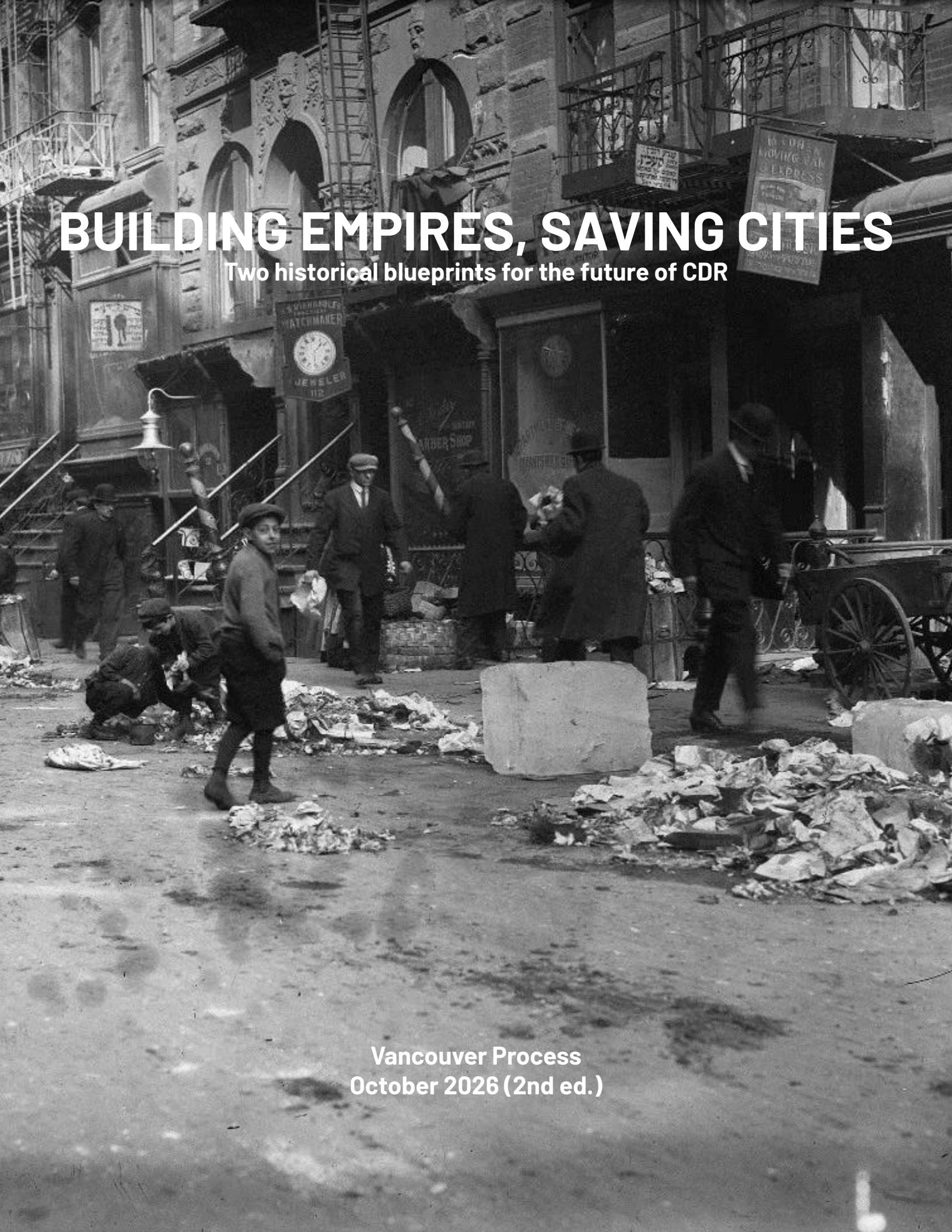

BUILDING EMPIRES, SAVING CITIES

Two historical blueprints for the future of CDR

Vancouver Process
October 2026 (2nd ed.)

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Front cover: ca. 1900 Lower East Side street scene from the New York City Department of Sanitation, glass negative no. 693, ca. 1900. Courtesy of the Municipal Archives, City of New York.

Back cover: The United States Well at Pithole, Pennsylvania, ca. 1870. Published by Frank Robbins. Library of Congress, Prints and Photographs Division, LC-DIG-stereo-1s01750.

Executive Summary

Calls for greater government involvement in carbon dioxide removal (CDR) usually resolve into a familiar list: fund more research, establish standards, create incentives, regulate markets, build infrastructure. All of these actions will be necessary. But history suggests scaling CDR to climate-relevant levels will also require something much larger: governments gradually building an entire social, financial, administrative and physical architecture around the undertaking, while accepting responsibility for an outcome that cannot safely be left to markets or individual action alone.

The histories of oil and waste management illustrate two different but complementary ways this can happen. Oil began as a valuable commercial product, driven largely by private entrepreneurship, but governments repeatedly helped create the conditions for expansion—building enabling infrastructure such as roads and ports, supporting research and strategic supply, shaping trade and investment conditions, and helping close virtuous cycles in which larger markets justified better infrastructure and better infrastructure enlarged markets further. None of this is to suggest that CDR should retrace oil's history, which also brought profound environmental damage, geopolitical conflict and social disruption. The broader lesson is that sustained government-market cooperation can transform an emerging technology into a civilization-scale system. CDR can learn from that achievement while proceeding with the safeguards, scrutiny and due diligence needed to avoid repeating oil's mistakes.

Waste management followed a different path. As cities grew, societies eventually stopped treating waste as a problem individuals and markets could be expected to solve on their own. Governments accepted civic responsibility for the outcome and built the financing systems, infrastructure, public authorities, regulations and administrative capacity needed to make reliable sanitation possible. Private enterprise remained essential, but commercial demand no longer determined whether the underlying problem would be addressed. Society decided that it had to be.

CDR will likely need both models. Governments can aggressively nurture technologies, markets and commercial uses for captured carbon, creating virtuous cycles that attract investment, reduce costs and allow private industry to shoulder as much of the task as possible. At the same time, governments must be prepared to ensure that necessary carbon removal occurs even where no self-sustaining market emerges. Doing this at enormous scale will require much more than good CDR policy. New financing mechanisms, institutions, legal authorities, coordinating bodies, liability systems, infrastructure, permitting processes, public engagement and other forms of administrative capacity will have to develop alongside the technologies themselves.

None of this will emerge from a single master plan. Oil and waste management developed iteratively over generations as experience revealed new possibilities, new problems and new institutional needs. CDR will have to undergo much the same process, but on a radically compressed timetable. Governments will need to learn quickly, tolerate some dead ends, share lessons across jurisdictions, and overcome political and perceptual barriers that make climate action especially difficult. The objective is not to prescribe a single global CDR system, but to begin building the capacity for societies to discover what works.

The central lesson from history, then, is not that government or markets should lead CDR. We will need both, working together at a depth and scale that today's CDR landscape only begins to approximate. Governments can accept responsibility for solving the carbon dioxide problem while simultaneously mobilizing markets, capital, technology and industry to help solve it. We cannot yet know exactly what institutional system will result. But if CDR is to reach climate-relevant scale within the next few decades, the process of building that system needs to begin now.

