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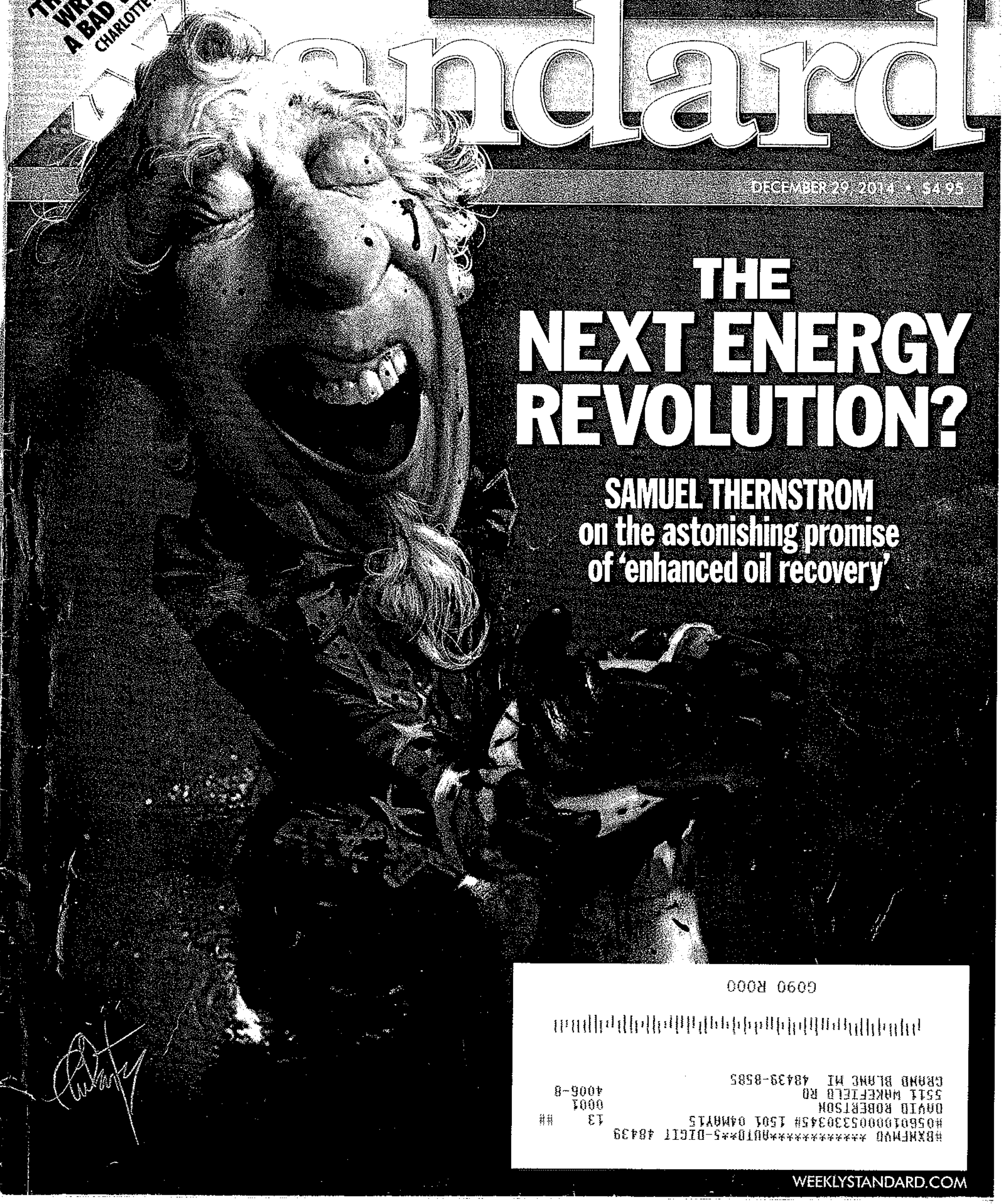
'THE GRAPES OF WRATH' WAS A BAD VINTAGE
CHARLOTTE ALLEN



THE NEXT ENERGY REVOLUTION?

SAMUEL THERNSTROM
on the astonishing promise of 'enhanced oil recovery'

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The Next Shale Revolution?

The astonishing promise of enhanced oil recovery

By Samuel Thernstrom

Just five years ago, almost no one outside the natural gas industry had heard of fracking, even though the basic technologies were not new; today, the shale gas revolution has transformed America's energy markets, with profound effects for economic growth, competitiveness, security, and environmental quality. In a nation still deeply concerned about its energy future, this extraordinary success story should prompt the question: Can we do it again?

The answer is yes—if we correctly understand both the model for innovation that shale gas exemplifies and an opportunity that now exists to emulate the shale model. That opportunity involves exploiting a technique called "enhanced oil recovery" (EOR).

