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Employment Effects of Investments in Select CO_2 Abatement Initiatives

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INTRODUCTION

The U.S. and other countries around the world are pursuing multiple technologies to reduce emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs) that contribute to global climate change. Analysis from the Intergovernmental Panel on Climate Change as well as other organizations has shown that carbon capture, utilization, and storage (CCUS) technologies are expected to be needed to deliver on net-zero emissions goals.[1] Thus, governments in several countries have begun to pursue near-term investment in the development of CO_2 infrastructure that would enable the collection of CO_2 from multiple sources and the transport of CO_2 to shared storage sites. In parallel with these efforts, countries have also begun to pursue alternatives to fossil fuels as well as technologies that convert fossil fuels to carbon-free energy carriers (e.g., hydrogen). To facilitate the development of carbon capture, utilization, and storage technologies as well as cleaner sources of energy, U.S. policymakers have recently proposed several initiatives, including the following:

- The **Storing CO_2 and Lowering Emissions (SCALE) Act** includes the authorization of funding to finance both the construction of CO_2 transport infrastructure and the development of commercial CO_2 storage capacity in underground geologic formations at several sites, among other provisions. More specifically, the bill authorizes $2.1 billion for a CO_2 infrastructure program over five years to jumpstart the construction of CO_2 transport infrastructure and $2.5 billion in federal matching funds to spur the development of geologic storage sites.
- The American Jobs Plan recently proposed by the Biden Administration calls for the **funding of ten carbon capture demonstrations** at large steel, cement, and chemical production facilities across the U.S., drastically reducing the CO_2 emissions from these facilities and serving as a model for how carbon capture technology might be deployed at other large manufacturing sites.
- The American Jobs Plan also proposes **funding for 15 hydrogen demonstration projects** for facilities that will produce clean-burning hydrogen that could be used across the economy, including for power generation, industrial heating, or as feedstock for various industrial applications.

While policymakers and the public will likely be interested in the CO_2 mitigation impacts of these investments, in terms of the tons of CO_2 emissions captured and permanently stored over time or the CO_2 emissions avoided altogether, there may also be significant interest in the employment impacts associated with these investments. Due to the effects of COVID-19, the unemployment rate has increased from 3.5 percent in February 2020 to 6.0 percent in March 2021 and the number of Americans with jobs has fallen from 158.7 million to 150.8 million over that same period.[2] In this environment, understanding the degree to which federal government expenditures are likely to help stimulate economic activity and increase

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[1] See IPCC (2018) *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, available at https://www.ipcc.ch/sr15/download/ and International Energy Agency (2020) *World Energy Outlook 2020*, available at https://www.iea.org/reports/world-energy-outlook-2020.

[2] U.S. Bureau of Labor Statistics, "The Employment Situation—December 2020" and "The Employment Situation—March 2021", released January 8, 2021, and April 2, 2021, respectively. Available at https://www.bls.gov/news.release/empsit.toc.htm.

employment is of critical importance. To that end, this document provides an assessment of the employment impacts associated with the three initiatives summarized above.

The scope of analysis for the SCALE Act and carbon capture demonstrations is limited to effects associated with capital expenditures on these projects; we do not assess the employment impacts associated with operating or maintaining these facilities. For hydrogen facilities, however, we developed our analysis based on a hydrogen technology—steam methane reformation—for which we were able to identify highly detailed data on both facility design and operations. Our analysis of employment impacts associated with hydrogen demonstrations therefore captures impacts associated with both capital expenditures on these facilities and their operation.

