Rhodium Group

Capturing New Jobs

The employment opportunities associated with scale-up of Direct Air Capture (DAC) technology in the US

PREPARED FOR THE LINDEN TRUST FOR CONSERVATION | JUNE 23, 2020

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About this analysis

The Linden Trust for Conservation commissioned Rhodium Group to assess and quantify the employment opportunities associated with the scale-up of Direct Air Capture technology in the US. The research was performed independently. The results presented in this report reflect the views of the authors, unswayed by those of the Linden Trust.

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 a Senior Analyst at Rhodium Group focusing on US energy markets and policy. She employs a range of energy and economic models to analyze the impact of policy proposals on the US electricity sector, energy market, and macroeconomy.

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.

Goal and components of this analysis

Goal: Quantify the employment opportunities of materials and services associated with the scale-up of Direct Air Capture deployment in the US.

Contents:

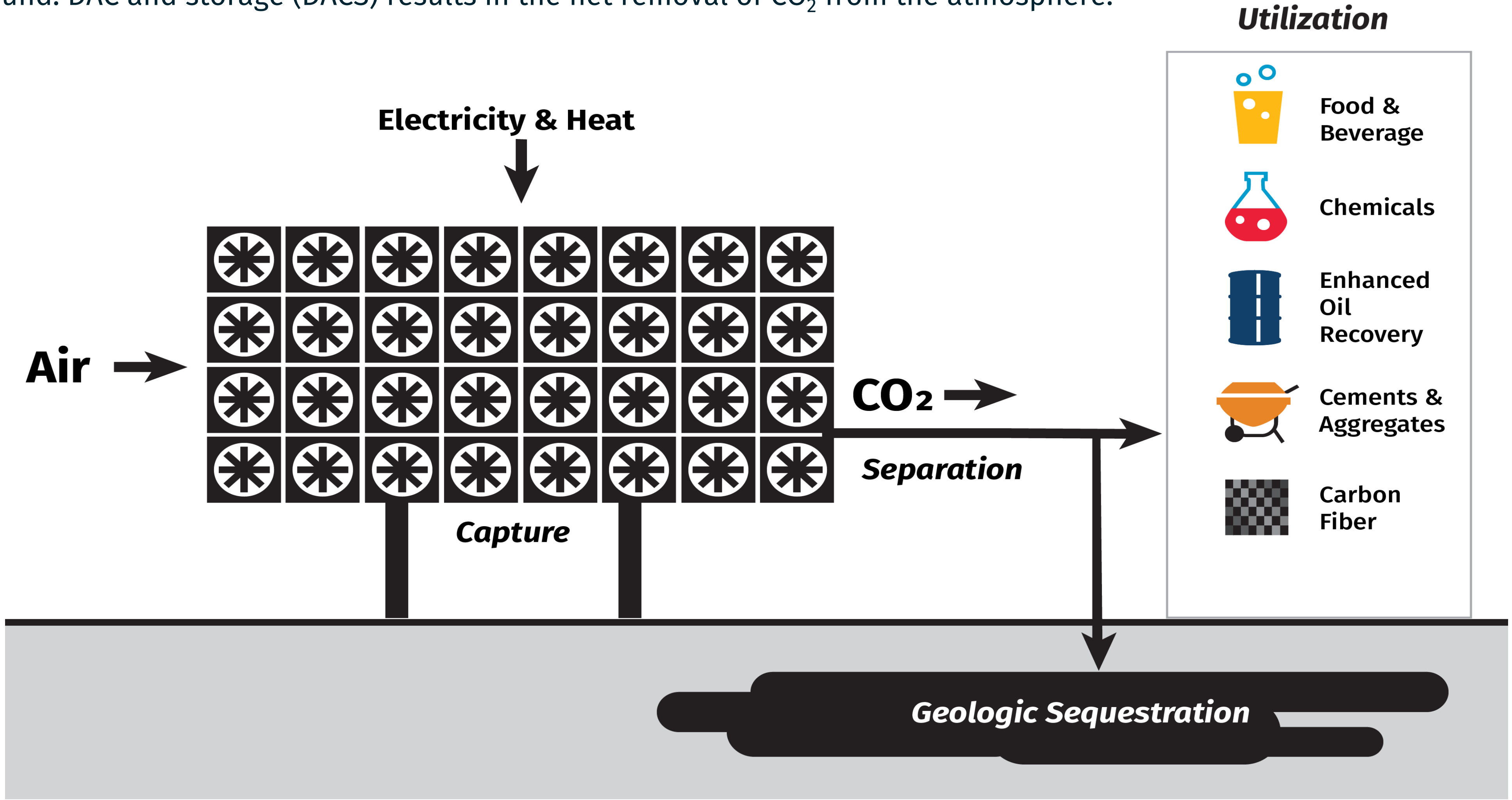
1. An introduction to Direct Air Capture technology
2. Methodology to estimate DAC employment opportunities
3. Job opportunity estimates
   - Comparison of current employment numbers in relevant sectors to projected number of jobs supported by Direct Air Capture scale-up by midcentury
   - Jobs associated with DAC plant investment
     - Equipment
     - Construction
     - Engineering
     - Steel
     - Cement
   - Jobs associated with DAC plant operations
     - Operations & Maintenance
     - Electricity
     - Fuel
     - Chemicals

SECTION 1

An Introduction to Direct Air Capture

Direct Air Capture (DAC) technology

DAC uses electricity and heat to filter carbon dioxide (CO_2) from the ambient air for utilization or for permanent storage deep underground. DAC and storage (DACS) results in the net removal of CO_2 from the atmosphere.

