MEETING THE
DUAL CHALLENGE

A Roadmap to At-Scale Deployment of CARBON CAPTURE, USE, AND STORAGE

APPENDIX D – ERM MEMO: *ECONOMIC IMPACTS OF CCUS DEPLOYMENT*

A Report of the National Petroleum Council

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Appendix D

ERM MEMO: *ECONOMIC IMPACTS OF CCUS DEPLOYMENT*

The National Petroleum Council retained ERM (Environmental Resource Management), a leading global provider of environmental, health, safety, risk, social consulting services and sustainability related services to conduct an economic analysis of deploying CCUS at-scale. This memo summarizes the potential total economic impacts of the investments in carbon capture, use, and storage (CCUS) deployment as described in Chapter 2, Volume II, of the NPC report. The at-scale deployment of CCUS technology could involve 379 facilities, which will have direct impacts on jobs, gross domestic product (GDP), income, and tax revenues. These investments will have additional "multiplier" effects that will create additional economic impacts (i.e., indirect and induced impacts).

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Memo

To	National Petroleum Council
From	Doug MacNair Ryan Callihan
Date	November 20, 2019
Subject	Economic Impacts of CCUS Deployment

1. EXECUTIVE SUMMARY

This memo summarizes the potential total economic impacts of the investments in Carbon Capture Use and Storage (CCUS) deployment as described in Chapter 2 of the NPC Report. The At-scale deployment of CCUS technology could involve 379 facilities, which will have direct impacts on jobs, gross domestic product (GDP), income, and tax revenues. These investments will have additional "multiplier" effects that will create additional economic impacts (i.e. indirect and induced impacts).

Chapter 2 of the NPC Report describes three phases of CCUS deployment: Activation, Expansion, and At-scale using a cost curve analysis. The investments by the facilities in each phase form the basis for this economic impact analysis.

The economic impacts result from two types of investments or expenditures:

- One-time:
  - Carbon capture capital costs for each facility, and
  - Pipeline infrastructure costs for connecting sources to sinks.
- On-going:
  - Facility annual operating and maintenance (O&M) costs (facilities including fuel and power),
  - Incremental oil production from CO_2 enhanced oil recovery (EOR) activities and,
  - Storage activities associated with operating Class VI injection wells.

Table ES-1 summarizes the *incremental* investments in CCUS for the three phases. The estimated 23 facilities that would deploy CCUS technology during the Activation Phase would invest $50.6 billion over 20 years. During the Expansion Phase, an estimated 47 additional facilities would deploy CCUS technology, leading to an additional $124.4 billion in investments over 20 years. By the time the At-scale CCUS deployment occurs, an additional 309 facilities would be participating and the investment would be $504.7 billion over 20 years.

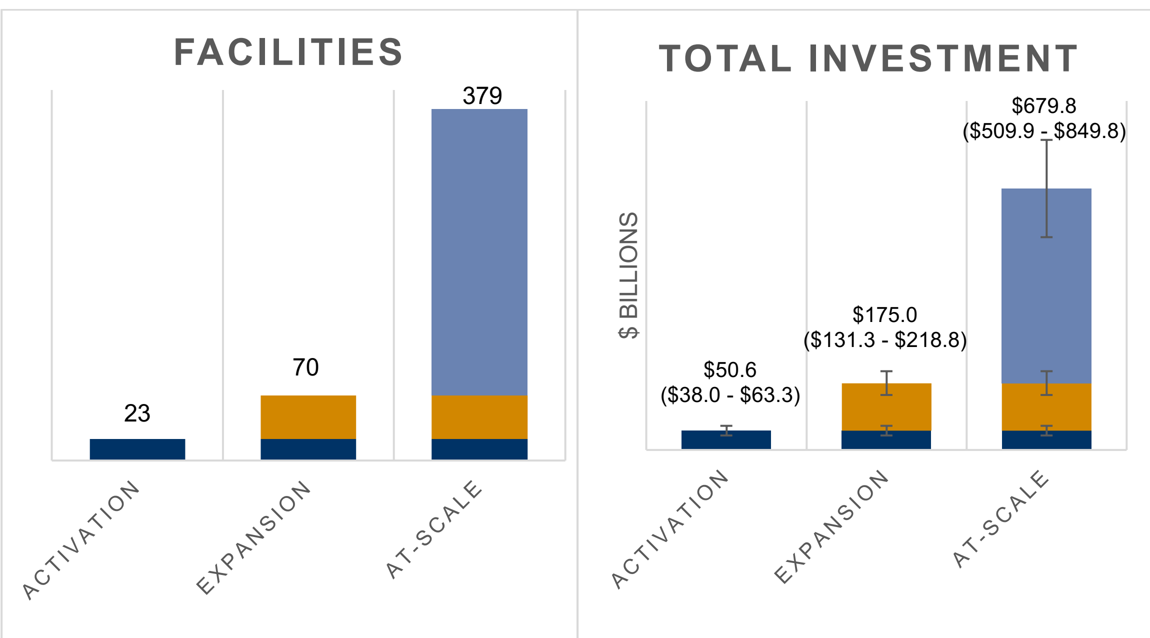
Table ES-1: Incremental On-going and One-Time Investments ($2018)