BUILDING EMPIRES, SAVING CITIES

Two historical blueprints for the future of CDR

Climate policymakers are increasingly aware that governments need to become more involved in carbon dioxide removal.[1] But what does this mean?

Our typical answers—so they can fund more research, develop better standards, promote international cooperation, and build infrastructure—are valid, but these only catalog the tools governments use to effect change. What's missing is a deeper appreciation of the change itself—the transformations that can occur to both governments and societies when governments decide a particular outcome is worth achieving.

There are many examples from history that illustrate how this happens. We will look at two in this essay. The first is oil, where private industry created an immensely valuable product while governments built the physical, financial, institutional and political environment around it. The second is how massive government involvement in waste management became accepted and expected over time because individual and market actions alone could no longer protect society from the consequences of inaction.

These two examples are intentionally different—one market-oriented, the other market failure oriented. The future of CDR will likely involve both approaches.

CASE STUDY 1: OIL

Humans have used oil for thousands of years. Around the world, oil was mopped up from surface pools, dug from shallow wells, traded locally, and used for lubrication, waterproofing, lighting, even medicines. But until the mid-1800s, we weren't extracting it from the ground in huge quantities, or refining and distributing it on a global scale.

The lighting needs of a rapidly growing population changed this. In the early 1800s, homes and streets were mostly illuminated with candles, vegetable oils, coal gas, and, for those who could afford it, whale oil. But cities were demanding more than these solutions could provide.

Kerosene—which is refined from either coal or oil—began emerging as an alternative. Kerosene burned with a high-quality, mostly odorless flame, plus it could be produced in the large quantities cities needed at a price they could afford.[2]

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1. This is the animating premise behind the Vancouver Process, an initiative bringing governments together to develop their joint capacity on carbon dioxide removal. The Carbon Dioxide Removal Action Network (CDRANet) made a similar argument last year in "Governments will lead CDR," which listed some of the specific tools already available to governments for this work — public procurement, mandates, utility involvement, research support, infrastructure investment, market incentives and international coordination — and showed how the pattern of government involvement has repeated throughout history with electric grids, railway networks, water systems, health systems and more.

2. Whale oil, especially sperm oil, was prized because it produced a bright, clean, relatively odorless flame. Coal-derived kerosene could deliver comparable lighting quality and brightness; it was somewhat smelly and initially not much cheaper than ordinary whale oil, but

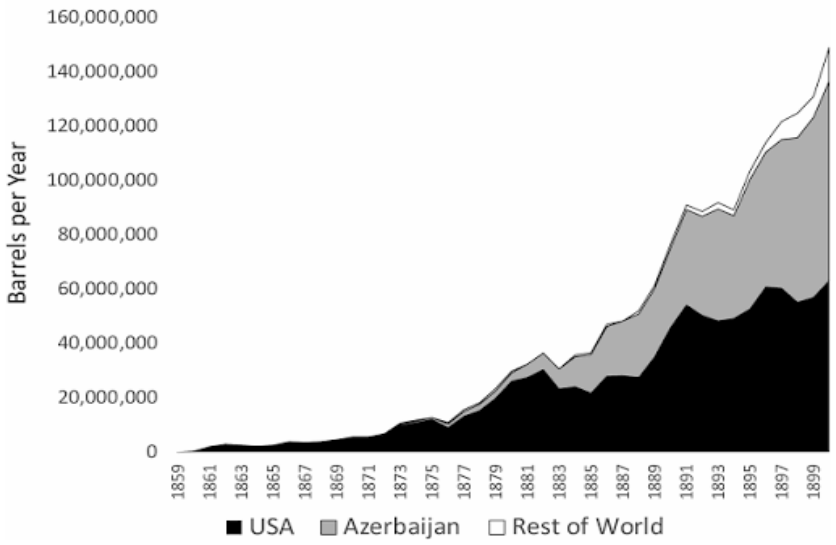
The Seneca Oil Company led the charge to turn kerosene into a commercially viable product. The company commissioned an exploratory well in Titusville, Pennsylvania in 1859, struck oil, and quickly ignited the world's first oil boom. Derricks soon sprawled across the landscape and an unruly mix of producers, refiners, barrel makers, railroads and merchants started competing for oil markets and distribution. Into this mix, John D. Rockefeller founded Standard Oil in 1870 to help bring order to a disordered market. Standard cut refining costs, negotiated favorable transportation rates, built storage and distribution networks, developed pipelines, improved product consistency, found uses for refinery byproducts like gasoline (then a low-value nuisance), and gradually integrated much of the industry from refinery to customer.

FROM LIGHTING OIL TO THE AUTOMOBILE AGE

By the late 1800s, oil was no longer a regional phenomenon. Drilling was beginning to spread globally—the fields of Baku (in Azerbaijan) were becoming the most productive in the world; Mexico, Iran and Venezuela soon followed suit.[3] And powering this growth at the turn of the century was kerosene refined from oil.[4]

Even electricity did little to slow kerosene's growth. Thomas Edison's incandescent lamp was introduced in 1879, but electric lighting required much more than a bulb. Generating stations had to be built, distribution networks extended, and homes and businesses wired for service. This infrastructure spread gradually, first in denser urban areas and much later in rural communities (as late as 1930, only one in ten American farms had electricity). Meanwhile, demand for lighting continued to grow, exports remained strong, and kerosene production kept climbing for decades.

Global crude oil production, 1859-1899



Source: Vassiliou and Mir-Babayev 2022.

Other oil byproducts like gasoline and fuel oil also started to find uses. When

it was still far preferable to highly volatile camphene, a turpentine-based lamp fuel. Oil-derived kerosene, by contrast, could be made far more cheaply than whale oil—roughly one-third the cost of ordinary whale oil and one-sixth the cost of highly prized sperm whale oil. Also, because crude oil could be pumped and piped rather than mined and hauled like coal, it was far easier to supply at the scale an international market demanded. Within a decade, refining efficiencies drove the price of oil-derived kerosene down sharply, eventually undercutting coal oil as well and pushing it out of the market entirely. This wasn't the first commercial use for oil—civilizations throughout history used oil from surface pools for waterproofing, lubrication, and even medicine—but the volumes of oil extracted for kerosene production dwarfed these previous uses (Nordhaus 1997).

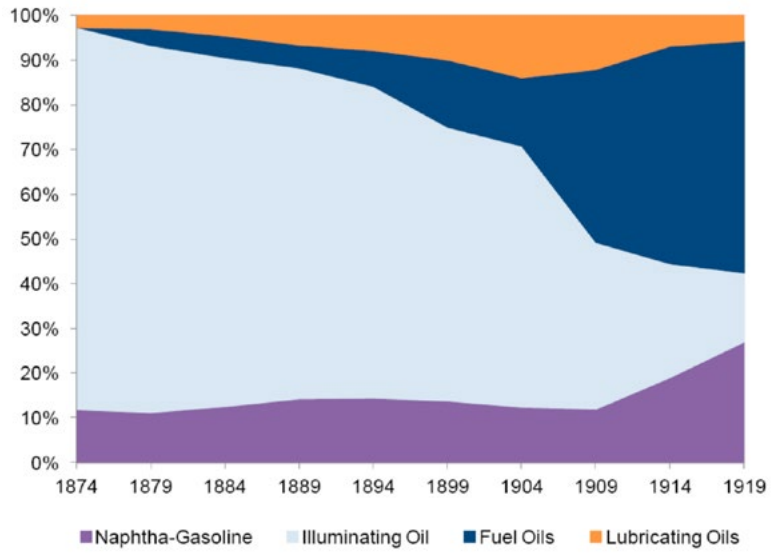
3. The Russian government (in Baku, Azerbaijan) sponsored one of the earliest efforts to drill for oil in 1846, but their motives were to increase the supply of oil, not break into the kerosene market. In subsequent years, the Nobel and Rothschild families helped turn Baku into one of the world's great commercial oil centers (Tolf 1976; Vassiliou and Mir-Babayev 2022).

