Rhodium Group

The Economic Benefits of Carbon Capture

Investment and employment opportunities for the contiguous United States

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About this analysis

The Great Plains Institute (GPI) commissioned Rhodium Group to assess and quantify the national economic benefits associated with carbon capture retrofit opportunities across the contiguous United States. The research was performed independently. The results presented in this report reflect the views of the authors, and not necessarily GPI's.

About Rhodium Group

Rhodium Group is an independent research provider combining economic data and policy insight to analyze global trends. Rhodium's Energy & Climate team analyzes the market impact of energy and climate policy and the economic risks of global climate change. This interdisciplinary group of policy experts, economic analysts, energy modelers, data engineers, and climate scientists supports decision-makers in the public, financial services, corporate, philanthropic and non-profit sectors. More information is available at www.rhg.com.

John Larsen is a Director at Rhodium Group and leads the firm's US power sector and energy systems research. John specializes in analysis of national and state clean energy policy and market trends. Previously, John worked for the US Department of Energy's Office of Energy Policy and Systems Analysis where he served as an electric power policy advisor.

Whitney Herndon is an Associate Director at Rhodium Group and manages the firm's US energy research. Whitney manages a team of analysts that use a range of energy and economic models to analyze the impact of policy proposals and market shifts on the US energy system and macroeconomy. Her expertise includes carbon capture, energy and electric power systems modeling, and economy-wide decarbonization.

Galen Hiltbrand is a Research Analyst at Rhodium Group, focusing on US energy policy and carbon management. She uses quantitative tools to assess the role that carbon capture and carbon removal technologies can play in decarbonizing the US energy system.

Ben King is a Senior Analyst at Rhodium Group, focusing on US energy policy and markets. Previously, Ben was an analyst in the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), where he worked on demand-side efficiency analysis and electricity market policy.

Contents

SECTION 1

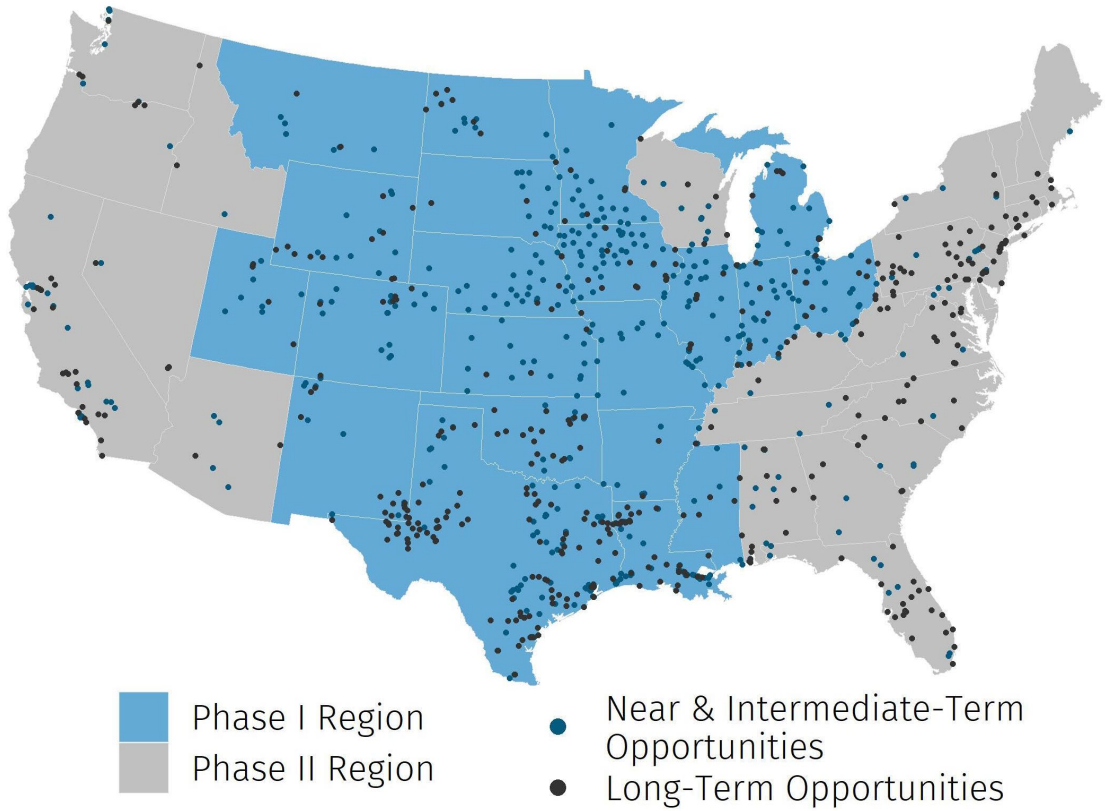
Study Objectives, Methodology, and Assumptions

Study Objectives

This study is Phase III of an analysis exploring the economic benefits associated with carbon capture retrofit opportunities at existing industrial and power facilities. This phase explores national opportunities through the mid-century. The analysis is split into two time periods: near & intermediate-term (2021-2035) and long-term (2036-2050). The direct economic benefits considered include private sector investment and employment opportunities associated with the construction and operation of carbon capture retrofits.

In the previous phases of research, we conducted state-by-state analyses of the near & intermediate-term economic benefits of carbon capture retrofits. Phase I analysis explored industrial and power sector opportunities in 21 of the states participating in the Regional Carbon Capture Deployment Initiative (highlighted in blue). Phase II analysis explored the industrial sector opportunities in Eastern & Western states (highlighted in gray).

Examined Carbon Capture Opportunities by State



Source: Rhodium Group analysis, The Great Plains Institute

Methodology and Assumptions

Employment Analysis

- We use the economic model IMPLAN's state level tools for this analysis.
- Results only include jobs associated with retrofitting of facilities.
- We estimate national jobs associated with the investment for carbon capture in the contiguous US.
- Jobs associated with capital investments are the average annual jobs over 15 years spurred by retrofitting facilities with carbon capture.
- Annual operation jobs represent the on-site and off-site jobs associated with operating the carbon capture retrofit equipment at each facility each year.
- Employment per industrial output is assumed to stay constant over time.

Facility Identification

- For purposes of analysis, it is assumed that any identified facilities remain operational through the study period regardless of their current or future economic viability.