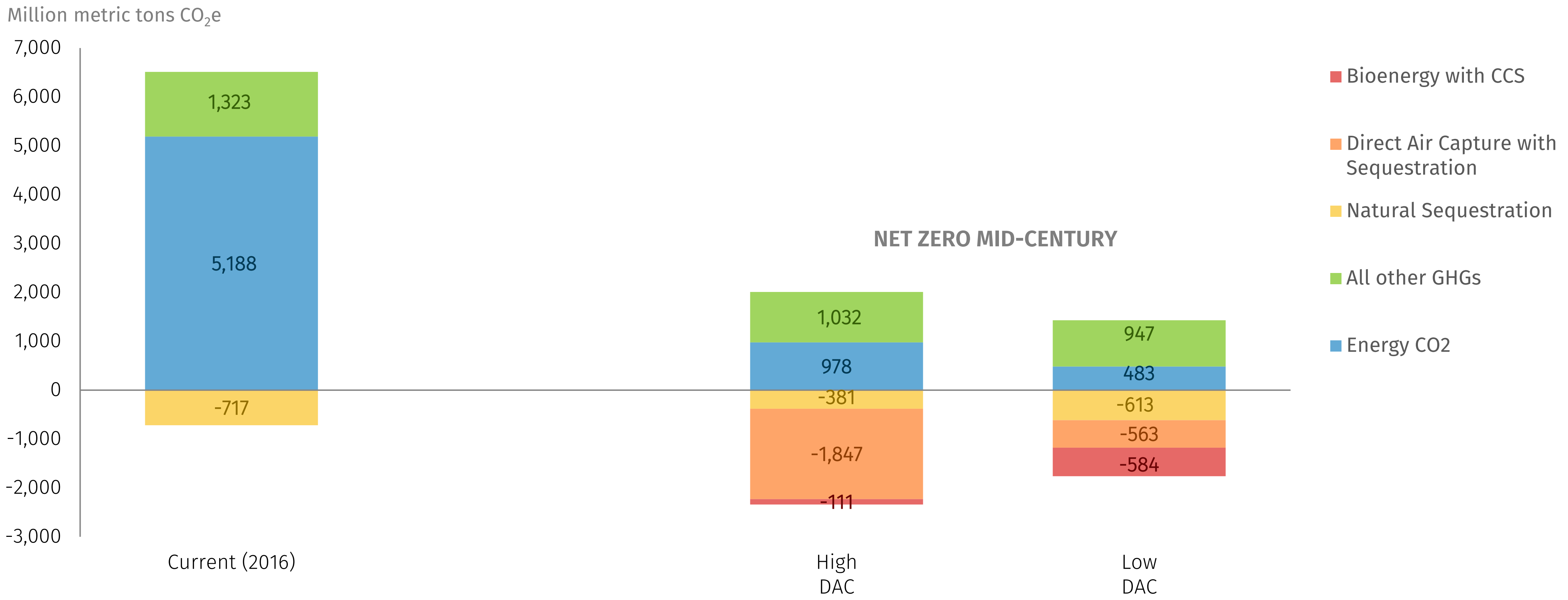


Source: Rhodium Group adapted from World Resources Institute

DAC is key to meeting climate targets

Previous Rhodium research found that DACS is an essential part of any US approach to reaching net-zero greenhouse gas (GHG) emissions by mid-century, which requires a 6 billion metric ton reduction compared to current levels. Decarbonization efforts including electrification, energy efficiency, synthetic fuels, and other types of carbon removal are all required. Even with rapid scale-up of each strategy, 563 million tons of CO_2 will need to be removed from the atmosphere using DACS (low DAC scenario) to meet a net-zero target. If other decarbonization options are slower to deploy, up to 1,847 million tons CO_2 removal using DACS will be needed (high DAC scenario).

US greenhouse gas emissions, current and 2050



Source: Rhodium Group and Evolved Energy Research analysis. Note: See Capturing Leadership for more information. 2050 results shown represent achieving net-zero GHG emissions by 2045 and negative emissions in 2050. DACS removal values are smaller than capacity values reported later in this presentation due to lower than 100% utilization.

DAC is a proven technology

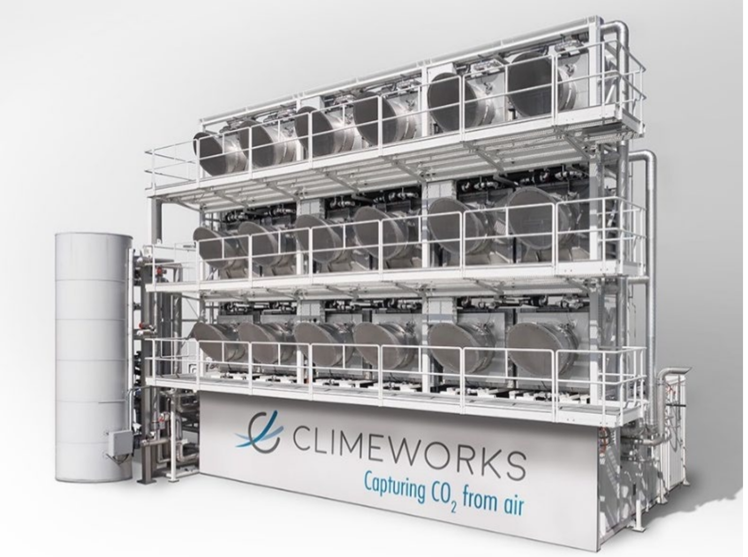
DAC has attracted hundreds of millions of dollars in private and public investment. There are three commercial companies with 11 pilot projects deployed across the world. One company, Carbon Engineering, plans to break ground on a megaton scale facility soon. Rhodium estimates that the first megaton scale DAC plant will have a levelized cost of $124-$325/metric ton of captured carbon with the range reflecting technology diversity and energy cost uncertainty. Costs are estimated to decline substantially with deployment.

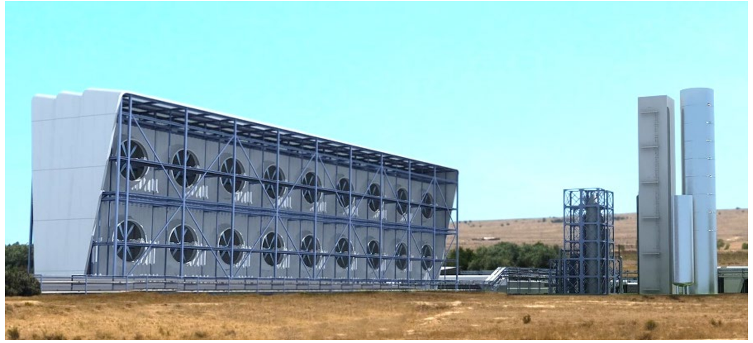
DAC companies with commercial technology

CLIMEWORKS

Carbon Engineering

Global Thermostat





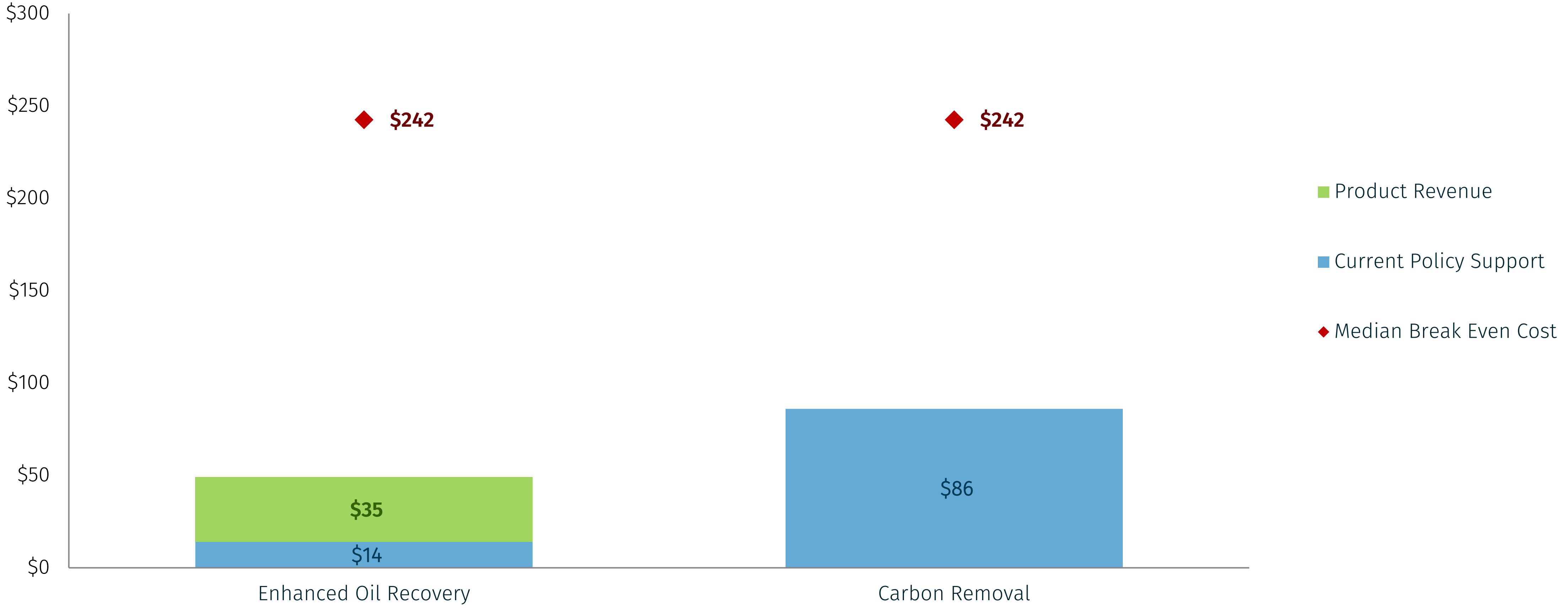
Source: Climeworks, Carbon Engineering

Federal action is needed for DAC scale-up

DAC has existing policy support from California's Low Carbon Fuel Standard (LCFS) and the federal 45Q tax credit. However, to overcome the current median costs of $242/ton, more federal policy support is needed for widespread DAC deployment. See Rhodium's Capturing Leadership for more on policy options for large-scale DAC deployment.