Phase	Number of Incremental Facilities	One-time Incremental Investment ($billions)	On-going Incremental Investment ($billions)	Total Incremental Investment ($billions)
Activation	23	$3.8	$46.8	$50.6
Expansion	47	$15.6	$108.8	$124.4
At-scale	309	$118.9	$385.8	$504.7

Note: One-time includes capital for carbon capture equipment and pipeline cost. On-going costs include spending on EOR, O&M and saline storage over 20 years. Facility counts include those deploying CCUS technology, not well-operators benefiting from EOR.

Figure ES-1 shows the *cumulative* investment for the three phases along with the uncertainty range of 25 percent for the total investment. Each phase of investment is in addition to the previous phase creating a total investment at the At-scale Phase for 379 facilities and $679.8 billion in investment. The uncertainty range of 25 percent on the total investment At-scale ranges from $509.9 billion to $849.8 billion[1].

Figure ES-1: Cumulative Facilities and Investment ($2018)



Note: Investments at each facility include one-time costs and on-going costs over 20 years

The economic impacts from the CCUS investments are estimated using IMPLAN, a well-accepted model for conducting economic impact studies. The IMPLAN model is discussed in more detail in Section 2.

[1] The uncertainty range of 25 percent is based on range used in Chapter 2 to derive cost estimates.

Table ES-2 summarizes the *incremental* average annual economic impacts for each of the three phases, while Figure ES-2 provides a graphical summary for the estimated *cumulative* jobs and GDP impacts. These economic impacts result from the investment spending described in Table ES-1.

In the Activation Phase, the CCUS investment and the multiplier effects of that investment will support 9,000 jobs annually. Additional investments by facilities that deploy CCUS technology in the Expansion Phase will support an additional 33,000 jobs and $3.2 billion to GDP, annually. At-scale deployment will support an additional 194,000 annual jobs and $16.3 billion in annual GDP.

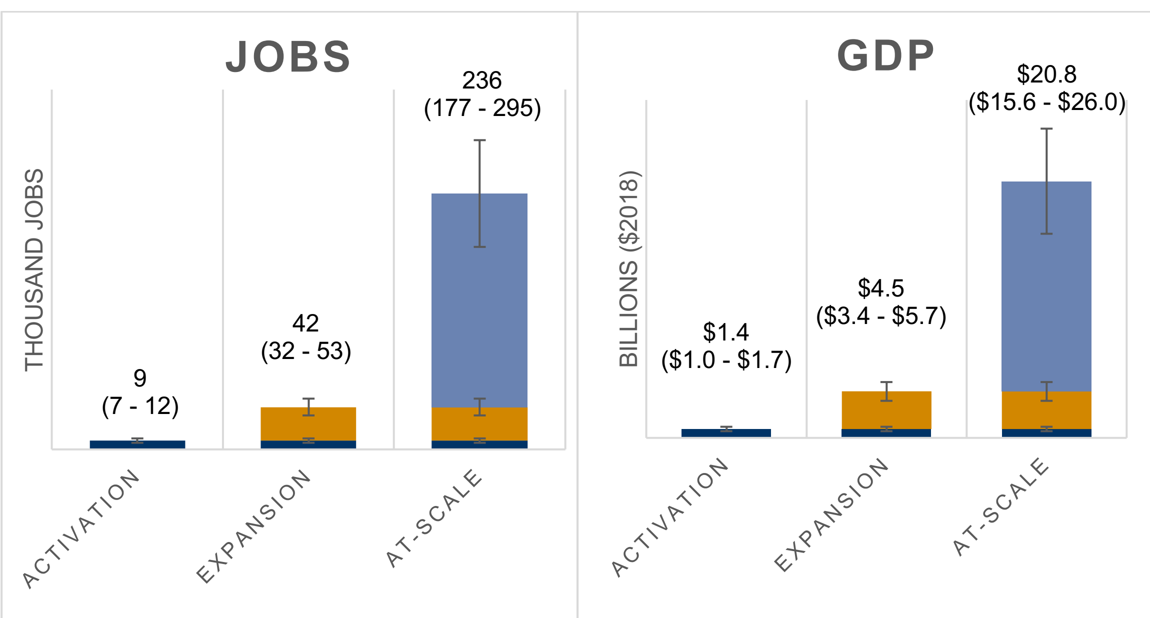
Table ES-2: Incremental Average Annual Economic Impacts ($2018)