Like fracking on the eve of its success, this concept is virtually unknown to most Americans, yet it rests not on pie-in-the-sky technological dreams but on the application and refinement of proven technologies that companies have been developing for decades. Like fracking, enhanced oil recovery has the potential to recover staggering quantities of hydrocarbons that were previously known but considered inaccessible. As with fracking, the primary players will be the private sector—but public policy has a crucial role to play in establishing the necessary conditions and providing the impetus for this market to take off. Most tantalizingly, enhanced oil recovery should be less controversial than fracking, because it also offers the opportunity to radically reduce greenhouse gas emissions from electric power generation (and other industries).

The shale gas revolution may have seemed to emerge out of nowhere, but it in fact represented the maturation of an industry that had been developing for decades, driven by advances in multiple technologies—hydraulic fracturing, directional drilling, and the combined-cycle natural gas power plant. In the nuance-allergic world of politics, this story is often spun either as a triumph of the free market or as proof of the power of government-funded R&D. In fact, both the government and the private sector deserve credit, and success depended in no small part on getting the relationship between the two sectors right.

Reviewing this history in a recent *National Affairs* essay, Jim Manzi identified three factors that drove the shale gas revolution: (1) America's system of property rights and pricing, which allowed innovators to reap the rewards of their work; (2) our highly skilled and competitive workforce and market for oil exploration, extraction, and associated services; and (3) government support for research, development, demonstration, and commercialization of these technologies.

As Manzi observes, we cannot know how much weight to give to the third factor—there's no way of knowing what would have happened without it—but the very companies that led the fracking revolution have been the first to acknowledge the significance of government support. It takes nothing away from the entrepreneurial geniuses who saw and pursued the potential of shale gas to acknowledge the public policy contributions to their success.

Federal support for shale gas development wasn't limited to basic research and development. It ran the gamut: early R&D support through the Eastern Shales Gas Project in 1976, a hand-off of technology to the private sector via the Gas Research Institute (a public-private institution funded by a charge on interstate gas sales), support for refinement of the technologies through further federal R&D in the 1980s, and a boost to its commercialization through tax incentives for the use of "unconventional gas" (as it was then called). Long after the core technologies were first developed, federal support for their refinement and commercialization continued.

Manzi's essay looks at the most important part of the equation—the revolutionary advances in technology for extracting gas from shale—but there was another element of

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the story that wasn't inconsequential: the combined-cycle gas turbines that turn the gas into electricity. Why do we have such efficient natural gas power plants? Because the Department of Defense invested well over a billion dollars over three decades to improve the performance of jet turbines for military aircraft—and then the Department of Energy spent millions more to apply that knowledge to power generation.

An unfortunate legacy of the Obama administration's tainted record on green energy investments has been a loss of conservative support for this model of innovation. Overreach-and-backlash may be an unavoidable dynamic in politics, but it would be a mistake to assume that this administration's missteps on energy innovation reflect inherent obstacles to success in the field.

In fact, the opportunity that enhanced oil recovery offers today is much clearer than that of shale gas in 1976, when President Ford first focused federal attention on its potential. EOR's core technologies work well, and the market is much more advanced than shale gas was in the 1970s. But a focused public push to expand the market for EOR and bring next-generation technologies forward could still have profound effects on America's energy future.

A Mississippi EOR facility using geologic CO_2

Using known and next-generation technologies and processes, enhanced oil recovery could increase domestic oil production—mostly from existing wells, not new fields—by tens of billions of barrels. Public policies to jump-start this nascent market could significantly enhance our energy security, improve our balance of trade, and generate tens of billions of dollars in revenue for the federal government and trillions in economic activity over the next half-century.

Equally important is the answer offered by EOR to two of the most pressing questions in energy policy: *What is the future of coal in this country, and what can the federal government do to reduce the risks of climate change?* The answer EOR offers is uniquely compelling: *Coal stays in our energy mix while almost all of its carbon gets trapped underground.*

The key to this opportunity lies in the fact that carbon dioxide is the essential ingredient in enhanced oil recovery operations. And in contrast to EPA's divisive, expensive, and likely ineffective approach to regulating carbon emissions, EOR would give American companies an opportunity to make money putting carbon dioxide underground while producing oil, making this a wealthier, more productive country with a stronger, more secure energy economy and a cleaner environment.

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Drillers have long understood that they leave most of their product in the ground. As oil is pumped, the pressure underground drops and it becomes harder to extract what remains. Typically, only about one-third of the oil in a given location can be economically removed. As a result, many supposedly "depleted" wells actually still contain most of their oil—just waiting for a technology that will make it economical to extract it.

