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Get Ready for Carbon Capture's Second Act

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Inside…

Key Points:

- The largest climate policy contribution of the Inflation Reduction Act (IRA) will likely be the market incentives tied to carbon capture for high-emitting industries. While competition, replacement and regulation will continue to decarbonize other segments of the economy, the hardest-to-abate industries would see little progress without the significant government support that this legislation provides.

- Now, federal incentives are squarely in the "Goldilocks" range for point-source carbon capture projects. What's more, IRA also supports greater options for recycling the carbon captured by these projects, opening the door to a circular carbon economy.

- Many high-purity CO_2 management projects, such as ethanol and gas processing, appear to be financially attractive today. Over a longer-term horizon, expanded demonstration projects and technology cost declines will accelerate projects with lower-purity CO_2 streams, including hard-to-abate industries (steel, cement, and refining) as well as power generation and hydrogen production. This is important, as the high-purity, quick-to-fund projects alone will not put the nation on a net-zero path.

- Just how big could carbon management's second act prove? New research suggests that IRA could boost carbon capture capacity 13-fold by 2030 – finally legitimizing this technology in a net-zero world.

The 'real' significance of the Inflation Reduction Act

The Inflation Reduction Act of 2022 (IRA) is the most significant climate legislation in U.S. history, with massive federal spending aimed at jump-starting the country's clean energy transition. For more than 200 years, much of the world has been engineered to run on fossil fuels, so just how quickly will this clean energy future unfold?[1] The scale of the change needed to remake the systems that power the global economy is mind-boggling and the transition economics – at least, for those industries with the hardest-to-abate emissions – have not been particularly supportive.

Yet, the U.S. billion-dollar federal spending spree now underway will likely change the equation, speeding the country toward a faster-than-anticipated transition this

decade. Thanks to the landmark legislation, researchers now suggest that the U.S. will be able to nearly double the amount of emission reductions that would otherwise take place. Or, more precisely, economy-wide emissions in the country are now anticipated to be 43% to 48% lower than 2005 levels by 2035 as compared to just 27% to 35% without the IRA stimulus.[2] Exciting news indeed, but most of the near-term reductions will come from sectors that are already well down the path toward deep de-carbonization.[3]

Aging fossil-fuel generation and the falling cost for renewable replacements, along with stricter regulations under the Clean Air Act,[4] will sustain the momentum for this sector. These same factors – competition, replacement and regulation (or climate policy's version of wash, rinse, repeat) – likewise appear to be hastening greater decarbonization for a sizeable chunk of transportation (that is, personal vehicles and buses)[5] without additional IRA spending. Consequently, where the billions of new spending might really make a difference are those industrial and transportation sectors that are simply too hard to decarbonize without government "moonshot-esque" financing.

Namely, seven of the world's hardest-to-abate sectors account for roughly one-third of global emissions, with little market incentive to reduce their carbon footprint. More than half of these sectors (steel, aluminum, cement and chemicals) grapple with significant process emissions, where post-combustion carbon capture is perhaps the only practical decarbonization option available. Meanwhile, the balance of the intractable heavy-emitters – namely, the transportation segments of trucking, aviation and shipping – can now benefit from the low-carbon substitutes produced from the captured CO_2 streams, creating a virtuous abatement cycle for all seven sectors.

Consequently, with Congress increasing carbon capture tax incentives under the IRA and making important new funding opportunities available for clean fuel substitutes, a dramatic new chapter for scalable emission-control systems could unfold.[6]

Inflation Reduction Act changes the economics for carbon capture

Our reference to carbon capture's second act suggests a more productive chapter will open up with new federal funding opportunities, including IRA.[7] Yet, the technology has been around more than 50 years with generous governmental R&D funding available for half that time. What's more, IRA is actually the third iteration of federal tax incentives supporting the technology.[8] While each component of carbon capture, utilization and storage (CCUS) is technologically feasible, subsidizing the sum of the parts in all the varieties required to make an impact has largely proved unattainable.[9,10] So much so that low-cost carbon capture for high-emitting, hard-to-abate sectors is often billed as a unicorn, unworthy of the time and effort spent hunting it down.

