COMMENT

SUBSIDIES FOR DIRECT AIR CAPTURE: LESSONS FROM THE SOLAR INDUSTRY

by Ben Brokesh

Ben Brokesh is a 2024 J.D. candidate at the University of California, Berkeley, School of Law.

The name of the climate game right now is fast, sustained progress. The world needs this both politically and technologically to effectively fight climate change. While the markets of today may efficiently drive innovation in software technologies like Facebook or TikTok, markets are on the wrong timescale for quickly addressing climate change, because they do not automatically internalize harmful impacts of greenhouse gas (GHG) emissions.[1] They do, however, rapidly internalize government incentives like subsidies.[2] To act as urgently as the world needs, government action must mobilize markets against climate change.

Progress was achieved both politically and technologically with the Inflation Reduction Act of 2022 (IRA). The IRA allocated $369 billion to "energy security and climate change," amounting to the United States' largest investment in climate action to date. Subsidies like the IRA can have a significant impact, so the IRA's passage has generated excitement within energy and climate circles.

However, this is not the first time subsidy money has been dedicated to solving climate change. The Energy Policy Act of 2005 (EPAct), the Energy Independence and Security Act of 2007, and the American Recovery and Reinvestment Act of 2009 (ARRA) all ushered money into renewable energy research and/or project development. This status quo around using subsidies to encourage progress in clean technology is followed in the IRA. The continued use of these subsidies, though, calls for some introspection around whether this status quo is best to achieve the technologies necessary for the future.

This Comment will focus on how subsidies can affect the growth of climate technologies and set them up for long-term progress. To do so, it investigates solar energy—one of the few clean technologies to become successful after a decades-long history of government subsidies—by tracking the solar industry's past subsidies and their effect on promoting the industry's long-term technological progress. It will then apply this history to direct air capture (DAC), a less-established technology that is critical to the climate change fight, and determine how past, current, and future subsidies can make DAC a reality. The Comment aims to supply a perspective, grounded in the history of a successful climate technology, that can help determine whether the subsidy status quo maintained by the IRA will be adequate for the development of DAC technologies.

I. The Subsidy Context

A. Subsidies and Energy

Throughout American history, policymakers have used subsidies to influence the energy industry.[3] In 1789, the U.S. Congress implemented the first federal tariff on coal to help protect the burgeoning industry from British imports.[4] This was not a subsidy as we would currently define them, but was a clear way to incentivize American coal in the energy industry. By the early 1900s, Congress was enacting subsidies similar to those of today.[5] These ranged from deducting intangible drilling costs for oil to initial capital investment deductions for companies investing in coal.[6]

In general, policymakers have had two goals in mind with energy subsidies: promoting development in fledgling technologies and incentivizing private investment in energy technologies for the public good.[7] While subsidizing energy innovation and investment was a major part of America's growth, it also created our current reliance on fossil fuels.[8] Even today, U.S. fossil fuel subsidies encourage a market that has benefited from more than a century

Editor's Note: This Comment received the 2023 Berkeley Law Energy and Climate Change Legal Writing Award, which is presented by the Center for Law, Energy, and the Environment and the Ecology Law Quarterly.

1. Zachary S. Simmons, *Subsidizing Solar: The Case for an Environmental Goods and Services Carve-Out From the Global Subsidies Regime*, 32 UCLA J. ENV'T L. & POL'Y 422, 429 (2014).
2. *Id.* at 429-30.
3. NANCY PFUND & BEN HEALEY, DBL INVESTORS, WHAT WOULD JEFFERSON DO? THE HISTORICAL ROLE OF FEDERAL SUBSIDIES IN SHAPING AMERICA'S ENERGY FUTURE 6 (2011), https://www.dbl.vc/wp-content/uploads/2012/09/What-Would-Jefferson-Do-2.4.pdf.
4. *See id.* at 14.
5. *See id.* at 21-22.
6. *See id.*
7. *See id.* at 10.
8. *See id.* at 34.

of support.[9] Fossil fuels have had quite the head start over clean energy technologies, resulting in widespread use that cannot easily be replaced.[10] With passage of bills like the IRA, subsidies for clean energy technologies are gaining more prominence, and, slowly, these technologies are benefiting in the same way. But all the sources of energy, including fossil fuels, that the United States grew up with relied on subsidies to enter the market.[11]

B. *Why Subsidies?*

The IRA relies almost entirely on subsidies—particularly tax incentives—to incentivize long-term progress in clean energy technologies. Subsidies, though, are not the only way to combat climate change; regulations could directly address emissions and force energy industries to adopt greener technologies. However, climate change has become increasingly politicized over the past 40 years,[12] degrading Congress' interest in direct climate measures.[13] Politicization has also led to rulings like *West Virginia v. Environmental Protection Agency* that gut the U.S. Environmental Protection Agency's (EPA's) authority to administer environmental regulations.[14]

Absent regulation, there are a few major market-based approaches discussed in climate circles. A green bank is one approach that could give clean energy projects favorable rates and low-cost capital.[15] Green banks are mission-driven, not profit-driven, so their goals center around financing projects that fight climate change.[16] They are typically started with public funding, and then leverage private money and the return on initial investments to fund more projects.[17] The IRA does include $27 billion for EPA to help establish green banks,[18] but state, local, regional, and tribal jurisdictions must apply for these grants themselves.[19] By leaving it to nonfederal jurisdictions to establish green banks, the IRA distanced itself from the political hurdles of establishing a national green bank policy that could incentivize climate technologies nationwide.

The IRA likewise did not implement any carbon taxes, which might apply to any polluting technology, raising its price and incentivizing nonpolluting clean technologies. Generally, economists favor a carbon tax as the best method for governments to mobilize markets against climate change.[20] An ideal carbon tax would be simple, broadly apply to all emissions, and accurately represent the cost of polluting technologies,[21] inducing significant changes in carbon-intensive sectors while moving the needle for small-scale polluters.

Public opinion, however, has consistently disfavored tackling climate change with a carbon tax,[22] largely due to its tangibility.[23] Voters can easily see the trade off they are making with a carbon tax,[24] which helps fight climate change in theory, but immediately raises gas prices.[25] In contrast, the trade off between climate action and a federal subsidy is much further removed and more difficult to identify. A subsidy plan is funded indirectly, keeps consumer costs low, and, as shown below, requires the involvement of and garners support from businesses.

Finally, a cap-and-trade system, though further removed from the consumer than a carbon tax, can still have much of the same perceived effect.[26] It can incentivize oil companies to increase the cost of fuel, just as a tax would.[27] Further, creating a new commodity—emission allowances—creates new markets that can be volatile and unpredictable, as has happened with the European Union's cap-and-trade program.[28] A cap-and-trade system can also struggle with optics, as it can look like a government handing polluters valuable emission allowances.[29]

Politically, at least, in the United States, subsidies have become the answer, despite having their own drawbacks. Unlike a carbon tax, subsidies cost the government money and cannot broadly attack all sources of carbon dioxide (CO_2) emissions.[30] The government must choose specific energy technologies to incentivize. These decisions on how and what to subsidize are complex, subject to lobby-

9. *See id.* at 17-18.
10. Simmons, *supra* note 1, at 423.
11. *See* Pfund & Healey, *supra* note 3, at 10-11.
12. *See generally* Sedona Chinn et al., *Politicization and Polarization in Climate Change News Content, 1985-2017*, 42 Sci. Commc'n 112 (2020), *available at* https://doi.org/10.1177/1075547019900290.
13. *See* Alec Tyson & Brian Kennedy, *Two-Thirds of Americans Think Government Should Do More on Climate*, Pew Rsch. Ctr. (June 23, 2020), https://www.pewresearch.org/science/2020/06/23/two-thirds-of-americans-think-government-should-do-more-on-climate/ ("While partisanship remains the predominant dividing line in many views of climate and the environment, there are meaningful differences within party coalitions.").
14. *See* Peggy Otum et al., *Inflation Reduction Act: Environmental Provisions*, WilmerHale (Sept. 1, 2022), https://www.wilmerhale.com/en/insights/client-alerts/20220901-inflation-reduction-act_environmental-provisions.
15. National Renewable Energy Laboratory, *Green Banks*, https://www.nrel.gov/state-local-tribal/basics-green-banks.html (last visited May 15, 2023).
16. Coalition for Green Capital, *What Is a Green Bank*, https://coalitionforgreencapital.com/what-is-a-green-bank/ (last visited May 15, 2023).
17. *What Are Green Banks?*, USAFacts (Sept. 7, 2022), https://usafacts.org/articles/what-are-green-banks/.
18. Bipartisan Policy Center, Inflation Reduction Act Summary: Energy and Climate Provisions (2022), https://bipartisanpolicy.org/download/?file=/wp-content/uploads/2022/08/Energy-IRA-Brief_R04-9.26.22.pdf.
19. *Id.*
20. *See* Gary M. Lucas Jr., *Behavioral Public Choice and the Carbon Tax*, 2017 Utah L. Rev. art. 3, at 121 (2017).
21. *Id.* at 122-23.
22. *Id.* at 130 (While most surveys find that the majority of Americans support government climate action, most strongly oppose a carbon tax and prefer command-and-control regulation or green subsidies.).
23. *See id.* at 142-43 (Polls show that policies with clear trade offs significantly lose more public support than ones without. Merely mentioning taxes calls trade offs to mind. So, the idea of a carbon tax is less popular with the public than subsidies that do not bring a trade off to mind as easily.).
24. *See id.*
25. *See* Craig Lord, *The Federal Carbon Tax Is Set to Rise April 1. How Will That Affect Gas Prices?*, Glob. News (Apr. 1, 2022), https://globalnews.ca/news/8721986/carbon-tax-hike-gas-prices-2022/.
26. *Id.*
27. *Id.*
28. *See* Feng Dong et al., *Exploring Volatility of Carbon Price in European Union Due to COVID-19 Pandemic*, 29 Env't Sci. & Pollution Rsch. 8269, 8270-71 (2021), https://doi.org/10.1007/s11356-021-16052-1.
29. Cornell Law School, *cap-and-trade*, https://www.law.cornell.edu/wex/cap-and-trade (last updated July 2022).
30. *See* Lucas, *supra* note 20, at 123.

ing, and, if chosen poorly, can waste a significant amount of money.[31]

Yet, subsidies can be incredibly effective for promoting new energy technologies through innovation and investment, hence their use throughout American history.[32] Since subsidies have been prominent, and are likely to be for the foreseeable future, learning to compensate for their flaws and keep their benefits is critical for effectively achieving a clean energy future. Solar energy is the clean technology with the longest history of federal subsidies, and thus is an apt case study for future climate technologies.