4. Kerosene was not the universal story of nineteenth-century lighting, however. Britain, for example, already had a well-developed coal-gas industry before petroleum kerosene arrived. (Nordhaus 1997).

it was first introduced in Germany in the mid-1880s, the automobile (used here broadly to include cars, trucks, tractors and other motorized vehicles) was mostly a curiosity—autos were expensive, roads were poor, and horses remained more practical for most people. But by 1925, Henry Ford's assembly line innovations made cars affordable.[5] Ownership soared, vehicles began clogging primitive roads, trucks began competing with railroads for shorter-haul freight, tractors transformed farming, and cities began expanding into suburbs.

Gasoline quickly emerged as the foundation of the new automobile revolution, while heavier fuel found growing markets in industry, ships and other large-scale uses.[6] The result was a dramatic change in the oil business. Kerosene accounted for more than 80 percent of US refinery output in the industry's early decades, but it was less than 20 percent by the time cars started taking hold. Kerosene was still a large and growing business; it simply was no longer the product around which the oil industry revolved.

Kerosene's shrinking market share, 1874-1919



Source: O'Connor and Cleveland 2014. See footnote 6 for definition of different oil fractions.

Government involvement was also beginning to grow around this industry. In the US, government-supported transportation networks helped move oil to markets, states began regulating kerosene quality and safety, and US diplomats eventually defended access to important overseas markets. In Russia, the state sponsored early drilling around Baku, opened oil lands to private development, adjusted taxes and tariffs to favor domestic production, and helped create the conditions for Baku oil to reach wider markets. Governments were not creating demand for kerosene, but they were already beginning to shape the environment in which the industry could grow.

OIL BECOMES A STRATEGIC ASSET

At this point, the histories of oil, gas, autos, roads, industrial growth and international relations became increasingly intertwined. Millions of new vehicles required infrastructure that no oil syndicate or car company could build alone, so governments stepped in to create traffic rules, fund and build

5. According to the Ford website, the Model T first debuted in 1908 for $825. By 1925, the price had dropped to $260.

6. As shown in the figure on this page, there are primarily four products separated from crude oil by heating it to different temperatures. Naphtha at the time was used mostly as an industrial solvent; however, it was so chemically similar to gasoline that the two fuel types were often used interchangeably for cars. Illuminating oil in this chart refers mostly to kerosene (there was also a tiny market for other lighting fuel distilled from oil). Fuel oils are the heavy, thick leftovers of the distillation process, sold to replace coal in large factory boilers and navy steamships; and lubricating oils are generally the heaviest, non-burning parts of the oil barrel.

roads, and plan future highway systems. More roads made travel easier and trucking more competitive, while businesses, housing, warehouses, filling stations and entire communities grew around highway access.

Gasoline was hardly the only force drawing governments deeper into the oil economy. Fuel oil was also becoming strategically important. Britain's Royal Navy began switching from coal to oil before the First World War because oil offered clear operational advantages, but this created an obvious problem, since Britain had abundant coal and little domestic oil. So in 1914, the British government acquired a controlling interest in the Anglo-Persian Oil Company, the firm that would eventually become BP, and secured a long-term fuel supply for the Admiralty. As warfare grew more mechanized, this connection deepened; by the Second World War, aircraft, tanks, trucks, ships and the logistical systems supporting them all depended on reliable oil and gas, and access to the commodity had become a matter of national security.

Producing countries were reaching their own conclusions about oil's importance. Countries holding many of the world's largest reserves often chafed under arrangements that left them with little control over an increasingly valuable asset, and governments responded in different ways. Mexico nationalized private companies, Saudi Arabia gradually took a controlling interest in Aramco, Norway created a state-run oil company, and others controlled and incentivized oil ventures through licensing and taxation.[7] The birth of OPEC in 1960 added another wrinkle, giving producer governments a mechanism for coordinating policy and asserting greater influence over the international oil market.

Over time, governments became even more deeply involved in virtually every part of the oil ecosystem: supporting exploration and research, building or enabling infrastructure, protecting supply routes, accumulating strategic reserves, structuring concessions and taxes,[8] regulating markets, and using oil policy to pursue industrial, economic, security and foreign-policy goals. Unfortunately, though not unpredictably, these relationships also became entangled with nationalism, colonialism and geopolitical rivalry.

INSTITUTIONAL & ECONOMIC MULTIPLIER MECHANICS

The relevant lesson for CDR from this history is that oil grew from being lamp fuel to a pillar of modern civilization through powerful feedback loops — not just a bit of research support here and regulation assistance there, but an evolving partnership where governments recognized oil's growing importance, helped this commodity grow, and rode the wave of subsequent change that this partnership unleashed on the world. The result wasn't simply a successful commodity market, but a vast economic and institutional ecosystem in which public need, private investment and government capacity evolved together. Importantly — and also relevant to some pathways for the future of CDR — governments didn't create the demand for oil, but they shaped the conditions under which the market developed through infrastructure, procurement, regulation and standards that made

7. Mexico expropriated the installations of foreign oil companies in 1938 and created Pemex. Saudi Arabia followed a very different path, acquiring 25 percent of Aramco in 1973, 60 percent in 1974 and 100 percent in 1980. Norway took yet another approach: after foreign companies dominated its early offshore development, the government created the wholly state-owned Statoil in 1972 and established a principle of 50 percent state participation in each production license. The mechanisms differed substantially, but all increased government control over the development and economic returns of national petroleum resources (Yergin 1991).

8. For example, US oil producers have long received favorable treatment for intangible drilling costs, allowing many exploration and development expenses to be deducted immediately rather than recovered gradually, improving cash flow and reducing the effective cost of risky drilling. Qualifying producers have also benefited from percentage depletion, which allows deductions based on a share of production revenue rather than solely on the amount originally invested. Together, these provisions made private investment in oil exploration and production more attractive (Pirog 2011).

private investment easier, safer and more profitable, helping this one commodity become the center of a vast web of social, industrial and economic activity.