Phase	Incremental Jobs (thousands)	Incremental GDP ($billions)	Incremental Labor Income ($billions)	Incremental Federal Taxes ($billions)	Incremental State and Local Taxes ($billions)
Activation	9	$1.4	$0.6	$0.1	$0.2
Expansion	33	$3.2	$2.0	$0.4	$0.3
At-scale	194	$16.3	$11.0	$2.2	$1.3

Notes: Averages are for a 20-year period.

Figure ES-2 shows the cumulative economic impact from the three phases and the uncertainty range at 25 percent. During the At-scale Phase, the annual economic impact from the investment in CCUS supports 236,000 jobs, with a range between 177,000 and 295,000 jobs. It will also generate $20.8 billion in annual GDP, with a range between $15.6 billion and $26.0 billion.

Figure ES-2: Cumulative Annual Job and GDP Impacts



Note: Averages are for a 20-year period.

2. IMPLAN

This section describes the methodology and model used for the economic impact analysis that provides the estimates of change in economic activity from deploying CCUS technology. Input-output models (I-O) are used for estimating the total change in demand for goods and services (in this case, demand for CCUS technology one-time and ongoing expenditures).[2] They quantify the inter-industry relationships within an economy (i.e., how output/activity from one sector becomes an input in another sector of the economy and their inter-industry effects).

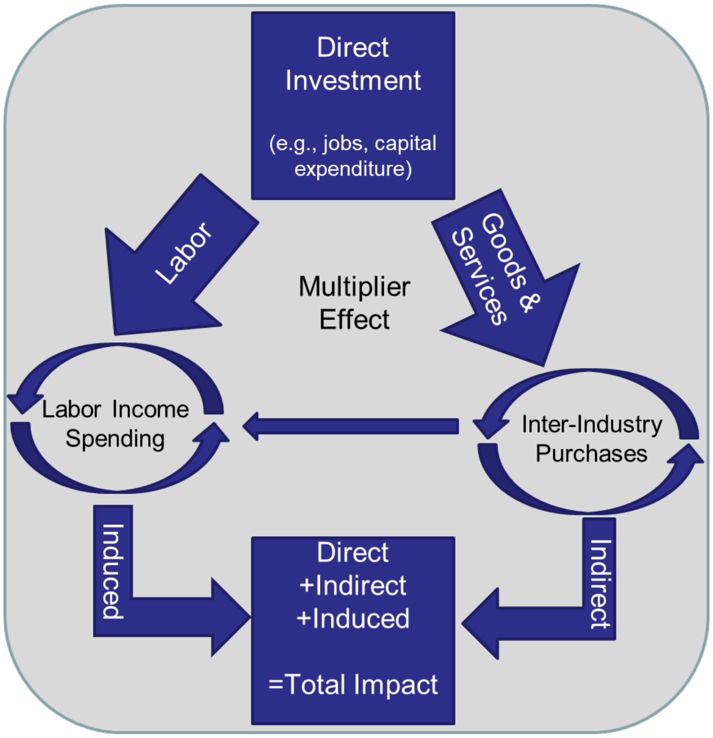
IMPLAN, the I-O model used in this analysis, relies on multipliers (Figure 1), which quantify interactions between firms, industries, and social institutions within a local economy. Each industrial or service activity within the economy (i.e., agriculture, mining, manufacturing, trade, services, etc.) is assigned to an economic sector.[3] The model starts with a 'shock' to the economy. The shock can be expressed as either a change in the number of jobs in an industry (e.g., 100 jobs for construction of a pipeline) or a change in expenditures (e.g., the dollar amount spent on construction). A change in expenditures (e.g. an investment) can be broadly divided into the purchase of goods and services and the purchase of labor. Both types of investment set off repeated rounds of economic activity (the multiplier effect). The additional jobs, GDP, income, and taxes generated by the inter-industry spending is called the indirect effect, while the impact from household spending is the induced effect.