II. Solar Energy

Solar energy's importance for fighting climate change is the same as other promising technologies—it can help us achieve net-zero CO_2 equivalent emissions. The United States alone emits around 6,000 million metric tons (MMt) of CO_2 equivalents per year.[33] Generating electricity accounts for 25% of those emissions, or 1,500 MMt.[34] To get those numbers to zero, the United States will likely need both technologies that generate electricity without polluting and ones that remove emissions from the air.[35] Studies from the U.S. Department of Energy (DOE) expect that the United States will need at least 1,600 gigawatts (GW) of solar capacity to achieve full grid decarbonization.[36]

Currently, the United States has about 140 GW of solar capacity,[37] a vast improvement from 2008—right before significant solar subsidies were implemented—when it only had about 1.30 GW.[38] It remains to be seen to what extent solar subsidies like those in the IRA will help the United States reach 1,600 GW. However, the rapid increase in solar capacity over the past 15 years suggests there is a lot to learn from how subsidies can affect a fledgling technology and make it a staple of the clean energy future.

A. The Technology

Solar energy is by no means new. It began in 1839 when Edmond Becquerel showed that blue and ultraviolet light could generate electricity when passed over electrodes coated with silver halides.[39] This was solar energy in its most rudimentary form. Throughout the 19th century, inventors sprinkled across the globe investigated potential solar energy technologies like selenium cells and thermopiles.[40] But everything changed with the discovery of the photoelectric effect, the advent of semiconductors, and the resulting silicon solar cells.[41] By 1954, Bell Laboratories had a silicon solar cell that was far more efficient than any solar technology before it, though even in direct sunlight, it was only 6% efficient.[42] That 6% efficiency was a great achievement, but still too low to revolutionize the world's energy system.

Things would change for solar with the space race. As the United States and Russia geared up their competition, scientists started discussing solar cells as a viable power system for satellites in space.[43] Thus, solar energy found a reason to keep developing, resulting in efficiency and manufacturing improvements, and soon enough, a human presence in space.[44] The first terrestrial solar cells were implemented in the 1970s.[45] By then, solar cells had advanced to 14% efficiency and cost $20 per watt.[46] Since the 1970s, solar technology has continued to develop, reaching efficiency values as high as 44.4%, but commercially, most solar arrays in use today are still between 10% and 20% efficient.[47]

The more important change since the 1970s is the cost of solar. Today, the cost of solar panels is down to $0.38 per watt and still decreasing.[48] In fact, the cost of solar has been driven so low that it is now competitive with (if not cheaper than) fossil fuels.[49]

B. Solar Subsidies and Sustained Technological Progress

The federal government did not get directly involved with solar for more than 100 years after its inception. The first direct federal funding for solar started with the National Aeronautics and Space Administration (NASA) and the space race in 1950.[50] In fact, from 1950 to 2006 NASA

31. *Id.* at 129.
32. Pfund & Healey, *supra* note 3, at 6.
33. U.S. EPA, *Sources of Greenhouse Gas Emissions*, https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions (last updated Apr. 28, 2023).
34. *Id.*
35. *See* National Academies of Sciences, Engineering, and Medicine, *Is It Possible to Achieve Net-Zero Emissions?*, https://www.nationalacademies.org/based-on-science/is-it-possible-to-achieve-net-zero-emissions (last visited June 5, 2023).
36. DOE Solar Energy Technologies Office, *Solar Futures Study*, https://www.energy.gov/eere/solar/solar-futures-study (last visited May 15, 2023).
37. Solar Energy Industries Association, *Solar Industry Research Data*, https://www.seia.org/solar-industry-research-data (last visited June 5, 2023).
38. *Id.*
39. Karthik Kumar, *A History of the Solar Cell, in Patents*, Intell. Prop. Mag. (Apr. 27, 2020), https://www.finnegan.com/en/insights/articles/a-history-of-the-solar-cell-in-patents.html.
40. *Id.*
41. *Id.*
42. *Id.*
43. DOE, The History of Solar, https://www1.eere.energy.gov/solar/pdfs/solar_timeline.pdf.
44. *Id.*
45. Lewis M. Fraas, *History of Solar Cell Development*, *in* Low-Cost Solar Electric Power 1, 2 (2014), *available at* https://doi.org/10.1007/978-3-319-07530-3_1.
46. Darya Tarassova, *Solar Energy: Then and Now*, Dash Energy (Sept. 12, 2020), https://dash.energy/2020/09/12/solar-energy-then-and-now/.
47. *See* Amos Han, *Efficiency of Solar PV, Then, Now, and Future*, Lafayette Coll.: Solar Photovoltaic, https://sites.lafayette.edu/egrs352-sp14-pv/technology/history-of-pv-technology/ (last visited May 15, 2023); Todd D. Gerarden, Demanding Innovation: The Impact of Consumer Subsidies on Solar Panel Production Costs 10 (June 2022), https://static1.squarespace.com/static/5bae7fdbfb22a57169d20c0d/t/62a23614455c9109a732b7db/1654797845347/gerarden_solar_innovation.pdf.
48. *See* Our World in Data, *Solar (Photovoltaic) Panel Prices*, https://ourworldindata.org/grapher/solar-pv-prices (last visited May 15, 2023); Tarassova, *supra* note 46.
49. *See* Press Release, International Renewable Energy Agency, Majority of New Renewables Undercut Cheapest Fossil Fuel on Cost (June 22, 2021), https://www.irena.org/news/pressreleases/2021/Jun/Majority-of-New-Renewables-Undercut-Cheapest-Fossil-Fuel-on-Cost.
50. *See* Adam Wilson, *The Future Looks Bright, or Does It? An Analysis of Solar Energy Law and Policy in the United States*, 22 J. Env't & Sustainability L. 333, 346 (2016).

spent almost $1 billion researching solar.[51] This direct funding for solar, however, was limited to NASA's interests until the 1970s.

In the 1970s, solar energy became more relevant to the United States with the oil crisis.[52] When oil prices skyrocketed and supply was constrained, America realized its perilous energy dependency on fossil fuels.[53] This realization stimulated many responses, including the establishment of DOE itself, the creation of the DOE Solar Energy Research Institute (now the National Renewable Energy Laboratory, or NREL), the Public Utility Regulatory Policies Act (PURPA), and the Energy Tax Act of 1978.[54]

PURPA for the first time required utilities to purchase power from renewable energies like solar.[55] The Energy Tax Act of 1978 was the first residential incentive for solar, giving homeowners a 30% tax credit (with a $2,000 cap) for solar installations.[56] Further, that Act got businesses involved by giving a 10% investment tax credit (ITC) for investment in solar power equipment.[57] These tax incentives became the model for many of the significant federal solar subsidies to date.

By the early 1980s, with the United States' head start in solar development through NASA and the 1970s push for alternative energies, the United States dominated the solar energy space, representing 80% of the world's market.[58] That changed with the Ronald Reagan Administration, which immediately disrupted the solar industry's progress. It rejected recommendations from the Solar Energy Research Institute (now NREL), slashed the Institute's budget by 77%, and allowed tax benefits to expire.[59] Further, President Reagan decided to focus on protecting the oil supply from the Middle East with U.S. military intervention, instead of committing to energy independence.[60] These shifts in public policy predictably triggered a decline in the U.S. solar industry.[61]

Over the next two decades, the rest of the world began participating in solar deployment while the United States receded, content with lower gas prices.[62] It took until the United States' next gas scare in the early 2000s for the federal government to reconsider solar as a means of energy independence.[63] These developments, plus a growing awareness of climate change, led to the main federal solar subsidies before the IRA: EPAct, the America Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science (COMPETES) Act of 2007, and ARRA.

1. The ITC

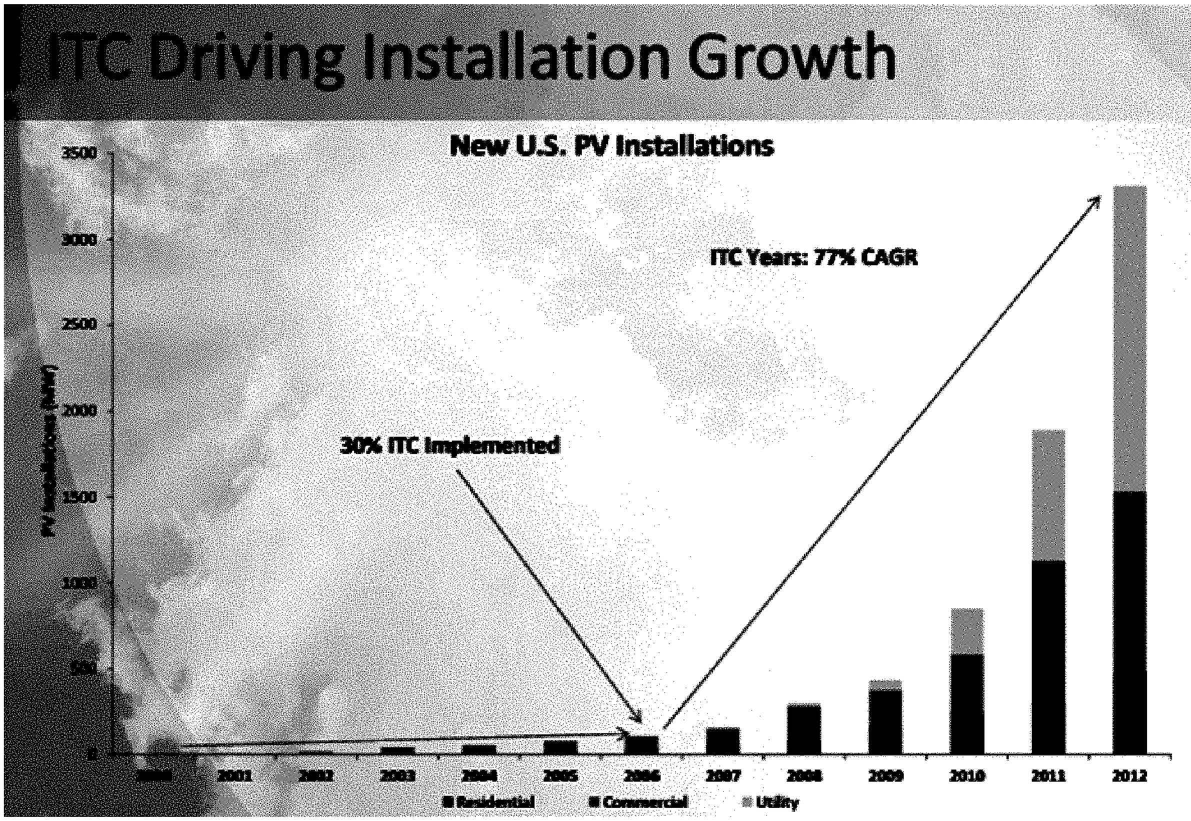
The most significant subsidy for solar to date came from the 2005 EPAct's re-adoption of the 1978 30% tax credit, this time without a cap.[64] It is commonly referred to as the "investment tax credit," but it applies to residential, commercial, and utility (public and investor-owned utility) customers, unlike the 1978's ITC, which only applied to commercial investment.[65] As a direct tax incentive, the ITC drives down the cost of solar that any individual or business installs, develops, or finances.[66] Since implementing the ITC in 2006, solar has proliferated, growing by more than 200 times with an average annual growth of 33%.[67] Figure 1 (next page) shows the growth of solar technology immediately after the ITC was implemented.

