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Electrifying the Columbus, Ohio Metro Area's Building Stock – Economic and Power Market Impacts

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Main Takeaways

- FTI Consulting ("FTI") modeled the impacts of a policy where all residential and commercial structures in the Columbus, Ohio metropolitan area ("Columbus MSA") would install electric space heating and water heaters, electric cooking and drying equipment, and convert all other appliances and energy needs from natural gas to electricity.
- According to inputs provided by the American Gas Association ("AGA"), the 20-year cost of ownership for a representative home with electrical equipment is between $27,200 and $31,000 – costs with high-efficiency natural gas would be $18,400. For a representative customer in the commercial sector, the 20-year cost of ownership for electrical equipment would be $167,200 compared to only $64,200 for gas-fired equipment.
- Converting the Columbus MSA's building stock to electricity would increase the load for the power sector, which would lead to slightly higher electricity prices (<1.2% in all years for the zone home to Columbus). Customers in the Midwest, Appalachia, and the Mid-Atlantic would face higher prices for electricity. Increased load would engender capacity additions of either 1.2 gigawatts ("GW") of natural gas combined cycle ("NGCC") units or, if the incremental builds must be renewables, then 2.0 GW of photovoltaic solar capacity.
- A critical question is if this policy would reduce emissions and, if so, at what cost. With carbon dioxide ("CO2"), we project emissions would total 52.9 million metric tons ("MMT") from 2021 to 2040 when the present fleet of gas-fired equipment sees its replacement by high-efficiency gas. Electrifying this demand would emit 48.3 MMT in a "market-based" scenario with NGCC additions or 65.6 MMT in a "renewables-only" scenario with the solar additions, which are 4.6 MMT less (-8.7%) and 12.8 MMT more (24.2%) respectively than baseline.
- For nitrogen oxides ("NOx") from 2021 to 2040, baseline emissions would be 58,200 short tons. Market-based emissions would be 10,000 short tons, and renewables-only emissions would be 38,400 short tons.[1] For sulfur dioxide ("SO2") from 2021 to 2040, baseline emissions would be 500 short tons. Market-based emissions would be 5,000 short tons, and renewables-only emissions would be 38,600 short tons.[2] The proposed policy would increase CO2 emissions in the renewables-only scenario but decrease them in the market-based scenario. The policy would reduce NOx emissions yet at the cost of higher SO2 emissions.
- The higher costs from electrification for customers in the Columbus MSA would come to $7.4 billion from 2021 to 2040. That market-based scenario would reduce CO2 emissions, but it would come at a cost of $1,615 per metric ton of saved emissions.

[1] Market-based NOx emissions are 82.9% less than baseline NOx; renewables-only is 46.3% less than baseline
[2] Market-based SO2 emissions are 908.2% more than baseline SO2; renewables-only is 7,657.0% more than baseline

- Using benefit-cost valuations for CO2, NOx, and SO2, the market-based scenario would create benefits of $377.5 million versus $7.4 billion in costs from 2021 to 2040. At a 5% discount rate, every $154 in higher costs would produce $1 in benefits. The renewables-only scenario would be counterproductive because it increases emissions, which translates to $2 billion in additional costs when monetized. These calculations include only the costs borne by the Columbus MSA and not the costs borne by customers throughout the region.
- The higher cost of living and higher cost of doing business would have negative implications within the Columbus MSA's economy. Consumers, facing higher utility bills and higher costs passed onto them from commercial establishments, would economize their spending on consumer staples (e.g., prepared food and retail products).
- By 2040, the Columbus MSA's economy would have 5,700 fewer jobs and $271 million less in GDP under electrification compared to a baseline of replacing the existing fleet of gas-fired equipment with high-efficiency gas through natural attrition. Impacts in the same vein would continue thereafter because the higher costs would continue.

Executive Summary

AGA engaged FTI to examine the potential impacts from converting the housing and commercial building stocks of the Columbus MSA from natural gas to electricity for their energy needs over the course of the next 20 years. This report examines the upshot of these conversions on power markets within Ohio and the Midwest and to the economy of the Columbus MSA.

Methodology and Approach

FTI approached this research with three primary tools: (1.) inputs from AGA, (2.) the PLEXOS model, and (3.) the IMPLAN model. Major inputs from AGA included the number of existing residential homes and commercial structures to convert plus new builds to adopt either high-efficiency natural gas or electricity in the next two decades. It also provided the upfront equipment and installation costs and the long-term maintenance and energy costs for high-efficiency natural gas and electricity and data describing the seasonal patterns of heating demand for the Columbus MSA.

According to these inputs, over 800,000 residential homes and commercial buildings in the Columbus MSA would have heating equipment and appliance installations from 2021 to 2040. ES Table 1 shows the exact numbers split between structure type and existing or new:

ES Table 1 – Annual and total new builds and conversions

Structure Classification	New Builds (annual)	Conversions (annual)	New Builds (2021-2040)	Total Conversions (2021-2040)
Residential	6,650	30,840	131,000	616,760
Commercial	760	2,410	15,220	48,180

The main thrust and driving force behind the results comes from inputs regarding the costs to buy, to install, and to operate the types of equipment. According to inputs from AGA, the 20-year lifecycle costs (in 2018 dollars) would be $18,411 for a high-efficiency natural gas home heating system versus $27,202 to $30,962 for an electric home heating system. The latter range depends on if homes need updated electric panels to handle higher amperage. For commercial customers, their average costs over the same period would be $64,240 with gas and $167,160 with electricity.

A net increase in utility bills for residential customers would reduce their purchasing power, which impacts the local economy and economic sectors dependent on consumer expenditures. The higher costs for the commercial sector would mean reduced competitiveness or higher costs passed along to their customers – again negatively affecting households' purchasing power.

FTI simulated the economic impact of these three effects (more demand for electricity, less demand for gas, and higher costs) in IMPLAN. IMPLAN is a widely applied model for answering questions on impacts from policy changes, and a diagram for it is in Appendix A.

The conversion of hundreds of thousands of homes and tens of thousands of commercial structures over to electric heating systems would increase total and peak electricity load for the Columbus MSA. To assess these conversions and impacts on wholesale electricity markets in Ohio and the Midwest, FTI applied its PLEXOS model of the North American electrical system.

PLEXOS determined the impacts on plant additions and plant retirements from the additional load as well as effects on wholesale prices for the zone encompassing Columbus. FTI integrated the outputs from PLEXOS for electricity prices into the IMPLAN inputs, as well.

FTI modeled a Base Case without any additional heating electrification and two scenarios in PLEXOS. For the first scenario, the market could respond to the load without other assumptions or restrictions ("market-based" or "MB"). In the second scenario, incremental capacity must be solar or wind only ("renewables-only" or "RO") without battery storage. The differences between these simulations produced the change in various types of emissions associated with electrification.

For the remainder of the Executive Summary, we discuss the results of the power market analysis, results for emissions, and then the results for the economic impact analysis. When then present a longer narrative and documentation of our inputs and assumptions.

Results

Power Market Results

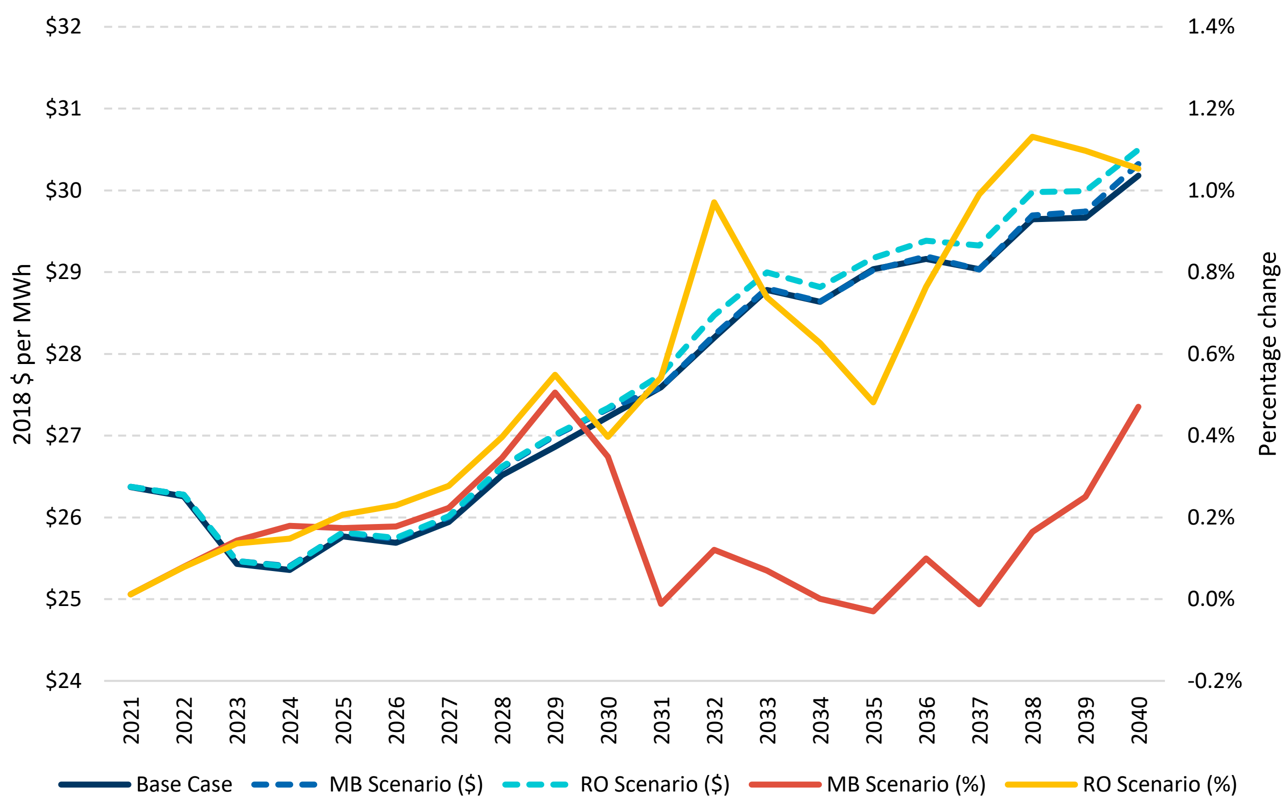
ES Table 2 summarizes the capacity expansion results for the two scenarios. In the MB Scenario, the increased energy and peak load induces 1.2 GW of NGCC builds relative to the Base Case. In the RO Scenario, capacity additions would be 2.0 GW of solar. The combination of the higher load and the operation of these plants would, in turn, influence market prices.

ES Table 2 – Capacity expansion from PLEXOS simulations for PJM (2021 to 2040, gigawatts)

Scenario versus Base Case	Solar	Wind	Biomass	NGCC	Thermal Retirements	Net Additions
MB Scenario	0.0	0.0	0.0	1.2	0.0	1.2
RO Scenario	2.0	-0.1	0.0	0.0	0.0	1.9

ES Figure 1 shows the electricity price forecast for the American Electric Power ("AEP") zone in central Ohio and neighboring states. Electricity prices would remain close to one another but increase in the MB Scenario and the RO Scenario. The RO Scenario would have the highest prices throughout the modeling horizon. In MB Scenario, prices are higher only in the 2020s and the late 2030s. The reason is that the additional NGCC builds in the MB Scenario from ES Table 2 would be flexible resources with low heat rates and dispatch costs, and hence their dispatch into the market throughout the year would help to hold average prices down despite the increase in the load.

ES Figure 1 – Annual AEP wholesale electricity price (2018 $)



We also included inputs related to changing electricity prices (the ones from ES Figure 1) in IMPLAN. The general effect of affecting households' purchasing power was the same.

ES Table 3 shows the difference in emissions between the Base Case and the two scenarios. PLEXOS produces reduces for CO2, NOx, and SO2. Relative to the Base Case, the MB Scenario would reduce CO2 emissions and the RO Scenario would increase them. Both scenarios would reduce NOx when compared to the Base Case, though the reduced NOx would come at an increase in SO2 of 4,500 short tons in the MB Scenario and 38,100 short tons in the RO Scenario.

ES Table 3 – Emissions results (2021 to 2040)

Scenario	CO2 (millions of metric tons)	NOx (thousands of short tons)	SO2 (thousands of short tons)
Base Case	52.9	58.2	0.5
MB Scenario	48.3	10.0	5.0
RO Scenario	65.6	31.3	38.4
MB Scenario versus Base Case	-4.6 (-8.7%)	-48.2 (-82.9%)	4.5 (908.2%)
RO Scenario versus Base Case	12.8 (24.2%)	-26.9 (-46.3%)	38.1 (7,657.0%)

For all three compounds, the MB Scenario would have lower emissions than the RO Scenario. Those results might seem counterintuitive, though they follow from electricity market dynamics. The 1.2 GW of new NGCC in the MB Scenario would produce emissions, but it would operate at a higher capacity factor and in more reliably high-load hours than the 2.0 GW of solar in the RO Scenario. NGCC would therefore be more effective at displacing existing coal generation compared to the incremental solar. The larger quantities of NOx and SO2 emissions in the RO Scenario relative to the RO Scenario further demonstrates the solar displaces less coal generation than the NGCC.

ES Table 4 shows the change in emissions from ES Table 3 monetized with federal valuations for CO2 ($51 per metric ton), NOx ($6,704 per short ton), and SO2 ($39,599 per short ton).

ES Table 4 – Valuation of the increased or decreased emissions in the scenarios (2018 $ millions)

Scenario	CO2	NOx	SO2	Total
MB Scenario versus Base Case	$233.1	$323.4	-$179.0	$377.5
RO Scenario versus Base Case	-$649.5	$180.7	-$1,508.8	-$1,977.6

The RO Scenario, despite its lower NOx emissions than the Base Case, would have a negative value in terms of saved emissions because it would increase CO2 and SO2 emissions. Compared to the Base Case, the MB Scenario would increase SO2 emissions yet decrease CO2 and NOx emissions, which contributes to its positive overall valuation ($377.5 million) in ES Table 4.

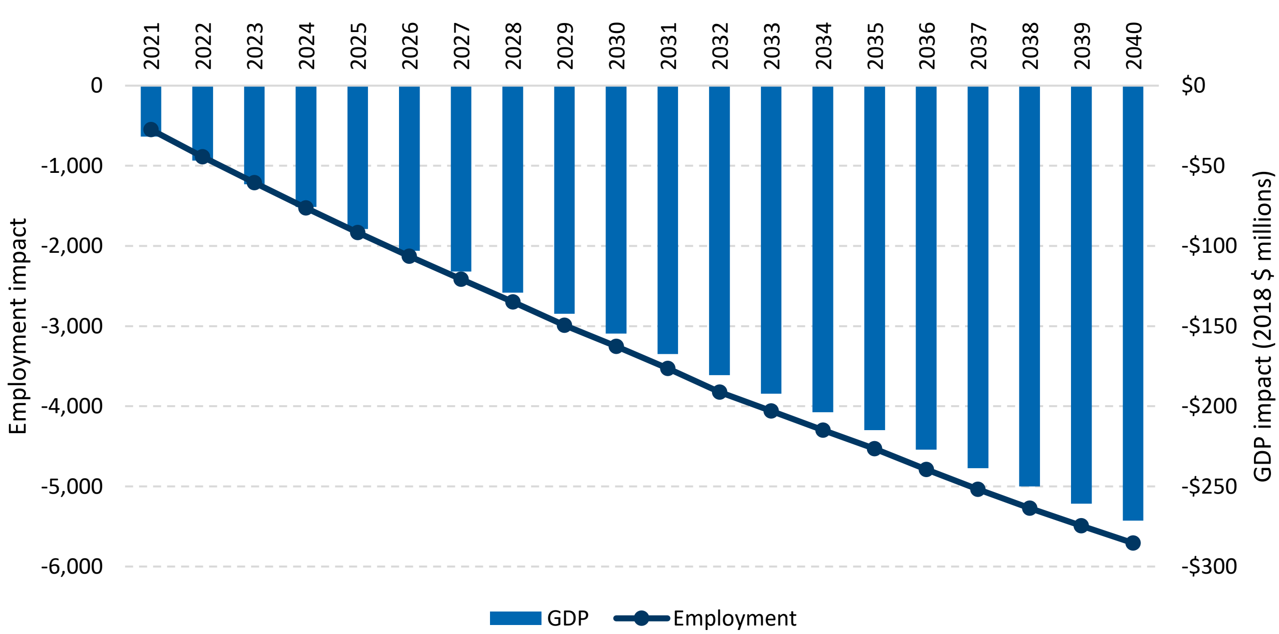
The RO Scenario would be counterproductive towards reducing emissions. The MB Scenario would achieve emissions reductions, though only at extremely high costs. For the $381.8 million worth of saved emissions from ES Table 4, customer costs in the Columbus MSA would increase by $7.4 billion to purchase, install, maintain, and operate electric equipment instead of upgrading to high-efficiency gas-fired equivalents. These costs are for the Columbus MSA only and do not include higher electricity prices paid by customers across the Midwest, Appalachia, and the Mid-Atlantic in territories for the utilities participating in the PJM Interconnection, LLC ("PJM").

For CO2 alone in the MB Scenario, the cost for the Columbus MSA for the saved emissions from ES Table 4 would be $1,615 per metric ton. Including NOx and SO2 alongside CO2 and with a 5% discount rate, every $154 in higher costs would yield $1 in benefits. Most of the emissions reductions in ES Table 4 would come in the 2030s, reducing their present value.

Economic Impact Results

Electrifying residential and commercial building stock would have a negative impact on the economy of the Columbus MSA over time. The incremental end-consumer expenditures on electricity as compared to gas expenditures for high-efficiency natural gas heating would gradually reduce expenditures on other household goods and services. The commercial customers facing the same higher costs would exacerbate the situation by passing higher costs along to customers.

ES Figure 2 – Economic impact of electrifying the Columbus MSA



ES Figure 2 shows results for employment and gross domestic product ("GDP"). As more homes and structures electrify, the economic impacts would become increasingly negative.

While the aggregate results from ES Figure 2 describe an overall negative impact, the distribution of those impacts would not be equal across economic sectors.

Electrification would increase the employment associated with the electric power and construction sectors and decrease the employment associated with natural gas distribution and pipelines. At the same time, the higher cost of living and the higher cost of doing business due to the electrification would decrease real incomes and purchasing power across the Columbus MSA, which leads to the reduced employment for the service sectors in ES Table 5.

ES Table 5 – Employment impact by economic sector

Economic Sector	2025	2030	2035	2040
Electric Power G, T, and D[3]	240	430	610	770
Construction	90	120	160	180
S&L[4] Government (Non-Education)	0	10	10	20
Coal Mining	0	0	0	0
Other Mining	0	0	0	0
S&L Government (Education)	0	0	0	0
Water and Sewage	0	0	0	0
Agriculture and Forestry	0	0	-10	-10
Federal Government	-10	-10	-20	-20
Manufacturing	-10	-10	-20	-20
Oil and Natural Gas Extraction	-10	-20	-30	-40
Information	-30	-50	-70	-90
Wholesale	-50	-100	-130	-170
Arts, Entertainment, and Recreation	-60	-110	-150	-180
Transportation and Logistics	-70	-130	-180	-230
Private Education	-80	-140	-200	-250
Natural Gas Distribution and Pipelines	-160	-290	-410	-510
Other Personal Services	-190	-320	-450	-560
Accommodation and Food Service	-230	-400	-550	-690
Finance, Insurance, and Real Estate	-240	-430	-610	-770
Retail	-250	-440	-620	-780
Professional and Business Services	-310	-550	-770	-970
Healthcare and Social Assistance	-460	-800	-1,100	-1,380
TOTAL	-1,830	-3,250	-4,530	-5,710

[3] Electric power generation, transmission, and distribution
[4] State and local government

Introduction

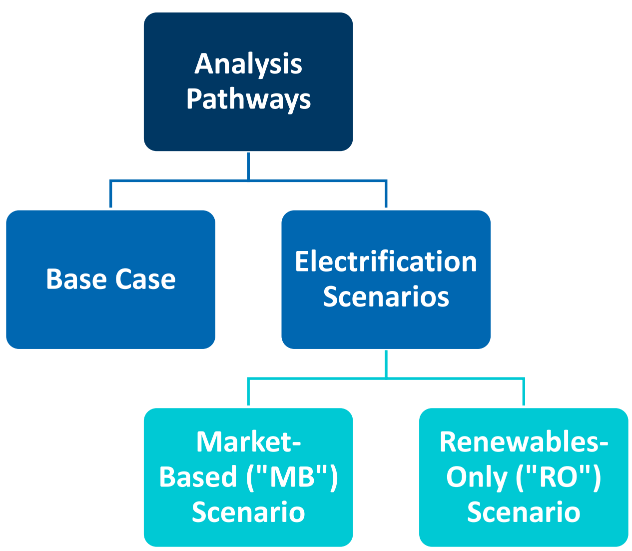
The American Gas Association ("AGA") engaged FTI Consulting, Inc. to assess impacts to the Columbus, Ohio metropolitan area (a 10-county region of central Ohio)[5] from electrifying its residential and commercial building stock, including needs for heating, cooking, and hot water.

According to data from the American Housing Survey ("AHS"),[6] most homes in Ohio and by extension the Columbus MSA use natural gas as their primary heating and cooking fuel. We have examined two situations for the heating equipment and appliances needs of residential and commercial buildings in the Columbus MSA. In our "Base Case," buildings relying on gas in the Columbus MSA would convert to newer and high-efficiency gas equipment over the next 20 years. Our projected new builds would also use high-efficiency gas. In our electrification analysis, new builds immediately use electricity for their heating and appliance needs, and the stock of existing buildings would convert from natural gas to electricity for their energy needs over the next 20 years.

The electrification would increase higher peak load and total energy in the American Electric Power ("AEP") zone of PJM. AEP serves most of the Columbus MSA for its electricity demand. We used a model of the system called PLEXOS to examine what the load would mean for wholesale electricity markets under two scenarios. In the "Market-Based Scenario," the electricity market could add any type of generation making economic sense to serve higher load. In the "Renewables-Only Scenario," we restricted any incremental additions to solar and wind plants only.

Figure 1 organizes the Base Case and our two scenarios for the electricity market modeling.