DAC costs exceed current revenue opportunities

30-year levelized USD (2018 dollars) per metric ton CO_2

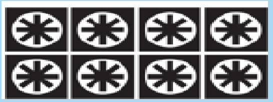


Source: Rhodium Group analysis. Note: all values reflect median DAC costs. See Capturing Leadership for more information.

Two main approaches to DAC

There are two main processes for commercial DAC technology. One uses a chemical solid sorbent to capture CO_2 and the other uses a liquid solvent. Each approach has different construction requirements and different costs and performance profiles. There is no clear front-runner technology. This analysis considers both approaches.

System	Step 1	Step 2	Step 3
Solid Sorbent	**Air Contactor** Ambient air enters air contactor and CO_2 is adsorbed onto a solid adsorbent	**Temperature/ Vacuum Adsorption** Heat exposure (with possible vacuum pressure) releases CO_2 from adsorbent and a concentrated stream of CO_2 is produced	**Regeneration of Sorbent or Solvent** Sorbent is cooled to reactivate it for reuse in the air contactor
Liquid Solvent	Ambient air enters air contactor and CO_2 reacts with capture solution to produce carbonate	**Pellet Reactor** Carbonate reacts with hydroxide to form small pellets **Calciner** Pellets are heated to produce lime and a concentrated stream of CO_2	Lime from the calciner reactivates capture solution for reuse in the air contactor



Source: Energy Futures Initiative. Process simplified.

DAC plant direct employment opportunities

In this analysis, we focus on the largest employment opportunities directly associated with DAC scale-up in three categories: Construction/Capital, Energy Requirements and Operations. For example, we estimate the jobs created in the cement industry associated with cement required for DAC plant construction. Due to a range of uncertainties, we do not estimate the indirect or induced jobs associated with DAC scale-up even though it is likely that such opportunities will be substantial. We rely on a range of data sources and previous Rhodium research to estimate the size of these direct employment opportunities.

Construction/Capital

Equipment

Cement

Steel

Construction

Engineering

Energy Requirements

Electricity

Heat
- Natural Gas
- Electric Heat

Operations

Chemicals

Operations & Maintenance

SECTION 2

Methodology to Estimate DAC Employment Opportunities

Methodology and assumptions

In this analysis, we focus on the employment opportunities associated with DAC scale-up. We rely on a range of data sources and previous Rhodium research to estimate the value of these opportunities.

Focus sectors

- Equipment
- Construction
- Engineering
- Steel
- Cement
- Electricity
- Natural Gas
- Operations & Maintenance
- Chemicals

DAC scale

A range of DAC deployment is quantified through 2050, associated with meeting a midcentury net-zero, economy-wide emissions target for the US.*

Technology

- Both solid sorbent and liquid solvent technologies
- Projections assume the market is supplied by 50% solid sorbent and 50% liquid solvent
- Today's technology and cost are used

Construction and inputs

- Each plant is assumed to have the capacity of 1MMt/year
- Median operating and cost parameters
- Heat and electric requirements are assumed to be supplied by 100% electricity in Solid Sorbent plants and 100% natural gas in Liquid Solvent plants
- Plant construction assumed to be completed within one year

Employment analysis

- Economic model IMPLAN used to input changes in expenditures in the focus sectors due to DAC scale-up
- We follow BLS and BEA's jobs definition: employment estimates represent annualized job numbers and include full-time, part-time, and seasonal jobs
- Employment per industry output assumed to stay constant over time
- Results include only direct jobs associated with DAC plants.

Data sources

- Energy Information Administration
- National Academy of Sciences
- Keith et al. 2018
- American Institute of Steel Construction
- U.S. Bureau of Labor Statistics
- IMPLAN Group
- Bureau of Economic Analysis

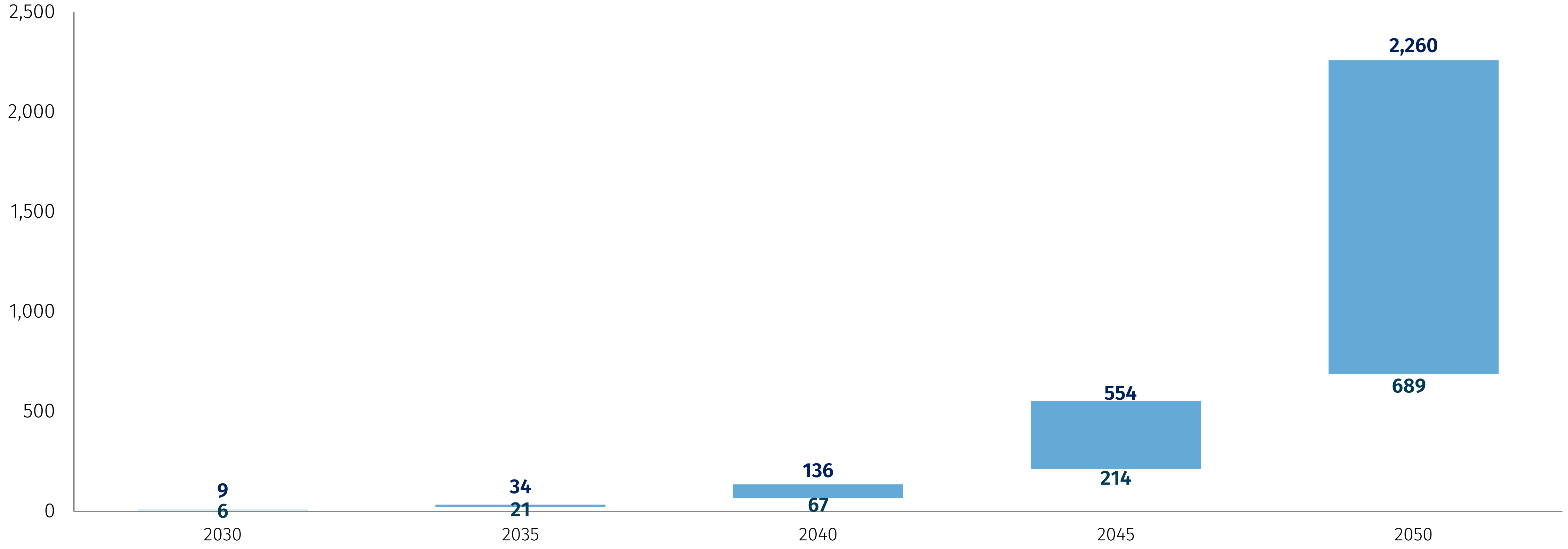
*See Capturing Leadership for more information.

Pathways to net-zero emissions by mid-century

Our previous research found that 689 to 2,260 million tons of capture capacity is necessary to achieve net-zero emissions by mid-century. We use this range for the level of DAC scale-up in this analysis. We assume a 50/50 split between liquid solvent and solid sorbent technologies. This rapid scale-up will only occur with ambitious federal policy action both in the near and long-term. Employment opportunities may be larger, and more near-term if policy action is quicker and more robust than this analysis assumes.

Range of DAC deployment in the US

Million metric tons/year capture capacity



Source: Rhodium Group analysis. Note: See Capturing Leadership for more information. Note: Capacity values shown here are larger than the carbon removal values shown earlier in the presentation due to less than 100% utilization. The emissions associated with materials used to construct DAC capacity are not considered in this analysis but will need to be addressed if the US Is to achieve net-zero emissions by mid-century.