The ITC has been the primary subsidy benefiting solar since its implementation, but subsidies discussed below also impacted the growth shown in Figure 1.[68] The benefits from the 30% ITC have been fairly steady since its implementation in EPAct, but its long-term impact relied on many extensions from Congress.[69] The most critical extension of the ITC was in 2008, when Congress voted for an eight-year extension.[70] A long-term implementation like this helped provide certainty to investors that the 30% credit would be available for prospective solar projects.[71] It allowed them to leverage billions of dollars for high-tech innovation and project development, allowing new solar products and services to launch, further driving down solar costs.[72]

The ITC, however, is not without flaws. First, as a tax incentive, it can only be valuable to entities that actually owe tax, as it only credits federal taxes equivalent to 30% of the cost of the solar project.[73] Thus, an organization that has a low tax bill or is losing money cannot take advan-

51. *Id.*
52. *See* Geoffrey Jones & Loubna Bouamane, *"Power From Sunshine": A Business History of Solar Energy* 16-21 (Harvard Business School, Working Paper No. 12-105, 2012), https://www.hbs.edu/ris/Publication%20Files/12-105.pdf.
53. *See id.*
54. *See id.*; Simmons, *supra* note 1, at 432; *see* DOE Office of Science, *History*, https://www.energy.gov/science/history (last visited June 5, 2023).
55. Simmons, *supra* note 1, at 432.
56. International Energy Agency, *Energy Tax Act of 1978*, https://www.iea.org/policies/4248-energy-tax-act-of-1978 (last updated Mar. 14, 2013).
57. *Id.*
58. *See* Jones & Bouamane, *supra* note 52, at 21.
59. *See id.* at 35; *see also* Laura T. Gebert, *A Survey of Selected Government-Sponsored Energy Plans and Recommendations for Florida's Future Energy Policy*, 8 Barry L. Rev. 149, 155 (2007).
60. *See* Fraas, *supra* note 45, at 4.
61. *See* Jones & Bouamane, *supra* note 52, at 35-36.
62. *See* Fraas, *supra* note 45, at 4.
63. There were other smaller acts like EPAct of 1992, but they are not relevant for this Comment.
64. *See* Molly F. Sherlock, Congressional Research Service, IF10479, The Energy Credit or Energy Investment Tax Credit (ITC) (2021), https://crsreports.congress.gov/product/pdf/IF/IF10479.
65. Simmons, *supra* note 1, at 433-34.
66. Lawrence Berkeley National Laboratory, *Utility Solar Project Development & EPC—Strategic Conditions*, https://ei-spark.lbl.gov/generation/utility-scale-pv/project/strat/ (last visited May 15, 2023).
67. Solar Energy Industries Association, *Solar Investment Tax Credit (ITC)*, https://www.seia.org/initiatives/solar-investment-tax-credit-itc (last visited May 15, 2023).
68. In writing this Comment, I did not find any studies clearly showing the ITC's impact on solar controlled for the effect of the other subsidies after it. Thus, there is room for a valuable study to track just how impactful tax incentives are to clean energy technologies.
69. *See* Sherlock, *supra* note 64.
70. *See id.*
71. *See* Daniel Spinozzi, *The ITC Cliff: Will Solar Be Economically Viable Without the ITC?*, Renewable Energy World (Nov. 23, 2017), https://www.renewableenergyworld.com/storage/the-itc-cliff-will-solar-be-economically-viable-without-the-itc/.
72. *See id.*; *see also* Solar Energy Industries Association, *supra* note 67.
73. *See* Sherlock, *supra* note 64.

Figure 1. ITC Drives Growth of Solar



Source: Solar Energy Industries Association, History of ITC Slides (2012), https://www.seia.org/sites/default/files/resources/History%20of%20ITC%20Slides.pdf.

tage of the ITC.[74] Most solar energy developers in the late 2000s were small companies with limited tax burdens, so they were forced to enter financial agreements with larger companies that could use the credit.[75] However, when the financial crisis hit in 2008, it became very difficult for small companies to find financial partners to leverage the ITC's tax benefits.[76]

Second, forcing small entities to contract with large companies to survive in the first place adds unnecessary transaction costs that hinder the ITC's efficiency in promoting innovation and sustained technological progress in solar.[77] Finally, the ITC as initially drafted was incredibly short-lived (2005 to 2008), and relied on extensions to have the positive effect it has had on the solar industry's technological progression.[78] The uncertainty around extensions, especially before the eight-year extension in 2008, created boom-and-bust cycles in solar development as developers questioned whether the ITC would be renewed.[79]

2. Section 1603

In 2009, ARRA created the Section 1603 Treasury Program (Section 1603), which gave federal grant money as an alternative to the ITC.[80] This program was temporary, applying only to companies that started before 2012.[81] It was created as a response to small renewable energy companies losing out on the ITC during the financial crisis.[82] Instead of relying on partnering with a big company, a qualifying commercial solar project could choose between the ITC and a cash grant equal to the ITC credit.[83]

More than 2,000 different clean energy companies took advantage of the Section 1603 cash grant in lieu of the ITC.[84] This option was so important during the financial crisis that NREL declared that it served as the most

74. *Id.*
75. *See* Executive Office of the President of the United States, A Retrospective Assessment of Clean Energy Investments in the Recovery Act 30 (2016), https://obamawhitehouse.archives.gov/sites/default/files/page/files/20160225_cea_final_clean_energy_report.pdf.
76. *Id.*
77. Joseph Aldy, *A Preliminary Review of the American Recovery and Reinvestment Act's Clean Energy Package* 22 (Harvard Kennedy School, Faculty Research Working Paper No. RWP11-048, 2011), https://dash.harvard.edu/bitstream/handle/1/5688917/RWP11-048_Aldy.pdf.
78. *See* Sherlock, *supra* note 64.
79. *See* Executive Office of the President of the United States, *supra* note 75, at 29.
80. *Id.*
81. *Id.* at 30.
82. *Id.*
83. Mark Bolinger et al., Ernest Orlando Lawrence Berkeley National Laboratory, Preliminary Evaluation of the Impact of the Section 1603 Treasury Grant Program on Renewable Energy Deployment in 2009, at 1 (2010), https://eta-publications.lbl.gov/sites/default/files/report-lbnl-3188e.pdf.
84. Dustin Mulvaney, Solar Power: Innovation, Sustainability, and Environmental Justice 53 (2019).

important federal incentive for solar in that time.[85] By 2017, the Section 1603 program had funded almost 9 GW of solar capacity and awarded grants to roughly 20,000 nonresidential solar projects that had started before the 2012 cutoff.[86]

Further, the program was particularly valuable because of its ability to encourage small solar projects and first-time developers.[87] Encouraging small solar projects and first-time developers is important because small firms have higher major invention rates, which arise from the innovation investment choices they make.[88] On the other hand, larger firms have comparatively less novelty in their innovations and focus their work on more conventional and internal projects.[89]

The major flaw in the Section 1603 subsidy is that it was temporary and only intended to fix a problem with the ITC. Had it been extended, more first-time solar players might have entered the market.

3. Sections 1703 and 1705 Loan Guarantee Programs

EPAct created another major subsidy, the DOE Loan Guarantee Program (LGP).[90] The LGP contained Section 1703—a permanent subsidy—that guarantees any outstanding balance on a qualifying initiative that limits air pollutants and employs new or significantly improved noncommercial technologies.[91] This program was seen mainly as an incentive for nuclear energy, as Section 1703 was intended for large-scale, highly capital-intensive, noncommercial projects.[92] To date, Section 1703 has only committed funds to two projects.[93]

For solar, the LGP only started to have an effect once ARRA added the temporary Section 1705 program.[94] The temporary Section 1705 LGP was created to aid "rapid deployment of renewable energy" projects, specifically for solar manufacturing and solar generation.[95] Notably, Section 1705 applied to projects using commercial technologies, unlike Section 1703.[96] Just like the temporary Section 1603 was a fix for smaller projects missing out on the ITC, the temporary Section 1705 LGP was meant to assist startups developing commercial technologies that lost access to capital markets still reeling from the financial crisis.[97]

On the whole, Section 1705 was a tremendously successful subsidy for solar.[98] This program invested $4 billion, and finished by allowing DOE to close almost $38 billion in loan guarantees for many clean energy programs.[99] Of these, $12 billion in loans were guaranteed for 12 utility-scale solar projects adding 3,500 megawatts (MW) of solar capacity.[100]

Unfortunately, Section 1705 was hit with a massive scandal that tainted the image of LGPs as a whole—Solyndra. Solyndra was a solar panel company, specializing in cylindrical tube technology, that received a $535-million loan guarantee under Section 1705.[101] However, just two years after the guarantee, Solyndra went bankrupt due to a 40% drop in traditional PV panel prices that made them uncompetitive in the market.[102] In that time, China had created their own subsidies for solar that accelerated their panel manufacturing and drove down overall costs of solar.[103] Solyndra's bankruptcy made them default on their Section 1705 loan, so the United States had to pay back all $535 million. The significant loss of money politically charged the entire program by giving critics of ARRA and its climate policies a real problem to discuss.[104]

While there was fighting over a potentially accelerated review process (though it had been in review since the George W. Bush Administration), the underlying issue was Section 1705's disruption of the startup process.[105] Section 1703 was for large-scale, capital-intensive, noncommercial projects, which typically limited its use to massive energy generation facilities like nuclear power plants.[106] Section 1705, on the other hand, was intended for smaller solar projects but encouraged the kind of loan guarantees that large energy facilities would get, unnaturally accelerating immature companies.[107] Guaranteeing a large amount of money to a massive generation facility with sophisticated players is much less risky than guaranteeing a large amount of money to immature startups, regardless of any due diligence a government runs. Section 1705's flaw, then, was exposing the taxpayer to the typical risks involved in a startup—like being undercut by China.