Highway systems in the US and elsewhere are perhaps the clearest example of this dynamic. No car or oil company alone could have built continental road networks simply to sell more product. Governments built these systems because transportation, commerce and national integration (and, in the US, defense) were public goals in their own right, and private investment then expanded around that infrastructure on a scale no advance planning could have anticipated.[9]

Much of this growth depended on complementary, mutually reinforcing investment. Public spending acted as insurance against coordination failure, giving private capital the confidence to commit for the long term, and that public positioning crowded in additional private capital rather than displacing it. Virtuous cycles followed, not always intentionally, as complementary investments helped the aviation industry develop, helped agriculture become more productive as tractors replaced horses, created new cities and housing opportunities as expanding road systems opened new land for development, multiplied manufacturing freight capacity, and spun off entirely new industries no government or company could have predicted in advance.

This is the underlying premise. Governments, when they take an active interest in promoting an outcome, have an unparalleled ability to create favorable conditions for economic activity.[10] Oil isn't the only example of this, of course. Governments everywhere have long supported scientific research, encouraged homeownership through tax policy, nurtured strategically important industries, and expanded educational opportunity. The tools vary, but the pattern is familiar. Government decides an outcome is worth achieving, changes the environment around it, and lets individuals, institutions and markets respond.[11]

It's important to note as well — to state the obvious — that these interventions and multipliers aren't always positive. The oil-government alliance has resulted in tremendous environmental damage and geopolitical chaos throughout history.[12] And government choices about which industries

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9. This pattern varied considerably around the world. The United States' low population density, enormous land area, suburban growth and political commitment to highway construction helped produce an unusually automobile-centered transportation system. European countries built extensive road networks too, but denser cities and shorter distances between major population centers allowed passenger rail and mass transit to remain more important parts of the transportation mix. Japan pushed this model even further, building its postwar transportation system around both highways and exceptionally dense rail networks. China, meanwhile, has spent the past several decades building vast highway and high-speed rail systems simultaneously. These different outcomes reflected geography, settlement patterns and policy choices: governments everywhere invested in mobility, but they did not all build the same systems (Cervero 1998; Wells 2012).

10. Not necessarily through central planning, which has a mixed record, or by picking winners and losers, but by establishing a general direction and an enabling environment where markets can discover what comes next.

11. Perhaps the most famous example of this dynamic is from the US after World War II, when Vannevar Bush argued that scientific progress was too important to national prosperity, health and security to be left to commercial research and private philanthropy alone. What followed wasn't a centrally planned research agenda but an enabling ecosystem of universities, grants, national laboratories, research agencies, training programs and sustained public financing, within which scientists could pursue ideas no government planner could have anticipated. Government didn't decide what discoveries scientists should make; it decided that scientific capacity itself was worth building, then created the conditions in which discovery could flourish (Bush 1945).

12. Discussion of oil's geopolitical and socioeconomic dynamics can be found in Corden and Neary 1982; Painter 2012; Mitchell 2011; and Grandin 2025 (which touches on the historical origins of "dependency theory"). A tangential dynamic is how these tensions are now impeding climate efforts. Developed economies, which grew as a result of oil and thoroughly polluted the Earth's atmosphere in the

and activities to favor can have lasting unintended consequences. Favoring houses and cars over apartments and mass transit systems, for example, has contributed to pollution and urban sprawl. The promise of government-entangled multiplier effects is real, but so is the peril.

CAN CDR LOOK LIKE OIL?

Drawing on our understanding of how oil evolved over its long history, the list of possible government interventions that might benefit CDR is long: supporting more research, funding more first-of-a-kind demonstration projects, helping standardize regulations, streamlining permitting processes, creating tax incentives and exemptions, helping coordinate international policy, building ports and storage facilities, and more. These are the familiar wish list items when we propose that governments get involved, and they're all good ideas and would no doubt be tremendously helpful.

But the most critical government intervention of all will be to stimulate demand, because without a robust CDR marketplace — at least through the lens of the CDR as oil scenario we're exploring here — the economic and institutional multipliers we're hoping to encourage will struggle to scale as quickly and as far as we need. People have always wanted to buy what the oil industry produces, while the carbon removal market, a decade in, is still searching for customers.[13]

Two different approaches might be needed, because the CDR industry currently relies on two different kinds of demand: demand for carbon dioxide removal as a service, and to a far lesser extent (at least for now), demand for carbon and CO2 as useful commodities. So from the service angle, for example, governments might stimulate demand by requiring companies to purchase verified removals. Governments can also become major buyers themselves; this hasn't happened at scale yet, but some are beginning to take this step. Other possible actions (among many, which also overlap with actions to help stabilize the CDR markets) might include using a portion of pollution tax revenues to purchase verified carbon removals,[14] or creating contracts for difference (as being developed in the UK) wherein the government can guarantee a minimum price for verified removals. From the commodities angle, governments might mandate more reuse. For example, in 1978 the US federal government began encouraging ethanol-blended gasoline through tax incentives, and in 2005 established mandatory renewable fuel blending requirements, helping create a stable market for American agricultural products while also advancing energy security goals. Doing something similar with carbon dioxide — establishing purchasing standards favoring materials that incorporate durably stored atmospheric carbon — could provide a valuable foothold for the CDR industry to grow.

Government actions like these can also help the CDR market grow, improve market stability and predictability, and give investors greater confidence to commit capital to CDR projects. As occurred with oil, when governments take a vital interest in the future growth of an industry, a web of market and institutional entanglement develops that becomes deeply influential.

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process, are now promoting the need to cut back on emissions. Indian Prime Minister Narendra Modi argued at COP21 that countries still climbing the development ladder shouldn't be held to the same climate rules as those who built their economies first.

13. Only about 50 million tons of durable CDR have been contracted to date (80 percent by Microsoft), of which only about 1.7 million tons have actually been delivered, almost all of it biochar. This is technically a market, but it is nowhere near large or broad enough to achieve the removal goals we need. This isn't to say the carbon market can't grow, only that it's far from clear whether it will ever be as robust as oil's.

14. One possible approach here is the Carbon Takeback Obligation, which would require fossil-fuel producers to arrange permanent storage for an increasing proportion of the carbon associated with their products (Jenkins 2021; this idea doesn't require CDR, but it could be modified). Cap-and-invest programs like those in California and Washington State could also direct additional funding toward CDR.

Another huge return on investment for government involvement in CDR will be to support the development of new removal methods that can scale to multi-gigaton levels, while also supporting the development of new industries that can make use of this carbon and new ways to store the coming excess. This forward-thinking approach is necessary, because the solutions currently succeeding in the CDR marketplace are mostly modest yield, and are unlikely to scale to the levels we will eventually need. As well, governments needn't pick one track or the other — a commodities focus or a service focus — because a combination of the two might have its advantages: companies can pay to have carbon removed from the atmosphere, while the cost of providing this service can be offset by the commercial value of the recovered carbon.

Finally, governments can also decide that regardless of market strategies or outcomes, carbon dioxide removal must become a cause of vital national interest because it's a necessary precaution to avoid the vast climate-related damage and costs we will incur without it. To do so, they can help build the necessary infrastructure, set aside land for testing and development, clear regulatory pathways, or as discussed, help increase demand and establish markets. There is a full and exhaustive set of tools governments can use to encourage outcomes to happen. So far with CDR, we've only scratched the surface.

But what if after all is said and done, our best efforts to develop the CDR market simply won't work — at least, not in terms of growing it to the size we need? What if carbon and carbon dioxide just don't have the commercial demand or multiplier potential needed to support an industry of this scale, even with government intervention? Shouldn't governments hedge against this possibility? If so, then the waste management future of CDR is worth exploring since it describes what happens when markets lack the means to solve civilization-scale problems by themselves.