The sum of the direct, indirect, and induced impacts equals the total economic impact. The multipliers vary by location and sector depending on the makeup of the local economy. The model treats the CCUS spending as a "shock", or a new source of spending, and estimates how each of the affected industries responds in terms of additional value added (GDP), jobs, income and taxes.

[2] Bess, R., & Ambargis, Z. O. (2011, March). Input-output models for impact analysis: suggestions for practitioners using RIMS II multipliers. In 50th Southern Regional Science Association Conference (pp. 23-27). Southern Regional Science Association Morgantown WV.

[3] IMPLAN uses data from the U.S. Bureau of Economic Analysis, Bureau of Labor Statistics, U.S. Census Bureau, and other sources. IMPLAN also uses detailed U.S. Department of Commerce information that relates the purchases of goods and services each industry makes from other industries to the value of output in each industry. As such, IMPLAN describes the supply chain of each industry in terms of output, value-added, labor income, employment levels, and state and local tax revenue. The latest version of IMPLAN data currently includes 536 sectors and regional detail at the state, county, and ZIP code level.

Figure 1: Economic Impact Model



IMPLAN estimates three types of impacts:

- **Direct impact** – the initial change in the value of the output, employment, and labor earnings from the CCUS investments.
- **Indirect impact** – the increase in the output, employment, and labor earnings in the industries supporting the CCUS investments.
- **Induced impact** (or household spending impact) – the increase in the spending of workers in the direct and indirect industries.

The IMPLAN results include the direct, indirect, induced, and total economic impacts for the following four categories.

- **Jobs** – Jobs are measured in "job years" and reflect one year of employment.
- **GDP** – GDP is the monetary or market value of all the finished goods and services produced in a year.
- **Labor Income** – All forms of annual employment income, including employee compensation (wages and benefits) and proprietor income.
- **Taxes** – Annual tax revenue generated at the local, state, and federal levels.

IMPLAN estimates the distribution of economic impacts on local economies and industrial sectors. It is important to note that IMPLAN results are not a benefit-cost analysis and do not evaluate whether a project provides an overall net benefit to society. IMPLAN does not estimate the impact of any changes in prices, such as electricity prices from power plants investing in CCUS, which may affect production, output and jobs in other industries. In addition, IMPLAN does not evaluate the opportunity costs of the private investment or public funds.[4]

IMPLAN is widely used by academics, government agencies, and private sector business to understand the economic impacts of spending on the local economy. The U.S. Environmental Protection Agency (EPA) uses economic impact analysis to look at distributional impacts of spending by entities directly affected by regulations.[5] The Department of Energy (DOE) also applies this approach (using IMPLAN) and recently analyzed the economy-wide impacts of the American Recovery and Reinvestment Act of 2009 (Recovery Act or ARRA) funding for Smart Grid project deployment in the United States.[6]

Table 1 provides additional examples of studies using IMPLAN conducted in the United States by government agencies, interest groups, and private companies. It represents a small sample of the total body of analysis and research using this modelling software.

Table 1: IMPLAN Study Examples

DOE (2013). “Economic Impact of Recovery Act Investments in the Smart Grid”
DOI (2016). “Economic Contributions of Outdoor Recreation on Federal Lands”
EPA (2018). “Estimating the Economic Benefits of Energy Efficiency and Renewable Energy.”
ICF (2017) “U.S. Oil and Gas Infrastructure Investment through 2035” Prepared for API
Massachusetts Division of Energy Resources (2007) “Energy from Forest Biomass: Potential Economic Impacts in Massachusetts”. Prepared by University of Massachusetts, Department of Resource Economics
NREL (2007) “Energy, Economic, and Environmental Benefits of the Solar America Initiative”
PWC (2017) “Impacts of the Oil and Natural Gas Industry on the US Economy in 2015” Prepared for API

Other economic input-output methods have been used recently in other studies that look at the benefits of carbon capture technology. A study in the United Kingdom (UK) concluded that CCUS could play a key role in sustaining direct jobs in the on-shore support industry that have traditionally been associated with oil and gas, as well as supply jobs associated with this industry

[4] The opportunity cost refers to the value of the next-highest-valued alternative use of that resource. Although investments in CCUS create economic benefits, the economic impacts do not take into account the next best use of those funds which presumably provides economic benefits in the absence of CCUS activities.