APPROACH

To assess employment impacts, we applied the *Status* input-output model developed and maintained by Inforum, an economic research organization affiliated with the University of Maryland. Input-output models are a well-established framework for assessing the economic impacts associated with a change in expenditures for one or several industries across multiple sectors of the economy. Using detailed data on inter-industry relationships, input-output models estimate how a positive or negative shock in one industry (e.g., a change in output) cascades across the broader economy. Thus, in addition to capturing direct economic impacts for industries with increased (or decreased) production, input-output models capture spillover effects to other industries. These spillover effects include indirect impacts and induced impacts. Indirect impacts reflect inter-industry purchases and arise from firms purchasing inputs from their suppliers. For example, in the context of expenditures to develop CO_2 pipeline infrastructure, indirect impacts would include the employment associated with manufacturing the steel used to construct pipelines. Induced impacts, by contrast, result from wages paid to workers, who may spend these wages on consumer electronics, clothing, etc. Again, in the context of CO_2 pipeline infrastructure development, induced effects include the employment impacts associated with pipeline construction workers spending their earnings.

The *Status* input-output model used for this analysis is based on the industry and commodity database maintained by Inforum based on data published by the U.S. Bureau of Economic Analysis and other U.S. government agencies. The model has 121 commodity sectors and 71 industry sectors, classified according to the 2012 North American Industry Classification System (NAICS). The input-output framework on which *Status* is built contains annual data in both current and constant prices, from 1997 to 2019. Projections of the database after 2019 are obtained from a standard projection of Inforum's sectoral and commodity database, which includes projections of changes in input-output coefficients over time. The *Status* model has been used in multiple analyses for federal agencies, including an assessment of domestic output and jobs related to agricultural exports and imports (for the U.S. Department of Agriculture's Economic Research Service) and analysis of the direct and indirect components of health care supply (for the Center for Medicare and Medicaid Services).

As described below, our application of *Status* involves slightly different approaches for the assessment of impacts related to capital expenditures and impacts related to facility operations.

IMPACTS ASSOCIATED WITH CAPITAL EXPENDITURES

Our use of *Status* to assess employment impacts associated with capital expenditures captures impacts related to facility design and construction. The analysis of these effects involved the following steps:

- **Specify investment amounts to be modeled in *Status*:** The dollar amount specified for the three policies identified above varies based on factors such as proposed funding included in legislative proposals (e.g., for the SCALE Act) and the capital costs of specific types of facilities. Similarly, the time horizon of expenditures varies based on factors such as the timing in legislative proposals and the time horizon over which expenditures could feasibly be made for individual project types. For the SCALE Act and carbon capture demonstrations, the investment amount analyzed in Status is more than the assumed appropriation by Congress. This reflects how these proposals are assumed to be structured. For example, the CCUS demonstrations are assumed to include a 50:50 cost share in which the federal government covers half the cost while the private sector, state government, or local government covers the other half. In cases such as this, we analyze the impacts of the full investment value, under the assumption that the capital expenditure would not be made at all in the absence of the federal funding allocated to the project. Exhibit 1 presents the capital expenditures, and time horizon of those expenditures, for each of the policies examined in this analysis.

- **Specify sectors in *Status* for modeling investment expenditures:** When modeling the employment impacts associated with each initiative, capital expenditures must be allocated to individual industries within *Status*, as the impacts associated with increased demand for one industry's output may differ from the corresponding impacts associated with output produced by another industry. Exhibit 2 summarizes the allocation of expenditures across sectors for each policy analyzed. As shown in the exhibit, capital expenditures may be allocated to any combination of the following:
    - **Individual sectors in *Status*:** In some cases, a portion or all of the expenditures are simply allocated to individual industry sectors included in the *Status* model. Expenditures allocated to these industries are, in effect, treated as an increase in demand for the goods and services produced by these industries. For example, as shown in Exhibit 2, the expenditures for CCUS demonstration projects are split across multiple *Status* sectors.
    - **Sectors associated with the investment profile for a given industry:** The policies that we examine involve significant investments for one or more sectors of the economy. The composition of an industry's investment spending, however, differs from the spending associated with the production of that industry's output. For example, although the development of CO_2 pipeline infrastructure involves spending by the pipeline transportation sector, this industry's investment spending focuses heavily on the purchase of raw materials and construction labor (to build pipeline capacity), while spending associated with the industry's output more broadly reflects non-investment activities such as the management of pipeline throughput and routine pipeline maintenance. For several of the stimulus policies that involve investment by a specific sector, we allocate expenditures based on a distribution of investment spending for that sector derived by Inforum from BEA's 1997 capital flow table, which Inforum has updated through 2019.
    - **Sectoral allocations associated with construction:** The policies in this analysis also involve construction activity. For several types of construction, Inforum maintains expenditure profiles that show the allocation of construction spending across individual sectors within *Status*. For example, Inforum's data includes the composition of spending associated with construction in the manufacturing industry. For policies that involve construction that aligns with one of Inforum's existing construction-focused expenditure distributions, we apply the distribution maintained by Inforum.