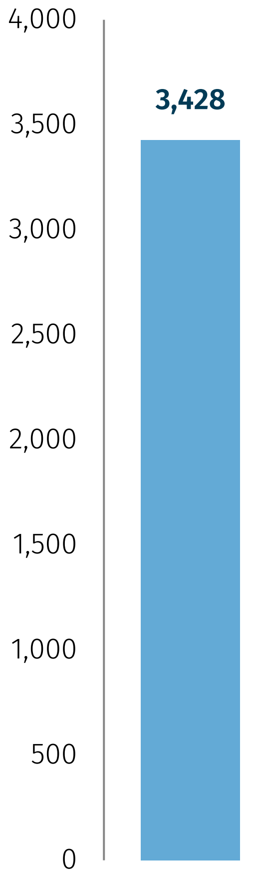
SECTION 3

Overview of DAC Employment Opportunities

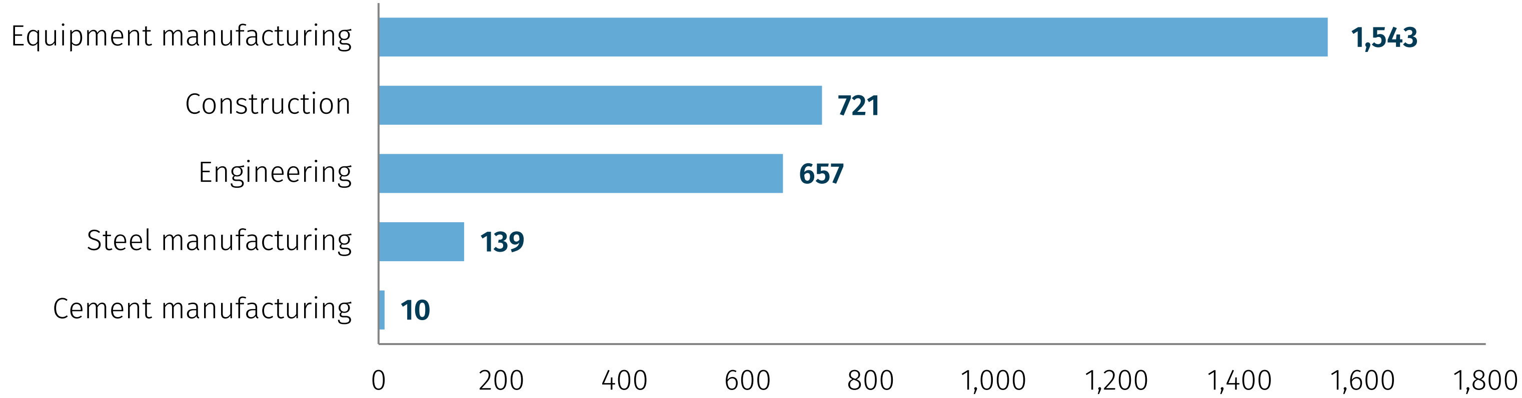
Average jobs created per one megaton DAC plant

The figures show the average jobs associated with building and operating a single one million ton capture capacity DAC plant. The majority of jobs are associated with design, engineering and construction of the plant as well as the manufacturing of plant equipment. A typical DAC plant requires 278 workers to maintain and operate the facility once it's constructed.

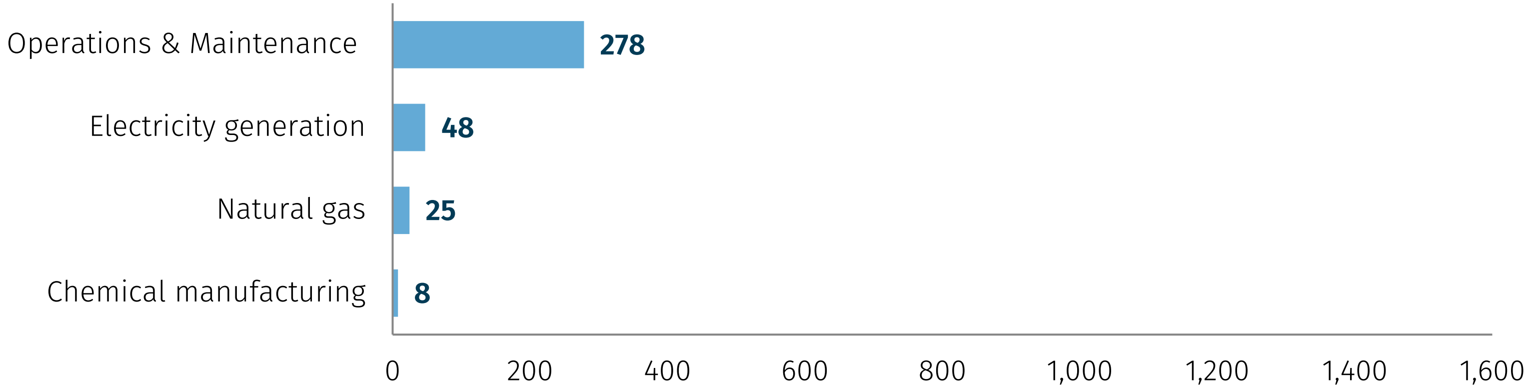
Total Jobs



Jobs from Plant Investment



Jobs from Plant Operations



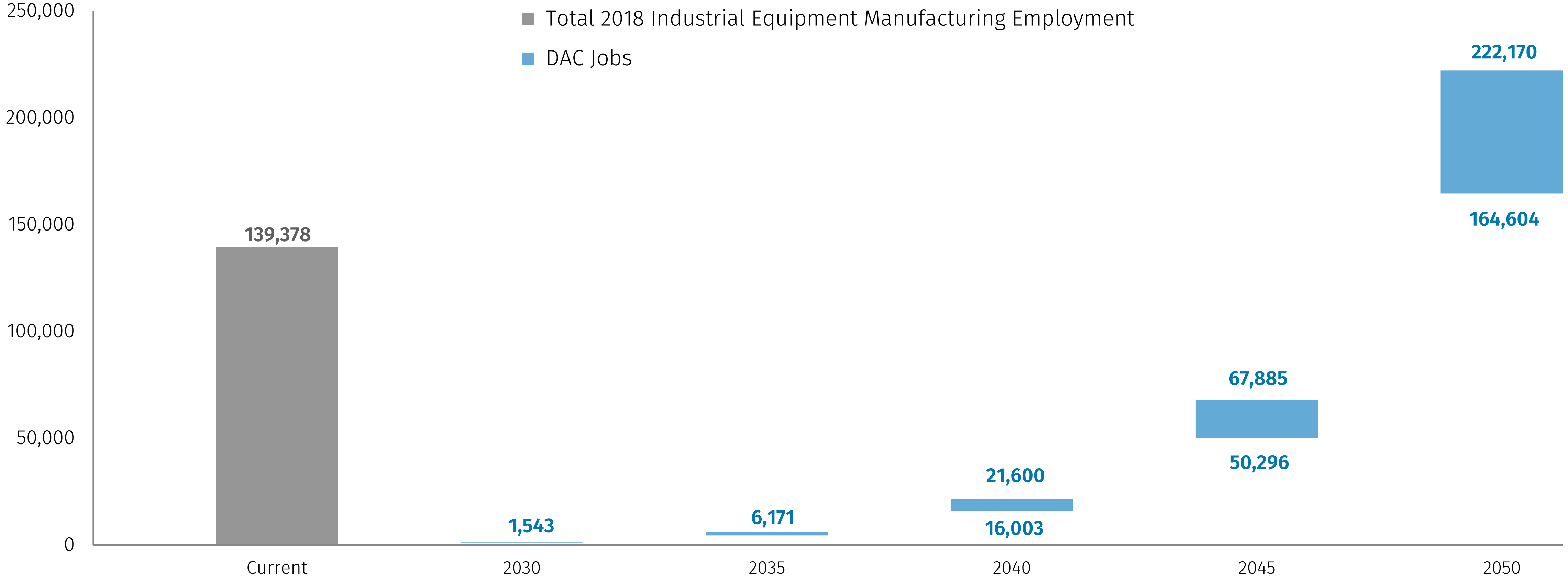
Source: IMPLAN Group, Keith et al. 2018. NAS, AISC, Rhodium Group analysis. Note: All values reflect DAC plant median cost and performance estimates. Values will vary depending on technology type and configuration.