85. Daniel K. Tracey, *The Missing Lending Link: Why a Federal Loan Guarantee Program Is Critical to the Continued Growth of the Solar Power Industry*, 16 N.C. Banking Inst. 349, 356 (2012).
86. *See* Lawrence Berkeley National Laboratory, *supra* note 66.
87. *See* Pete Danko, *1603: A Big Renewable Energy Subsidy, Yes; Just Don't Call It a Bailout*, Breaking Energy (Dec. 23, 2014), https://breakingenergy.com/2014/12/23/1603-a-big-renewable-energy-subsidy-yes-just-dont-call-it-a-bailout/.
88. Ufuk Akcigit & William R. Kerr, *Growth Through Heterogeneous Innovations*, 126 J. Pol. Econ. 1374, 1377 (2018); *see also* Shai Bernstein, *Does Going Public Affect Innovation?*, 70 J. Fin. 1365, 1397 (2015) ("This section offers suggestive evidence that agency problems between management and shareholders . . . lead publicly traded firms to pursue lower quality innovation").
89. Bernstein, *supra* note 88, at 1379.
90. Simmons, *supra* note 1, at 435.
91. *Id.* at 435-36.
92. Mulvaney, *supra* note 84, at 51-52.
93. Phillip Brown, Congressional Research Service, IN11984, Inflation Reduction Act of 2022 (IRA): Department of Energy Loan Guarantee Programs (2022), https://crsreports.congress.gov/product/pdf/IN/IN11984.
94. Mulvaney, *supra* note 84, at 52. Section 1705 was temporary, expiring in 2011.
95. Tracey, *supra* note 85, at 364.
96. *Id.*
97. Mulvaney, *supra* note 84, at 52.
98. *See* Christina Jovanovic, *Precious and Few: Solving Renewable Energy's Critical Minerals Problem*, 9 LSU J. Energy L. & Res. 21, 50 (2021).
99. *Id.*
100. Tracey, *supra* note 85, at 364; *see* Fraas, *supra* note 45.
101. *See* Tracey, *supra* note 85, at 366; D'Angelo Gore, *Obama's Solyndra Problem*, FactCheck.org (Oct. 7, 2011), https://www.factcheck.org/2011/10/obamas-solyndra-problem/.
102. Tracey, *supra* note 85, at 366.
103. *See* Gerarden, *supra* note 47, at 7; *Jeffrey Ball: China's Solar-Panel Boom and Bust*, Stan. Bus. (June 7, 2013), https://www.gsb.stanford.edu/insights/jeffrey-ball-chinas-solar-panel-boom-bust.
104. *See* Tracey, *supra* note 85, at 366.
105. *See id.* at 367-68.
106. *See id.* at 363-64; *see also* Mulvaney, *supra* note 84, at 51-52.
107. *See* Tracey, *supra* note 85, at 367-68.

4. Advanced Research Projects Agency-Energy and SunShot

In 2007, the America COMPETES Act was signed into law, establishing the Advanced Research Projects Agency-Energy (ARPA-E) within DOE.[108] ARPA-E was modeled after the Defense Advanced Research Projects Agency (DARPA), and focuses on funding energy technologies that are too new for private investment.[109] Before ARPA-E, private investment attempted to enter the clean technology space and failed.[110] Returns from the projects were too low for the average venture capital (VC) firm because of the longer development cycles, the high capital needs of energy innovation, and the incumbent fossil fuel competition.[111] ARPA-E's goal was to fill this gap for emerging energy technologies.[112] However, the America COMPETES Act did not create the ARPA-E as it is known today; it first needed $400 million in funding from ARRA to come to life.[113]

Today, ARPA-E provides research and development (R&D) funding for "future energy technologies" like new materials for solar energy.[114] ARPA-E selects investment areas by finding alignments between the science and technology, the market, and the regulatory landscapes of a field that "enable transformative, breakthrough discoveries" that have market-scalable potential.[115] The areas selected become official programs like Solar ADEPT—a program that supports solar projects that improve solar performance.[116] Periodically, ARPA-E will issue funding opportunity announcements, which solicit project proposals from energy technology players.[117]

After proposals are collected, specific projects are selected based on "their compatibility with ARPA-E's mission, the novelty of their approach to energy innovation, and the extent to which they meet technical needs currently underserved" by DOE or the private sector.[118] Once a project is accepted, ARPA-E provides both funding and hands-on guidance for project teams with things like company formation, patents and publications, follow-on private investment, strategic partnerships, and other public funding opportunities.[119] These measures help ARPA-E reach its goal of enabling transformative energy innovation by positioning energy ventures to engage in subsequent development once ARPA-E funding finishes.[120]

One effective ARPA-E program was the SunShot Initiative.[121] SunShot's original goal was to make solar fully cost-competitive in the energy industry by 2020.[122] Solar was cost-competitive by 2017.[123] SunShot succeeded so quickly, in part by the price drops due to Chinese manufacturing in the early 2010s mentioned above, but also by funding R&D efforts around new approaches to decreasing the cost of solar systems.[124]

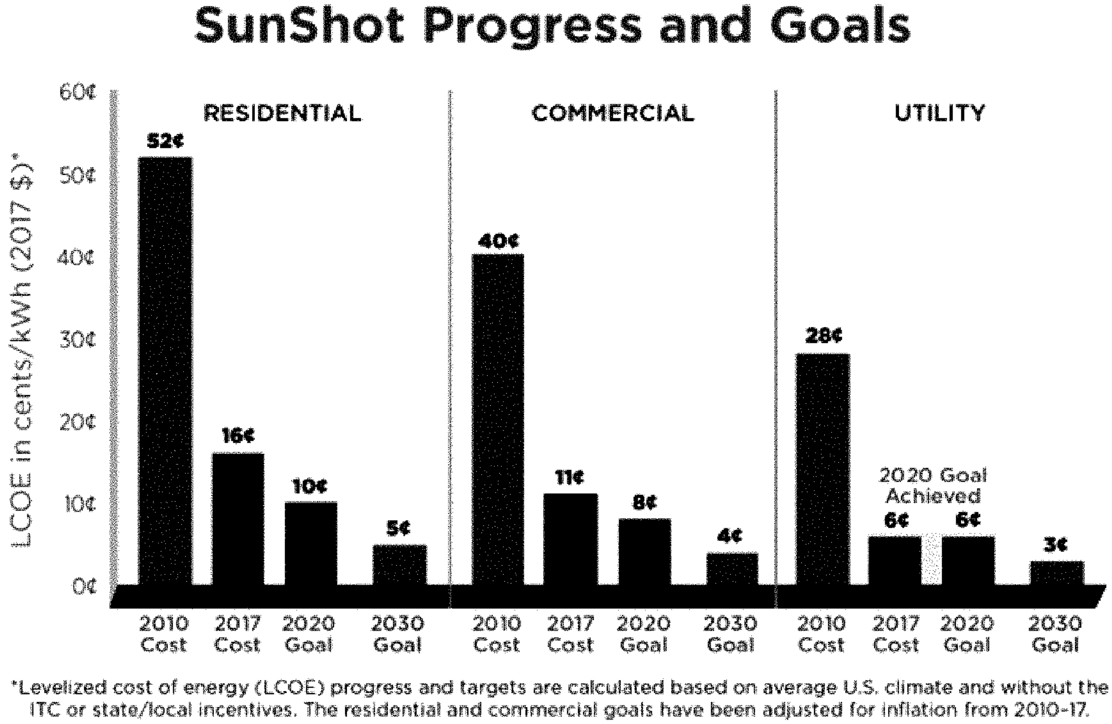
For these efforts, measurable goals were set for increasing efficiency, shortening commercialization time, investing in education to remove solar deployment barriers, developing cost-effective solutions to integrate solar with the national grid, and many other targeted goals.[125] An example of SunShot innovation is Gridmates—an energy-sharing resource that created a technology to help distribute excess solar energy in the grid.[126] Overall, SunShot has been an incredibly effective piece of ARPA-E in terms of generating long-term technological progress throughout the solar industry, as shown in Figure 2 (next page).