Figure 1 – Summary of the scenarios for analysis



[5] A 10-county region of central Ohio including Delaware, Fairfield, Franklin, Hocking, Licking, Madison, Morrow, Perry, Pickaway, and Union Counties

[6] "American Housing Survey," *U.S. Census Bureau*, https://www.census.gov/programs-surveys/ahs.html

The main body of this report describes the Base Case, scenarios, their inputs, and their assumptions with additional details. We then describe the impacts of electrifying the Columbus MSA's residential and commercial building stock with the results from simulations in PLEXOS and IMPLAN.[7] IMPLAN is an "input-output" model of regional economies designed to show the impacts of changes to economies and public policy. Where appropriate, we have included appendices with more detailed data tables documenting our results and describing PLEXOS and IMPLAN.

Methodology and Approach

AGA provided the inputs and assumptions underlying the FTI simulations in PLEXOS and IMPLAN.[8] AGA based its analysis on federal and regional data sources, such as the U.S. Census Bureau, and previous research on the relative cost and efficiency of natural gas-fired appliances and heating equipment relative to using electricity-powered alternatives for the same purposes.

Number of New Builds and Conversions

The first major consideration across the analysis was the number of homes and commercial buildings to convert to high-efficiency gas (in the Base Case) or electricity (under electrification). On top of these are new homes and structures being built, which could have either high-efficiency gas (in the Base Case) or electricity (in the two electrification scenarios). Table 1 describes our inputs for new builds and conversions annually and for the next 20 years.

Table 1 – Annual and total new builds and conversions

Structure Classification	New Builds (annual)	Conversions (annual)	New Builds (2021-2040)	Total Conversions (2021-2040)
Residential	6,650	30,840	131,000	616,760
Commercial	760	2,410	15,220	48,180

We chose 20 years as our horizon because it is a reasonable estimate of the service life for equipment of this nature. We are not analyzing any "early" conversions and instead assume upgrades to new gas or electrified equipment comes as the existing fleet naturally turns over.

The Base Case and scenarios would require the conversion of 616,760 homes and 48,180 commercial buildings over the course of 20 years, which are estimates of the size of the stock for the Columbus MSA in 2020. These conversions would proceed in a linear fashion with 5% of the initial total having conversion each year. On top of these would be 6,650 residential new builds and 760 commercial new builds each year, eventually adding to the aggregate totals in Table 1.

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[7] "Where It All Started," *IMPLAN*, https://implan.com/history/
[8] For diagrams of PLEXOS and IMPLAN, please see Appendix A

In addition, many older homes would require upgrades to their electrical panel to handle the electric heating equipment and appliances imagined under electrification. Our estimate is 32% of older homes (the ones built before 1960) in the Columbus MSA would require these upgrades. The plan for the electrification would require that 9,870 homes year and 197,360 overall homes from 2021 to 2040 would require modernizing their panel to higher amperage.

Figure 2 shows a graphical representation of the data from Table 1 for residential structures. Figure 3 displays the equivalent data but for commercial structures. Under both situations, existing structures begin with gas-fired equipment at present efficiency. For the Base Case, existing structures would convert to new, high-efficiency gas equipment over time. New builds would also come online with high-efficiency gas equipment. For the electrification, the conversions and new builds would instead come up to speed with electrified equipment and appliances.

Figure 2 – Existing residential structures, conversions, and new builds (thousands)

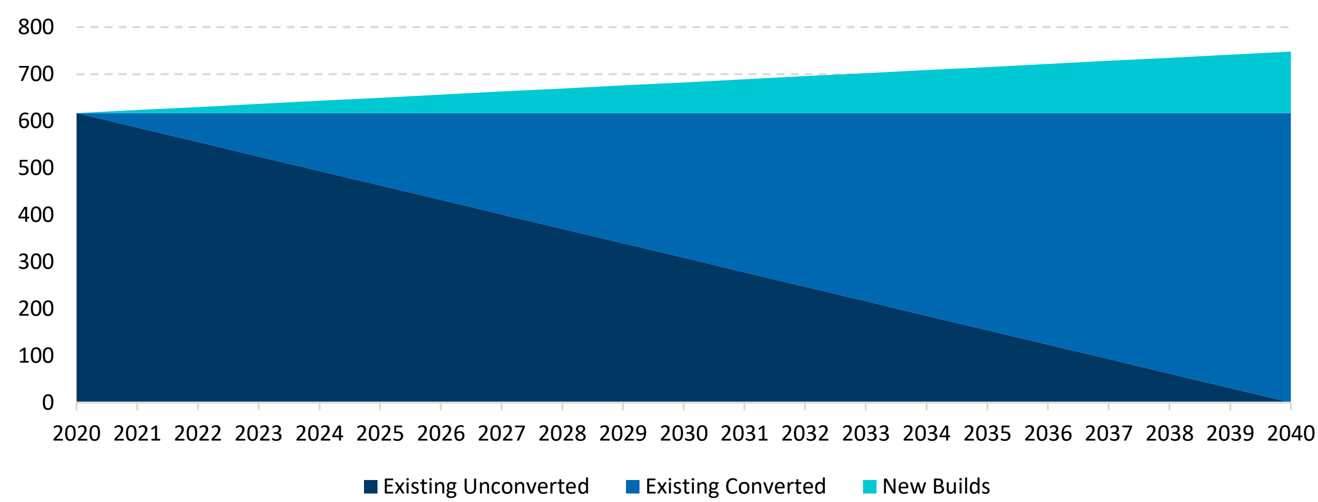
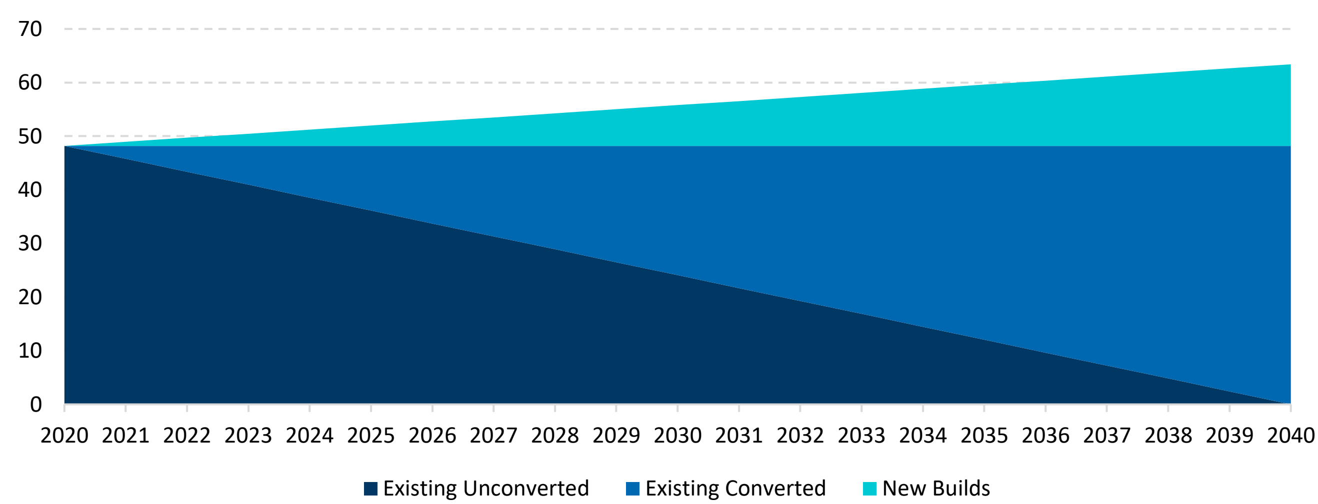


Figure 3 – Existing commercial structures, conversions, and new builds (thousands)



Assumptions and Inputs for Modeling Conversions

AGA provided FTI with inputs and assumptions for the cost of new gas-fired equipment, the cost of new electrical equipment, and the ongoing energy costs to operate them.

The AGA model of residential and commercial natural gas customers is derived from the U.S. Energy Information Administration ("EIA") and its data sources, including its monthly consumption and its customer count data for 2018. Using these sources, AGA estimated a space heating load by subtracting the average summer consumption from total annual consumption. Hourly heating load data comes from allocating the monthly demand load by hourly heating degree data.

Limiting the input data to 2018 was a deliberate choice. That year had nominal winter weather both locally and nationally compared to 30-year heating degree day averages. Additionally, by using a single year for reference instead of a long-term average the peak of the peak energy demand for the coldest hours of the year would be present in the shape data. Preserving this facet of the shape helps provide the electricity sector modeling with more realistic conditions.

Heat pump performance on the handbook produced by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers ("ASHRAE"). This analysis assumes a nameplate efficiency of 300% at 35°F and a maximum output of 100% of the demand load. The maximum output and the efficiency at 35°F can increase though only by oversizing the unit and thereby increasing costs to consumers paying to purchase, install, maintain, and operate the unit.

To account for a wider range of air compressor abilities, if the outdoor air temperature remained above -27°F, the heat pump would continue to function. However, its performance and its maximum output would decrease as the temperature drops from -35°F. These assumptions are consistent with the ASHRAE handbook for heat pump operations. The model determined approximately 25% of space heating demand comes from backup resistance. The model also determined the actual efficiency for modeled representative heat pumps in the Columbus MSA to be 230%.

Customers converting to heat pumps would install a 300% rated unit in exchange for a retired 80% efficient gas-fired unit along with a heat pump water heater and all-electric appliances. The baseload appliance performance derived from a regional weighted average developed using RECS 2015[9] and CBECS 2012[10] surveys. AGA found the average residential customer has a baseload efficiency of 73% and the average commercial customer has a baseload efficiency of 72%.

For residential customers, AGA assumed the average efficiency of heat pump water heaters had a minimum rating of 200% and, on average, all non-space heating appliances fit a profile of 178%. For

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[9] "2015 Residential Energy Consumption Survey," *U.S. Energy Information Administration*, https://www.eia.gov/consumption/residential/data/2015/

[10] "2012 Commercial Buildings Energy Consumption Survey," *U.S. Energy Information Administration*, https://www.eia.gov/consumption/commercial/data/2012/

commercial customers, who have much greater needs for water heating and baseload, AGA used a conversion profile of 125% efficiency compared to a gas equivalent.

Table 2 and Table 3 summarize these inputs. Because commercial customers have widely diverging requirements for space heating capabilities, AGA did not evaluate the installation costs between gas furnaces and electric heat pumps for the commercial customer segment.

Table 2 – Summary of assumptions and inputs for residential conversions

Demand Category	Equipment Type	Efficiency	Annual Site Energy (MMBtu)	Annual Fuel Costs (2018 $)	Installation Costs (2018 $)	Equipment Costs (2018 $)
Space Heating	Gas Furnace	80%	70.3	$460	$1,600	$4,026
Space Heating	Gas Furnace	96%	58.6	$383	$1,903	$4,788
Space Heating	Heat Pump	300%	24.7	$717	$2,224	$4,158
Baseload	Gas Furnace	73%	16.4	$203	-	-
Baseload	Heat Pump	178%	6.7	$249	-	-

Table 3 – Summary of assumptions and inputs for commercial conversions

Demand Category	Equipment Type	Efficiency	Annual Site Energy (MMBtu)	Annual Fuel Costs (2018 $)
Space Heating	Gas Furnace	80%	480.0	$2,284
Space Heating	Gas Furnace	96%	400.0	$1,904
Space Heating	Heat Pump	300%	169.7	$4,371
Baseload	Gas Furnace	72%	243.5	$1,308
Baseload	Heat Pump	125%	142.2	$3,987

Cost of New Builds and Conversions by Fuel Type

Table 4 describes this input data for the residential sector. We have divided these costs between the "equipment costs" for the physical equipment, "installation costs" for the labor associated with setting them up, and "energy costs" for the cost of the natural gas or the electricity to operate the equipment and maintain it for one year. The numbers in Table 4 include the heating costs and the baseload costs associated with other activities, such as heating water.

Table 4 – Input costs and assumptions for residential conversions (2018 $)[11]

Type of Equipment	Equipment Costs	Installation Costs	Energy Costs[12]	Total Costs (2021-2040)[13]
Existing Gas	-	-	$663	-
High-Efficiency Gas	$4,788	$1,903	$586	$18,411
Electrification	$4,158	$2,224	$1,041	$27,202
Electrification (older homes)	$7,918[14]	$2,224[15]	$1,041	$30,962

Replacing existing gas equipment at fleet average efficiency with new, high-efficiency gas equipment would save on energy costs but requires the equipment and installation costs in Table 4. All homes in the Columbus MSA, however, must upgrade between 2021 and 2040 because of our 20-year horizon and 20-year assumption of the useful lifespan of the equipment.

When developers build a new home or an existing home needs to replace its equipment, the choice is between high-efficiency gas and electrification. Electrification would have higher energy costs and higher installation costs, though the cost of equipment would be lower for newer homes. For the 32% of older homes built before 1960 requiring additional upgrades, the equipment costs for choosing electrification would also be higher than new gas. With an example new build or conversion in early 2021, the 20-year cost for the new gas customer is $18,411 and the 20-year cost for electrification is either $27,202 for newer homes or $30,962 for older homes.

Differences in the costs for customers over the age of the equipment – between $8,800 and $12,500 depending if an electric panel upgrade is required – would be a force behind the economic impact of

[11] Assumptions regarding installation costs for natural gas and electric air-sourced heat pump systems imported from, "Implications of Policy-Driven Residential Electrification," *American Gas Association*, 5 September 2018, https://www.aga.org/research/reports/implications-of-policy-driven-residential-electrification/

[12] Includes the annual and ongoing costs of both energy and maintenance

[13] Equipment costs, plus installation costs, plus energy costs times 20 – representative of a conversation from 2021 only because conversions from subsequent years would have less than 20 years of energy costs

[14] Cost to upgrade the water heater branch circuit and electrical panel to higher amperage

[15] Assumed to be the same as for newer homes

electrifying the home and building stocks. Residential customers would have overall higher utility bills with electrification relative to the Base Case. This forces households to economize their spending on the other fixtures of life, such as retail spending or prepared food. Figure 2 illustrates the size of this effect increases over time as more and more homes come online or convert.

Table 5 summarizes our inputs for commercial buildings. For this sector, we have assumed equipment and installation costs are the same between new high-efficiency gas and electrification. All differences in costs for this sector would be, therefore, based on energy costs alone. There is no special carveout for older commercial structures to upgrade their electrical panels.

Table 5 – Input costs and assumptions for commercial conversions (2018 $)[16]

Type of Equipment	Energy Costs	Total Costs (2021-2040)
Existing Gas	$3,592	-
High-Efficiency Gas	$3,212	$64,240
Electrification	$8,358	$167,160

As is the case with residential customers, the difference in lifecycle costs for commercial customers in Table 5 would be a driving factor in the impact of electrifying the Columbus MSA. For the average commercial conversion or new build in early 2021, their costs under electrification would be $102,920 than in the Base Case when using high-efficiency gas.

Facing higher utility bills after electrification of their equipment, commercial enterprises would need to economize as much as residential customers. We have modeled this through a mixture of passing those higher costs along to their customers in the Columbus MSA and reducing their output because high costs reduces their competitiveness on national markets.

Additional Total Energy and Peak Load

AGA also provided FTI with data on the increase in electricity load likely under the electrification. This includes an hourly "load shape" for the average customer by type[17] and the average baseload.[18] The

[16] Assumptions regarding installation costs for natural gas and heat pump systems imported from, "Implications of Policy-Driven Residential Electrification," *American Gas Association*, September 2018, https://www.aga.org/research/reports/implications-of-policy-driven-residential-electrification/

[17] Average residential and commercial space heating and general non-space heating load derived from monthly natural gas consumption data and the Ohio customer count for 2018, "Natural Gas Consumption," *U.S. Energy Information Administration*, https://www.eia.gov/naturalgas/data.php#consumption

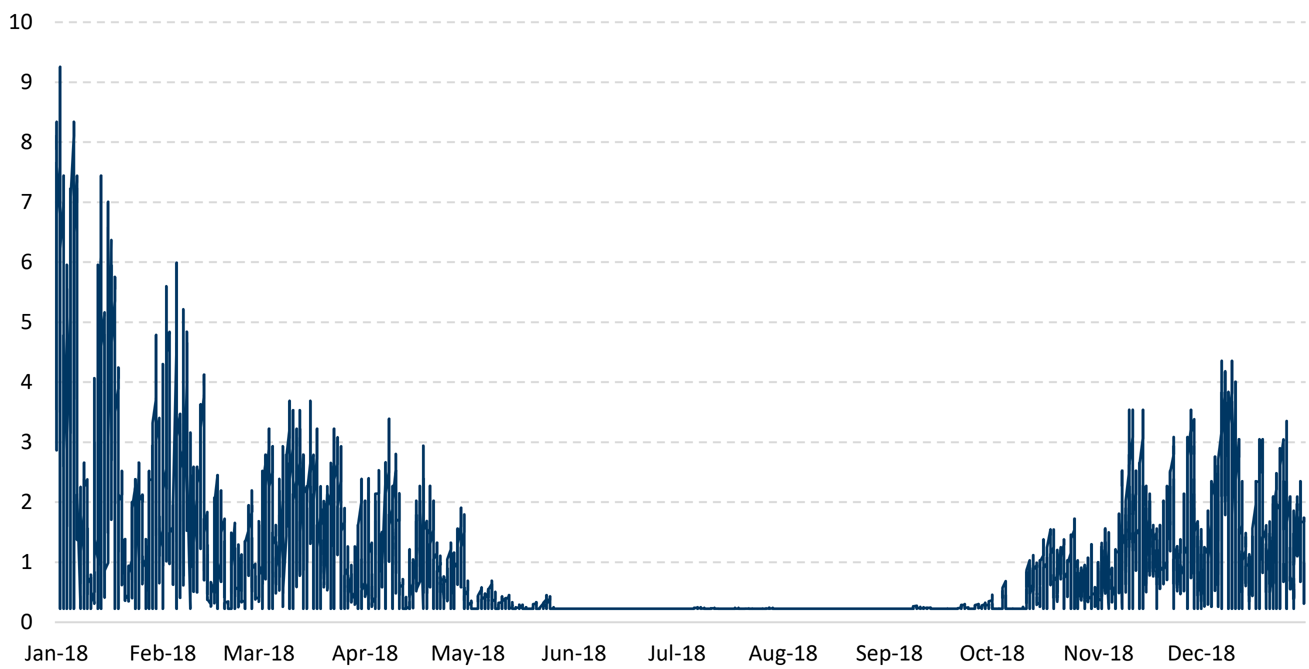
[18] Monthly non-space heating demand determined as the average consumption per Ohio customer in the months of July and August using the Residential Energy Consumption Survey, and an average natural gas customer profile created to convert that demand into general load, "Residential Energy Consumption Survey 2015," *U.S. Energy Information Administration*, https://www.eia.gov/consumption/residential/index.php and, "Commercial Buildings Energy Consumption Survey 2012," *U.S. Energy Information Administration*, https://www.eia.gov/consumption/commercial/

baseload occurs across all hours of the year while the hourly shape represents the hourly and seasonal variations in energy demand for heating and other requirements. AGA analyzed weather data from 2018[19] and a heating degree days methodology to determine the shape.[20]

Our input baseload for the average residential customer was 1,974 kilowatt-hours ("kWh") per year, or 0.23 kWh in any given hour. For the average commercial customer, our input for their annual baseline was 41,709 kWh, or 4.76 kWh of baseload for any given hour of the year. The analysis here does not address the potential for electrification in the industrial sector.

Figure 4 shows the load shape for the average residential customer from the AGA data. The shape implies the load from electrified homes would be at their lowest during the summer months of June, July, August, and into September, which have little heating load.

Figure 4 – Hourly load shape for the average residential customer (kWh)



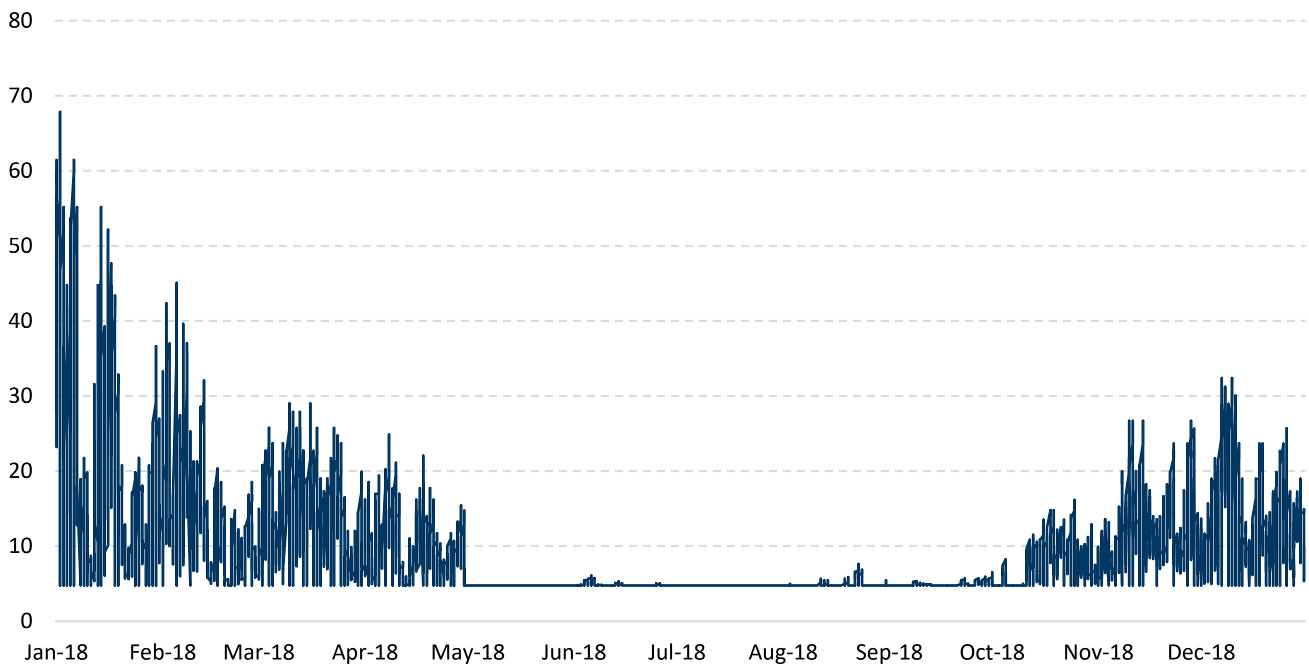
The load for heating begins to appear in October and November, peaks in January, and decreases throughout the rest of the late winter and early spring with numerous oscillations along the way to account for daily and weekly temperature variations in Ohio.