CASE STUDY 2: WASTE MANAGEMENT

For most of human history, waste, like oil, was a low-key reality of everyday life. It was managed locally, and often privately, with food scraps fed to animals, worn textiles rewoven, ash and metal recovered, and human waste returned to the soil as fertilizer. Where waste had economic value, small markets of scavengers, "night-soil men" and rag-pickers emerged around collecting and selling it. Where it didn't, people buried it, burned it, dumped it, or moved away from it. These informal, often circular arrangements worked well for millennia as long as populations stayed small and waste streams stayed mostly biodegradable.[15]

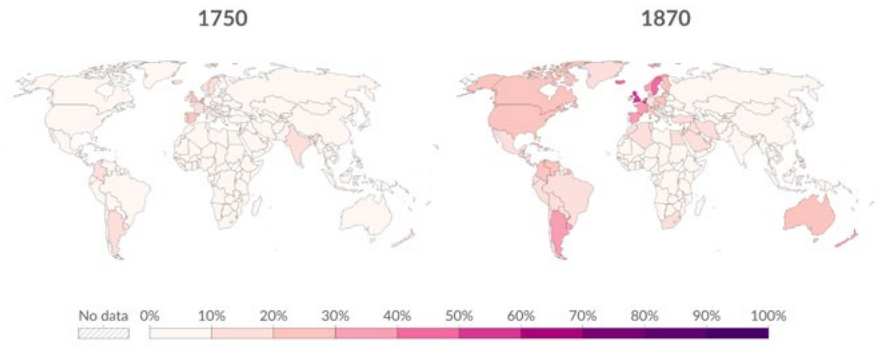
FROM PRIVATE DISPOSAL TO PUBLIC CRISIS

Industrialization and urbanization changed this relationship. During the nineteenth century, cities grew at staggering speeds, concentrating people, factories and animals into dense spaces where older disposal practices instantly collapsed. The resulting crisis was global. Fast-growing cities like New York and Paris choked on mountains of solid waste, from thousands of tons of daily horse

15. This wasn't universally true across all of history. Several ancient civilizations built centralized sewer systems, generally at the initiative of the state. Minoan Crete had integrated drainage at palace complexes as early as 2000 BC, and Rome's Cloaca Maxima was substantially complete by the first century AD. But these were narrow achievements, not general public services. In Mohenjo-daro, many houses had bathing areas that drained into street sewers, but private lavatories were relatively rare. In Rome, direct household connections to the sewer system were the exceptions rather than the rule, with most residents relying on public latrines or private arrangements instead. And with a few exceptions, these systems didn't survive their civilizations: Rome's fell into disrepair after the empire's collapse, and Europe reverted to essentially private, ad hoc sanitation for well over a thousand years, up to the crisis described here. See De Feo 2014 for additional discussion.

manure to toxic industrial slag and household trash that overwhelmed traditional waste management practices.[16]

Share of population living in urban areas, 1750 vs. 1870



Source: OurWorldInData.org

A parallel liquid-waste crisis was building below ground. Cities like London had managed sewer systems for centuries through local, patchwork authorities, but their brick networks had evolved mainly to capture rainwater and surface drainage. As populations surged, residents increasingly routed domestic filth into these same channels. The widespread adoption of the indoor flush toilet in the mid-1800s, hailed as a triumph of modern hygiene, only accelerated the crisis as torrents of flush-water overwhelmed residential cesspits, saturating the surrounding soil and contaminating the shallow neighborhood wells used for drinking water.[17] Water and sewer systems also became mutually reinforcing: the more water cities piped in, the more urgently they needed a way to carry it—and the waste it collected—back out.

GOVERNMENTS TAKE OVER

In the early 1800s, governments everywhere spent decades responding to these compounding crises. The British Parliament first tried consolidating local sewer commissions and building broader metropolitan institutions, but early reforms repeatedly stalled over lagging finance and political turf wars. The breaking point came with the Great Stink of 1858, when the stench of the Thames became so overwhelming that Parliament finally unlocked the sweeping regulatory and financing powers that authorities needed to engineer a sewer system that actually worked.

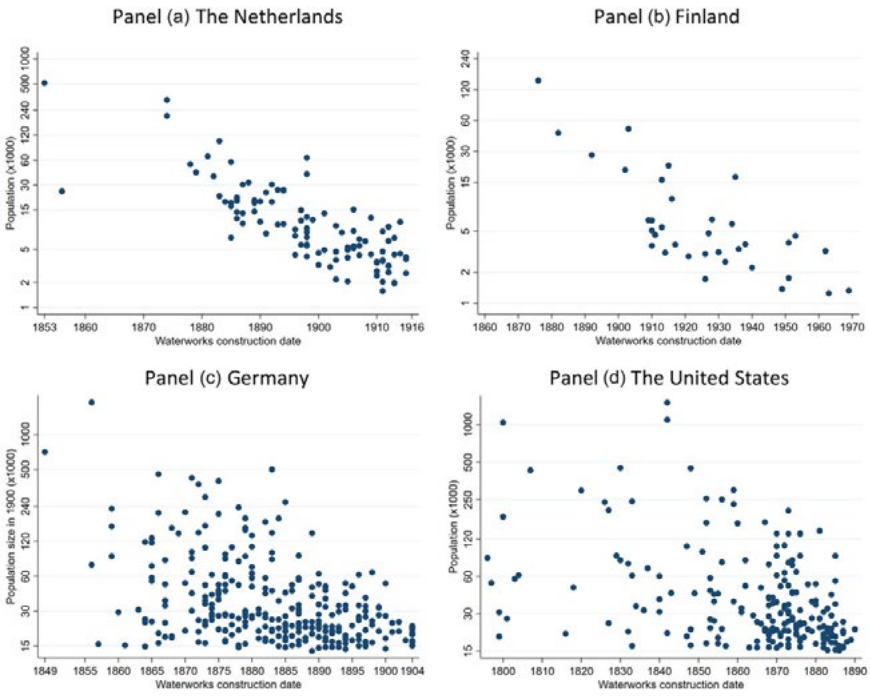
Initial engineering triumphs, though, marked only the beginning of a long-running cycle in which each successful intervention revealed the next problem. Unified sewer systems successfully cleared the streets, but they also piped raw sewage directly into waterways, poisoning downstream drinking-water intakes and forcing the slow, costly construction of water treatment plants. To replace uncontrolled city dumping, municipalities created landfills instead, which eventually began leaching toxic chemicals into local groundwater. To control air pollution, cities required towering smokestacks that routed soot away from dense populations, only to disperse these same pollutants over vast distances.

This pattern repeated itself thousands of times across the globe as governments gradually accepted permanent responsibility for waste management, motivated not by abstract sentiment but by

16. This essay focuses more on sewers than solid waste because sewers are a closer parallel to the CDR challenge in terms of infrastructure needs. But the horse manure problem does touch on the issue of markets. In cities like New York, scavengers collected manure from streets and stables and sold it to farmers as fertilizer, yet enormous urban dumps still accumulated. Commercial markets helped recycle this waste, but demand was not sufficient to solve the larger civic problem (McShane & Tarr 2007).