Cost Characterization

- Capital and operations & maintenance costs are independently assessed by Rhodium.
- Carbon capture at each plant is determined as part of the cost analysis.

Methodology and Assumptions

Employment analysis

Step 1: Apply Costs

- Identify and separate near & intermediate-term opportunities and long-term opportunities
- Apply Rhodium's own capital and operations and maintenance (O&M) costs to each facility
  - Apply capacity decisions
  - High and low capital and O&M costs
- Aggregate costs in each study time period by present industries
  - Ammonia, cement, ethanol, gas processing, hydrogen, refineries, steel, coal power generation, and gas power generation

Step 2: IMPLAN Inputs

- Conduct in-depth research on how distribution of costs for carbon capture vary by industry
  - Each facility type requires different equipment, materials, maintenance, and energy inputs which lead to different costs
- Apply cost breakdowns for each industry and sort into appropriate IMPLAN sectors
- Run national IMPLAN analysis with a high and low scenario for each present industry

Step 3: Aggregate Jobs

- Jobs Associated with Capital Investment: include jobs associated with retrofitting the facility with carbon capture
  - Equipment, materials, construction, engineering
- Operation Jobs: include the increase in jobs associated with operating the retrofit facility
  - Can include maintenance, labor, chemicals, water treatment, and energy
  - Includes both on-site and off-site jobs necessary for retrofit operations. On-site jobs are approximately 5-15% of total operation jobs depending on the industry

SECTION 2

Key Takeaways

Key Takeaways

Carbon capture is a multi-billion dollar investment opportunity

- Pursuing all carbon capture retrofit opportunities at the facilities identified in this study will require $330 - $500 billion in capital investment through midcentury.
- Jobs will be created in a variety of industries including ethanol, hydrogen, cement, refineries, steel, and power plants.

Carbon capture investment will lead to good jobs

- Over the next 15 years, up to 64,000 jobs will be created by capital investment in these retrofits. Additionally, up to 43,000 jobs will be created from retrofit operations.
- Additional jobs will occur in the long-term. Post-2035, capital investment will drive up to 78,000 jobs. Up to 53,000 jobs will also be created in this time-period from retrofit operations.

Carbon capture is a key technology for achieving net-zero emissions

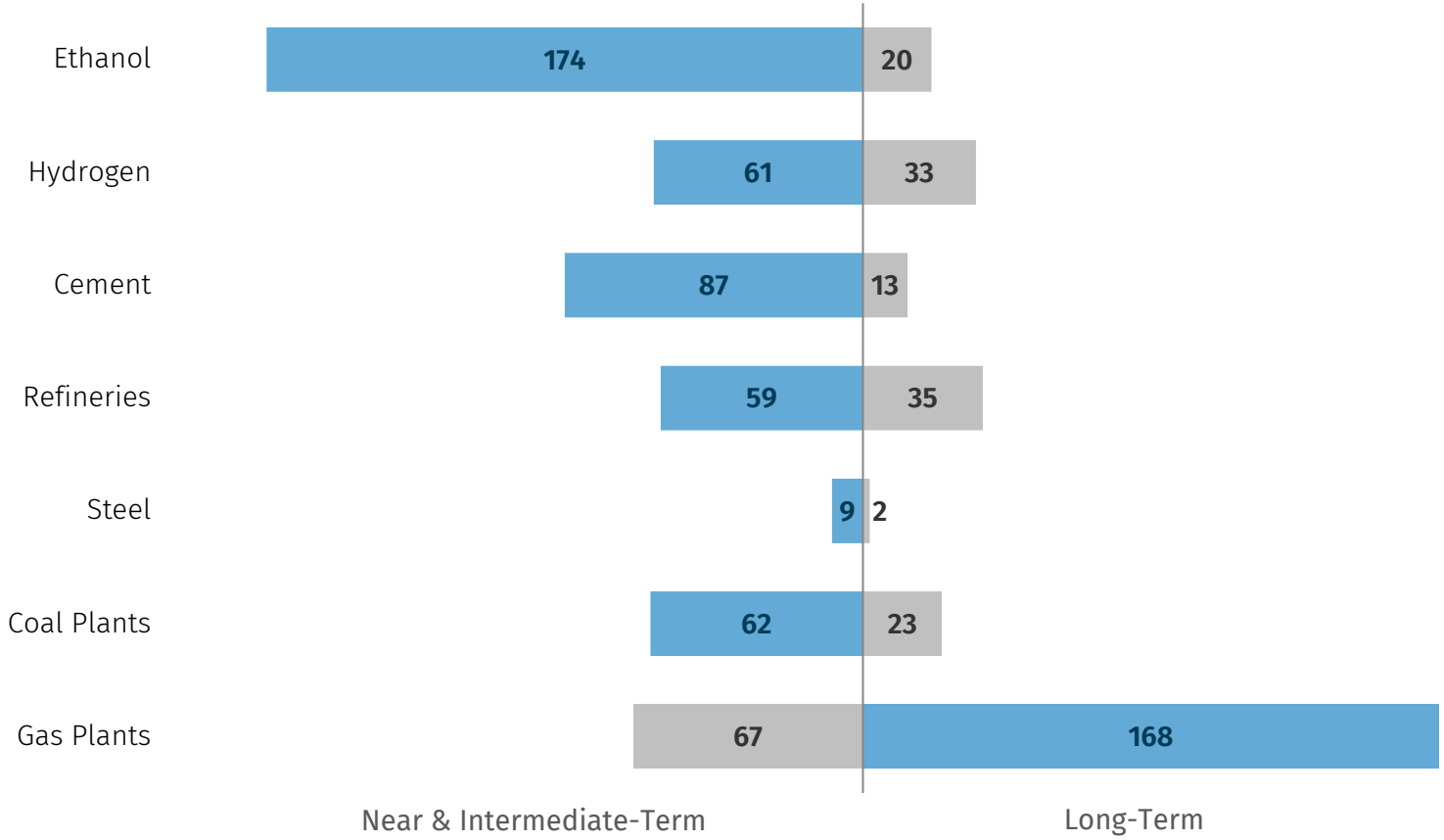
- Near & intermediate-term retrofit opportunities account for 704 MMt of annual CO_2 capture.
- Long-term opportunities account for an additional 408 MMt of annual CO_2 capture.