SunShot, though, is only one part of DOE and ARPA-E. ARPA-E itself has multiple other programs that help early-stage solar projects ranging from semiconductor improvements to grid interconnectivity. Projects that receive ARPA-E's funding and development support have been shown to benefit, as compared to non-ARPA-E projects, from more innovation and short-term business prospect advantages.[127]

ARPA-E is not without its flaws or criticism. It has been shown to bring near-term advantages to energy technologies, but has not led to better long-term business outcomes when comparing ARPA-E funded energy technologies to energy technology startups that did not use ARPA-E funds.[128] Further, there has been criticism of how little ARPA-E funding was granted and how slowly the funding was dispersed.[129] All told, the agency received 3,700 entries to begin with, but through limited funding and slow staffing, only 121 projects ended up receiving money.[130] This disparity likely left many qualifying and promising projects without government support.[131]

108. ARPA-E, DOE, The Advanced Research Projects Agency-Energy Overview, https://arpa-e.energy.gov/sites/default/files/ARPA-E%20Fact%20Sheet.pdf.
109. DOE, *Advanced Research Projects Agency-Energy (ARPA-E)*, https://www.energy.gov/science-innovation/innovation/arpa-e (last visited May 15, 2023).
110. *See* Anna Goldstein et al., *Patenting and Business Outcomes for Cleantech Startups Funded by the Advanced Research Projects Agency-Energy*, 5 Nature Energy 803, 804 (2020).
111. *Id.*
112. *See* ARPA-E, DOE, *supra* note 108.
113. *Id.*; *see* Aaron Tucker, *Government Intervention in Clean Energy Technology During the Recession*, 42 Tex. Env't L.J. 347, 361-62 (2012).
114. *See* ARPA-E, DOE, *supra* note 108.
115. DOE, ARPA-E FY14 Budget Request AR-11 (2014), https://arpa-e.energy.gov/sites/default/files/ARPA-E%20FY14%20Budget%20Request.pdf.
116. DOE ARPA-E, *Solar ADEPT*, https://arpa-e.energy.gov/technologies/programs/solar-adept (last visited May 15, 2023).
117. DOE ARPA-E, *General Questions*, https://arpa-e.energy.gov/faqs/general-questions (last visited May 15, 2023).
118. DOE, *supra* note 115, at AR-11.
119. *See* ARPA-E, DOE, *supra* note 108.
120. *Id.*
121. *Id.*
122. DOE, The SunShot Initiative: Making Solar Energy Affordable for All Americans (2016), https://www.energy.gov/sites/prod/files/2016/06/f32/SunShot-factsheet-6-10_final-508.pdf.
123. DOE Office of Energy Efficiency and Renewable Energy, *SunShot 2030*, https://www.energy.gov/eere/solar/sunshot-2030 (last visited May 15, 2023).
124. *See* DOE, *supra* note 122.
125. *Id.*
126. *See* Ashley Wichman, *An Innovation Framework That Delivers: The SunShot Catalyst Program*, Digital.gov (Aug. 7, 2015), https://digital.gov/2015/08/07/an-innovation-framework-that-delivers-the-sunshot-catalyst-program/.
127. *See* Goldstein et al., *supra* note 110, at 807-08.
128. Anna Goldstein et al., *Startups Supported by ARPA-E Were More Innovative Than Others but an Investment Gap May Remain*, 5 Nature Energy 741 (2020).
129. *See* Tucker, *supra* note 113, at 368.
130. *Id.* at 370.
131. *Id.*

Figure 2. SunShot Generates Long-Term Progress



Source: DOE Office of Energy Efficiency and Renewable Energy, *SunShot 2030*, https://www.energy.gov/eere/solar/sunshot-2030 (last visited May 15, 2023).

Finally, government programs like ARPA-E require governments to make a decision about what technology to fund. This is great for the chosen technologies, but risks inefficiencies in addressing climate change by potentially disregarding a necessary technology that does not meet ARPA-E's desired characteristics.[132]

5. From ARRA to IRA

After ARRA, no more major federal statutes promoted solar until the IRA. A few smaller statutes preserved the ITC, most of which kept it as a 30% tax credit.[133] Also, some states have solar subsidy programs of their own.[134] But federally, solar energy has mostly been left to rely on the ITC and ARPA-E to support its long-term development.

C. *Lessons Learned From Solar Subsidies for Sustained Technological Progress*

The first, and broadest, lesson to learn from past solar subsidies is that the United States has a concerning tendency to wait until a crisis hits to act, for example waiting until the 1970s oil crisis to directly fund solar energy. The trend was shown more clearly with EPAct, since it was in part a reaction to oil uncertainty after the invasion of Iraq.[135] Instead, the government must become more proactive by funding energy technologies that can help avoid future crises spurred by energy dependence and climate change. Bills like the IRA and programs like ARPA-E and SunShot are promising steps in this direction.

The second lesson from past solar subsidies is that targeting a technology with subsidies is critical for fast, sustained advancement. Without subsidies, solar likely could not have established itself as a viable alternative energy as quickly as it has over the past 15 years.[136] Based on studies done by the Solar Energy Industries Association and the Energy Information Administration, by the passage of ARRA, solar capacity had tripled by 2010 compared with 2008 capacity, and was growing at twice the rate it would have without a stimulus.[137] Further, the success of SunShot and ARPA-E show that targeting a technology and setting specific goals can lead to significant and measurable improvements in the technology of interest—like decreasing the overall cost to produce solar energy,

132. *See* Lucas, *supra* note 20, at 123.
133. *See* Sherlock, *supra* note 64.
134. *See* Sunrun, *Solar Incentives by State*, https://www.sunrun.com/solar-lease/cost-of-solar/state-rebates (last visited May 15, 2023).

135. *See* Ballotpedia, *Energy Policy Act of 2005*, https://ballotpedia.org/Energy_Policy_Act_of_2005 (last visited May 15, 2023).
136. *See* Gerarden, *supra* note 47, at 2-3. This is one study on the effect, but there is room for much more research into the exact effect of subsidies on solar energy, particularly around the individual subsidies mentioned above.
137. Aldy, *supra* note 77, at 14; *see also* Energy Information Administration, An Updated Annual Energy Outlook 2009 Reference Case Reflecting Provisions of the American Recovery and Reinvestment Act and Recent Changes in the Economic Outlook (2009), https://www.nrc.gov/docs/ML1020/ML102030440.pdf; Solar Energy Industries Association, *U.S. Solar Market Insight Q1 2011*, https://www.seia.org/research-resources/us-solar-market-insight-q1-2011 (last visited May 15, 2023).

amplifying innovation, and achieving better short-term business prospects.

The third lesson is that sustained subsidy support is necessary to achieve long-term technological progress in a clean energy technology. While solar had made progress throughout the 20th century, it was not until the first push by the federal government in the 1970s that it really took off. Still, the brief incentives in the 1970s were not enough to make solar competitive, especially after those incentives were quickly cut by the Reagan Administration. To start its replacement of fossil fuels, solar needed dedicated incentives.

The ITC has been the dedicated incentive for solar and was critical in overcoming its cost barriers.[138] Its success is a clear example of how a long-term subsidy can support long-term technological progress within a climate technology.[139] But the ITC's many benefits have been limited by its inconsistency and its scope. With the long development cycles and the high capital costs of solar projects, investors need consistency with solar subsidies to confidently invest.[140] Thus, the constant uncertainty around ITC renewal has been a huge drawback.[141]

The fourth lesson is that grants have proven better than tax credits at developing a technology. This lesson stems directly from the implications of the ITC's limited application. As a tax credit, the ITC is only available to those with sizable tax liabilities. This restricts small innovators from the solar industry by forcing them to contract with larger firms, which creates unnecessary transaction costs.[142] As small firms have higher major invention rates, a subsidy plan that ignores their needs is an inadequate incentive for innovation.[143] Instead, the ITC encourages consumers to invest in solar. Therefore, the ITC's defining value is as an incentive for commercialization of a necessary product.

In contrast, Section 1603 temporarily fixed the ITC's limited scope by giving a grant option. Under Section 1603, 2,000 different clean energy companies—particularly small-scale developers—were able to receive government funding regardless of the size of their tax liability.[144] Thus, Section 1603 was more effective for incentivizing innovation and small-scale applications.[145] Had Section 1603 operated for a longer term, it would have been incredibly useful for small-scale innovation outside of an ARPA-E program and would have continued to benefit ARPA-E projects once they graduated.

The final lesson is that coupling early-stage technology grants with support beyond funding is critical. This lesson underpins a concern with LGPs like Section 1705. Section 1705 was targeted for solar and was largely beneficial. But when trying to address the high capital risks for startups, it exposed the systems to far more risk than was politically sustainable. So while it largely paid off, it was significantly damaged by the failed Solyndra bet. Fundamentally, LGPs are not fit to replace a VC firm or a program like ARPA-E, because a security blanket loan guarantee does not bring the critical coaching necessary for innovation. Thus, LGP subsidies only fit into generating long-term progress for solar by securing its use in large-scale generation projects that have more sophisticated players and operate under less risky conditions.

Programs like ARPA-E and SunShot, on the other hand, that merge funding with other resources, seem to be incredibly effective. SunShot's dedicated goals allowed it to push the solar industry exactly where they wanted it to be. R&D funding like this at the small-scale level drives innovation because it fills the gap between climate technology needs and private investor business models. This then sets the technology up for longevity.

The primary issue, though, is that dedicated R&D funding must be placed somewhere instead of being a blanket incentive on the solar industry. Thus, if the government picks the wrong parts of the technology to incentivize, the technology may not reach its potential as quickly as possible or may fall out of favor due to a false assumption of failure. But when a clear technology area is identified as necessary, such as solar, R&D funding programs like ARPA-E and SunShot are effective ways to stimulate the industry.

III. Direct Air Capture

DAC is a type of carbon capture, utilization, and sequestration (CCUS) technology.[146] These technologies suck CO_2 out of the air, making them a potential pathway to achieving net-zero GHG emissions.[147] Historically, though, carbon capture technologies have been controversial in climate action circles.[148] The major concern is that improving these technologies will only encourage fossil fuel producers to continue burning fossil fuels and use carbon capture to greenwash their actions.[149]

This concern is understandable; however, a comprehensive reaction to climate change must include technologies like DAC. To just keep warming below 2 degrees Celsius (°C) by the end of the century, studies have shown that the world needs massive decarbonization or the extensive

138. Wilson, *supra* note 50, at 341.
139. *See* Solar Energy Industries Association, *Solar Investment Tax Credit (ITC) 101*, https://www.seia.org/research-resources/solar-investment-tax-credit-itc-101 (last visited May 15, 2023).
140. Blake Harrison, *Expanding the Renewable Energy Industry Through Tax Subsidies Using the Structure and Rationale of Traditional Energy Tax Subsidies*, 48 U. Mich. J. L. Reform 845, 864-65 (2015).
141. *See id.*
142. *See* Aldy, *supra* note 77, at 22.
143. Akcigit & Kerr, *supra* note 88, at 1377; *see also* Bernstein, *supra* note 88, at 1397.
144. *See* Mulvaney, *supra* note 84, at 53.
145. *See* Aldy, *supra* note 77, at 17-18.
146. *See* Malin Edvardsson, *CCS, BECCS, and DAC—What Is the Difference?*, Biolin Sci. (Mar. 10, 2020), https://www.biolinscientific.com/blog/what-is-the-difference-between-ccs-beccs-and-dac (also called negative emission technologies (NETs)).
147. *Id.*
148. *See Carbon Capture and Storage: An Expensive and Dangerous Plan for Louisiana*, Ctr. for Int'l Env't L. (June 25, 2021), https://www.ciel.org/carbon-capture-and-storage-an-expensive-and-dangerous-proposition-for-louisiana-communities/.
149. *Id.*

use of carbon-removal technologies.[150] Further, the studies have shown that limiting warming to 1.5°C is now virtually impossible without carbon removal.[151]

Just as important is the perspective of developing nations. It is not fair to withhold the benefits of industrialization and economic progress from developing nations now that rich countries are concerned with climate change. What needs to be funded and developed are technologies for adaptation that allow these nations to improve the lives of their people while balancing the emissions that are usually a byproduct.[152] Carbon capture technologies like DAC can help compensate for emissions that cannot be avoided based on current technologies.

