Options

Emissions from LULUCF are highly uncertain. For this study we assume that two different levels of sequestration are available to count against carbon emissions. The different levels of sequestration can also be thought of as allowing different levels of offsets such as more or less international forestry offsets. This section compares the impacts on the U.S. economy under these different levels of sequestration. With higher levels of sequestration, less emissions reduction needs to occur from the various economic sectors (see Table 36)

Table 36: Emission Reductions in the Broad Sectors under Average and High sequestration (Percentage Change from Baseline)

	Scenario 1- Average Sequestration			Scenario 1 - High Sequestration		
	2025	Avg.(2022 -2031)	Avg.(2034-2040)	2025	Avg.(2022-2031)	Avg.(2034-2040)
Industry	-44%	-46%	-64%	-33%	-37%	-59%
Electric Sector	-14%	-17%	-42%	-13%	-16%	-40%
Transportation	-2%	-9%	-40%	-2%	-9%	-37%
Other	-1%	-10%	-45%	-0.4%	-10%	-43%

The benefits of requiring fewer emission reductions to occur among the covered sectors can be seen in Table 37 by the lower abatement costs under the High Sequestration scenario. Less costly measures are required in every sector when the target for fossil fuel emissions is made less restrictive due to better results from sequestration and reductions in other GHGs.[53]

Table 37: Allowance Price by Sector under the Average and High Sequestration (2015 $/TCO$_2$)

	Scenario 1 - Average Sequestration			Scenario 1 - High Sequestration		
	2025	Avg.(2022 -2031)	Avg.(2034-2040)	2025	Avg.(2022 -2031)	Avg.(2034-2040)
Transportation	0	180	2,000	13	170	1,790
Industry	340	340	540	170	190	390
Electric Sector	0	2	20	0	2	20
Other	0	130	790	0	130	700

To further show the benefit of flexibility and allowing sequestration projects even if they are outside the U.S. Table 38 reports the change in GDP and consumption under the two different levels of sequestration.

Table 38: Change in GDP and Consumption for Scenario 1 with different levels of sequestration (Percentage Change from Baseline)

	Change in GDP (%)			Change in Consumption (%)		
	2025	Avg.(2022-2031)	Avg.(2034 -2040)	2025	Avg.(2022-2031)	Avg.(2034 -2040)
Avg. Sequestration	-1.1%	-1.7%	-7%	-0.14%	-0.6%	-4%
High Sequestration	-0.8%	-1.3%	-6%	-0.05%	-0.5%	-4%

However, moving from the average to the high sequestration still results in significant economic harm in the long-run with consumption loss of about 6% and GDP loss a bit under 4%.

[53] We do not include low sequestration reported in the USSBR 2016 for the study, which would imply a larger gap and a much more stringent target for the industrial sector.

VI. STATE LEVEL RESULTS

The GHG policy has different impacts across states and regions of the U.S. economy. Even though the states face the same carbon price, they may not face the same percentage change in energy prices since the starting points for energy prices differ across states. States that experience larger percentage changes in energy prices will face greater percentage cost increases in their production and hence, all else equal, greater losses in output. States that depend heavily on energy and carbon intensive industries will face the largest impact. The heterogeneity in impacts across states is due to different composition of industries and energy intensity of states' economies. We analyze impacts on four states – Michigan, Missouri, Pennsylvania, and Ohio – under the broad sectoral NDC cap on the industrial, transportation, and the other sector and CPP for the power sector. In this scenario, we assume average net sequestration. Carbon permits are handed to the states based on the share of their respective baseline emissions. These states rely on manufacturing sectors to support their economies. The sections below discuss high level macroeconomic impacts on these four states.

A. MICHIGAN

1. Background

Michigan's GDP was $447 billion in 2014, making it the thirteenth largest state economy.[54] The manufacturing sector is an integral part of the state's economy contributing to about 20% of the state's GDP, as seen in the figure below.[54] Production of durable goods comprises about 77% of the state's manufacturing output.[54]

Figure 18: Gross Domestic Product for Michigan by Sector, 2014

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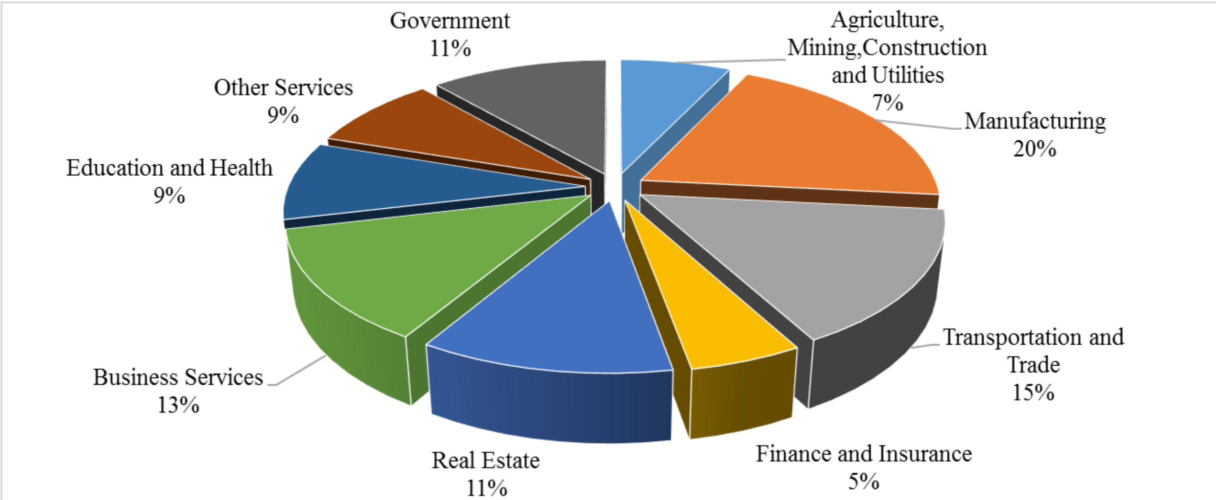
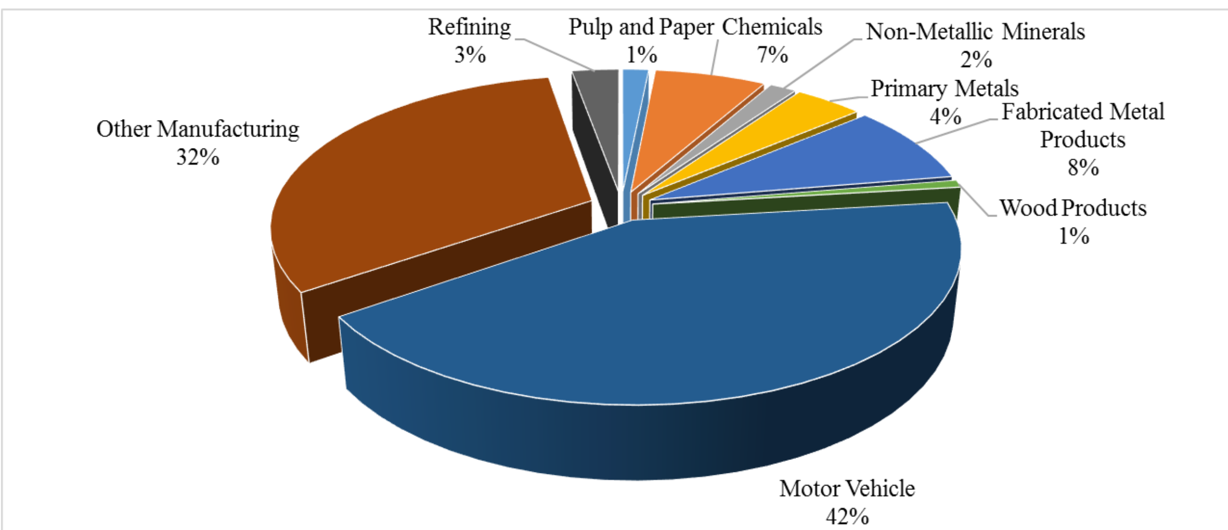
[54] Regional Data, Bureau of Economic Analysis, U.S. Department of Commerce.



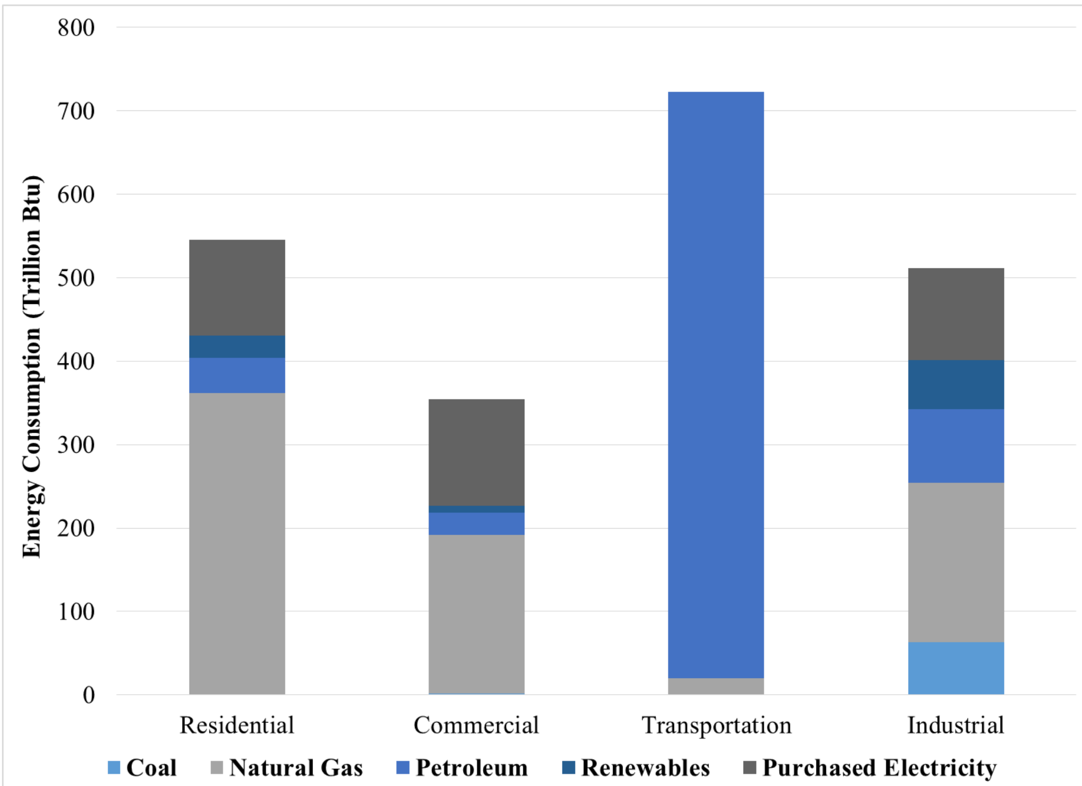
In 2014, the motor vehicle manufacturing sub-sector contributed the most to the manufacturing sector GDP with a share of about 42% followed by the other manufacturing sub-sector comprised primarily of non-energy intensive manufacturing with a share of 32% and fabricated metal products contributing around 8% to the total manufacturing sector GDP.[54]

Figure 19: Share of Gross Domestic Product for Michigan by Manufacturing Sub-Sector, 2014



The transportation and residential sectors consume the largest amount of energy in Michigan. Figure 18 presents energy consumption by fuel for the four broad sub-sectors for 2014. Across the residential, commercial and industrial sectors, natural gas was the dominant fuel comprising about 66%, 54% and 37%, respectively in the three sectors while the energy consumption mix in the transportation sector consisted almost entirely of petroleum products.[55] In 2014, Michigan's electricity generation mix was comprised primarily of coal (49%). Natural gas contributed to about 12% while nuclear energy accounted for about 29% of the net electricity generation.[55] The Michigan economy is about 13% more energy intensive than the U.S. as a whole with the economy-wide energy intensity of the state in 2014 estimated to be 6,400 Btu/$ of GDP in comparison to the U.S. energy intensity of 5,700 Btu/$ of GDP.[55]

Figure 20: Energy Consumption Mix by Fuel for Michigan, 2014

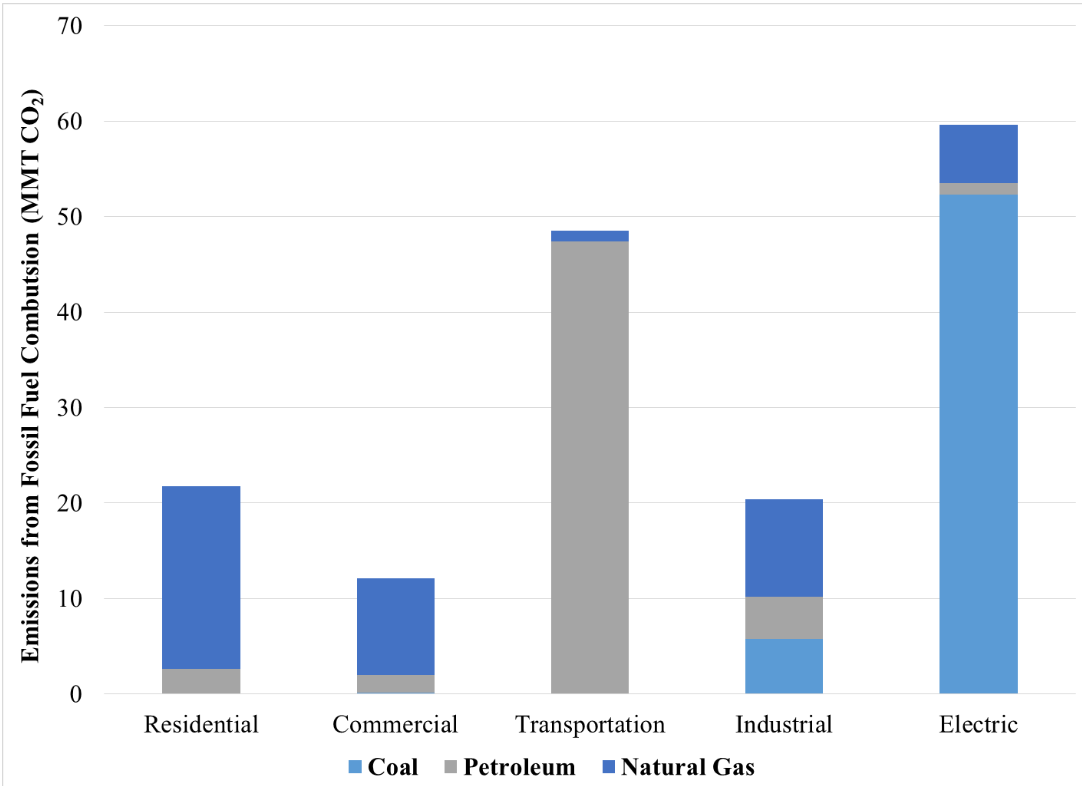


Currently, the combustion of natural gas is the dominant source of emissions in the residential, commercial, and industrial sector with its share of emissions in these three sectors amounting to 88%, 83% and 50% respectively.[55] Emissions from the electric sector come predominantly from the use of coal (about 88%); while almost all emissions from the transportation sector derive from the use of petroleum products.[55] The economy-wide carbon intensity of the state in 2014 was 0.36 TCO_2/'000$ of GDP in comparison to the U.S. wide energy intensity of 0.31 TCO_2/'000$ of GDP making it about 16% more carbon intensive than the U.S. as a whole.[55] At the industrial sector level, Michigan is the 15th highest energy and carbon intensive state in the

[55] State Profiles and Energy Estimates, State Energy Data System (SEDS), U.S. Energy Information Administration.

U.S. Its overall industrial energy and carbon intensity are about 15% higher than that of the U.S. industrial sector.

Figure 21: Emissions by Fuel Mix for Michigan, 2014



Since Michigan is a manufacturing based economy that is relatively energy and carbon intensive, a GHG policy that restricts carbon emissions leads to a significant impact on the state's manufacturing sectors and the overall economy. Higher costs of energy lead to increasing costs of production of manufacturing goods and hence lower their demand. The loss in manufacturing sectoral output leads to lower wage income and hence lower consumption and overall economic activity in Michigan.

2. State Level Impacts

In 2025, Michigan's GDP declines by about 0.8% while the U.S. as a whole experiences a GDP loss of about 1%. Although, Michigan is relatively energy and carbon intensive, its losses are marginally mitigated by positive contribution from the motor vehicle sector in the short run as described below. Michigan still suffers economic loss relative to the baseline since its economy depends on other energy-intensive manufacturing sectors that rely on fossil energy. The GHG policy has a direct effect on the manufacturing sector by raising energy costs. Michigan's overall economy is negatively impacted by higher energy costs leading to lower overall economic activity.

In 2025, Michigan's GDP is projected to decrease by about 0.8% relative to the baseline; which amounts to a loss of about $5 billion. In the medium term, the losses could increase to about $11 billion; while in the long run the economy could shrink by about 7%, which is equivalent to a loss of $59 billion as seen in Table 39.

Table 39: Gross Domestic Product for Michigan

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Difference (2015B$)	-5	-11	-59
Percentage Change (%)	-0.8%	-2%	-7%

The GHG policy leads to higher gasoline prices that induce consumers to shift towards use of more efficient vehicles. In the short run, in 2025, Michigan's motor vehicle sector benefits from higher demand for efficient vehicles as consumers seek to avoid the higher fuel costs. The motor vehicle sector output increases in the short run to about 1.5% in 2025 and 1% on average between 2022 and 2031. However, as the stringency of the GHG policy increases over time the motor vehicle sector is impacted negatively as the demand for motor vehicles declines sharply. By 2040, the motor vehicle sector output could decrease by 13% and about 9% on average between 2034 and 2040.

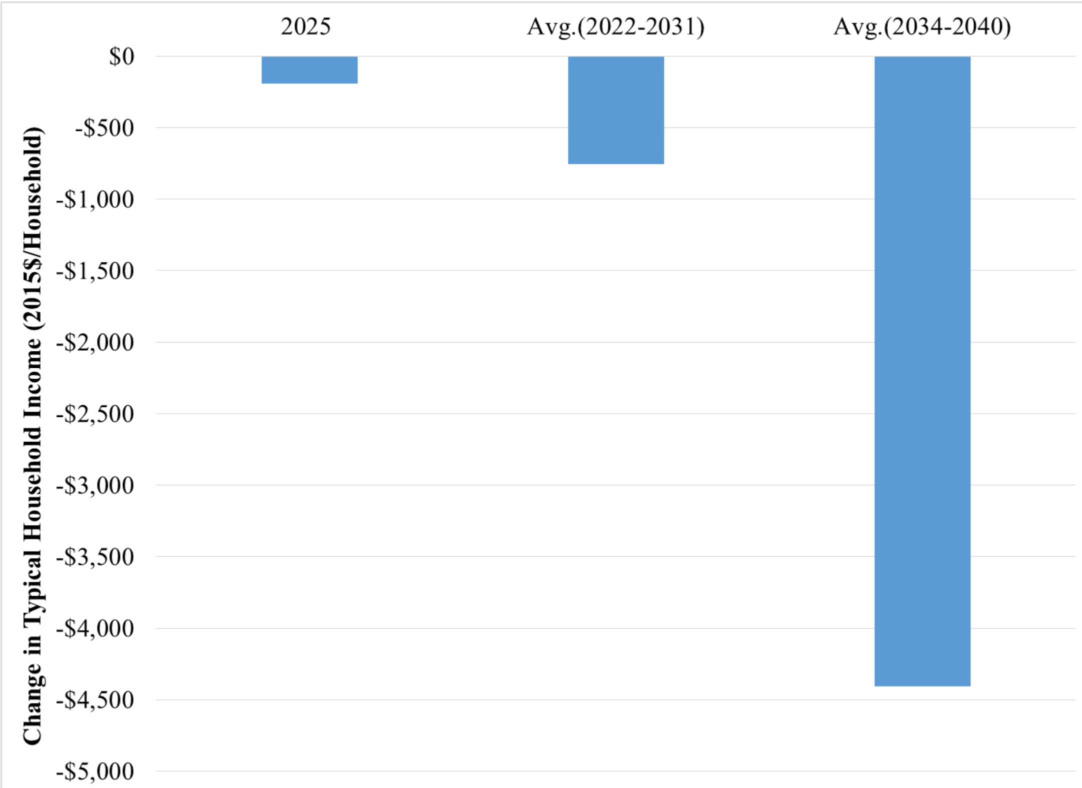
Other sectors, in particular energy-intensive sectors, are negatively impacted throughout the model horizon. Output from the chemicals and fabricated metal sub-sector are projected to decline by about 2% relative to the baseline in 2025. In the long run, the output impact could be about 8%. As for demand for petroleum products, output from Michigan's refinery sector also suffers. Refinery output in 2025 could decline by 9%; while in the long run the sectoral output could decline by one-third relative to the baseline. The iron and steel sub-sector is impacted to a greater extent with output forecasted to decline by 14% relative to baseline output in 2025. The lower demand for fossil fuels results in significant impacts on the natural gas and the coal sectors. Output from the natural gas and coal sub-sectors decreases by 9% and 11%, respectively from the baseline in 2025. The average annual impacts for the four topic sectors relative to the baseline between 2022-2031 and 2034-2040 when the stringency of the policy increase significantly are seen in Table 40.