Note: Near & intermediate term is defined as 2021-2035, long-term is defined as 2036-2050. Job numbers are annual averages over the studied time period.

The timing of retrofit opportunities varies by industry.

Carbon capture retrofit potential by time period

Number of facilities by industry in the near & intermediate-term (2021-2035) and long-term (2036-2050)



- The majority of industrial and coal opportunities happen in the near & intermediate-term.
- More than 60% of industrial facilities and more than 70% of coal plant retrofit opportunities occur by 2035.
- Whereas, about 70% of the gas plant opportunities occur in the long-term.

Source: Rhodium Group analysis, The Great Plains Institute.

SECTION 3

Near & Intermediate-Term Opportunities 2021-2035

Methodology and Assumptions

Near & intermediate-term opportunities

Employment Analysis

- We assume the near & intermediate-term carbon capture retrofits will be built over a 15-year time period, 2021 to 2035.
- This assumption does not represent Rhodium Group's view on carbon capture infrastructure deployment.

Facility Identification

- For purposes of analysis, it is assumed that any identified facilities remain operational through the study period regardless of their current or future economic viability.
- GPI identified the facilities analyzed in the Phase I (Regional Carbon Capture Deployment Initiative) states.
- Rhodium Group identified the facilities analyzed in the Phase II (Eastern & Western) states.

Cost Characterization

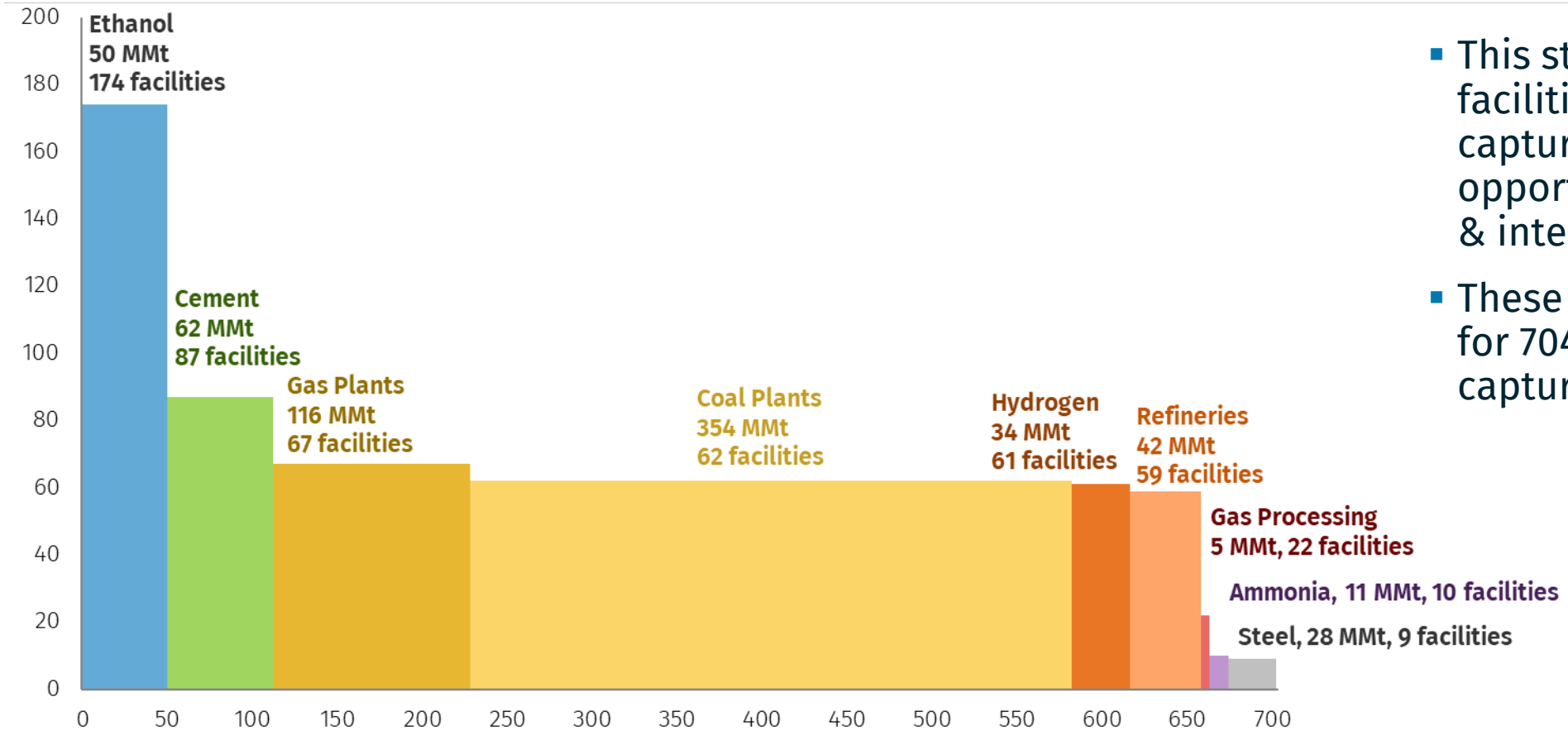
- Capital and operations & maintenance costs are independently assessed by Rhodium.
- Carbon capture at each plant is determined as part of the cost analysis.

Near & Intermediate-Term Carbon Capture Potential

Retrofit opportunities across the contiguous United States, 2021-2035

Carbon Capture Potential by Industry

X-axis is million metric tons (MMt) of annual CO_2 capture, y-axis is the number of facilities by industry



- This study identified 553 facilities with carbon capture retrofit opportunities in the near & intermediate-term.
- These retrofits account for 704 MMt of annual CO_2 capture.