The carbon pricing conversation is changing

Economists tend to agree that the most cost-effective policy mechanism available to reduce carbon emissions is setting a price on carbon, with 73 carbon pricing initiatives currently announced or in place by governments around the world. The basic idea of carbon pricing is to raise prices on carbon-intensive products, so that we buy less of them. The IRA takes a slightly different tact, but also changes the relative prices of clean and dirty products, by paying companies to make cleaner products. But this nuance is important as the domestic conversation has changed, from one focused on taxing polluters to one based on using the tax system to reward developers and buyers of renewable technologies.

EXHIBIT 1: CCUS project costs by application, $ per metric ton

Industry	Capture[1]	Transport and Storage[2]	Total CCS
Ethanol	12-30	25	37-55
Ammonia	15-21	25	40-46
Gas Processing	11-16	25	36-41
Cement	40-75	25	65-100
Refineries	43-68	25	68-93
Steel	55-64	25	80-89
Petrochemicals	57-60	25	82-85
Hydrogen	36-57	25	61-82
Gas Plant	54-63	25	79-88
Coal Plant	46-60	25	71-85

Source: Bright, Matt."The Inflation Reduction Act creates a whole new market for carbon capture," The Clean Air Task Force, Aug. 22, 2022.

[1] *Transport Infrastrastructure for Carbon Capture and Storage, Great Plains Institute and University of Wyoming, 2020.*

[2] *CATF national estimate used in this analysis. Low could be $3/metric ton to $40/metric ton.*

The 2000s saw the largest U.S. push to commercialize the technology, with private industry and government investing tens of billions of dollars in dozens of industrial and power plant capture projects.[11] It was during the height of this initial outpouring of capital that section 45Q of the U.S. Internal Revenue Code was introduced in 2008. At the time, the tax incentive paid out $20 per metric ton for the first 75 million tons of captured CO_2 and was thought to be more than sufficient to bridge the investment gap between government funding for 'pilot' demonstration projects and the much needed private-sector commercial hand off. It didn't work out as planned.

Market enthusiasm peaked by mid-decade, and contracted over the next decade with the uneven track record of the government-sponsored demonstration projects and the very narrow window of commercial success for stand-alone tax-incentive supported projects. According to the IEA, over 500 global CCUS projects of all types have been proposed while only around 40 commercial capture facilities are now in operation globally. This amounts to a total global capture capacity of ~45 millions of tons of CO_2 per annum (MTPA), with slightly more than half of that capacity or ~24 MTPA located in the U.S. That's a drop in the bucket, comparatively speaking, to the agency's forecast need of 1,150 MTPA by 2030 and the ~8 gigatons per annum (GTPA) by 2050.