In the early 1970s, drillers in west Texas figured out how to do just that, and the remarkable secret to their success was carbon dioxide. Pumping carbon dioxide into depleted wells not only increases the pressure, it also acts as a solvent, helping to separate oil from the cavities in the rock where it is trapped and the water it is often mixed with. This process enables oil companies to extract as much as another third of a site's oil—essentially doubling a well's productivity.

One might think that such a remarkable technology would be an overnight sensation. But in fact, we are nowhere near capitalizing upon EOR's full potential. Since the 1970s, oil companies have injected about a billion tons of carbon dioxide into "depleted" wells, producing roughly 2.5 billion barrels of oil. About 6 percent of the oil produced in America is now extracted using this technique. We know it works—but it's still a niche market.

What's holding us back? A shortage of carbon dioxide. The carbon dioxide used in EOR operations is predominantly geologic—companies tap into underground deposits and extract CO_2 for enhanced oil recovery and other commercial applications. That's how it's been done since the 1970s, but two important things have changed in recent years. Climate change has become the preeminent environmental concern, and new studies have shown that there is *much* more oil reachable through EOR than had been previously understood—so much so that geologic carbon dioxide supplies aren't nearly sufficient. If we want to get that oil, we'll have to capture carbon dioxide from industrial sources, such as coal-fired power plants.

Which brings us to the interesting place we find ourselves today: Our nation's top environmental goal is reducing carbon dioxide emissions. And one of our top energy priorities is maximizing production from domestic oil reserves. Capturing carbon dioxide from power plants and using it for EOR could produce billions of barrels of oil while simultaneously putting billions of tons of carbon dioxide underground forever. Yet policymakers are doing next to nothing to take advantage of this unique opportunity. Instead, Washington is preparing to fight a pitched legal and political battle over proposed EPA power plant regulations that will, even if implemented, make barely a dent in America's carbon emissions.

Why is so much carbon dioxide being released into the atmosphere if it's valuable? Because the costs and benefits don't quite align—yet. But Congress could easily change that. There isn't much of a market for carbon dioxide from power plants because the costs of capture typically exceed the market price of carbon dioxide. Oil companies might pay $30 or $40 a ton for carbon dioxide, but capturing it from a power plant can cost $80 a ton or more.

So imagine what would happen if the federal government provided a tax credit that bridged the difference—a credit, say, of $40 a ton. All of a sudden, we would have a market: Oil companies could continue to pay market prices for carbon dioxide, while utilities and other industrial sources could make money selling it to them. Instead of leaving all that oil underground while carbon continues to accumulate in the atmosphere, we could be in the business of sequestering billions of tons of carbon dioxide while producing billions more barrels of oil.

Fine, say the skeptics—but who wants to pay the cost of all those tax credits? New subsidies for energy aren't exactly popular on Capitol Hill these days. The difference, though, is that an EOR tax credit would more than pay for itself. Over time, its net effect on the Treasury would be positive to the tune of tens of billions of dollars.

Pumping a ton of carbon dioxide into a well produces roughly two-and-a-half to three barrels of oil; on average, each barrel generates $23 or so in federal and state taxes and royalties (depending on the location and price of the oil, of course). So each ton of carbon dioxide used for enhanced oil recovery would create about $58 in revenues. Even after covering the cost of a $40 per ton tax credit, the Treasury would come out ahead. And when the additional oil production is measured in the billions of barrels, the revenues—not even counting the effect of the added oil production on economic growth—would be substantial.

It's worth noting that not all sources of carbon dioxide would require that level of subsidy, but power plants are the largest potential supplier of carbon dioxide. And over time, as technology and efficiency improve, costs should come down and the need for tax incentives should as well.

Other public policies could also make EOR more attractive, reducing the need for tax credits. Tax-free bonds, for example, would improve the economics of many EOR projects; we issue such bonds for many other privately owned pollution-control systems but not for carbon capture. Congress could grant that authority, and advocates of this concept believe it would make many EOR projects economically feasible.

The EOR industry is going to grow on its own in the coming years, but public policy could greatly increase the pace and scale of its expansion. And while the market-focused mechanisms just described would have the most immediate effect, the shale gas model suggests that continued federal support for advanced R&D might be helpful as well.

To maximize the EOR opportunity, public policies should seek to ensure that the technologies can be applied widely and that the industry and its markets mature as quickly as possible, phasing out the need for financial incentives. Achieving both of those goals depends upon the same thing: development and demonstration of next-generation EOR technologies that will increase their efficiency and expand their applicability in geologically suboptimal conditions. Federal support could speed up that process.

