



SHALE 2.0
Technology and the
Coming Big-Data Revolution
in America's Shale Oil Fields

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With petroleum prices down 50 percent over the past year, many analysts and pundits are predicting the end of America's shale oil boom. Recent headlines include: "Oil Price Fall Forces North Dakota to Consider Austerity" (*New York Times*);¹ "Oil Price Drop Hurts Spending on Business Investments" (*Wall Street Journal*);² "The American Oil Boom Won't Last Long at \$65 per Barrel" (Bloomberg Business);³ and "The Shale Oil Revolution Is in Danger" (*Fortune*).⁴

High prices, shale skeptics argue, created a bubble of activity in unsustainably expensive shale fields. As shale-related businesses contract, consolidate, and adjust to the new price regime, a major shale bust is inevitable, they add, with ghost towns littering idle fields from Texas to North Dakota.

It is true that the oil-price collapse was caused by the astonishing, unexpected growth in U.S. shale output, responsible for three-fourths of new global oil supply since 2008. And as lower prices roil operators and investors, the shale skeptics' case may seem vindicated. But their history is false: the shale revolution, "Shale 1.0," was sparked not by high prices—it began when prices were at today's low levels—but by the invention of new technologies. Now, the skeptics' forecasts are likely to be as flawed as their history. This paper explains how continued technological progress, particularly in big-data analytics, has the U.S. shale industry poised for another, longer boom, a "Shale 2.0."

The End of the Beginning

John Shaw, chair of Harvard's Earth and Planetary Sciences Department, recently observed: "It's fair to say we're not at the end of this [shale] era, we're at the very beginning."⁵ He is precisely correct. In recent years, the technology deployed in America's shale fields has advanced more rapidly than in any other segment of the energy industry. Shale 2.0 promises to ultimately yield break-even costs of \$5–\$20 per barrel—in the same range as Saudi Arabia's vaunted low-cost fields.

The shale industry is unlike any other conventional hydrocarbon or alternative energy sector, in that it shares a growth trajectory far more similar to that of Silicon Valley's tech firms. In less than a decade, U.S. shale oil revenues have soared, from nearly zero to more than \$70 billion annually (even after accounting for the recent price plunge). Such growth is 600 percent greater than that experienced by America's heavily subsidized solar industry over the same period.⁶

Shale's spectacular rise is also generating massive quantities of data: the \$600 billion⁷ in U.S. shale infrastructure investments and the nearly 2,000 million well-feet drilled have produced hundreds of petabytes of relevant data. This vast, diverse shale data domain—comparable in scale with the global digital health care data domain—remains largely untapped and is ripe to be mined by emerging big-data analytics.

Shale 2.0 will thus be data-driven. It will be centered in the United States. And it will be one in which entrepreneurs, especially those skilled in analytics, will create vast wealth and further disrupt oil geopolitics. The transition to Shale 2.0 will take the following steps:

1. Oil from Shale 1.0 will be sold from the oversupply currently filling up storage tanks.
2. More oil will be unleashed from the surplus of shale wells already drilled but not in production.
3. Companies will "high-grade" shale assets, replacing older techniques with the newest, most productive technologies in the richest parts of the fields.
4. As the shale industry begins to embrace big-data analytics, Shale 2.0 begins.

Further, if the U.S. is to fully reap the economic and geopolitical benefits of Shale 2.0, Congress and the administration should:

1. Remove the old, no longer relevant, rules prohibiting American companies from selling crude oil overseas.
2. Remove constraints, established by the 1920 Merchant Marine Act, on transporting domestic hydrocarbons by ship.
3. Avoid inflicting further regulatory hurdles on an already heavily regulated industry.
4. Open up and accelerate access to exploration and production on federally controlled lands.

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Mills is a contributor to Forbes.com and is coauthor of *The Bottomless Well: The Twilight of Fuel, the Virtue of Waste, and Why We Will Never Run Out of Energy* (Basic Books, 2005), which rose to #1 on Amazon's science and math rankings. His articles have been published in various popular outlets, including the *Wall Street Journal* and *New York Times Magazine*. Mills is also a frequent guest on CNN, FOX, NBC, and PBS, and has appeared on *The Daily Show with Jon Stewart*.

Earlier, Mills was a technology adviser for Bank of America Securities, and a coauthor of a successful energy-tech investment newsletter, the *Huber-Mills Digital Power Report*. He has testified before Congress and has briefed many state public service commissions and legislators. Mills served in the White House Science Office under President Reagan, and subsequently provided science and technology policy counsel to numerous private sector firms, the Department of Energy, and U.S. research laboratories.

Early in his career, Mills was an experimental physicist and development engineer, working at Bell Northern Research (Canada's Bell Labs) and the RCA David Sarnoff Research Center on microprocessors, fiber optics, missile guidance, nuclear energy, and non-proliferation. He earned several patents for his work in these fields. Mills holds a degree in physics from Queen's University, Canada.

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SHALE 2.0

TECHNOLOGY AND THE COMING BIG-DATA REVOLUTION IN AMERICA'S SHALE OIL FIELDS

Mark P. Mills

INTRODUCTION

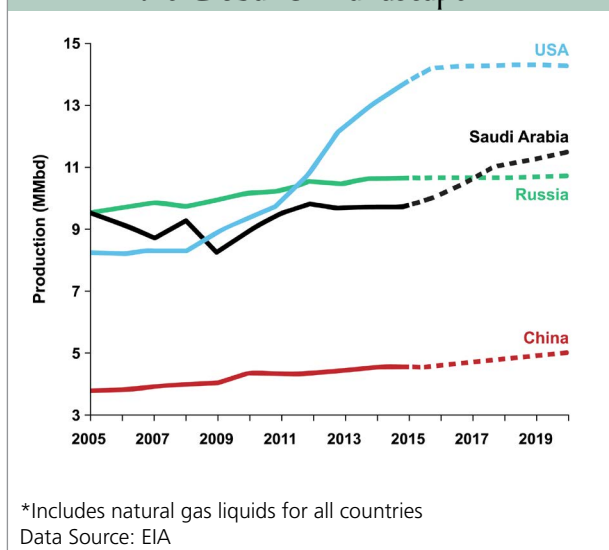
In 2014, America's oil production grew by 1.2 million barrels per day (MMbd)—the greatest single-year increase since the oil age began more than a century ago.⁸ Over the past half-dozen years, U.S. oil output rose by a total of 4 MMbd, with most of the growth in the past three years (**Figure 1**).

The invention by American entrepreneurs of a new way to manufacture oil from shale, at volumes and prices that have moved global markets, has been the biggest disruption to the energy landscape in 30 years. If the U.S. shale industry alone were a country, it would rank as the world's fifth-largest hydrocarbon producer.