Figure 5 has the same data for commercial customers. The trends between Figure 4 and Figure 5 are generally similar. Summer load from electrified commercial customers is at its nadir, and it is usually the same as the baseload. Heating load becomes a factor in October and November, again peaks in

[19] Monthly space heating load weighted by local hourly weather data from the National Centers for Environmental Information ("NOAA"), https://www.ncdc.noaa.gov
[20] FTI added 7% to the AGA data to account for transmission and distribution losses

January, and slowly decays throughout the first half of the year to May. Despite the straightforward seasonal patterns of the additional load, there are complex and seemingly random fluctuations for hourly and daily load data because of varying temperatures.

Figure 5 – Hourly load shape for the average commercial customer (kWh)



Appendix B summarizes the average electricity load by month and hour for the two customer types. Table 11 covers residential customers, and Table 12 covers commercial customers.

FTI used the load shapes in Figure 4 and Figure 5 as well as the conversions and new builds detailed in Figure 2 and Figure 3 to estimate the additional load on an hourly basis from the start of 2021 through to the end of 2040. First, for any given years, FTI multiplied the load shapes by the sum of all previous conversions and new builds from previous years. Second, we added to that with new conversions and new builds from the present year while assuming the present year's load came online throughout the year linearly (i.e., without season trends). Third, we added this incremental load to the electrification scenarios on top of the preexisting load for AEP in the PLEXOS model.[21]

Building Inputs to the IMPLAN Model

We used the information from the previous subsections to build inputs into the IMPLAN model to simulate the economic impacts of electrification on the Columbus MSA. The inputs represent the net

[21] The heat pumps have a theoretical coefficient of performance of 3.0 and a space heating operating range between 65°F and -27°F. The optimal breaking point was assumed to be 35°F, which would suggest each unit was properly sized to fit the *ASHRAE Handbook* description for heat pump installation, *2016 ASHRAE Handbook, HVAC Systems and Equipment*, Chapter 49, p. 10, Figure 13, "Operating Characteristics of Single-State Unmodulated Heat Pump"

difference between the Base Case and the electrification scenarios. We simulated the results on an annual basis starting in 2021 and concluding at the end of 2040.

Residential Customers

For residential customers, our inputs into IMPLAN take the form of six categories. Those categories include those from Table 4 as well as some additional details:

1. Equipment Spending
2. Installation Spending
3. Maintenance Spending
4. Natural Gas Spending
5. Electricity Spending
6. Consumption Reallocation

"Consumption reallocation" is the money available to residential consumers that they could spend on their own preferences in one scenario but cannot in another because of higher costs. Table 4 shows the electrification of homes would require residential customers to spend more of their incomes on energy-related bills (including #1 through #5 on the list) compared to the Base Case with its lower overall costs. The difference is the consumption reallocation.

Because of the consumption reallocation, households would reallocate their spending away from daily needs for goods and services at the margin. Instead, they would use that same money to cover higher energy-related costs. Such an approach assumes consumers' price elasticity of demand for energy needs is perfectly inelastic. One of the main economic impacts of electrifying the Columbus MSA is the effect that this reallocation has on the economic sectors depending on consumers in the region, such as retail, healthcare, food services, and arts and entertainment.

The following list summarizes how FTI inputted each of these as inputs into IMPLAN:

1. **Equipment Spending** – We inputted net changes in equipment spending by year as added or reduced demand for the relevant manufacturing sectors for gas-fired heating equipment, for electric heat pumps, and for electrical panels. We assumed retrofitting homes would pay for the difference in costs in the immediate year. For new homes, we assumed the difference in costs become part of the purchase price of the home. Hence, we amortized any difference in costs across 30 years of payments. We estimated the interest rate attached to 30-year fixed mortgages in the future based on data from the Congressional Budget Office ("CBO")[22] and from the Federal Reserve. CBO projects the interest rate for 10-year U.S. Treasury Notes from

[22] "The Budget and Economic Outlook: 2020 to 2030," *Congressional Budget Office*, 28 January 2020, https://www.cbo.gov/publication/56020

2021 through 2030,[23] which we extended by assuming the rate for 2030 (3.1%) remains the rate through 2040. We then analyzed the historical difference between interest rates on 10-year U.S. Treasury Notes[24] and 30-year fixed mortgages.[25] We found the difference between the two was 1.76% on average over the past 20 years. We applied this difference to the extended CBO forecast to generate a forecast of mortgage rates out through 2040.

2. **Installation Spending** – We inputted net changes in installation spending by year through demand for the relevant construction and maintenance sectors in IMPLAN. We applied similar assumptions to these inputs as the ones for equipment spending – installation costs for new homes become part of the purchase price, and the costs are part of amortizing the price of the structure. Retrofits are considered a cost in the immediate year.
3. **Maintenance Spending[26]** – For maintenance, we entered net changes in spending by year by changing demand for the relevant construction and maintenance sectors in IMPLAN. We assumed maintenance spending is a cost in its immediate year.
4. **Natural Gas Spending** – We entered the net changes in natural gas spending – which was a reduction when moving from the Base Case to the electrification scenarios – as a decrease in demand for the natural gas distribution sector in IMPLAN. The gas distribution sector in IMPLAN includes local gas utilities and, through the input-output linkages inherent within the model, it links into natural gas pipelines and extraction.
5. **Electricity Spending** – We entered the net changes in electricity spending as a decrease in the demand for the electric power transmission and distribution sector in IMPLAN. Such spending increased in the electrification scenarios relative to the Base Case, and we considered energy expenditures as something covered in their immediate year.
6. **Consumption Reallocation** – For any given year, we entered the opposite number as the sum of the other five factors as consumption reallocation. For instance, if for each year the net effect regarding the sum of the costs for the other five factors was $2,000, then we reallocated the level of household consumption by -$2,000 in IMPLAN. We used the underlying consumption equation in IMPLAN to determine which economic sectors would experience a decrease in their demand through the apportionment of the consumption reallocation.

Figure 6 provides an example of the IMPLAN inputs for the residential sector in 2040. Spending for equipment would be slightly higher ($4 million) in the Base Case, though higher expenditures for

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[23] "10-Year Economic Projections," *Congressional Budget Office*, 28 January 2020, https://www.cbo.gov/system/files/2020-01/51135-2020-01-economicprojections_0.xlsx

[24] "10-Year Treasury Constant Maturity Rate," *Federal Reserve Economic Data*, https://fred.stlouisfed.org/series/DGS10

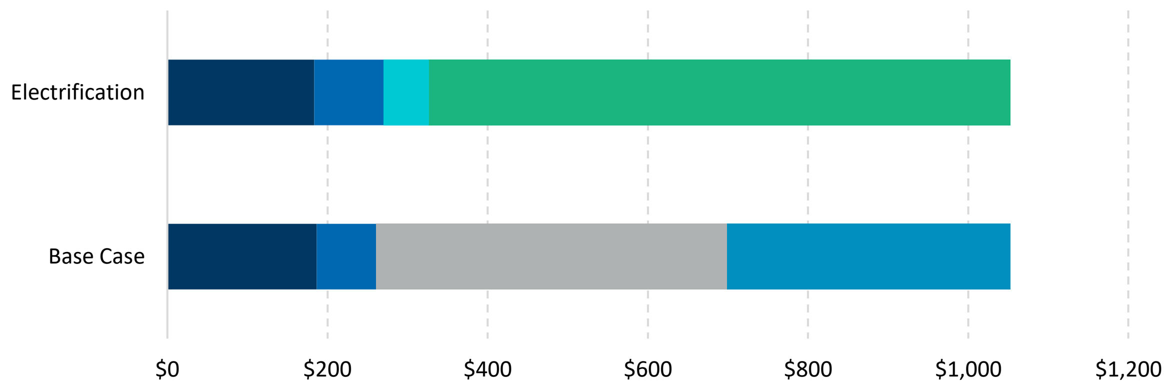
[25] "30-Year Fixed Rate Mortgage," *Federal Reserve Economic Data*, https://fred.stlouisfed.org/series/DGS10

[26] Considered separately here and in the inputs to the IMPLAN model even if combined with the ongoing expenditures for energy/operations in Table 4

installation and maintenance in the electrification scenarios mean cost for equipment and labor would be higher ($66 million) in that scenario. The lion's share of the difference in costs between the situations comes from energy costs. In the Base Case, the residential sector spends $439 million on natural gas compared to $726 million when under electrification.

The difference in total expenditures between the two – which is $354 million – becomes the data for the consumption reallocation in Figure 6. Household consumers in the Base Case would have more leftover income to spend on their typical needs and wants.

Figure 6 – IMPLAN inputs for 2040 for the residential sector (2018 $ millions)



	Base Case	Electrification
Equipment Spending	$187	$183
Installation Spending	$74	$87
Maintenance Spending	$0	$57
Natural Gas Spending	$439	$0
Electricity Spending	$0	$726
Consumption Reallocation	$354	$0

Commercial Customers

The process for building IMPLAN inputs related to commercial customers was like the approach for residential customers. However, there were two important differences:

1. We assumed equipment costs, installation costs, and maintenance costs were the same for commercial customers between the Base Case and the electrification scenarios (as we earlier described in Table 5). Hence, there was no need to consider if commercial customers would amortize their costs over a 30-year loan period, and we assumed they covered their higher costs for electricity relative to natural gas in the immediate year.
2. FTI treated the equivalent concept to "consumption reallocation" for commercial customers differently than we did for residential customers, which we document here.

Under the electrification scenarios, commercial customers would have higher energy costs than they would under the Base Case. We need to reflect these higher costs in the IMPLAN model, though commercial customers are not like households where they would simply reduce their consumption on the margin like households would when paying higher utility bills.

We have modeled this reallocation in IMPLAN through two paths. For the share of each commercial sector's business done within the Columbus MSA,[27] we have assumed they pass the same proportion of their higher costs along to customers within the Columbus MSA. For instance, IMPLAN estimates 76.4% of hospital activities[28] in the Columbus MSA are for consumers in the Columbus MSA with the remainder (24%) "exported" to customers outside the Columbus MSA.

We consider the 76.4% estimate from IMPLAN reasonable for three reasons. First, it is lower than the other healthcare sectors (such as ambulatory care). Other healthcare sectors in the Columbus MSA derive more than 95% of their business from the Columbus MSA, which is sensible when patients in need of ambulatory services are more likely to seek services close to home. Second, the 76.4% figure is much higher than sectors that purely depend on exports. For instance, sectors such as hotels generate less than 5% of their business from local customers in IMPLAN.

Our third reason is the most notable and requires additional context. The Columbus MSA has a large healthcare sector that services not just local customers but also the surrounding rural areas, the rest of Ohio, and even other states. Example institutions include the Ohio State University's Wexner Medical Center,[29] OhioHealth, Mount Carmel Health System,[30] and Nationwide Children's Hospital. Each of these institutions employs thousands and has multiple facilities. All rank among the largest employers in the Columbus MSA along with the state of Ohio.[31] Thus, IMPLAN illustrating the economy and the healthcare system of the Columbus MSA as "most" (76.4%) of inpatients are from the Columbus MSA with 24% of inpatients from the surrounding region is reasonable.

For the share of higher energy costs attributed to exports, we have reduced the direct outputs of commercial sectors themselves. Higher costs for businesses in the Columbus MSA would degrade their competitiveness relative to the other options in the regions for consumers. For instance, to continue with the example of hospitals, their higher energy costs to provide inpatient care would discourage patients and insurance companies from the regions outside of the Columbus MSA from using their services. Instead, nonlocal patients could instead choose to utilize local facilities or similarly renowned facilities in Cincinnati, Cleveland, Pittsburgh, or southeast Michigan.

[27] IMPLAN calls this the "local use ratio" or the "regional supply coefficient," the "RSC"

[28] NAICS 622, "Industries in the Hospitals subsector provide medical, diagnostic, and treatment services that include physician, nursing, and other health services to inpatients and the specialized accommodation services required by inpatients, https://www.census.gov/cgi-bin/sssd/naics/naicsrch?code=622&search=2017%20NAICS%20Search

[29] "About Us," *The Ohio State University Wexner Medical Center*, https://wexnermedical.osu.edu/about-us

[30] "About Us," *Mount Carmel*, https://www.mountcarmelhealth.com/about-us/

[31] Robin Smith, "Here are Central Ohio's largest employers: Our rankings found 120+ organizations with 100+ workers," *Columbus Business First*, 12 July 2019, https://www.bizjournals.com/columbus/news/2019/07/12/here-are-central-ohios-largest-employers-our.html

Figure 7 shows an example flowchart of this process for the hospital sector. The process is similar in all other commercial sectors within the IMPLAN model.[32]

Figure 7 – Calculation process in 2040 for the hospital sector

1. **Increase in energy costs for all commercial customers** = $326.3 million
2. **Hospitals' share of all commercial customers' natural gas demand in IMPLAN** = 3.2%
3. **Increase in hospitals' energy costs in 2040** = $10.5 million[33]
4. **Share of hospitals' customers coming from the Columbus MSA** = 76.4%
5. **Higher costs passed along to local customers in the Columbus MSA** = $8.0 million
    a. Add these costs to the "consumption reallocation" from the previous section
    b. Similar effects to economic sectors depending on consumer expenditures
6. **Costs borne by hospitals as reduced output from reduced competitiveness** = $2.5 million

We repeated a similar set of calculations for all commercial sectors in the IMPLAN model for all years, which we then inputted into the model for our simulations.

Electricity Prices

We also modeled the impacts of higher electricity prices in IMPLAN. As described, the electrification scenarios would engender additional electricity load in PJM and AEP specifically. For both the MB Scenario and the RO Scenario, two important results of this would be higher average annual prices for electricity and more pronounced seasonality between summer and winter.

To calculate the increase in the "bill"[34] between the Base Case and electrification scenarios for all customers in the Columbus MSA,[35] we first multiplied the underlying load from the Base Case in PLEXOS for AEP by the percent increase in electricity prices for the RO Scenario. To capture the seasonality in prices, we calculated this difference on a monthly basis.

After consultation with AGA, we simulated the economic impact of electrifying the Columbus MSA under the RO Scenario. AGA felt that electrification paired with the requirement that new capacity additions to service that load must be renewables was a more realistic and relevant representation of potential policy designs related to electrifying the regional building stock.

The AEP zone includes most of the Columbus MSA but also much of Ohio and parts of other states. These include southeastern Ohio, the region of Ohio between Dayton and Toledo, much of northwest

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[32] In NAICS order, starting with wholesale trade and ending with services to private households

[33] Assumed gas demand in IMPLAN by sector was a superior factor for apportionment than electricity demand by sector because the situations examine converting from natural gas to electricity

[34] Consumption times prices

[35] Including industrial customers

Indiana and southeast Michigan, some of the West Virginia panhandle and the southwest of the state, eastern Kentucky, and stretches of southern and western Virginia.[36]

We calculated the Columbus MSA's share of AEP load by calculating the average per capita electricity consumption in Ohio.[37] Using this methodology and the population of the Columbus MSA, we found that the Columbus MSA accounted for roughly 20% of the load for the AEP zone. While some outer suburbs of Columbus are outside of AEP's service territory, they are either (1.) still part of the AEP zone, such as if serviced by a cooperative, or (2.) part of PJM even if in another zone inside of the PJM system. For simplicity, we have illustrated the whole MSA as in AEP.

We multiplied the change in the bill between the Base Case and the electrification scenarios by 20% to specify the bill change for the Columbus MSA (as opposed to the grand total for the AEP zone). We allocated this total by year between residential, commercial, and industrial customers based on their share of retail electricity demand in Ohio from EIA data.

For residential customers, we applied the same approach with consumption reallocation that we did with their higher costs for switching from natural gas to electricity for their heating and appliance needs. As before, the higher residential bill implies higher utility bills for existing electricity demand (such as for their air conditioners, electronics, or lighting). When residential customers face higher utility bills at the end of the month, they trim consumption elsewhere.

For commercial and industrial customers, we applied a similar approach to the one with commercial customers converting from natural gas to electricity. The share of their business with local customers is the share of their costs passed through to local consumers. The remainder becomes a reduction in their direct output to illustrate a reduction in competitiveness. Unlike the approach with commercial customers, this applies to industrial customers, as well, because their preexisting load would have to experience higher prices even if they are not electrifying their processes.

Because we used a bill methodology based on wholesale prices only, we are assuming distribution costs – the markup electricity utilities charge to cover their costs to bring electricity from wholesale markets to local distribution – would remain unchanged.

We also increased the energy costs from Table 4 and Table 5 for homes and commercial structures electrifying over time. Electrified residential customers would pay $966 in 2021 for energy, which would increase to $971 in 2040.[38] For electrified commercial customers, the same figures would rise from $8,359 in 2021 to $8,407 in 2040 (or a change of 0.6%). These higher costs for the customers in the Columbus MSA would become an important factor in IMPLAN.

[36] "PJM releases 2018 load forecast," *PJM*, 28 December 2017, https://insidelines.pjm.com/wp-content/uploads/2016/01/2015-Load_Report_Cover.png
[37] "Ohio," *U.S. Energy Information Administration*, https://www.eia.gov/state/?sid=OH
[38] 2018 dollars

Simulation Results

We have organized the results of the simulations in PLEXOS and IMPLAN into two sections. The first section describes the power market simulations in PLEXOS for the MB Scenario, the RO Scenario, and the important distinctions between the two. The economic impact results from IMPLAN are from the RO Scenario only and include the fiscal impacts of electrification, as well.

Power Market Results

Results for the power market modeling divide into several subsections. These include those for the incremental load added by the electrification scenarios, the impact on capacity expansion and on the price of electricity in the AEP zone, and emissions throughout PJM.

Electricity Load

Figure 8 shows the additional load required in the AEP zone because of the electrification scenarios. Impacts increase over time as more and more structures electrify per Figure 2 and Figure 3. By 2040, the impact is around 11.7 million megawatt-hours ("MWh"). Compared to the underlying load for existing customers, this is around a 7.8% increase in the total energy.

Figure 8 – Annual AEP zone total energy

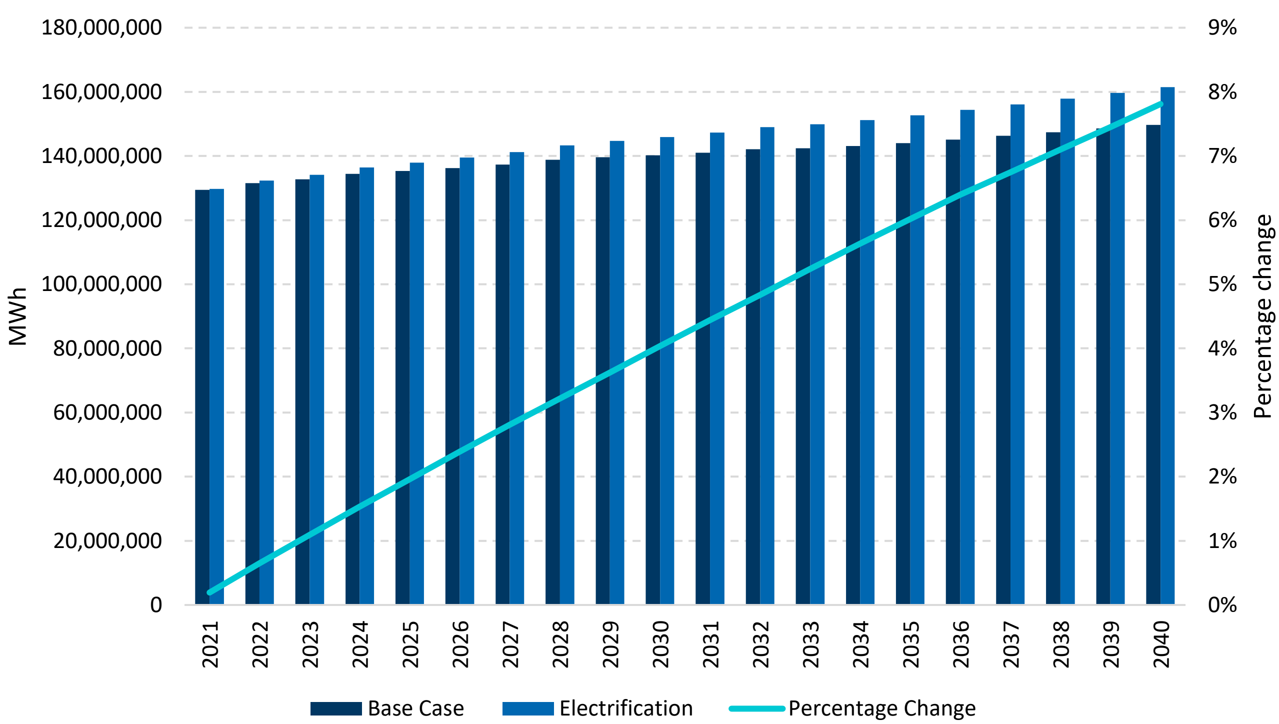


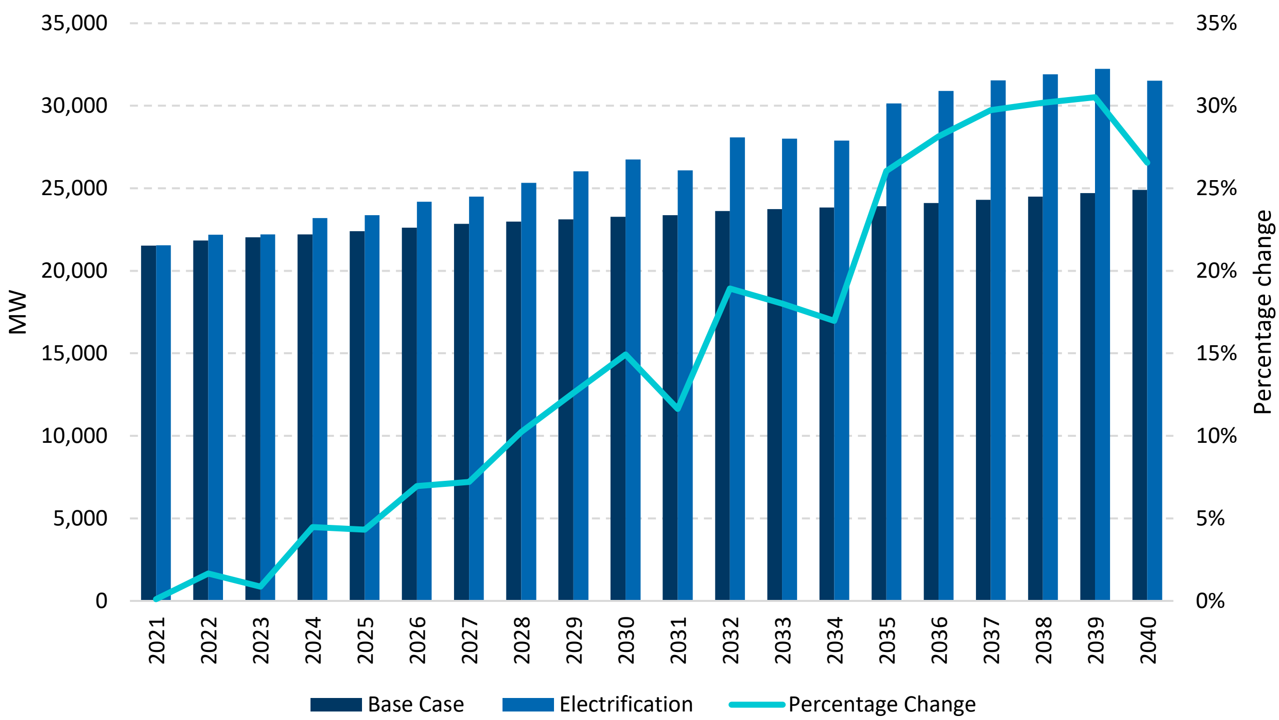
Figure 9 relies on the same underlying dataset as Figure 8 but looks at the peak load for the AEP zone. Total energy would increase in a dependable fashion year-by-year as structures electrify. On the other hand, peak load would be more complex because heating demand for the Columbus MSA would not necessarily be coincident with the peak load for the rest of the AEP zone.