Table 40: Sectoral Output for Michigan (Percentage Change from Baseline)

	2025	2040	Avg.(2022-2031)	Avg.(2034-2040)
Key Sectors				
M_V	-1.5%	-13%	0.8%	-9%
ONM	-4%	-11%	-4%	-9%
FAB	-2%	-10%	-2%	-8%
Topic Sectors				
PAP	-3%	-10%	-3%	-8%
CMT	-3%	-18%	-4%	-16%
CHM	-2%	-9%	-3%	-7%
I_S	-14%	-25%	-13%	-21%

Lower demand for goods and services produced in Michigan translates to fewer people employed in the manufacturing sector as well as in other sectors leading to lower income for the labor force. Lower wage income translates directly to loss in household income. A typical household in Michigan in 2025 could see its income fall by about $180 relative to current levels. Between 2022 and 2031, the impacts increase to about $700 per household; while in the long run impacts are disproportionately larger as seen in Figure 22.

Figure 22: Change in Consumption per Household for Michigan ($/Household)



Lower overall manufacturing output also affects employment with Michigan's manufacturing sector projected to face 13,000 full-time equivalent jobs losses in 2025 relative to the baseline; while the economy as a whole could lose about 70,000 full-time equivalent jobs. Jobs impacts could more than double in the medium term (between 2022 -2031) and increase significantly in the long run as seen in the table below.

Table 41: Employment Impacts for Michigan (Change from Baseline in Thousands of Job Equivalents)[56]

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Total	-74	-155	-699
MAN-IND	-13	-23	-102

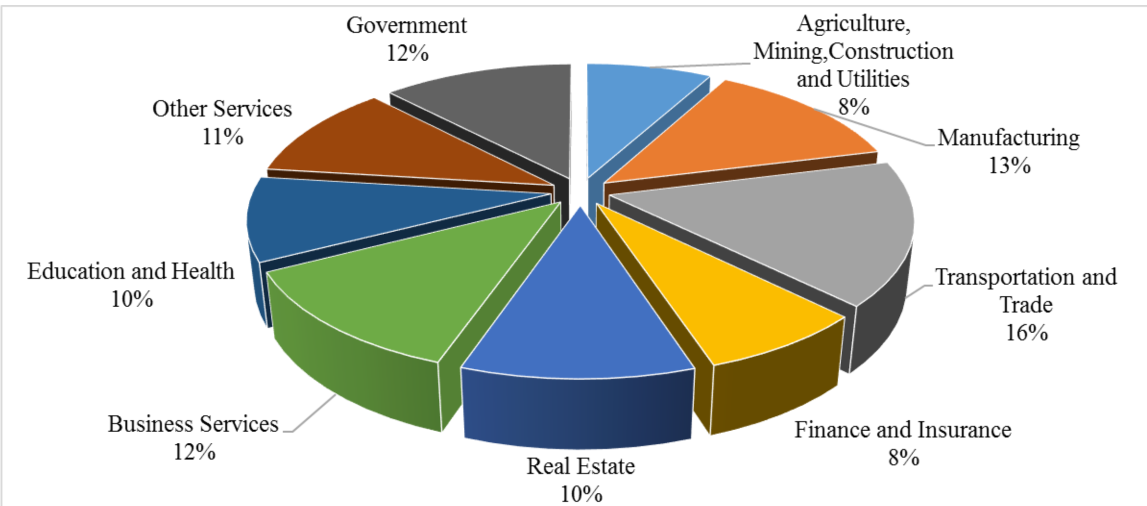
[56] Total job-equivalents equals total labor change divided by the average annual income per job. This does not represent a projection of numbers of workers that may need to change jobs and/or be unemployed, as some or all of it could be spread across workers who remain employed.

B. MISSOURI

1. Background

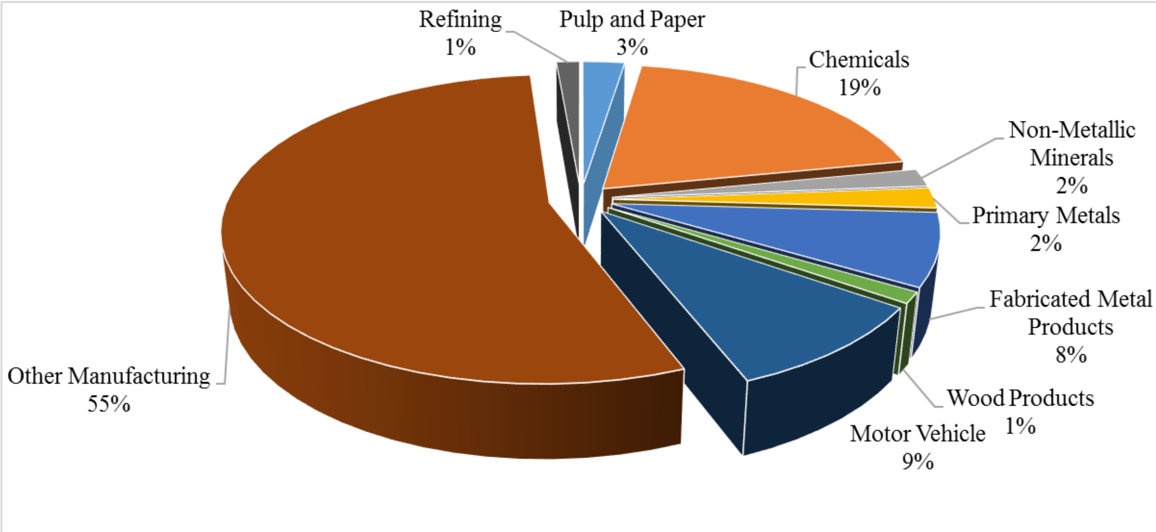
Missouri's GDP was $283 billion in 2014, making it the twenty-first largest state economy.[54] As seen in the figure below, transportation and trade had the greatest contribution to the state's GDP at 16% followed by the manufacturing sector contributing to about 13% of the state's GDP.[54]. About 48% of the state's manufacturing output consists of production of durable goods.[54]

Figure 23: Gross Domestic Product for Missouri by Sector, 2014



In 2014, the other manufacturing sub-sector contributed the greatest to the manufacturing sector GDP with a share of about 55% followed by the chemicals sector with a share of 19% and motor vehicle manufacturing contributing around 9% to the total manufacturing sector GDP.[54]

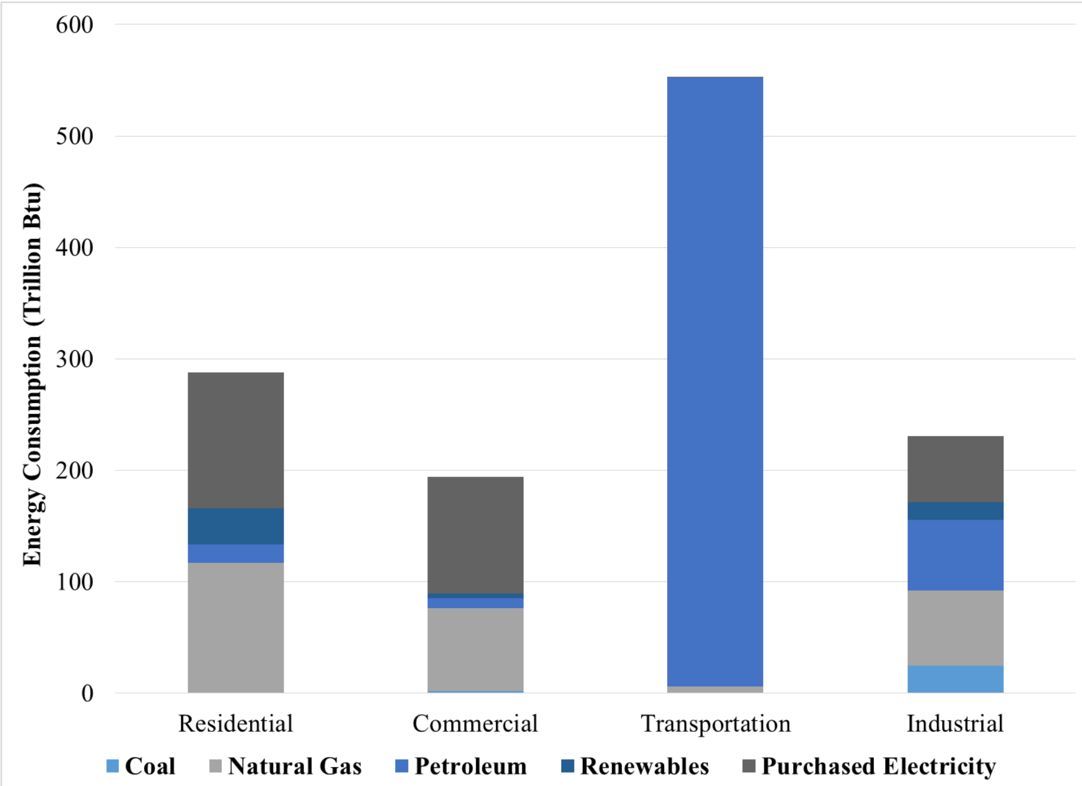
Figure 24: Share of Gross Domestic Product for Missouri by Manufacturing Sub-Sector, 2014



The transportation and residential sectors consume the largest amount of energy in Missouri. The following chart presents energy consumption by fuel for the four broad sub-sectors for 2014. Across the residential and the commercial sectors, electricity was the dominant fuel source comprising of about 42% and 54% of the total energy consumption in the two sectors.[55] The mix of energy used by the industrial sector is fairly well balanced while the energy consumption mix in transportation sector was comprised almost entirely of petroleum products.[55]

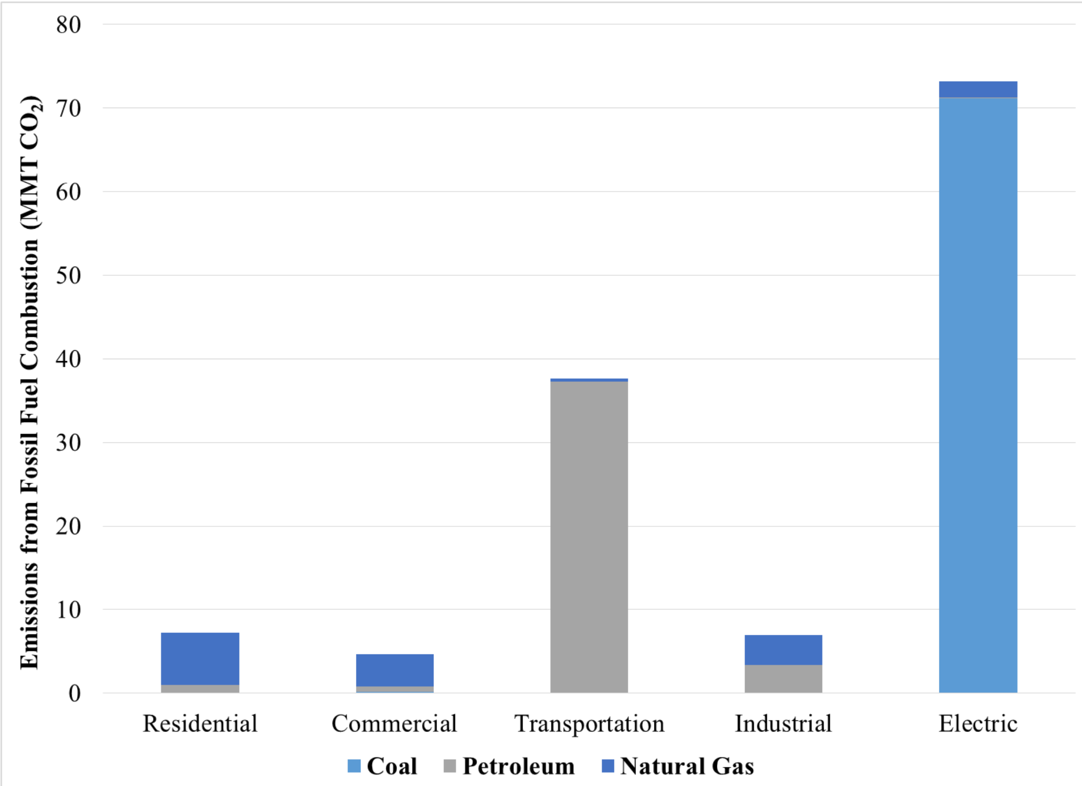
In 2014, Missouri's electricity generation mix was comprised largely of coal (82%). Natural gas contributed to about 5% while nuclear energy accounted for most of the remaining generation at about 11% of the electricity generation mix.[55] The Missouri economy is about 17% more energy intensive than the U.S. as a whole with the economy-wide energy intensity of the state in 2014 estimated to be 6,700 Btu/$ of GDP in comparison to the U.S. energy intensity of 5,700 Btu/$ of GDP.[55] Although Missouri's industrial sector is relatively small, it is highly carbon intensive compared to the U.S. average. Missouri's carbon intensity is almost 50% higher than the national average. Missouri's industrial sector is also relatively energy intensive, 18% higher than the national average.

Figure 25: Energy Consumption Mix by Fuel for Missouri, 2014



Combustion of natural gas is the pre-dominant source of emissions in the residential, commercial, and industrial sector accounting for 86%, 83%, and 51%, respectively, of the three sectors' emissions.[55] Emissions from the electric sector come predominantly from the use of coal (about 97%); while almost all emissions from the transportation sector derive from the use of petroleum products.[55] The economy-wide carbon intensity of the state in 2014 was 0.47 TCO_2/'000$ of GDP in comparison to the U.S. wide energy intensity of 0.31 TCO_2/'000$ of GDP making it about 50% more carbon intensive than the U.S. as a whole.[55]

Figure 26: Emissions by Fuel Mix for Missouri, 2014



2. State Level Impacts

Missouri's 2025 GDP loss of 1% is on par with the U.S. as a whole since its manufacturing base is dominated by other manufacturing and motor vehicle sub-sectors that are relatively less energy intensive compared to the other manufacturing sectors. However, since the energy-intensive sectors are highly carbon intensive the impacts on these sectors are significant. Overall Missouri's economy is negatively impacted from higher energy costs leading to lower overall economic activity. Missouri's 1% loss in GDP in 2025 amounts to a loss of about $4 billion. In the medium term the losses could increase to about $7 billion; while in the long run the economy could shrink by about 7%, which is equivalent to a loss of $39 billion as seen in Table 42.

Table 42: Gross Domestic Product for Missouri

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Difference (2015B$)	-4	-7	-39
Percentage Change (%)	-1%	-2%	-7%

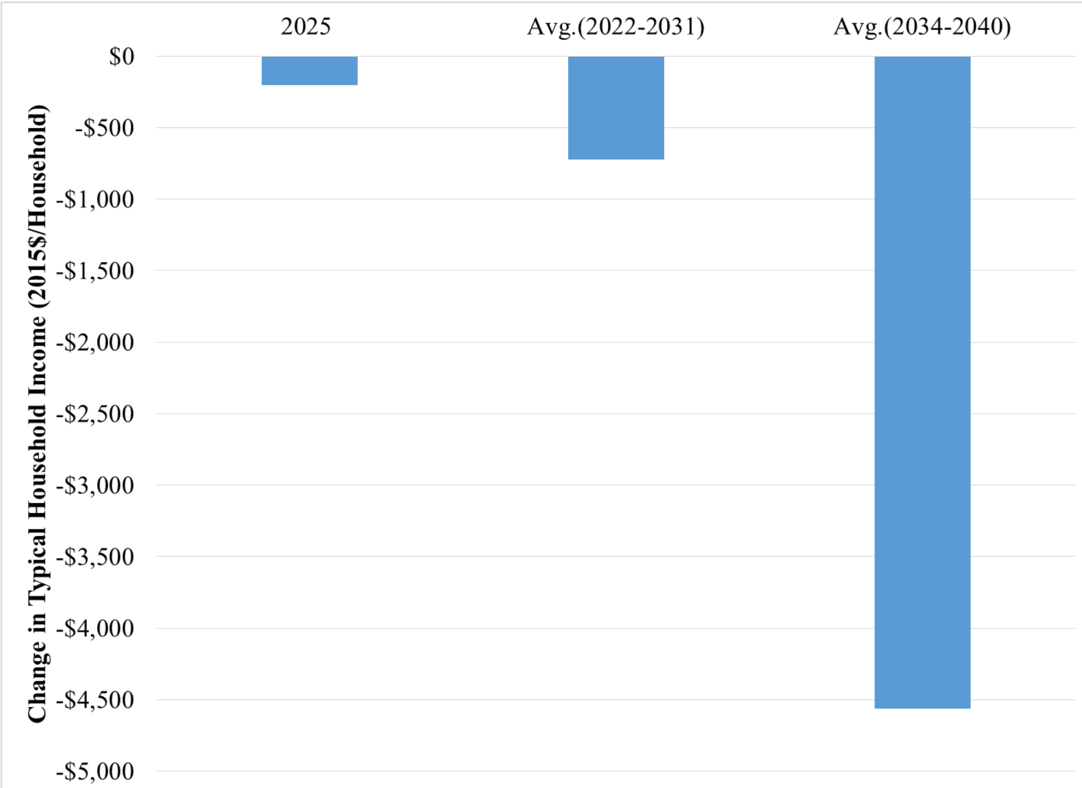
On average in 2025, industrial output declines by about 6% with Iron and Steel and Cement suffering the most. The output from the chemicals and fabricated metal sub-sector are projected to decline by about 1% and 2%, respectively, relative to the baseline output. Other energy intensive sub-sectors, such as cement and iron and steel are impacted the most. Output from these sectors is projected to decline by 18% and 20%, respectively, relative to baseline output in 2025. The lower demand for fossil fuels as a result of the GHG policy results affects significantly the coal sector. Coal sub-sector output decreases by about 20% from the baseline in 2025. Average annual impacts for the four topic sectors relative to the baseline between 2022-2031 and 2034-2040 when the stringency of the policy increases significantly are shown in Table 43.

Table 43: Sectoral Output for Missouri (Percentage Change from Baseline)

	2025	**2040**	**Avg.(2022-2031)**	**Avg.(2034-2040)**
Key Sectors				
ONM	-2%	-12%	-3%	-9%
M_V	1.2%	-16%	0.2%	-12%
FAB	-3%	-11%	-3%	-9%
Topic Sectors				
PAP	-2%	-9%	-2%	-7%
CMT	-18%	-17%	-13%	-15%
CHM	-0.8%	-9%	-1.2%	-6%
I_S	-20%	-24%	-19%	-22%

Lower demand for goods and services produced in Missouri means that there are fewer employment opportunities in the manufacturing sector as well. Lower real wage in combination with lower employment means that total wage income also decrease. Lower wage income translates directly to a loss in household income and its ability to demand goods and services. A typical household in Missouri in 2025 could see its annual household income reduce by about $190 relative to current levels. Between 2022 and 2031, the impacts could be $700 per household; while in the long run impacts household could lose an even more significant portion of its income as seen in Figure 27.