The last time so much oil was added in such a short period to world markets was in 1986, when Saudi Arabia—which then enjoyed far greater spare capacity than it now does⁹—made a strategic decision to increase output by 3 MMbd. That flood of oil drove global prices down to \$20 per barrel (2014 USD). This time, the plunge in prices was caused not by a foreign oil monarchy but by thousands of American entrepreneurs drilling on state and private lands.

The new American oil landscape is not the result of government programs or incentives; in recent years, the federal government's role in the oil business has been neutral, at best, and oppositional, at worst. America's new oil landscape is also not the result of recent discoveries: the vast hydrocarbon shale fields were discovered and mapped a century ago. Instead, the recent disruption to the global supply-demand balance is the result of the maturation and

Figure 1. U.S. Shale Production Changed the Global Oil Landscape*



deployment of new technologies that enabled the economic production of oil from shale.

Although America’s shale industry is new, its scale is such that it is now a permanent fixture of the U.S. techno-industrial base. The U.S. shale ecosystem has exploded—from essentially nonexistent, just over a decade ago—to a \$300 billion component of GDP, featuring thousands of companies. The U.S. shale ecosystem is also a distinctly different industry, in structure, operation, and technique, compared with its cousin, the conventional hydrocarbon industry.

But the price collapse has started to affect U.S. shale oil production. In January 2015, output trended down, by 0.12 MMbbl, compared with the previous month, for the first time since 2010. Lower prices mean that certain shale companies with weak financials will end up being acquired, while others will go bust.¹⁰

Over the past six months, the tone of media coverage of America’s shale industry has shifted, from awe to alarm and pessimism. Recent headlines include: “Oil Price Fall Forces North Dakota to Consider Austerity” (*New York Times*);¹¹ “Oil Price Drop Hurts Spending on Business Investments” (*Wall Street Journal*);¹² “The American Oil Boom Won’t Last Long at

\$65 per Barrel” (*Bloomberg Business*);¹³ “The Shale Oil Revolution Is in Danger” (*Fortune*);¹⁴ and “United States Will Not Become the ‘New Saudi Arabia’ of Global Energy” (*Telegraph*).¹⁵

What if—absent exogenous events such as major wars and short-term price oscillations—oil never again sells for much more than \$60 per barrel for decades? This is a real possibility in a world consistently fully or episodically oversupplied with oil, especially if U.S. shale output continues. But can America’s shale industry survive?

In fact, in the roughly 150-year history of oil prices, there have been just three short periods where oil sold for more than (inflation-adjusted) \$50 per barrel (Figure 2). Yet over the same period, technological progress has enabled world oil production to soar by 6,500 percent.

But the recent plunge in oil prices has caused a precipitous drop in the use of U.S. drilling rigs (Figure 3). With the rig count the easiest, most widely publicized, measure of activity in the oil and gas industry, numerous media reports and pundits now argue that this is an ominous indicator of future oil output.

But the rig count alone is not a reliable indicator of what the future holds. The shale business is as

Figure 2. Oil Prices, 1861–2014

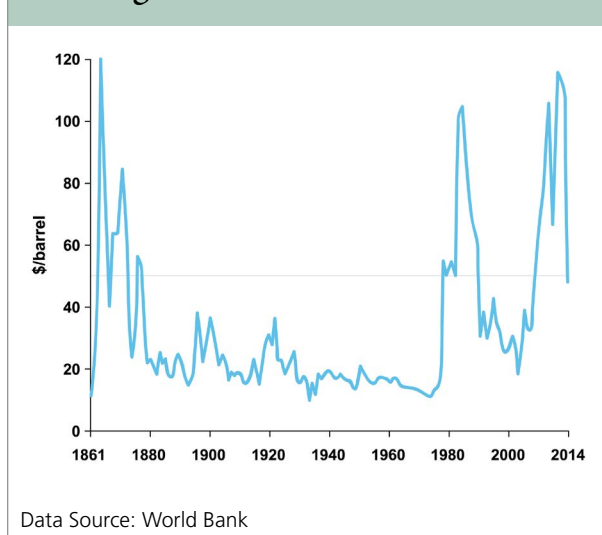
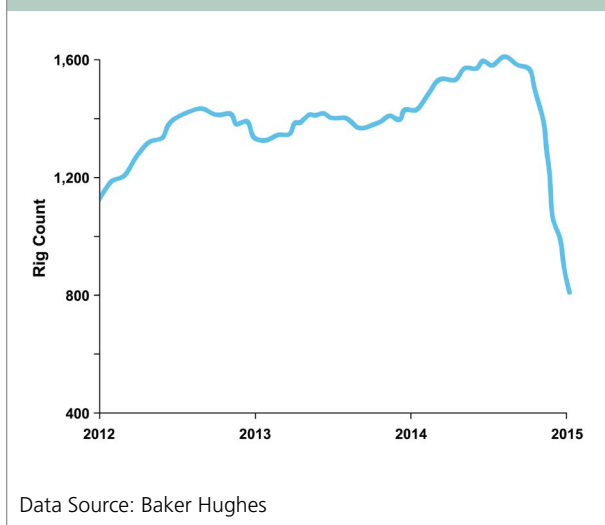


Figure 3. U.S. Oil Rig Count



different from its predecessor, conventional oil and gas, as the smartphone ecosystem is different from telephony. And just as the smartphone ecosystem is new and rapidly evolving, so, too, is the industrial ecosystem of shale hydrocarbons.

In the end, shale technology, as with any technology, is only useful if it can deliver the goods at ever-decreasing cost. Thus the central questions for analysts and investors about the future of America's young shale industry are: Where is the technology going? Can more oil be unlocked at lower costs and with fewer rigs?¹⁶

I. TECHNOLOGY: THE EPICENTER OF A NEW INDUSTRY

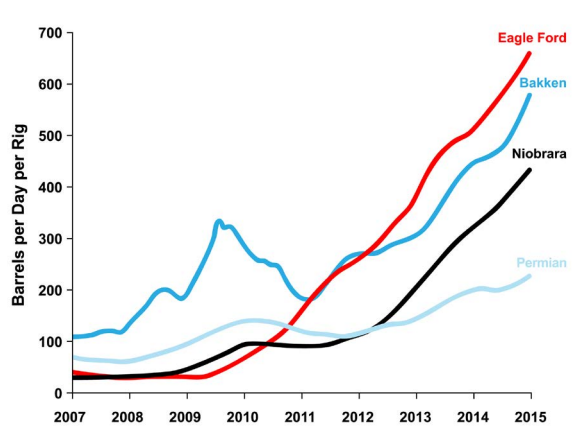
The price and availability of oil (and natural gas) are determined by three interlocking variables: politics, money, and technology. Hydrocarbons have existed in enormous quantities for millennia across the planet. Governments control land access and business freedoms. Access to capital and the nature of fiscal policy are also critical determinants of commerce, especially for capital-intensive industries. But were it not for technology, oil and natural gas would not flow, and the associated growth that these resources fuel would not materialize.