SECTION 4

Jobs Associated with DAC Plant Construction

Industrial equipment manufacturing jobs

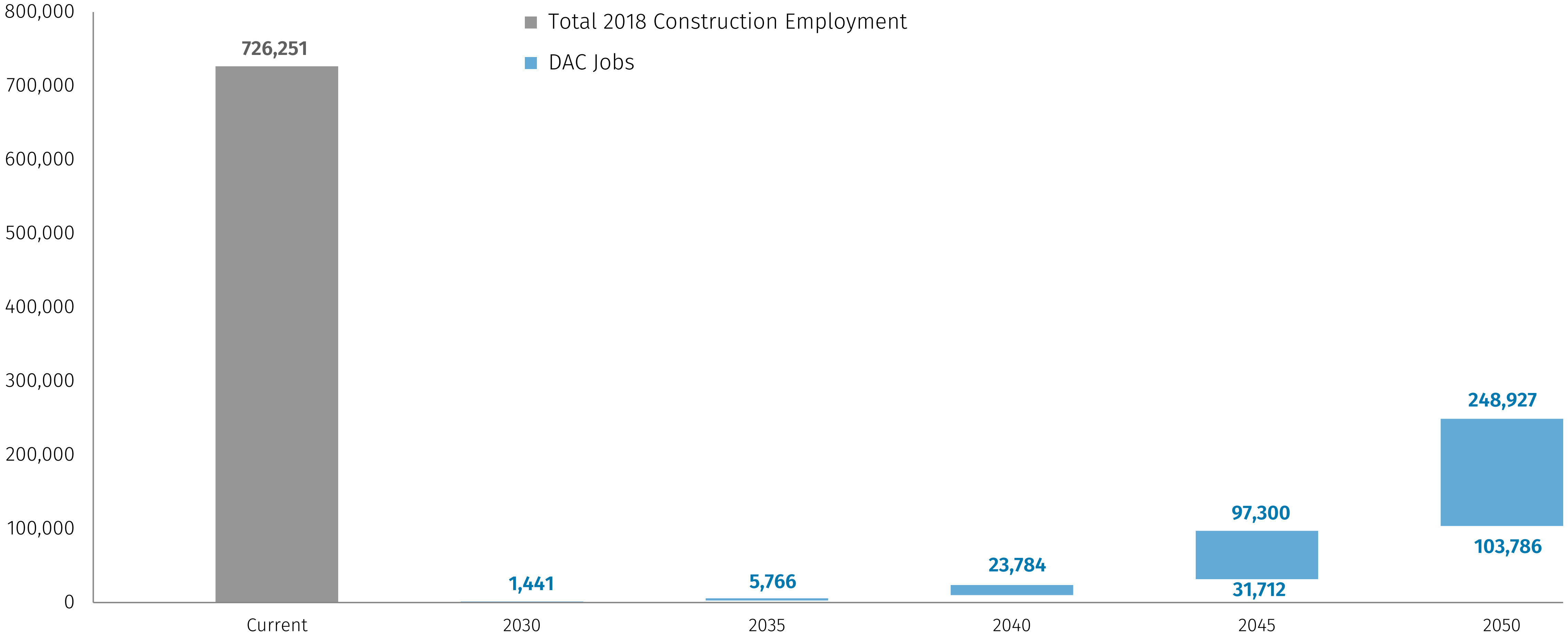
DAC can increase industrial equipment manufacturing jobs beyond their current levels. Industrial equipment manufacturing employment includes air purification and ventilation equipment manufacturing, turbine manufacturing, power boiler and heat exchanger manufacturing, and other commercial service industry machinery manufacturing. Additional indirect employment opportunities may materialize in industries that supply equipment manufacturers such as steel. Estimates of these additional opportunities are outside of the scope of this analysis but may be substantial.



Source: IMPLAN Group, Keith et al. 2018, NAS, Rhodium Group analysis.

Construction jobs

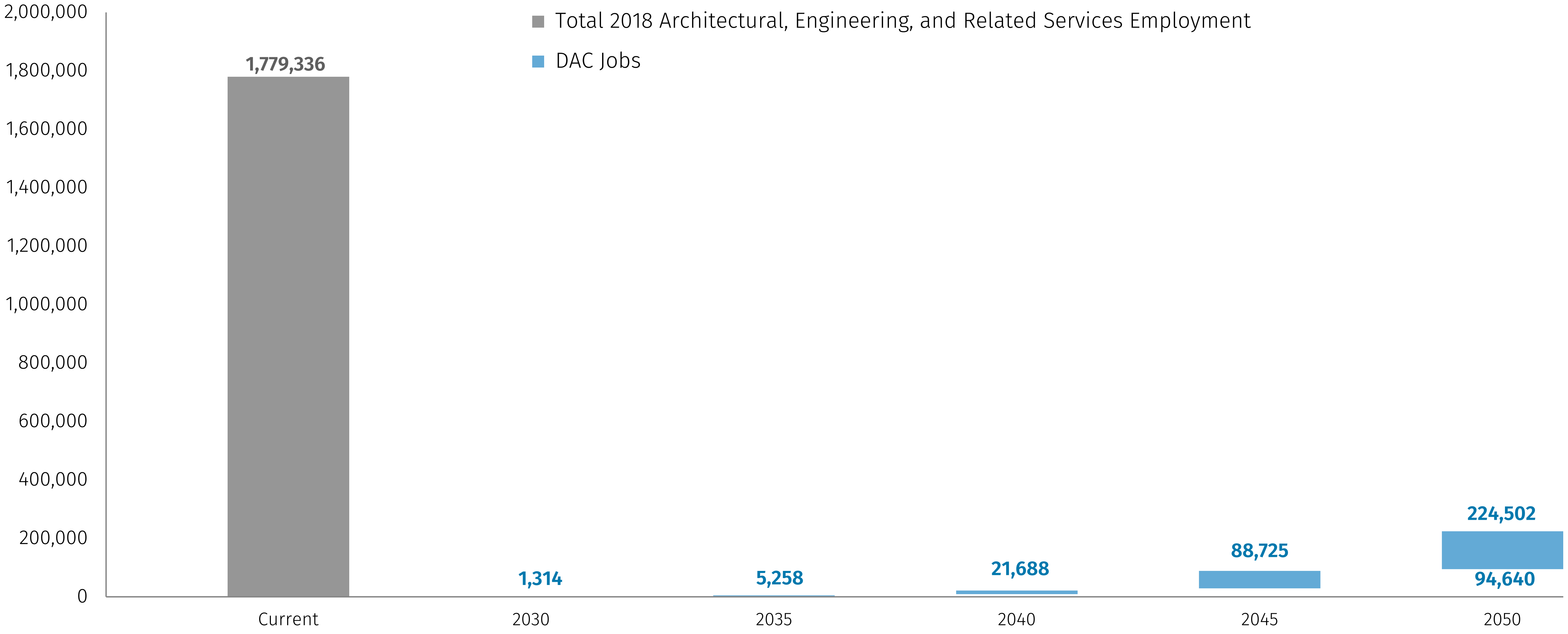
By 2050, DAC can support up to one-third of current relevant construction jobs. Construction jobs include employment from power, communication line, and related structures construction.