[5] EPA (2010). “Guidelines for Preparing Economic Analyses” Available at: https://www.epa.gov/environmental-economics/guidelines-preparing-economic-analyses

[6] DOE (2013). “Economic Impact of Recovery Act Investments in the Smart Grid”. Smart Grid Investment Grants Program; Available at: https://www.smartgrid.gov/files/Smart_Grid_Economic_Impact_Report.pdf

and the emerging offshore renewables sectors.[7] A study by Orion Innovation in the UK showed that CCUS could create thousands of annual jobs by 2030 due to increases in construction employment and ongoing O&M.[8]

An economic impact analysis by Patrizio et al. (2018) assessed the potential effects of reducing emissions in the coal industry.[9] The results show that deployment of carbon capture technology will not only reduce job losses from coal plant retirements, but also increase employment through construction and O&M jobs along with further multiplier effects.[10]

[7] Turner, Karen and Alabi, Oluwafisayo and Low, Ragne and Race, Julia (2019) Reframing the Value Case for CCUS: Evidence on the Economic Value Case for CCUS in Scotland and the UK (Technical Report).

[8] Orion Innovation (2013). "A UK Vision for Carbon Capture and Storage". Available at: www.ccsassociation.org/index.php/download_file/view/750/76/

[9] The study used the JEDI input-output model, developed by the National Renewable Energy Laboratory.

[10] Patrizio, P., Leduc, S., Kraxner, F., Fuss, S., Kindermann, G., Mesfun, S.& Lundgren, J. (2018). Reducing US coal emissions can boost employment. Joule, 2(12), 2633-2648.

3. FACILITIES, PHASES AND INVESTMENTS

This section summarizes the investments by the three phases described in Chapter 2. As described in the Chapter, the CCUS cost curve (Figure 2) depicts the total cost to capture, transport and store CO_2 from stationary sources, plotted against the volume of CO_2 that is abated from those sources. The curve is arranged from lowest combined cost to highest combined cost. The cost curve provides the basis for the inputs into the economic model for each phase.

Figure 2: U.S CCUS Cost Curve

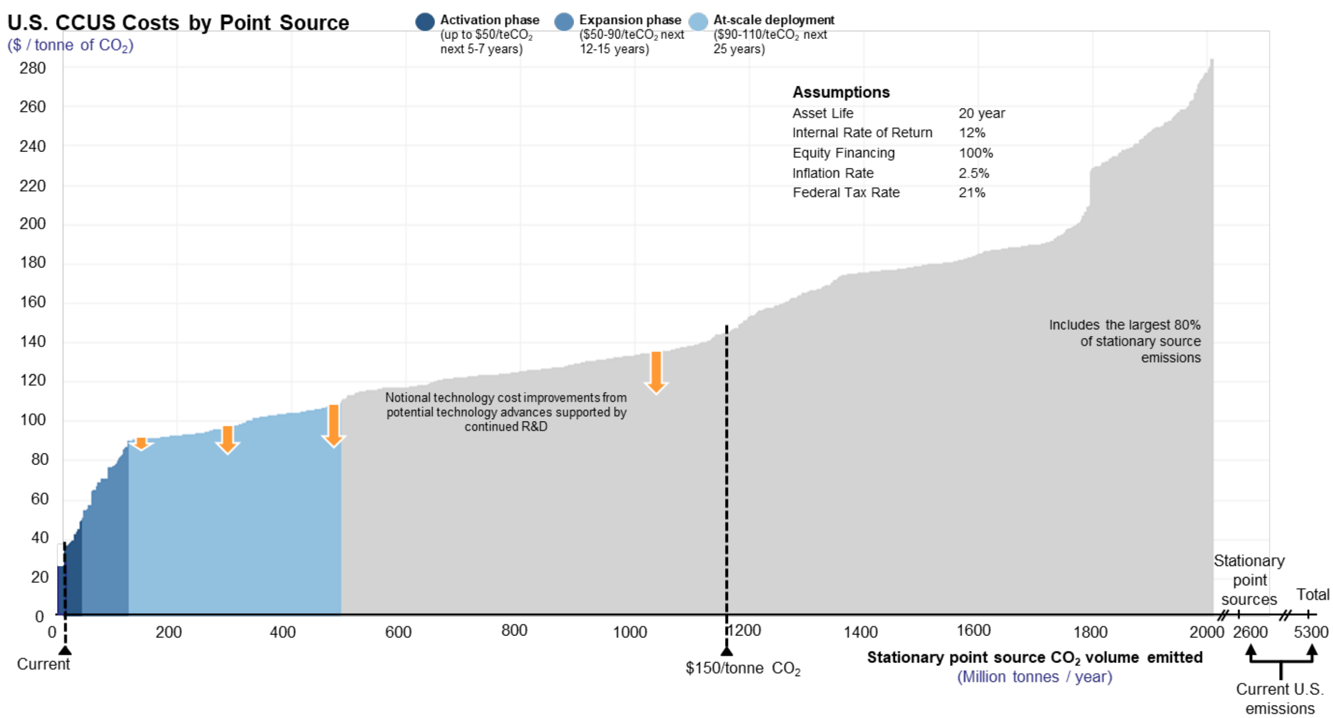


Table 2 summarizes the inputs for the economic model for each of the three phases. The number of facilities and total investment increases significantly from the Activation Phase to the At-scale Phase.