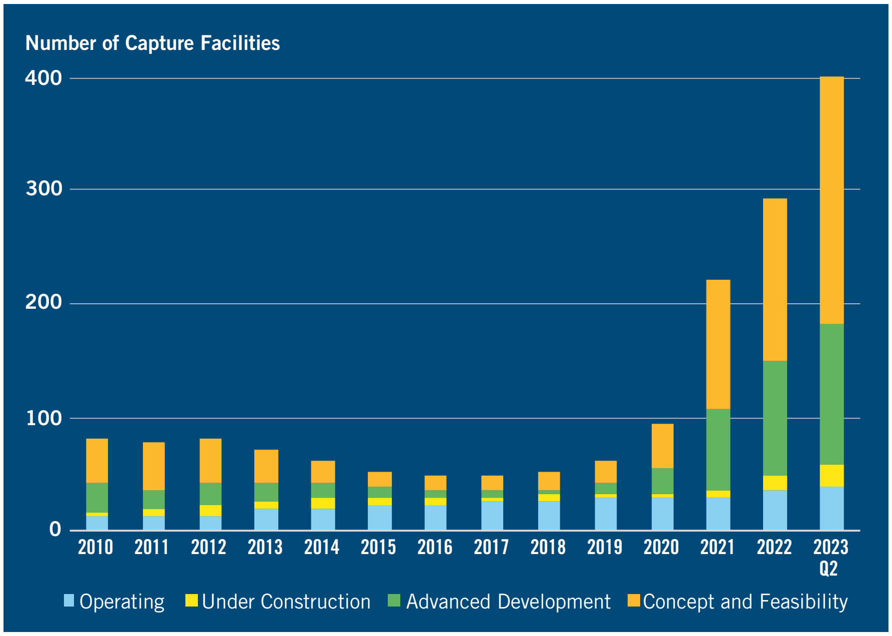
By the end of the first commercial wave — a rough timeline between 2010 and 2018 — the number of facilities being actively invested in was halved.[12] Cooling investor interest could be tied to the fact that most (>80%) of the announced initiatives ended in failure. But, another important reason why investors fled was that the targeted abatement market simply disappeared. About 550 U.S. coal-fired power units — totaling about 102 gigawatts or one-third of the country's generating capacity — prematurely retired during the 2010s because of competition from natural gas and renewables.

To prop up flagging interest in building CCUS projects, Congress again interceded in late 2018, raising the existing CO_2 capture incentives to $50 per metric ton for permanent storage or $35 per metric ton for use. But before final guidance could be issued in early 2021, policy momentum was already shifting, signaling to the market that more expansive incentives were in the pipeline. The climate priorities from the new administration were evolving with the growing body of research, showing every conceivable pathway to net-zero required domestic carbon management to scale — and scale quickly. However, that same research also made plain that the existing federal incentive framework was broken and would fail to re-ignite a new, more substantial wave of investment to reach those goals.

How can the broken CCUS incentives be fixed?

The cost of CCUS can vary significantly by application *(Exhibit 1)*, with capture costs rising rapidly as proportion of CO_2 in the flue gas decreases — simply put, higher volume, purer carbon streams improve the economies of scale for capture, use and storage. At the lower end of

EXHIBIT 2: Evolution of the CO_2 capture project pipeline, 2010-Q2 2023



Source: International Energy Agency. License: CC by 4.0

the cost-scale, CO_2 capture for natural gas processing and ethanol production projects are somewhere around $20 per ton. And at the high end of capture costs are hydrogen production, heavy industries (such as cement or steel) and power generation, with project costs rising three-fold for capture or about $60 per ton. By comparison, while atmospheric concentrations are at an all-time high, direct capture applications work with the lowest concentration CO_2 and face capture costs between $125 per ton to $335 per ton. Consequently, direct air capture technologies (as opposed to point-source capture) are the most expensive applications for removal.

With IRA, Congress has seemingly placed the CCUS incentive squarely in the "Goldilocks" range for point-source projects, with the 45Q tax credit now allowing projects to earn $85 per ton for CO_2 permanently stored and $60 per ton for utilization. Additional user-friendly revisions to the code also make the credit easier to claim by lowering capture volume requirements, implementing direct pay for a period of five years[13] and enabling the credit to be transferred to other parties.[14] Yet, the real test of whether IRA will enable carbon capacity to scale by 2030 is whether the hardest-to-abate sectors actually respond. And on that front, there is reason for optimism.