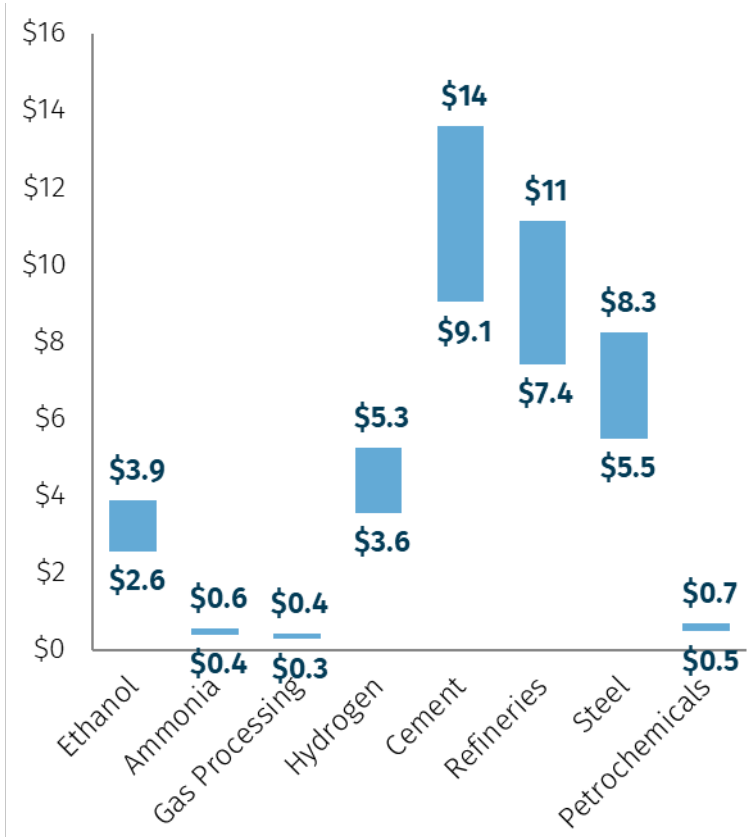
Source: Rhodium Group analysis, The Great Plains Institute. Note: The chart above does not include 2 petrochemical facilities analyzed in this study, which account for 2 MMt of annual CO_2 capture.