Table 2: Profile of Investments in CCUS

	Activation Phase	Expansion Phase	At-scale Phase
Number of Facilities	23	47	309
Annual Captured Emissions ($MtCO_2$/year)	35	75	380
One-time costs			
Carbon Capture Costs ($ billion)	$1.9	$7.4	$98.3
Pipeline ($ billion)	$1.9	$6.4	$20.2
On-going costs			
Annual Incremental Oil Revenue from EOR ($ billion/year)	$2.3	$4.7	$2.1
Annual O&M Costs ($ billion/year)	$0.3	$1.3	$12.5
Annual Storage Costs ($ billion/year)	$0.1	$0.2	$2.9

Carbon capture capital costs are calculated by multiplying the estimated industry specific per-ton capture costs (Table 3) by facility specific annual $MtCO_2$/year per year based on EPA data. The estimated costs range from $71/tonne CO_2 for ethanol and ammonia facilities and up to $472/tonne CO_2 for industrial furnaces. The O&M costs are a percent of the total capital expenditures by facility type. O&M costs include the non-energy O&M while the energy cost include natural gas and electricity costs.

The incremental revenue from EOR is estimated using an approach suggested by Cook (2012). This study looked specifically at economic impacts from incremental oil revenue. The EOR revenue estimate assumes one additional barrel of oil is produced per metric ton of CO_2 used. The revenue estimate is based on a projected $86 per barrel of oil, which is the average projected price of West Texas Intermediate between 2020 and 2040 (EIA Annual Energy Outlook 2019).[11] EOR does not represent an industry in IMPLAN, as a proxy we use the oil and gas industry spending pattern. Some of the standard IMPLAN parameters have been altered to reflect unique characteristics of the EOR oil revenue. The employment per dollar of revenue and labor income

[11] The economic contributions from EOR is based on the approach used in Cook, B. R. (2012). The Economic Contribution of CO2 Enhanced Oil Recovery in Wyoming.

per employee ratios are modified to match the results from Cook (2012). Since EOR is not an industry in IMPLAN, using the literature to inform the methodology provides an accepted approach to estimate the economic impact in this sector.[12]

Table 3: One-time and On-going Input Costs by Industry

Facility Type	Carbon Capture Capital Cost (US$/tonne)	Non-Energy O&M (Percent of Total Capital Expenditures)	Energy Cost* ($/tonne)
Ethanol	71	7%	6
Ammonia	71	5%	5
Natural Gas Processing (low)	80	6%	5
Natural Gas Processing (high)	276	6%	5
Cement	199	7%	17
Hydrogen	196	5%	18
Steel/Iron	275	5%	17
Coal Power Plant	327	4%	17
Refinery-FCC	412	4%	16
Natural Gas Power Plant	354	5%	18
Industrial Furnaces	472	4%	17

*Energy costs consist of both gas and electricity costs

The direct investments described have ripple effects that create additional impacts throughout the economy (i.e., indirect and induced impacts), which are captured by the IMPLAN multipliers. The annual economic impacts are averaged over a 20-year horizon during which the one-time investments occur over several years. In the analysis, the timeframes associated with these investments are consistent with the durations outlined in the NPC Report. In the Activation Phase, the one-time investment spend profile is assumed to occur equally over six years (between year 1 and year 6) (i.e., 1/6th of the estimated total one-time investment occurs during each of the first six years of the 20-year period). Similarly, for the Expansion Phase the one-time investments occur over the first nine years and At-scale Phase over the first ten years.