We used the same load shape (from AGA) for all years to estimate the hourly peak heating demand. According to both Figure 4 and Figure 5, this would be at 7:00 AM and 8:00 AM on January 2. The load shape for the existing load in PLEXOS is more dynamic and realistic. Based on its own 2018 load shape, PLEXOS varies the peak hour for the preexisting load throughout late January and early February on different days each year though typically at 7:00 AM or 8:00 AM.

Upon adding the electrification load to the preexisting load, we should expect their peaks to occur in different hours. The Columbus MSA is around 20% of the load for the AEP zone, which stretches from east of the Appalachian Mountains in Virginia to the shores of Lake Michigan. Weather conditions for the same hour can vary across such a large area,[39] so we should imagine the long-term trend from electrifying the Columbus MSA to increase peak load for the zone but not for the trend to be steady or constant because of hourly weather variations between the years.

Figure 9 and its data reflects the logic of this construction. Peak load in 2040 absent electrification is 24,900 megawatts ("MW"). With the electrification load added, it is 26.5% higher at 31,500 MW. Conversely, because of the realistic year-by-year variations in our load inputs to PLEXOS, this is less compared to 2039 when the impact to peak load would instead be 30.5%. The trend over 20 years is nonetheless upwards as more structures undergo their conversions.

Figure 9 – Annual AEP zone peak load



39 For example, Benton Harbor, Michigan to Danville, Virginia (at the extreme ends of the zone to the northwest and the southeast, respectively) would require a 12-hour drive of approximately 700 miles

Figure 10 shows the same data as Figure 8 only on a monthly basis. It delineates between months of relatively high load compared to months of comparatively low load. In the earliest years of Figure 10 for both the Baseline Simulation and the electrification scenarios, the AEP zone has peak months in the midwinter and the midsummer with shoulder months in the spring and fall. With the electrification scenarios, this situation changes over time. Summer months, such as June, July, and August, would become secondary peaks compared to January and February.

Figure 10 – Monthly AEP zone total energy

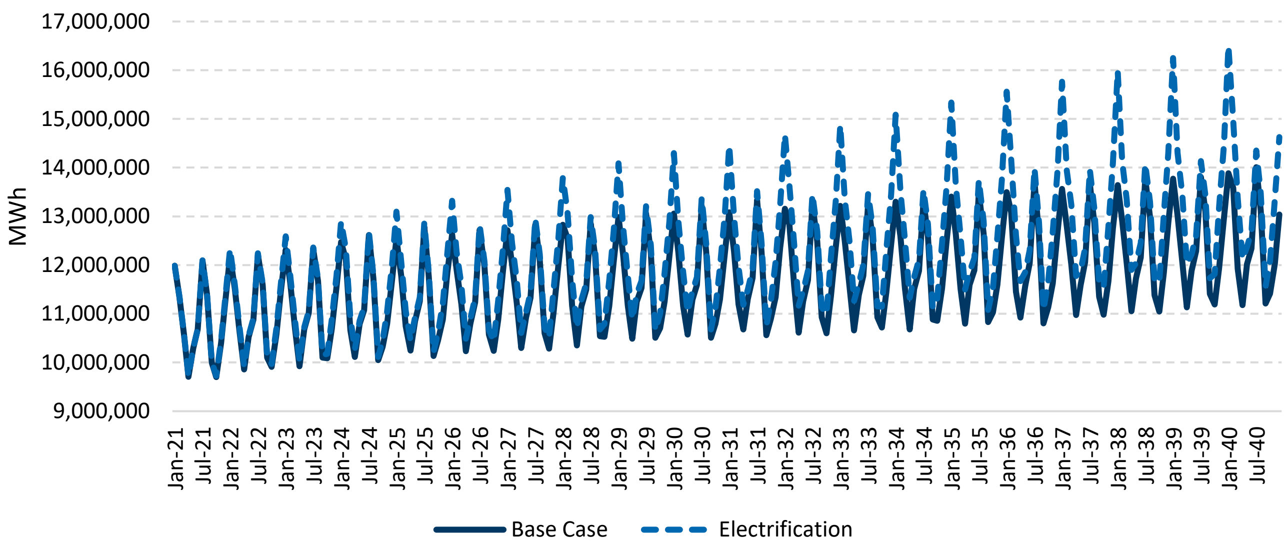
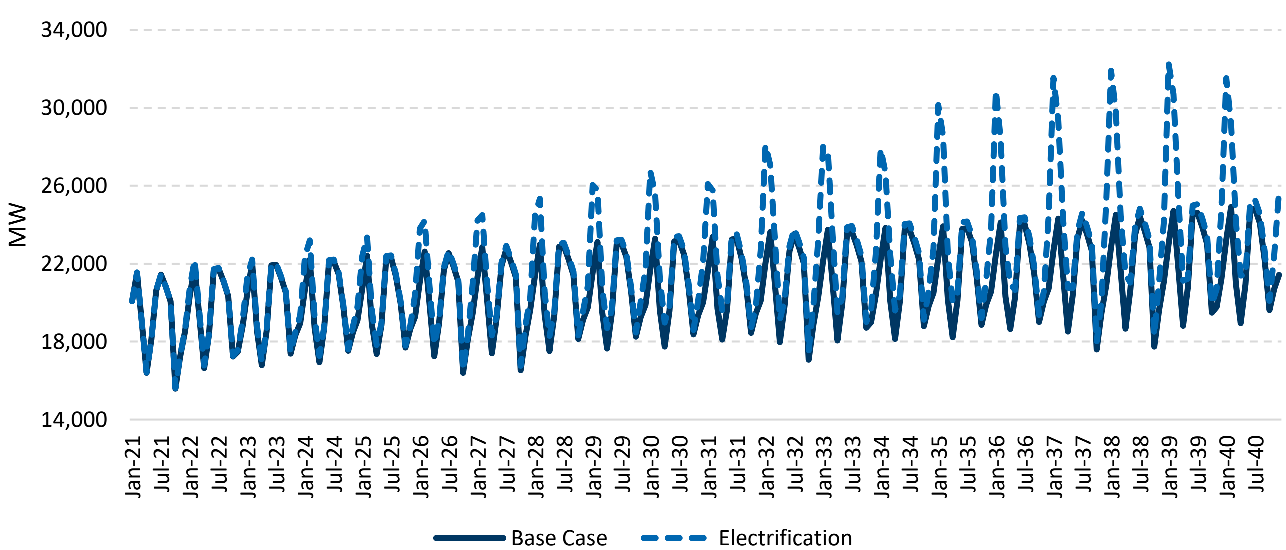


Figure 18 has similar seasonal patterns. In the Base Case, peak summer load and peak winter load were close to each other. Over time, the electrification scenarios would increase peak winter load higher and higher in comparison to the peak load experienced during the summer months.

Figure 11 – Monthly AEP zone peak load



Capacity Expansion

We simulated the impacts of the additional load from Figure 8 through Figure 11 in PLEXOS without other changes (e.g., natural gas prices or renewable portfolio standards). PLEXOS makes capacity additions to the power market based on the economics of potential additions and the need for the electricity system to maintain appropriate planning reserve margins.[40]

Table 6 summarizes the capacity expansion results for the Base Case and the two scenarios under the electrification from 2021 through 2040.[41] The bottom rows summarize the difference of additions between the electrification scenarios and the Base Case. For more detailed, year-by-year results of the simulations, please see the tables included in Appendix C.

Table 6 – Capacity expansion from PLEXOS simulations for PJM (2021 to 2040, gigawatts)[42]

Scenario	Solar	Wind	Biomass	Natural Gas (Combined Cycle)[43]	Thermal Retirements[44]	Net Additions
Base Case	49.9	4.1	0.2	14.6	2.6	66.2
MB Scenario	49.9	4.1	0.2	15.8	2.6	67.4
RO Scenario	51.9	3.9	0.2	14.6	2.6	68.1
MB Scenario versus Base Case	0.0	0.0	0.0	1.2	0.0	1.2
RO Scenario versus Base Case	2.0	-0.1	0.0	0.0	0.0	1.9

Table 6 reveals several important trends driving the results for electricity prices and emissions under the different setups. Across PJM and between 2021 and 2040, the Base Case would add 51.9 GW of

[40] The planning reserve margin measures the amount of generating capacity available to meet expected demand, and an adequate planning reserve margin ensures the system can meet instances of high and peak load
[41] There would be no additions of other generation types in the simulations, such as nuclear plants
[42] Numbers may not add exactly due to rounding
[43] Natural gas additions all used combined cycle technology – there were no "peaker" unit additions
[44] Includes coal and older natural gas-fired units

solar capacity, 3.9 GW of wind capacity, 0.2 GW of biomass, and 14.6 GW of natural gas plants using combined cycle technology. There would also be 2.6 GW of retirements from coal and older gas plants, bringing total net capacity additions over 20 years to 66.2 GW.

Under the MB Scenario, these changes would mostly be the same except for NGCC plants. Because of the additional load throughout the year from Figure 8 and Figure 10 and the peak load from Figure 9 and Figure 11, PJM would add 1.2 GW of NGCC plants. This is less than the increase in peak load from Figure 9 and Figure 11, which in 2039 would be roughly 7.5 GW. The NGCC additions would be less than the increase in peak load from the Columbus MSA for two reasons.

Firstly, the incremental additions to peak load would not necessarily be coincident with peak load across the whole of the PJM system. AEP is one of the largest zones in PJM by land area, but PJM stretches from Illinois, to North Carolina, to New Jersey. It encompasses portions of the Midwest, Appalachia, and the Mid-Atlantic regions. In most instances, its sizeable footprint would give PJM ample "slack" capacity to meet peak heating demand in the Columbus MSA. Secondly, PLEXOS allows for imports from other systems, such as the Midcontinent Independent System Operator ("MISO"),[45] which gives AEP and PJM another avenue for satiating peak load.

Nevertheless, additional load in the electrification scenarios would engender conditions suitable for adding the 1.2 GW of NGCC plants from the MB Scenario. New NGCC plants like the 1.2 GW would be competitive on the market – new NGCC plants have low heat rates and dispatch at lower costs than existing thermal units, and they would also be a flexible resource. This pair of factors would help contribute to any new NGCC plants running at a high capacity factor.

In the RO Scenario, the results would be largely alike to the MB Scenario save for incremental builds of solar plants and NGCC plants. Instead of 1.2 GW of NGCC plants, the RO Scenario would add 2.0 GW of solar capacity. There would also be a small (145 MW) reduction in the wind builds, though the key contrast between the MB and RO Scenarios would be with solar and gas.

Appendix C has specific year-by-year additions by plant and simulation. The consideration to note with the year-by-year additions is they would be "stepwise" or "lumpy" over time. That is, future power plants would not come online in a smooth, linear fashion. They would instead come online when reserve margins require them or market economics are favorable, such as a new NGCC plant typically having a capacity between 350 MW and 850 MW.[46] Such effects would create discontinuities when the incremental plants come online in the electrification scenarios.

Additionally, considering IMPLAN again for a moment, FTI did not attempt to model the economic impact of plant construction or operations on the Columbus MSA. Our results in Table 6 cover the

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[45] "About MISO," *Midcontinent Independent System Operator*, https://www.misoenergy.org/about/

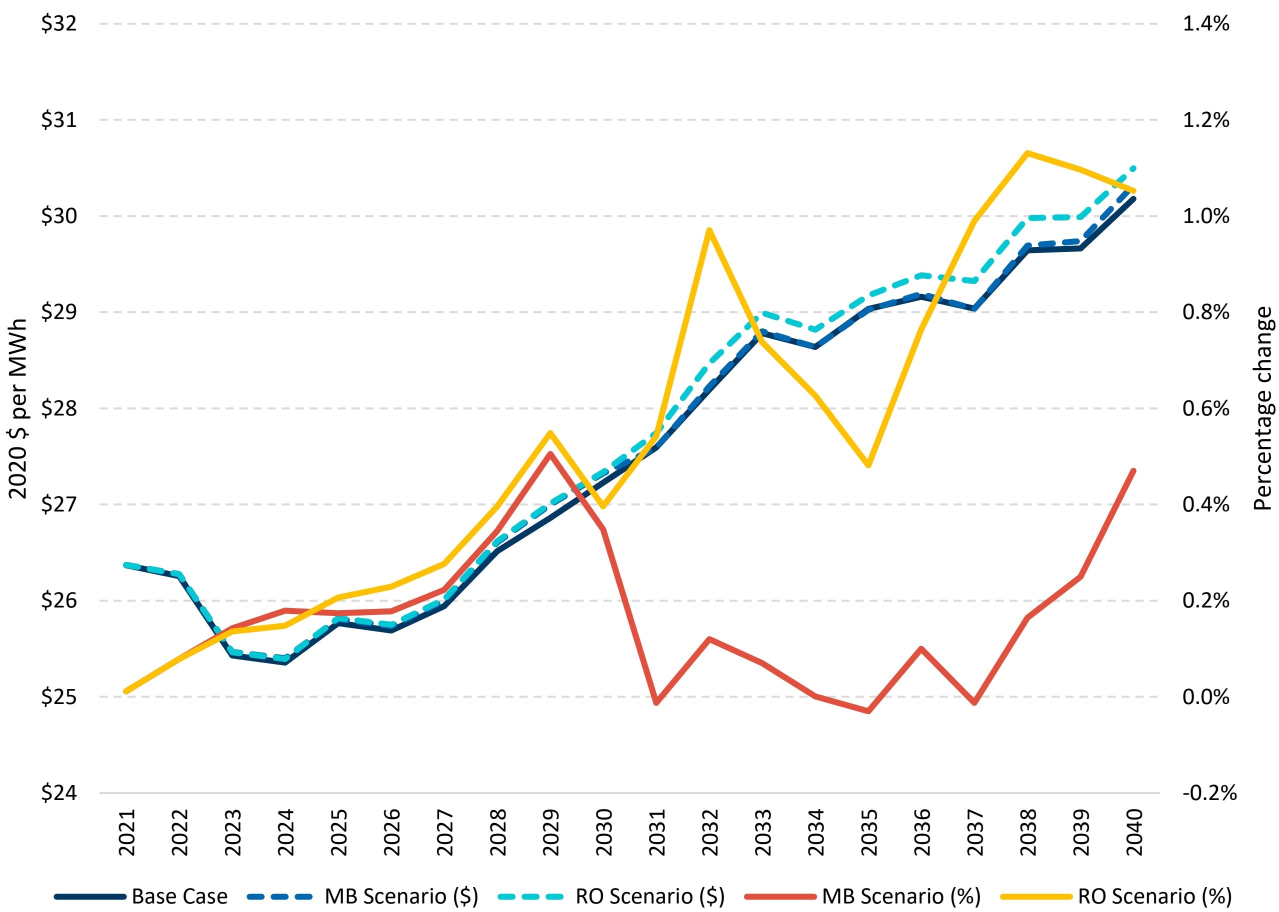
[46] "Power blocks in natural gas-fired combined cycle plants are getting bigger," *U.S. Energy Information Administration*, 12 February 2019, https://www.eia.gov/todayinenergy/detail.php?id=38312

whole of PJM and, even if the 1.2 GW of NGCC in the MB Scenario or the 2.0 GW of solar in the RO Scenario were in AEP, they would be unlikely to be in the Columbus MSA. Utility scale generation is generally in rural areas and away from populated metropolitan areas. Impacts from construction or operations of plants would likely be minimal in the Columbus MSA.

Electricity Prices

Figure 12 shows electricity prices and the impacts to the same across the Base Case and the scenarios for the AEP zone. The three lines for prices – in the varying shades of blue – would stay close to one another across the three simulations, though the MB Scenario would typically have higher prices than the Base Case and the RO Scenario would be higher still than that.

Figure 12 – Annual AEP wholesale electricity price (2018 $)

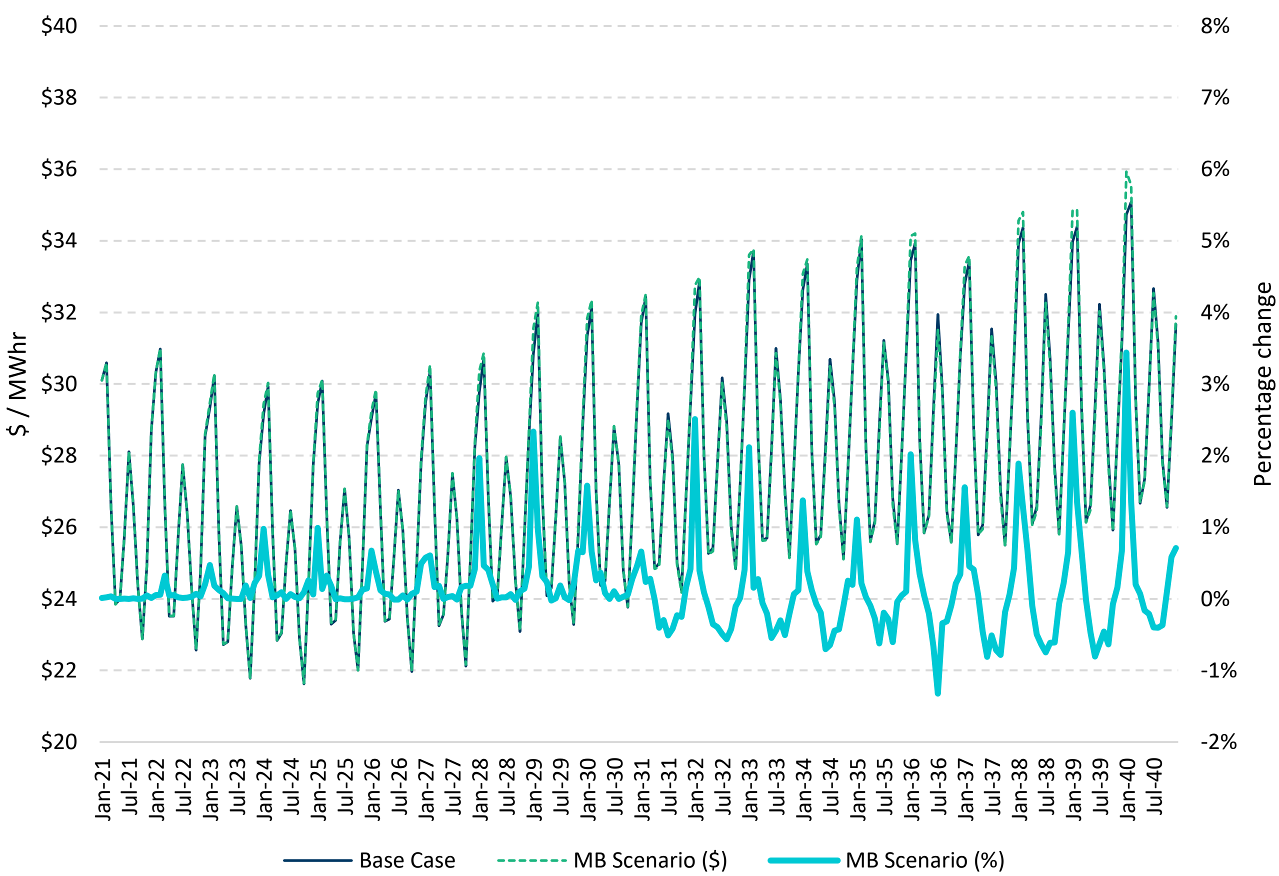


The most important trends in Figure 12 come with the percentage differences. Between 2021 and 2029, there would be little difference in the electricity price impact relative the Base Case with either of the electrification scenarios. The impact in both would peak around 0.5% in 2029. Starting in 2030 and the early 2030s, however, they would diverge. The impact for the MB Scenario would be close to zero until the late 2030s, while the impact for the RO Scenario would be between 0.5% and 1.0% for the remaining years in the 2030s, which is higher than the MB Scenario.