Source: IMPLAN Group, Keith et al. 2018. NAS, Rhodium Group analysis

Engineering jobs

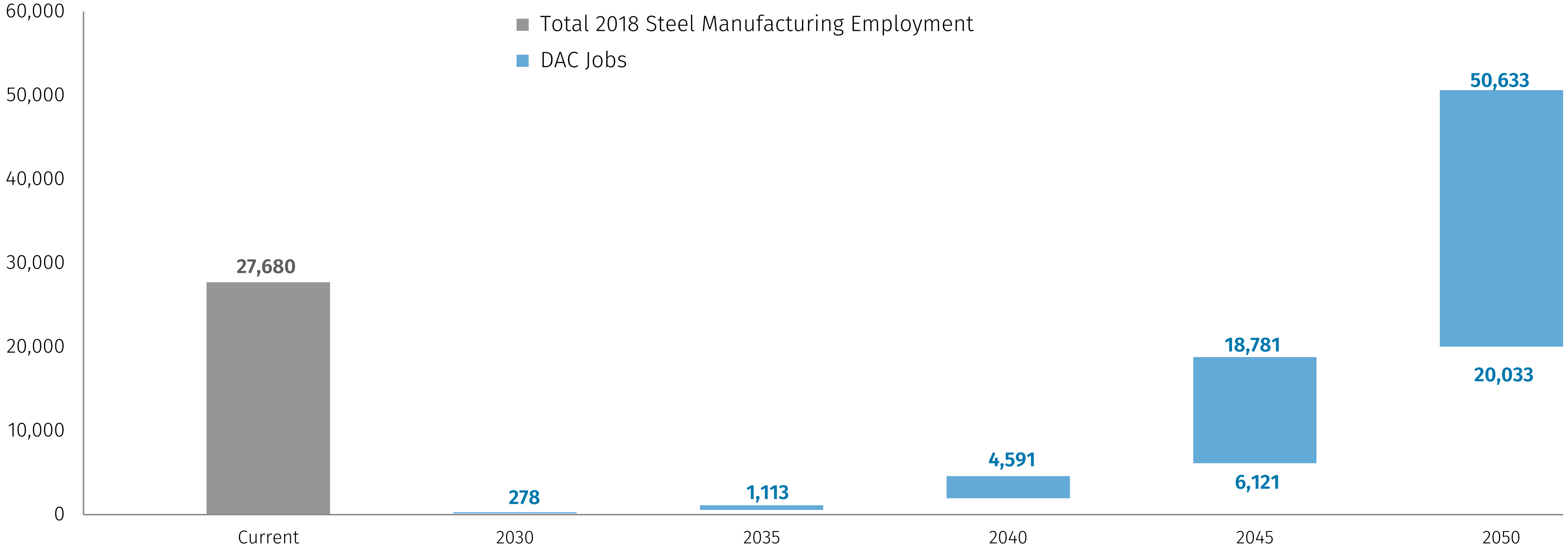
Engineering jobs associated with DAC plant construction could add an additional 13% to current engineering employment levels.



Source: IMPLAN Group, Keith et al. 2018. NAS, Rhodium Group analysis.

Steel manufacturing jobs

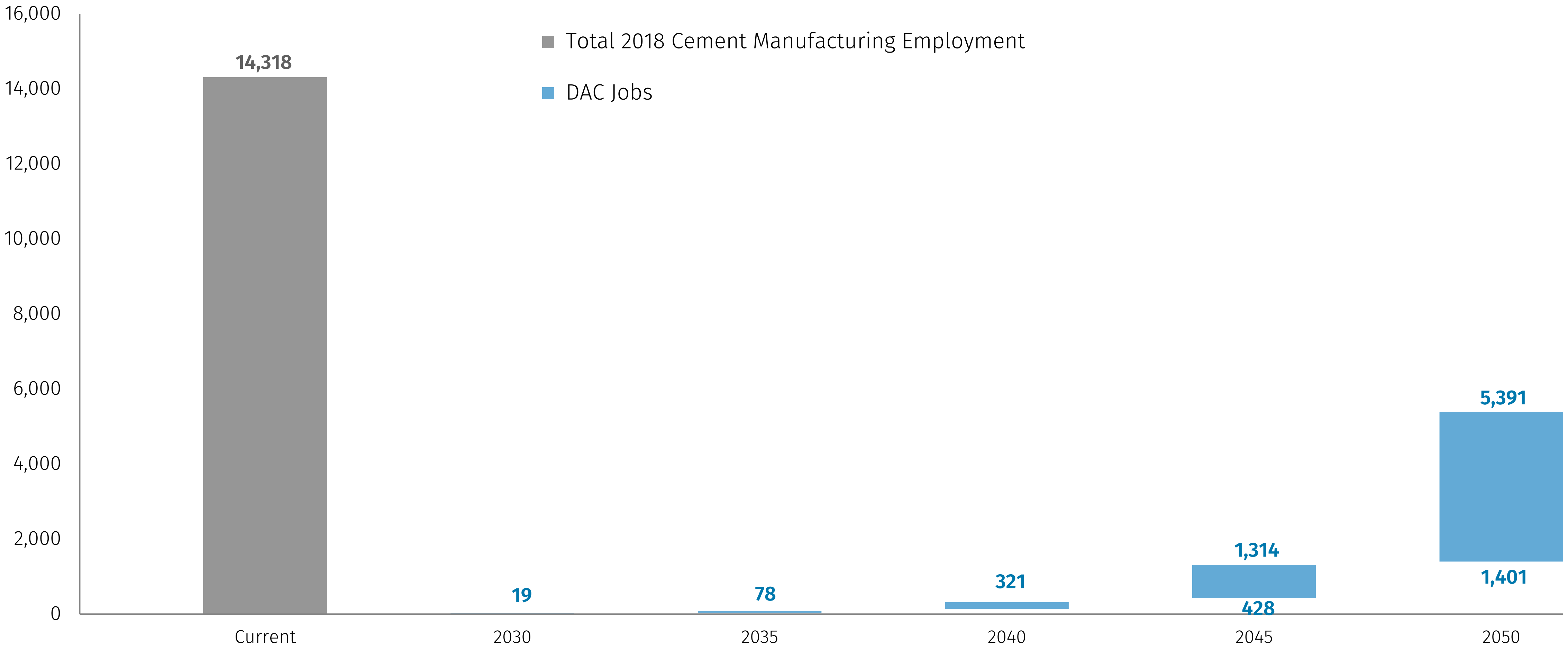
The construction of DAC plants can support over a doubling of steel manufacturing jobs. The estimates reflect jobs in manufacturing steel products and do not include indirect jobs at iron and steel productions mills that supply product manufacturers. Steel is also an important input in renewable energy construction, pipelines and natural gas production; activities that will scale in association with DAC. Indirect steel employment associated with all of these opportunities could be substantial, roughly the same order of magnitude as direct jobs associated with DAC shown here.



Source: IMPLAN Group, Keith et al. 2018. NAS, AISC, Rhodium Group analysis

Cement manufacturing jobs

DAC plant construction could support up to one-third of current cement manufacturing jobs. Additional indirect cement job opportunities may arise in association with natural gas and electricity production needed to supply DAC plants.