To meet the 1.5°C mark by the end of the century, the Intergovernmental Panel on Climate Change reports show that the world will need 17 gigatons (billions of tons) of CO_2 removal per year.[153] By 2050, the world needs to be removing about 10 gigatons of CO_2 per year.[154] Currently, the world's capacity for CO_2 removal is around 0.045 gigaton.[155]

A. DAC Background

Generally, CCUS consists of two different technologies: carbon capture and sequestration (CCS, also called point capture) and DAC. CCS has been an idea since 1938, with the first project starting in 1972 and a few more beginning since.[156] CCS is implemented at the emission point of a power plant or industrial facility—the flue.[157] CCS takes in the emitted gases, separates out the CO_2, and then compresses it into a liquid for transportation and storage.[158] This method can capture up to 90% of the CO_2 released in the process of burning fossil fuels at a power plant.[159]

DAC, as an idea for fighting climate change, first emerged in 1999.[160] DAC is a form of carbon capture that can operate separately from a power plant or other emitter. Instead of only working in a flue of a power plant like CCS, DAC in theory can capture CO_2 directly from the atmosphere anywhere on earth and then undergo the same compression into liquid CO_2 as CCS.[161] The ability to operate anywhere on earth allows DAC to remove itself from some of the concerns around encouraging the continued use of fossil fuels. With CCS, a polluter can try to justify emissions by pointing to the reduction in what is emitted from their plant. A polluter can attempt the same justification with DAC, but it would only be relevant from a broader perspective, and would ignore the immediate impact of pollution in the nearby communities.

Once a DAC or CCS device captures and compresses the CO_2, the capturing facility must find a use for it. Today, to meet our climate needs, the liquified CO_2 needs to be sequestered.[162] There are many sequestration ideas out there—biological options like reforestation, geological options like injecting CO_2 into porous rock underground, carbon mineralization techniques like calcification, and so on.[163] Unfortunately, the original funding and development of carbon capture was largely driven by oil companies using the liquefied CO_2 for enhanced oil recovery (EOR).[164] With EOR, oil drillers shoot gases like CO_2 into an oil reservoir to push out additional oil.[165] This remains one of the few viable markets for the liquid CO_2 output of carbon capture technologies.[166]

Today, DAC only has three major developers: Carbon Engineering in Canada, Climeworks in Switzerland, and Global Thermostat in the United States.[167] Worldwide, as of 2019, there were only 15 operational DAC facilities.[168] The largest DAC facility currently in operation, run by Climeworks in Iceland and named "Orca," can capture up to 4,000 tons of CO_2 per year.[169] Collectively, the operational DAC facilities are only capable of capturing around 8,000 tons of CO_2 per year.[170] While there are more DAC projects on the way, including a one-megaton facility in the United States, DAC is still almost nonexistent compared to 10 gigatons of CO_2 removal per year that the world needs by 2050.[171]

---

150. *See* Jonas Meckling & Eric Biber, *A Policy Roadmap for Negative Emissions Using Direct Air Capture*, 12 Nature Commc'ns art. 2051, at 1 (2021).
151. *Id.*
152. *See* Bill Gates, How to Avoid a Climate Disaster 165 (2021).
153. Jon Gertner, *The Dream of Carbon Air Capture Edges Toward Reality*, Yale Env't 360 (Aug. 25, 2021), https://e360.yale.edu/features/the-dream-of-co2-air-capture-edges-toward-reality.
154. *See* Gates, *supra* note 152, at 95.
155. International Energy Agency, *Carbon Capture, Utilisation, and Storage*, https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage (last visited May 15, 2023).
156. Anuradha Varanasi, *You Asked: Does Carbon Capture Technology Actually Work?*, Colum. Climate Sch.: State Planet (Sept. 27, 2019), https://news.climate.columbia.edu/2019/09/27/carbon-capture-technology/.
157. Edvardsson, *supra* note 146.
158. *Id.*
159. *What Is Carbon Capture, Usage, and Storage (CCUS) and What Role Can It Play in Tackling Climate Change?*, London Sch. Econ. & Pol. Sci. (Mar. 13, 2023), https://www.lse.ac.uk/granthaminstitute/explainers/what-is-carbon-capture-and-storage-and-what-role-can-it-play-in-tackling-climate-change/.
160. Geoffrey Ozin, *Direct Air Capture: A Little History*, Advanced Sci. News (Sept. 7, 2022), https://www.advancedsciencenews.com/direct-air-capture-a-little-history/.
161. *Id.*
162. *See* Noelle Eckley Selin, *Carbon Sequestration*, Britannica (Apr. 21, 2023), https://www.britannica.com/technology/carbon-sequestration.
163. *See generally* National Academies of Sciences, Engineering, and Medicine, Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (2019), https://doi.org/10.17226/25259.
164. *Id.*
165. *See* DOE Office of Fossil Energy and Carbon Management, *Enhanced Oil Recovery*, https://www.energy.gov/fecm/enhanced-oil-recovery (last visited May 15, 2023).
166. *See* Meckling & Biber, *supra* note 150, at 2.
167. Noah McQueen et al., *A Review of Direct Air Capture (DAC): Scaling Up Commercial Technologies and Innovating for the Future*, Progress Energy, Apr. 16, 2021, at 2.
168. *Id.*
169. *See* Jameson Dow, *World's Largest Direct Air Carbon Capture Facility Will Reduce CO_2 by .0001%*, Electrek (June 28, 2022), https://electrek.co/2022/06/28/worlds-largest-direct-air-carbon-capture-facility-will-reduce-co2-by-0001/.
170. *See* Katie Lebling et al., *6 Things to Know About Direct Air Capture*, World Res. Inst. (May 2, 2022), https://www.wri.org/insights/direct-air-capture-resource-considerations-and-costs-carbon-removal.
171. Sara Budinis, International Energy Agency, Direct Air Capture: Technology Deep Dive (2022), https://www.iea.org/reports/direct-air-capture.

B. DAC Challenges

Both DAC and CCS are still relatively underdeveloped technologies—comparable to solar when it was just a NASA interest—but CCS is much farther along. CCS devices that operate in a flue take in gas with a 10%-15% CO_2 concentration.[172] DAC, however, deals with ambient air and thus takes in a gas with only a 0.041% concentration of CO_2.[173] This makes DAC much more technologically challenging and more expensive.[174]

Today, DAC costs anywhere from $100/ton of CO_2 captured to $1,000/ton,[175] as compared to CCS, which typically costs less than $100/ton, varying based on the concentration of CO_2 in the flue.[176] Further, DAC struggles to recoup costs because its output lacks monetization and utility. Unlike solar, which produces usable energy, DAC produces liquid CO_2, which instead of being used for economic gain (like EOR) must be sequestered. Thus, DAC facilities cannot make money from their operations as easily as a solar project (built to provide energy—a commodity with a huge market) to recoup their initial investments or turn a profit.

DAC also has energy and infrastructure limitations. It is an energy-intensive process, so minimizing its energy use will be a critical improvement to lessen the burden on the renewable sources needed in the energy transition.[177] Its energy needs also act as an infrastructure limitation because DAC must be connected to a nearby significant energy source. Further, DAC plants either need adequate infrastructure to transport the captured CO_2 to a storage site or they must be placed at a proper site for immediate geological storage.[178] Finally, some DAC methods require large water sources and must be placed accordingly. Even with these limitations, though, locations for DAC are less restricted than for CCS because CCS is restricted to the flue of polluters.

These limitations show why DAC needs subsidies. DAC is currently too expensive because of its nascency and its infrastructure limitations, and options like a carbon tax cannot address this issue, as taxing an output does not encourage capturing it.[179] In reality, for DAC to be a viable technology, it needs a market and needs to cut costs quickly to produce liquid CO_2 desirable in markets outside of EOR.[180] This could be achieved through subsidies where the federal government effectively buys the liquid CO_2 and its sequestration and through subsidies that incentivize improvements in DAC technology.

172. Edvardsson, *supra* note 146.
173. *Id.*
174. *Id.*
175. Sara Budinis et al., International Energy Agency, Direct Air Capture: A Key Technology for Net Zero 27 (2022).
176. *See* Adam Baylin-Stern & Niels Berghout, *Is Carbon Capture Too Expensive?*, Int'l Energy Agency (Feb. 17, 2021), https://www.iea.org/commentaries/is-carbon-capture-too-expensive.
177. Ozin, *supra* note 160.
178. *See* Meckling & Biber, *supra* note 150, at 1-2.
179. *See* Justin Gundlach, *To Negotiate a Carbon Tax: A Rough Map of Interactions, Tradeoffs, and Risks*, 43 Colum. J. Env't L. 269, 320 (2018).
180. *See* Meckling & Biber, *supra* note 150, at 2.