Right now, EOR operations are centered in west Texas in the Permian Basin, in fields with very favorable geology. Under such optimal conditions, particularly in higher quality fields, the process is efficient: For every metric ton of carbon dioxide injected, 2.5 barrels of oil are produced. To maximize the market, though, we would want companies to be able to operate in more geologically challenging settings such as the Rocky Mountains, the Mid-Continent, and second-tier Permian Basin fields. In those places, EOR is pricier and less efficient; productivity tends to fall to 2 barrels of oil per ton of carbon dioxide injected.

How to overcome that? Even modest federal (and/or state) support for research and development and, importantly, incentives for demonstration of more efficient EOR technologies for these geologically challenging contexts could be very helpful. Will the industry get there on its own? Probably, someday—but federal funding would almost certainly accelerate that process.

The issue is not merely maximizing the geographic scope and scale of EOR operations; this is also the path to making the markets self-sufficient, which would certainly be in the public interest. More efficient next-generation EOR technologies would make carbon dioxide more productive and consequently more valuable, reducing the need for tax incentives.

For example: If oil producers in the more challenging Rockies or Gulf Coast oil fields are able to recover only two barrels of oil per metric ton of carbon dioxide, and a ton of carbon dioxide costs $40, the CO_2 cost per barrel of oil produced is $20. But next-generation technology might make it possible to recover three barrels of oil for every ton of carbon dioxide used. That would mean the industry could afford to pay $60 per ton of carbon dioxide while keeping its costs constant at $20 per barrel. And as carbon dioxide becomes more valuable, tax credits could be phased out.

If public policies can accelerate the rate at which the industry moves along that cost curve—more efficient technologies, bigger markets—the payoff will be enormous. Domestic EOR operations now produce about 300,000 barrels of oil a day, but if the market took off, they could produce 10 times that amount.

People will understandably be skeptical of these claims. They've heard too many overblown promises from energy and environmental advocates. One important attraction of this concept, however, is that it puts the private sector in the role of evaluating commercial risks and financing projects; it only costs the government money once the process is nearly complete. So if the tax credit fails, it'll fail cheaply. To earn the credit, the carbon dioxide would have to be captured and injected into an oil field; at that point, we can be pretty confident that oil is going to be produced as a result. If the assumptions about the market effect of the tax incentive turn out to be wrong and companies don't find it profitable to do EOR, there simply won't be take-up on the tax credit; net cost, nothing.

This sort of public policy decision seems categorically different from government bureaucrats placing blind (if not biased) bets on an individual company's ability to build a new plant to produce a new commercial product that has to compete in complex, ever-changing global markets, as was the case with Obama administration missteps such as Solyndra, the now-bankrupt maker of solar panels, and Fisker, the failed maker of electric cars.

Aspects of this concept are, of course, somewhat out of step with the desire for broad tax simplification and technology-neutral public policies—but given the lack of progress on those fronts, it seems unwise to hold this opportunity hostage to larger goals that may never be accomplished. And of course this is not a never-ending federal handout to a fundamentally unproductive technology, but a revenue-positive tax credit to jump-start a market that would generate trillions of dollars of new economic activity based around increased supplies of a commodity that is a linchpin of our economy.

Still, skeptics will rightly wonder why the government should be involved in something like this. The answer comes down to the fact that there is a compelling public interest at stake in two critical dimensions: Expanding EOR markets could arguably do more to improve American energy security—in both transportation and electricity-generation fuels—while simultaneously moving us closer to a zero-emissions energy system than any other single policy we could pursue. Even small-government conservatives should be willing to consider policies that leverage such significant outcomes out of limited federal interventions, particularly when the alternative is an expensive and ineffective regulatory approach to these issues.

This last point bears emphasizing: Industrial sources of carbon dioxide such as power plants would no longer be just electric generators in this context; they would become an integral part of the oil production process. There are places in America where there's a lot of oil to be had—if we had carbon dioxide to extract it. An EOR initiative would mean that the impetus to install carbon capture on power plants would no longer be a politically contentious pollution control measure imposed by Washington; instead, it would be a profitable way to harness an essential chemical for oil production.

It's also worth noting that EOR isn't the only way carbon might be productively utilized, although it is by far the largest, most reliable near-term opportunity. But there are a number of other potential markets for carbon dioxide, ranging from water desalination (where its use could cut costs significantly) to the production of chemicals, algae biofuels, and other commercial products. (In fact, carbon dioxide might even be used in fracking itself.) A host of companies are exploring these prospects; in October, a $125 million factory opened in Texas that uses a cement plant's carbon dioxide to make chemicals. If an EOR initiative created a multibillion-dollar market for carbon dioxide, supported by an extensive infrastructure for capturing and transporting the gas, these other potential uses of carbon dioxide would likely benefit as well.

It might seem fanciful to imagine that utilization could possibly compare to regulation as a tool for reducing carbon emissions, but the numbers suggest otherwise.

