It is becoming increasingly likely that if the world is to avoid warming beyond 1.5 or 2 degrees Celsius that we will have to actively remove carbon dioxide from the atmosphere, rather only rapidly decarbonizing global economies. Without carbon dioxide removal, the rate of decarbonization that would be required to meet a 1.5 or 2 degrees standard involves relatively unlikely massive and rapid changes in global economies and societies. Indeed, many of the leading models for climate policy and forecasting that demonstrate meeting 1.5 or 2 degrees Celsius warming thresholds rely heavily on active removal of carbon dioxide from the atmosphere.

However, there are real questions about the feasibility of many of the most commonly proposed alternatives for carbon removal. Restoration and expansion of global forests can remove carbon – but requires enormous amounts of land, may not be permanent if climate change causes forests to decay or burn, and may in fact be counterproductive in higher latitudes where reforestation may decrease the reflectivity of the surface and thus increase warming on net. Many models rely heavily on biofuels and carbon capture and sequestration (BECCS) – growing crops to produce fuels that can be combusted for energy, and capturing the carbon released from the combustion and sequestering that carbon underground. BECCS is relatively unproven, and requires massive amounts of land, including land that might be otherwise needed to produce food. Changes in agricultural methods may allow for greater sequestration of carbon in soils, but there is uncertainty about these methods and the permanence of sequestration. Another option that has received attention lately is direct air capture with sequestration (DACS), in which technology is used to capture carbon dioxide from the ambient air, and the captured carbon is then sequestered in geological formations underground.

Each of these approaches have advantages and disadvantages, and so a portfolio of them will likely be required. Reforestation and agricultural soils may be extremely low cost, but require substantial amounts of land and may not be permanent. BECCS is potentially expensive, and the land requirements may create serious conflicts with food production, which in turn creates significant equity issues. Among these methods, DACS has a range of advantages – sequestration is permanent and likely reliable, and it does not require the amount of land that other methods require.

However, DACS is currently extremely expensive – with current estimates ranging between $100 and $600/ton for the cost of capturing and sequestering carbon. There are a range of start-up companies investing in development and deployment of the technology. But a key question is whether enough investment can be provided for DACS that can produce innovations that can in turn drive down the cost of the technology. Similar investments have paid off dramatically in dropping the price of renewable energy and the batteries in electric vehicles.

Both renewable energy and electric vehicles have one key advantage over DACS in driving investment – they both produce a revenue stream. People will pay for renewable electricity; people will pay for an electric car. Who will pay for carbon to be stuffed into the ground? Policy decisions were crucial in driving the investments for renewable energy and electric vehicles – they will be even more crucial for DACS.

Any policy also has to be one that has the promise of creating interest group support in the future for additional DACS investment and deployment. If carbon capture is to be a crucial component of global climate policy, it will require a massive scaling up of all of the carbon capture approaches, including DACS. So it's a question of what policy measures will lay the groundwork for future political support for more aggressive action.

This is a question that I have worked on with a range of collaborators, and together with Jonas Meckling here at UC Berkeley, we took those analytic tools and applied them to DACS. What policy approaches have a good shot of driving investment and innovation in DACS, are politically feasible to enact now, and have the ability to lay the political groundwork for more action in the future? Our analysis has just been published in Nature Communications (available here in open access), but below I summarize the key points of our piece.

Our first key point is that carbon pricing will not help advance DACS. Such a price would have to be at least $100/ton, far beyond any politically feasible price point as history suggests. Instead, as we have found in a range of other sectors – and as was the case in both renewable energy and electric vehicles – subsidies and regulatory mandates are the only politically plausible approaches. That is because they can drive focused investments in the targeted sector – the high implicit cost of these approaches is much more politically feasible because they are less salient than carbon prices, and because they are focused on very narrow sectors of the economy.

Our second key point is identifying the key leverage points for DACS in terms of the economic sectors that should be the focus for subsidies and mandates. The lack of major economic uses for DACS creates a challenge here, compared to renewable energy (where an obvious entry point is the electricity industry) or electric vehicles (the automobile industry). The primary economic use for carbon dioxide at the moment is, ironically, extracting oil out of geologic formations through Enhanced Oil Recovery (EOR). A range of oil companies currently use EOR, primarily from naturally-occurring carbon dioxide. However, DACS could obtain carbon dioxide from the atmosphere, and the carbon dioxide used for EOR could be sequestered geologically. The revenue from the extracted oil can help offset the cost of DACS, at least at the margins.

Using EOR as the initial entry point for policy to advance DACS has a few advantages. First, the oil and gas industry has substantial capital that it can invest in the technology, and significant technological expertise in geologic sequestration, a key component of DACS.

Second, given the global footprint of the industry, there are a range of jurisdictions that might be able to initiate DACS policy at a national or sub-national level. Some jurisdictions that have significant oil and gas industries could impose “upstream” regulation on the extraction of oil and gas from the ground requiring that a certain amount of carbon dioxide be sequestered for each gallon of oil extracted. Countries like Norway or sub-national jurisdictions like California that have substantial oil and gas industries but also have been leaders on climate policy could lead the way. Other jurisdictions could impose “downstream” regulation, requiring the sequestration of a certain amount of carbon dioxide for each gallon of oil sold. This would be similar to the Low Carbon Fuel Standard in California, which already has a direct air capture option for compliance. Almost any country with substantial amounts of oil consumption could take this approach. And either kind of jurisdiction could use subsidies to encourage DACS.

Third, the global footprint of the industry also creates possibilities that pro-DACS policy in one jurisdiction might encourage development of DACS in other countries. In the context of electric vehicles, the global nature of automobile supply chains and research and development means that if enough major markets (e.g., China, California, the EU) mandate electric vehicle development, auto makers will deploy electric vehicles on a global scale. In contrast, because electricity utilities are national or regional in scope, the primary extraterritorial effect of renewable energy policy in one jurisdiction is to advance technological innovation and cost reductions that might apply in other countries. Adoption of DACS by the global oil and gas industry probably falls within these examples – it is more globally integrated than the electricity industry, but unlike automobiles, an oil and gas company could easily deploy DACS in jurisdictions where it is mandated, but not in others. Still, the global nature of the industry means that learning within a global company can spread throughout the organization to other parts of the world, which might facilitate the spread of DACS.

A pro-DACS policy that is based on EOR has real limits – EOR can only cover a fraction of the carbon sequestration that we will require in the 21st century. So it is crucial that any pro-DACS policy can create new interest group coalitions that can advance DACS going forward, in addition to reducing the costs of the technology through investment and innovation. One possibility is that pro-DACS policies cause incumbent oil and gas companies to become more sympathetic to climate policy that is DACS-focused, since they now have investments in DACS. Another possibility is that pro-DACS policies might inspire new entrants – such as Tesla in the electric vehicle space – that provide DACS and compete with established incumbents. In the automobile context, both pathways appear to be occurring, and there is no reason why that could not occur in this context as well.

It is also important to set pro-DACS policies in a way that they truly do force, over time, a reduction in emissions from the oil and gas industry and advance real carbon reductions, rather than simply extending the lifetime of business-as-usual for existing fossil fuel companies. Thus, any pro-DACS policies should have aggressive ratchets in regulatory stringency or policy targets for subsidies.

Building on the models of prior decarbonization policies in renewable energy and electric vehicles – both in terms of political feasibility now and in the future – will be essential if we are to deploy DACS at the scale we need to stabilize the global climate in the 21st century.