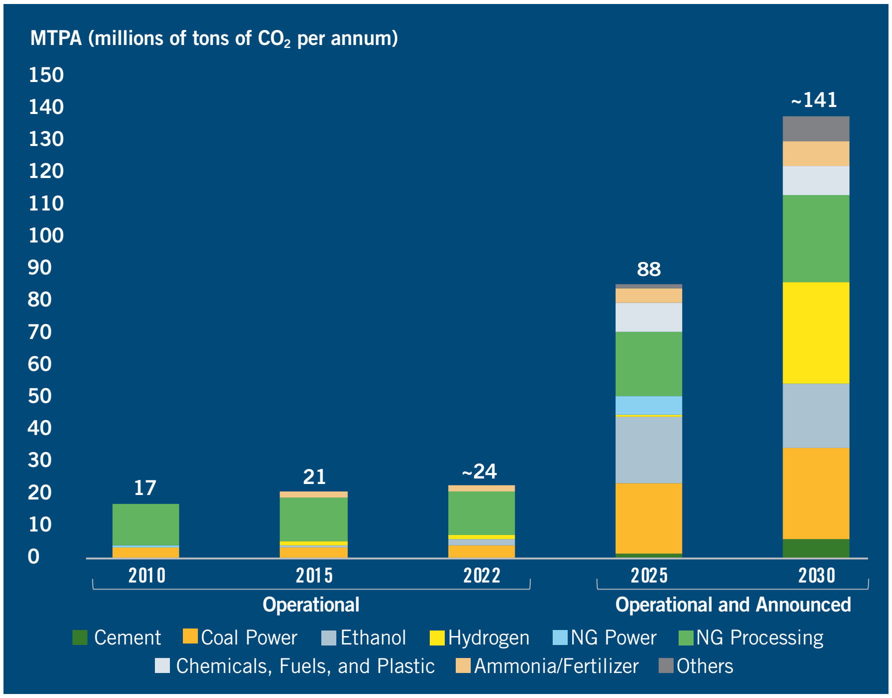
The fact is that 2022 turned out to be a watershed year for new project announcements, leaving little doubt that these incentives have firmly captured the investment community's attention. According to PwC, more than one quarter of all venture capital funding is now focused on climate technology, with increased attention on those technologies that have the most potential to cut emissions. One industry database has tracked ~140 MTPA of new announced capacity from 60 CCUS projects this past year alone *(Exhibit 2),* with robust year-to-date investment in 2023 possibly seeing these estimates doubled.[15,16]

New math: Leveraging the "use" case and other IRA synergies to unlock value

And, while the stand-alone 45Q tax incentives are largely responsible for the initial investor response, there are additional incentives that could make CCUS project economics even more compelling.

According to McKinsey, most CCUS business cases assume that captured CO_2 will be transported to a local site and sequestered, effectively turning the nascent industry into a waste-disposal business. Yet, while it's true that the 'S' (storage) in CCUS is currently more profitable under IRA than the 'U' (use), emerging applications could put captured CO_2 to more beneficial use, radically upending this assumption. Moreover, given the challenges of a timely buildout of pipeline transportation and permanent storage sites, finding commercial on-site applications for larger emitters might prove a necessity.[17]

EXHIBIT 3: U.S. point source CCUS capture capacity by year



Source: Bloomberg New Energy Finance, "2022 CCUS Market Outlook" per Pathways to Commercial Liftoff: Carbon Management report, U.S. Department of Energy, p. 10, April 24, 2023.

Right now, captured CO_2 is mostly repurposed for urea fertilizer production or for enhanced oil recovery.[18] But in the future, carbon waste could be recycled into any number of higher-value products, opening the door to a circular carbon economy. Indeed, a significant amount of research has been poured into recycled carbon pathways to examine their technical potential to remake certain industries as carbon-neutral. Down the road, use-cases that are now being piloting across the nation could significantly offset the cost of capture, with the future state of the industry seeing captured emissions winding up as CO_2-based synthetic fuels, chemicals and/or building aggregates.