The difference would come down to the preponderance of NGCC or solar additions between the MB and RO Scenarios, respectively, and their influence on electricity markets. The 1.2 GW of NGCC plants within the MB Scenario are lower cost resources to construct and, with their high capacity factors, they would have more of an effect on the market. The 2.0 GW of solar plants within the RO Scenario are higher cost resources to construct and, with their lower capacity factors, they would have less of an impact on the market despite their higher nameplate capacity.

In Figure 13, we show the electricity price for AEP in the Base Case and the MB Scenario. In simple supply-and-demand terms, higher overall load should lead to higher prices. However, because heating load is heavily seasonal, the effect on price would vary throughout the year. For the 2020s, impacts on price would include higher prices in the winter with little effect during the summer and shoulder months. Once 1.2 GW of new NGCC plants begin operating in the 2030s, the increase relative to the Base Case for the winter months would remain yet the price impact for the summer and shoulder months would be one of neutral or even decreasing prices.

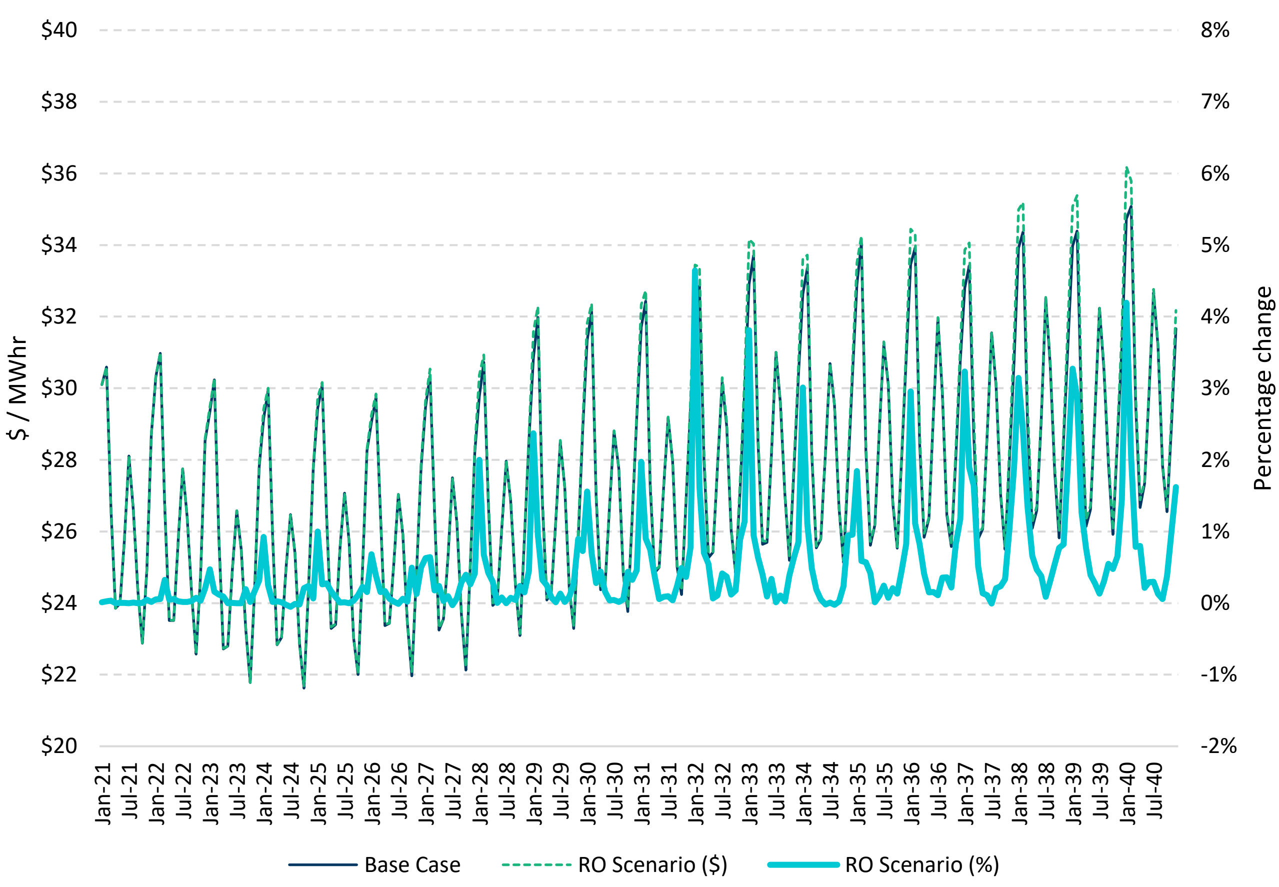
Figure 13 – Monthly AEP wholesale electricity price in the MB Scenario (2018 $)



A price decrease in a scenario involving higher load might seem counterintuitive, yet it follows from understanding the market dynamics. The 1.2 GW of NGCC capacity, built to handle the higher peak load and total energy throughout the year, would not only operate in January to coincide with peak heating load in the Columbus MSA. The plants' low and attractive heat rates would mean they would operate throughout the year and displace other resources with higher costs. Displaced plants would likely be older coal and natural gas units, which the new NGCC units would supplant on the market because they can dispatch at lower prices for electricity.

Figure 14 describes monthly trends in prices for the RO Scenario. In the 2030s, in a similar trend with the MB Scenario, the added heating load would increase prices in the winter while having no strong impact on prices during the summer and shoulder months. Unlike the MB Scenario, this trend would continue in the 2030s instead of the summer and shoulder months having lower prices in scenario compared to the Base Case. As within the MB Scenario, the reason for the higher prices with the RO Scenario involves changing market dynamics with new capacity.

Figure 14 – Monthly AEP wholesale electricity price in the RO Scenario (2018 $)



The RO Scenario adds 2.0 GW of solar power, which would have less of an influence on the market in summer and shoulder months compared to the 1.2 GW of NGCC plants. The solar plants would run at lower capacity factors than the NGCC plants, and the NGCC plants would be able to increase their dispatch quickly when power is most in demand and electricity prices are highest. Their intermittency would constrain the solar plants from having the same impact on the market.

Taken together, the NGCC plants in the MB Scenario would be able to displace more coal and gas than the solar in the RO Scenario, leading to the results in Figure 14.

Emissions Results

The PLEXOS modeling produced results for emissions of CO2, NOx, and SO2. Table 7 includes summary results for 2021 to 2040 for the three different types of emissions across 20 years. Appendices have results on an annual basis. Table 7 includes both the emissions from generators in PJM and emissions from generation outside of PJM yet imported into the system.

Table 7 – Emissions results (2021 to 2040)

Scenario[47]	CO2 (millions of metric tons)	NOx (thousands of short tons)	SO2 (thousands of short tons)
Base Case[48]	52.9[49]	58.2[50]	0.5[51]
MB Scenario	48.3	10.0	5.0
RO Scenario	65.6	31.3	38.4
MB Scenario versus Base Case	-4.6 (-8.7%)	-48.2 (-82.9%)	4.5 (908.2%)
RO Scenario versus Base Case	12.8 (24.2%)	-26.9 (-46.3%)	38.1 (7,657.0%)

Table 7's results vary depending on the electrification scenario and the compound. For CO2, the MB Scenario would reduce emissions compared to the Base Case by 4.6 MMT. The RO Scenario, on the other hand, would increase CO2 emissions by 12.8 MMT. Like with prices, the higher CO2 emissions results for a scenario designed around expanding renewable capacity might seem counterintuitive, though they descend from the earlier discussion on market dynamics.

As discussed earlier, the price impact of the MB Scenario would be less severe because NGCC plants would be more effective at displacing coal and older gas plants than the solar added under the RO Scenario. Despite the new NGCC plants emitting when they generate, the quantity of coal that they

[47] Emissions results for the MB Scenario and RO Scenario are outputs of the PLEXOS model
[48] For homes converted to high-efficiency natural gas, we modeled each home requiring 77.7 million cubic feet ("Mcf") of gas each year; for commercial structures, we modeled their gas demand as 666.7 Mcf per year
[49] 117.1 pounds of CO2 per Mcf of natural gas
[50] 0.117 pounds of NOx per Mcf of natural gas
[51] 0.001 pounds of SO2 per Mcf of natural gas

would displace would overcome the solar plants' advantage of zero direct emissions. The stronger displacement of coal under the MB Scenario is evident in the NOx and SO2 results from Table 7 with the MB Scenario having less NOx and SO2 compared to the RO Scenario.

For NOx and SO2, the results in Table 7 depend on the compound. The Base Case would have higher NOx emissions compared to either scenario, though both scenarios would have higher SO2 emissions compared to the Base Case. With a different "story" for each of the compounds across the various simulations, analyzing the "efficiency" of electrifying energy demand from residential and commercial customers in reducing emissions depends on a handful of factors. Those factors include the costs for achieving those reductions and a reasonable valuation for the same.

Table 8 undertakes this valuation using social costs. The social costs under the calculations are $50.86 per metric ton for CO2;[52] $6,704 per short ton for NOx, and $39,599 per short ton for SO2. The table includes the difference in the valuations between the electrification scenarios and the Base Case for each individual compound as a sum of the totals in the rightmost column.

Table 8 – Valuation of the increased or decreased emissions in the scenarios (2018 $ millions)

Scenario	CO2	NOx	SO2	Total
MB Scenario versus Base Case	$233.1	$323.4	-$179.0	$377.5
RO Scenario versus Base Case	-$649.5	$180.7	-$1,508.8	-$1,977.6

The RO Scenario would have lower NOx emissions than the Base Case, but it would be counter to the purpose of reducing CO2 emissions or improving air quality given results for SO2 emissions in Table 7 and Table 8. The MB Scenario presents the more interesting argument, though its reduction in CO2 and NOx emissions relative to the Base Case comes only at enormous cost.

Extending Figure 6 out to all years and customer types would mean the Columbus MSA's customers face $7.4 billion in additional costs from electrification. That figure includes only the Columbus MSA and none of the costs borne by customers paying slightly higher prices for electricity throughout the geographical footprint of PJM. Consequently, for CO2 alone, the costs for emissions reductions would be $1,615 per metric ton. If including NOx and SO2 in a benefit-cost using a 5% discount rate and the valuations from Table 8, then the Columbus MSA would pay $154 in costs for each $1 in benefits. Most of the saved emissions would be in the 2030s, which reduces present values.

[52] 3% average for 2020 inflated to 2018 dollars, "The Social Cost of Carbon," *U.S. Environmental Protection Agency*, https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

Economic Impact Results

This subsection summarizes the results of the economic impact analysis. While the previous section regarding the power market modeling reveals important differences in the results of the MB Scenario and the RO Scenario, these are less critical for the economic impact analysis.

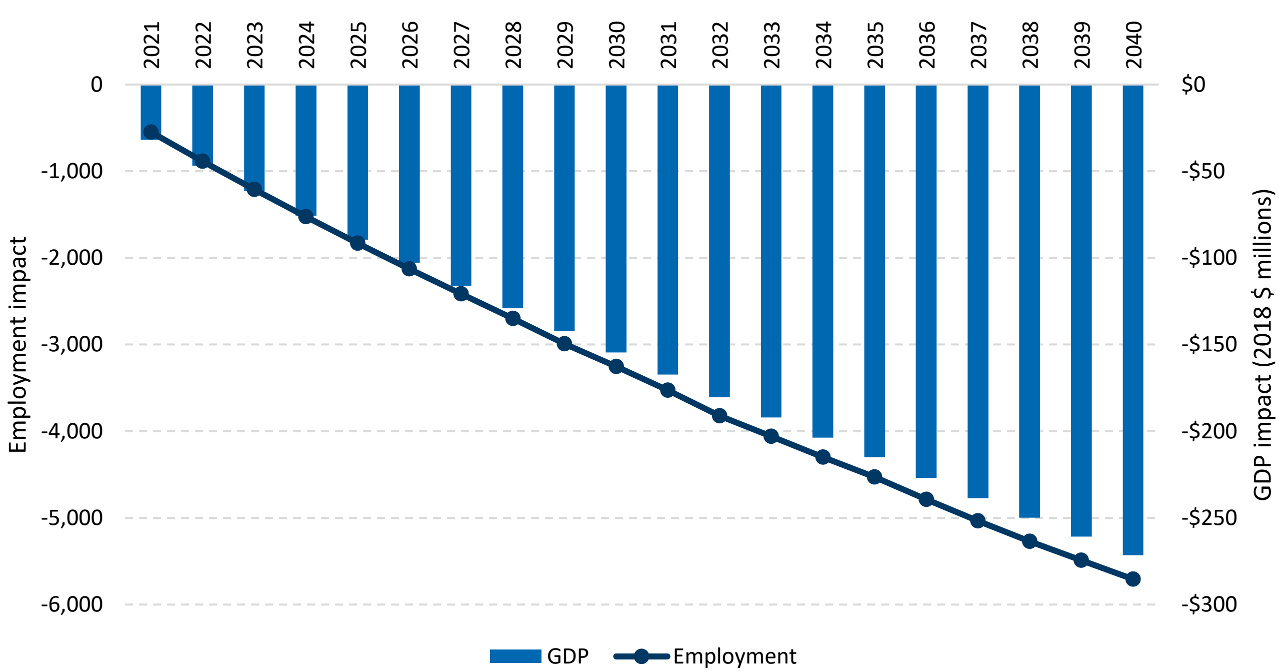
The main factors driving the economic impacts of electrifying the Columbus MSA's residential and commercial building stock would be the higher cost to customers to use electricity instead of natural gas for energy. These factors create the consumption reallocation and reduced competitiveness for industry described in the methodology section, and these are the main inputs into IMPLAN. Higher electricity prices are important though a secondary consideration.

Based on the scope of the study, we have reported only the economic impacts of the RO Scenario under the electrification scenarios. The economic impacts under the MB Scenario would be generally similar in magnitude and directionality to the results from the RO Scenario, and the same factors would drive results for both scenarios. Including both would be largely superfluous given the similarity of results between the scenarios and the limited additional insights to gain.

Macroeconomic Summary

Figure 15 summarizes the economic impact over time from the RO Scenario. The impacts would gradually increase as more and more homes and commercial structures undergo conversions, which would increase the costs borne by the Columbus MSA's economy for energy. In comparison to the Base Case by 2040, the Columbus MSA would have 5,700 fewer jobs and roughly $271 million less in GDP generated by the economy of the Columbus MSA otherwise.

Figure 15 – Economic impact of the RO Scenario compared to the Base Case



Employment Impacts

Table 9 describes the employment impacts from Figure 15 by economic sector for five-year increments between 2025 and 2040. Rather than leave the results in NAICS order,[53] we have sorted Table 9 in descending order based on 2040 results. Therefore, the sectors at the top of the list (such as power and construction) have the most positive impacts, and sectors at the bottom of the list (such as the healthcare sector or professional services) have the most negative ones. The effect across all the sectors would be negative – as much as 5,710 fewer jobs by 2040.

Table 9 – Employment impact of the RO Scenario by economic sector in 2040[54]

Economic Sector	2025	2030	2035	2040
Electric Power G, T, and D	240	430	610	770
Construction	90	120	160	180
S&L Government (Non-Education)	0	10	10	20
Coal Mining	0	0	0	0
Other Mining	0	0	0	0
S&L Government (Education)	0	0	0	0
Water and Sewage	0	0	0	0
Agriculture and Forestry	0	0	-10	-10
Federal Government	-10	-10	-20	-20
Manufacturing	-10	-10	-20	-20
Oil and Natural Gas Extraction	-10	-20	-30	-40
Information	-30	-50	-70	-90
Wholesale	-50	-100	-130	-170
Arts, Entertainment, and Recreation	-60	-110	-150	-180
Transportation and Logistics	-70	-130	-180	-230
Private Education	-80	-140	-200	-250
Natural Gas Distribution and Pipelines	-160	-290	-410	-510
Other Personal Services	-190	-320	-450	-560
Accommodation and Food Service	-230	-400	-550	-690
Finance, Insurance, and Real Estate	-240	-430	-610	-770
Retail	-250	-440	-620	-780
Professional and Business Services	-310	-550	-770	-970
Healthcare and Social Assistance	-460	-800	-1,100	-1,380
TOTAL	-1,830	-3,250	-4,530	-5,710

[53] North American Industrial Classification System
[54] Sectoral aggregations documented in the appendix

The results for Table 9 built upon the inputs described in the Methodology and Approach section and narrative several crucial trends for the economic impact of electrifying the Columbus MSA. We have organized these effects and trends into the following three categories:

1. The electric power generation, transmission, and distribution sector in the Columbus MSA would have a higher level of employment in the RO Scenario as compared to the Base Case. Because the energy demand of the Columbus MSA would gradually shift from natural gas distribution and its supply chain towards electricity and its supply chain, the latter sector would have increased employment. The construction sector in Table 9 would also have increased employment levels because of the increased labor costs to install electrified equipment ($2,224 versus $1,903 for homes per Table 4).
2. The first effect would be the upshot of more dollars flowing into the electricity sector and its supply chain, and the second effect would be its opposite – fewer dollars flowing into the gas supply chain and therefore contracting the sector. By 2040, Table 9 reports there would be 40 fewer oil and natural gas extraction jobs and 510 fewer natural gas distribution and pipeline transportation jobs in the Columbus MSA. Summing the losses from the gas sector would be less than the gains reported in Table 9 for the power sector. However, compared these alone does not account for the higher costs (from Table 4 and Table 5) for customers when using electricity instead of natural gas and consumption reallocation.
3. Most other economic sectors in Table 9 (stretching from information to healthcare and social assistance) would have fewer jobs under the RO Scenario. Under electrification, residential customers would trim their spending because of higher utility bills and commercial customers would pass some of their higher costs along to local households.

   Both effects would have a depressive influence on consumer spending in the Columbus MSA and for sectors primarily depending on expenditures by households. For instance, a household facing higher utility bills might choose to reduce its external food or shopping budget, which would negatively impact the foodservice and retail sectors, respectively. The results of such reallocation across the whole of the Columbus MSA's economy would add up to the thousands of jobs lost from electrification relative to the Base Case.

   Healthcare and social assistance would have the most negative impacts to jobs numbers by 2040, which makes the sector worthy of discussion. Much of healthcare spending is a baseline "need," but some types of healthcare (e.g., elective or cosmetic procedures or the amount of preventative care consumed by families) are "wants" and elastic to rising and falling incomes. Healthcare is a labor-intensive sector and, except for inpatient care, healthcare and social assistance are generally localized sectors without extensive import and export flows between metropolitan areas. All these in addition to the previous discussion on the large healthcare sector in the Columbus MSA would help to create the impact.

GDP Contributions

Table 10 recaps the change in GDP contribution by sector from IMPLAN. We use the same pattern of five-year increments between 2025 through 2040 and sort the results in descending order based on results from 2040 (which is the same format as in Table 9). The sectors with the greatest increase in their GDP contributions would include electric power generation, transmission, and distribution and construction. The sectors with the greatest decrease would include retail; professional and business services; healthcare and social assistance; finance, insurance, and real estate ("FIRE"); and sectors in natural gas' value chain, such as local gas distributors and gas pipelines.

Table 10 – GDP impact of the RO Scenario by economic sector in 2040 (2018 $ millions)

Economic Sector	2025	2030	2035	2040
Electric Power G, T, and D	$146.9	$269.7	$379.8	$478.1
Construction	$8.0	$11.4	$14.5	$17.1
S&L Government (Non-Education)	$3.3	$6.1	$8.7	$10.9
Coal Mining	$0.0	$0.0	$0.0	$0.0
Other Mining	$0.0	$0.0	$0.0	$0.0
S&L Government (Education)	$0.0	$0.0	$0.0	$0.0
Water and Sewage	$0.0	-$0.1	-$0.1	-$0.1
Agriculture and Forestry	-$0.1	-$0.1	-$0.1	-$0.2
Federal Government	-$0.6	-$1.0	-$1.4	-$1.8
Manufacturing	-$1.5	-$2.2	-$2.9	-$3.6
Arts, Entertainment, and Recreation	-$2.6	-$4.5	-$6.3	-$7.8
Oil and Natural Gas Extraction	-$2.6	-$4.7	-$6.6	-$8.2
Private Education	-$4.0	-$6.9	-$9.5	-$11.9
Transportation and Logistics	-$4.8	-$8.6	-$11.9	-$15.0
Wholesale	-$7.0	-$12.5	-$17.5	-$22.0
Information	-$6.8	-$12.2	-$17.4	-$22.4
Accommodation and Food Service	-$8.6	-$15.0	-$20.7	-$25.9
Other Personal Services	-$10.2	-$17.7	-$24.6	-$30.9
Retail	-$13.6	-$24.6	-$34.4	-$43.6
Professional and Business Services	-$25.7	-$45.8	-$64.0	-$80.6
Healthcare and Social Assistance	-$32.1	-$56.3	-$77.8	-$97.7
Finance, Insurance, and Real Estate	-$48.5	-$86.4	-$121.1	-$153.4
Natural Gas Distribution and Pipelines	-$79.2	-$143.3	-$201.7	-$252.5
TOTAL	-$89.5	-$154.6	-$215.0	-$271.4

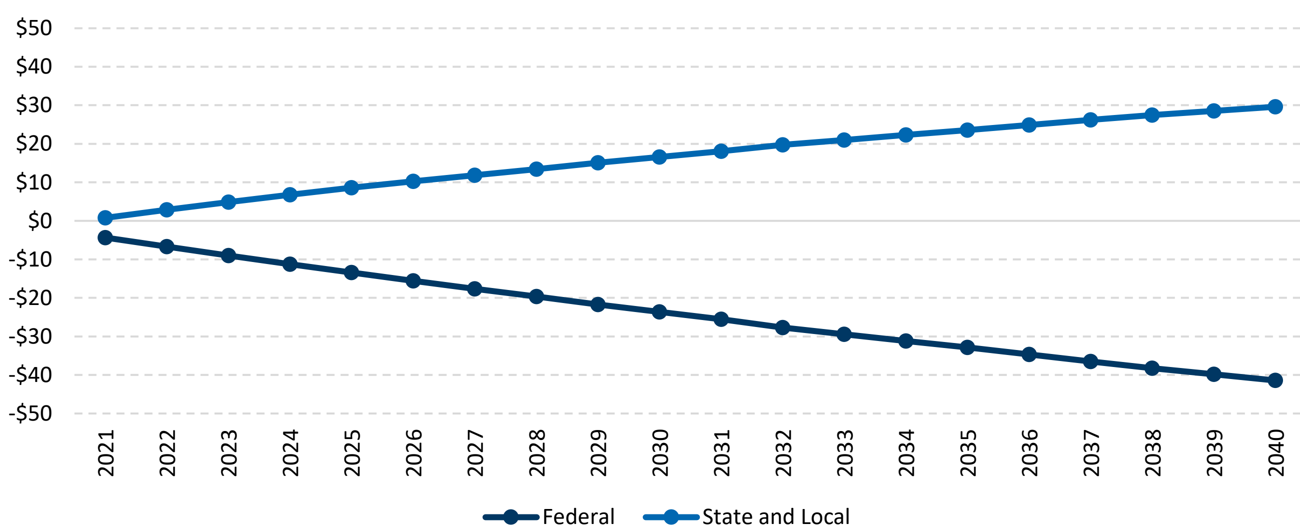
The driving forces behind the results in Table 10 would be generally the same as those for Table 9. The increase in expenditures for energy (and specifically electricity) under electrification would increase the GDP contribution of the electric power sector. The increase would come at the expense of natural gas distribution and pipelines. Because of the consumption reallocation, the sectors depending the most on local consumer expenditures would have reduced GDP contributions.