Figure 27: Change in Consumption per Household for Missouri ($/Household)



Lower overall manufacturing output also impacts employment in Missouri's manufacturing sector. The manufacturing sector could lose about 7,000 full-time equivalent jobs in 2025 relative to the baseline; while the Missouri economy as a whole could lose about 50,000 full-time equivalent jobs. The total number of jobs lost could more than double in the medium term (between 2022 -2031) to about 100,000 and decline by as much as 460,000 on average relative to the baseline in the long run as seen in the table below.

Table 44: Employment Impacts for Missouri (Change from Baseline in Thousands of Job Equivalents)

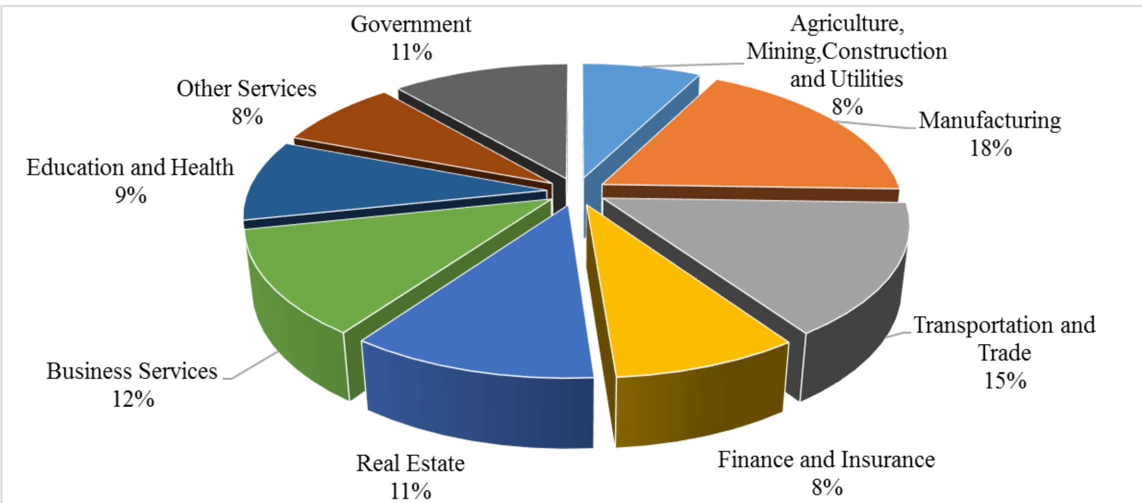
	2025	Avg.(2022-2031)	Avg.(2034-2040)
Total	-53	-100	-460
MAN-IND	-7	-12	-50

C. OHIO

1. Background

Ohio's GDP was $589 billion in 2014, making Ohio the seventh largest state economy.[57] Ohio ranks fourth among the 50 states in manufacturing gross domestic product. The manufacturing sector is an important economic activity and is the largest contributor (18% of GDP) of Ohio's GDP, as seen in the figure below;[54] whereas manufacturing represents about 12% of U.S. GDP.[58] The productions of durable goods comprise about 53% of the state's manufacturing output.[57] Transportation equipment and fabricated metal are two of Ohio's largest manufacturing industries with motor vehicles and machinery representing the state's two leading export commodities.[54 57]

Figure 28: Gross Domestic Product for Ohio by Sector, 2014



In 2014, the Other Manufacturing sub-sector comprised primarily of non-energy intensive manufacturing contributed the greatest to the manufacturing sector GDP with a share of about 40%.[54] In terms of individual sectors with the highest contribution, the refining sector has the highest share at 14% followed by chemicals manufacturing at 13% and fabricated metal products and motor vehicle manufacturing both contributing around 11% each to the total manufacturing sector GDP.[54]

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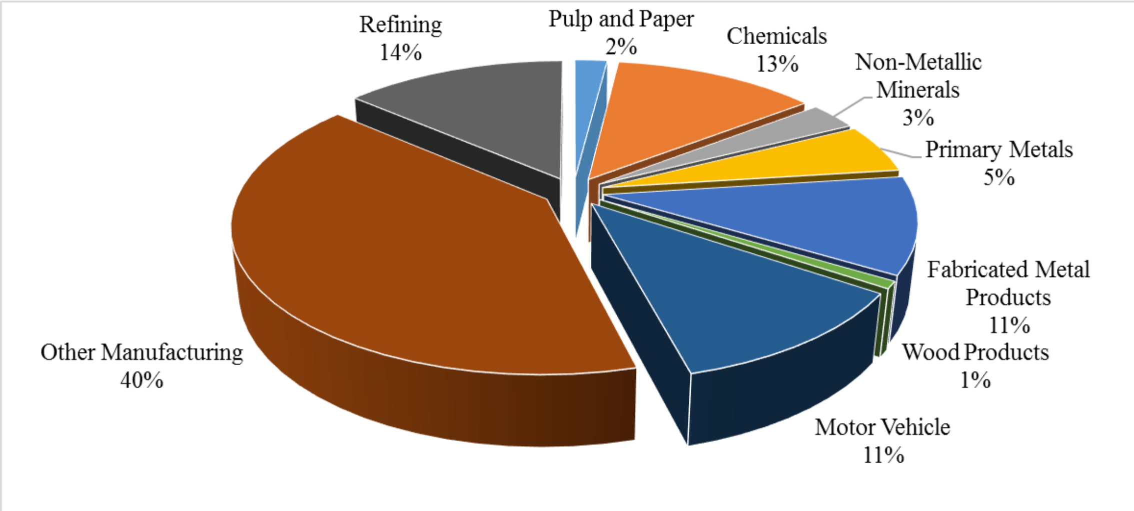
[57] Regional Data, Bureau of Economic Analysis, U.S. Department of Commerce.

[58] National Accounts Data, World Bank.

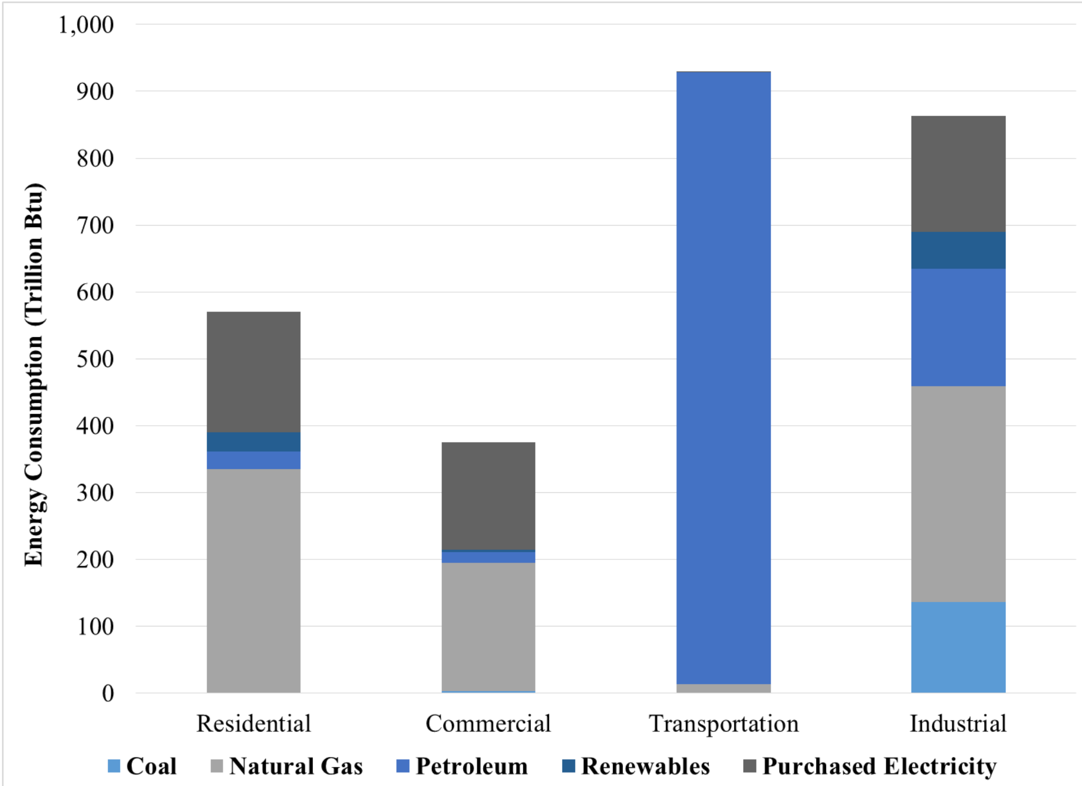
Figure 29: Share of Gross Domestic Product for Ohio by Manufacturing Sub-Sector, 2014



Transportation and the industrial sector consume the largest amount of energy in Ohio. The following chart presents energy consumption by fuel for the four broad sub-sectors for 2014. Across the residential, commercial and industrial sectors, natural gas was the dominant fuel comprising about 59%, 51%, and 37%, respectively, in the three sectors while the energy consumption mix in the transportation sector was comprised almost entirely of petroleum products. [55] In 2014, Ohio's net electricity generation comes mainly from coal (67%). Natural gas contributed about 18%, and nuclear energy accounted for most of the remainder of the generation at 12% of the electricity generation mix.[59] The Ohio economy is about 14% more energy intensive than the U.S. as a whole. The economy-wide energy intensity of Ohio in 2014 was 6,500 Btu/$ of GDP in comparison to the U.S. energy intensity of 5,700 Btu/$ of GDP.[55]

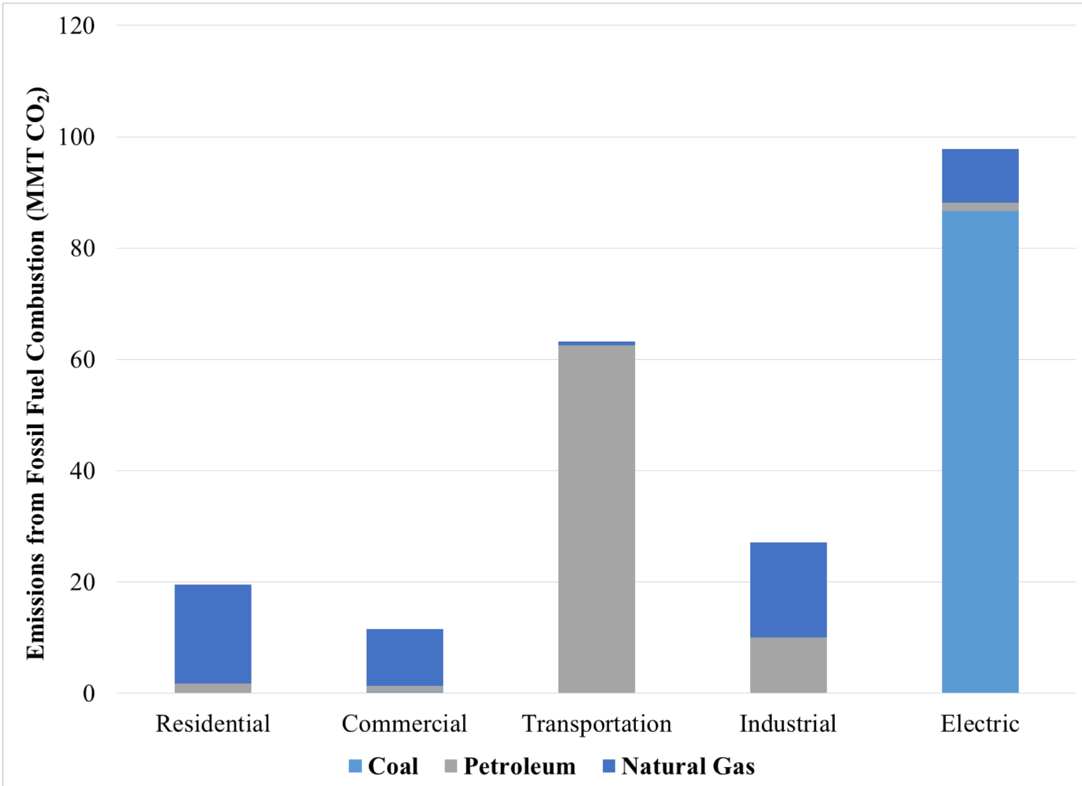
[59] State Profiles and Energy Estimates, State Energy Data System (SEDS), U.S. Energy Information Administration.

Figure 30: Energy Consumption Mix by Fuel for Ohio, 2014



Natural gas is the primary source of fuel in the residential, commercial, and industrial sectors. Hence emissions from natural gas combustion in these three sectors is about 91%, 88% and 63%%, respectively.[55] Emissions from the electric sector derive predominantly from coal usage (about 89%); while almost all emissions from the transportation sector come from the use of petroleum products.[55] The economy-wide carbon intensity of the state in 2014 was 0.39 TCO_2/'000$ of GDP in comparison to the US wide energy intensity of 0.31 TCO_2/'000$ of GDP making it about 26% more carbon intensive than the U.S. as a whole.[55] As for the industrial sector, Ohio's industrial sector is 13% and 25% more energy and carbon intensive than the average U.S. industrial sector, respectively.

Figure 31: Emissions by Fuel Mix for Ohio, 2014



Given that Ohio is a manufacturing based economy that is relatively energy and carbon intensive, GHG policy that restricts carbon negatively affects its manufacturing sectors and the overall economy. Higher costs of energy lead to increased costs of production of manufacturing goods and hence lower demand. The loss in manufacturing sectoral output leads to lower wage income and hence lower consumption and overall economic activity in Ohio.

2. State Level Impacts

Ohio's GDP loss is about 1.2% while the U.S. as a whole experiences a GDP loss of about 1% in 2025. Ohio suffers greater economic loss than the nation as a whole relative to the baseline since its economy depends more on the manufacturing sector, which relies on fossil fuel energy. By raising energy costs, the GHG policy has a direct effect on the manufacturing sector. Ohio's overall economy is negatively impacted from higher energy costs leading to lower overall economic activity.

In 2025, the 1.2% loss in Ohio's GDP amounts to a loss of about $9 billion. In the medium term the losses could increase to about $14 billion; while in the long run the economy could shrink by about 7% or equivalent to a loss of $72 billion as seen in Table 45.

Table 45: Gross Domestic Product for Ohio

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Difference (2015B$)	-9	-14	-72
Percentage Change (%)	-1%	-2%	-7%

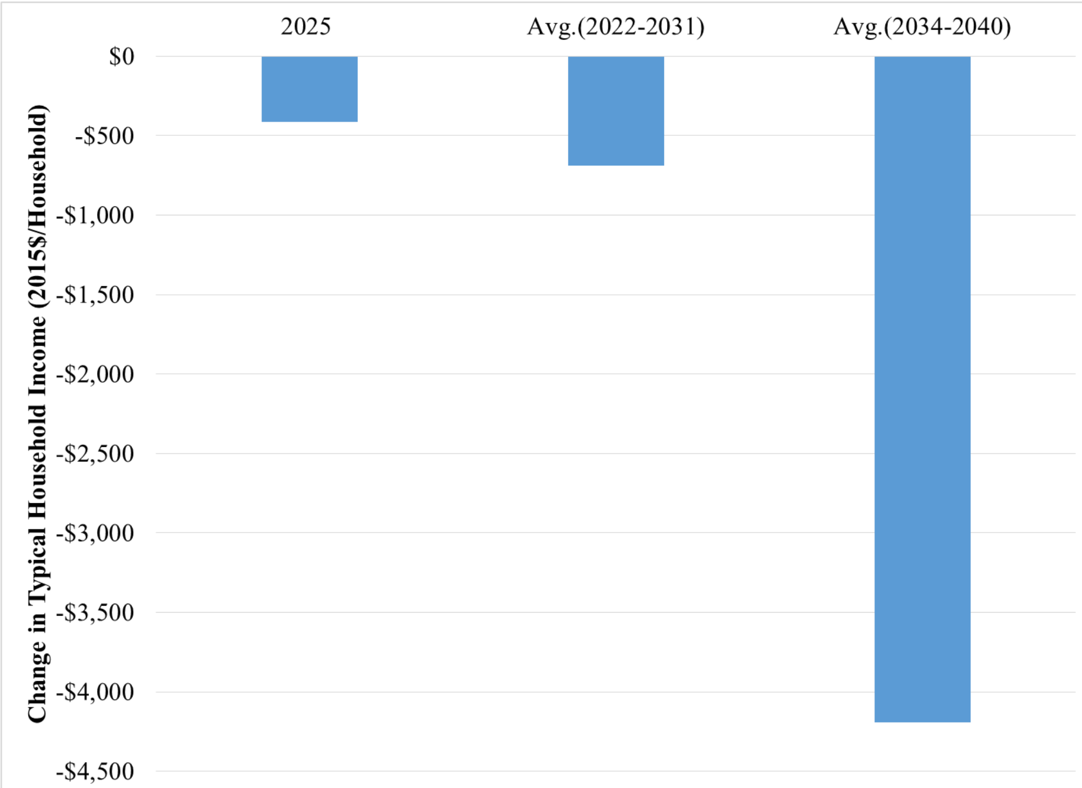
In 2025, the sectoral output from the refinery sub-sector is projected to decline by 8%; while other major manufacturing sectors also are impacted negatively. Output from the chemicals and fabricated metal sub-sector are projected to fall by about 3% and 2%, respectively, relative to the baseline output. Other energy intensive sub-sectors, such as cement and iron and steel are impacted to a greater extent with output from these sectors forecasted to decline by 16% and 13%, respectively, relative to baseline output. The demand for more efficient motor vehicles could increase as the fuel costs increase, especially in the long run when the carbon price increases significantly. The lower demand for fossil fuels results in significant impacts on the natural gas and coal sectors. Output from the natural gas and coal sub-sectors decreases by 11% and 22%, respectively, from the baseline in 2025. Average annual impacts for the four topic sectors relative to the baseline between 2022-2031 and 2034-2040 when the stringency of the policy increase significantly are shown in in below table.

Table 46: Sectoral Output for Ohio (Percentage Change from Baseline)

	2025	2040	Avg.(2022-2031)	Avg.(2034-2040)
Key Sectors				
ONM	-5%	-13%	-5%	-11%
OIL	-8%	-43%	-13%	-40%
FAB	-2%	-11%	-3%	-8%
Topic Sectors				
PAP	-3%	-11%	-3%	-8%
CMT	-16%	-27%	-16%	-23%
CHM	-3%	-13%	-4%	-10%
I_S	-13%	-30%	-13%	-24%

Lower demand for goods and services produced in Ohio signifies fewer people are employed in the manufacturing sector as well as in other sectors leading to lower income for the labor force. Lower wage income translates directly to a loss in household income. A typical Ohio household in 2025 could see its household income reduce by about $390 relative from current levels. Between 2022 and 2031, the impacts are about $700 per household; while in the long run impacts are disproportionately larger as seen in Figure 32.

Figure 32: Change in Consumption per Household for Ohio ($/Household)



Lower overall manufacturing output also impacts employment with Ohio's manufacturing sector projected to face 24,000 full-time equivalent jobs losses in 2025 relative to the baseline; while the economy as a whole could lose about 110,000 full-time equivalent jobs. Jobs impacts could more than double in the medium term (between 2022 -2031) and increase significantly in the long run as seen in Table 47.