EXHIBIT 1. POLICY DESCRIPTIONS AND FUNDING LEVELS

POLICY NAME	POLICY DESCRIPTION	TOTAL FUNDING LEVEL	TIMELINE OF EXPENDITURES
SCALE Act - Jumpstart the construction of CO_2 Transport Infrastructure	Based on provisions of the SCALE Act, this policy includes authorization of funding to finance the construction of CO_2 transport infrastructure, specifically long-distance interstate trunk lines.	$2.1 billion, consistent with CO_2 transport infrastructure provisions of the SCALE Act. Based on an assumed 50:50 split between loan credit subsidies and growth grants, an assumed credit subsidy rate of 10 percent, and a maximum 80% federal contribution to a project, the total investment generated is expected to be ~$14 billion.	Funding uniformly distributed over a 5-year period.
SCALE Act - Geologic storage of CO_2	Based on provisions of the SCALE Act, this policy includes authorization of funding for the development of underground CO_2 storage capacity, through DOE's CarbonSAFE Program.	$2.5 billion, consistent with geologic storage provisions of the SCALE Act. Based on the 50:50 cost share stipulated in the SCALE Act, the $2.5 billion authorized by the Act would enable $5 billion in investments.	Funding uniformly distributed over a 5-year period.
Carbon capture, utilization, and storage (CCUS) – Demonstration Projects	Under this policy, Congress would authorize additional funding for 10 industrial commercial-scale CCUS demonstration projects.	$8.325 billion in federal funding with a 50:50match, implying total investment of $16.65 billion.	Funding uniformly distributed over a 5-year period.
Hydrogen demonstration projects	This policy would authorize funding for 15 hydrogen demonstration projects for facilities that produce clean-burning hydrogen. For the purposes of this analysis, all 15 demonstration projects are assumed to be blue hydrogen produced from natural gas feedstock using steam methane reformation (SMR), as opposed to green hydrogen produced from water by way of electrolysis. This is due to the relative maturity of SMR technology and the feasibility of initiating demonstration projects in the 2021 calendar year.	$6.45 billion in total funding for all 15 demonstration projects. This value is based on a per-facility cost of approximately $430 million, which reflects plant costs of $401.9 million per facility and owner's costs of $28.1 million.[1] These values are for a plant with a production capacity of 8,994 kilograms of hydrogen per hour.	Investments in 15 demonstration projects assumed to be staggered over 7 years (2021-2027).

Notes:

1. IEA Greenhouse Gas R&D Programme. "Techno-Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS", 2017/02, February 2017. This document includes data for multiple cases of hydrogen facility development. For the purposes of this analysis, we relied upon data for Case 3, which includes the capture of CO_2 from SMR flue gas using mono-ethanol amine (MEA).