The most important difference between Table 9 and Table 10, accounting for the different ordering of the economic sectors, is labor productivity. Sectors such as healthcare or retail are labor-intensive, requiring higher levels of labor input to produce the same quantities of output as capital-intensive sectors. Examples of capital-intensive sectors include utilities, certain types of heavy manufacturers, and FIRE (especially the real estate sector). Table 10 examines only the GDP contribution by sector, while Table 9 adjust for labor productivity to show the impact on employment.

Tax Revenues

Figure 16 details the fiscal impact of the RO Scenario. The policy design would reduce tax revenues paid to the federal government yet increase them to state and local governments. By 2040 for the federal government, tax revenues would decrease by $41.4 million compared to the Base Case (and part of a cumulative decrease of $480.1 million over 20 years). With state and local governments, the increase in revenues for 2040 would be $29.6 million (a cumulative increase of $332.4 million relative to the scenario without electrification for the Columbus MSA).

Figure 16 – Tax revenue impact of the RO Scenario (2018 $ millions)

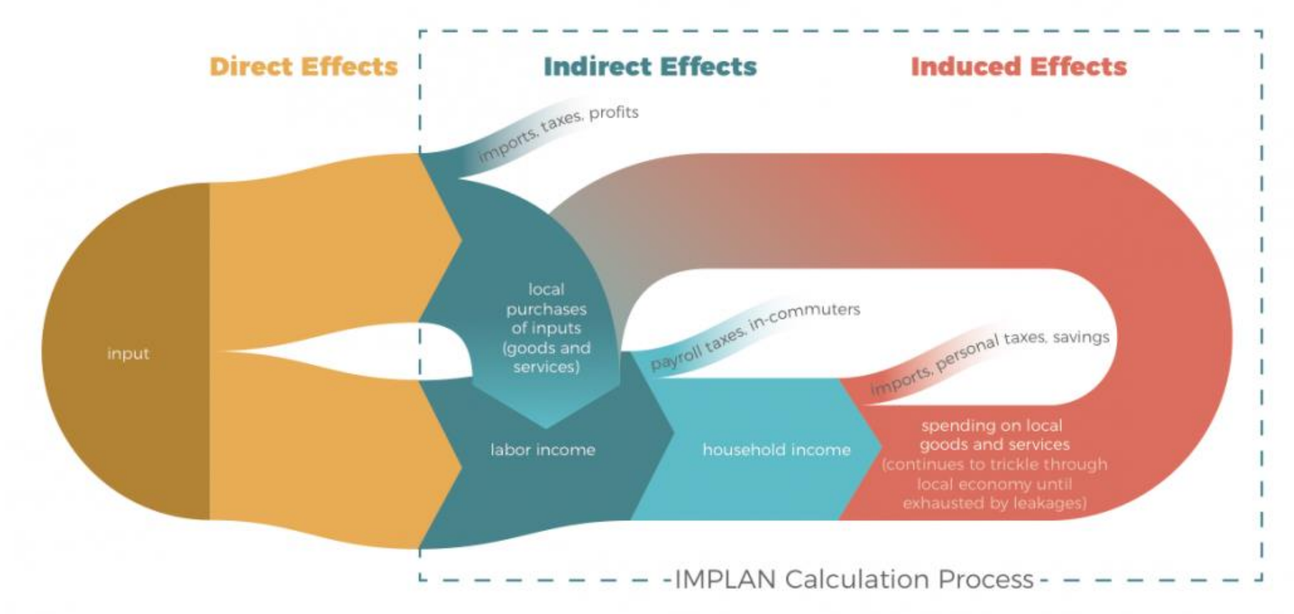


The contrasting results from Figure 16 might seem counterintuitive, though they follow the structure of federal, state, and local taxes in IMPLAN. Federal revenues strongly depend on labor markets. Jobs and income translate into payroll and income tax revenues, which are the main sources of federal revenues. State and local taxes rely on a mixture of income, sales, and property taxes along with fees. Fees, which include state and local utility fees and surcharges, would make up the difference between the revenue types in Figure 16 to the point that increase GDP contributions from electric power overcomes reduced tax revenues from reduced economic activity.

Appendix A – Model Diagrams

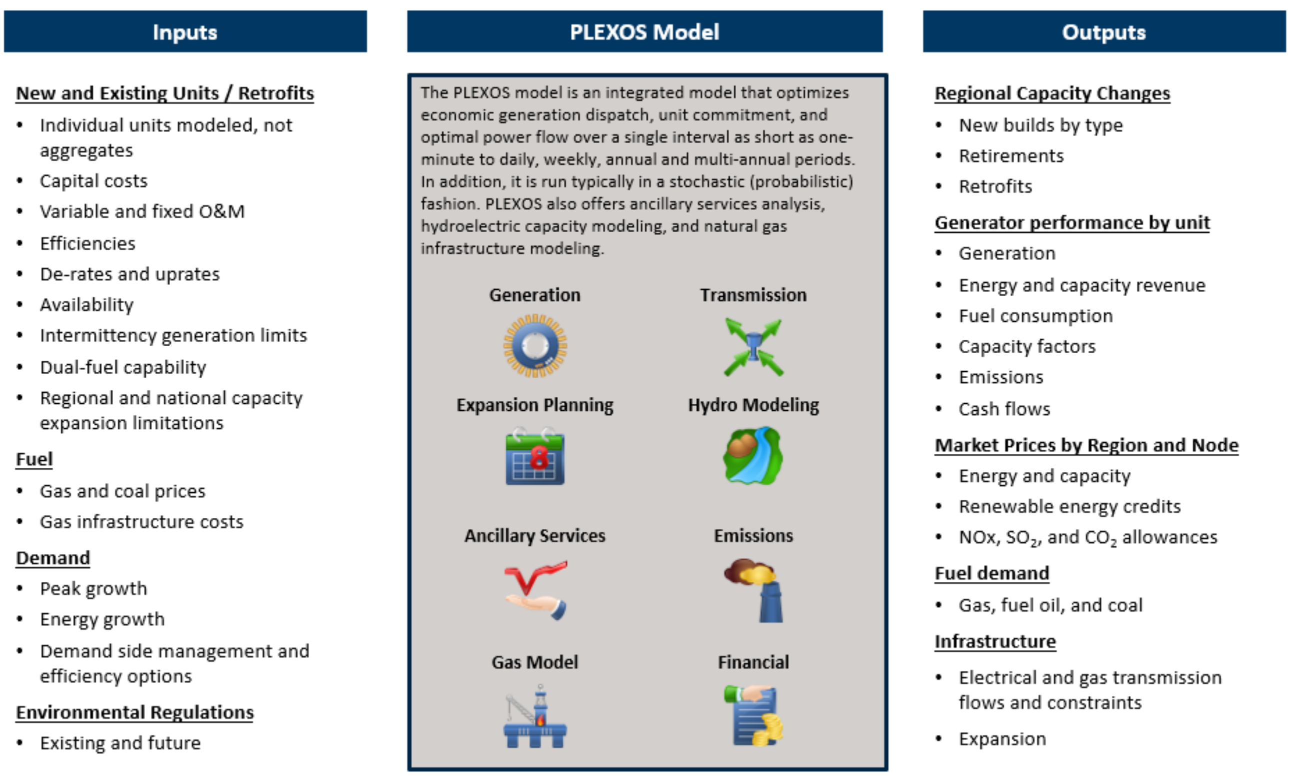
IMPLAN Model Diagram

Figure 17 – IMPLAN model diagram



PLEXOS Model Diagram

Figure 18 – PLEXOS model diagram



Appendix B – Load Shapes

Average Residential Customer

Table 11 – Average load by month and hour for the average residential customer (kWh)

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
0:00	3.01	1.58	1.61	1.07	0.29	0.23	0.23	0.23	0.24	0.61	1.48	1.72	1.02
1:00	3.25	1.83	1.98	1.19	0.32	0.23	0.23	0.23	0.24	0.71	1.50	1.92	1.14
2:00	3.28	1.89	1.97	1.33	0.32	0.23	0.23	0.23	0.24	0.72	1.61	1.92	1.16
3:00	3.31	1.84	2.06	1.34	0.31	0.23	0.23	0.23	0.24	0.74	1.68	1.92	1.18
4:00	3.23	2.02	2.14	1.40	0.34	0.23	0.23	0.23	0.24	0.74	1.74	1.73	1.19
5:00	3.28	1.98	2.07	1.41	0.33	0.23	0.23	0.23	0.24	0.72	1.59	2.15	1.21
6:00	2.93	1.89	2.10	1.43	0.29	0.23	0.23	0.23	0.24	0.70	1.62	2.11	1.16
7:00	3.68	1.80	1.88	1.13	0.26	0.23	0.23	0.23	0.24	0.68	1.64	1.97	1.16
8:00	3.56	1.65	1.66	1.05	0.24	0.23	0.23	0.23	0.24	0.59	1.60	2.01	1.11
9:00	3.30	1.50	1.48	0.89	0.23	0.23	0.23	0.23	0.23	0.54	1.42	1.75	1.00
10:00	2.67	1.44	1.29	0.92	0.23	0.23	0.23	0.23	0.23	0.50	1.28	1.61	0.90
11:00	3.05	1.32	1.26	0.83	0.23	0.23	0.23	0.23	0.23	0.48	1.34	1.29	0.89
12:00	2.84	1.29	1.15	0.81	0.23	0.23	0.23	0.23	0.23	0.44	1.21	1.30	0.85
13:00	2.60	1.38	1.13	0.79	0.23	0.23	0.23	0.23	0.23	0.42	1.25	1.26	0.83
14:00	2.60	1.37	1.10	0.75	0.23	0.23	0.23	0.23	0.23	0.39	1.22	1.28	0.82
15:00	2.57	1.35	1.08	0.74	0.23	0.23	0.23	0.23	0.23	0.42	1.22	1.34	0.82
16:00	2.57	1.43	1.12	0.76	0.23	0.23	0.23	0.23	0.23	0.46	1.27	1.34	0.84
17:00	2.91	1.49	1.21	0.74	0.23	0.23	0.23	0.23	0.23	0.49	1.24	1.54	0.90
18:00	2.37	1.49	1.30	0.81	0.23	0.23	0.23	0.23	0.23	0.56	1.22	1.51	0.87
19:00	2.92	1.53	1.40	0.91	0.24	0.23	0.23	0.23	0.23	0.57	1.53	1.67	0.97
20:00	3.03	1.72	1.48	0.97	0.24	0.23	0.23	0.23	0.23	0.60	1.49	1.64	1.01
21:00	2.79	1.82	1.70	1.02	0.25	0.23	0.23	0.23	0.23	0.65	1.46	1.86	1.04
22:00	3.02	1.88	1.75	1.06	0.27	0.23	0.23	0.23	0.24	0.62	1.32	1.72	1.05
23:00	3.02	1.73	1.68	1.06	0.28	0.23	0.23	0.23	0.24	0.61	1.40	1.72	1.03
AVG	2.99	1.63	1.57	1.02	0.26	0.23	0.23	0.23	0.23	0.58	1.43	1.68	1.01

Average Commercial Customer

Table 12 – Average load by month and hour for the average commercial customer (kWh)

HOUR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AVG
0:00	24.22	14.25	14.47	10.13	4.76	4.85	4.76	4.87	4.90	7.68	13.07	14.79	10.23
1:00	25.93	16.00	17.07	10.92	4.76	4.88	4.76	4.92	4.94	8.42	13.19	16.14	10.99
2:00	26.15	16.40	16.97	11.77	4.76	4.89	4.76	4.97	4.94	8.56	13.95	16.14	11.19
3:00	26.32	16.04	17.59	11.85	4.76	4.90	4.76	4.98	4.92	8.70	14.37	16.09	11.27
4:00	25.78	17.32	18.17	12.20	4.76	4.92	4.76	5.07	4.94	8.68	14.80	14.85	11.35
5:00	26.13	17.01	17.70	12.31	4.76	4.89	4.76	5.04	4.95	8.55	13.77	17.67	11.46
6:00	23.64	16.42	17.85	12.39	4.76	4.82	4.76	4.91	4.95	8.38	14.01	17.38	11.19
7:00	28.91	15.79	16.34	10.51	4.76	4.79	4.76	4.79	4.91	8.18	14.15	16.48	11.20
8:00	28.07	14.75	14.78	10.02	4.76	4.79	4.76	4.76	4.88	7.50	13.84	16.72	10.80
9:00	26.24	13.71	13.53	9.02	4.76	4.78	4.76	4.76	4.83	7.17	12.70	14.96	10.10
10:00	21.84	13.30	12.22	9.15	4.76	4.78	4.76	4.76	4.81	6.84	11.74	14.02	9.42
11:00	24.48	12.41	12.01	8.60	4.76	4.78	4.76	4.76	4.79	6.73	12.16	11.92	9.35
12:00	23.04	12.22	11.21	8.48	4.76	4.77	4.76	4.76	4.79	6.37	11.27	11.95	9.03
13:00	21.36	12.86	11.08	8.34	4.76	4.77	4.76	4.76	4.78	6.24	11.57	11.66	8.91
14:00	21.38	12.75	10.89	8.06	4.76	4.76	4.76	4.76	4.79	5.99	11.35	11.84	8.84
15:00	21.11	12.65	10.74	8.01	4.76	4.76	4.76	4.76	4.79	6.26	11.32	12.25	8.85
16:00	21.14	13.17	10.99	8.13	4.76	4.76	4.76	4.76	4.79	6.53	11.67	12.22	8.97
17:00	23.49	13.58	11.63	8.06	4.76	4.76	4.76	4.76	4.80	6.80	11.49	13.55	9.37
18:00	19.75	13.64	12.28	8.46	4.76	4.76	4.76	4.76	4.84	7.34	11.32	13.33	9.17
19:00	23.58	13.89	13.00	9.13	4.76	4.78	4.76	4.77	4.85	7.38	13.37	14.47	9.89
20:00	24.35	15.24	13.53	9.50	4.76	4.79	4.76	4.78	4.85	7.62	13.13	14.21	10.13
21:00	22.72	15.91	15.10	9.81	4.76	4.77	4.76	4.80	4.87	8.02	12.94	15.72	10.35
22:00	24.31	16.34	15.46	10.04	4.76	4.80	4.76	4.84	4.92	7.75	12.00	14.76	10.40
23:00	24.26	15.30	14.96	10.09	4.76	4.83	4.76	4.85	4.91	7.72	12.54	14.78	10.31
AVG	24.09	14.62	14.15	9.79	4.76	4.81	4.76	4.83	4.86	7.48	12.74	14.50	10.12

Appendix C – Capacity Expansion Results

Base Case

Table 13 – Capacity additions in the Base Case (GW)

Year	Solar	Wind	Biomass	NGCC	Thermal Retirements	Net Additions
2021	4.3	1.0	0.2	0.0	0.0	5.4
2022	4.6	1.0	0.0	0.0	0.0	5.5
2023	5.5	0.4	0.0	0.0	0.6	5.3
2024	2.7	1.0	0.0	0.0	0.0	3.6
2025	5.5	0.5	0.0	0.5	0.0	6.4
2026	4.2	0.0	0.0	2.3	0.0	6.4
2027	5.5	0.4	0.0	0.0	1.6	4.3
2028	0.9	0.0	0.0	0.0	0.0	0.9
2029	3.2	0.0	0.0	0.0	0.0	3.2
2030	3.0	0.0	0.0	1.5	0.0	4.5
2031	3.0	0.0	0.0	0.5	0.0	3.6
2032	4.0	0.0	0.0	0.0	0.0	4.0
2033	0.0	0.0	0.0	0.0	0.4	-0.4
2034	0.2	0.0	0.0	1.5	0.0	1.6
2035	0.5	0.0	0.0	1.5	0.0	2.0
2036	0.4	0.0	0.0	1.5	0.0	1.9
2037	0.9	0.0	0.0	1.6	0.0	2.4
2038	0.5	0.0	0.0	0.3	0.0	0.8
2039	0.7	0.0	0.0	1.5	0.0	2.2
2040	0.4	0.0	0.0	2.0	0.0	2.5
TOTAL	49.9	4.1	0.2	14.6	2.6	66.2

Electrification – MB Scenario

Table 14 – Capacity additions under electrification for the MB Scenario (GW)

Year	Solar	Wind	Biomass	NGCC	Thermal Retirements	Net Additions
2021	4.3	1.0	0.2	0.0	0.0	5.4
2022	4.6	1.0	0.0	0.0	0.0	5.5
2023	5.5	0.4	0.0	0.0	0.6	5.3
2024	2.7	1.0	0.0	0.0	0.0	3.6
2025	5.5	0.5	0.0	0.6	0.0	6.5
2026	4.2	0.0	0.0	2.3	0.0	6.4
2027	5.5	0.4	0.0	0.0	1.6	4.3
2028	0.9	0.0	0.0	0.0	0.0	0.9
2029	3.2	0.0	0.0	0.0	0.0	3.2
2030	3.0	0.0	0.0	1.5	0.0	4.5
2031	3.0	0.0	0.0	1.2	0.0	4.3
2032	4.0	0.0	0.0	0.4	0.0	4.4
2033	0.0	0.0	0.0	0.0	0.4	-0.4
2034	0.2	0.0	0.0	1.5	0.0	1.7
2035	0.5	0.0	0.0	1.5	0.0	2.0
2036	0.4	0.0	0.0	1.5	0.0	1.9
2037	0.9	0.0	0.0	2.0	0.0	2.8
2038	0.5	0.0	0.0	0.0	0.0	0.5
2039	0.7	0.0	0.0	1.3	0.0	2.0
2040	0.4	0.0	0.0	2.1	0.0	2.5
TOTAL	49.9	4.1	0.2	15.8	2.6	67.4

Electrification – RO Scenario

Table 15 – Capacity additions under electrification for the RO Scenario (GW)

Year	Solar	Wind	Biomass	NGCC	Thermal Retirements	Net Additions
2021	4.3	1.0	0.2	0.0	0.0	5.5
2022	4.6	1.0	0.0	0.0	0.0	5.5
2023	5.5	0.4	0.0	0.0	0.6	5.3
2024	3.8	0.1	0.0	0.0	0.0	4.0
2025	5.5	0.5	0.0	0.5	0.0	6.4
2026	4.2	0.0	0.0	2.3	0.0	6.5
2027	5.5	1.0	0.0	0.0	1.6	4.9
2028	0.8	0.0	0.0	0.0	0.0	0.8
2029	3.5	0.0	0.0	0.0	0.0	3.5
2030	2.8	0.0	0.0	1.5	0.0	4.3
2031	3.1	0.0	0.0	0.5	0.0	3.7
2032	4.0	0.0	0.0	0.0	0.0	4.0
2033	0.1	0.0	0.0	0.0	0.4	-0.4
2034	0.3	0.0	0.0	1.5	0.0	1.8
2035	0.0	0.0	0.0	1.5	0.0	1.5
2036	0.9	0.0	0.0	1.5	0.0	2.4
2037	0.9	0.0	0.0	1.6	0.0	2.5
2038	1.8	0.0	0.0	0.3	0.0	2.0
2039	0.0	0.0	0.0	1.5	0.0	1.5
2040	0.3	0.0	0.0	2.0	0.0	2.3
TOTAL	51.9	3.9	0.2	14.6	2.6	68.1

Appendix D – Emissions Results

Emissions Results – Base Case

Table 16 – Base Case emissions

Year	CO2 (millions of metric tons)	NOx (thousands of short tons)	SO2 (thousands of short tons)
2021	312.0	165.0	241.0
2022	310.1	160.3	227.0
2023	300.0	155.6	218.2
2024	298.6	155.2	216.2
2025	285.2	144.8	198.3
2026	277.2	137.9	190.6
2027	273.6	136.1	192.8
2028	277.3	140.2	200.9
2029	274.8	139.3	195.2
2030	271.8	135.2	187.6
2031	277.2	138.2	192.9
2032	284.5	144.0	203.8
2033	292.0	148.1	209.4
2034	291.1	145.9	205.6
2035	298.6	149.3	211.7
2036	305.1	151.7	216.0
2037	309.9	151.4	214.4
2038	321.8	157.4	220.7
2039	324.5	156.9	220.3
2040	312.2	145.0	197.2
TOTAL	5,897.3	2,957.5	4,159.6

Emissions Results – MB Scenario

Table 17 – CO2 emissions (millions of metric tons)