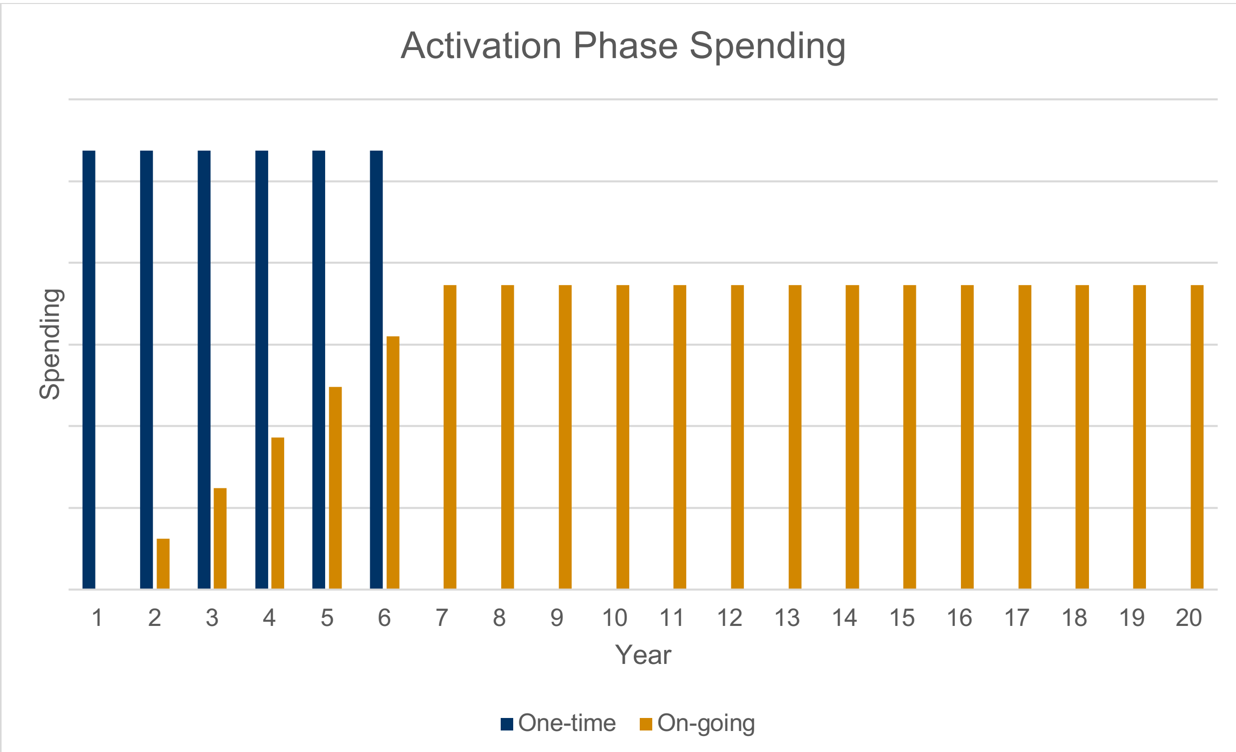
On-going investments begin a year later following the one-time investments and ramp up proportionately over the one-time investment period until full capital deployment occurs. These costs then remain constant for the remaining years of the 20 year period. The economic impact values are averaged over the 20 year period.

Figure 3 illustrates the investment spending timeframe for the Activation Phase. The one-time investment is spread out equally over the first six years. The on-going investment begins in year 2

[12] The Cook ratios are 2.6 direct jobs per $10 million in incremental oil revenue and $115,000 in labor income per job.

and continues for the rest of the 20 year period. Summing all of the bars and dividing by 20 yields the average annual investment over the Activation Phase. The same approach is used for the other two phases.

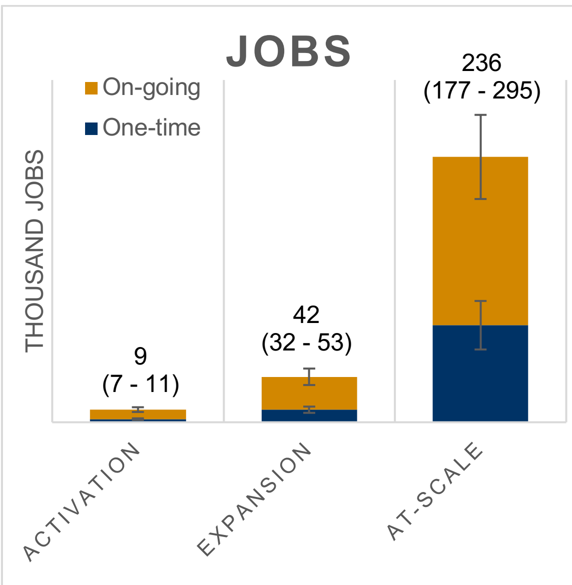
Figure 3: Accounting for Timing of the Impacts



4. IMPLAN RESULTS - EMPLOYMENT

Figure 4 presents the cumulative employment impacts by investment source (one-time and on-going) and impact type (direct, indirect, and induced) for each of the three phases. Table 4 summarizes the incremental job impacts for the three phases. The At-scale Phase totals 236,000 jobs per year, which consist of 127,000 direct, 17,000 indirect, and 50,000 induced jobs per year. The At-scale Phase has a longer construction period so a greater percentage of the impacts come from one-time expenditures relative to the other two phases. The 25 percent range parallels the results from Chapter 2 and account for the uncertainty in the input assumptions. At-scale deployment has a range of 177,000 – 295,000 thousand jobs cumulatively per year. This figure includes the job estimates from the previous two phases.