Table 47: Employment Impacts for Ohio (Change from Baseline in Thousands of Job Equivalents)

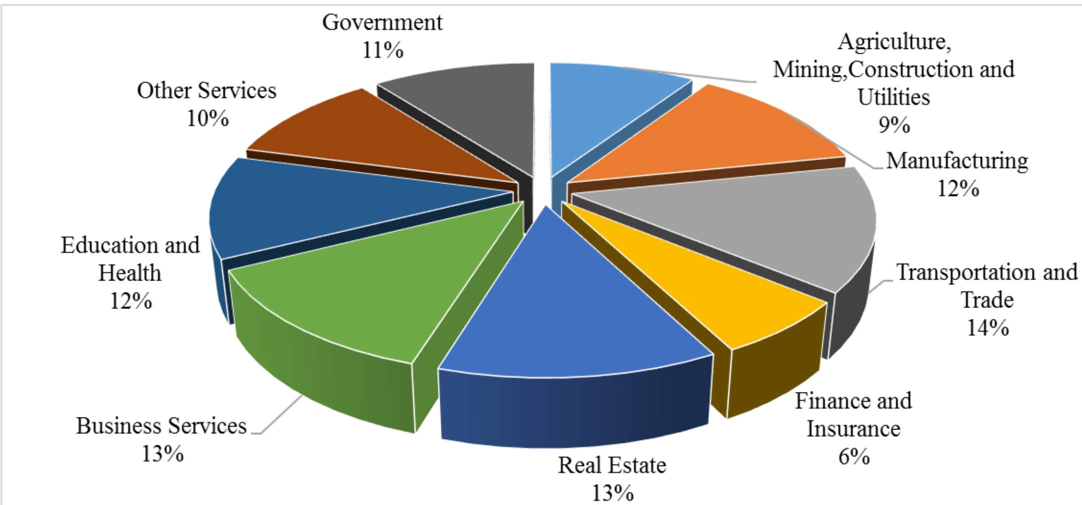
	2025	Avg.(2022-2031)	Avg.(2034-2040)
Total	-110	-200	-880
MAN-IND	-24	-35	-130

D. PENNSYLVANIA

1. Background

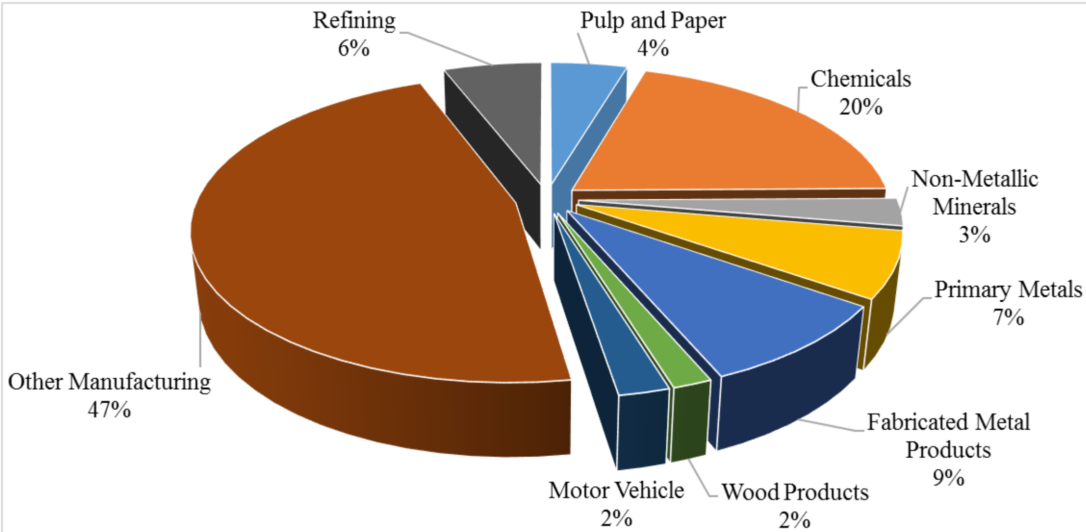
Pennsylvania's GDP was $672 billion in 2014, making it the sixth largest state economy.[54] As seen in the figure below, transportation and trade made the greatest contribution to the state's GDP at 14%.[54] The manufacturing sector contributed to about 12% of the state's GDP.[54]. About 48% of the state's manufacturing output is involved in the production of durable goods.[54]

Figure 33: Gross Domestic Product for Pennsylvania by Sector, 2014



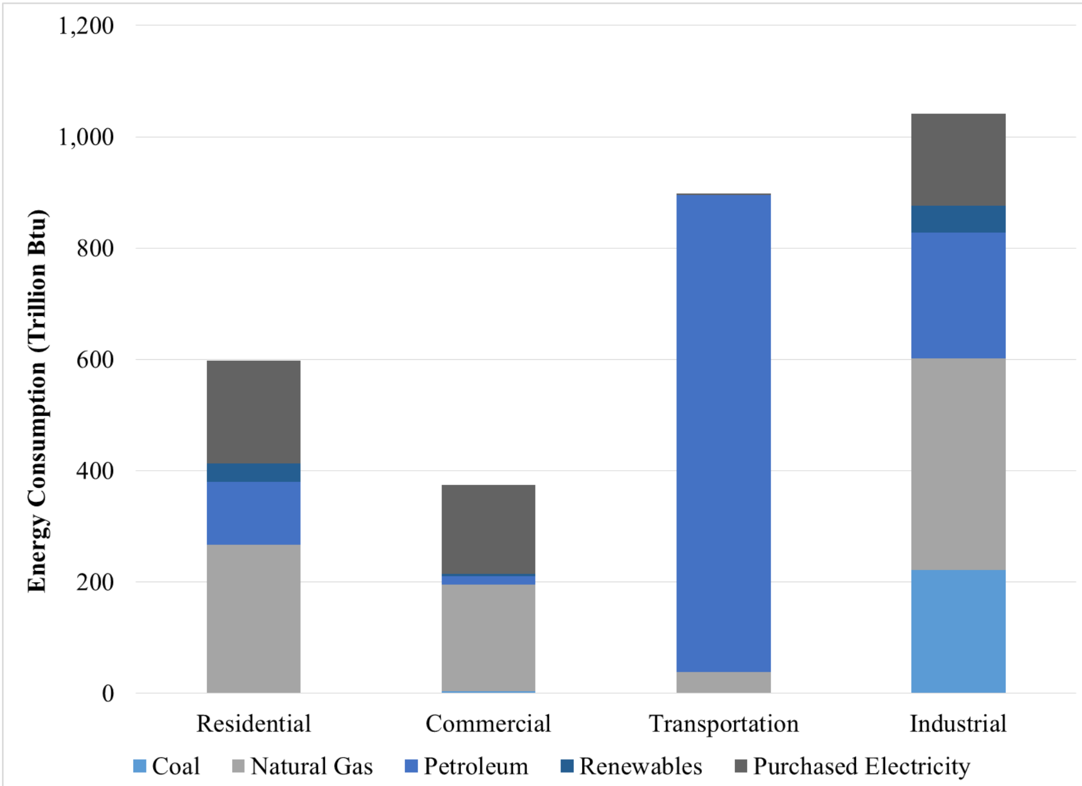
In 2014, the other manufacturing sub-sector contributed the greatest to the manufacturing sector GDP with a share of about 47% followed by the chemicals sector with a share of 20% and fabricated metal products contributing around 9% to the total manufacturing sector GDP.[54]

Figure 34: Share of Gross Domestic Product for Pennsylvania by Manufacturing Sub-Sector, 2014



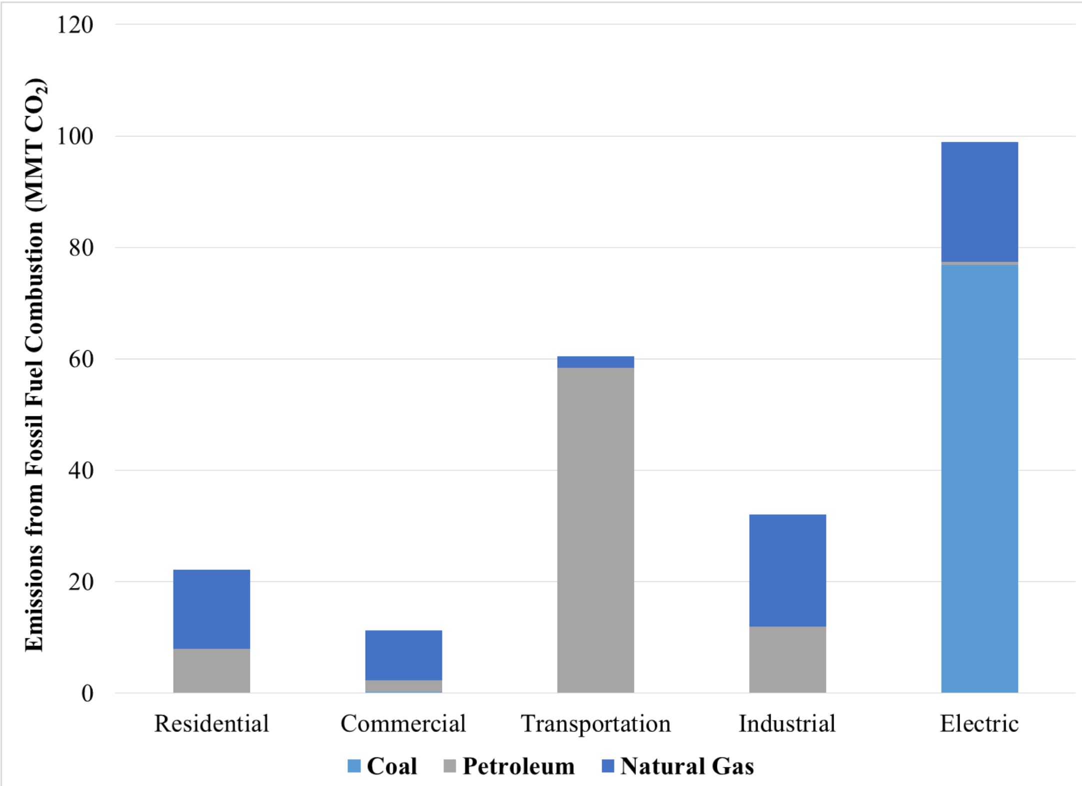
The transportation and industrial sectors consume the largest amount of energy in Pennsylvania. The following chart presents energy consumption by fuel for the four broad sub-sectors for 2014. Across the residential, commercial, and industrial sectors, natural gas was the dominant fuel source comprising about 45%, 51%, and 36% of the total energy consumption, respectively, in the three sectors while the energy consumption mix in transportation sector was comprised almost entirely of petroleum products.[55] In 2014, Pennsylvania's electricity generation mix was comprised largely of coal and nuclear each contributing to about 35% of the total net electricity generation while natural gas contributed to about 24% of the total generation.[55] The energy intensity of Pennsylvania's economy is quite similar to that of the U.S. as a whole. Pennsylvania's economy-wide energy intensity in 2014 is estimated to be 5,800 Btu/$ of GDP in comparison to the U.S. energy intensity of 5,700 Btu/$ of GDP[55] only a 2% difference.

Figure 35: Mix of Energy Consumed by Fuel for Pennsylvania, 2014



Combustion of natural gas is the pre-dominant source of emissions in the residential, commercial, and industrial sector with the share of emissions from natural gas combustion in these three sectors amounting to 64%, 79%, and 63%, respectively.[55] Emissions from the electric sector come predominantly from the use of coal (about 78%); while almost all emissions from the transportation sector come from the use of petroleum products.[55] The economy-wide carbon intensity of the state in 2014 was 0.36 TCO_2/'000$ of GDP in comparison to the U.S. wide energy intensity of 0.31 TCO_2/'000$ of GDP making it about 16% more carbon intensive than the U.S. as a whole.[55] . Pennsylvania industrial energy consumption per dollar of output is on par with the national average, but its industries are relatively more carbon intensive than the U.S. industry average.

Figure 36: Emissions by Fuel Mix for Pennsylvania, 2014



2. State Level Impacts

Pennsylvania's overall economy is negatively impacted from higher energy costs leading to lower overall economic activity. Compared to the U.S. GDP loss of 1% in 2025, Pennsylvania GDP loss in 2025 is about 1.8%. The large loss is due to the fact that the state is much more carbon intensive than the nation as a whole. Pennsylvania's 2025 GDP loss amounts to a loss of about $15 billion. In the medium term the losses could increase to about $22 billion; while in the long run the economy could shrink by about 8% equivalent to a loss of $91 billion as seen in the table below.

Table 48: Gross Domestic Product for Pennsylvania

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Difference (2015B$)	-16	-22	-91
Percentage Change (%)	-2%	-2%	-8%

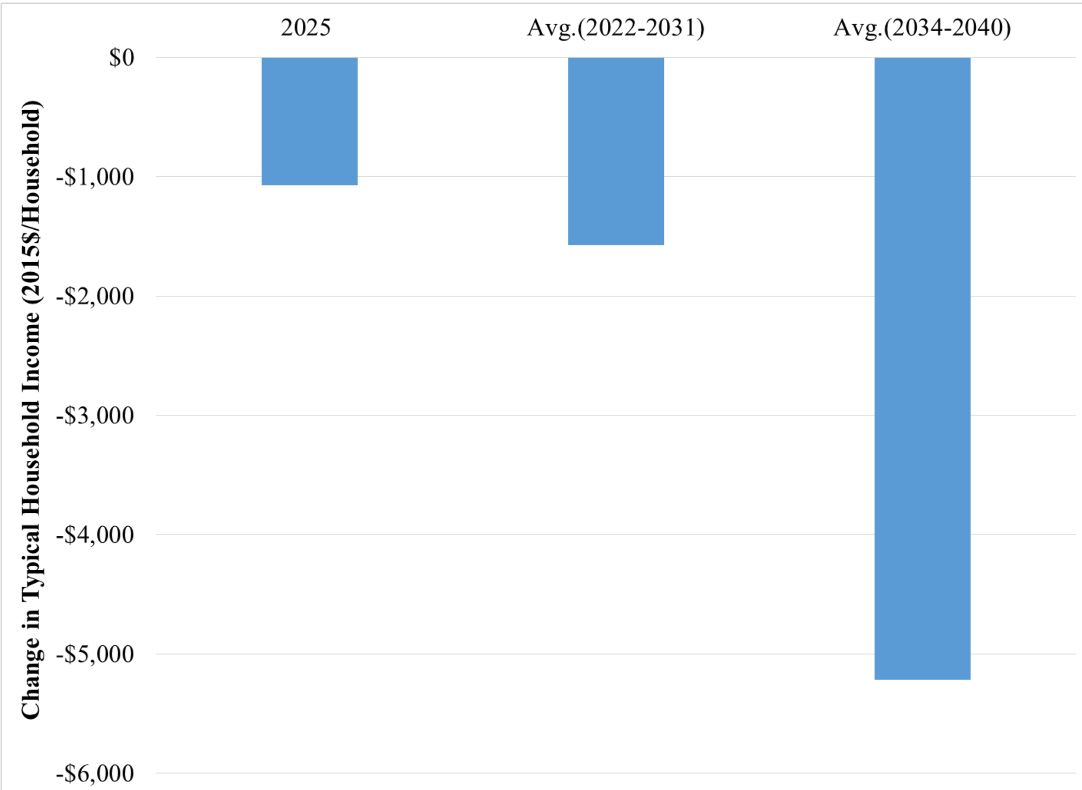
In 2025, the output from the chemicals and fabricated metal sub-sector are projected to decline by about 1% and 2%, respectively, relative to the baseline output. Other energy intensive sub-sectors, such as cement and iron and steel are impacted to a greater extent with output from these sectors forecasted to decline by 15% and 16%, respectively, relative to baseline output. The lower demand for fossil fuels results in significant impacts on the natural gas and coal sectors. Output from the natural gas and coal sub-sectors decreases by 19% and 22%, respectively, from the baseline in 2025. Average annual impacts for the four topic sectors relative to the baseline between 2022-2031 and 2034-2040 when the stringency of the policy increases significantly are shown in Table 49.

Table 49: Topic Sectoral Output for Pennsylvania (Percentage Change from Baseline)

	2025	**2040**	**Avg.(2022-2031)**	**Avg.(2034-2040)**
Key Sectors				
ONM	-5%	-14%	-5%	-11%
FAB	-2%	-11%	-3%	-8%
OEM	-10%	-25%	-10%	-20%
Topic Sectors				
PAP	-7%	-13%	-7%	-12%
CMT	-15%	-20%	-15%	-18%
CHM	-1%	-6%	-1%	-5%
I_S	-16%	-31%	-15%	-26%

Lower demand for goods and services produced in Pennsylvania signifies that the manufacturing sector as well as other sectors employs fewer people leading to lower income for the labor force. Lower wage income translates directly to a loss in household income. A typical household in Missouri in 2025 could see its household income decline by about $1,000 relative to current levels. Between 2022 and 2031, the impacts are about $1,500 per household; while in the long run impacts are disproportionately larger as seen in Figure 37.

Figure 37: Change in Consumption per Household for Pennsylvania ($/Household)



Lower overall manufacturing output also impacts employment in Pennsylvania's manufacturing sector. It is projected to face 26,000 full-time equivalent jobs losses in 2025 relative to the baseline; while the economy as a whole could lose about 140,000 full-time equivalent jobs. Employment impacts could more than double in the medium term (between 2022 -2031) and increase significantly in the long run as seen in Table 50.

Table 50: Employment Impacts for Pennsylvania (Change from Baseline in Thousands of Job Equivalents)

	2025	Avg.(2022-2031)	Avg.(2034-2040)
Total	-140	-230	-910
MAN-IND	-26	-34	-110

VII. CONCLUSION

For this study we use NERA's N_{ew}ERA model to assess macroeconomic impacts on the U.S. economy from potential future policies to regulate greenhouse gas emissions. The N_{ew}ERA integrated model, which consists of a top-down general equilibrium macroeconomic model of the U.S. economy and a detailed dispatch model of the North American electricity system, captures interactions between all parts of the economy and transmits the effects of sectoral responses of the policies throughout the economy. The model represents five U.S. regions (four manufacturing based states and the rest of the U.S.) and captures manufacturing at a subsector level. The model includes 16 industrial sub-sectors, of which five are energy-related sectors and 11 are non-energy sectors. Of the 11 non-energy sectors reflected in the model, eight are manufacturing sectors and the other three represent the non-manufacturing subsectors. The model is run from 2016 through 2040 in three-year time steps.

We develop a slate of scenarios to bracket the potential economic impacts. We simulate six scenarios. The core scenarios are constructed so that the U.S. as a whole meets its U.S. NDC emission target. We also design a scenario to capture the effect of reducing emissions from feasible direct measures and another that includes a nationwide cap and trade program with regulatory programs to meet the U.S. NDC target. There is a great deal of uncertainty in the availability of LULUCF offset to count against emissions target. To capture this uncertainty we run the core scenarios using two different estimates of sequestration.