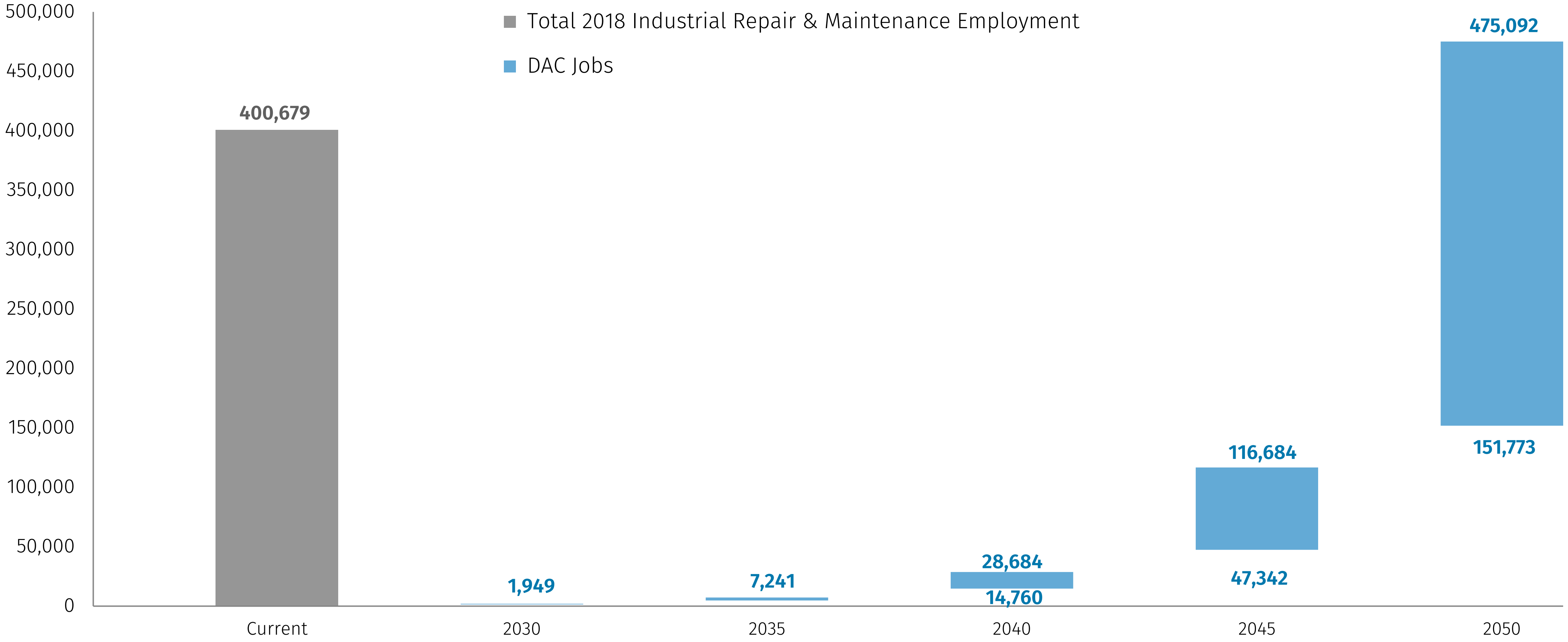
Source: IMPLAN Group, Keith et al. 2018. NAS, AISC, BEA, Rhodium Group analysis

SECTION 5

Jobs Associated with DAC Plant Operations

Operations & Maintenance jobs

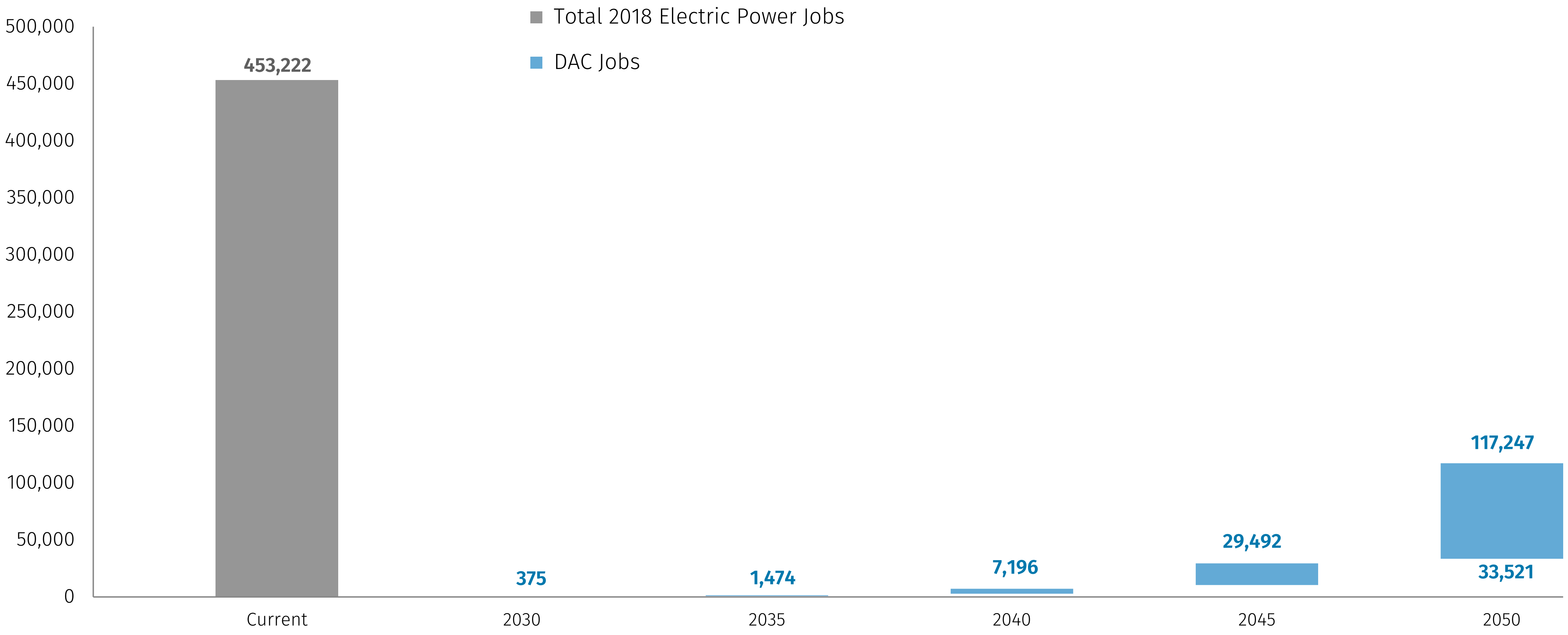
Jobs associated with operating and maintaining DAC plants could double current industrial repair and maintenance jobs. Current Industrial Repair & Maintenance jobs include employment from commercial and industrial machinery and equipment repair and maintenance.