C. DAC Subsidies Before the IRA

The underdevelopment, infrastructure, and cost challenges of DAC are exactly what subsidies are supposed to address. A few subsidy programs for DAC existed even before the passage of the IRA. The primary subsidy for DAC is the Section 45Q tax credit, the carbon capture corollary to the ITC (or wind power's production tax credit), which grants tax relief to entities that capture and sequester CO_2. It was added to the tax code in 2008, largely to encourage more responsible uses of coal.[181] Originally, it credited geologically sequestered carbon at around $23 per Mt of CO_2 and credited sequestered carbon used for EOR at around $11/Mt.[182] This credit was only available until 75 million tons had been captured at a facility that sequestered at least 500,000 Mt a year.[183] The provision did not distinguish between the types of carbon capture.[184]

In 2018, the Bipartisan Budget Act enhanced the 45Q credit. For equipment placed in service after the bill, credits for geological sequestration are $31/Mt (increasing to $50 by 2026) and any other qualified uses of CO_2 are $20.22/Mt (increasing to $35 by 2026).[185] The Act also removed the cap, opting for a 12-year period of credits for all facilities beginning construction before 2026.[186] Finally, the 45Q credits were opened up to DAC and other facilities that captured at least 100,000 Mt/year and limited the credits for power plants to those capturing at least 500,000 Mt/year.[187] Unlike the ITC, 45Q credits are transferable, but only to another entity that accomplishes the capture and sequestration.[188] This transferability measure opens up the option for a small entity to contract with a large company (with a sizable tax burden) to benefit from the 45Q credit.[189]

45Q had a few flaws, some similar in nature to the ITC. First, while it applies to any "qualified carbon oxide," it does not apply to all GHG emissions, ignoring the need to capture and sequester many other harmful pollutants like methane or nitrous oxide.[190] Second, it suffers from the same inaccessibility the ITC had for taxpayers with low or no tax liability.[191] Just like solar, carbon capture technologies typically have large upfront capital costs that dwarf initial revenues, so most new facilities cannot take advantage of the credit.[192] Thus, large entities (like oil and gas companies) get to leverage the 45Q credit directly or

181. Angela C. Jones & Molly Sherlock, Congressional Research Service, IF11455, The Tax Credit for Carbon Sequestration (Section 45Q) (2021), https://sgp.fas.org/crs/misc/IF11455.pdf.
182. *Id.*
183. *Id.*
184. *See The Inflation Reduction Act Includes Significant Benefits for the Carbon Capture Industry*, Gibson Dunn (Aug. 16, 2022), https://www.gibsondunn.com/the-inflation-reduction-act-includes-significant-benefits-for-the-carbon-capture-industry/.
185. Jones & Sherlock, *supra* note 181.
186. *Id.*
187. *Id.*
188. Ryan M. Gurule, *Captured: Regulating to 1.5C Through Tax and Escaping From Regressive Pitfalls*, 75 Tax Law. 233, 262 (2022).
189. *Id.* at 262-63.
190. *Id.* at 259.
191. *Id.* at 262.
192. *Id.* at 262-63.

through a smaller company, and a smaller company, like a DAC startup, must rely on finding big company contracts. Finally, 45Q's incentives, even with the Bipartisan Budget Act upgrade, were too small to ensure that carbon capture projects, and DAC, were viable at their cost.[193]

A few other subsidies were promulgated over the past few years. ARPA-E has begun to subsidize DAC through its MOSAIC project, which started working on improvements to the two most common methods for capturing CO_2 in a DAC system.[194] Further, starting in 2020, Congress has been appropriating money for DAC.[195] Through appropriation bills in 2020 and 2021, DAC research, development, and demonstration received $40 million of funding through DOE.[196]

More interesting is the "Carbon Negative Shot" (Carbon Shot), created in 2021 as the SunShot corollary for carbon capture.[197] The goal of Carbon Shot is to find pathways to capture and store CO_2 at gigaton scales for less than $100/Mt to "achieve a net-zero carbon economy" and help address the climate crisis by removing "legacy carbon pollution."[198] In addition to reducing cost, Carbon Shot will focus on three other goals: ensuring the sustainability of building carbon capture facilities, developing secure storage techniques that can be monitored and verified, and enabling gigaton-scale removal.[199]

D. DAC Subsidies From the IRA

The DAC portion of the IRA focused heavily on improving the Section 45Q tax incentive. Under the IRA, the credit for CCS technology is now $85/Mt for geologically sequestered CO_2 and $60/Mt for other sequestration applications.[200] However, the Act emphasizes DAC even more by upgrading the credit to $180/Mt for geologically sequestered CO_2 and $130/Mt for all other sequestration applications.[201] These credits will be inflation-adjusted, available for 12 years after the equipment is in service, and given to projects that begin construction before 2033.[202]

Further, under the IRA, DAC projects only need capacity for capturing 1,000 Mt/year as opposed to the 100,000 Mt/year required before.[203] Finally, the IRA expands the transferability of the 45Q credit by monetizing it, allowing a qualified owner to sell credits to third parties and in some circumstances to the U.S. Treasury.[204]

The IRA will also contribute funding to Carbon Shot, though it remains unclear exactly how much of the $99.6 billion for all CO_2 reduction programs will be allocated to it.[205] The IRA also dedicated $3.5 billion for DOE to establish four regional DAC hubs.[206] A hub is a "network of projects, potential CO_2 utilization off-takers, connective carbon dioxide transport infrastructure, subsurface resources, and sequestration infrastructure located within a region."[207] The locations for these hubs have not been announced, but each must facilitate the deployment of DAC projects, be able to capture and sequester 1,000,000 Mt of CO_2 per year, be able to demonstrate legitimate use, and be able to develop into a network to sequester or use carbon.[208]

Additionally, the IRA significantly invested in LGPs. The IRA increased Section 1703 lending authority from $21.9 billion to $40 billion.[209] As discussed above, Section 1703 can technically apply to carbon capture technology, but has only applied to two projects and is unlikely to apply to DAC projects because of their smaller size.[210] More interestingly, the IRA created a temporary Section 1706 program, which is similar to the Section 1705 program covered above, but not focused on assisting startups.[211]

The Section 1706 program is available through 2026, and provides $250 billion of lending authority for "energy infrastructure reinvestment financing."[212] To qualify, projects must "retool, repower, repurpose, or replace" unused energy infrastructure as long as renewed fossil fuel projects "avoid, reduce, utilize, or sequester" GHG emissions, or the projects must "enable operating energy infrastructure to avoid, reduce, utilize, or sequester" GHG emissions.[213]

Thus, some portion of this $250 billion LGP can apply to updating energy infrastructure with CCUS.[214] Since the

---

193. *Id.* at 258.
194. *See* DOE ARPA-E, *Mosaic Materials*, https://arpa-e.energy.gov/technologies/projects/integration-ultrahigh-capacity-sorbents-direct-air-capture-systems (last visited May 15, 2023).
195. *See* Eric Burns & Vanessa Suarez, *Everything You Need to Know About Federal Funding for Carbon Removal*, Carbon180 (Aug. 31, 2020), https://carbon180.medium.com/everything-you-need-to-know-about-federal-funding-for-carbon-removal-bb2548595b41.
196. *Id.*
197. *See* Geoffrey Ozin, *"Carbon Negative Earthshot" Takes Aim at Atmospheric Carbon Dioxide*, Advanced Sci. News (Nov. 23, 2021), https://www.advancedsciencenews.com/carbon-negative-earthshot-takes-aim-at-atmospheric-carbon-dioxide/.
198. DOE Office of Fossil Energy and Carbon Management, *Carbon Negative Shot*, https://www.energy.gov/fecm/carbon-negative-shot (last visited May 15, 2023).
199. DOE, Carbon Negative Shot—An Introduction (2022), https://www.energy.gov/sites/default/files/2022-07/Carbon-Negative-Shot-Fact-Sheet_7.5.22%20Updates.pdf.
200. *The Inflation Reduction Act Includes Significant Benefits for the Carbon Capture Industry*, *supra* note 184.
201. *Id.*
202. Clean Air Task Force, Carbon Capture Provisions in the Inflation Reduction Act of 2022, https://cdn.catf.us/wp-content/uploads/2022/08/19102026/carbon-capture-provisions-ira.pdf.
203. *The Inflation Reduction Act Includes Significant Benefits for the Carbon Capture Industry*, *supra* note 184.
204. *Id.*
205. *See* Herman K. Trabish, *DOE to Attack CO_2 Emissions With Billions in Funding From Inflation Reduction, Infrastructure Laws*, Util. Dive (Aug. 22, 2022), https://www.utilitydive.com/news/carbon-capture-doe-funding-45q-ccs-direct-air/629624/.
206. BCG, US Inflation Reduction Act: Climate & Energy Features and Potential Implications 14 (2022), https://media-publications.bcg.com/BCG-Executive-Perspectives-US-Inflation-Reduction-Act-16August2022.pdf.
207. Kristin Lee et al., *Department of Energy Announces Significant Investment in Direct Air Capture*, Brownstein (May 26, 2022), https://www.jdsupra.com/legalnews/department-of-energy-announces-3583842/.
208. DOE Office of Clean Energy Demonstrations, *Regional Direct Air Capture Hubs*, https://www.energy.gov/bil/four-regional-clean-direct-air-capture-hubs (last visited May 15, 2023).
209. Brown, *supra* note 93, at 3.
210. *Id.*
211. *Id.*
212. *Id.*
213. *Id.*
214. DOE Loan Programs Office, *Inflation Reduction Act of 2022*, https://www.energy.gov/lpo/inflation-reduction-act-2022 (last visited May 15, 2023).

Section 1706 program is focused on updating energy infrastructure, the majority of CCUS funding here is likely to be for CCS technologies that sequester CO_2 from polluting facilities. But the program is worded such that DAC may be able to find some support.

Congress also authorized funding of $1 billion for carbon removal research outside of the IRA with the CHIPS Act.[215] These funds would be available for three years starting in 2023 and largely support Carbon Shot's efforts.[216] The authorized funding still must be appropriated, so currently there is no information on how much of this will impact DAC.[217]

E. DAC Subsidy Lessons From Solar

The IRA laid excellent groundwork for DAC, but there are two main improvements that could be made to encourage innovation and to sustain technological progress in DAC technology. First, Section 45Q needs some measure, beyond monetization, to make sure that low tax liability projects are subsidized. Second, while the billions of dollars for general carbon capture projects are necessary, the IRA should have been passed alongside detailed goals for DAC under Carbon Shot and other ARPA-E projects. This detail is important because of how well federally funded R&D advances young technologies. After discussing these two improvements, the remainder of this Comment analyzes the IRA's hub and LGP provisions, largely concluding that the provisions are well-crafted.