While the conventional and so-called unconventional (i.e., shale) oil industries display clear similarities in basic mechanics and operations—drills, pipes, and pumps—most of the conventional equipment, methods, and materials were not designed or optimized for the new techniques and challenges needed in shale. By innovatively applying old and new technologies, shale operators propelled a stunningly fast gain in the productivity of shale rigs (Figure 4), with costs per rig stable or declining.

Shale companies now produce more oil with two rigs than they did just a few years ago with three rigs, sometimes even spending less overall.¹⁷ At \$55 per barrel, at least one of the big players in the Texas Eagle Ford shale reports a 70 percent financial rate of return.¹⁸ If world prices rise slightly, to \$65 per barrel, some of the more efficient shale oil operators today would enjoy a higher rate of return than when oil stood at \$95 per barrel in 2012.¹⁹

Extracting hydrocarbons from shale is fundamentally different from extracting hydrocarbons from conventional wells. The former requires two distinct steps: (1) after drilling down vertically, 5,000–10,000 feet, to reach a shale formation, operators drill long, 5,000–10,000-foot horizontal wells; (2) hydraulic pressure is then used to fracture the rock (“frack”), releasing oil and gas.

Figure 4. Average Oil Production per Shale Well, Four Major Shale Fields, 2007–15



Data Source: EIA Drilling Productivity Report, February 2015

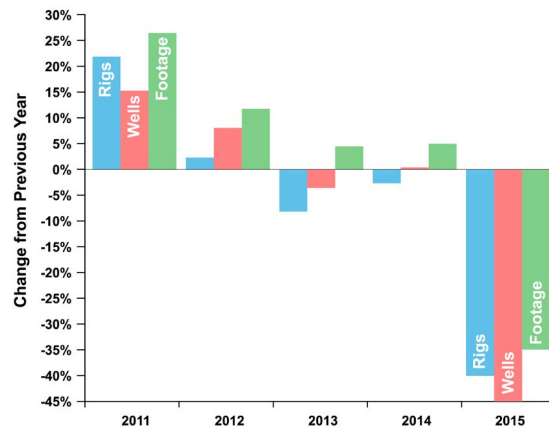
The time it takes to drill wells is a critical component of cost. On this front, the speed of improvement has been remarkable: with virtually no increase in capital costs (in some cases, costs are down),²⁰ the three key measures of drilling—time to drill, wells per rig, and total distance drilled—have improved by 50–150 percent in less than five years (Figure 5).

The number of feet of shale rock tapped is the first-order determinant of how much oil and gas are produced. Here, the net result of technology and operational innovation is clearly visible: total footage drilled grows faster than the growth in rig count (Figure 6). The inverse is true as well: a forecasted 40 percent drop in rig count will have a more modest (35 percent) decline in total new footage drilled.

The “walking rig” is one technological advance that has contributed greatly to gains in rig productivity. Rather than drill a single well from a well-pad, a walking rig can move around the pad, drilling multiple wells (sometimes dozens) (Figure 7).²¹ Since 2006, the use of such so-called pad drilling has grown dramatically, from a few percent to over 50 percent of new wells, with the potential to rise higher.²²

The use of older, less efficient “Generation 1” (Gen 1) and “Generation 2” (Gen 2) rigs began declining

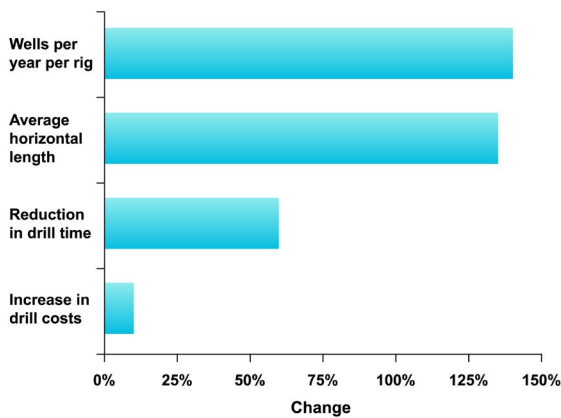
Figure 6. Technology Causes Rig Count to Disconnect from Well-Feet Drilled



Data Source: Drilling Contractor; and Spears & Associates, “Drilling Market Outlook”

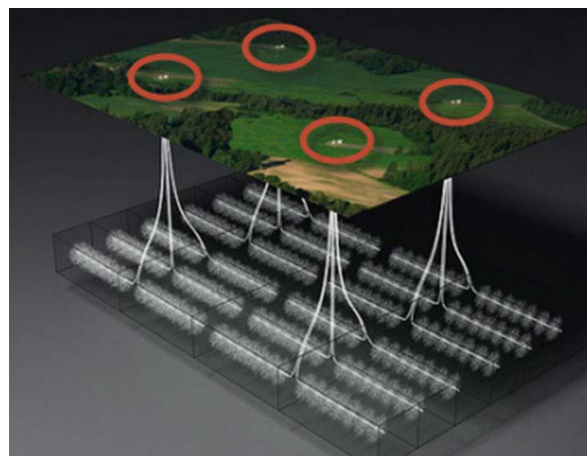
in 2011, long before the late 2014 overall rig falloff. (As of the first quarter of 2015, the number of Gen 1 rigs was down by 60 percent from peak use.) During 2011 to late 2014, as Gen 1 and Gen 2 rig use declined, the number of newer, faster, more powerful “Generation 3” (Gen 3) rigs rose by 60 percent. Even now, the number of Gen 3 rigs is down by only 25 percent, compared with the deeper overall plunge in Gen 1 and Gen 2 rigs (Figure 8).²³