One thing that climate and energy issues have in common: *It's all about scale.* Whether the question is carbon reduction or energy production, it only really matters if you're talking about big numbers. So let's look at the potential size of enhanced oil recovery.

Recall that most "depleted" oil fields still contain a lot of oil. Last year, the leading consulting firm in this field, Advanced Resources International, took a fresh look at how much oil remains in major deposits in the Lower 48 where EOR might be used (and in 2014 extended their analysis, the findings of which are included here). The figures are eye-opening.

Of the 600 billion barrels originally in those reservoirs, 182 billion barrels have been produced, and another 22 billion barrels are proven reserves that can be extracted economically with existing technologies and practices. That accounts for 204 billion barrels, meaning that nearly 400 billion barrels—more than twice the total amount produced to date—are "stranded" in these oil fields.

Advanced Resources International estimates that today's EOR technologies—including the next-generation technologies that an EOR initiative could bring to market—would make an additional 85.4 billion barrels economical to extract (this assumes oil prices at or above $90 a barrel and carbon dioxide prices at or below $40 a ton).

Those figures are conservative; for one thing, every time new oil fields are discovered, these numbers increase. Also, this estimate doesn't factor in the potential to reach into "residual oil zones," where oil is typically mixed with water and unavailable through conventional means. Residual oil zones contain another 140 billion barrels of oil, some significant fraction of which might be accessible using advanced EOR technologies. And, of course, if oil prices are higher than $90 a barrel—which, despite their recent decline, remains likely in the long run—or if EOR technologies and practices improve, then even more oil will become economical to produce.

Given that America's oil consumption is just under 7 billion barrels a year and domestic production is projected to top 3.1 billion barrels in 2014, the opportunity for federal policy to unlock access to 85 billion barrels of economical oil—potentially producing as much as an additional 2 to 3 million barrels of oil per day for the next 50 years—seems worthy of serious consideration to say the least.

The EOR opportunity is much bigger than Keystone XL—and it's American oil, not Canadian tar sands. It's bigger than the Arctic National Wildlife Refuge—and it involves extracting additional oil from existing fields; even the Natural Resources Defense Council approves of enhanced oil recovery as a pragmatic alternative to drilling new fields. And it could arguably do more for decarbonization than EPA regulations, yet it remains at the margins of the national conversation about energy and climate.

So the numbers are extraordinary on the energy supply side, but what about on the carbon reduction side? Democrats aren't likely to support a policy that's just drill-baby-drill; what's in it for them? Here too the tonnage is significant—and the strategic implications for decarbonization are even greater than the numbers alone suggest.

To produce the 85 billion barrels of oil that Advanced Resources International estimates EOR could economically reach in the United States, nearly 24 billion tons of carbon dioxide would be needed. Geologic (and low-cost industrial) sources might provide as much as 3 billion tons but other industrial and agricultural sources of carbon dioxide would be needed for the remainder—21 billion tons. When carbon dioxide is used in EOR operations, an initial fraction of it (roughly a third) remains underground; the rest comes up with the oil, where it can be recaptured and reused until it is all sequestered. You could think of EOR as a sophisticated form of carbon recycling and disposal.

If the only thing an EOR initiative did was to sequester 21 billion tons of carbon dioxide, it would still merit serious consideration. But the real measure of success is in innovation: What can EOR do to drive development of carbon capture and sequestration technologies?

Because carbon dioxide emissions are cumulative (carbon dioxide accumulates in the atmosphere), climate policies can't aspire simply to bend the U.S. emissions curve a bit. Stabilizing atmospheric concentrations of carbon dioxide—at any level, on any timeframe—depends on our ability to virtually eliminate emissions from key sectors such as electric power generation, and to do it globally. Incremental reductions aren't enough; you've got to get to zero.

Naturally, incremental reductions that reflect real progress toward that goal are productive—but not all policies that reduce emissions incrementally lead to zero. Natural gas proponents like to call it a "bridge fuel," neatly sidestepping the question of what lies on the other side of the bridge or how the two ends connect. Using more gas and less coal will lower emissions, but, without carbon capture, the improvement is 50 percent at best (and probably less). So if the goal is near-zero emissions, whether the fuel is coal or gas, there's no way to get there without carbon capture and sequestration.

Given the extraordinary abundance and affordability of coal and natural gas and the enormous established infrastructure for those fuels, pragmatists recognize that there is no practical path to decarbonization that doesn't start with the assumption that the world is going to continue to burn them for the foreseeable future. Progress on decarbonization depends therefore not on dreams of a day when the world agrees to leave fossil fuels in the ground but rather on finding practical ways to put their carbon dioxide back underground through carbon capture and sequestration, not just in advanced economies but also in the developing world. The metric of success for a climate policy should not be just the tonnage of avoided annual emissions; the more important question is whether we are making decarbonization possible and practical on a global scale.