This study only models CO_2 emissions from fossil fuel combustion. However, in designing the emissions cap we assume that sequestration and reduction in other greenhouse gases comes at zero cost. As a result our impacts represent a lower bound for range of the impacts if costs for reducing non-CO_2 gases were considered. The impacts reported ignore potential benefits from climate change. Below are some key insights from the study:

- Regulatory measures are an inefficient way to achieve climate goals. In every case, scenarios that allow more flexibility achieve the same or greater emission reductions at lower cost;

- An industry's vulnerability under a U.S. GHG emissions abatement policy would be determined by its energy and carbon intensity as well as its level of specialization. That is, the most carbon and intensive industrial sectors that are also commodity based would likely experience the greatest losses in production as they would experience the greatest cost increases from using energy and be the most susceptible to international competition;

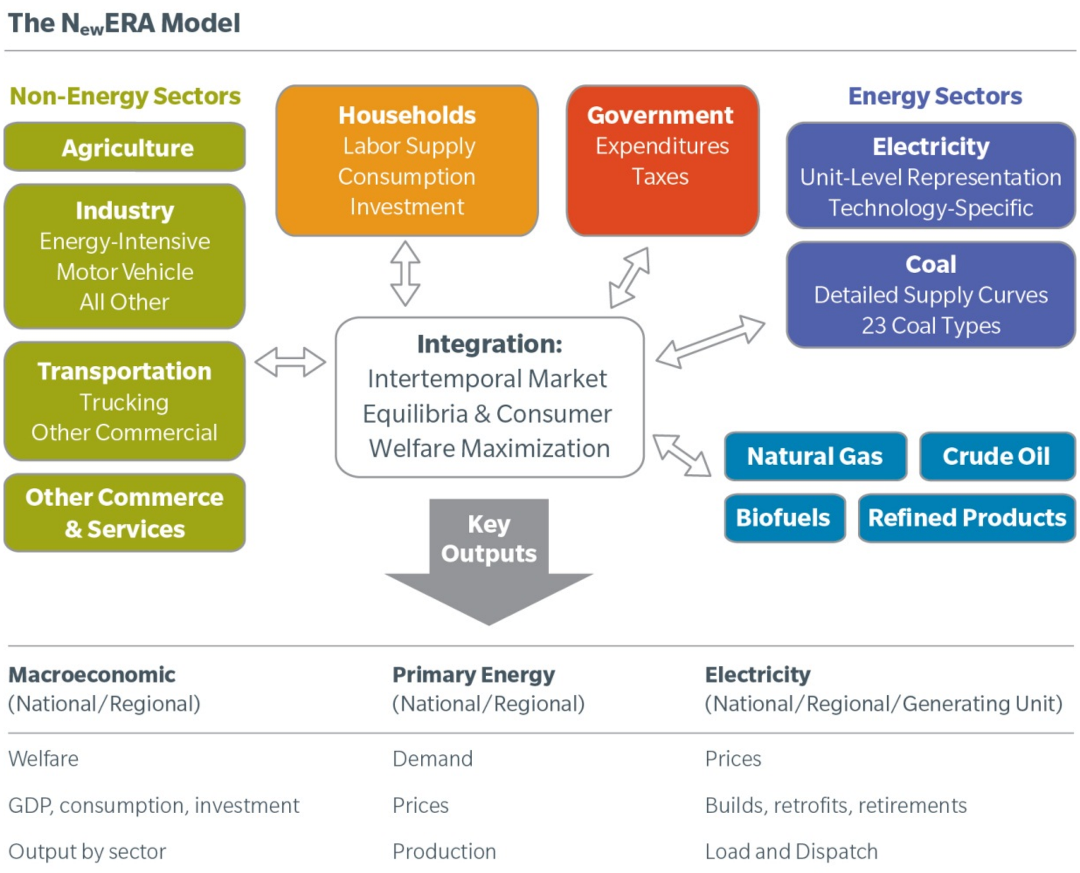
- The ability to use offsets as compliance mechanisms can significantly reduce costs; equivalently the more sequestration and reductions in other GHGs are available to achieve national targets for all GHGs the less the burden will be from regulation of CO_2 emissions;

- In the next 10 years, regulation of the industrial sector to achieve NDC goals would be responsible for most of the overall impact on the economy;
- Without appearance of new technology yet to be developed, the costs of meeting recently announced deep decarbonization goals will be approximately 9 times as costly as meeting the 2025 NDC targets;
- States with a large share of energy-intensive manufacturing will be particularly severely damaged by climate regulations;
- Gains from adding a cap and trade program would be larger with pre-emption than if regulatory measures continue to be applied; and
- Generally, stopping with the CPP for the electric sector leaves the cost of additional reductions in electricity generation far below the costs other sectors must incur to achieve their targets. It would be much less costly to allow other sectors to purchase credits from the electric sector for emission reductions than to meet NDC targets on their own.

APPENDIX A. DESCRIPTION OF THE N$_{EW}$ERA MODEL

NERA's N$_{ew}$ERA modeling system is an integrated energy and economic model that includes a bottom-up representation of the electricity sector with unit-level details that affect costs of compliance. N$_{ew}$ERA integrates the electricity sector model with a macroeconomic model that includes all other sectors of the economy (except for the electricity production) using a top-down representation. Figure 38 provides a simplified representation of the key elements of the N$_{ew}$ERA modeling system.

Figure 38: N$_{ew}$ERA Modeling System Representation



The following discussions discuss the overarching N$_{ew}$ERA macroeconomic model, and the electric sector module.

A. NewERA Macroeconomic Model

1. Overview of the N_{ew}ERA Macroeconomic Model

The N_{ew}ERA macro model is a forward-looking, dynamic, computable general equilibrium model of the United States. The model simulates all economic interactions in the U.S. economy, including those among industry, households, and the government. The economic interactions are based on the IMPLAN ©[60] 2008 database that is updated for 2015 benchmark year, which includes regional detail on economic interactions among 440 different economic sectors. The macroeconomic and energy forecasts that are used to project the benchmark year going forward are calibrated to the most recent *Annual Energy Outlook (AEO) 2016* without the CPP produced by the Energy Information Administration (EIA). Because the model is calibrated to an internally-consistent energy forecast, the use of the model is particularly well-suited to analyze economic and energy policies and environmental regulations.

2. Model Data (IMPLAN and EIA)

The economic data is taken from the IMPLAN 2008 database, which includes balanced Social Accounting Matrices (SAM) for all states in 2008. These inter-industry matrices provide a snapshot of the economy. Since the IMPLAN database contains only economic values, we benchmark energy supply, demand, trade, and prices to EIA historical statistics to capture the physical energy flows. We integrate the EIA energy quantities and prices and update the SAM to be consistent with 2015 aggregate macroeconomic metrics, such as aggregate consumption, investment, and GDP. The resulting database is a balanced energy-economy dataset that reflects 2015.

Future economic growth is calibrated to macroeconomic GDP, energy supply, energy demand, and energy price forecasts from the EIA *AEO 2016*. Labor productivity, labor growth, and population forecasts from the U.S. Census Bureau are used to project labor endowments along the baseline and ultimately employment by industry.

3. Brief Discussion of Model Structure

The theoretical construct behind the N_{ew}ERA model is based on the circular flow of goods, services, and payments in the economy (every economic transaction has a buyer and a seller whereby goods/service go from a seller to a buyer and payment goes from the buyer to the seller). As shown in Figure 39 the model includes households, businesses, government, financial

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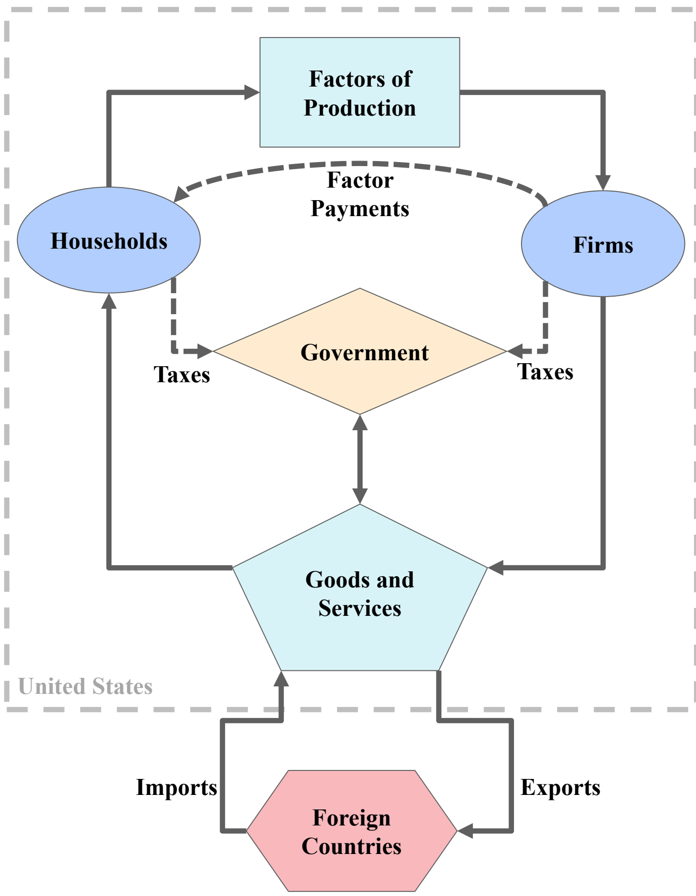
[60] IMPLAN produces unique set of national structural matrices. The structural matrices form the basis for the inter-industry flows which we use to characterize the production, household, and government transactions. See www.implan.com.

markets, and the rest of the world economy as they interact economically in the global economy. Households provide labor and capital to businesses, taxes to the government, and savings to financial markets, while also consuming goods and services and receiving government subsidies. Businesses produce goods and services, pay taxes to the government and use labor and capital. Businesses are both consumers and producers of capital for investment in the rest of the economy. Within the circular flow, equilibrium is found whereby goods and services consumed is equal to those produced and investments are optimized for the long term. Thus, supply is equal to demand in all markets.

The model assumes a perfect foresight, zero profit condition in production of goods and services, no changes in monetary policy, and full employment within the U.S. economy.

Figure 39: Circular Flow of Income



4. Production and Consumption Characterization

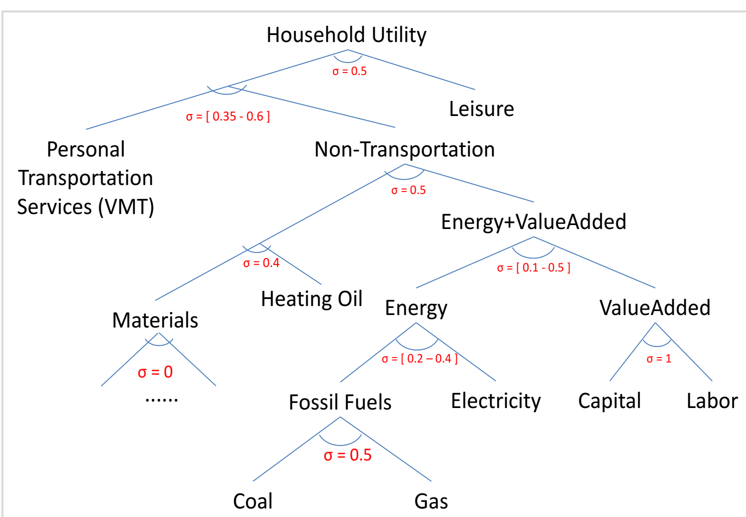
Behavior of households, industries, investment, and government is characterized by nested constant elasticity of substitution (CES) production or utility functions. Under such a CES structure, inputs substitute against each other in a nested form. The ease of substitutability is determined by the value of the elasticity of substitution between the inputs. The greater is the value of the substitution elasticity between the inputs; the greater is the possibility of tradeoffs.

The CES nesting structure defines how inputs to a production activity compete with each other. In the generic production structure, intermediate inputs are aggregated in fixed proportion with a composite of energy and value-added inputs. The energy input aggregates fossil and non-fossil energy sources, and the value-added input combine capital and labor. Sectors with distinctive production characteristics are represented with structures different from the generic form. For bulk chemicals sector we assume natural gas and oil feedstock are in fixed proportion to output. Similarly for the iron and steel we assume a share of met coal as feedstock which is consumed in fixed proportion to the output. The characterization of nonrenewable resource supply adds a fixed resource that is calibrated to a declining resource base over time, so that it implies decreasing returns to scale. This also implies rising marginal costs of production over time for exhaustible resources. The detailed nesting structure of the households and production sectors, with assumed elasticity of substitution parameters, is shown in figures below.

5. Households

Consumers are represented by a single representative household. The representative household derives utility from both consumption of goods and services, transportation services, and leisure. The utility is represented by a nested CES utility function. The elasticity of substitution parameters between goods are shown in Figure 40.

Figure 40: N$_{ew}$ERA Household Representation



6. Other Sectors

The trucking and commercial transportation sector production structure is shown in

Figure 41. The trucking sector uses diesel as transportation fuel. This sector has limited ability to substitute into other fossil fuels. The other industrial sectors (excluding bulk chemicals, iron and steel, paper and allied products, and construction sector) and the services sector production structure with assumed elasticity of substitution is shown in Figure 42.

In the model, each region has a single representative refinery sector that has a production structure similar to other industrial sectors. We assume that crude oil is traded in the world market as a homogenous good that responds to a single world price. This means that the domestic price of crude oil is set by the world price.

For this study, we employ some specialized production structure for the bulk chemicals, iron and steel, wood products, and the construction sector. The production structure for bulk chemicals and iron and steel allows for modeling of energy feedstock inputs. We estimate, based on AEO 2016, natural gas and oil feedstock inputs into the bulk chemicals sector and met coal feedstock input into the iron and steel sector. We assume that these feedstocks are consumed in fixed proportion to the sectoral output. For the paper and allied product production, we assume bio-energy (proxy by agriculture commodity input) to be available as energy inputs in the energy nest with limited substitutability against the fossil fuels. The bio-energy inputs are calibrated in the baseline based on the AEO 2016. For the construction sector, we assume a separate building material nest that allows substitution between three building material inputs: wood products, cement, and fabricated metals.

Figure 41: NewERA Trucking and Commercial Transportation Sector Representation

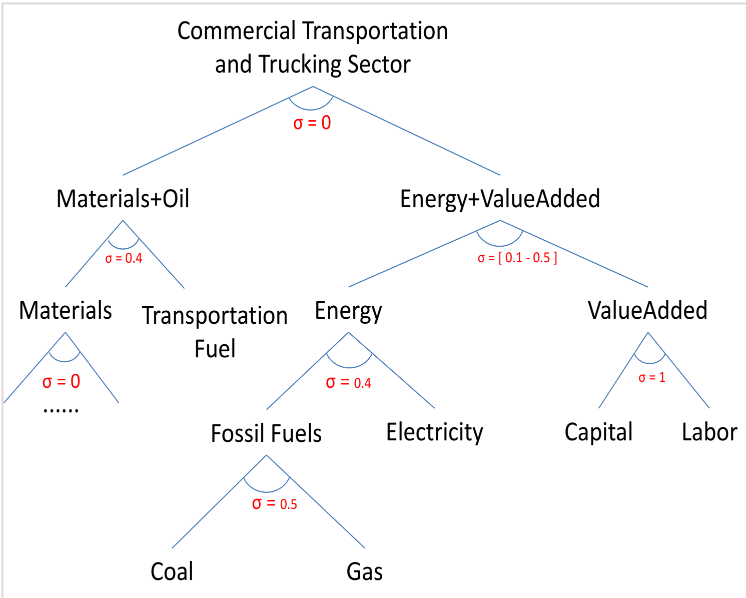


Figure 42: NewERA Other Production Sector Representation

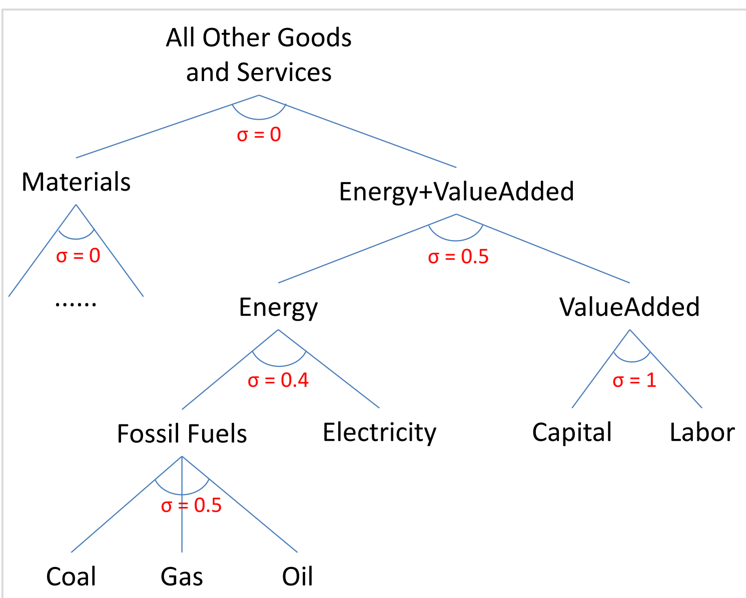
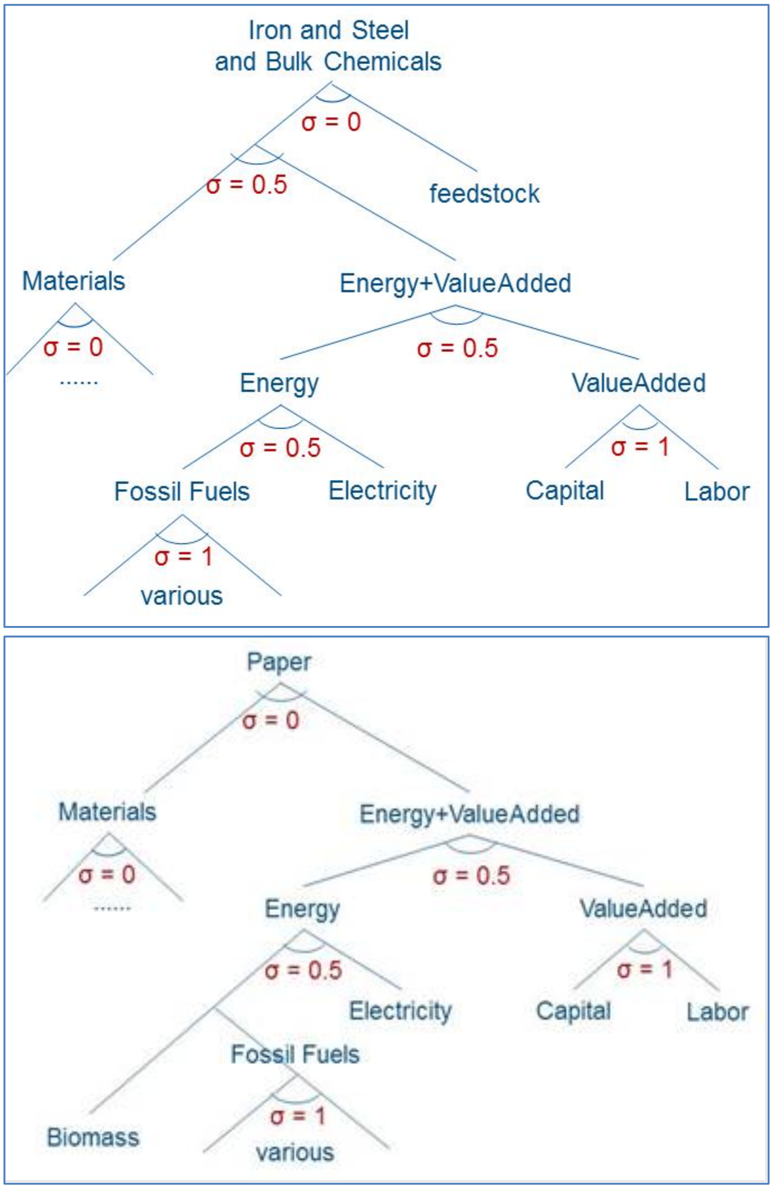
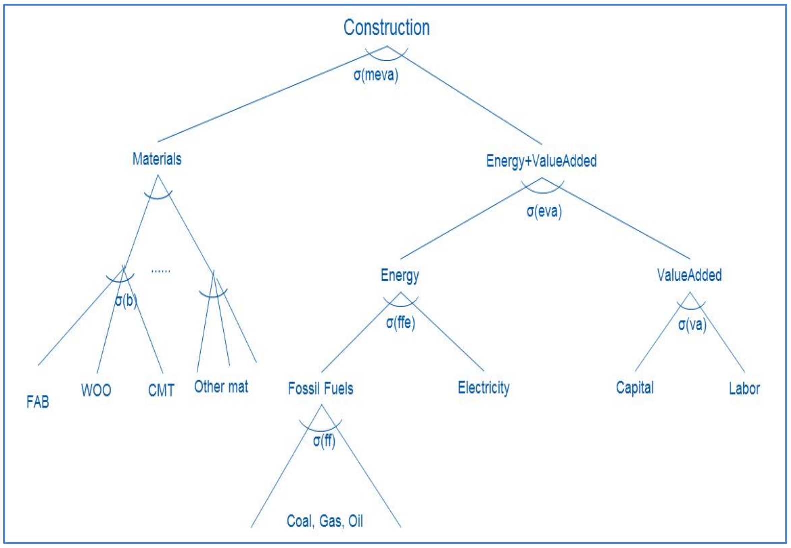


Figure 43: Specialized NewERA Production Sector for Iron and Steel, Bulk Chemicals, Paper, and Construction Sectors



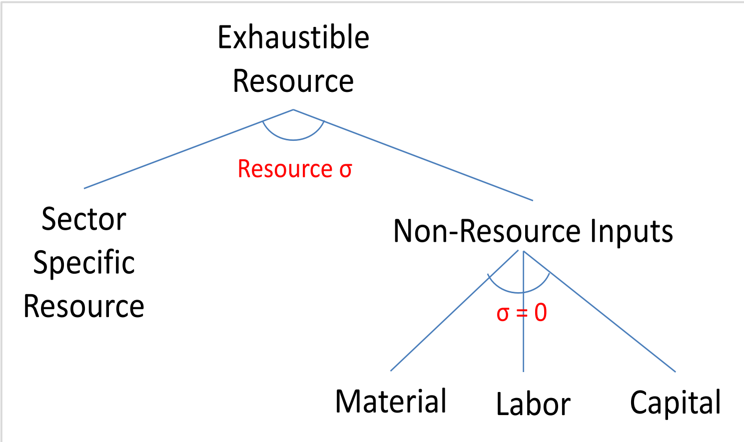


7. Exhaustible Resource Sector

The simplest characterization of non-renewable resource supply adds a fixed resource that is calibrated to decline over time, so that the decreasing returns to scale implied for the non-resource inputs lead to rising marginal costs of production over time. The top level elasticity of substitution parameter is calibrated to be consistent with resource supply elasticity. We assume the natural gas resource supply elasticity varies with the U.S. resource supply scenario.