17. The Public Health Act of 1848 required newly built homes to include a sufficient water closet or privy and ashpit. The requirement formed part of the broader mid-century sanitary transformation that accompanied the rapid spread of water-based household sanitation and placed still greater pressure on inadequate urban drainage and sewer systems (Hamlin 1998).

The early growth of municipal water systems in select regions



There is no solid accounting of the growth of global sewer systems, but there is for water systems. These generally (but not always) preceded sewer systems and often helped make them necessary: as cities piped larger volumes of water into homes and businesses, they also needed increasingly extensive systems to carry wastewater and sewage away. Sewer construction therefore tended to follow the same broad diffusion pattern, usually with a lag that varied by place. For example, Madrid built its waterworks in 1858 but sewer construction didn't start until 1865. As well, as noted below in footnote 18, wealthy areas typically received sewer service first. Source: Gallardo-Albarrán 2025.

the hard-nosed economic reality that cleaner cities were healthier, more attractive, more livable, and ultimately wealthier and more productive.[18] As these systems matured, it also became clear no city could manage waste in isolation. Waste crossed jurisdictional boundaries, which meant cooperating with neighbors to protect the common good. The establishment of the US Environmental Protection Agency in 1970 reflected this reality — waste required an administrative authority capable of reaching across fragmented federal programs dealing with air, water, solid waste, pesticides and radiation and treating pollution as an interconnected environmental system.

The cost of environmental remediation also started growing far beyond what local communities could afford unassisted, pushing cities to invent new ways of mobilizing long-term capital, not only to build railways and roadways, but to keep their environments safe and livable enough that residents would stay, build businesses and spend money there.[19] None of this would have been possible without an increasingly strong civic infrastructure behind it—without the commitment to act, plus the growing experience, capacity, and normalcy of acting.

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18. A recent global review finds that major cities across Europe, the Americas, Asia, Africa and Australia began constructing modern water and sewer systems broadly between the 1850s and 1890s. What varied much more dramatically was how quickly these systems subsequently spread across countries and throughout individual cities. As well, these systems didn't always emerge universally or equitably. Sanitary infrastructure often reached wealthier neighborhoods first, and in many cities substantial portions of the population remained outside the new systems for decades (Gallardo-Albarrán 2025).

19. Sanitation projects had a transformative impact on municipal finance. Cities had borrowed before for roads, docks, canals and railroads, but nineteenth-century water and sewer systems required investment on a new scale and over generations. Nineteenth-century cities increasingly relied on bonds, government loans and other forms of long-term debt to build water and sewer systems whose enormous upfront costs could not be met from annual revenues. In London, the cost of the great sewer works eventually exceeded what the existing municipal mortgage market could provide, helping spur the Metropolitan Board of Works to issue tradable municipal stock. By the end of the century, borrowing to finance water, sewers and other civic systems had become a routine feature of modern urban government. Indeed, by around 1910, water- and canal-related investments accounted for roughly one-fifth of the debt of larger German municipalities and about one-third of municipal debt in large American cities (Gallardo-Albarrán 2025; Webster 2022).

SHIFTING THE CIVIC BASELINE

There are at least three lessons from this history worth noting. These lessons contrast in some ways with the oil model, complement it in others:

LESSON 1: ACCEPT RESPONSIBILITY

In the mid-1800s, governments finally stopped treating waste as something individuals and markets should sort out, and instead began treating it as a shared civic responsibility. The obvious parallel for today is whether governments can start to acknowledge that carbon dioxide pollution poses a threat to societies everywhere, and that leaving the fate of CO2 to individuals and markets will not end well.

LESSON 2: COST ISN'T THE GATEKEEPER

In today's CDR world, a great deal of attention is devoted to establishing a high-functioning carbon market, driving the cost of removal below $100 per ton while keeping the price high enough to attract investors and low enough that buyers will purchase the service at scale. With waste management, by contrast, the decision to act was never contingent on whether private demand was sufficient to sustain the service commercially. The central concern was solving the problem because the value of reliable waste collection to society extends far beyond price per ton, showing up instead in public health, property values and economic vitality, all of which suffer when waste management fails.[20]

This government involvement didn't exclude private-sector opportunity then, nor would it now. Citizens can invest in the bonds that finance major projects, and private firms are needed to provide services, build infrastructure, and supply the expertise and machinery that make the system function. The difference is that commercial demand no longer determines whether the underlying problem gets addressed at all. Governments set the outcome, then use whatever mix of public and private activity is needed to achieve it.

A New York City Department of Street Cleaning cart, 1908, carries the message, "You Live in the Greatest City in the World—Let's Make it the Cleanest and Healthiest." By this point, sanitation had evolved from largely private and contracted disposal into an increasingly permanent function of city government, complete with dedicated workers, equipment, rules and public campaigns. Source: *New York City Municipal Archives, Department of Street Cleaning Photograph Collection.*

20. Electricity offers another useful illustration. Governments and regulated utilities don't wait to see whether voluntary buyers will purchase enough electricity to justify building a reliable power system. They forecast demand, plan and finance generation and transmission capacity, regulate providers, and set rates that sustain the system over time. The public obligation comes first; markets, prices and private investment operate inside that framework. CDR may eventually need a similar shift in logic, where the central question is no longer how much removal buyers are willing to purchase, but how governments ensure that the amount of removal society needs actually happens.

LESSON 3: SOLUTIONS ARRIVE THROUGH ITERATION

London's sewer system wasn't conceived once and then built. It evolved as experience revealed what else was needed in the way of authority, finance, infrastructure and administrative capacity. The same will be true for CDR. No single plan will get it right the first time, and the ability to iterate will matter as much as the initial design.

CAN GOVERNMENT ACT, THOUGH?

Some have questioned, however, whether modern governments can even accomplish what their nineteenth- and mid-twentieth-century counterparts did. Modern governments are, in many respects, far more capable, with much greater fiscal, technical, informational and administrative capacity. But they may also, paradoxically, be less able to act boldly.

Political scientists point to several reasons for this: greater transparency and accountability, more constraints from rules and regulations, and more risk aversion, driven partly by transparency and also blame avoidance—the fear that public failure can carry professional, political and budgetary consequences.[21] Together, these forces create an environment where modern governments may be less willing and institutionally less able than their predecessors to take big swings on issues of major civic importance, even though these same governments have more capacity and ability than ever before.

Still, political scientists also note that regardless of whether modern governments can easily act through routine processes, other influences can still motivate action. Crises are one. In the 1800s, it took a crisis—the Great Stink—to force Parliament to act decisively. Sometimes, bold leadership in the wake of crisis is the missing ingredient: governments formed the United Nations in the aftermath of World War II, President Kennedy mobilized Americans to reach the moon (responding to the threat of falling behind the Soviets in the space race), and Sidney Farber

Pew Research Center poll: Is climate change a major threat to your country?