Here's the thing about carbon capture and sequestration: We know how to do it—but it's far from being a mature technology. Capturing carbon dioxide from power plants is a challenging business, and doing it on a global scale will require advanced technologies and practices, a skilled workforce, robust markets, and extensive infrastructure. It's a long road from here to there. We can see the technology's potential, but without a practical path to commercialization, its development will be slow.

Although basic carbon capture and sequestration technologies have been demonstrated in varying configurations for decades, companies are only just beginning to do carbon capture and sequestration at full scale on power plants (including one that just opened in Canada, and another that will open in Mississippi in 2015). That means the technology is still at the most expensive stage of the learning curve, and there is almost no market demand for it today that would drive the necessary investments in innovation.

For carbon capture and sequestration to work well enough for both developed and developing nations to use it at scale, the core technologies and their associated markets and regulations will need to be much more developed, and costs will have to come down considerably. Assessments of the technology strongly suggest that can happen—but it will require finding a way to build a lot of these facilities and their supporting infrastructure, learn how to operate them efficiently, and learn how to build better ones. What is needed most is not just more research (although there's a role for that) but rather a way to pay the cost of building carbon capture and sequestration projects today at scale—to "learn by doing"—and to create market demand for next-generation technologies.

Regardless of one's stance on climate risks, finding cost-effective ways to develop carbon capture and sequestration technologies is important. The EPA's regulatory approach won't be the death of coal, but it will bring stagnation and long-term decline for the industry. Just the threat of EPA regulations—which will persist for years as the regulatory and legal processes play out—will deter the capital investments the industry needs to move forward. Over the long run, for coal to continue to serve as one of the bedrock fuels for electric generation in America, technologies to manage its carbon emissions will be indispensable. Unfortunately, EPA's regulatory proposals look like they may do little, if anything, to drive their development, so if we want to find ways to make carbon capture and sequestration work, we'll have to think about other approaches.

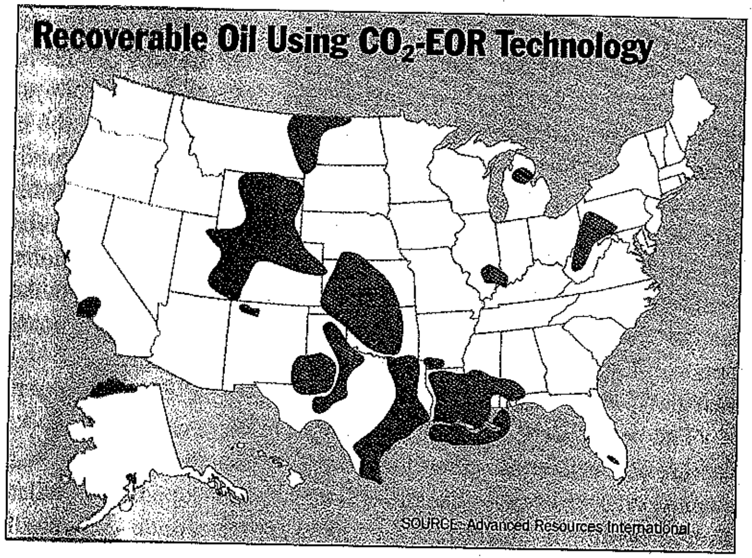
Policymakers looking to advance the development of carbon capture and sequestration techniques have three basic models at their disposal.

Option 1 is to have the federal government fund demonstration projects directly. We tried that during the George W. Bush administration, which selected a project known as FutureGen to be built in Illinois. After more than a decade of delays, that project has only just broken ground, so no one is looking to build on that model. The Bush administration also created, and Obama expanded, a Clean Coal Power Initiative that has helped fund the few carbon capture and sequestration projects that are getting underway—but since it requires a 50 percent cost-share from project developers, it's still a far cry from what would be needed to make a significant number of carbon capture and sequestration projects economical. That approach costs taxpayers too much while providing project developers too little support.

Option 2 is the Obama administration's approach: EPA limits on power plant emissions. It's anyone's guess what will emerge from the legal, political, and bureaucratic battles over EPA's proposed regulations, but one thing is fairly clear. The primary effect of whatever regulations survive scrutiny will be to encourage utilities to burn more natural gas and less coal, particularly over the next 15 years. This is one of the problems with setting modest targets for emissions reductions—industry's primary incentive is to seek low-cost compliance options such as fuel-switching rather than investing in development of deep decarbonization technologies such as carbon capture and sequestration.