Figure 5. Shale Rig Drilling Efficacy, Typical Four-Year Changes



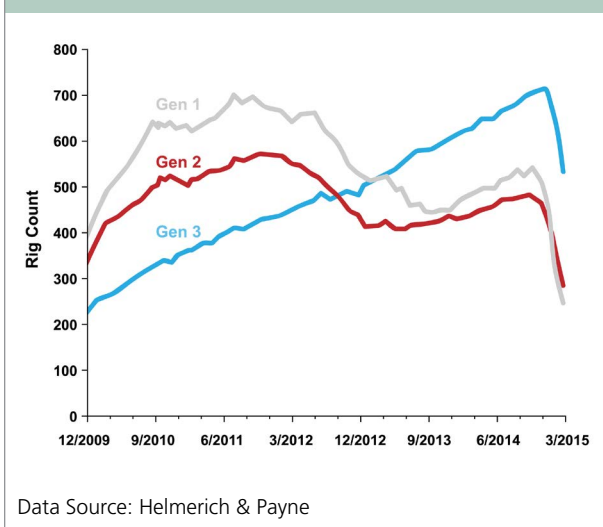
Data Source: Baker Hughes; and Spears & Associates

Figure 7. Drilling Multiple Wells from a Walking Rig



Source: EIA

Figure 8. Rig Count by Type of Technology



Once a well is drilled and 1–2 miles of horizontal pipe placed in the shale, the key factor that determines the well’s value is the effectiveness of the completion step (i.e., when hydrocarbon-bearing rock is stimulated to produce oil and gas). Spending on completion typically accounts for 50–60 percent of the total development cost of shale wells.²⁴ Here, too, productivity gains have been remarkable, with a 400 percent rise in output during a well’s first month of operation; even two to three years into production, technological advances have boosted output by 200 percent in just a few years.²⁵

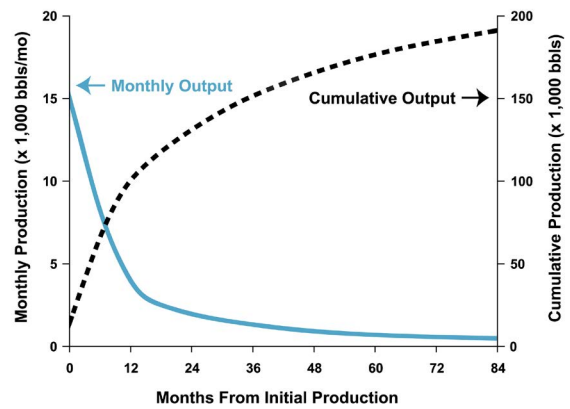
While all oil and gas wells deplete as they produce, shale wells do so at a faster rate than conventional wells. Half of a shale well’s lifetime output typically occurs in the first year and 75 percent during its first three years—investors thus enjoy a very fast return on capital. But a well’s cumulative production continues to rise over time. In a typical shale field, because shale wells are so much cheaper and quicker to drill, multiple wells are drilled, yielding steadily rising cumulative production (Figure 9 and Figure 10).

Gains in rig productivity also continue to emerge, thanks to growing operational experience, the application of higher pressures, more effective chemicals, better spacing of multiple wells, more efficient

motors, and better cementing and perforating of pipe.²⁶ Operators, for example, increasingly use more powerful pumps to move the water-sand mixture faster and at higher pressures, greatly increasing the amount of sand used to keep shale cracks open (Figure 11).

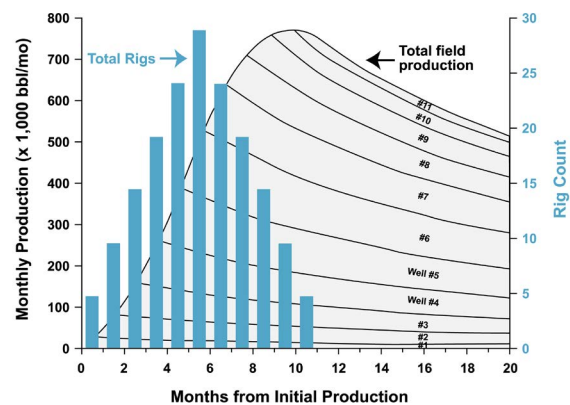
Sand used per well has risen, from 5 million to 15 million pounds, on average; the additional sand adds 2 percent to completion costs but boosts output by 40 percent.²⁷ A typical shale well, which involves a

Figure 9. Monthly vs. Cumulative Output for Typical Shale Well



Data Source: The Oil Drum

Figure 10. Rig Count vs. Total Output in Representative Shale Field



Data Source: Force Majeure

Figure II. Sand Delivery and Logistics*



*Custom-designed truck converts into sand silo.
Source: Halliburton

bewildering array of pipes, pumps, motors, valves, gauges, engines, tanks, trucks, and people—most onsite only temporarily—truly represents “a study in mechanical excellence.”²⁸

II. RIG COUNT VS. OUTPUT

With rig counts down but rig productivity soaring, what next? The consequences of a price and rig-count collapse have played out before. The shale revolution, in fact, began with the extraction of natural gas in the Texas Barnett shale. In 2008, after natural gas from this abundant new source flooded the U.S. market, gas prices plunged threefold. The gas rig count fell; but gas production kept rising and has been growing ever since.²⁹ Figure 12 illustrates the effect of radical gains in rig productivity for shale gas.³⁰

As for oil, the impact of rising shale-rig productivity was visible before the current, widely publicized drop in rig count. A sixfold rise in shale oil rigs, beginning in 2006, yielded only modest output growth. Then, starting in about 2012, the growth in rigs slowed and nearly stopped, but output soared (Figure 13). Also noteworthy is the fact that when, in 2006, entrepreneurs first began profitably deploying then-nascent shale

technologies, oil sold for less than \$50 per barrel; when production first took off, the price was still below \$60 per barrel.

III. TECHNOLOGY HIGH-GRADING, THEN SHALE 2.0

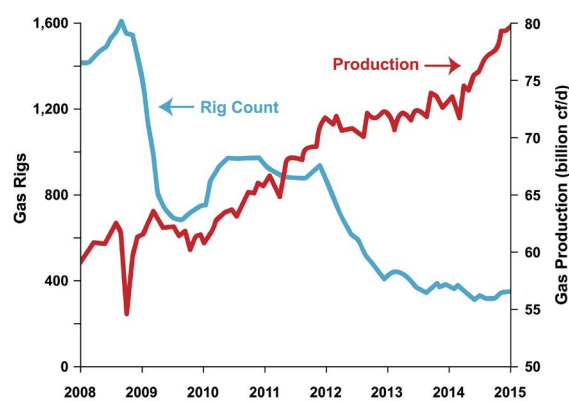
Four developments will likely determine the future supply of shale oil:

- Oil will be sold from the oversupply currently placed in storage tanks.
- Operators will more efficiently unleash oil from wells drilled but not completed.
- Operators will swiftly adopt the best new technologies and use them in the best parts of the shale (“high-grade assets”).
- Operators will embrace big-data analytics, unleashing Shale 2.0—greater production at lower cost.