High-income countries	'13	'16	'17	'18	'20	'22	'25	'22-'25 change
	%	%	%	%	%	%	%	
Poland	45	54	42	55	-	68	55	**-13**
Greece	87	84	79	90	-	86	75	**-11**
Italy	64	72	65	71	83	82	71	**-11**
Netherlands	-	56	64	70	70	77	66	**-11**
UK	48	58	59	66	71	75	66	**-9**
Hungary	-	66	59	66	-	80	72	**-8**
Australia	52	60	58	60	59	71	63	**-8**
Spain	64	89	89	81	83	78	72	**-6**
Germany	56	65	63	71	69	73	67	**-6**
Sweden	-	64	64	69	63	70	64	**-6**
South Korea	85	-	79	86	81	82	77	**-5**
Canada	54	61	60	66	67	65	60	**-5**
Israel	30	-	38	38	-	47	42	-5
Japan	72	68	67	75	80	82	78	-4
France	54	73	72	83	83	81	78	-3
U.S.	40	53	56	59	58	54	51	**-3**
Middle-income countries								***Change since last asked***
Mexico	52	-	72	80	-	-	74	**-6**
South Africa	48	59	59	59	-	-	57	-2
Kenya	57	71	76	71	-	-	72	+1
Brazil	76	-	67	72	-	-	77	+5
Argentina	71	-	76	73	-	-	80	**+7**
India	53	53	47	-	-	-	55	**+8**
Indonesia	59	-	56	56	-	-	65	**+9**
Nigeria	41	42	43	41	-	-	54	**+13**
Turkey	47	-	53	-	-	-	70	**+17**

Source: Pew Research Center 2025. See source for notes.

21. Political scientist Donald Moynihan uses the term "proceduralism" to describe the gradual accumulation of rules, processes, veto points and delays that can constrain governments from achieving important public goals, even when the individual safeguards involved serve legitimate purposes (Moynihan 2025; Weaver 1986).

and Mary Lasker's campaigning through the 1950s and 60s led to the 1971 National Cancer Act, built on the argument that dying patients cannot wait for a perfect solution (Mukherjee 2010).[22] And then sometimes, change simply accumulates. Expert consensus reshapes how policymakers understand a problem; organized public pressure changes what's politically possible; experimentation reveals workable approaches; and governments watch each other and borrow what works.

All of these mechanisms can work alone or overlap, until an idea that once seemed radical becomes an ordinary responsibility of government. Momentous change, in other words, doesn't always arrive through a single momentous decision.

Here again, the future of CDR may unfold along a similar path—governments will hopefully accept responsibility for CO2 removal and then discover, over decades, where that commitment leads. And that commitment might emerge routinely, or it might emerge as a result of crises, unique leadership, expert consensus or other mechanisms. What matters most will be that first step to accept responsibility.

PERCEPTION MATTERS

In addition, the unfolding story of CO2 has a few perception challenges the history of garbage and sewers didn't have. Cause and effect is one. Garbage was clearly connected to rats, which were connected to disease; filthy water was clearly connected to sewage, which—at least later as our science improved—was clearly connected to cholera outbreaks. With CO2, there is no bright red line for the casual observer that makes the connection clear between increasing temperatures and our increasingly unstable climate, especially when also trying to discern climate truth from climate disinformation.

Timescale is another perception challenge. Our climate crisis is unfolding slowly, and gradual change doesn't motivate the already hard-to-convince.

Add equity to our perception challenges as well, as our climate crisis unfolds differently in different parts of our world. Riyadh and Barcelona are becoming unlivable in the summer; Seattle and Vancouver, BC, much less so. Many island nations may not exist in a few hundred years; states in the northern US interior will be warmer but still around; the US eastern seaboard may become an archipelago if Greenland melts, while Hudson Bay could see thousands of miles of new waterfront development.

How does the world unite in common cause around a common threat when different places are experiencing different impacts at different rates, and when not all these impacts are, in the here and now, all that fast moving or obviously connected to climate change? One country's future Armageddon will be another's future Garden of Eden. Perception may be the single biggest difference between the politics of waste management in the 1800s and the politics of climate today, and may end up being one of our hardest problems to solve.

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22. Historian Douglas Brinkley notes that the Apollo program cost more than $25 billion (about $320 billion in 2026 dollars), but employed or engaged more than 400,000 Americans and thousands of companies while accelerating advances in computing, satellites, medical technology, materials, weather forecasting and other fields. He argues that these technological returns ultimately repaid the investment "multiple times over." Apollo therefore offers a useful precedent for CDR: large public investments undertaken to achieve a necessary societal objective can generate substantial economic, technological and social benefits well beyond the value of the immediate task itself (Brinkley 2019, xxi-xxii).

FITTING THE PIECES TOGETHER

Glimpses of the future of how governments will become more involved in carbon removal are already appearing around the world, by way of public procurement programs, tax incentives, carbon-management strategies, CO2 transport and storage systems, carbon budgets and credit markets. Denmark is using public procurement and subsidies to purchase durable carbon removal; the UK and Sweden have incorporated engineered removals into carbon budgets and net-zero planning; Norway is enabling shared CO2 transport and storage infrastructure; Australia is integrating removals into its safeguard and carbon-credit systems; and cap-and-invest approaches being pioneered by California and Washington offer another potentially important model. Through a kind of halting institutionalization, CDR is being planned for, funded experimentally, and gradually woven into government policy.

Three intertwined questions are still far from settled, though, and our answers to these will shape what "more government involvement" ends up meaning in practice.

A CLEARER IDENTITY

The first question is whether CDR will continue to be treated as a subset of mitigation policy, competing with emissions reduction for funding and attention, or whether it develops as a climate policy pillar in its own right. Scientifically and economically, these two portfolios are quite different. One focuses on reducing the flow of new carbon into the atmosphere, the other on drawing down the enormous legacy stock already there. Politically, CDR to date has mostly been treated as mitigation's competitor rather than its complement, with critics arguing that attention to CDR distracts from emissions reductions. Giving CDR a clearer identity and policy focus of its own, without needing to justify itself against mitigation's agenda, is a prerequisite for governments to seriously grapple with what our CDR undertaking actually requires.

COORDINATION WITHOUT CONFORMITY

The second unsettled (or at least evolving) question is coordination. This is part of the purpose of the Vancouver Process, which aims to help normalize a deeper government relationship with CDR while creating a low-risk framework where governments can begin working together now, building expert networks and communication channels, sharing policy approaches and lessons of experience, developing a shared understanding of needs, and aligning standards where useful. Governments don't need to make identical choices, but neither should every government have to invent its CDR policies, institutions and infrastructure from scratch.

HOW FAR SHOULD ALIGNMENT GO?

The third question is what this essay has been circling: What does substantially greater government involvement eventually look like? Will CDR develop as a hodge-podge of national and subnational programs pursuing objectives defined largely by sovereign climate policies, or will governments increasingly align policies, practices and perhaps even resources around a common global objective—one that distributes risks and benefits more equitably and stays more alert to unintended consequences than governments were during the oil era? We don't know yet. This is where things stand today, trying to fit the pieces together.

BUILDING ADMINISTRATIVE CAPACITY

Working down from these larger questions, suppose a government suddenly decides to become much more involved in CDR. Does it simply announce "let's do this" and everything falls into place? Obviously not. Government capacity itself has to be built to match the ambition, and that capacity takes several distinct forms.