Industrial Facilities

Near & intermediate-term carbon capture opportunities

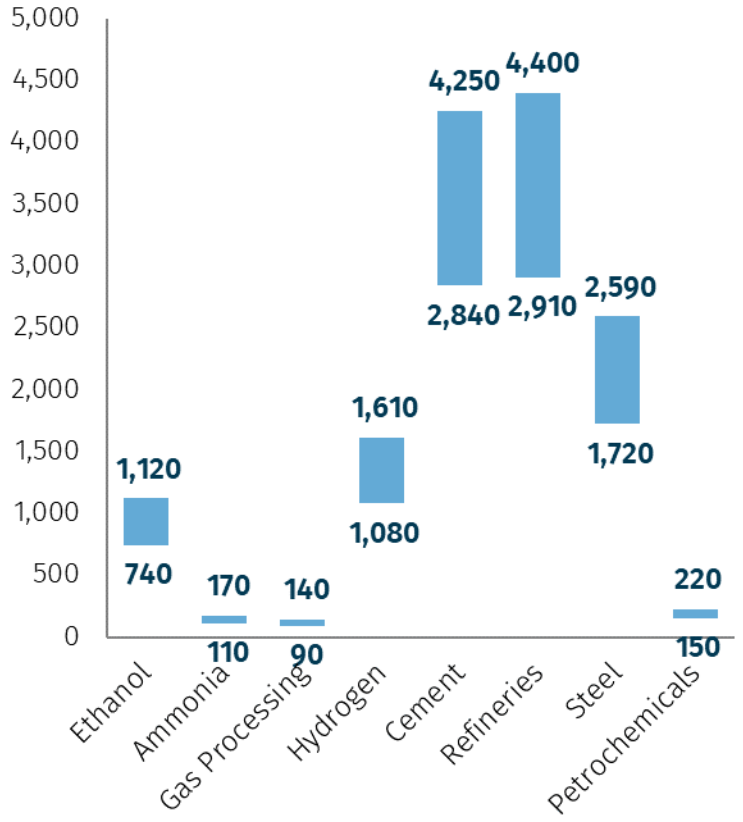
Capital Investment Requirement

Billion $ USD



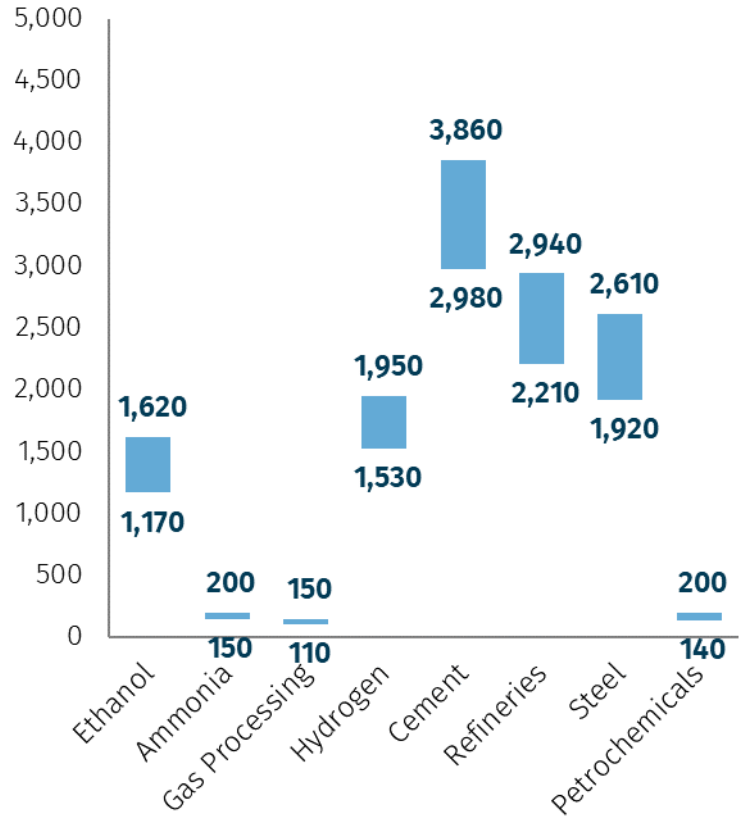
Jobs Associated with Capital Investment

Average jobs each year, 2021-2035



Ongoing Jobs

Annual operation jobs



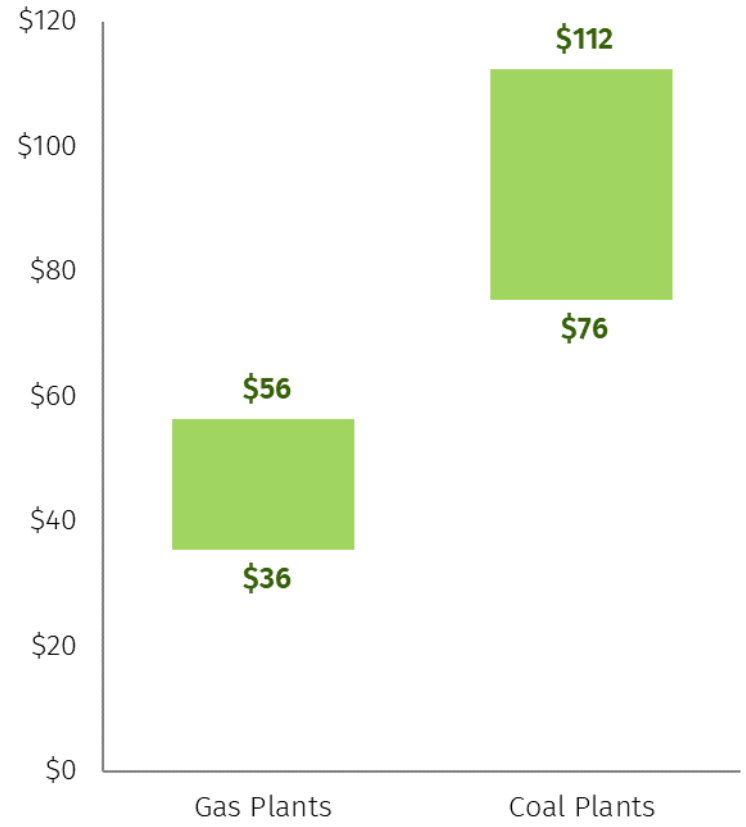
Source: Rhodium Group analysis. Note: The values above are not cumulative. The actual jobs associated with capital investment in any given year will depend on the pace of project development. Capital investment job values above reflect the average over the 15-year study period.

Electric Power Sector

Near & intermediate-term carbon capture opportunities

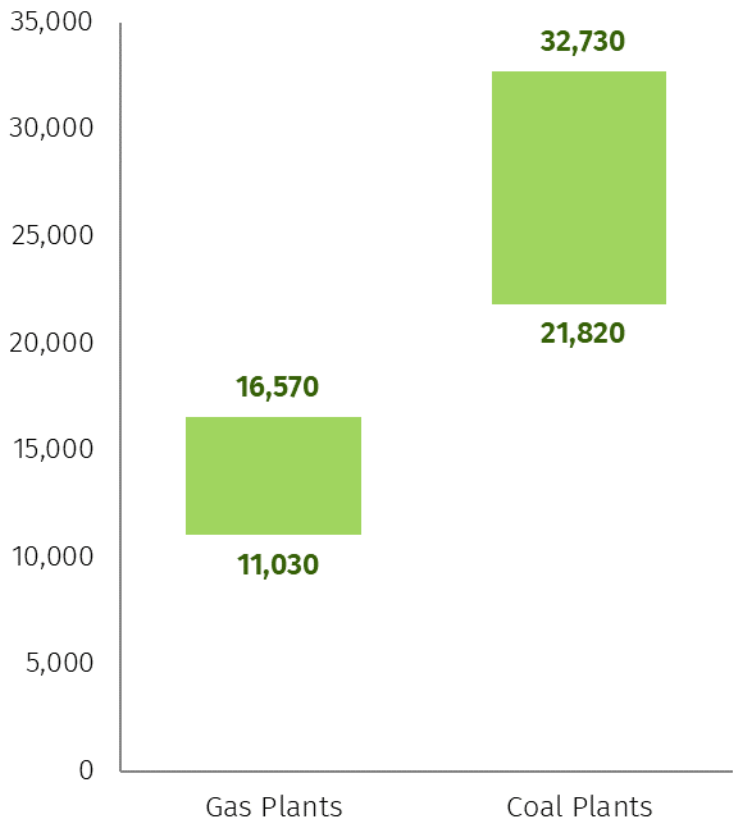
Capital Investment Requirement

Billion $ USD



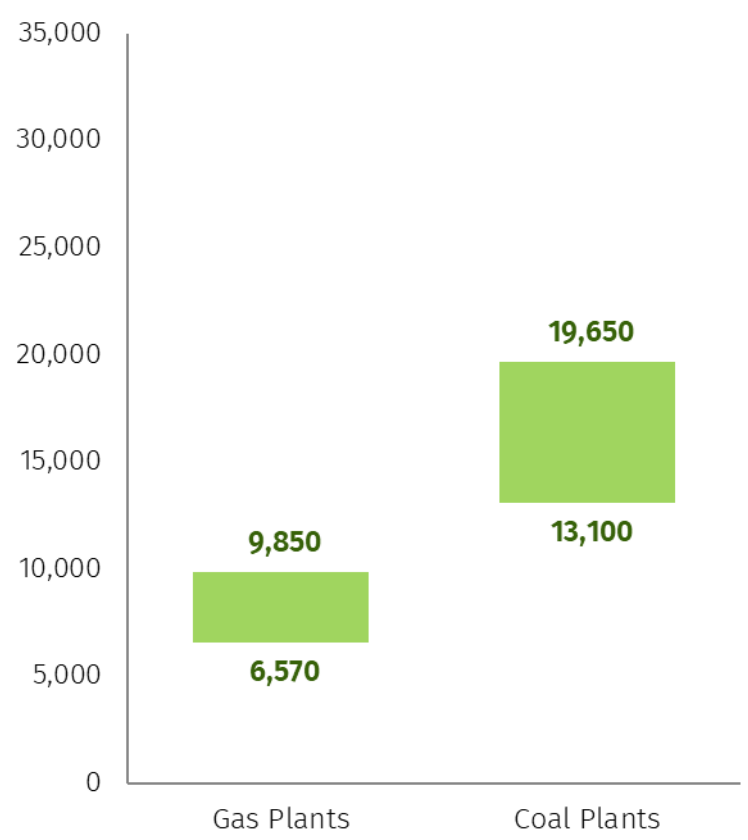
Jobs Associated with Capital Investment

Average jobs each year, 2021-2035



Ongoing Jobs

Annual operation jobs



Source: Rhodium Group analysis. Note: The values above are not cumulative. The actual jobs associated with capital investment in any given year will depend on the pace of project development. Capital investment job values above reflect the average over the 15-year study period.