Year	Base Case (Total)	MB (PJM)	Difference (PJM)	Percentage (PJM)	Difference (Imports)	Difference (Total)
2021	312.0	312.1	0.1	0.0%	0.1	0.2
2022	310.1	310.4	0.3	0.1%	0.1	0.4
2023	300.0	300.7	0.7	0.2%	0.5	1.2
2024	298.6	299.8	1.2	0.4%	0.2	1.4
2025	285.2	286.4	1.2	0.4%	0.3	1.6
2026	277.2	278.8	1.6	0.6%	0.5	2.1
2027	273.6	275.7	2.1	0.8%	0.3	2.4
2028	277.3	279.6	2.3	0.8%	0.4	2.7
2029	274.8	277.3	2.5	0.9%	0.4	3.0
2030	271.8	274.5	2.6	1.0%	0.8	3.4
2031	277.2	279.4	2.1	0.8%	0.3	2.4
2032	284.5	285.9	1.4	0.5%	-0.4	1.0
2033	292.0	294.0	2.0	0.7%	0.3	2.3
2034	291.1	293.2	2.1	0.7%	0.4	2.5
2035	298.6	301.2	2.6	0.9%	0.2	2.8
2036	305.1	308.0	3.0	1.0%	0.8	3.7
2037	309.9	312.2	2.3	0.7%	-0.2	2.1
2038	321.8	325.2	3.4	1.1%	0.4	3.8
2039	324.5	328.3	3.8	1.2%	1.4	5.2
2040	312.2	316.1	3.9	1.3%	0.3	4.2
TOTAL	5,897.3	5,938.6	41.2	0.7%	7.0	48.3

Table 18 – NOx emissions (thousands of short tons)

Year	Base Case (Total)	MB (PJM)	Difference (PJM)	Percentage (PJM)	Difference (Imports)	Difference (Total)
2021	165.0	165.1	0.1	0.0%	0.0	0.1
2022	160.3	160.5	0.1	0.1%	-0.1	0.0
2023	155.6	155.9	0.3	0.2%	0.4	0.7
2024	155.2	155.7	0.6	0.4%	0.2	0.8
2025	144.8	145.4	0.5	0.4%	0.2	0.7
2026	137.9	138.7	0.8	0.6%	0.2	1.0
2027	136.1	137.1	1.0	0.8%	0.0	1.1
2028	140.2	141.3	1.1	0.8%	0.2	1.3
2029	139.3	140.5	1.2	0.9%	0.3	1.4
2030	135.2	136.5	1.3	1.0%	0.4	1.7
2031	138.2	138.4	0.2	0.2%	0.3	0.5
2032	144.0	143.5	-0.4	-0.3%	-0.9	-1.3
2033	148.1	147.7	-0.4	-0.3%	0.2	-0.2
2034	145.9	145.6	-0.3	-0.2%	0.3	0.0
2035	149.3	149.2	-0.1	-0.1%	0.2	0.1
2036	151.7	151.7	0.0	0.0%	0.6	0.6
2037	151.4	150.7	-0.8	-0.5%	-0.2	-0.9
2038	157.4	157.6	0.2	0.1%	0.0	0.2
2039	156.9	157.6	0.7	0.5%	0.8	1.5
2040	145.0	145.6	0.6	0.4%	0.0	0.6
TOTAL	2,957.5	2,964.3	6.8	0.2%	3.2	10.0

Table 19 – SO2 emissions (thousands of short tons)

Year	Base Case (Total)	MB (PJM)	Difference (PJM)	Percentage (PJM)	Difference (Imports)	Difference (Total)
2021	241.0	241.0	0.0	0.0%	0.0	0.1
2022	227.0	227.1	0.1	0.1%	0.1	0.3
2023	218.2	218.5	0.3	0.1%	0.5	0.8
2024	216.2	216.7	0.6	0.3%	0.5	1.0
2025	198.3	198.7	0.4	0.2%	0.2	0.6
2026	190.6	191.6	1.0	0.5%	0.5	1.5
2027	192.8	194.0	1.2	0.6%	0.1	1.4
2028	200.9	202.3	1.4	0.7%	0.3	1.6
2029	195.2	196.3	1.0	0.5%	0.3	1.3
2030	187.6	188.7	1.1	0.6%	0.8	1.9
2031	192.9	192.7	-0.2	-0.1%	0.1	-0.1
2032	203.8	202.7	-1.2	-0.6%	-0.2	-1.4
2033	209.4	208.6	-0.9	-0.4%	0.4	-0.4
2034	205.6	204.6	-1.0	-0.5%	0.3	-0.6
2035	211.7	211.1	-0.6	-0.3%	0.1	-0.5
2036	216.0	215.6	-0.4	-0.2%	0.7	0.3
2037	214.4	213.1	-1.3	-0.6%	-0.4	-1.7
2038	220.7	220.4	-0.3	-0.1%	-0.2	-0.4
2039	220.3	220.2	0.0	0.0%	0.6	0.6
2040	197.2	197.1	-0.1	0.0%	-1.2	-1.3
TOTAL	4,159.6	4,160.9	1.3	0.0%	3.7	5.0

Emissions Results – RO Scenario

Table 20 – CO2 emissions (millions of metric tons)

Year	Base Case (Total)	RO (PJM)	Difference (PJM)	Percentage (PJM)	Difference (Imports)	Difference (Total)
2021	312.0	312.1	0.1	0.0%	0.1	0.2
2022	310.1	310.4	0.3	0.1%	0.1	0.5
2023	300.0	300.7	0.6	0.2%	0.1	0.8
2024	298.6	299.9	1.3	0.4%	-0.2	1.1
2025	285.2	286.7	1.5	0.5%	0.1	1.6
2026	277.2	279.1	1.9	0.7%	0.3	2.2
2027	273.6	275.8	2.3	0.8%	-0.1	2.1
2028	277.3	279.7	2.4	0.9%	0.1	2.5
2029	274.8	277.4	2.7	1.0%	0.2	2.8
2030	271.8	274.6	2.8	1.0%	0.5	3.3
2031	277.2	280.3	3.1	1.1%	0.7	3.8
2032	284.5	286.9	2.5	0.9%	-0.6	1.9
2033	292.0	295.2	3.1	1.1%	1.2	4.3
2034	291.1	294.6	3.6	1.2%	1.4	4.9
2035	298.6	302.8	4.2	1.4%	1.2	5.3
2036	305.1	309.4	4.3	1.4%	1.2	5.5
2037	309.9	314.8	4.9	1.6%	1.1	6.0
2038	321.8	326.2	4.4	1.4%	0.5	4.9
2039	324.5	328.8	4.4	1.3%	1.9	6.2
2040	312.2	317.1	4.9	1.6%	0.9	5.8
TOTAL	5,897.3	5,952.6	55.3	0.9%	10.3	65.6

Table 21 – NOx emissions (thousands of short tons)

Year	Base Case (Total)	RO (PJM)	Difference (PJM)	Percentage (PJM)	Difference (Imports)	Difference (Total)
2021	165.0	165.1	0.1	0.0%	-0.1	0.0
2022	160.3	160.5	0.1	0.1%	-0.1	0.0
2023	155.6	155.9	0.3	0.2%	0.2	0.4
2024	155.2	155.8	0.7	0.4%	0.0	0.6
2025	144.8	145.6	0.8	0.5%	0.0	0.8
2026	137.9	139.1	1.1	0.8%	0.2	1.4
2027	136.1	137.4	1.3	0.9%	-0.1	1.2
2028	140.2	141.5	1.3	0.9%	0.1	1.3
2029	139.3	140.7	1.4	1.0%	0.2	1.6
2030	135.2	136.7	1.5	1.1%	0.3	1.8
2031	138.2	139.8	1.6	1.2%	0.4	2.0
2032	144.0	145.3	1.3	0.9%	-1.5	-0.1
2033	148.1	149.6	1.5	1.0%	0.5	2.0
2034	145.9	147.7	1.8	1.2%	0.8	2.6
2035	149.3	151.2	1.9	1.3%	0.5	2.4
2036	151.7	153.5	1.8	1.2%	0.7	2.5
2037	151.4	153.8	2.4	1.6%	0.6	2.9
2038	157.4	159.6	2.2	1.4%	0.3	2.5
2039	156.9	158.9	2.0	1.2%	0.9	2.8
2040	145.0	147.5	2.5	1.7%	0.0	2.5
TOTAL	2,957.5	2,985.0	27.5	0.9%	3.8	31.3

Table 22 – SO2 emissions (thousands of short tons)

Year	Base Case (Total)	RO (PJM)	Difference (PJM)	Percentage (PJM)	Difference (Imports)	Difference (Total)
2021	241.0	241.0	0.1	0.0%	0.0	0.1
2022	227.0	227.1	0.1	0.1%	0.2	0.3
2023	218.2	218.5	0.3	0.2%	0.4	0.7
2024	216.2	216.9	0.7	0.3%	0.2	0.9
2025	198.3	199.0	0.8	0.4%	0.1	0.9
2026	190.6	192.0	1.4	0.7%	0.6	2.0
2027	192.8	194.4	1.6	0.9%	0.2	1.8
2028	200.9	202.6	1.7	0.9%	0.2	2.0
2029	195.2	196.8	1.5	0.8%	0.4	1.9
2030	187.6	189.1	1.5	0.8%	0.8	2.3
2031	192.9	194.8	1.9	1.0%	0.5	2.4
2032	203.8	205.3	1.4	0.7%	-1.1	0.4
2033	209.4	211.0	1.6	0.8%	0.9	2.5
2034	205.6	207.5	1.9	0.9%	1.2	3.1
2035	211.7	214.1	2.4	1.1%	1.0	3.4
2036	216.0	217.9	2.0	0.9%	1.4	3.3
2037	214.4	217.4	3.0	1.4%	0.6	3.6
2038	220.7	222.4	1.8	0.8%	0.4	2.2
2039	220.3	221.5	1.2	0.6%	1.4	2.7
2040	197.2	199.5	2.3	1.2%	-0.2	2.1
TOTAL	4,159.6	4,188.9	29.2	0.7%	9.1	38.4

Emissions Results – CO_2 in the Base Case, MB Scenario, and RO Scenario

Table 23 – Energy demand and CO2 emissions (millions of metric tons)

Year	Gas Demand (MMcf)	Base Case (CO2)	MB Scenario (CO2)	RO Scenario (CO2)	MB minus Base Case (CO2)	RO minus Base Case (CO2)
2021	2,086	0.1	0.2	0.2	0.1	0.1
2022	7,104	0.4	0.4	0.5	0.1	0.1
2023	12,123	0.6	1.2	0.8	0.6	0.1
2024	17,142	0.9	1.4	1.1	0.5	0.2
2025	22,160	1.2	1.6	1.6	0.4	0.4
2026	27,178	1.4	2.1	2.2	0.6	0.8
2027	32,197	1.7	2.4	2.1	0.6	0.4
2028	37,216	2.0	2.7	2.5	0.7	0.5
2029	42,234	2.2	3.0	2.8	0.7	0.6
2030	47,252	2.5	3.4	3.3	0.9	0.8
2031	52,271	2.8	2.4	3.8	-0.4	1.0
2032	57,290	3.0	1.0	1.9	-2.0	-1.1
2033	62,308	3.3	2.3	4.3	-1.0	1.0
2034	67,326	3.6	2.5	4.9	-1.0	1.3
2035	72,345	3.8	2.8	5.3	-1.0	1.5
2036	77,364	4.1	3.7	5.5	-0.4	1.4
2037	82,382	4.4	2.1	6.0	-2.3	1.6
2038	87,400	4.6	3.8	4.9	-0.8	0.2
2039	92,419	4.9	5.2	6.2	0.3	1.3
2040	97,438	5.2	4.2	5.8	-1.0	0.6
TOTAL	995,234	52.9	48.3	65.6	-4.6	12.8

Emissions Results – NOx in the Base Case, MB Scenario, and RO Scenario

Table 24 – Energy demand and CO2 emissions (thousands of short tons)

Year	Gas Demand (MMcf)	Base Case (NOx)	MB Scenario (NOx)	RO Scenario (NOx)	MB minus Base Case (NOx)	RO minus Base Case (NOx)
2021	2,086	0.1	0.1	0.0	0.0	-0.1
2022	7,104	0.4	0.0	0.0	-0.4	-0.4
2023	12,123	0.7	0.7	0.4	-0.1	-0.3
2024	17,142	1.0	0.8	0.6	-0.2	-0.4
2025	22,160	1.3	0.7	0.8	-0.6	-0.5
2026	27,178	1.6	1.0	1.4	-0.6	-0.2
2027	32,197	1.9	1.1	1.2	-0.8	-0.7
2028	37,216	2.2	1.3	1.3	-0.9	-0.8
2029	42,234	2.5	1.4	1.6	-1.0	-0.9
2030	47,252	2.8	1.7	1.8	-1.0	-1.0
2031	52,271	3.1	0.5	2.0	-2.6	-1.1
2032	57,290	3.4	-1.3	-0.1	-4.7	-3.5
2033	62,308	3.6	-0.2	2.0	-3.9	-1.6
2034	67,326	3.9	0.0	2.6	-3.9	-1.4
2035	72,345	4.2	0.1	2.4	-4.1	-1.8
2036	77,364	4.5	0.6	2.5	-3.9	-2.0
2037	82,382	4.8	-0.9	2.9	-5.7	-1.9
2038	87,400	5.1	0.2	2.5	-4.9	-2.7
2039	92,419	5.4	1.5	2.8	-3.9	-2.6
2040	97,438	5.7	0.6	2.5	-5.1	-3.2
TOTAL	995,234	58.2	10.0	31.3	-48.2	-26.9

Emissions Results – SO2 in the Base Case, MB Scenario, and RO Scenario

Table 25 – Energy demand and CO2 emissions (thousands of short tons)

Year	Gas Demand (MMcf)	Base Case (SO2)	MB Scenario (SO2)	RO Scenario (SO2)	MB minus Base Case (SO2)	RO minus Base Case (SO2)
2021	2,086	0.0	0.1	0.1	0.1	0.1
2022	7,104	0.0	0.3	0.3	0.3	0.3
2023	12,123	0.0	0.8	0.7	0.8	0.7
2024	17,142	0.0	1.0	0.9	1.0	0.9
2025	22,160	0.0	0.6	0.9	0.6	0.9
2026	27,178	0.0	1.5	2.0	1.5	2.0
2027	32,197	0.0	1.4	1.8	1.3	1.8
2028	37,216	0.0	1.6	2.0	1.6	2.0
2029	42,234	0.0	1.3	1.9	1.3	1.9
2030	47,252	0.0	1.9	2.3	1.9	2.3
2031	52,271	0.0	-0.1	2.4	-0.1	2.4
2032	57,290	0.0	-1.4	0.4	-1.4	0.4
2033	62,308	0.0	-0.4	2.5	-0.5	2.5
2034	67,326	0.0	-0.6	3.1	-0.7	3.1
2035	72,345	0.0	-0.5	3.4	-0.5	3.4
2036	77,364	0.0	0.3	3.3	0.3	3.3
2037	82,382	0.0	-1.7	3.6	-1.7	3.6
2038	87,400	0.0	-0.4	2.2	-0.5	2.2
2039	92,419	0.0	0.6	2.7	0.6	2.7
2040	97,438	0.0	-1.3	2.1	-1.3	2.1
TOTAL	995,234	0.5	5.0	38.6	4.5	38.1

Appendix E – IMPLAN Sectoral Aggregation

Sectoral Aggregation

Table 26 – Sectoral aggregation from IMPLAN to economic impact results

Sector ID	IMPLAN Sector	Aggregation
1	Oilseed farming	Agriculture and Forestry
2	Grain farming	Agriculture and Forestry
3	Vegetable and melon farming	Agriculture and Forestry
4	Fruit farming	Agriculture and Forestry
5	Tree nut farming	Agriculture and Forestry
6	Greenhouse, nursery, and floricult…	Agriculture and Forestry
7	Tobacco farming	Agriculture and Forestry
8	Cotton farming	Agriculture and Forestry
9	Sugarcane and sugar beet farming	Agriculture and Forestry
10	All other crop farming	Agriculture and Forestry
11	Beef cattle ranching and farming, …	Agriculture and Forestry
12	Dairy cattle and milk production	Agriculture and Forestry
13	Poultry and egg production	Agriculture and Forestry
14	Animal production, except cattle a…	Agriculture and Forestry
15	Forestry, forest products, and tim…	Agriculture and Forestry
16	Commercial logging	Agriculture and Forestry
17	Commercial fishing	Agriculture and Forestry
18	Commercial hunting and trapping	Agriculture and Forestry
19	Support activities for agriculture…	Agriculture and Forestry
20	Oil and gas extraction	Oil and Natural Gas Extraction
21	Coal mining	Coal Mining
22	Copper, nickel, lead, and zinc min…	Other Mining
23	Iron ore mining	Other Mining
24	Gold ore mining	Other Mining
25	Silver ore mining	Other Mining
26	Uranium-radium-vanadium ore mining	Other Mining
27	Other metal ore mining	Other Mining
28	Stone mining and quarrying	Other Mining
29	Sand and gravel mining	Other Mining
30	Other clay, ceramic, refractory mi…	Other Mining
31	Potash, soda, and borate mineral m…	Other Mining
32	Phosphate rock mining	Other Mining
33	Other chemical and fertilizer mine…	Other Mining

34	Other nonmetallic minerals	Other Mining
35	Drilling oil and gas wells	Oil and Natural Gas Extraction
36	Support activities for oil and gas…	Oil and Natural Gas Extraction
37	Metal mining services	Other Mining
38	Other nonmetallic minerals service…	Other Mining
39	Electric power generation - Hydroe…	Electric Power G, T, and D
40	Electric power generation - Fossil…	Electric Power G, T, and D
41	Electric power generation - Nuclea…	Electric Power G, T, and D
42	Electric power generation - Solar	Electric Power G, T, and D
43	Electric power generation - Wind	Electric Power G, T, and D
44	Electric power generation - Geothe…	Electric Power G, T, and D
45	Electric power generation - Biomas…	Electric Power G, T, and D
46	Electric power generation - All ot…	Electric Power G, T, and D
47	Electric power transmission and di…	Electric Power G, T, and D
48	Natural gas distribution	Natural Gas Distribution and Pipelines
49	Water, sewage and other systems	Water and Sewage
50	Construction of new health care st…	Construction
51	Construction of new manufacturing …	Construction
52	Construction of new power and comm…	Construction
53	Construction of new educational an…	Construction
54	Construction of new highways and s…	Construction
55	Construction of new commercial str…	Construction
56	Construction of other new nonresid…	Construction
57	Construction of new single-family …	Construction
58	Construction of new multifamily re…	Construction
59	Construction of other new resident…	Construction
60	Maintenance and repair constructio…	Construction
61	Maintenance and repair constructio…	Construction
62	Maintenance and repair constructio…	Construction
63	Dog and cat food manufacturing	Manufacturing
64	Other animal food manufacturing	Manufacturing
65	Flour milling	Manufacturing
66	Rice milling	Manufacturing
67	Malt manufacturing	Manufacturing
68	Wet corn milling	Manufacturing
69	Soybean and other oilseed processi…	Manufacturing
70	Fats and oils refining and blendin…	Manufacturing
71	Breakfast cereal manufacturing	Manufacturing

72	Beet sugar manufacturing	Manufacturing
73	Sugar cane mills and refining	Manufacturing
74	Nonchocolate confectionery manufac…	Manufacturing
75	Chocolate and confectionery manufa…	Manufacturing
76	Confectionery manufacturing from p…	Manufacturing
77	Frozen fruits, juices and vegetabl…	Manufacturing
78	Frozen specialties manufacturing	Manufacturing
79	Canned fruits and vegetables manuf…	Manufacturing
80	Canned specialties	Manufacturing
81	Dehydrated food products manufactu…	Manufacturing
82	Cheese manufacturing	Manufacturing
83	Dry, condensed, and evaporated dai…	Manufacturing
84	Fluid milk manufacturing	Manufacturing
85	Creamery butter manufacturing	Manufacturing
86	Ice cream and frozen dessert manuf…	Manufacturing
87	Frozen cakes and other pastries ma…	Manufacturing
88	Poultry processing	Manufacturing
89	Animal, except poultry, slaughteri…	Manufacturing
90	Meat processed from carcasses	Manufacturing
91	Rendering and meat byproduct proce…	Manufacturing
92	Seafood product preparation and pa…	Manufacturing
93	Bread and bakery product, except f…	Manufacturing
94	Cookie and cracker manufacturing	Manufacturing
95	Dry pasta, mixes, and dough manufa…	Manufacturing
96	Tortilla manufacturing	Manufacturing
97	Roasted nuts and peanut butter man…	Manufacturing
98	Other snack food manufacturing	Manufacturing
99	Coffee and tea manufacturing	Manufacturing
100	Flavoring syrup and concentrate ma…	Manufacturing
101	Mayonnaise, dressing, and sauce ma…	Manufacturing
102	Spice and extract manufacturing	Manufacturing
103	All other food manufacturing	Manufacturing
104	Bottled and canned soft drinks & w…	Manufacturing
105	Manufactured ice	Manufacturing
106	Breweries	Manufacturing
107	Wineries	Manufacturing
108	Distilleries	Manufacturing
109	Tobacco product manufacturing	Manufacturing

110	Fiber, yarn, and thread mills	Manufacturing
111	Broadwoven fabric mills	Manufacturing
112	Narrow fabric mills and schiffli m...	Manufacturing
113	Nonwoven fabric mills	Manufacturing
114	Knit fabric mills	Manufacturing
115	Textile and fabric finishing mills	Manufacturing
116	Fabric coating mills	Manufacturing
117	Carpet and rug mills	Manufacturing
118	Curtain and linen mills	Manufacturing
119	Textile bag and canvas mills	Manufacturing
120	Rope, cordage, twine, tire cord an...	Manufacturing
121	Other textile product mills	Manufacturing
122	Hosiery and sock mills	Manufacturing
123	Other apparel knitting mills	Manufacturing
124	Cut and sew apparel contractors	Manufacturing
125	Mens and boys cut and sew apparel ...	Manufacturing
126	Womens and girls cut and sew appar...	Manufacturing
127	Other cut and sew apparel manufact...	Manufacturing
128	Apparel accessories and other appa...	Manufacturing
129	Leather and hide tanning and finis...	Manufacturing
130	Footwear manufacturing	Manufacturing
131	Other leather and allied product m...	Manufacturing
132	Sawmills	Manufacturing
133	Wood preservation	Manufacturing
134	Veneer and plywood manufacturing	Manufacturing
135	Engineered wood member and truss m...	Manufacturing
136	Reconstituted wood product manufac...	Manufacturing
137	Wood windows and door manufacturin...	Manufacturing
138	Cut stock, resawing lumber, and pl...	Manufacturing
139	Other millwork, including flooring	Manufacturing
140	Wood container and pallet manufact...	Manufacturing
141	Manufactured home (mobile home) ma...	Manufacturing
142	Prefabricated wood building manufa...	Manufacturing
143	All other miscellaneous wood produ...	Manufacturing
144	Pulp mills	Manufacturing
145	Paper mills	Manufacturing
146	Paperboard mills	Manufacturing
147	Paperboard container manufacturing	Manufacturing