Peak Storage

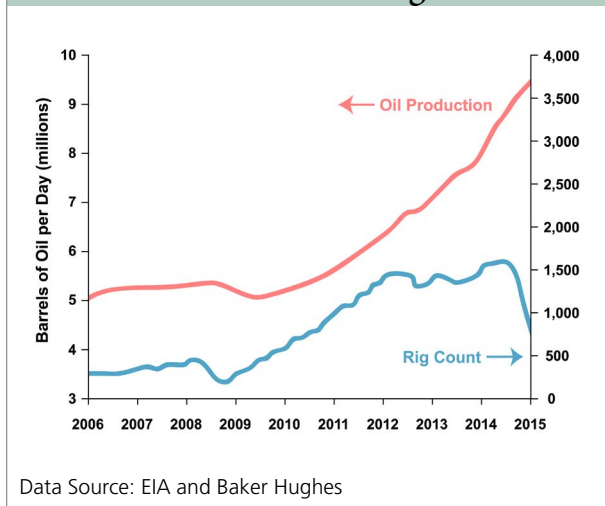
The total quantity of American petroleum now parked in huge steel tanks is at levels not seen for 80 years. A decade ago, no one thought that the U.S. would experience challenges associated with “peak storage,” rather than “peak oil.” In February 2015, one massive oil

Figure 12. Natural Gas:
Fewer Rigs, Far More Output



Data Source: EIA and Baker Hughes

Figure 13. Petroleum:
Shale Production vs. Rig Count



storage farm, in Cushing, Oklahoma, was 75 percent full; in February 2014, it was 48 percent full.³¹

The current oil storage glut is mainly a consequence of two factors: inadequate infrastructure and misguided law. American oil transport infrastructure, both pipelines and railroads, is still catching up to the recent, radical increase in domestic production. But even if the necessary infrastructure existed, half-century-old federal rules prohibit American companies from selling crude oil internationally—despite the fact that it is legal to sell refined oil (gasoline, diesel, aviation fuel) overseas. This outdated statute not only inhibits private investment in export infrastructure; it also violates the basic market principles that guide U.S. export policy for nearly all other products.³²

Still, it is unlikely that this law will soon be replaced or that new export infrastructure will be built overnight. In the upcoming 2015 summer driving season, however, oil currently held in storage will likely begin to be sold, as production slows slightly and domestic demand grows and finally surpasses pre-2008 levels.³³ Far from America entering a “post-oil-economy,” U.S. oil demand, as the EIA’s forecast shows, was down in recent years largely because of slow economic

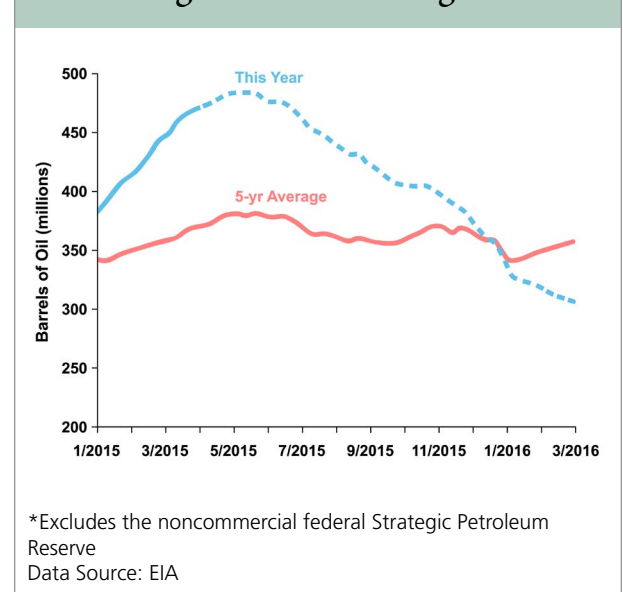
growth (and, accordingly, lower incomes). If oil in storage returns to recent average storage levels (Figure 14), nearly a million barrels of oil per day could enter the market.

The Fracking Backlog

Even more oil supply is now, de facto, being stored underground. As noted, production begins with the distinct second stage of well construction. Once a shale site is mapped and long horizontal wells completed, operators can delay the expensive step of fracking. Since the latter constitutes 50–60 percent of total costs, significant spending can be deferred with no loss of the core asset. The oil is simply left stored, in situ, until markets and prices make retrieval more attractive. When such sites are eventually stimulated, operators will be able to harness technological advancements that have occurred in the interim.

The U.S. currently has roughly 3,000 drilled wells awaiting completion—likely rising by the end of 2015, to more than 5,000.³⁴ Given current market realities, many—if not most—such wells will remain idle.³⁵ The amount of ready-to-flow oil stored in those 5,000 wells is at least four times greater than

Figure 14. Oil in Storage*



all the oil stored in steel tanks around the country. Because it takes only a few months to complete a well, such wells, once completed, could swiftly add 2–3 MMbd to U.S. supply.

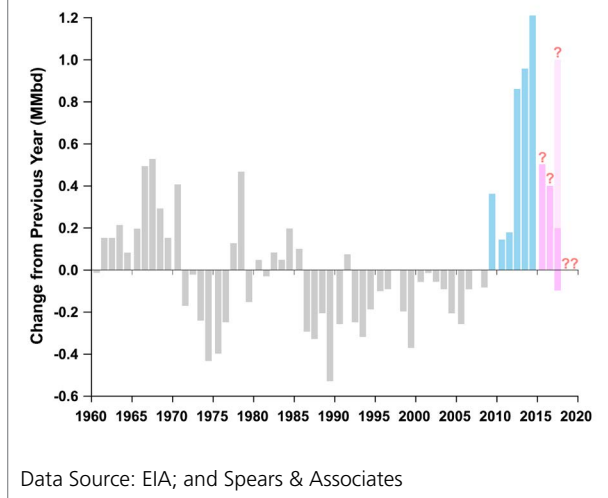
Embracing Technology

As operators gained experience during the first shale boom, Shale 1.0, a popular strategy involved duplicating every aspect of the development of a successful well on successive wells within the same field. This repetitive, “factory drilling” strategy made sense during the industry’s expansion because it eliminated the risks associated with continued experimentation. And when factory drilling in new parts of the same field yielded poorer results, due to variations in shale geology, the (coincidental) surge in oil prices reduced the incentive to innovate. (When oil hovered at \$100/barrel, a factory-drilled well that was 30–50 percent less productive than previous factory-drilled wells was still a big moneymaker.)