EXHIBIT 2. ASSUMED COMPOSITION OF CAPITAL EXPENDITURES BY POLICY

POLICY	TOTAL FUNDING LEVEL	COMPOSITION OF EXPENDITURES
SCALE Act - Jumpstart the construction of CO_2 Transport Infrastructure	$2.1 billion in federal funding, enabling ~$14 billion in investment.	Assuming that funding used for pipeline construction and development, all expenditures are allocated according to Inforum's existing sectoring scheme for investment by the Pipeline Transportation Sector.
SCALE Act - Geologic storage of CO_2	$2.5 billion in federal funding with 50:50 cost share, enabling $5 billion in investment.	Expenditures allocated as follows: • 65% allocated to Inforum's sectoring scheme for construction for Mining exploration – shafts and wells • 35% allocated to Architectural, Engineering, and Related Services
CCUS demonstrations/ commercialization (demonstration projects)	$8.325 billion in federal funding with a 50:50match, implying total investment of $16.65 billion.	Expenditures allocated as follows: • 20% allocated to Architectural, Engineering, and Related services • 20% allocated to Inforum sectoring scheme for construction for Mining exploration – shafts and wells • 20% allocated to Fabricated Metal Products • 20% allocated to Industrial Machinery • 20% allocated to Inforum sectoring scheme for construction within the Electric Power sector
Hydrogen demonstration projects	$6.45 billion in total funding for all 15 demonstration projects.	Separate distributions developed for owner's costs; materials for plant costs; construction component of plant costs; and engineering, procurement, and construction (EPC) component of plant costs: **Owner's Costs** • 60% allocated to Architectural, Engineering, and Related services • 20% allocated to Management of Companies and Enterprises • 20% allocated to Administrative and Support Services **Materials for Plant Costs[1]** • 19% allocated to Fabricated Metal Products • 52% allocated to Industrial Machinery • 7% allocated to Ventilation, Heating, Air-conditioning, and Ventilation Equipment • 12% allocated to Measure and Control Instruments, and Media • 10% allocated to Electrical Equipment **Construction Component of Plant Costs** • 100% allocated to Inforum sectoring scheme for construction within the manufacturing sector **EPC Component of Plant Costs** • 50% allocated to Architectural, Engineering, and Related services • 50% allocated to Management of Companies and Enterprises

Notes:
1. The distribution presented here for materials reflected in plant costs represents a composite weighted average for five categories of materials: hydrogen plant, CO_2 capture, CO_2 compression, power island, and utilities & balance of plant.

- **Perform *Status* runs:** Based on the investment amounts above and the allocation of investment spending to individual sectors in *Status*, we performed *Status* model runs that estimated the direct, indirect, and induced economic impacts associated with capital expenditures supported by the SCALE Act, the CCUS demonstrations, and the hydrogen demonstrations.

IMPACTS ASSOCIATED WITH OPERATION OF HYDROGEN FACILITIES

As described above, we estimated employment impacts associated with investment in facility design and construction for all three policies. For the analysis of hydrogen demonstration projects, we also assessed the direct, indirect, and induced employment impacts associated with the operation of these facilities. Similar to our approach for estimating impacts related to capital expenditures, our approach for estimating impacts associated with facility operations involves use of the *Status* input-output model. When analyzing effects related to facility operations, however, the approach for applying *Status* differs somewhat from the approach outlined above. The primary elements of this approach are as follows:

- **Estimate direct employment effects by year:** To estimate the economic impacts associated with the operation of hydrogen facilities, *Status* requires a measure of the level of activity at these facilities in a given year. Such measures may include the output of these facilities (i.e., sales), value added, or employment. We use employment as the industry activity measure for the purposes of this analysis. Based on data reported by the International Energy Agency (IEA) for a blue hydrogen plant with a capacity of 8,994 kilograms of hydrogen per hour,[3] we estimate that each hydrogen facility would employ 65.1 full time equivalent workers, inclusive of workers directly involved in hydrogen production and workers in supporting roles. The IEA estimates that each facility would employ 43 individuals directly involved in hydrogen production operations and also estimates per-facility labor costs for overhead functions such as management, administration, personnel services, and technical services. To convert overhead labor costs to employees, we assume the same cost per employee that the IEA analysis applies to labor directly involved in blue hydrogen production.[4] This yields an estimate of 22.1 full time equivalent employees in overhead functions. To the extent that the cost per employee for overhead labor is lower (higher) than the cost per employee for production labor, we may underestimate (overestimate) the number of workers that serve in overhead functions. The IEA also estimates that 40 percent of maintenance costs would be for maintenance labor but states that external subcontractors would likely be used for all medium to major types of maintenance work.[5] We therefore assume that none of the annual maintenance costs reported by the IEA are for internal labor. To the extent that in-house labor is reflected in these maintenance costs, we may underestimate the number of maintenance workers at hydrogen facilities.