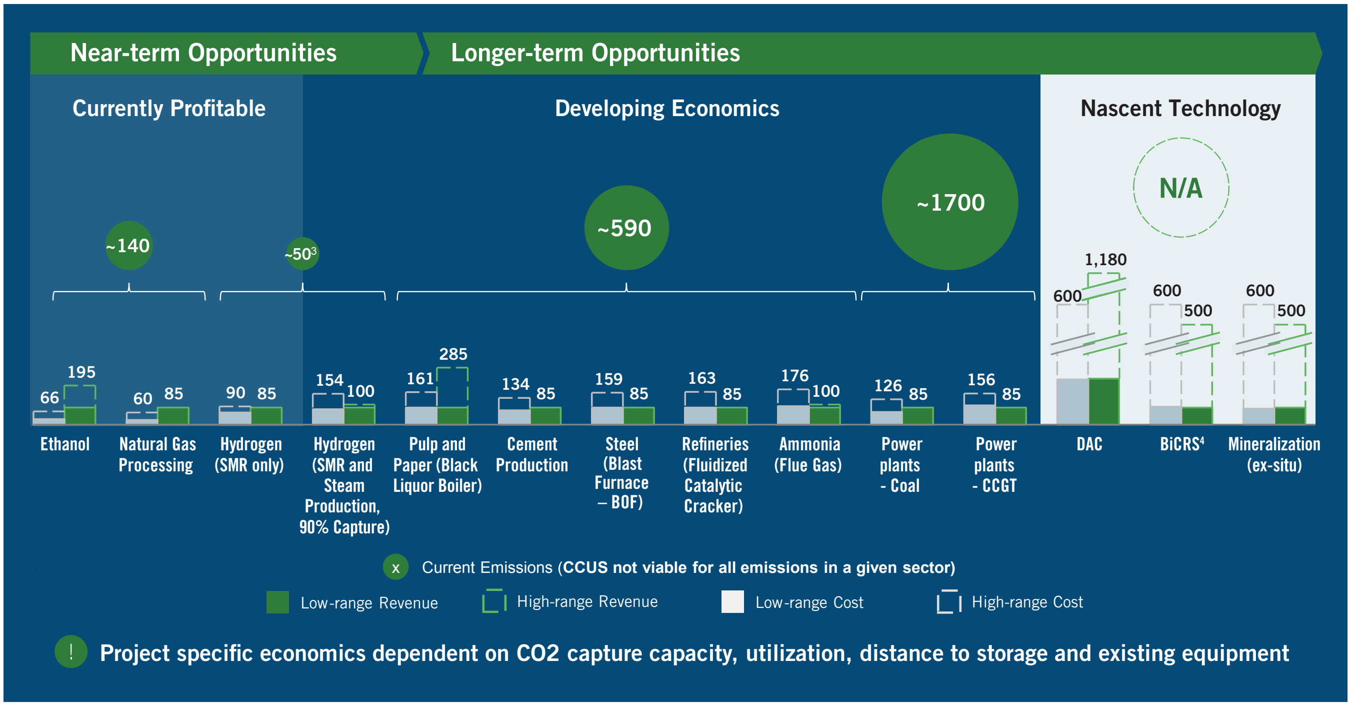
Already, synthetic fuels have emerged as a front-runner category for recycled carbon, given greater policy focus on this segment and the manifestation of IRA clean fuel tax incentives to realize those ambitions. Synthetic fuels produced from renewable power and captured CO_2 can be used to produce low-carbon substitutes for jet fuel, diesel or gasoline and represent a promising decarbonization option for hard-to-abate transportation segments. What's more, there is significant growing downstream demand from those shipping, aviation and long-haul trucking companies that will likely provide viable long-term outlets for the fuel.[19]

Because carbon waste utilization is seen as a central building block for the broader administrative goals of reducing the emission intensity of fuels and chemicals by 85% by 2035, additional CCUS revenue synergies can be found in the IRA from 45Z (the Clean Fuel Production Credit)[20], 45V (Clean Hydrogen Production)[21] and 40B (Sustainable Aviation Fuel Credit).[22] While these low-carbon fuel credits cannot be stacked on top of 45Q, they can be utilized in succession or synergistically, further enhancing CCUS project economics.[23] Already, the ethanol industry (which captures about 25% of its CO_2 emissions) has pilot projects underway to utilize these linked IRA (CCUS and Clean Fuel) tax incentives.[24]

The second chapter: New cycle of carbon management investment

How exactly will IRA influence investments in U.S. CCUS projects? The U.S. Department of Energy (DOE) weighed in with its report, "Pathways to Commercial Liftoff: Carbon Management," predicting that the increase in the 45Q tax credit will ultimately lead to 70-110 MTPA of additional carbon-management capacity by 2030. Importantly, the agency sees a greater array of decarbonization or application diversification[25] taking place over the next decade, with increased opportunities for a larger segment of the economy to participate in carbon management – from ethanol plants, chemical manufacturers, power plants, hydrogen, cement and steel[26] manufacturers.