SECTION 4

Long-Term Opportunities 2036-2050

Methodology and Assumptions

Long-term opportunities

Employment Analysis

- We assume the long-term carbon capture retrofits will be built over a 15-year time period, 2036 to 2050.
- This assumption does not represent Rhodium Group's view on carbon capture infrastructure deployment.

Facility Identification

- Rhodium identified the facilities analyzed in the long-term scenario.
- For purposes of analysis, it is assumed that any identified facilities remain operational through the study period regardless of their current or future economic viability.
- The future for coal is particularly uncertain. To identify the coal facilities, we use our Taking Stock 2020 forecast which assumes no carbon or climate policy and select the most economic coal plants that are still in operation through 2050.

Cost Characterization

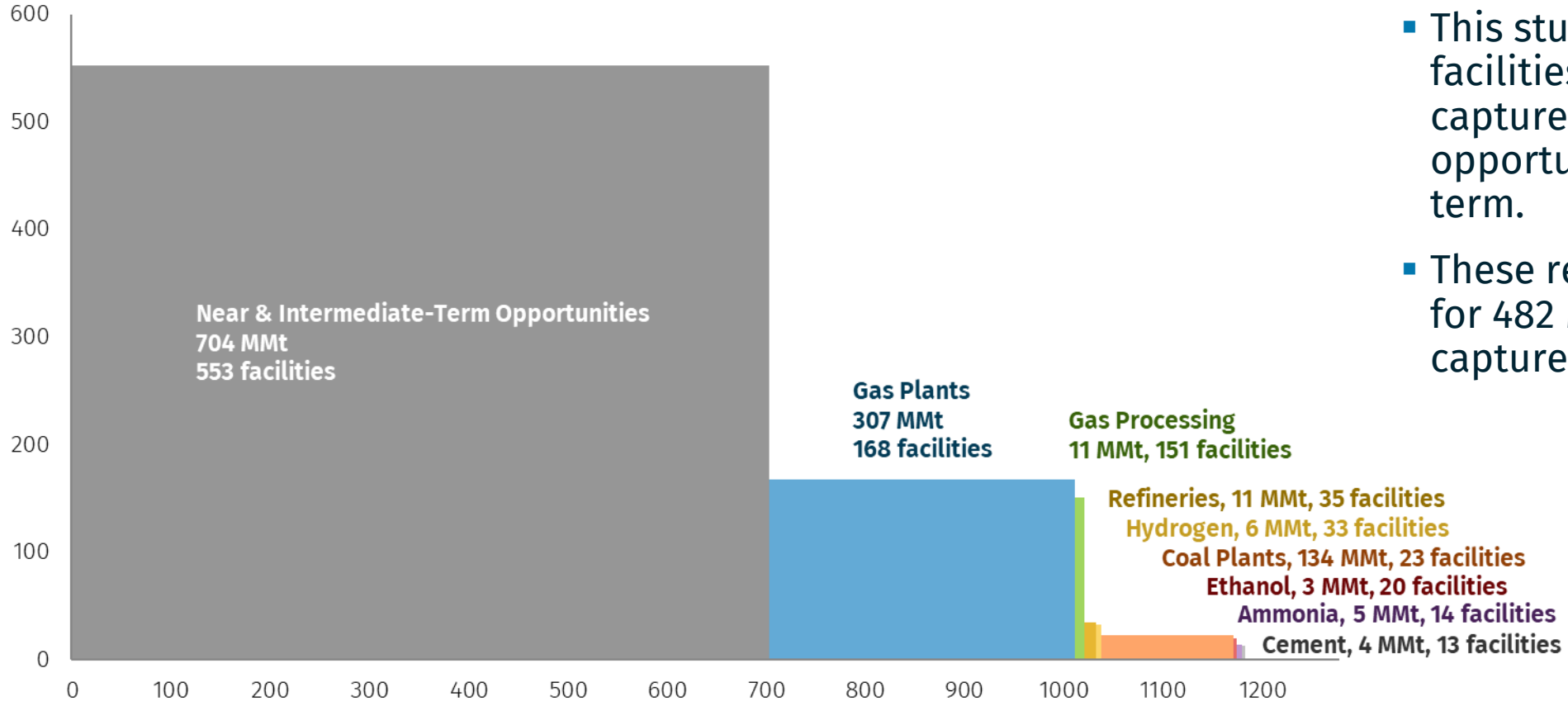
- Capital and operations & maintenance costs are independently assessed by Rhodium.
- Carbon capture at each plant is determined as part of the cost analysis.

Long-Term Carbon Capture Potential

Retrofit opportunities across the contiguous United States, 2036-2050

Carbon Capture Potential by Industry

X-axis is million metric tons (MMt) of annual CO_2 capture, y-axis is the number of facilities by industry



- This study identified 459 facilities with carbon capture retrofit opportunities in the long-term.
- These retrofits account for 482 MMt of annual CO_2 capture.