Before directly addressing the lessons from solar, however, it is necessary to cover the expected impacts on DAC from the IRA. With the new Section 45Q credits helping reduce the effective cost of DAC, researchers believe that DAC is now investable.[218] Further, by 2030, the same researchers expect the cost of geologically stored DAC to be cut to only $20-$70/ton as compared to $400-$600/ton today.[219]

The "hubs" are expected to produce three benefits. First, is concentration of knowledge. DOE uses the same hub model to encourage interaction between scientists that worked for many innovation projects, including the Manhattan Project (which produced the atomic bomb) and Bell Laboratories, which spawned the first semiconductor solar cell.[220]

Second, is shared infrastructure. CO_2 sources like DAC will need to be connected to geological sequestration sites (and inevitably some EOR sites) for effective sequestration.[221] Having regional hubs can help organize this infrastructure. Finally, organization like this can help develop the supply chain for sequestered CO_2 to mitigate the issues inherent in the lack of a large defined market for the sequestered CO_2.[222]

Finally, for the Carbon Shot funding, there are no clear expectations yet, other than the four stated goals above, with the primary goal of achieving capture and storage of CO_2 at gigaton scale for less than $100/Mt.[223] With the success of SunShot in its goal to drive cost of solar down through specific R&D funding, Carbon Shot will be expected to do the same.

The IRA programs are critical for DAC's success, but based on the solar industry's history with subsidies, there are clear ways the IRA could have been better. The first lessons to draw from past solar subsidies come from the ITC and its Section 1603 temporary fix. Like the ITC, Section 45Q is the main federal subsidy for carbon capture. But just like the ITC, Section 45Q is only valuable to those that owe taxes. Like solar, DAC projects require large initial inputs of capital, which means that many entities pursuing DAC facilities will not have a significant tax burden to use the 45Q credit.

The monetization of credits helps, but it still includes transaction costs (finding a buyer, completing the sale, etc.) that are not included in a grant option. Plus, these entities can only start using the monetized aspect once the facility starts capturing carbon. So, while monetizing tax credits is an improvement, it misses the real issue of getting DAC projects up and running.

The innovation DAC needs to become practical requires the significant innovation potential that small firms can bring. Thus, small players need to be supported, as they were under the Section 1603 temporary provision for solar. During the short Section 1603 era, more than 200 different clean energy companies took advantage of the cash grant, and it significantly contributed to small solar projects and first-time developers.

Section 45Q, then, should have an option like Section 1603 that encourages small, independent entities to get involved. Further, the option should at least extend until the DAC technology is commercially viable. For example, the provision could be written to keep an upfront grant option like Section 1603 until DAC technology has reached the goals of the Carbon Shot initiative ($100/Mt for capture).

Just like Section 1603 did for solar, an upfront grant option for DAC would drive small-scale innovation and increase the adoption of DAC technologies. This would help leverage small-scale innovation that tends to be more innovative.[224] Thus, a grant option like the example above could more effectively drive the innovation that DAC needs to become viable than the general tax grant of Section 45Q. Moreover, putting innovation into the hands of smaller players would help separate DAC from the large

215. *See The CHIPS and Science Act Doubles DOE Investment in Carbon Removal Research*, Carbon180 (Aug. 25, 2022), https://carbon180.medium.com/the-chips-and-science-act-doubles-doe-investment-in-carbon-removal-research-e9146015d62c.
216. *Id.*
217. *Id.*
218. BCG, *supra* note 206, at 17.
219. *Id.*
220. *See* Sam Wenger, *Let's Get Excited About DAC Hubs*, Bipartisan Pol'y Ctr. (Sept. 15, 2021), https://bipartisanpolicy.org/blog/dac-hubs/.
221. *See id.*
222. *See id.*
223. DOE Office of Fossil Energy and Carbon Management, *supra* note 198.
224. Akcigit & Kerr, *supra* note 88, at 1377; *see also* Bernstein, *supra* note 88, at 1397.

oil and gas players that may use it to continue their use of fossil fuels.

While the actual provisions of Section 45Q could be improved, it still will be incredibly valuable, just as the ITC was to solar. In that light, 45Q needs staying power. One of the major drawbacks of the ITC was the constant concern that it would not be renewed or that its terms may change. To drive long-term innovation and adoption for DAC, Section 45Q must be stable. The IRA does so by detailing that the Section 45Q credits will be available for 12 years after a project is in service, and that it will be available for any qualifying facility beginning construction before 2033.

These provisions provide much more certainty than the ITC historically had. Further, the 12-year timeline strikes a good balance, by giving carbon capture technologies time to develop while still allowing Congress to back out after that time if the technologies fail. However, even before the 12-year period lapses, the reliability of the IRA's tax credits can always be undone if the wrong players get into power.

The next lesson to learn from solar subsidies comes from ARPA-E and SunShot—that government-funded R&D works incredibly well to advance a fledgling technology. This is what DAC needs to overcome its technological barriers, to overcome its early VC funding barriers, and to establish itself as a legitimate carbon capture technology. Thus, one of the main problems with the IRA is that it only declared large sums of money for carbon capture R&D projects. Instead, it should have worked alongside DOE and Carbon Shot to detail specific project requirements, and intended funding, for DAC modeled after ARPA-E and SunShot.

Now that Carbon Shot has been launched and will get some (unclear) sum of money from the IRA, it should follow SunShot's model of success. Therefore, Carbon Shot needs more granularity, beyond the four broad goals, that focuses on measurable achievements.[225] The only measurable achievement already set is decreasing costs of capture to $100/Mt. But Carbon Shot needs goals that detail how it will get to a price of $100/Mt. These more specific goals can fall in line with the hub model, by working toward shorter commercialization time for DAC facilities and developing adequate infrastructure for CO_2 transportation and sequestration. But it should also aim to drive down the input costs to these systems like the solvent technologies needed to capture the CO_2.[226]

Further, for ensuring the sustainability of creating DAC facilities, Carbon Shot should set goals like maximum emission levels allowed to construct a facility, energy-efficiency minimums for the facility, and renewable energy quotas for powering the facility. Additionally, for securing the storage of CO_2, Carbon Shot should set goals for the effectiveness of sequestration sites like desired length of time a site can store CO_2 and maximum leakage allowances from the site. Finally, DAC also needs specifics around what federal R&D projects like those in ARPA-E will be developed that can act as an incubator for innovative technologies.

The hub model put forth by the IRA does not have a direct comparison to the subsidies studied above. However, its similarity to other projects, like the Manhattan Project and Bell Laboratories, is encouraging. Bell Labs created many critical inventions in the 20th century, including the semiconductor solar cell.[227] If these hubs can create innovation like that, then they will be worth it.

The final lesson from solar subsidies comes from the Sections 1703 and 1705 LGPs. As described above, the Section 1703 LGP (as created) is only well-suited to help massive industrial projects like nuclear. For this reason, even with the additional funding from the IRA, it is not likely to affect DAC outside of a hypothetical large-scale DAC system. Before that can even happen, DAC needs to develop its technology and then be commercialized. An LGP like Section 1705, which ushered billions of dollars into solar projects, is much more in line with developing DAC's technology and could have been incredibly helpful for DAC.

The Section 1706 program that the IRA added has potential to help DAC in this way, but it focuses exclusively on updating energy infrastructure, which likely limits its application to DAC. Section 1706's limitation to energy infrastructure is understandable, based on the severe criticism leveled against Section 1705 for exposing taxpayers to large losses by supporting solar startups. In addition, as noted, the Section 1705 program was best suited for funding projects on the utility scale with more sophisticated buyers. So while an explicit LGP for DAC could have a much stronger impact than the current Section 1706 program, the program likely strikes an acceptable balance: leaving room for funding DAC, but restricting the funding to less risky projects.

Lacking clear support from an LGP is likely not a huge concern for DAC anyway. While any loans or guarantees can help DAC projects, other subsidies like Carbon Shot funding or direct grants can help drive innovation and sustain technological progress more effectively. Plus, avoiding a clear LGP for DAC reduces the risk that an LGP will have a large loss, like Solyndra, that could reduce political support for subsidizing DAC in general.

In sum, the IRA laid excellent groundwork for DAC by improving the Section 45Q tax credit and appropriating funds for R&D projects. But there are still improvements that could be made to encourage innovation and to sustain technological progress in DAC technology. Primarily, Section 45Q should have some upfront grant measure to make sure that low tax liability projects are subsidized, thus leveraging a wider cast of innovators in the DAC field.

225. *See* DOE Office of Fossil Energy and Carbon Management, *supra* note 198 (The four goals: cost of carbon capture less than $100/Mt, ensuring the sustainability of building carbon capture facilities, developing secure storage techniques that can be monitored and verified, and enabling gigaton-scale removal.).

226. *See* David Kearns et al., Global CCS Institute, Technology Readiness and Costs of CCS 12 (2021), https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf.

227. *See* Kumar, *supra* note 39.

Secondarily, the billions of dollars for general carbon capture projects are necessary, but Congress should have worked directly with DOE to provide specific goals and funding levels for Carbon Shot and other ARPA-E DAC projects. Details around R&D goals and clarifying specific funding amounts is critical because of how well federally funded R&D can advance new technologies like DAC. Beyond these improvements, the IRA seemed to appropriately craft subsidies based on the lessons learned from the solar industry. The hub provisions seem promising given the success of Bell Labs for solar, and the lack of a clear LGP for DAC seems to balance the successes of the solar LGP with the concerns and controversies it created.

IV. Conclusion

By following a typical model for energy technologies—subsidizing with tax incentives and R&D—the IRA will greatly benefit DAC. Within the context of the solar industry's past subsidies, however, the federal incentives still have holes in terms of stimulating DAC's long-term technological progress.

Generally, the common subsidy focuses on tax incentives and R&D have worked for ages on technologies like gas and solar, and are likely to work for the technologies that the world needs going forward, like DAC. These incentives do have related, but distinct, impacts that are important to understand. Tax incentives, like the ITC and Section 45Q, are better equipped for commercializing a climate technology because they incentivize purchasing and operating the technologies. In contrast, R&D programs like ARPA-E and Carbon Shot are better suited to drive innovation within a climate technology, because they can be crafted to address specific problems in the technologies.

Thus, tax credits should be emphasized more for technologies that need commercialization—like solar today—and R&D funding should be emphasized more for technologies that need to develop—like DAC today. Finally, subsidies, while not the only option, are a critical method of market intervention that climate technologies will need going forward. Continually evaluating the successes and failures of these subsidies will be an important practice for effectively reaching climate goals.