In the new low-price oil environment, however, operators will increasingly—and soon, exclusively—adopt a high-grading strategy that the industry’s top performers have pursued for years. High-grading calls for operators to use analysis not only to modify techniques for each well but also to use the best tools and techniques in only the best parts of the shale. One implication of high-grading is that conventional forecasts for future supply likely represent underestimates because they are based on historical averages that incorporate the previous proliferation of low-performing wells drilled during the price boom.³⁶

The effect of so many wells and acres subjected to high-grading will be to maintain output even with declining rig count and to add substantial uncertainty to near-term supply forecasts (**Figure 15**). Even in the aftermath of the recent oil-price collapse, as the industry cuts spending, consolidates, and cools, output from U.S. shale wells will keep rising—though more slowly than in recent years. If prices edge up, they will stimulate even more production.³⁷

Figure 15. U.S. Oil Production, Past and Forecast



IV. BIG-DATA ANALYTICS WILL MAKE SHALE OIL CHEAPER

Incremental and dramatic improvements will continue in all aspects of the many technologies used in shale production: logistics, planning, seismic imaging, well-spacing, fluid and sand handling, chemistry, drilling speed, pumping efficiency, instrumentation, sensors, and high-power lasers.³⁸ Shale fields will increasingly be developed using advanced automation, mobile computing, robotics, and industrial drones. At present, barely 10 percent of projects use fully automated drilling and pressure-control systems, for example.³⁹

Largely because of the tremendous scale of investment already in place, there is every reason to believe that such improvements—which portend greater and cheaper American oil production—will collectively be at least as significant in the coming several years as have innovations in the recent past.⁴⁰

But the single biggest disruption now coming to the shale industry, one that will define the emergence of Shale 2.0, comes not from individual technologies or digital connectivity but from the use of big data for radically better asset optimization and operations.

In every sector of the U.S. economy, the availability and collection of data from machines, services, and business operations are growing at an astonishing rate. Still, a large amount of the data remains disparate and disordered. The use of big-data analytics offers nearly all industries the potential for unprecedented insight, efficiency, and economic value. America's shale industry is similar to many other large, complex businesses—such as aviation, agriculture, manufacturing, entertainment, and health care—in the scale and diversity of its operations. What distinguishes shale is its unique combination of youth, the diversity and scale of data associated with its operations, and the variety of environments in which operations occur.

While such challenges could delay the industry's embrace of big-data analytics, the opportunity in oil and gas has not escaped the attention of IT firms such as IBM, Microsoft, Accenture, Cisco, and SAP, as well as various hydrocarbon-service companies. Conferences and books dedicated to the new specialty are rapidly appearing, including a new professional society focused on data-driven petroleum analytics.⁴¹ The CEO of EOG, a shale firm founded in 1999 and now with \$18 billion in revenue, promotes his company's aggressive, proprietary use of big data.⁴² ConocoPhillips, founded in the nineteenth century and now with revenues of \$55 billion, was ranked Number Two on InformationWeek's 2013 list of the 500 top IT-using firms.⁴³

Big-data analytics can already optimize the subsurface mapping of the best drilling locations; indicate how and where to steer the drill bit; determine, section by section, the best way to stimulate the shale; and ensure precise truck and rail operations. Mobile computing, using app-centric analytics, can increase uptime, reduce maintenance, improve workforce productivity, reduce errors and rework, and enable low-cost compliance.

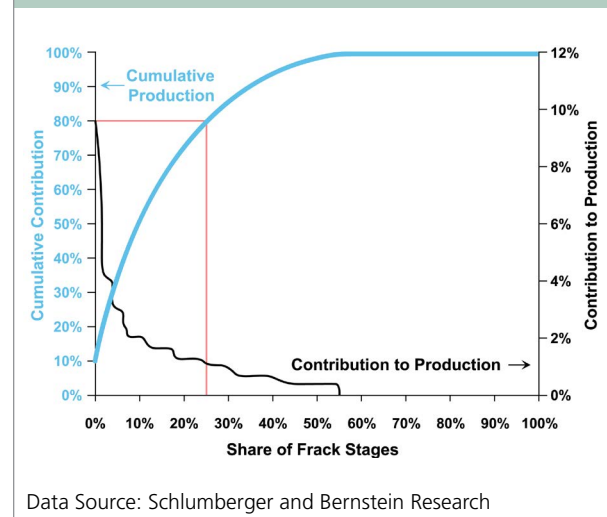
Though many companies are keeping their big-data projects proprietary, some information is publicly available. Halliburton reports that its analytic tools achieved a 40 percent reduction in the cost of delivering a barrel of oil.⁴⁴ Baker Hughes says that analytics have helped it double output in older wells.⁴⁵

Schlumberger announced a 50 percent gain in production, thanks to its use of analytics.⁴⁶ ConocoPhillips combined the latest sensors (which extract data by the minute rather than daily), wireless networks (often requiring building dedicated remote cell and Wi-Fi towers), and big-data analytics to boost output by 30 percent in existing wells.⁴⁷

Given such results and current low oil prices, it is little wonder that Baker Hughes, for instance, received more inquiries about its big-data analytics in the first quarter of 2015 than in the previous two years combined.⁴⁸ This confluence of technological maturity and market opportunity is ideally aligned for the upcoming pivot to data-centric Shale 2.0. Big-data analytics has also arrived at a time when demand and supply are well aligned: global demand for oil continues to rise, while America's shale fields are generating vast new supply.

Perhaps the most portentous indicator of the near-term opportunity for big-data analytics to yield more oil at lower cost is the surprisingly ineffective current mechanisms for stimulating shale to yield oil or gas (**Figure 16**). At present, each long horizontal well is typically stimulated in 24–36 stages, with, on average, only one-fourth to one-third of those stages productive.⁴⁹ At present, in other words, about 20 percent of stages generate 80 percent of output.

Figure 16. Effectiveness of Frack Stages in Horizontal Wells



The current state of stimulation technology means that, on average, at least 300–400 percent more oil is not extracted. Bringing analytics to bear on the complexities of shale geology, geophysics, stimulation, and operations to optimize the production process would potentially double the number of effective stages—thereby doubling output per well and cutting the cost of oil in half.

At present, break-even costs across U.S. shale fields range from \$10 per barrel–\$55 per barrel.⁵⁰ Delivering North Dakota oil to Gulf Coast refineries and ports by rail can add another \$15 per barrel. Using analytics to double output, thus cutting oil costs in half, means that shale break-even costs would drop to \$5 per barrel–\$25 per barrel. America’s shale fields would then be competitive in volume *and* in price with Saudi Arabia’s vaunted ultralow-cost oil fields.

V. \$100 OIL SET THE STAGE FOR SHALE 2.0

That world oil prices reached \$100 per barrel in tandem with the expansion of the shale revolution accelerated the appetite of financial markets to invest in shale wells. The result: extraordinarily rapid expansion of the industry’s physical and knowledge assets.