That provides politicians the satisfying appearance of progress—*look, we're reducing emissions!*—while doing little to move us towards commercialization of near-zero emissions technologies such as carbon capture. Policies that promote fuel-switching take us on a slightly faster path to a somewhat lower but still-high emissions plateau. If we want to get to near-zero emissions from these power plants, we'll need policies that specifically target development of carbon capture and sequestration technologies and markets.

Which brings us to option 3, enhanced oil recovery. To provide the 21 billion tons of carbon dioxide needed for EOR to reach the 85 billion barrels of economical oil, utilities would need to install carbon capture equipment on about 122 gigawatts worth of coal-fired power plants (assuming for the sake of simplicity that all the carbon dioxide came from power plants—in fact, some would come from other sources). That would mean putting carbon capture and sequestration on roughly *half of the coal plants*



expected to be in operation over the next 30 years (taking anticipated plant retirements into account).

The significance of that figure can hardly be overstated. EPA regulations aren't going to put carbon capture and sequestration on half the coal fleet—not even close. Federal demonstration projects and grants certainly won't. EOR demand could generate over $800 billion in revenue from carbon dioxide sales, much of which could be invested in developing and operating the infrastructure of carbon capture and transportation. Where else is that level of investment going to come from?

EOR's revenues offer what is almost certainly the only practical path to making the investments necessary to demonstrate carbon capture and sequestration technologies at scale, build out supporting infrastructure, and develop the legal, financial, commercial, and institutional structures and relationships that would make the industry a credible option for decarbonization. And a policy push for EOR would put American companies at the forefront of another energy revolution, just as they are with fracking, with the opportunity to sell technologies and services in potentially vast global markets.

The best evidence for EOR's potential to drive carbon capture and sequestration development is that it's doing so already, even without the benefit of strong federal support. Every new carbon capture and sequestration project underway or recently opened in North America—Southern Company's Kemper project in Mississippi, a new power plant with carbon capture and sequestration; SaskPower's Boundary Dam project retrofitting carbon capture and sequestration to an existing coal-fired power plant in Saskatchewan, Canada; and NRG Energy's newly announced W. Parish project near Houston—relies heavily on EOR revenues (as well as government grants). Because of the location of the plant, NRG is also able to take advantage of tax-free bonding of the kind that could help other EOR projects.

Having said that EOR's potential to drive carbon capture and sequestration could hardly be overstated, I should make sure that I haven't done just that. EOR is a way to instigate and pay for the development of advanced carbon capture and sequestration technologies and infrastructure, as well as the legal, governmental, and commercial structures necessary for the industry to thrive. The size of the EOR opportunity will probably increase over time. But recycling carbon into oil production and other products won't solve the carbon dioxide issue entirely. EOR markets might cover the costs of sequestering an awful lot of carbon dioxide for a long time—but not forever. Some day, policymakers would have to revisit the question of how much they might be willing to pay to continue sequestration.

But by that time, they wouldn't be fighting a pitched battle over whether a federal agency can and should impose regulations requiring the use of an immature technology that is not yet proven on a commercial scale, where the price and performance of the technology remain uncertain and daunting. Instead, they would be making a well-informed decision about the continued use of a highly refined technology with well-understood costs and performance characteristics that is supported by an extensive, sophisticated physical and commercial infrastructure. By that point, costs of sequestration should be dramatically lower than they are today.

We can't know how much society might value decarbonization in the future, we can only work on finding practical ways to develop tools that could do the job, recognizing that the lack of such options is the primary source of political conflict over carbon today. Instead of placing blind bets on Rube Goldberg regulatory schemes resting on creative interpretations of outdated laws and a host of farfetched assumptions, climate advocates would be asking governments to make informed choices about using proven, affordable technologies. That would be a very different conversation.

One other issue requires consideration: the emissions from burning the oil that enhanced oil recovery would produce. To many environmentalists, using carbon to produce more fossil fuels could hardly be more perverse. How does this get us ahead? This is, unfortunately, a very complex question. Let me sketch the outlines of an answer.

Emissions from transportation and from generating electricity are in a sense almost entirely separate issues. In both sectors, decarbonization using today's technologies is impractical; success depends on developing innovative technologies with far better price and performance than we have today. If we want decarbonization options for electric power, we need policies that will develop those technologies; if we want better transportation options, we need polices that target those technologies.

Enhanced oil recovery, as I have argued, is the only realistic path to developing carbon capture and sequestration technologies, which will be needed for decarbonizing electric generation. Decarbonizing transportation systems is mostly a different question—although it's worth noting that carbon capture and sequestration is also essential for low-carbon transportation options such as electrification and some alternative fuels.