Production from the crude oil and natural gas sectors is either supplied to the domestic market or exported. Crude oil that is supplied to the domestic market is comingled with imported crude oil and is supplied to the domestic refinery. Natural gas also follows a similar supply chain.

Figure 44: N_{ew}ERA Resource Sector Representation



8. Trade Structure

All goods and services except crude oil are treated as Armington goods, which assume that domestic and foreign goods are differentiated and thus are imperfect substitutes. The level of imports depends upon the elasticity of substitution between the imported and domestic goods. The Armington elasticity among imported goods is assumed to be twice as large as the elasticity between domestic and aggregate imported goods, characterizing greater substitutability among imported goods.

We balance the international trade account in the N_{ew}ERA model by constraining changes in the current account deficit over the model horizon. The condition is that the net present value of the foreign indebtedness over the model horizon remains at the benchmark year level. This prevents distortions in economic effects that would result from perpetual increases in borrowing, but does not overly constrain the model by requiring current account balances in each year.

9. Investment Dynamics

Periods in the model are linked by capital and investment dynamics. Capital turnover in the model is represented by the standard process that capital at time $t + 1$ equals capital at time t plus investment at time t minus depreciation. The model optimizes consumption and savings decisions in each period, taking account of changes in the economy over the entire model horizon with perfect foresight. The consumers forego consumption to save for current and future investment.

10. Labor Representation

The underlying assumptions of labor growth and initial capital stock drive the economy over time in the model. The model assumes full employment in the labor market. This assumption means total labor demand in a policy scenario would be the same as the baseline labor projection. The baseline labor projections are based on population growth and labor productivity forecasts over time. Hence, the labor projection can be thought to be a forecast of efficient labor units. The model assumes that labor is fungible across sectors. That is, labor can move freely out of one production sector into another without any adjustment costs or loss of productivity. Like labor, each region is endowed with its own capital stock and can move across sectors without any adjustment cost.

11. Tax Representation

The N_{ew}ERA macroeconomic model includes a simple tax representation. The model accounts for the following categories of taxes: corporate income tax rate, personal income tax rate on capital and labor, payroll taxes collected for Social Security under the Federal Insurance Contributions Act (FICA) and for Medicare hospital insurance. The tax rates are based on the National Bureau of Economic Research (NBER) tax simulation model, TAXSIM[61] and Tax Foundation[62]. Other indirect taxes such as excise and sales are included in the output values and not explicitly modeled.

B. Electric Sector Module

The electric sector module that is part of the NewERA modeling system is a bottom-up model of the electric and coal sectors. Therefore, this module represents the supply and demand for electricity and coal. Consistent with the macroeconomic model described in the prior section, the electric sector module is fully dynamic and includes perfect foresight (under the assumption that future conditions are known). Thus, all decisions made within the module are based on minimizing the present value of costs over the entire time horizon of the module run while meeting all specified constraints, including demand, peak demand, emissions limits, transmission limits, renewable portfolio standard (RPS) regulations, fuel availability and costs, and new build limits. This aspect of the module set-up (i.e. minimizing the present value of cost to meet demand and satisfy a given set of physical constraints) is intended to mimic the general approach that electric sector investors use to inform their decisions. In determining the least-cost method of satisfying all these constraints, the module endogenously decides:

[61] For details on the TAXSIM model please see: http://users.nber.org/~taxsim/

[62] See http://taxfoundation.org/ for more information.

- What investments to undertake (*e.g.*, addition of retrofits, build new capacity, repower unit, add fuel switching capacity, or retire units);

- How to operate each modeled unit (*e.g.*, when and how much to operate units, which fuels to burn) and what is the optimal generation mix; and

- How demand will respond to changes in electricity prices.

The module thus assesses the trade-offs between the amount of demand-side management (DSM) to undertake and the level of electricity usage. Each unit in the module has certain actions that it can undertake. For example, all units can choose to retire before the end of their natural life, and many coal units can retrofit with pollution control equipment. Any publicly-announced actions, such as planned retirements, planned retrofits (for existing units), or new units under construction can be specified exogenously as a module input.

The operation of each unit in a given year depends on the policies in place (*e.g.*, unit-level standards), electricity demand, and operating costs, especially energy prices. The module accounts for all these conditions in deciding when and how much to operate each unit. The module also considers system-wide operational issues such as environmental regulations, limits on the share of generation from intermittent resources, transmission limits, and operational reserve margin requirements in addition to annual reserve margin constraints.

Throughout the time horizon of the module run, in order to meet any increase in electricity demand, increase in reserve margin requirements, and/or replacement of retired generation, the electric sector must build new generating capacity. Future environmental regulations, system constraints (e.g., reserve margin requirements), capital costs, and forecasted energy prices influence which technologies to build and where. For example, if a national RPS policy is to take effect, some share of new generating capacity will need to come from renewable power. On the other hand, if there is a policy to address emissions, it might elicit a response to retrofit existing fossil-fired units with pollution control technology or enhance existing coal-fired units to burn different types of coals, biomass, or natural gas. All of these policies may also affect retirement decisions. The NewERA electric sector module endogenously captures all of these different types of decisions.

NewERA divides the U.S. into thirty four power pools, or regional networks of the grid between which load is balanced. The module also includes five Canadian electricity regions to represent the extensive trade in electricity between Canada and the U.S.

The electric sector module is fully flexible in the time horizon and the years for which it solves. When used in an integrated manner with the macroeconomic model described in the prior section, as is done in this analysis, the solution years are synchronized.

C. Integrated N_{ew}ERA Model

The coupling of the macroeconomic model with the electric sector model characterizes the N_{ew}ERA modeling framework. It fully integrates the macroeconomic model and the electric sector model so that the final solution is a consistent equilibrium for both models, and thus for the entire U.S. economy.

To analyze any policy scenario, the system first solves for a consistent baseline solution, and then it iterates between the two models – prices being sent from the macroeconomic model to the electric sector model and quantities being sent from the electric sector model to the macroeconomic model – until the prices and quantities converge in the two models.

D. Model Scope: Regions, Sectoral Aggregation, and Time Horizon

1. Model regions

The U.S. economy is represented by five regions: Missouri, Michigan, Ohio, Pennsylvania, and rest of the U.S.

2. Sectoral Aggregation

The model has the flexibility to represent sectors at different levels of aggregation. For this specific study, the N_{ew}ERA model includes 19 sectors: five energy sectors (coal, natural gas, crude oil, electricity, refined petroleum products) and fourteen non-energy sectors (services, bulk chemical, cement, fabricated metal products, motor vehicle manufacturing, wood products, iron and steel, other energy-intensive manufacturing, other non-energy-intensive manufacturing, pulp and allied products, agriculture, commercial transportation, and trucking.

Other sectors in the model are Residential, Commercial, and the Transportation sectors. Transportation sector in the model is represented by two types of transportation services: Commercial transportation which includes air, rail, and water borne transportation services and the Trucking sector. The detailed sectors in the model are classified into four broad sectors.

3. Time Horizon

The model was run from 2016 through 2040 in three-year time steps.

APPENDIX B. PROJECTED BASELINE EMISSIONS BY INDUSTRIAL SUB-SECTOR

Table 51: Projected CO_2 Emissions from Fossil Fuel Combustion by Industrial Sector and Fuel Type ($MMTCO_2$) [63]

	2016	2019	2022	2025	2028	2031	2034	2037	2040
AGR									
Total	**67.3**	**69.4**	**69.6**	**70.2**	**69.4**	**69.1**	**68.6**	**68.2**	**68.1**
Petroleum	63.2	65.4	65.8	66.4	65.6	65.3	64.9	64.5	64.3
Natural Gas	4.1	4.0	3.8	3.8	3.7	3.7	3.8	3.8	3.8
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CNS									
Total	**35.0**	**44.2**	**47.7**	**48.8**	**49.0**	**50.1**	**50.5**	**51.9**	**52.9**
Petroleum	34.6	43.8	47.2	48.4	48.5	49.6	50.1	51.5	52.6
Natural Gas	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MIN									
Total	**68.8**	**73.3**	**76.5**	**79.6**	**81.0**	**83.0**	**85.0**	**87.2**	**89.2**
Petroleum	16.9	18.7	19.9	20.7	21.1	21.3	21.6	21.9	22.2
Natural Gas	51.0	53.6	55.6	57.8	58.9	60.6	62.4	64.3	65.9
Coal	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1
OIL									
Total	**241.8**	**240.4**	**240.4**	**241.1**	**240.6**	**242.2**	**244.8**	**248.6**	**253.9**

[63] The emissions forecast for the Cement is based on the feedback from the Portland Cement Association. Similarly, Paper and Allied Products sector's emissions projection is based communication from the American Forest and Paper Association.

Petroleum	153.8	153.8	156.1	158.4	157.8	158.4	158.9	159.5	162.3
Natural Gas	84.9	83.5	81.3	79.7	79.8	80.8	82.9	86.1	88.7
Coal	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.9
PAP									
Total	**42.8**	**39.7**	**38.9**	**41.4**	**43.4**	**43.0**	**42.6**	**42.3**	**43.0**
Petroleum	1.8	1.7	1.6	1.8	1.8	1.8	1.8	1.8	1.8
Natural Gas	21.8	20.2	19.8	21.1	22.1	21.9	21.7	21.5	21.9
Coal	19.2	17.8	17.5	18.5	19.5	19.3	19.1	19.0	19.3
CHM									
Total	**127.1**	**140.4**	**148.6**	**154.5**	**157.3**	**159.8**	**162.5**	**165.1**	**167.5**
Petroleum	13.9	14.7	15.4	16.5	16.1	15.6	15.0	14.6	14.3
Natural Gas	99.0	111.4	118.7	123.3	126.5	129.6	133.1	136.3	139.0
Coal	14.2	14.3	14.5	14.7	14.7	14.6	14.4	14.3	14.2
CMT									
Total	**26.3**	**28.7**	**30.6**	**31.8**	**32.1**	**32.5**	**32.7**	**32.9**	**33.0**
Petroleum	2.5	4.5	5.5	6.3	7.1	7.8	8.4	8.7	9.0
Natural Gas	0.8	0.9	0.9	0.9	0.9	1.0	1.0	1.1	1.1
Coal	23.0	23.3	24.3	24.6	24.2	23.7	23.4	23.2	22.9
I_S									
Total	**83.4**	**77.3**	**82.0**	**90.2**	**90.1**	**88.8**	**86.6**	**85.1**	**84.6**
Petroleum	5.7	6.5	8.2	10.0	10.8	11.1	11.5	12.0	12.8
Natural Gas	30.6	28.4	31.3	34.2	33.9	33.4	33.5	33.8	34.8
Coal	47.1	42.4	42.5	45.9	45.5	44.2	41.6	39.2	37.0
WOO									
Total	**5.2**	**5.4**	**5.4**	**5.6**	**5.5**	**5.8**	**5.9**	**6.1**	**6.2**

Petroleum	2.0	2.0	2.0	2.0	1.9	1.9	1.8	1.8	1.8
Natural Gas	3.0	3.2	3.3	3.4	3.5	3.7	3.9	4.2	4.2
Coal	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
FAB									
Total	**14.5**	**13.4**	**13.6**	**13.4**	**13.1**	**13.2**	**13.6**	**14.0**	**14.9**
Petroleum	0.9	1.0	1.0	1.0	0.9	0.9	0.9	0.9	1.0
Natural Gas	13.5	12.5	12.6	12.5	12.2	12.3	12.7	13.1	13.9
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M_V									
Total	**15.59**	**16.91**	**17.03**	**17.76**	**18.48**	**19.19**	**20.11**	**20.79**	**21.59**
Petroleum	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Natural Gas	14.3	15.6	15.7	16.4	17.1	17.8	18.8	19.5	20.3
Coal	0.5	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
OEM									
Total	**25.7**	**27.7**	**29.5**	**30.5**	**31.1**	**31.6**	**31.3**	**31.2**	**30.5**
Petroleum	5.4	7.4	8.4	8.9	9.2	9.2	9.1	9.1	8.8
Natural Gas	20.3	20.3	21.1	21.5	21.9	22.4	22.3	22.1	21.7
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ONM									
Total	**239.4**	**262.4**	**283.4**	**302.4**	**313.2**	**324.7**	**339.3**	**353.6**	**368.8**
Petroleum	22.5	24.5	25.3	28.1	27.4	26.7	26.5	26.4	26.7
Natural Gas	169.7	185.7	203.0	215.7	225.3	235.7	248.2	260.3	272.5
Coal	47.2	52.2	55.1	58.5	60.5	62.4	64.7	66.9	69.6

APPENDIX C. TOPIC INDUSTRY BASELINE CO_2 AND ENERGY PROFILES

Cement

Combustion for heat generation during the cement manufacturing process and the calcination reactions that occur in the kiln are two primary sources of GHG emissions.[64] Emissions from the combustion of fossil fuels include CO_2, N_2O, and CH_4 from the cement kiln and other onsite combustion equipment. Of these the cement kiln leads to the highest level of energy related emissions and is typically fueled with coal. The other sources of CO_2 emissions include transportation equipment used in the mining and transport of raw and finished materials and fuels required for process operation.[65] Emissions from direct energy use can be reduced through fuel switching and efficiency measures. Potential candidates for alternative fuels for use in the cement industry include natural gas, biomass, and waste-derived fuels such as tires, sewage sludge, and municipal solid wastes. Efficiency improvements can reduce emissions by addressing the production process through measures such as switching from wet to dry kilns, adjustments in fan speed for greater efficiency and through technical and mechanical improvements such as preventative maintenance and more efficient motors. Emissions from the calcination process can be offset (not addressed) to a limited degree through the use of blended cements where limestone based clinker is replaced by other materials such as fly ash and blast furnace slag.

In the baseline, the carbon intensity of the cement sector from fossil fuel combustion is projected to decrease by about 20% relative to 2016 levels. This decline can primarily be attributed to a decrease in emissions from coal and gas use with the carbon intensity associated with these fuel sources projected to decline by about 37% and16%, respectively relative to 2016 levels. This decline is partially offset by an increase in emissions from petroleum use with its carbon intensity projected to more than double by 2040 as seen in Figure 45.

Figure 45: Trajectory of Baseline Carbon Intensity of Cement Manufacture by Fuel Source

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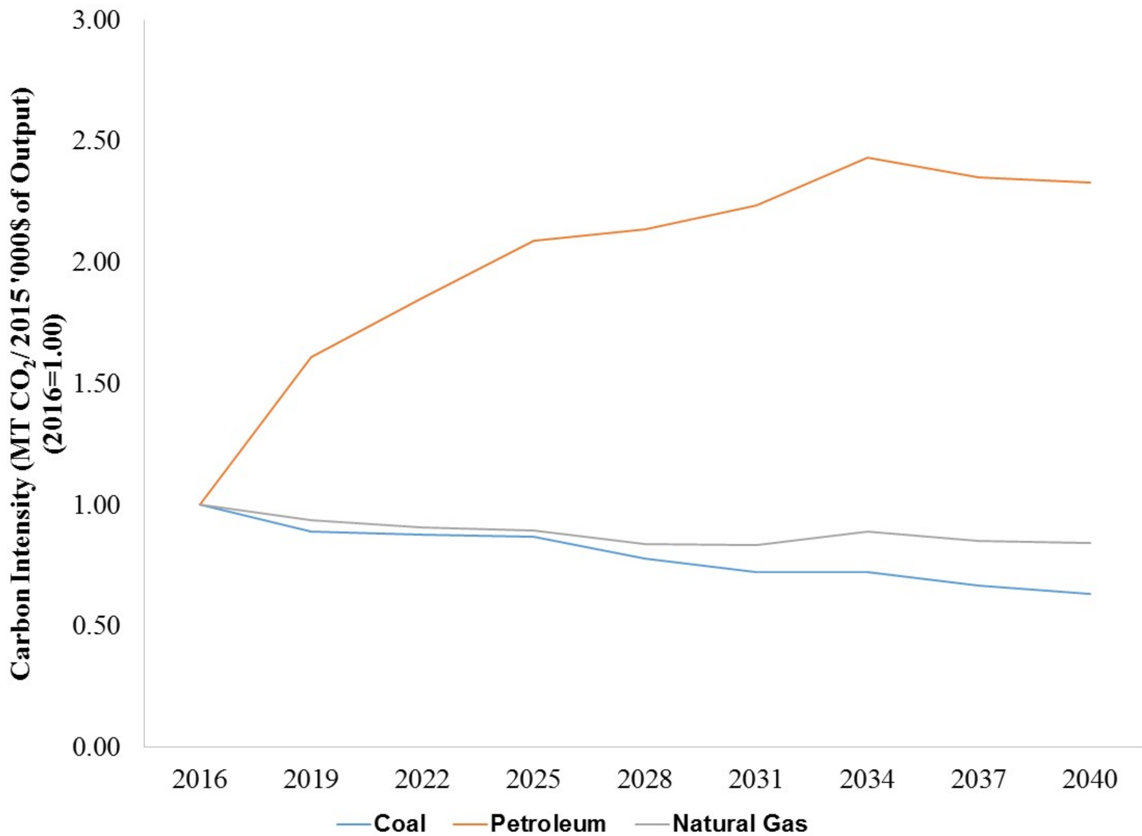
[64] Recent research supports that a significant proportion of the emissions associated with the production of cement are later offset by the carbonation process that occurs in cement materials used in building construction and infrastructure. Xi, et al., "Substantial global carbon uptake by cement carbonation," *Nature Geoscience* (Nov. 21, 2016).

[65] Emissions from the transport of raw and finished materials in cement manufacture are accounted for in petroleum use by the cement industry for purposes of modeling.