EXHIBIT 4: Cost and revenue per industry or technology today, $ per metric ton



Source: Pathways to Commercial Liftoff: Carbon Management report, U.S. Department of Energy, p. 2, April 24, 2023.

At present, total U.S. CCUS capture capacity stands at ~24 MTPA and is highly concentrated in a narrow band of gas processing projects, which amount to 14 MTPA or 58% of the total installed base. Yet, with the recent swell of newly announced projects, upwards of ~141 MTPA capacity could be in place by 2030, with a much wider breadth of heavy-emitting industry sectors represented *(Exhibit 3).* DOE's expectation of high project conversion, from announced to operational, and the diversification of carbon capture applications, is particularly noteworthy — a stark contrast from the investment cycle of the 2010s, where projects witnessed a high rate of failure and application heterogeneity.[27]

Specifically, the DOE pathway for commercial lift off for large-scale CCUS begins expediently, now through 2025, with IRA-linked tax incentives for low-cost, high-purity CO_2 streams, such as gas processing, ethanol and ammonia (fertilizer) plants. Thereafter, through 2030, these IRA tax incentives combined with new funding support from the Bipartisan Infrastructure Law,[28] will help bridge the financing for lower-emitting, more costly industries — such as power generation, heavy industry and hydrogen. The saturation of these near-term opportunities combined with a handful of longer-term opportunities (that are seeded with additional federal and state funding) will firmly place the U.S. on course for agency's 2030 carbon capture capacity forecast of 110 MTPA, setting the stage for the 400 to 1,800 MTPA needed by 2050.

Explicit in the DOE report is the idea that costs will rapidly decline, so those projects that won't pencil now with the generous tax breaks will ultimately find economic footing in the not-so-distant future. Consequently, a clearer understanding of whether this hand off will actually take place (between projects that are immediately viable and those that are not) is important. Whether or not carbon management can get off the ground this time around is dependent on achieving broader economy-wide capture — the low-cost, low-hanging fruit variety of capture will not alone achieve the nation's net-zero aspirations.

To break this down:

The United States Government Accountability Office confirms that the DOE near-term opportunities (from high-purity CO_2 streams in gas processing and ethanol production) might only account for ~140 MTPA of total carbon management. Whereas, longer-term opportunities (or those that might not be immediately viable with the boost from 45Q alone), such as power generation fall in the ~1,500 to 1,700 MTPA range *(Exhibit 4).* As a result, a significant number of carbon management projects in the long-term opportunity set will need to gain economic traction in order for the historic legislation passed last year to accomplish what it set out to do.

Assuming DOE's commercial lift-off takes place, just how big could this next chapter in carbon management prove? DOE provided a realistic 'middle of the road' target for new capacity upwards of 110 MTPA. But what if the sky was the limit (pun intended)? What amount of capacity could we see developed as a result of IRA? A recent Princeton University analysis estimated that the legislation would increase the use of carbon capture 13-fold by 2030 relative to current policy. These researchers also see that important hand off occurring: "Incentives for carbon capture, storage, and use in the Inflation Reduction Act would build on demonstration funding in the Bipartisan Infrastructure Law to make carbon capture a viable economic option for the most heavily emitting industries, such as steel, cement, and refineries, as well as power generation from coal and natural gas."