One indicator of just how much shale-related data have been generated is found in the hundreds of billions of dollars invested in data-generating hardware, infrastructure, and equipment. Another indicator of the scale of this new data set is the total distance of horizontal well-feet drilled. Ten years ago, only a handful of horizontal wells in shale formations existed. Two billion feet—enough to circle the earth more than 25 times—have since been drilled horizontally (**Figure 17**), in hundreds of thousands of wells in U.S. shale fields.⁵¹

The quantity of shale-related data generated can reach 1 megabyte per foot drilled;⁵² the total quantity of data generated per well can vary, from 1 to 15 terabytes.⁵³ With the proliferation of ever-better sensors and the continued decline in the cost of accessing, transmitting, and storing bytes, such data flows will certainly expand. Data are now collected for all aboveground

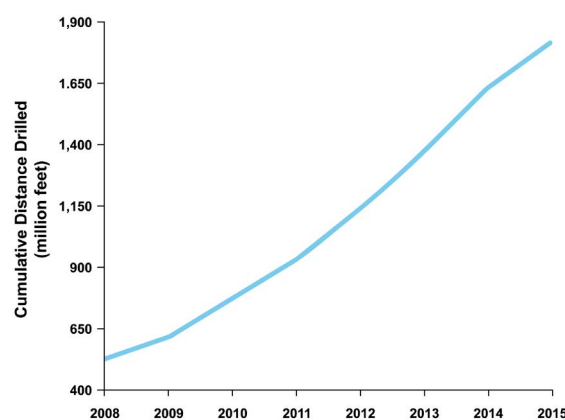
equipment, too. For example, a total of about 15 million horsepower in powerful diesel-driven pressure pumps are used to stimulate shale.⁵⁴ Few industries deploy so much engine power—it is more horsepower than used by FedEx’s global fleet of trucks and rivals that used by Delta’s entire aircraft fleet.⁵⁵

In general, data are associated with and often collected for every foot of well drilled and operated, including: for the seismic subsurface maps; for the sensors used to analyze the earth during drilling; for the trains and trucks carrying sand and equipment to the site; for the pumps and flow meters pushing sand and water underground; for the hardware and software moving the product to market; and for safety and environmental compliance-related equipment. Spread across disconnected operational silos and different companies, there is likely (no one yet tracks it) on the order of 600 petabytes of data—there are, for comparison, about 500 petabytes of global digital health care data⁵⁶—associated with finding, stimulating, extracting, and moving shale hydrocarbons.⁵⁷

VI. BIG DATA IS THE NEW OIL

“Data is the new oil!” became a popular metaphor in the big-data analytics community.⁵⁸ Big-data analytics, it turns out, can also unlock oil itself.

Figure 17. Cumulative Distance Drilled in Horizontal Shale Wells*



*Excludes vertical distances drilled for all classes of wells
Data Source: Spears & Associates

In 2011, Bill Gates predicted as much: “The one thing that is different today [in energy] is software, which changes the game.”⁵⁹ Continuous innovation in materials sciences, basic engineering, and analytics is having a greater impact on oil and gas cost-effectiveness than on solar, wind, and battery technology (Figure 18), despite the fact that the latter are popularly viewed as epicenters of energy innovation.

In terms of energy output, per unit of capital cost, for energy-producing hardware, shale technology has improved by some 500 percent during the past five years;⁶⁰ wind turbines, solar cells, and lithium batteries have improved as well, but far less spectacularly.⁶¹ Further, efficiency gains in alternative-energy technologies are slowing,⁶² while shale technology shows few signs of a slowdown. Such trends refute the belief that tech progress is bypassing hydrocarbons.

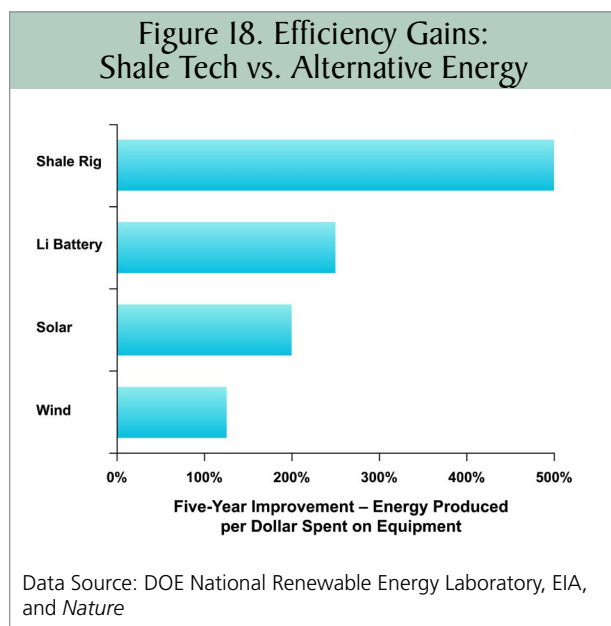
The potential of big data is making analytics among the fastest-growing job categories in all industries, including hydrocarbons.⁶³ This will make it difficult for oil and gas firms to recruit such talent,⁶⁴ forcing shale firms to increasingly purchase services and tools directly from analytic-centric tech firms (such as Teradata, Splunk, Qlik, Palantir, and TIB-

CO Spotfire) and from hydrocarbon-centric tech companies (including FracKnowledge, NEOS Geo-Solutions, Blade Energy Partners, and Austin-based Ayata). All will seek to mine the rich, often untapped data available in the thousands of connected sectors that constitute America’s shale industry.

Physical scale and enormous capital resources are critical for firms engaged in conventional hydrocarbons. Shale fields, on the other hand, are friendlier to start-ups and other small companies because of sharply lower capital costs and scale; ease of access to domestic (often private) land; and domestic infrastructure. Such advantages are now magnified by better sensors, communications, and inexpensive cloud-based supercomputing—a boon for the thousands of small and midsize American oil and gas companies that pioneered the Shale 1.0 revolution.