  To estimate total operational labor per year, we apply the estimated 65.1 workers per facility to the estimated number of hydrogen facilities in operation each year. Based on the time required for facility design and construction (approximately four years) and assuming a staggered initiation of

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[3] IEA Greenhouse Gas R&D Programme. "Techno-Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS", 2017/02, February 2017.

[4] IEA assumes a labor cost per employee of €60,000, based on costs in late 2014. To use this value, we apply a 2014 exchange rate of $1.25 per euro and adjust for inflation using the U.S. GDP deflator.

[5] IEA Greenhouse Gas R&D Programme, *op. cit.*

demonstration projects, we assume a ramp up of operational facilities beginning in 2026. Specifically, we assume that 5 of the 15 demonstration projects would be operational that year, 10 projects would be operational in 2027, and 15 projects would be operational in 2028 and through the end of our analysis time horizon in 2035. Based on this trajectory and the estimated 65.1 workers employed by each facility, we estimate approximately 325.3 direct jobs in 2026, 650.6 direct jobs in 2027, and 975.9 direct jobs in 2028 and through 2035.

- **Specify sectors in *Status* for facility operations:** To assess the economic impacts associated with operational activity at hydrogen facilities, we must assign this activity to a sector (or combination of sectors) in *Status*, similar to the allocation of capital expenditures described above. Choosing from industries as they are defined in *Status*, we allocate the direct job impacts summarized above to the "Other Chemicals" industry within the model. Based on the direct input-output multipliers in *Status*, the model converts the increase in employment to increased output by the "Other Chemicals" industry.
- **Modify multipliers to reflect O&M costs for hydrogen production:** The multipliers within *Status* for the "Other Chemicals" industry are composite values that reflect the cost structure of multiple segments of the U.S. chemical industry. The IEA report referenced above, however, presents the O&M cost structure specific to a blue hydrogen facility. To make the results generated by *Status* representative of blue hydrogen production rather than a composite of multiple products produced by the chemical industry, we used the O&M cost data presented in the IEA report to modify the industry multipliers in *Status* for the "Other Chemicals" industry. Before modifying the industry multipliers, however, we made an adjustment to the data presented in the IEA report to reflect the U.S. context. Because the report presents information on the construction and operation of a hydrogen facility in the Netherlands, the estimated cost of natural gas feedstock reflects European natural gas prices (in 2014) instead of U.S. prices, which have been much lower than European prices for several years. Based on the price differential between U.S. and Europe and the change in natural gas prices between 2014 and 2019, we applied a scaling factor of 0.46 to the natural gas line item presented in the IEA report.[6] After making this change, we estimated that natural gas accounts for 74.7 percent of blue hydrogen facility O&M costs and that labor accounts for 8.2 percent of O&M costs. These percentages were used to modify the multipliers for the "Other Chemical" industry in *Status*.
- **Perform *Status* runs:** Based on the level of direct employment at hydrogen facilities, the allocation of this direct employment to the "Other Chemicals" industry, and modification of the economic multipliers for this industry based on the estimated O&M cost structure of blue hydrogen facilities, we performed *Status* model runs that estimated the direct, indirect, and induced economic impacts associated with operation of the hydrogen facility demonstrations through 2035.

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[6] The natural gas price used in the IEA report is €6/GJ, which represents the price in 2014. The U.S. price for industrial customers in 2019 was $3.90 per thousand cubic feet. Based on inflation between 2014 and 2019, the dollar-euro exchange rate, and converting from thousand cubic feet to GJ, the U.S. price translates to €2.73/GJ. Based on the ratio of this value to the €6/GJ used in the IEA report, we derived the scaling factor of 0.46. We used the 2019 natural gas price instead of the 2020 price to avoid capturing market conditions unique to the COVID-19 pandemic.