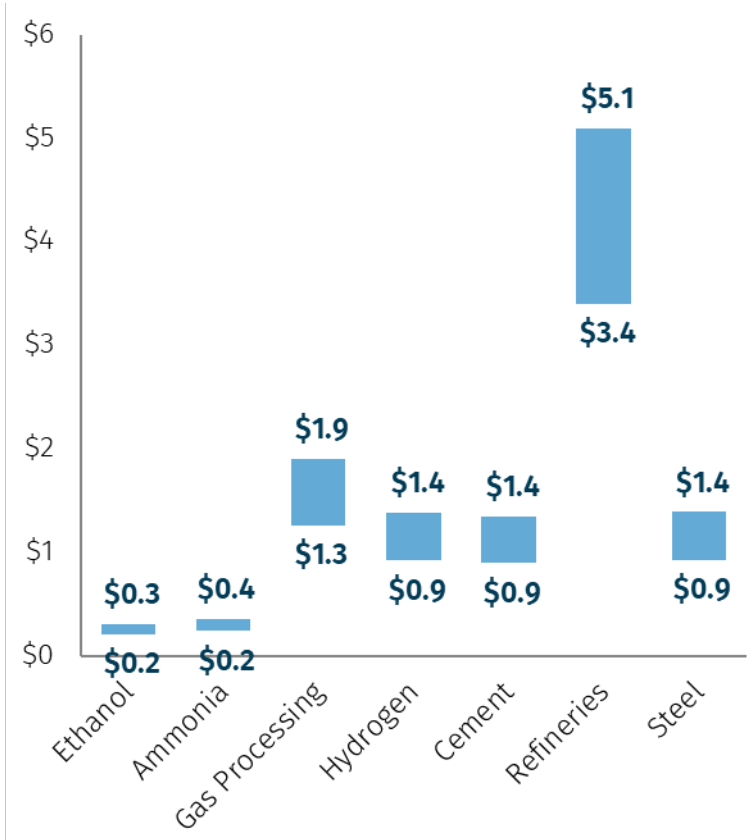
Source: Rhodium Group analysis, The Great Plains Institute. Note: The chart above does not include 2 steel facilities analyzed in this study, which account for 2 MMt of annual CO_2 capture. To identify the coal facilities, we use our Taking Stock 2020 forecast which assumes no carbon or climate policy and select the most economic coal plants that are still in operation through 2050.