With data-driven productivity and automation leading Shale 2.0, we will see more jobs, not fewer. During Shale 1.0, as productivity soared, the number of workers per rig remained roughly constant, but the total number of people employed, directly and indirectly, in the shale ecosystem expanded. Indeed, in the six years following the Great Recession, America’s shale sector led the country in job creation.⁶⁵

As the industry adjusts to lower prices, slowing investment, and rising consolidation, however, layoffs are inevitable before the next expansion can begin. U.S. shale oil and gas is now, after software, the largest target for private-equity buy-outs.⁶⁶ Much of this activity is below the public radar, though private-equity titans Blackstone and Carlyle have made headlines by launching multi-billion-dollar funds dedicated to the sector.⁶⁷ The components are thus in place for a quick return—likely within a year or two—to the production growth rate of 2014. Should such a development materialize, the U.S. will roil global energy geopolitics yet again; but this time, there will be little competition from other countries, which have largely abandoned their own shale projects for lack of expertise and infrastructure.⁶⁸



VII. THE STRUCTURE OF TECHNOLOGICAL REVOLUTIONS

America's young shale industry is following a well-established historical pattern for technological revolutions. When innovation spawns entirely new industries, from the car to the cell phone, the scale and impact of the technology, as well as the associated businesses deploying and using it, expand in two broad phases. The first involves an initial boom, when new products and production ramp up and experience is gained by trial and error. The second, significantly larger, boom arrives later—sometimes preceded by a bust—spurred by experience and continued innovation.

The automobile era progressed from phase one in 1914, year of the first mass-produced cars, to phase two in the early 1950s, with the dominance of low-cost auto-making and associated infrastructure (national highways). The computer industry went from phase one in 1955, year of the first commercially deployed mainframes, to phase two in 1984, year of the first mass-produced personal computers. The cell phone advanced from phase one in 1990, with the first affordable phones, to phase two in 2007, with the introduction of smartphones and associated high-speed infrastructure.

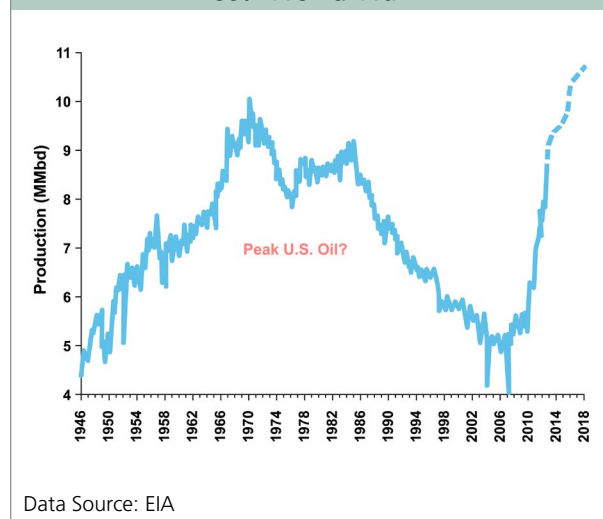
The history of conventional oil started in 1858, with Edwin Drake's 69-foot well in Titusville, Pennsylvania. Drake used a steam engine and salt-well drill, but his breakthrough involved placing iron pipes into the ground to keep the well bore open and drilling inside the pipes. The innovation was quickly copied, and an industry was born. Yet early drills could only make several feet of progress per day; so wells were shallow, and oil remained expensive. Phase two for conventional oil began in 1909 in Goose Creek, Texas, when Howard Hughes, Sr. demonstrated his revolutionary drill bit that could drill faster and deeper. The new technology launched the era of wildcatters, oil riches, and copiously cheap fuel—and with it, the start of a global transportation revolution.

Unconventional oil is set to follow a similar trajectory. Phase one started in 1991 in Texas's Barnett shale, when George Mitchell combined a subsurface seismic map, horizontal drilling, and hydraulic fracturing to stimulate rock to release hydrocarbons. In the process, Mitchell Energy (now part of Devon Energy) unleashed a shale boom similar in scale and character to the first oil era, and similar to previous industrial cycles. Twenty-five years later, history now awaits the name of the person or company that will be identified with launching Shale 2.0. In the meantime, shale's position as an enduring and soon-to-be \$100 billion/year U.S. industry is secure (Figure 19).

CONCLUSION

In recent decades, developed nations have spent hundreds of billions of government dollars trying, and failing, to invent a cost-effective replacement for petroleum. Yet without taxpayer largesse, American entrepreneurs invented a new method to extract astounding quantities of oil from rock, upending the global hydrocarbon trade in the process. In a world where oil still powers 95 percent of air and ground miles and will remain dominant for decades, this represents a very positive development.⁶⁹

Figure 19. U.S. Crude Oil Production, Post-World War II



Compared with 1986—the last time the world was oversupplied with oil—there are now 2 billion more people living on earth, the world economy is \$30 trillion bigger, and 30 million more barrels of oil are consumed daily.⁷⁰ The current 33 billion-barrel annual global appetite for crude will undoubtedly rise in coming decades. Considering that fluctuations in supply of 1–2 MMBd can swing global oil prices,⁷¹ the infusion of 4 MMBd from U.S. shale did to petroleum prices precisely what would be expected in cyclical markets with huge underlying productive capacity.

While sellers naturally prefer higher prices, the dramatic recent oil-price slump has set the stage for America's upcoming Shale 2.0 revolution. Given petroleum's continued economic and geopolitical importance, what policies should the U.S. pursue to maximize the benefits that it secures from Shale 2.0?

Legislators have yet to recognize and incorporate into law the far-reaching implications of how the energy landscape has fundamentally changed. U.S. energy law remains anchored in the decades-old paradigm of insatiable U.S. demand and resource shortages. The modern reality has instead utterly reversed, with de minimis growth in U.S. oil demand, exploding global demand, and an ascendant second era of American petroleum production. Congress should thus undertake a comprehensive review and rewrite of the 1974 Energy Policy & Conservation Act, which enshrined the now-antiquated paradigm. In the meantime, Congress can:

1. Remove counterproductive rules prohibiting U.S. companies from selling crude oil overseas, as well as rules inhibiting similar shale gas sales.
2. Remove the 1920 Merchant Marine Act's constraints on transporting domestic hydrocarbons by ship. This will require finding a more cost-effective solution to the national security interests associated with subsidizing a domestic shipbuilding industry.
3. Avoid inflicting further regulatory burdens on the already heavily regulated shale industry. Ominously, the U.S. Bureau of Land Management has announced plans for new standards that will affect about one-fifth of shale-based hydrocarbon production.⁷²
4. Open up and accelerate access to exploration and production on federally controlled lands. This would boost domestic economic opportunities and send a powerful message about America's oil export ambitions—rivaling, in inverse, the announcement of the 1973 Arab oil embargo.

Further, while Congress works to unshackle a shale industry adjusting to lower prices, hydrocarbon firms might consider launching a “Shale Ready Vets” program—a private alternative to President Obama's new Solar Ready Vets⁷³—offering instruction in vital, high-paying shale-related jobs, from machinery and supply-chain logistics to big-data analytics. At a time of growing scarcity for skilled labor in such fields, such a program would help prepare the U.S. workforce for the emergence of Shale 2.0.

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