148	Paper bag and coated and treated p...	Manufacturing
149	Stationery product manufacturing	Manufacturing
150	Sanitary paper product manufacturi...	Manufacturing
151	All other converted paper product ...	Manufacturing
152	Printing	Manufacturing
153	Support activities for printing	Manufacturing
154	Petroleum refineries	Manufacturing
155	Asphalt paving mixture and block m...	Manufacturing
156	Asphalt shingle and coating materi...	Manufacturing
157	Petroleum lubricating oil and grea...	Manufacturing
158	All other petroleum and coal produ...	Manufacturing
159	Petrochemical manufacturing	Manufacturing
160	Industrial gas manufacturing	Manufacturing
161	Synthetic dye and pigment manufact...	Manufacturing
162	Other basic inorganic chemical man...	Manufacturing
163	Other basic organic chemical manuf...	Manufacturing
164	Plastics material and resin manufa...	Manufacturing
165	Synthetic rubber manufacturing	Manufacturing
166	Artificial and synthetic fibers an...	Manufacturing
167	Nitrogenous fertilizer manufacturi...	Manufacturing
168	Phosphatic fertilizer manufacturin...	Manufacturing
169	Fertilizer mixing	Manufacturing
170	Pesticide and other agricultural c...	Manufacturing
171	Medicinal and botanical manufactur...	Manufacturing
172	Pharmaceutical preparation manufac...	Manufacturing
173	In-vitro diagnostic substance manu...	Manufacturing
174	Biological product (except diagnos...	Manufacturing
175	Paint and coating manufacturing	Manufacturing
176	Adhesive manufacturing	Manufacturing
177	Soap and other detergent manufactu...	Manufacturing
178	Polish and other sanitation good m...	Manufacturing
179	Surface active agent manufacturing	Manufacturing
180	Toilet preparation manufacturing	Manufacturing
181	Printing ink manufacturing	Manufacturing
182	Explosives manufacturing	Manufacturing
183	Custom compounding of purchased re...	Manufacturing
184	Photographic film and chemical man...	Manufacturing
185	Other miscellaneous chemical produ...	Manufacturing

186	Plastics packaging materials and u...	Manufacturing
187	Unlaminated plastics profile shape...	Manufacturing
188	Plastics pipe and pipe fitting man...	Manufacturing
189	Laminated plastics plate, sheet (e...	Manufacturing
190	Polystyrene foam product manufactu...	Manufacturing
191	Urethane and other foam product (e...	Manufacturing
192	Plastics bottle manufacturing	Manufacturing
193	Other plastics product manufacturi...	Manufacturing
194	Tire manufacturing	Manufacturing
195	Rubber and plastics hoses and belt...	Manufacturing
196	Other rubber product manufacturing	Manufacturing
197	Pottery, ceramics, and plumbing fi...	Manufacturing
198	Brick, tile, and other structural ...	Manufacturing
199	Flat glass manufacturing	Manufacturing
200	Other pressed and blown glass and ...	Manufacturing
201	Glass container manufacturing	Manufacturing
202	Glass product manufacturing made o...	Manufacturing
203	Cement manufacturing	Manufacturing
204	Ready-mix concrete manufacturing	Manufacturing
205	Concrete block and brick manufactu...	Manufacturing
206	Concrete pipe manufacturing	Manufacturing
207	Other concrete product manufacturi...	Manufacturing
208	Lime manufacturing	Manufacturing
209	Gypsum product manufacturing	Manufacturing
210	Abrasive product manufacturing	Manufacturing
211	Cut stone and stone product manufa...	Manufacturing
212	Ground or treated mineral and eart...	Manufacturing
213	Mineral wool manufacturing	Manufacturing
214	Miscellaneous nonmetallic mineral ...	Manufacturing
215	Iron and steel mills and ferroallo...	Manufacturing
216	Iron, steel pipe and tube manufact...	Manufacturing
217	Rolled steel shape manufacturing	Manufacturing
218	Steel wire drawing	Manufacturing
219	Alumina refining and primary alumi...	Manufacturing
220	Secondary smelting and alloying of...	Manufacturing
221	Aluminum sheet, plate, and foil ma...	Manufacturing
222	Other aluminum rolling, drawing an...	Manufacturing
223	Nonferrous metal (exc aluminum) sm...	Manufacturing

224	Copper rolling, drawing, extruding...	Manufacturing
225	Nonferrous metal, except copper an...	Manufacturing
226	Secondary processing of other nonf...	Manufacturing
227	Ferrous metal foundries	Manufacturing
228	Nonferrous metal foundries	Manufacturing
229	Custom roll forming	Manufacturing
230	Crown and closure manufacturing an...	Manufacturing
231	Iron and steel forging	Manufacturing
232	Nonferrous forging	Manufacturing
233	Cutlery, utensil, pot, and pan man...	Manufacturing
234	Handtool manufacturing	Manufacturing
235	Prefabricated metal buildings and ...	Manufacturing
236	Fabricated structural metal manufa...	Manufacturing
237	Plate work manufacturing	Manufacturing
238	Metal window and door manufacturin...	Manufacturing
239	Sheet metal work manufacturing	Manufacturing
240	Ornamental and architectural metal...	Manufacturing
241	Power boiler and heat exchanger ma...	Manufacturing
242	Metal tank (heavy gauge) manufactu...	Manufacturing
243	Metal cans manufacturing	Manufacturing
244	Metal barrels, drums and pails man...	Manufacturing
245	Hardware manufacturing	Manufacturing
246	Spring and wire product manufactur...	Manufacturing
247	Machine shops	Manufacturing
248	Turned product and screw, nut, and...	Manufacturing
249	Metal heat treating	Manufacturing
250	Metal coating and nonprecious engr...	Manufacturing
251	Electroplating, anodizing, and col...	Manufacturing
252	Valve and fittings, other than plu...	Manufacturing
253	Plumbing fixture fitting and trim ...	Manufacturing
254	Ball and roller bearing manufactur...	Manufacturing
255	Small arms ammunition manufacturin...	Manufacturing
256	Ammunition, except for small arms,...	Manufacturing
257	Small arms, ordnance, and accessor...	Manufacturing
258	Fabricated pipe and pipe fitting m...	Manufacturing
259	Other fabricated metal manufacturi...	Manufacturing
260	Farm machinery and equipment manuf...	Manufacturing
261	Lawn and garden equipment manufact...	Manufacturing

262	Construction machinery manufacturi…	Manufacturing
263	Mining machinery and equipment man…	Manufacturing
264	Oil and gas field machinery and eq…	Manufacturing
265	Semiconductor machinery manufactur…	Manufacturing
266	Food product machinery manufacturi…	Manufacturing
267	Sawmill, woodworking, and paper ma…	Manufacturing
268	Printing machinery and equipment m…	Manufacturing
269	All other industrial machinery man…	Manufacturing
270	Optical instrument and lens manufa…	Manufacturing
271	Photographic and photocopying equi…	Manufacturing
272	Other commercial service industry …	Manufacturing
273	Air purification and ventilation e…	Manufacturing
274	Heating equipment (except warm air…	Manufacturing
275	Air conditioning, refrigeration, a…	Manufacturing
276	Industrial mold manufacturing	Manufacturing
277	Special tool, die, jig, and fixtur…	Manufacturing
278	Cutting tool and machine tool acce…	Manufacturing
279	Machine tool manufacturing	Manufacturing
280	Rolling mill and other metalworkin…	Manufacturing
281	Turbine and turbine generator set …	Manufacturing
282	Speed changer, industrial high-spe…	Manufacturing
283	Mechanical power transmission equi…	Manufacturing
284	Other engine equipment manufacturi…	Manufacturing
285	Pump and pumping equipment manufac…	Manufacturing
286	Air and gas compressor manufacturi…	Manufacturing
287	Elevator and moving stairway manuf…	Manufacturing
288	Conveyor and conveying equipment m…	Manufacturing
289	Overhead cranes, hoists, and monor…	Manufacturing
290	Industrial truck, trailer, and sta…	Manufacturing
291	Power-driven handtool manufacturin…	Manufacturing
292	Welding and soldering equipment ma…	Manufacturing
293	Packaging machinery manufacturing	Manufacturing
294	Industrial process furnace and ove…	Manufacturing
295	Fluid power cylinder and actuator …	Manufacturing
296	Fluid power pump and motor manufac…	Manufacturing
297	Scales, balances, and miscellaneou…	Manufacturing
298	Electronic computer manufacturing	Manufacturing
299	Computer storage device manufactur…	Manufacturing

300	Computer terminals and other compu…	Manufacturing
301	Telephone apparatus manufacturing	Manufacturing
302	Broadcast and wireless communicati…	Manufacturing
303	Other communications equipment man…	Manufacturing
304	Audio and video equipment manufact…	Manufacturing
305	Printed circuit assembly (electron…	Manufacturing
306	Bare printed circuit board manufac…	Manufacturing
307	Semiconductor and related device m…	Manufacturing
308	Capacitor, resistor, coil, transfo…	Manufacturing
309	Electronic connector manufacturing	Manufacturing
310	Other electronic component manufac…	Manufacturing
311	Electromedical and electrotherapeu…	Manufacturing
312	Search, detection, and navigation …	Manufacturing
313	Automatic environmental control ma…	Manufacturing
314	Industrial process variable instru…	Manufacturing
315	Totalizing fluid meter and countin…	Manufacturing
316	Electricity and signal testing ins…	Manufacturing
317	Analytical laboratory instrument m…	Manufacturing
318	Irradiation apparatus manufacturin…	Manufacturing
319	Watch, clock, and other measuring …	Manufacturing
320	Blank magnetic and optical recordi…	Manufacturing
321	Software and other prerecorded and…	Manufacturing
322	Electric lamp bulb and part manufa…	Manufacturing
323	Lighting fixture manufacturing	Manufacturing
324	Small electrical appliance manufac…	Manufacturing
325	Household cooking appliance manufa…	Manufacturing
326	Household refrigerator and home fr…	Manufacturing
327	Household laundry equipment manufa…	Manufacturing
328	Other major household appliance ma…	Manufacturing
329	Power, distribution, and specialty…	Manufacturing
330	Motor and generator manufacturing	Manufacturing
331	Switchgear and switchboard apparat…	Manufacturing
332	Relay and industrial control manuf…	Manufacturing
333	Storage battery manufacturing	Manufacturing
334	Primary battery manufacturing	Manufacturing
335	Fiber optic cable manufacturing	Manufacturing
336	Other communication and energy wir…	Manufacturing
337	Wiring device manufacturing	Manufacturing

338	Carbon and graphite product manufa…	Manufacturing
339	All other miscellaneous electrical…	Manufacturing
340	Automobile manufacturing	Manufacturing
341	Light truck and utility vehicle ma…	Manufacturing
342	Heavy duty truck manufacturing	Manufacturing
343	Motor vehicle body manufacturing	Manufacturing
344	Truck trailer manufacturing	Manufacturing
345	Motor home manufacturing	Manufacturing
346	Travel trailer and camper manufact…	Manufacturing
347	Motor vehicle gasoline engine and …	Manufacturing
348	Motor vehicle electrical and elect…	Manufacturing
349	Motor vehicle transmission and pow…	Manufacturing
350	Motor vehicle seating and interior…	Manufacturing
351	Motor vehicle metal stamping	Manufacturing
352	Other motor vehicle parts manufact…	Manufacturing
353	Motor vehicle steering, suspension…	Manufacturing
354	Aircraft manufacturing	Manufacturing
355	Aircraft engine and engine parts m…	Manufacturing
356	Other aircraft parts and auxiliary…	Manufacturing
357	Guided missile and space vehicle m…	Manufacturing
358	Propulsion units and parts for spa…	Manufacturing
359	Railroad rolling stock manufacturi…	Manufacturing
360	Ship building and repairing	Manufacturing
361	Boat building	Manufacturing
362	Motorcycle, bicycle, and parts man…	Manufacturing
363	Military armored vehicle, tank, an…	Manufacturing
364	All other transportation equipment…	Manufacturing
365	Wood kitchen cabinet and counterto…	Manufacturing
366	Upholstered household furniture ma…	Manufacturing
367	Nonupholstered wood household furn…	Manufacturing
368	Other household nonupholstered fur…	Manufacturing
369	Institutional furniture manufactur…	Manufacturing
370	Wood office furniture manufacturin…	Manufacturing
371	Custom architectural woodwork and …	Manufacturing
372	Office furniture, except wood, man…	Manufacturing
373	Showcase, partition, shelving, and…	Manufacturing
374	Mattress manufacturing	Manufacturing
375	Blind and shade manufacturing	Manufacturing

376	Surgical and medical instrument ma...	Manufacturing
377	Surgical appliance and supplies ma...	Manufacturing
378	Dental equipment and supplies manu...	Manufacturing
379	Ophthalmic goods manufacturing	Manufacturing
380	Dental laboratories	Manufacturing
381	Jewelry and silverware manufacturi...	Manufacturing
382	Sporting and athletic goods manufa...	Manufacturing
383	Doll, toy, and game manufacturing	Manufacturing
384	Office supplies (except paper) man...	Manufacturing
385	Sign manufacturing	Manufacturing
386	Gasket, packing, and sealing devic...	Manufacturing
387	Musical instrument manufacturing	Manufacturing
388	Fasteners, buttons, needles, and p...	Manufacturing
389	Broom, brush, and mop manufacturin...	Manufacturing
390	Burial casket manufacturing	Manufacturing
391	All other miscellaneous manufactur...	Manufacturing
392	Wholesale - Motor vehicle and moto...	Wholesale
393	Wholesale - Professional and comme...	Wholesale
394	Wholesale - Household appliances a...	Wholesale
395	Wholesale - Machinery, equipment, ...	Wholesale
396	Wholesale - Other durable goods me...	Wholesale
397	Wholesale - Drugs and druggists su...	Wholesale
398	Wholesale - Grocery and related pr...	Wholesale
399	Wholesale - Petroleum and petroleu...	Wholesale
400	Wholesale - Other nondurable goods...	Wholesale
401	Wholesale - Wholesale electronic m...	Wholesale
402	Retail - Motor vehicle and parts d...	Retail
403	Retail - Furniture and home furnis...	Retail
404	Retail - Electronics and appliance...	Retail
405	Retail - Building material and gar...	Retail
406	Retail - Food and beverage stores	Retail
407	Retail - Health and personal care ...	Retail
408	Retail - Gasoline stores	Retail
409	Retail - Clothing and clothing acc...	Retail
410	Retail - Sporting goods, hobby, mu...	Retail
411	Retail - General merchandise store...	Retail
412	Retail - Miscellaneous store retai...	Retail
413	Retail - Nonstore retailers	Retail

414	Air transportation	Transportation and Logistics
415	Rail transportation	Transportation and Logistics
416	Water transportation	Transportation and Logistics
417	Truck transportation	Transportation and Logistics
418	Transit and ground passenger trans…	Transportation and Logistics
419	Pipeline transportation	Natural Gas Distribution and Pipelines
420	Scenic and sightseeing transportat…	Transportation and Logistics
421	Couriers and messengers	Transportation and Logistics
422	Warehousing and storage	Transportation and Logistics
423	Newspaper publishers	Information
424	Periodical publishers	Information
425	Book publishers	Information
426	Directory, mailing list, and other…	Information
427	Greeting card publishing	Information
428	Software publishers	Information
429	Motion picture and video industrie…	Information
430	Sound recording industries	Information
431	Radio and television broadcasting	Information
432	Cable and other subscription progr…	Information
433	Wired telecommunications carriers	Information
434	Wireless telecommunications carrie…	Information
435	Satellite, telecommunications rese…	Information
436	Data processing, hosting, and rela…	Information
437	News syndicates, libraries, archiv…	Information
438	Internet publishing and broadcasti…	Information
439	Nondepository credit intermediatio…	Finance, Insurance, and Real Estate
440	Securities and commodity contracts…	Finance, Insurance, and Real Estate
441	Monetary authorities and depositor…	Finance, Insurance, and Real Estate
442	Other financial investment activit…	Finance, Insurance, and Real Estate
443	Direct life insurance carriers	Finance, Insurance, and Real Estate
444	Insurance carriers, except direct …	Finance, Insurance, and Real Estate
445	Insurance agencies, brokerages, an…	Finance, Insurance, and Real Estate
446	Funds, trusts, and other financial…	Finance, Insurance, and Real Estate
447	Other real estate	Finance, Insurance, and Real Estate
448	Tenant-occupied housing	Finance, Insurance, and Real Estate
449	Owner-occupied dwellings	Finance, Insurance, and Real Estate
450	Automotive equipment rental and le…	Finance, Insurance, and Real Estate
451	General and consumer goods rental …	Finance, Insurance, and Real Estate

452	Video tape and disc rental	Finance, Insurance, and Real Estate
453	Commercial and industrial machiner...	Finance, Insurance, and Real Estate
454	Lessors of nonfinancial intangible...	Finance, Insurance, and Real Estate
455	Legal services	Professional and Business Services
456	Accounting, tax preparation, bookk...	Professional and Business Services
457	Architectural, engineering, and re...	Professional and Business Services
458	Specialized design services	Professional and Business Services
459	Custom computer programming servic...	Professional and Business Services
460	Computer systems design services	Professional and Business Services
461	Other computer related services, i...	Professional and Business Services
462	Management consulting services	Professional and Business Services
463	Environmental and other technical ...	Professional and Business Services
464	Scientific research and developmen...	Professional and Business Services
465	Advertising, public relations, and...	Professional and Business Services
466	Photographic services	Professional and Business Services
467	Veterinary services	Professional and Business Services
468	Marketing research and all other m...	Professional and Business Services
469	Management of companies and enterp...	Professional and Business Services
470	Office administrative services	Professional and Business Services
471	Facilities support services	Professional and Business Services
472	Employment services	Professional and Business Services
473	Business support services	Professional and Business Services
474	Travel arrangement and reservation...	Professional and Business Services
475	Investigation and security service...	Professional and Business Services
476	Services to buildings	Professional and Business Services
477	Landscape and horticultural servic...	Professional and Business Services
478	Other support services	Professional and Business Services
479	Waste management and remediation s...	Professional and Business Services
480	Elementary and secondary schools	Private Education
481	Junior colleges, colleges, univers...	Private Education
482	Other educational services	Private Education
483	Offices of physicians	Healthcare and Social Assistance
484	Offices of dentists	Healthcare and Social Assistance
485	Offices of other health practition...	Healthcare and Social Assistance
486	Outpatient care centers	Healthcare and Social Assistance
487	Medical and diagnostic laboratorie...	Healthcare and Social Assistance
488	Home health care services	Healthcare and Social Assistance
489	Other ambulatory health care servi...	Healthcare and Social Assistance

490	Hospitals	Healthcare and Social Assistance
491	Nursing and community care facilit…	Healthcare and Social Assistance
492	Residential mental retardation, me…	Healthcare and Social Assistance
493	Individual and family services	Healthcare and Social Assistance
494	Child day care services	Healthcare and Social Assistance
495	Community food, housing, and other…	Healthcare and Social Assistance
496	Performing arts companies	Arts, Entertainment, and Recreation
497	Commercial Sports Except Racing	Arts, Entertainment, and Recreation
498	Racing and Track Operation	Arts, Entertainment, and Recreation
499	Independent artists, writers, and …	Arts, Entertainment, and Recreation
500	Promoters of performing arts and s…	Arts, Entertainment, and Recreation
501	Museums, historical sites, zoos, a…	Arts, Entertainment, and Recreation
502	Amusement parks and arcades	Arts, Entertainment, and Recreation
503	Gambling industries (except casino…	Arts, Entertainment, and Recreation
504	Other amusement and recreation ind…	Arts, Entertainment, and Recreation
505	Fitness and recreational sports ce…	Arts, Entertainment, and Recreation
506	Bowling centers	Arts, Entertainment, and Recreation
507	Hotels and motels, including casin…	Accommodation and Food Service
508	Other accommodations	Accommodation and Food Service
509	Full-service restaurants	Accommodation and Food Service
510	Limited-service restaurants	Accommodation and Food Service
511	All other food and drinking places	Accommodation and Food Service
512	Automotive repair and maintenance,…	Other Personal Services
513	Car washes	Other Personal Services
514	Electronic and precision equipment…	Other Personal Services
515	Commercial and industrial machiner…	Other Personal Services
516	Personal and household goods repai…	Other Personal Services
517	Personal care services	Other Personal Services
518	Death care services	Other Personal Services
519	Dry-cleaning and laundry services	Other Personal Services
520	Other personal services	Other Personal Services
521	Religious organizations	Other Personal Services
522	Grantmaking, giving, and social ad…	Other Personal Services
523	Business and professional associat…	Other Personal Services
524	Labor and civic organizations	Other Personal Services
525	Private households	Other Personal Services
526	Postal service	Federal Government
527	Federal electric utilities	Federal Government

528	Other federal government enterpris...	Federal Government
529	State government passenger transit	S&L Government (Non-Education)
530	State government electric utilitie...	S&L Government (Non-Education)
531	Other state government enterprises	S&L Government (Non-Education)
532	Local government passenger transit	S&L Government (Non-Education)
533	Local government electric utilitie...	S&L Government (Non-Education)
534	Other local government enterprises	S&L Government (Non-Education)
539	* Employment and payroll of state ...	S&L Government (Education)
540	* Employment and payroll of state ...	S&L Government (Non-Education)
541	* Employment and payroll of local ...	S&L Government (Education)
542	* Employment and payroll of local ...	S&L Government (Non-Education)
543	* Employment and payroll of federa...	Federal Government
544	* Employment and payroll of federa...	Federal Government