Figure 4: Annual Cumulative Employment Impacts by Investment Source and Impact Type



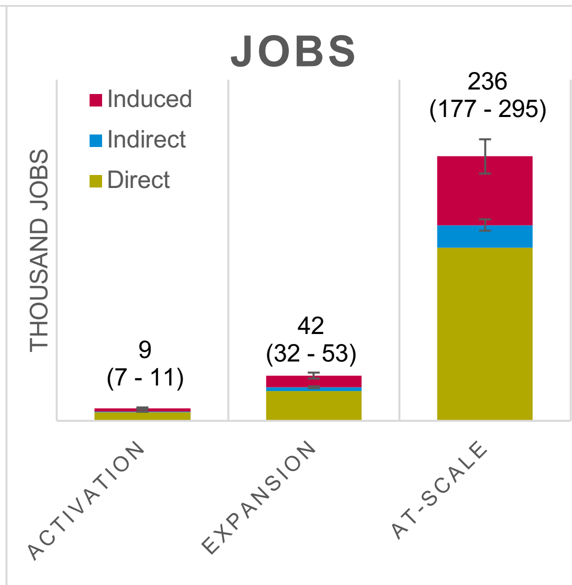


Table 4: Annual Average Employment Impacts by Phase (Thousands)

Impact	Activation Phase	Expansion Phase	At-scale Phase
Direct	4	14	118
Indirect	3	10	27
Induced	3	9	48
Total	9	33	194
Uncertainty Factor (+/- 25%)	7 – 11	25 – 42	145 - 242

5. IMPLAN RESULTS – GDP, INCOME, AND TAXES

Table 5, 6, and 7 show the annual *incremental* monetary economic impacts of the CCUS activities for each of the phases. As shown in Table 7, during the At-scale Phase, *incremental* CCUS investments result in an annual GDP impact of $16.26 billion. These investments also yield annual tax revenues of $1.25 billion at the state and local level and $2.25 billion at the federal level.

The uncertainty factor accounts for a plus and minus 25 percent range in the cost of the CCUS inputs for the IMPLAN model. The total incremental economic impacts At-scale range between $12.19 billion and $20.24 billion in GDP annually.

Table 5: Activation Phase Incremental Average Annual Economic Impacts

Impact	GDP ($ billions)	Labor Income ($ billions)	Federal taxes ($ billions)	State and Local taxes ($ billions)
Direct	0.79	0.28	0.07	0.11
Indirect	0.34	0.21	0.04	0.03
Induced	0.25	0.13	0.03	0.03
Total	1.39	0.62	0.15	0.16
Uncertainty Factor (+/- 25%)	1.04 – 1.74	0.46 – 0.77	0.11 – 0.18	0.12 – 0.21

Note: Average annual values over 20 years

Table 6: Expansion Phase Incremental Average Annual Economic Impacts

Impact	GDP ($ billions)	Labor Income ($ billions)	Federal taxes ($ billions)	State and Local taxes ($ billions)
Direct	1.51	0.95	0.19	0.14
Indirect	0.94	0.64	0.13	0.08
Induced	0.71	0.40	0.09	0.07
Total	3.15	1.99	0.41	0.29
Uncertainty Factor (+/- 25%)	2.37 – 3.94	1.49 – 2.48	0.31 – 0.52	0.22 – 0.37

Note: Average annual values over 20 years

Table 7: At-scale Phase Incremental Average Annual Economic Impacts

Impact	GDP ($ billions)	Labor Income ($ billions)	Federal taxes ($ billions)	State and Local taxes ($ billions)
Direct	9.53	7.05	1.38	0.59
Indirect	2.74	1.68	0.36	0.26
Induced	4.00	2.23	0.50	0.40
Total	16.26	10.96	2.25	1.25
Uncertainty Factor (+/- 25%)	12.19 – 20.24	8.22 – 13.70	1.69 – 2.81	0.94 – 1.56

Note: Average annual values over 20 years