The test, of course, is whether the hardest-to-abate sectors will opportunistically install and continue to operate the technology based on these incentives. While the first chapter of investing in CCUS proved an expensive failure, the lessons learned from that investment cycle now seemingly provide greater opportunities for success in the second chapter, thanks in no small part to new IRA funding and the revived investment interest for once again developing these projects. ■

Sources used

[1] *According to the United Nations, over the next decade, every aspect of national energy systems will be affected by changes in climate and energy policy, financing, continuous technological advancement, and shifts in energy supply and demand. "Economic Growth and Carbon Emissions Used to Go Together. In Some Countries, That's Changing", Time Magazine, 29 October 2021.*

[2] *"Emissions and energy impacts of the Inflation Reduction Act", Science, 29 Jun 2023.*

[3] *The electricity sector is expected to deliver about 64% of IRA-induced mitigation by 2030. IBID 2.*

[4] *The federal government has proposed several major environmental regulations since the passage of the IRA, including limits on emissions of carbon dioxide and other harmful pollutants. The agency argues that the policies in both the IRA and the Bipartisan Infrastructure Law make the proposed regulation feasible. These proposals target greenhouse gas emissions from power plants and passenger vehicles.*

[5] *According to the U.S. Congressional Budget Office, "personal vehicles – cars, light-duty trucks (including sport utility vehicles, crossover utility vehicles, minivans, and pickup trucks), and motorcycles – were responsible for 58 percent of emissions in the transportation sector in 2019". Electric vehicle adoption for this segment will contribute to lowering emissions for the entire transportation sector.*

[6] *"Carbon Capture: A Technology Assessment", Congressional Research Service, July 2010.*

[7] *"Get Ready for Carbon Capture's Second Coming", Washington Post, 13 June 2023. "Carbon Removal in the Bipartisan Infrastructure Law and Inflation Reduction Act", World Resources Institute, December 2022.*

[8] *"Lessons captured from 50 years of CCS projects", P. Loria, M.B.H. Bright, Electricity Journal, 2021.*

[9] *Commercial viability depends on how the entire system operates at scale and about 70% of the commercial* CO^2 *capture has solely been deployed in gas processing plants for use in EOR.*

[10] “Explaining successful and failed investments in U.S. carbon capture and storage using empirical and expert assessments”, Abdulla, Hanna, Schell, Babacan, and Victor, Environmental Research Letters, December 2020.

[11] IBID 8.

[12] Specifically, the number of active projects _ either in early development, advanced development, under construction _ declined from 77 to 37. “Carbon capture and storage at the end of a lost decade,” Martin-Roberts, Scott, Flude, Johnson, Haszeldine, Gilfillan, One Earth Journal, November 2021.

[13] More specifically, 45Q is eligible for “direct pay” provisions for the first five years of the incentive for (tax-paying) private parties, followed by seven years of enhanced transferability for corporate taxpayers. Tax-exempt entities such as governmental, cooperative, and tribal owners of CCS projects can now use direct pay provisions for all 12 years of claiming the credits.

[14] Previously, only the largest carbon-emitting projects could meet the capture requirements under Section 45Q: Power plants were required to capture at least 500,000 metric tons per year, industrial facilities were required to capture at least 100,000 metric tons per year, and direct air capture (DAC) facilities were required to capture at least 100,000 metric tons per year. The IRA modifies the definition of “Qualified Facility” under Section 45Q such that the carbon-capture threshold for power plants is reduced to 18,750 metric tons per year, the threshold for industrial facilities is reduced to 12,500 metric tons per year, and the threshold for DAC facilities is reduced to 1,000 metric tons per year.

[15] “Pathways to Commercial Liftoff: Carbon Management”, U.S. Department of Energy, April 2023.

[16] “Carbon Capture, Utilisation and Storage”, IEA, last update July 2023.

[17] According to a 2021 Princeton University–led study, reaching net-zero carbon emissions in the United States will require CCUS technology supported by roughly 66,000 miles of CO^2 pipelines. As of February 2023, the U.S. DOT reported fewer than 5,400 miles of U.S. pipelines carrying CO^2 (more than half in West Texas, supporting Permian oil production). “Onshore U.S. Carbon Pipeline Deployment: Siting, Safety, and Regulation”, NARUC, June 2023.