Industrial Facilities

Long-term carbon capture opportunities, 2036-2050

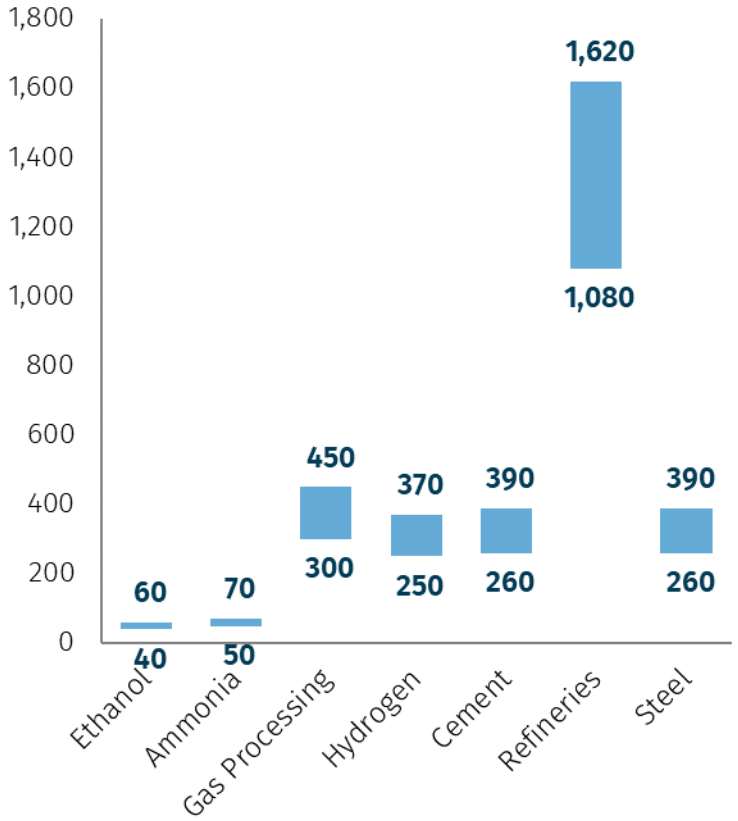
Capital Investment Requirement

Billion $ USD



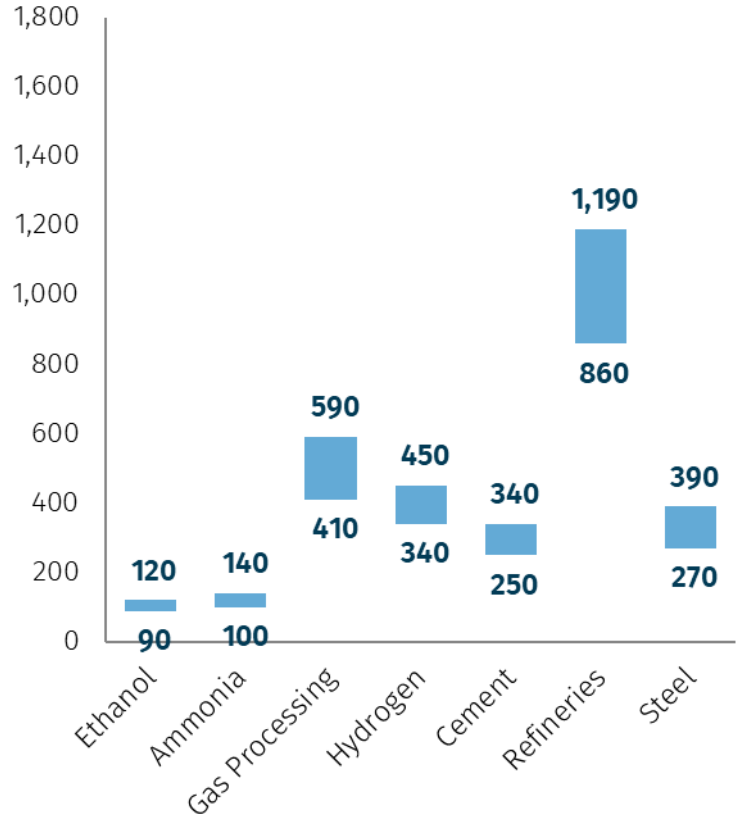
Jobs Associated with Capital Investment

Average jobs each year, 2036-2050



Ongoing Jobs

Annual operation jobs



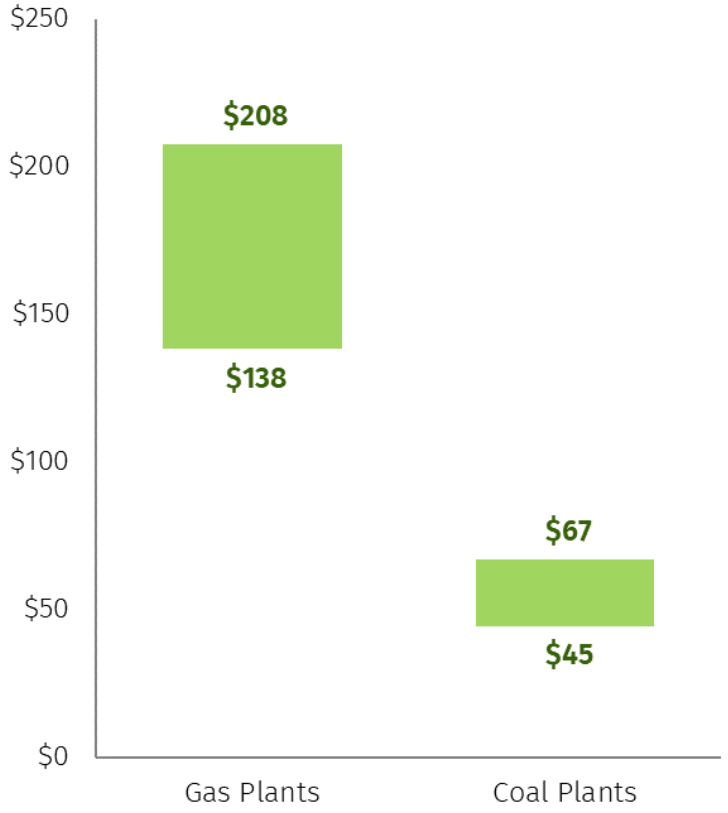
Source: Rhodium Group analysis. Note: The values above are not cumulative. The actual jobs associated with capital investment in any given year will depend on the pace of project development. Capital investment job values above reflect the average over the 15-year study period.

Electric Power Sector

Long-term carbon capture opportunities, 2036-2050

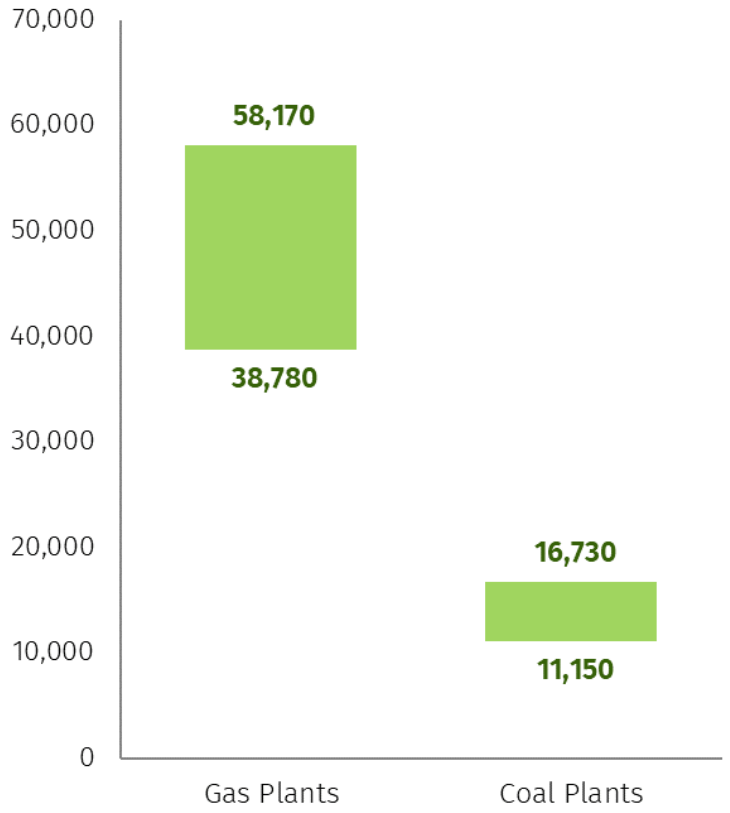
Capital Investment Requirement

Billion $ USD



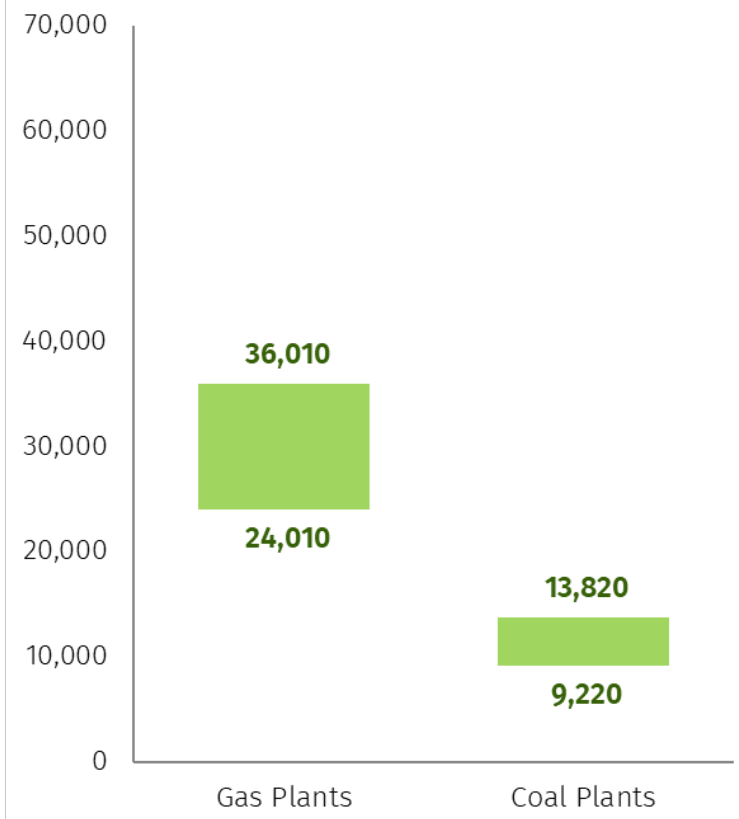
Jobs Associated with Capital Investment

Average jobs each year, 2036-2050



Ongoing Jobs

Annual operation jobs



Source: Rhodium Group analysis. Note: The values above are not cumulative. The actual jobs associated with capital investment in any given year will depend on the pace of project development. Capital investment job values above reflect the average over the 15-year study period. To identify the coal facilities, we use our Taking Stock 2020 forecast which assumes no carbon or climate policy and select the most economic coal plants that are still in operation through 2050.

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