RESULTS

Following the approach outlined above, we estimated the employment impacts associated with the SCALE Act, the CCUS demonstrations, and the hydrogen demonstrations. Exhibit 3 presents the results of this analysis over the 2021 to 2035 period for each policy. In addition, results for the SCALE Act are broken out between CO_2 transportation infrastructure and geologic storage of CO_2, and the estimated employment impacts associated with the hydrogen demonstrations are presented separately for capital expenditures on hydrogen facilities and the operation of these facilities. In total, the employment impacts of the three policies combined vary over time, though the range of annual employment impacts is fairly narrow between 2021 and 2025, with annual employment impacts ranging from 55,100 jobs to 65,400 jobs during this period. During the latter half of the 2020s and the first half of the 2030s, estimated employment impacts across the three policies combined decline relative to the first half of the 2020s. This decline, however, at least partially reflects the exclusion of operations-related employment impacts for the SCALE Act and the CCUS demonstrations. If the scope of the analysis were broadened to include these effects, our estimates of post-2025 employment impacts would be higher, and the decline in employment impacts would be smaller than shown in Exhibit 3.

Focusing on the years for which we generated employment impact estimates for all three policies, employment impacts associated with the SCALE Act and CCUS demonstrations are much higher than the estimated impacts for the hydrogen demonstration projects. This reflects the total capital investments associated with each policy. As indicated in Exhibit 1, the capital expenditures associated with the SCALE Act and the CCUS demonstrations are approximately $19 billion and $16.65 billion, respectively, whereas the investments related to hydrogen demonstrations are an estimated $6.45 billion.

Building on the results shown in Exhibit 3 for each individual policy, Exhibit 4 shows the distribution of each policy's employment impacts between direct, indirect, and induced job impacts. As shown in the exhibit, the distribution across the three categories is fairly similar for the SCALE Act and CCUS demonstrations, with direct employment impacts accounting for between 30 and 40 percent of the total, indirect impacts 15 to 20 percent, and induced impacts between 40 and 50 percent. The hydrogen demonstrations exhibit a similar pattern during the first half of the 2020s but skew much more heavily toward indirect and induced effects from the mid-2020s through 2035. This shift coincides with the end of the construction phase of the hydrogen demonstration facilities and the commencement of operations. Although the operation of blue hydrogen facilities involves less direct employment than the design and construction of these facilities, the significant raw material purchases by these facilities—mostly natural gas feedstock and fuel—lead to significant indirect and induced effects, relative to the estimated directed employment impacts.

EXHIBIT 3. ESTIMATED EMPLOYMENT IMPACTS, BY YEAR (PERSONS EMPLOYED)

POLICY	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
SCALE Act	**28,700**	**27,200**	**25,700**	**24,400**	**23,100**	-	-	-	-	-	-	-	-	-	-
CO2 transportation infrastructure	21,100	19,900	18,800	17,700	16,700	-	-	-	-	-	-	-	-	-	-
Geologic storage of CO2	7,600	7,200	6,900	6,700	6,400	-	-	-	-	-	-	-	-	-	-
CCUS Demonstration projects	**28,700**	**27,400**	**26,400**	**25,300**	**24,300**	-	-	-	-	-	-	-	-	-	-
Hydrogen Demonstration Projects	**300**	**500**	**4,600**	**12,800**	**18,100**	**17,900**	**13,500**	**11,000**	**10,800**	**10,600**	**10,400**	**10,200**	**10,000**	**9,900**	**9,700**
Capital expenditure impacts	300	500	4,600	12,800	18,100	14,100	6,000	0	0	0	0	0	0	0	0
O&M Impacts	0	0	0	0	0	3,800	7,500	11,000	10,800	10,600	10,400	10,200	10,000	9,900	9,700
TOTAL	**57,600**	**55,100**	**56,700**	**62,500**	**65,400**	**17,900**	**13,500**	**11,000**	**10,800**	**10,600**	**10,400**	**10,200**	**10,000**	**9,900**	**9,700**

EXHIBIT 4. DISTRIBUTION BETWEEN DIRECT, INDIRECT AND INDUCED EMPLOYMENT IMPACTS