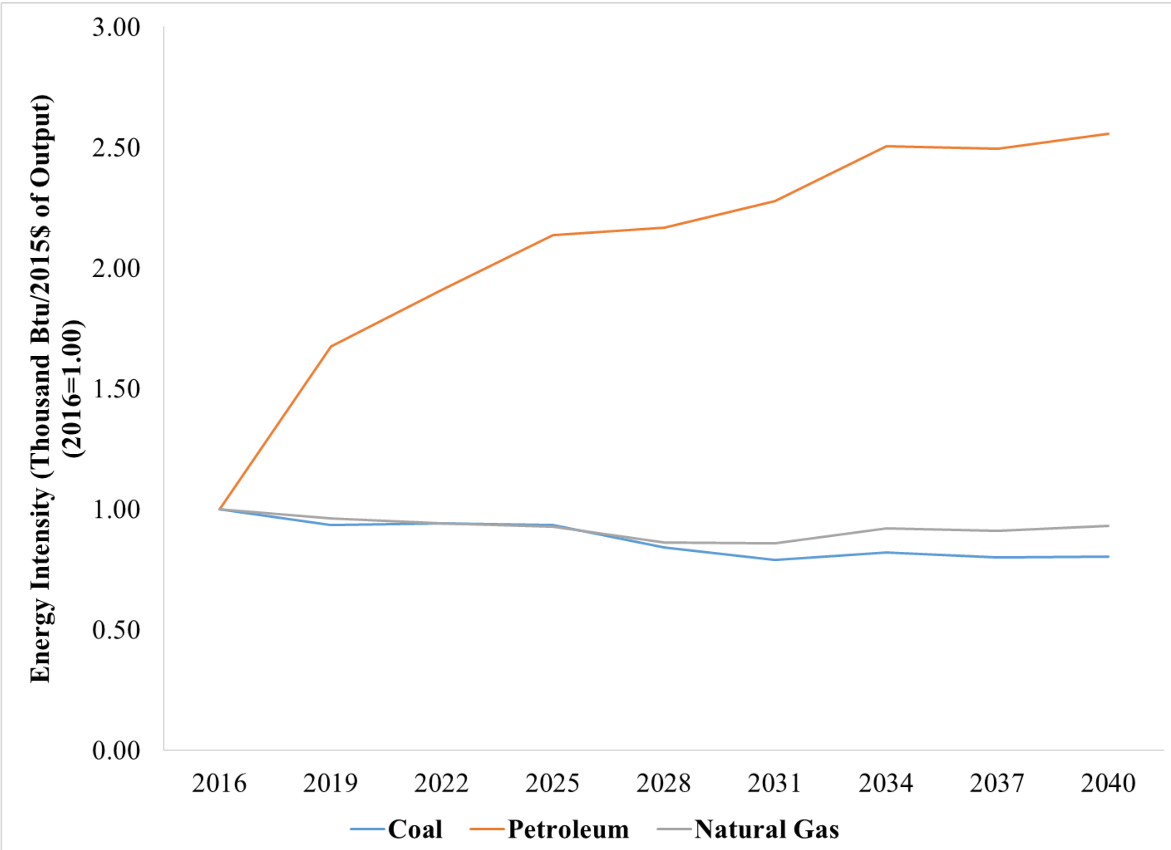
Although the cement industry's energy consumption is only about one-quarter of one-percent of total U.S. energy consumption, it was the most energy intensive of all manufacturing industries.[66] On average, the share of energy use for other energy intensive industries was roughly twice their share of gross output. Cement is also unique in its heavy reliance on carbon-intensive fossil fuels such as coal and petroleum coke. Over the long term, EIA projections forecast an increasing contribution from the cement industry to energy consumption as well as an increasing share of total gross output of goods and services.

In the model baseline, the energy intensity of the cement sector from fossil fuel combustion is projected to increase by about 13% by 2040 relative to 2016 levels. This increase can primarily be attributed to an increase in the energy use from petroleum products with its energy intensity forecasted to more than double by 2040. This decline is partially offset by an increase in

[66] The cement industry is the most energy intensive of all manufacturing industries, Today in Energy, U.S EIA, July 2013.Available: http://www.eia.gov/todayinenergy/detail.cfm?id=11911

emissions from coal and natural gas use which is projected to decline by 20% and 7% by 2040 respectively as seen in Figure 46.

Figure 46: Trajectory of Baseline Energy Intensity of Cement Manufacture by Fuel Source



Paper and Allied Products

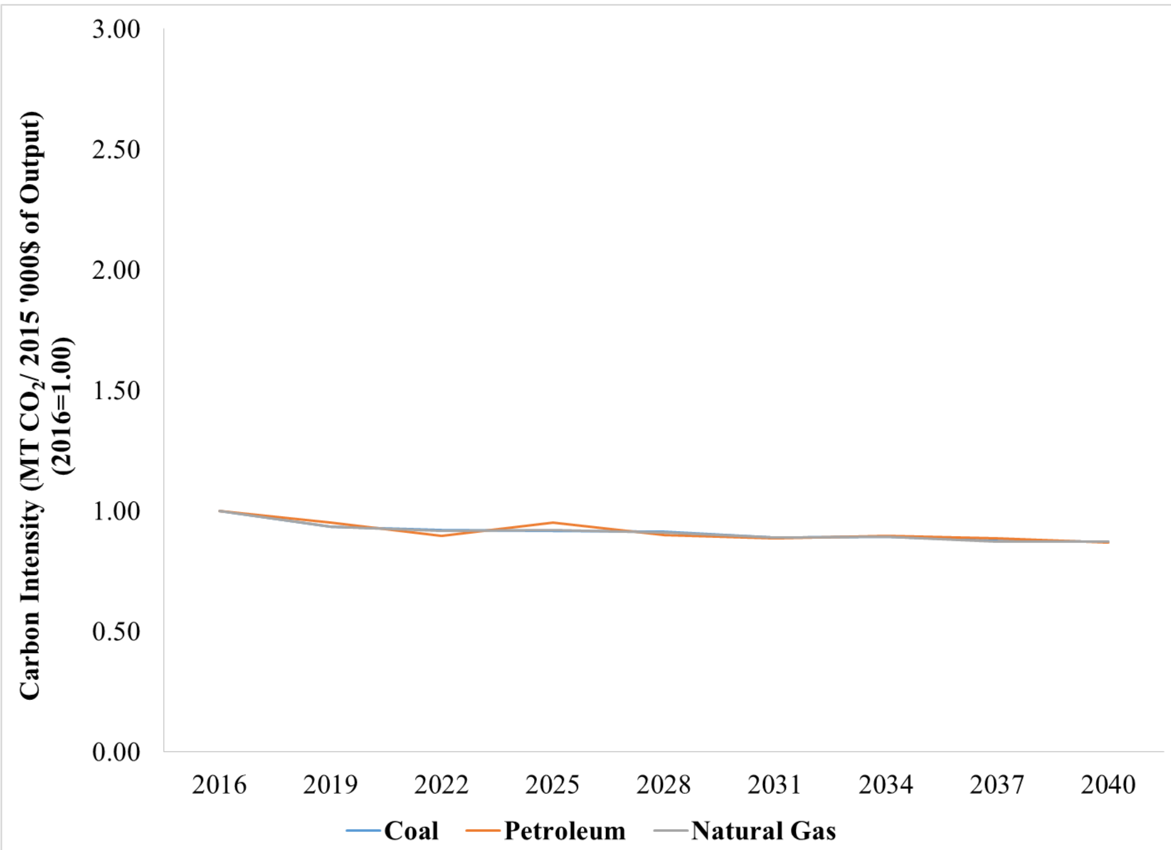
GHG emissions from paper and allied products manufacturing are predominantly CO_2 with smaller amounts of CH_4 and N_2O. The emissions associated with paper and allied products manufacturing can be attributed to:

(1) Combustion of on-site fossil fuels; and

(2) Non-energy related emission sources, such as by-product CO_2 emissions from the lime kiln chemical reactions and CH_4 emissions from wastewater treatment. These emissions come directly from the paper and allied products mill. Additionally, indirect emissions of GHGs can result from the off-site generation of electricity purchased by the mill.

Natural gas, fuel oil, purchased electricity, and coal are the key energy-related GHG emission sources for the paper and allied products manufacturing process. The carbon intensity of paper and allied products manufacture from fossil fuel combustion is projected to decrease by about13% by 2040 relative to 2016 levels with the carbon intensities of coal, gas, and oil following a similar trajectory of decline as seen in Figure 47 .

Figure 47: Trajectory of Baseline Carbon Intensity of Paper and Allied Products by Fuel Source



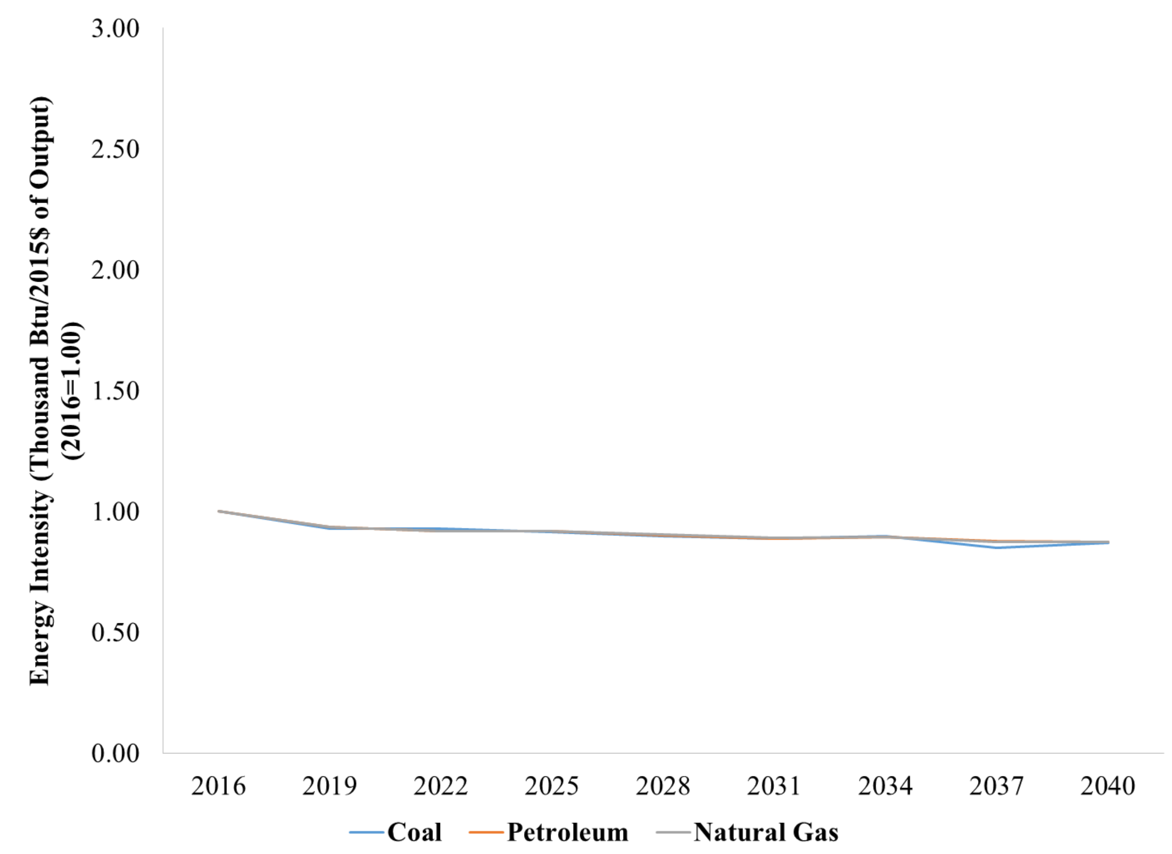
Electricity is used throughout a paper and allied products mill to power motors and machine drives, conveyors, pumps, and building operations such as lighting and ventilation. The largest use of fuels is in boilers, which are used to generate steam for use in pulping, evaporation, papermaking, and other operations. Black liquor is the most widely used fuel for boilers followed by hog fuel[67] and natural gas and to a much lesser extent, coal. Natural gas and oil are typically employed as fuel sources in lime kilns.

The primary technique identified for reduction of GHG emissions and lowering the energy intensity of the paper and allied products manufacturing process is improvement in energy efficiency. Given that steam is the largest end use of energy followed by electricity, energy efficiency techniques targeted towards reducing steam system losses and improving the efficiency of equipment using process steam are likely to reduce the energy intensity the most. Additionally the use of two key biomass by-products – black liquor and hog fuel – from the manufacturing process as fuel can significantly reduce the industry's dependence on purchased fossil fuels and electricity and also contribute towards lowering the energy intensity.

Similar to the trajectory for carbon intensity, the energy intensity of paper and allied products manufacture from fossil fuel combustion is projected to decrease by about13% by 2040 relative to 2016 levels with energy intensities for coal, gas, and oil declining at a similar rate as seen in Figure 48.

[67] Hog fuel is a mixture of bark and other wood waste usually produced by sawmills. It is burned to produce energy and steam.

Figure 48: Trajectory of Baseline Energy Intensity of Paper and Allied Products by Fuel Source



Iron and Steel

GHG Emissions from steelmaking are generated from one of the following sources:

(1) Process emissions, where both raw materials and combustion may contribute to CO_2 emissions;
(2) CO_2 emissions from combustion sources alone; and
(3) Indirect emissions resulting from electricity consumption (primarily in the EAF) and in finishing operations such as rolling mills at both integrated and EAF plants).

For integrated steelmaking, the primary sources of GHG emissions are blast furnace stoves (43 percent), miscellaneous combustion sources which burn natural gas and other process gases (30 percent), other process units (15 percent), and indirect emissions from electricity use (12 percent).[68] For EAF steelmaking, the primary sources of GHG emissions include indirect emissions from electricity use (50 percent), combustion of natural gas in combustion units (40 percent), and steel production in the EAF (10 percent).[68] For Coke facilities, the battery stack is the highest source contributing to over 95% of the GHG emissions for recovery coke plants and 99% of the GHG emissions for non-recovery plants.[68]

The carbon intensity of iron and steel manufacture from fossil combustion is projected to decrease by nearly 40% by 2040 relative to 2016 levels. This decline is attributed to a decrease in CO_2 emissions from coal and natural gas use with the larger contributor to this decrease being coal use, where carbon intensity is projected to decline by nearly half by 2040 relative to 2016 levels as seen in Figure 49. The decrease is partially offset by an increase in carbon intensity from petroleum, which is projected to grow by about 23% by 2040 relative to 2016 levels.

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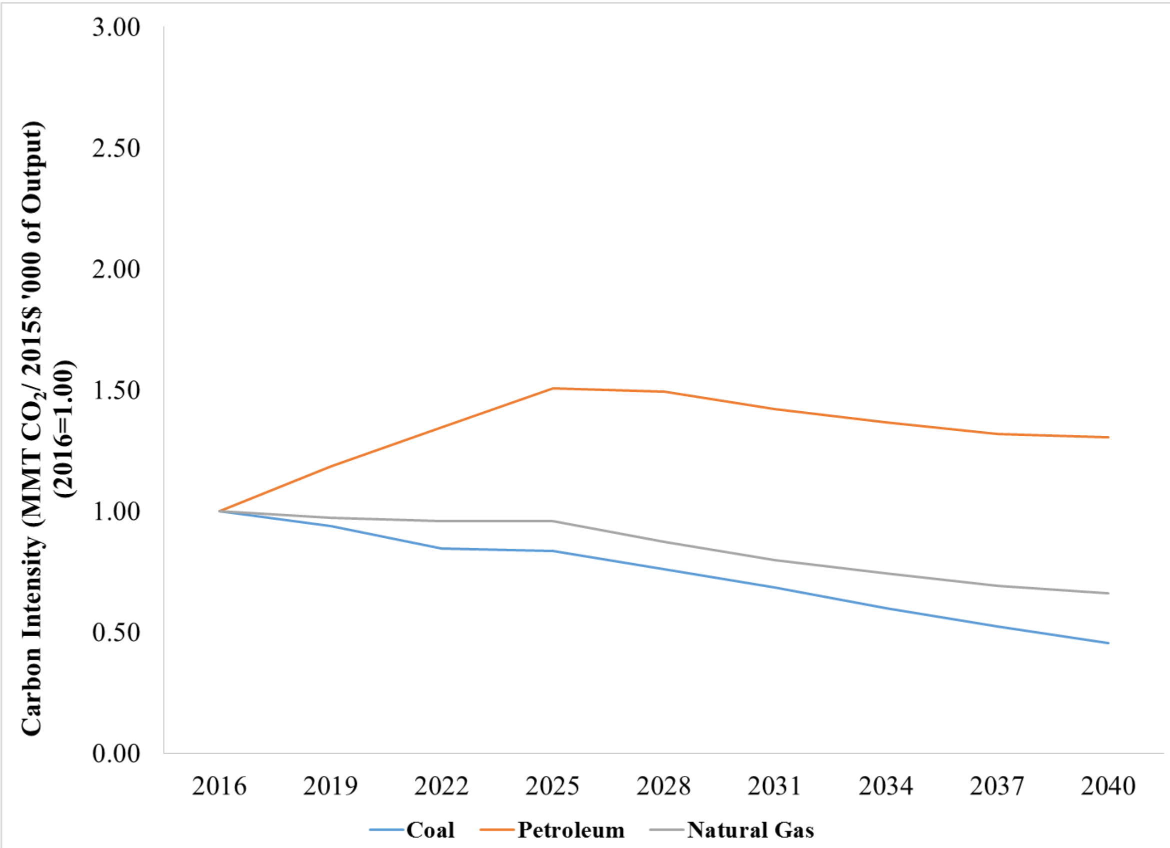
[68] Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Iron and Steel Industry, U.S. EPA, September 2012. Available: https://www.epa.gov/sites/production/files/2015-12/documents/ironsteel.pdf

Figure 49: Trajectory of Baseline Carbon Intensity of Iron and Steel Manufacture by Fuel Source



Energy consumption in the steel industry is largely used for crude steel production through the BOF and EAF technology routes. The overall energy intensity in EAF, which is used primarily to melt scarp steel, is significantly lower than the BOF route where steel is created by reducing iron ore.[69] In 2014, BOF technology accounted for about 37% of total U.S. steel production, and EAF accounted for 63% of the total.[70] Over the past two decades, a shift from BOF to EAF has contributed to a substantial reduction in the energy intensity of the U.S. steel industry.