THE MACHINERY

Building the right machinery for this undertaking will be government's first challenge. New mechanisms will be needed to finance CDR at scale, like granting utility districts the power to issue bonds for CDR projects. As well, new institutions (or reorganized current agencies) will need to be given the expertise and authority to manage CDR issues, along with new procedures spanning agencies and jurisdictions. Since national and subnational governments will be collaborating, as well as multiple agencies across these governments, coordinating bodies will also be needed. So will clear rules for how decisions are made and appealed, which authorities oversee this work, and where international rules and regulations may eventually be needed apart from market rules.

ALIGNMENT

Less visible, but no less important, is the architecture ensuring that this machinery is empowered to attract investment and work well with industry. Private capital will need predictable policy signals, workable permitting and regulatory systems, access to enabling infrastructure, and enough certainty about future markets to justify very large and often long-lived investments. Governments may also need to use procurement, guarantees, public-private financing, or other tools to bridge the gap between technologies that appear socially valuable and investments the private sector can reasonably make on its own.

Risk is another part of this equation. New industries like CDR often create liabilities that private insurance and ordinary contracts handle poorly, particularly where responsibility may persist for decades. As with nuclear waste containment, private capital tends to flee multi-generational risk unless the state steps in as ultimate guarantor. Governments will need to clarify who remains responsible for stored carbon, what happens if operators fail, how financial assurance and risk-pooling work, and when responsibility transfers. Risk is easy to overlook, but unresolved liability can stall progress just as effectively as unresolved technology.

PUTTING THE MACHINERY TO WORK

And then there's everything that needs to happen once the machinery is in place and alignment is achieved. Physical infrastructure will take decades to build: extraction and processing facilities, pipelines, storage sites, test sites and monitoring networks, each needing financing, permits, community input, environmental review and coordination across agencies and jurisdictions before construction even begins, typically involving years of rulemaking, approvals, court challenges and funding cycles, followed by bidding, construction, oversight and refinement. Regulations will be needed, built with input from affected stakeholders. RD&D support will be needed, along with streamlined testing and permitting, and cross-jurisdictional coordination to scale joint solutions. We will need no small amount of public education, as well as support for communities with regard to training, zoning, risk reduction, and much else. And as government engages more and more in CDR work, it will want to support the growth of virtuous cycles—for example, by investing in carbon reuse and in CDR approaches that can also improve the efficiency or economics of existing industrial systems.

The list goes on. Some of this resembles what's already happening today—a scattershot collection of actions that support CDR one-offs but not necessarily CDR strategy. These one-offs are helpful inroads and test beds, but only a strategy—whether this simply develops over time as an accumulation of actions, or as a more deliberate, thoughtful approach—will give CDR a realistic chance of reaching climate-relevant scale through government support in a reasonable amount of time.

In short, the most powerful and effective form of government involvement means much more than spending on RD&D or setting marketplace rules. At its most impactful, as the histories of oil and waste management both show, government involvement spins up a vast and interconnected web of government and social obligation, and that web requires an equally interconnected web of government and quasi-government machinery in return, from legal and regulatory bodies to codes, review and appeal mechanisms, and inspection and insurance systems. None of this machinery is visible in the way we interact with daily life, but it is the actual bridge between CDR's ambition and its ability to scale.

THE TWIN TRACKS OF CDR

By now, the case for drawing on both models should be clear. We can estimate how much carbon removal our climate will require, but we have no idea how much of this removed carbon will ever have commercial value. As well, some CDR approaches may eventually produce carbon or carbon-containing materials that find large markets, while other approaches are designed to remove carbon and store it somewhere.

This delineation suggests a practical strategy. Governments should move aggressively on methods capable of removing and durably storing carbon regardless of commercial value, while also nurturing technologies and markets that might someday convert part of this enormous material flow into economically valuable products. The first approach addresses the crisis directly. The second potentially lowers future public cost and raises future economic benefit. We need both, and the balance between them will shift as technologies and markets develop. Governments don't need to know in advance where that balance settles. What they need is a robust, unequivocal commitment to the outcome, from which the practical machinery described above can begin to grow.

SCALE AND TIME

The biggest two complications we face today (other than the perception issue noted earlier and, of course, the actual decision to act) are scale and time. With regard to scale, the amount of carbon dioxide we'll likely need to capture from our sky and oceans is at least twice the size of the current global oil market—roughly 10 gigatons per year, versus around five for oil. Picture everything that goes into global oil extraction, refining and transportation, then double it (this is a mass-flow comparison, not a claim that CDR infrastructure will literally resemble an oil system twice the size).

On time, modern oil and waste-management systems built their institutional architecture over generations. CDR has only decades to do the same, essentially from a standing start, which is hard to imagine happening without a massive, concerted effort by governments everywhere to treat carbon emissions as a waste-management problem.

INTENSITY

Intensity matters as well, and right now we don't have much of it. We're still relying on annual COP meetings to stimulate progress on CDR, still trying to catalyze market activity through UN agreements and mechanisms, still quarreling over the market price for carbon, and still extraordinarily tentative about moving potential home-run solutions like ocean alkalinity enhancement from laboratories into serious field trials. What has happened to our planet's atmosphere is a tragedy of the commons writ large, and time is not on our side. Governments everywhere need to decide within the next few years whether carbon dioxide removal will be part of the future they intend to build, and commit to this challenge accordingly.

Along these lines, we may also need to reconsider whether the world's prevailing approach to RD&D (described earlier in footnote 11)—a broad, publicly supported research capacity focused on basic science and discovery—is sufficient for the challenge ahead. History has seen very different approaches as well, like the Manhattan Project and the US and Soviet space programs, designed not to build capacity but to mobilize the full resources of government around a highly technological outcome on an impossibly tight deadline. CDR likely needs both the broad scientific ecosystem that produces unexpected breakthroughs, and a mission-driven apparatus capable of turning promising ideas into climate-scale systems with extraordinary speed.

DECIDING TO ACT

Future generations will likely forgive us if we fail to predict every technology, market or institutional outcome correctly, or head down a few dead ends along the way. They will be far less forgiving if, knowing what needs to be done, we wait much longer to begin. Whichever path we choose, whatever motivations finally tip the scales and urge us to get underway, this process needs to begin now.

History clearly shows what government involvement can mean when societies decide a problem is too important to leave unresolved. Government can accept civic responsibility for the outcome while simultaneously creating the conditions in which markets can do what they do best: invest, compete, innovate, build and scale. That means far more than funding research or setting marketplace rules. It means building the legal, financial, administrative and physical architecture that makes large-scale action possible, while using public authority and resources to help private enterprise succeed where markets alone cannot carry the full burden. This is not government instead of markets. It is government and markets, each doing what the other cannot, in pursuit of an outcome neither is likely to achieve alone.

If CDR is to reach climate-relevant scale within the next few decades, there has hardly been a clearer case for this kind of partnership. The first step is for governments to recognize that carbon dioxide is not simply a commodity awaiting a better market, but a civic problem requiring an organized response. From there, institutions can be built, markets can be mobilized, mistakes can be corrected, and solutions we cannot yet see can emerge. We do not need to know exactly where this path ends before setting out.

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