Source: IMPLAN Group, Keith et al. 2018. NAS, Rhodium Group analysis

Electricity generation and distribution jobs

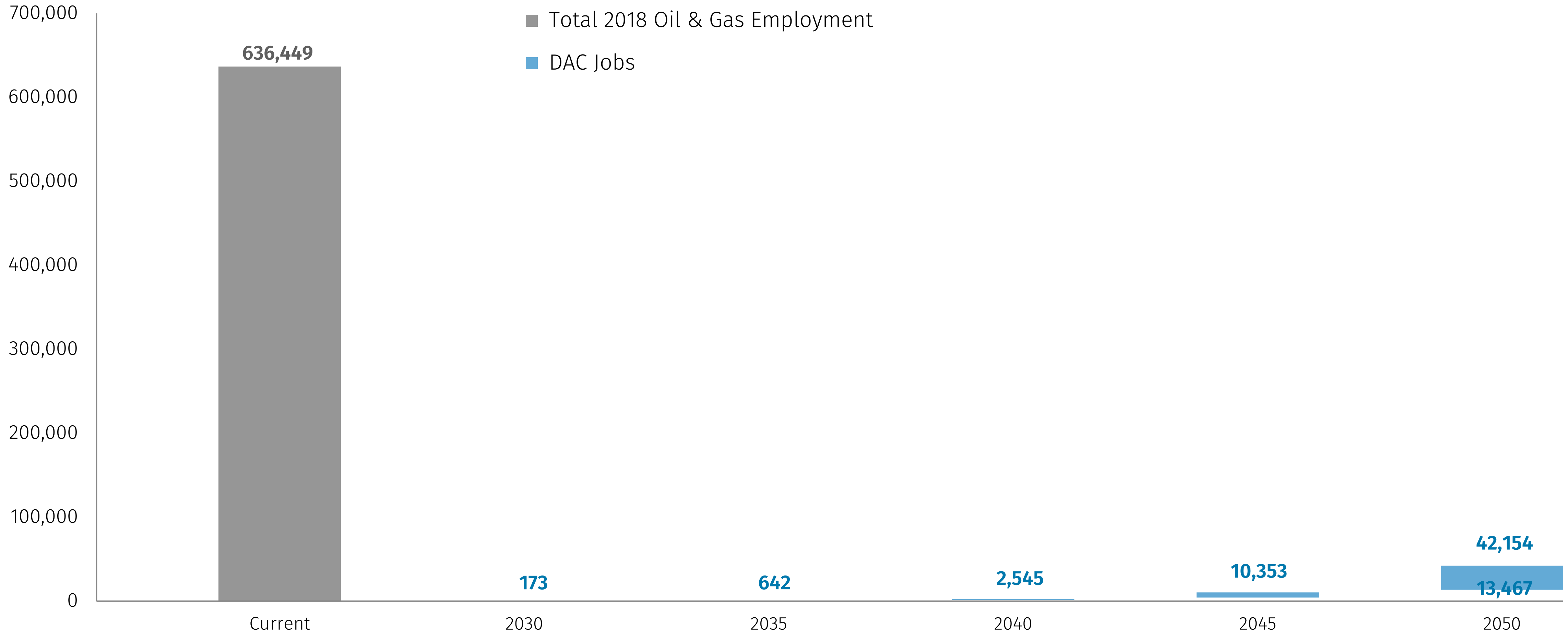
The electricity consumption of solid sorbent DAC plants can support up to one-fourth of current electric power jobs. Employment shown here includes electric power generation from solar, wind, fossil fuel with CCS, hydroelectric, and nuclear sectors, as well as electric power transmission and distribution. This analysis assumes solid sorbent plants are powered entirely by electricity and liquid solvent plants are powered entirely by natural gas.



Source: IMPLAN Group, EIA, Keith et al. 2018. NAS, Rhodium Group analysis

Natural gas industry jobs

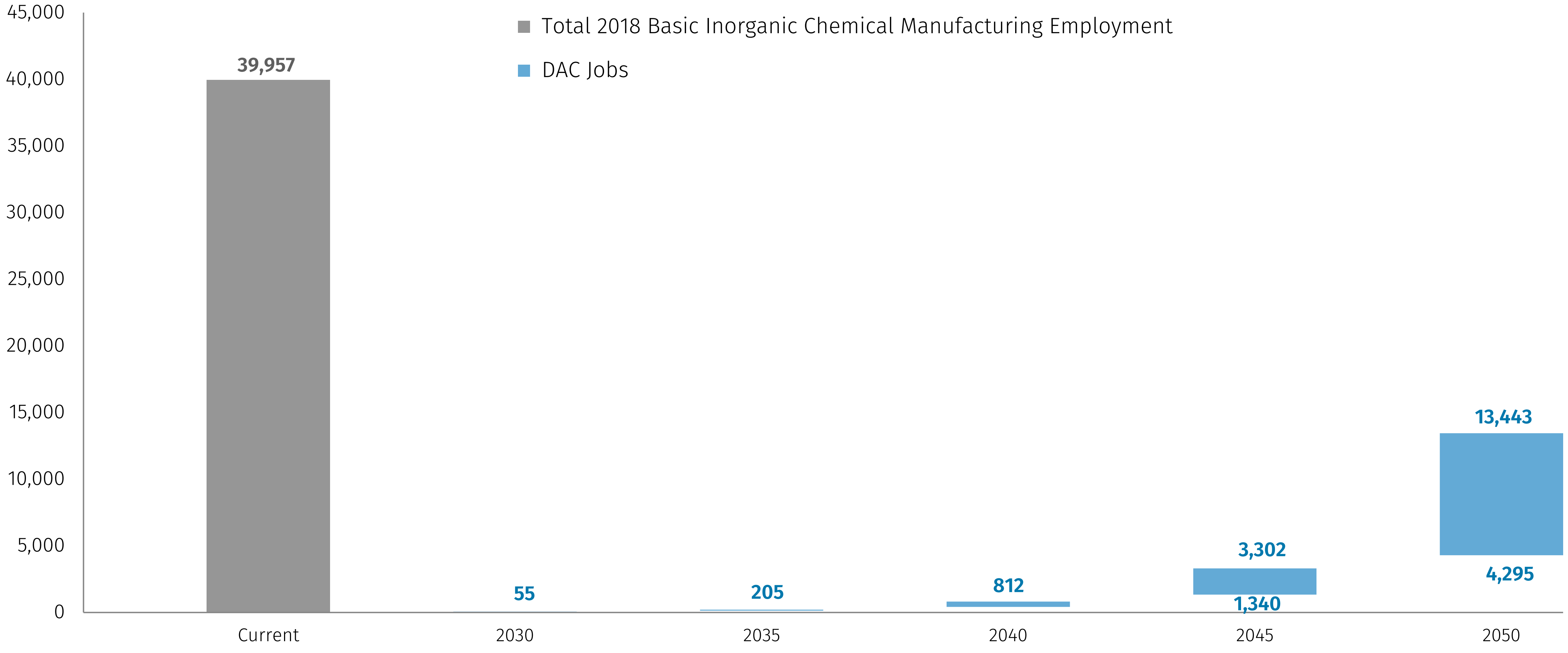
The jobs supported by liquid solvent DAC plants powered by natural gas could increase current oil and gas employment by 7%. This analysis assumes solid sorbent plants are powered entirely by electricity and liquid solvent plants are powered entirely by natural gas.



Source: IMPLAN Group, EIA, Keith et al. 2018. NAS, Rhodium Group analysis

Chemical manufacturing jobs

Chemical manufacturing to operate DAC plants could support up to one-third of current basic inorganic chemical manufacturing jobs.



Source: IMPLAN Group, Keith et al. 2018. NAS, Rhodium Group analysis

Significant employment opportunities associated with DAC are there for the taking. We find that:

DAC is essential to address climate change and needs federal policy support

- DAC technology is commercially ready with hundreds of millions in investor backing and large-scale projects in the pipeline.
- New federal policy is required to drive initial deployment of DAC because early-stage costs are higher than existing revenue opportunities.*
- Long-term federal policy frameworks are needed for DAC to scale by mid-century. More policy action sooner can accelerate employment opportunities.

When DAC reaches full scale, workers in key trades will see a surge in demand

- Construction, engineering, and equipment manufacturing sectors combined could see at least 300,000 new jobs with DAC at full scale.
- Steel employment could increase by at least 50% relative to current levels. Additional indirect employment opportunities for the sector could materialize through renewable energy and natural gas production supporting DAC plants and could be roughly the same order of magnitude.
- Operation and maintenance jobs at DAC plants could be a major source of jobs for the communities that host them.
- DAC represents a major new job growth opportunity for cement, electricity, chemicals and natural gas workers.
- Most employment opportunities associated with DAC are high wage jobs.
- While these opportunities are substantial, they will not materialize for 2-3 decades and are dependent on policy action.

Employment opportunities will accelerate with supportive DAC policies and established early supply chains

- More ambitious policy action in the near-term can accelerate job creation associated with DAC.
- Manufacturers that supply the first wave of DAC projects stand to lead in a major new growth market opportunity.

*See Capturing Leadership for more information.

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