[18] According to IEA, around 230 Mt of CO^2 are currently used each year, mainly in direct use pathways in the fertilizer industry for urea manufacturing (~130 Mt) and for enhanced oil recovery (~80 Mt).

[19] Green methanol (as opposed to grey methanol, which is created from a fossil fuel stream) is a key chemical building block for these synthetic fuels but also may be used for other applications such as a feedstock for plastics. Ironically, methanol was first identified as a liquid fuel to achieve energy security by satisfying U.S. transportation demand in response to the OPEC crisis of the 1970s. For more see: “Methanol as an alternative transportation fuel in the US: Options for sustainable and/or energy-secure transportation,” Bromberg and Cheng, prepared for the U.S. Department of Energy, November 2010.

[20] Section 45Z, also known as the Clean Fuel Production Credit (CFPC), provides a tax credit for fuels relative to how low their carbon intensity (CI) score is against a baseline level, defined as 50 CI (kg CO^2e/MMBtu) in statute, under the Argonne Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model (for nonaviation fuel). The value of this credit is $0.02 cents per gallon for each CI point under 50. Entities can qualify for fuel produced and sold between 2025 and 2027.

[21] The Inflation Reduction Act (IRA) introduced the 45V Hydrogen Production Tax Credit, which awards up to $3 per kg of hydrogen produced to projects with a lifecycle greenhouse gas emissions intensity of less than 0.45 kilograms per kilogram of hydrogen (kg CO^2e/kg H2). See, “How the 45V Tax Credit Definition Could Make or Break the Clean Hydrogen Economy”, CSIS, 22 May 2023.

[22] Section 40B, is a sustainable aviation fuel (SAF) tax credit. Congress provides five years of SAF tax incentives. In 2023 and 2024 SAF will qualify for a standalone blender credit (40B) if the fuel reduces lifecycle greenhouse gasemissions by at least 50 percent. The value of this credit is determined on a sliding scale, equal to $1.25 plus anadditional $0.01 for each percentage point by which the lifecycle emissions reduction of such fuel exceeds 50percent. Then, SAF incentives will become part of 45Z from 2025 to 2027.

[23] For example, any fuel sold from 2025 to 2027 with a lifecycle emissions rate below 50 kilograms of CO^2/MMBtu (“Carbon Intensity or CI”) would be eligible under the new IRC Section 45Z for $0.02/gallon for each CI point of reduction up to $1.00. This benefit could be exhausted prior to seeking out 45Q.

[24] While CCUS projects cannot “stack” 45Q with 45V, 40B or 45Z, these incentives can be linked together. For more information, see https://growthenergy.org/wp-content/uploads/2023/06/02-Spring-Fly-in-Tax-Incentives.pdf.

[25] Application heterogeneity is really important for carbon capture commercial 'uplift' and refers to the deployment of CO^2 capture technologies in new industrial settings. Current carbon capture technologies have been engineered and optimized for specific flue gas characteristics such as temperature, pressure, CO^2 concentration and the presence of other chemicals and impurities. While there is considerable expertise and experience in these settings, the same cannot be said for the variety of retrofit scenarios across industrial and power sector applications – settings for which carbon capture is key to materially reduce emissions. "Turning CCS projects in heavy industry & power into blue chip financial investments", The Energy Futures Initiative, February 2023.

[26] Steelmaking is responsible for about 8% of energy sector emissions, and today, producing a ton of steel results in nearly two tons of CO^2 emissions.

[27] According to a recent report from the Government Accountability Office, only one of the eight clean-coal projects that received funding from Department of Energy (DOE) programs is currently operating, although two of the three industrial projects are.

[28] The Bipartisan Infrastructure Law (BIL) provides ~$12 billion in funding for high-potential projects across the carbon management value chain, including funding for demonstration and pilot projects. BIL also includes $8B for Regional Clean Hydrogen Hubs, at least one of which must prioritize projects that use CCUS to generate clean hydrogen and $500M for Industrial Emissions Demonstration Projects that could include carbon management technologies.

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