[69] E. Worrell, P. Blinde, M. Neelis, E. Blomen, and E. Masanet, *Energy Efficiency Improvement and Cost Saving Opportunities for the U.S. Iron and Steel Industry* (Berkeley, CA: Lawrence Berkeley National Laboratory, October 2010) Available: https://www.energystar.gov/ia/business/industry/Iron_Steel_Guide.pdf

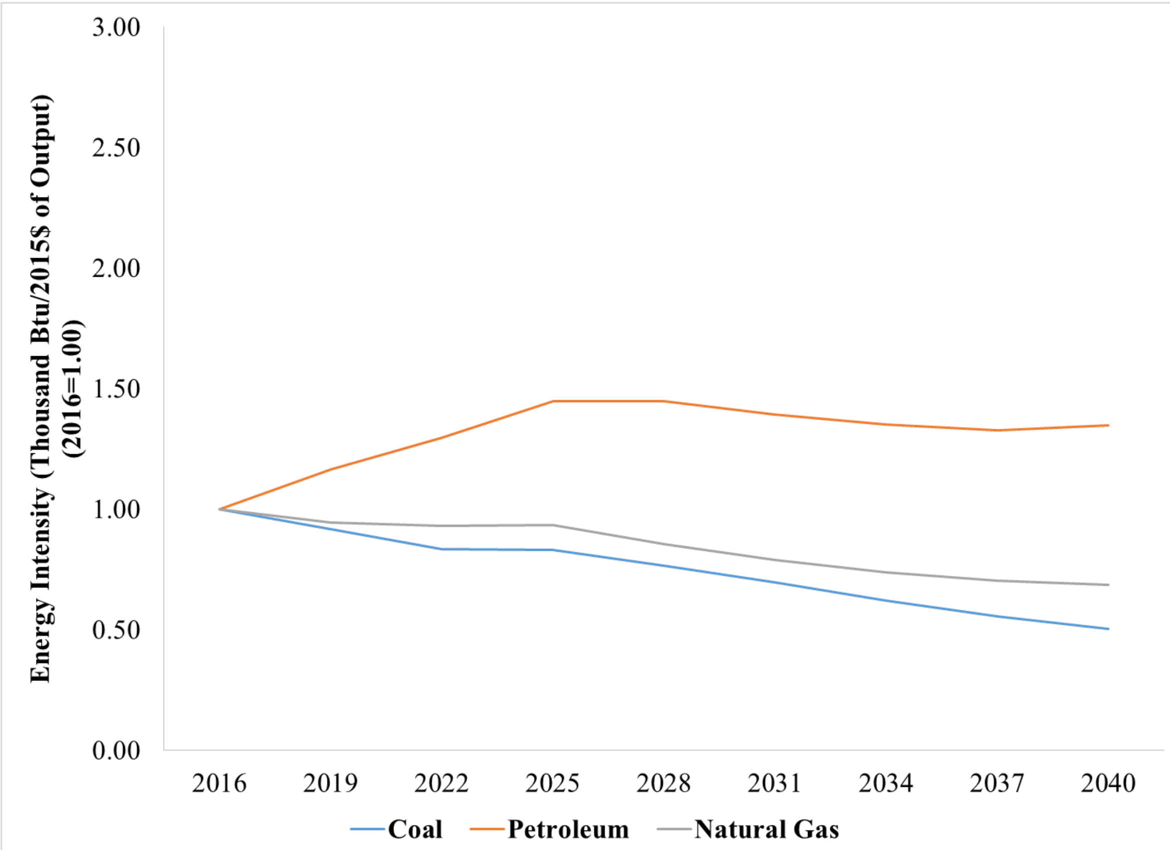
[70] U.S. Geological Survey, "2015 Mineral Commodity Summaries: Iron and Steel," Available: http://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel/mcs-2015-feste.pdf

Apart from the basic process choice for crude steel production, technology choices which are based on the desired product specifications, demand, fuel prices, and environmental policies can affect energy intensity. Technology advances in both BOF and EAF crude steel production processes such as blast furnace gas recovery, pulverized coal injection, and scarp pre-heating as well as advances in the rolling and casting processes have contributed towards lowering of the energy intensity for iron and steel manufacturing.[71]

The energy intensity of the iron and steel sector from fossil fuel combustion is projected to decrease by about 33% relative to 2016 levels. This decrease can be attributed to a decrease in energy use from coal whose energy intensity is forecasted to decrease by about half relative to 2016 levels by 2040. The decline is partially offset by an increase in energy from petroleum use whose energy intensity is projected to increase by about 35% by 2040 as seen in Figure 50.

[71] Steel Industry Energy Consumption: Sensitivity to Technology Choice, Fuel Prices, and Carbon Prices in the AEO 2016 Industrial Demand Module, July 2016. Available at https://www.eia.gov/forecasts/aeo/section_issues.cfm#steel_industry

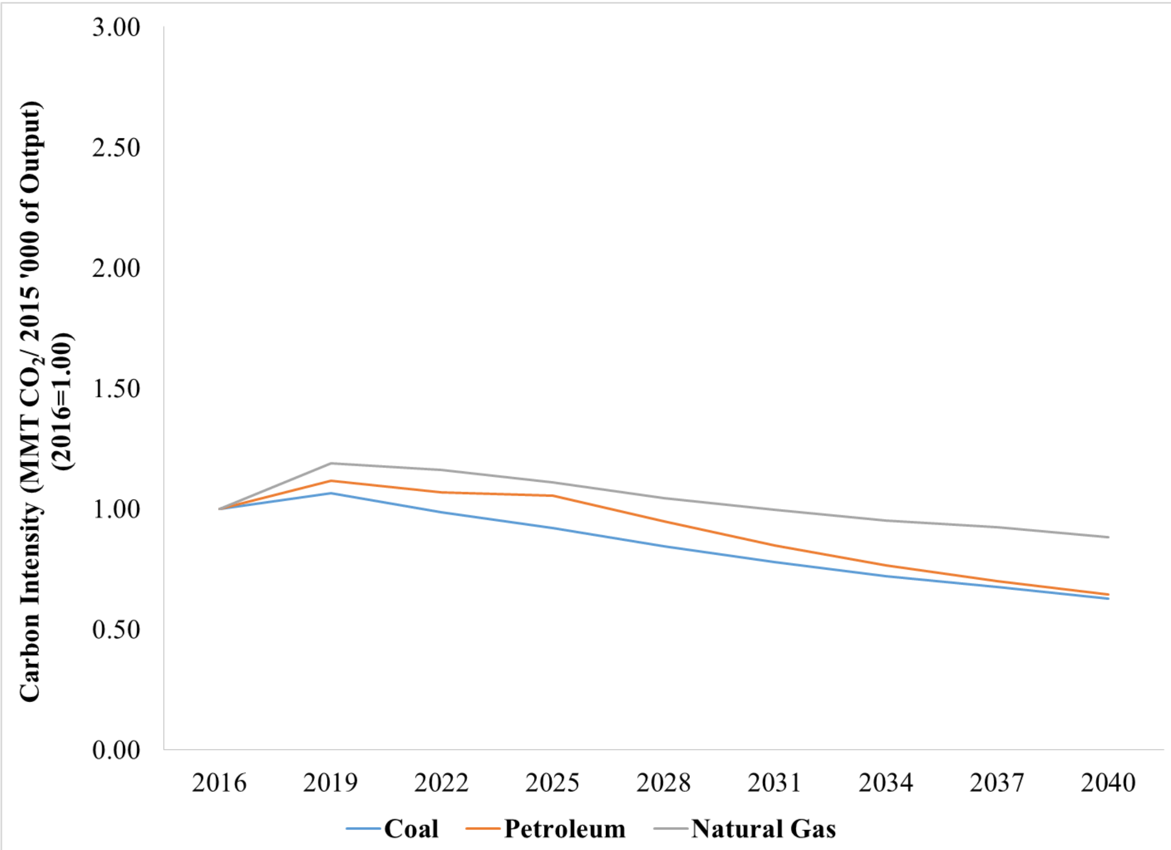
Figure 50: Trajectory of Baseline Energy Intensity of Iron and Steel Manufacture by Fuel Source



Bulk Chemicals

Natural gas, liquefied petroleum gases, and natural gas liquids are the major energy sources used in the bulk chemicals industry. The carbon intensity of bulk chemicals manufacture from fossil fuel combustion is projected to increase initially and then decline post 2022 with the carbon intensity declining by 17% by 2040 relative to 2016 levels. The carbon intensities of coal, oil and natural gas are projected to decline by about 37 percent, 35% and 12% by 2040 respectively vs. 2016 levels as seen in Figure 51.

Figure 51: Trajectory of Baseline Carbon Intensity of Bulk Chemicals Manufacture by Fuel Source



The bulk chemicals industry is fairly energy intensive requiring large amount of energy for the production of basic chemicals, plastics, and agricultural chemicals. In 2010, bulk chemicals accounted for about 5% of the nation's energy use and were estimated to provide the nation's economy with 1.4% of its GDP.[72] Over the long term, EIA projections forecast a declining contribution from the bulk chemicals industry to the economy and energy consumption. The energy intensity of bulk chemicals manufacture is projected to decline by about 17% by 2040 relative to 2016 levels as seen in the figure below. The energy intensities of coal, oil and natural gas use are projected to decline by about 34 percent, 38% and 14% by 2040 respectively vs. 2016 levels as seen in Figure 52.

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[72] Bulk Chemicals industry uses 5% of U.S. energy, Today in Energy, U.S. EIA, June 2013. Available: http://www.eia.gov/todayinenergy/detail.cfm?id=11531

Figure 52: Trajectory of Baseline Energy Intensity of Bulk Chemicals Manufacture

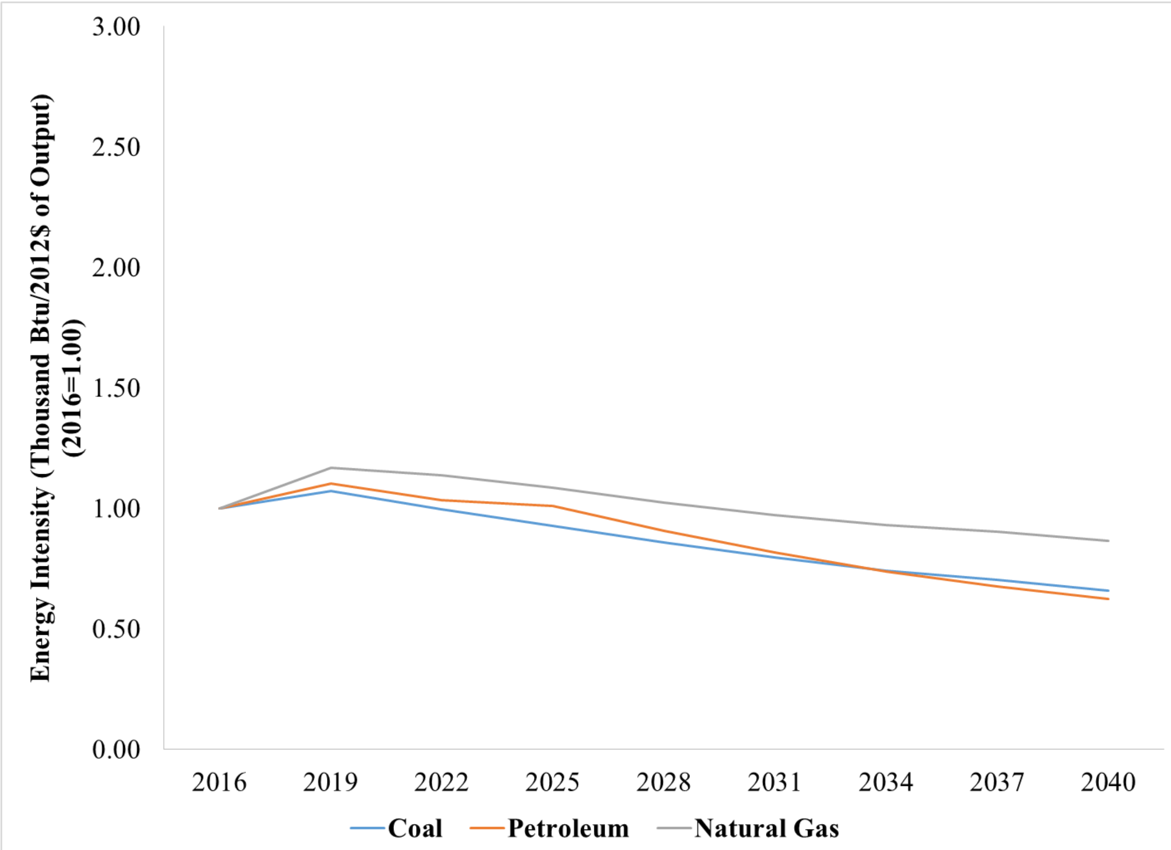

Table 52 and Table 53 outline the carbon and energy intensity for the topic industries and other key industrial categories measured relative to 2016 levels.

Table 52: Baseline Carbon Intensity for Key Industrial Sector Categories (TCO_2 per 2012 '000$s of Output) [2016 = 1.00]

	2016	2019	2022	2025	2028	2031	2034	2037	2040
AGR	1.00	1.05	0.95	0.87	0.79	0.73	0.68	0.63	0.59
CNS	1.00	0.97	1.00	0.95	0.90	0.87	0.87	0.84	0.80
MIN	1.00	0.81	0.79	0.76	0.73	0.70	0.72	0.68	0.65
REF	1.00	0.94	0.90	0.88	0.86	0.85	0.82	0.89	0.87
PAP	1.00	0.94	0.92	0.92	0.91	0.89	0.89	0.88	0.87
CHM	1.00	1.17	1.13	1.08	1.01	0.95	0.91	0.87	0.83
CMT	1.00	0.96	0.97	0.98	0.91	0.87	0.89	0.83	0.80
I_S	1.00	0.97	0.92	0.93	0.85	0.78	0.70	0.64	0.59
FAB	1.00	0.87	0.81	0.73	0.66	0.62	0.61	0.58	0.58
WOO	1.00	0.91	0.86	0.82	0.75	0.74	0.72	0.70	0.66
OEM	1.00	1.11	1.06	1.00	0.93	0.88	0.81	0.74	0.67
ONM	1.00	s1.04	1.03	1.00	0.96	0.93	0.92	0.90	0.87

Table 53: Baseline Energy Intensity for Key Industrial Sector Categories (thousand Btu per 2012 $ of Output) [2016=1.00]

	2016	2019	2022	2025	2028	2031	2034	2037	2040
AGR	1.00	1.05	0.94	0.86	0.78	0.71	0.66	0.61	0.57
CNS	1.00	0.86	0.84	0.81	0.79	0.79	0.82	0.80	0.79
MIN	1.00	0.80	0.78	0.76	0.72	0.71	0.72	0.69	0.67
REF	1.00	0.98	0.94	0.93	0.92	0.90	0.88	0.94	0.93
PAP	1.00	0.93	0.92	0.92	0.90	0.89	0.89	0.87	0.87
CHM	1.00	1.16	1.12	1.07	1.00	0.95	0.90	0.87	0.83
CMT	1.00	1.07	1.12	1.15	1.08	1.06	1.13	1.11	1.13
I_S	1.00	0.95	0.92	0.94	0.87	0.80	0.74	0.70	0.67
FAB	1.00	0.84	0.76	0.68	0.61	0.57	0.55	0.53	0.52
WOO	1.00	0.92	0.87	0.82	0.77	0.76	0.75	0.72	0.69
OEM	1.00	1.06	0.98	0.91	0.85	0.80	0.73	0.67	0.60
ONM	1.00	0.99	0.99	0.96	0.91	0.87	0.87	0.83	0.80

APPENDIX D. DESCRIPTION OF DIRECT MEASURES

A. Improvements in Energy Intensity from Process Industries

To compute improvements in energy intensity from the deployment of more energy-efficient technologies, we use AEO 2016's Energy-Efficient Technology Case as our reference. This case assumes improvements in technological energy efficiency over time for when compared to the Reference Case in five process industries in particular – aluminum, cement and lime, glass, iron and steel, and paper with no demand-side energy efficiency incentives. The scenario assumes that existing technologies are assumed to be retired sooner, and new technologies have a shorter lifespan than in the improvements come from AEO 2016 Reference Case which in turn provides more opportunities for the deployment of more energy-efficient technologies. We calculate the energy intensity for each sector by fuel category (coal, petroleum, natural gas and purchased electricity) for the five process industries by dividing the energy consumption by fuel type with the total value of shipments for each sector. A similar calculation is carried out for AEO 2016's Reference Case without CPP which we have adopted as our baseline. We then calculate percent changes in the computed energy intensity values between the two cases by fuel category. Table 54 presents the% reductions from the baseline for the five process industries.

Table 54: Percent Reduction in Energy Intensity for Key Process Industries [Energy Efficient Technology Case vs. Reference Case without CPP]

		2016	2019	2022	2025	2028	2031	2034	2037	2040
PAP	Petroleum	-2%	-6%	-11%	-15%	-15%	-13%	-13%	-13%	-12%
	Natural Gas	-3%	-7%	-13%	-19%	-21%	-20%	-20%	-20%	-19%
	Coal	-3%	-8%	-13%	-17%	-16%	-13%	-12%	-12%	-11%
	Electricity	-5%	-10%	-16%	-22%	-22%	-17%	-17%	-16%	-14%
CMT	Petroleum	2%	6%	9%	11%	8%	1%	-1%	-3%	-4%
	Natural Gas	-7%	-10%	-11%	-13%	-14%	-16%	-16%	-16%	-16%
	Coal	-7%	-9%	-11%	-14%	-16%	-15%	-14%	-14%	-14%
	Electricity	-7%	-9%	-11%	-12%	-14%	-14%	-16%	-16%	-17%
I_S	Petroleum	-1%	0%	-1%	-3%	-2%	-2%	-3%	-2%	-1%
	Natural Gas	-7%	-8%	-13%	-14%	-17%	-16%	-14%	-14%	-15%
	Coal	6%	4%	5%	-7%	1%	8%	0%	0%	3%
	Electricity	-2%	0%	-1%	0%	-1%	-2%	-2%	-2%	-2%

OEM	Petroleum	-1%	0%	0%	-1%	-2%	-2%	-2%	-3%	-4%
	Natural Gas	-3%	-5%	-6%	-7%	-8%	-12%	-14%	-14%	-14%
	Coal	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Electricity	-9%	-8%	-9%	-10%	-11%	-12%	-9%	-9%	-8%

B. Improvements in Vehicle Fuel Economy for LDV and Energy Intensity Improvement for the Trucking Sector

We impose direct measures that call for improvement in the fuel economy standard for light duty vehicles. To represent improvements in vehicle fuel economy, we use AEO 2016's Extended Policies Case as our reference. This forecast includes the joint-attribute CAFE and vehicle GHG emissions for model years MY 2012 to 2025 for light duty vehicles (LDV). While in the Reference Case without CPP, the CAFE standards are assumed to remain constant at MY 2025 levels in subsequent model years, the Extended Policies Case assumes that there is a continued increase in CAFE standards at an annual average rate of 1.4% for new LDV's after 2025. Table 55 presents a comparison of the fleet miles per gallon for the two cases.

Table 55: Fleet Miles per Gallon for AEO 2016's Reference Case without CPP and Extended Policies Case

	2016	2019	2022	2025	2028	2031	2034	2037	2040
Reference Case without CPP	22.0	23.4	25.1	27.3	29.7	31.9	33.7	35.2	36.2
Extended Policies	22.0	23.4	25.1	27.3	29.8	32.5	35.0	37.4	39.4

To represent improvements in energy intensity from the trucking sector, we use AEO 2016's Phase 2 Standards case as our reference. The proposed standards that are part of the side case build on the Phase 1 GHG standards for medium-duty vehicles and heavy duty vehicles that were implemented beginning in MY 2014. While the Phase 1 standards extend through MY 2018, the Phase 2 standards begin in MY 2021 and increase in stringency through MY 2027. We compute energy intensity by year for the trucking sector (which comprises of commercial light and freight trucks) by dividing the energy use with the vehicle miles travelled. A percent reduction is then calculated for the energy intensity vs. the Reference Case without CPP. Table 56 presents the percent reduction in energy intensity.

Table 56: Energy Intensity Improvements from Trucking

2016	2019	2022	2025	2028	2031	2034	2037	2040
-	-	-3%	-6%	-10%	-14%	-16%	-18%	-20%

C. CO_2 Emission Reductions in the Electricity Sector

To represent reductions in the carbon intensity for the electricity sector, we use AEO 2016's Extended Policies Case as our reference. While the Reference Case includes the CPP which is phased in over 2022-2030 with mass based compliance strategies covering both existing and new generators, the Extended Policies Case assumes a further reduction in targets post 2030. In the Extended Policies Case, the power sector CO_2 emission reductions are about 35% below 2005 levels in 2030 followed by a linear decline to 45% below 2005 emission levels in 2040. Table 57 presents the mass based emission limits modeled for the Extended Policies Case. Also, following California's SB 350 we implement a national RPS target of 33% in 2022 rising to 50% by 2030 and beyond.

Table 57: Mass-based Emission Limits for the Extended Policies Case (MMTCO$_2$)

2016	2019	2022	2025	2028	2031	2034	2037	2040
-	-	1,800	1,677	1,583	1,521	1,456	1,391	1,327

D. Reduction in Delivered Energy Consumption for the Buildings Sector

We represent reduction in the delivered energy consumption for the building sector based on AEO 2016's Extended Policies Case. The delivered energy consumption in the buildings sector decreases from its 2015 level with renewable distributed generation (DG) technologies providing much of the energy savings. Table 58 presents the percent reduction in delivered energy consumption compared to the Reference Case.

Table 58: Percent Reduction in Delivered Energy Consumption for the Building Sector [Extended Policies Case vs. Reference Case]

2016	2019	2022	2025	2028	2031	2034	2037	2040
-0.01%	-0.2%	-1%	-2%	-3%	-3%	-4%	-5%	-5%

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