The important thing to appreciate is that the development of those transportation technologies is not going to be hindered by the production of another 60 or 80 or even 100 billion barrels of oil in the United States. Those technologies will rise or fall on their merits, and when they can compete with conventional cars and trucks and buses, they'll win; the marginal effect that EOR will have on the price and production of oil won't hinder that process.

That's a conceptual answer to the question, but some people will want to understand the math as well: Will producing more oil in America using EOR increase or decrease carbon dioxide emissions?

The long-term answer to that depends not on simple carbon-in, carbon-out arithmetic but on one's assumptions about EOR's influence on the oil and electric power markets. If one thinks of EOR's oil as *additive*—additional oil that would otherwise not be consumed—and doesn't take into account the displacement of more carbon-intensive electric power by carbon capture and sequestration, then EOR could release more carbon dioxide than it eliminates. But if you believe that oil produced by EOR will mostly *displace* imported oil, and that low-carbon electricity from carbon capture and sequestration will displace higher-carbon power—which seems likely, at least to some extent—then EOR will sequester more carbon dioxide than it produces.

To give an example of the complexity of the calculations: Critics of EOR often cite a 2009 study by Carnegie Mellon's Paulina Jaramillo (with coauthors W. Michael Griffin and Sean T. McCoy), which concluded that each ton of carbon dioxide injected in EOR operations produces oil that releases 3.7 to 4.7 tons of carbon dioxide emissions.

Sounds pretty bad, right? But that figure assumes the oil and electricity from EOR are added to what's already available; naturally, that means net emissions increase. If you incorporate the more realistic assumption that the oil and electricity produced by EOR and carbon capture and sequestration would displace other energy from the market, Jaramillo concedes that EOR reduces net emissions by about 20 percent, a figure that rises to 30 percent when compared with Canadian tar sands oil and new coal plants. The National Environmental Technology Laboratory (NETL) also looked at this question last year and came to similar conclusions (although their figure for EOR's additive emissions is 1.7 tons of carbon dioxide, a much lower figure than Jaramillo's).

These studies are far from perfect—answers to these questions depend on long-term projections about the behavior of oil and electricity markets during periods of significant change—but the broad picture they paint is probably not far from the mark.

Here's a simpler way to think about this question in present-day terms: A barrel of oil contains 0.43 metric tons of carbon dioxide. As mentioned previously, current EOR operations in the Permian Basin use 0.4 metric tons of carbon dioxide per barrel of oil recovered; even without taking displacement into account, that process is essentially carbon neutral. Add in the displacement of conventional oil and we are well on our way to net sequestration.

One can think of the combination of enhanced oil recovery with carbon capture and sequestration as providing low-carbon power or low-carbon-dioxide oil, or arguably both, but certainly not neither. EOR's direct effect on carbon dioxide emissions may be somewhat uncertain, but at worst it's a wash, and more likely it sequesters more carbon than it produces. What is indisputable is the progress it could provide toward the metric that matters most: EOR is the only plausible way to pay for the development of advanced carbon capture and sequestration technologies and the billions of dollars of infrastructure investments that will be necessary to make the technology a workable option for controlling carbon dioxide emissions from fossil fuels.

Whatever one concludes about the direct sequestration question, anyone who is serious about practical decarbonization pathways cannot afford to ignore EOR. It's difficult to compare EOR's direct annual emissions reductions to the possible effects of EPA's regulatory proposals, but if our ultimate goal is a practical pathway to commercialization of carbon capture and sequestration, the potential power of markets for carbon dioxide utilization cannot be denied.

Carbon utilization is not receiving nearly the attention it deserves. We should be having a national conversation about enhanced oil recovery; instead, we are obsessed with issues that are almost trivial in comparison. The basic facts of the matter seem clear: Carbon capture and sequestration is probably indispensable to any pragmatic approach to decarbonization, and EOR appears to be the only practical way to underwrite the extensive upfront costs of developing carbon capture and sequestration technologies, infrastructure, and markets.

Using carbon capture and sequestration to enable enhanced oil recovery is the path to keeping coal in our energy economy while simultaneously achieving our environmental goals; without it, we are likely to lose both battles. The choice is between a declining-but-not-disappearing coal industry that can't invest in innovation and a thriving, productive industry that could develop effective carbon management technologies. EOR could produce tens of billions of barrels of oil in America while sequestering billions of tons of carbon dioxide and driving over $800 billion in investments in decarbonization and energy production technologies. And it would establish a different model for meeting the climate challenge: *Make decarbonization technologies affordable and productive rather than trying to make carbon-intensive energy more expensive.*

A national enhanced oil recovery initiative wouldn't entirely protect America from the vagaries of global oil markets or fully eliminate carbon dioxide emissions from our electric power plants—but it would make genuine, important progress on both fronts, and that would be no small feat. ♦