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PROXIMITY COUNTS: HOW HOUSTON DOMINATES THE OIL INDUSTRY

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Say Detroit, and people think cars. Houston is no different. The city's oil and gas industry is a broad reflection of the industry as a whole, from the oil and gas extraction, oil services, machinery and fabricated metals that make up the upstream sector to the midstream pipeline construction and management; the Houston Ship Channel is home to a major downstream refining and petrochemical complex. This article focuses narrowly on Houston's upstream oil business and explains why it stands well apart from other oil-producing cities like Midland, Tulsa or Oklahoma City.

When we think of Houston and oil, the better economic model is an oil city, in the same way other cities operate as headquarters and technical centers for their respective industries, such as Detroit and the auto industry, San Jose and tech, New York and finance, and Hollywood as home to the movie industry.

Houston stands apart from other oil-producing cities in both its scale and its daily operations. There are 175,000 Houston-based employees working directly in production, oil services and machinery and fabricated metals, and tens of thousands more serve as suppliers or contractors. Measured statewide, oil-extraction workers based in Houston earn 64.5% of the sector's payroll in Texas, and almost half of the U.S. total. For oil services, Houston's share of Texas extraction payrolls is 45.3% and 32.0% for the U.S. (See Table 1 for details on this and other comparisons.)

However, while the other oil cities are operational centers for oil production, any oil and gas drilling activity in Houston is now a relic of the past. Earlier this year, the nine-county Houston metro area accounted for only 0.8% of Texas oil production, and 0.9% of natural gas output.

The explanation is simple. Modern Houston is a headquarters city, and the chief technical center for a global oil industry. Houston's daily oil operations are dominated by executives, geoscientists and high-end engineers, not roughnecks and tool pushers. The compensation rates paid by the oil industry in Houston versus the rest of Texas or the U.S. clearly reflect these differences in skills. (See Table 2.) The more difficult and complicated the drilling job, the more likely that a phone call for technical help will be placed to Houston from somewhere around the world.

Table 1: Houston's Share of Oil-Industry Activity

	Houston Share By Industry	
Compensation	**Texas**	**U.S**
Extraction	64.5%	45.6%
Services	45.3%	32.0%
Fab Metal	43.8%	40.2%
Machinery	51.8%	48.9%
Employment		
Extraction	38.6%	24.3%
Services	22.3%	14.3%
Fab Metal	3.8%	3.4%
Machinery	5.1%	4.0%

Note: Compensation is wages, salaries and employer-paid benefits; employment is payroll employment only .
Source: Bureau of Economic Analysis, Texas Workforce Commission, and calculations of the Institute for Regional Forecasting, University of Houston

Source: Houston Share of Oil Industry Activity

Table 2: U.S. Oil Industry Compensation Rates

Annual Payroll Compensation Rates, 2016

Industry	Houston	Texas ex. Houston	U.S. ex. Houston
Extraction	$314,601	$145,347	$160,869
Services	$149,057	$84,728	$86,766
Fab Metal	$75,718	$65,393	$67,329
Machinery	$105,595	$163,845	$83,076
Oil & Gas Mining	$238,100	$108,668	$114,655
Fab Metal + Machinery	$89,917	$103,676	$74,079
All Four Industries	$158,983	$106,302	$79,262

Source: Bureau of Economic Analysis, Texas Workforce Commission, and calculations of Institute for Regional Forecasting, University of Houston

Source: US Oil Industry

Historical Accident

The best way to think of Houston's upstream oil sector is as a cluster of headquarters and technical companies like Wall Street, San Jose, Detroit or Hollywood. All these cities operate on similar fundamentals, driven by key decision makers, major suppliers and a deep concentration of technical talent. Once these cities form, the proximity of hundreds of industry-specific companies generates large cost savings for every company that join the cluster, and these lower operating costs becomes the glue that binds these cities together for decades.

Historical accident often plays an important role in the formation of these cities. Tech and San Jose, for example, were linked in the 1930s by Stanford University's aggressive promotion and commercialization of inventions like the vacuum tube and the audio oscillator. Wall Street moved to center stage by the early 19th Century, when the newly opened Erie Canal generated great wealth by linking New York Harbor to the Great Lakes. Detroit's role as an auto center was cemented by Henry Ford's new mass production techniques and construction of the huge River Rouge plant. Before the invention of powerful electric lights, the movies needed good weather and California sunshine, and the first studios were in Hollywood by 1911.

For Houston, the historical trigger was Spindletop in 1900, serving as the first of a string of salt dome discoveries in southeast Texas that would bring a huge new wave of American oil production. A series of new discoveries led from Beaumont to Batson, to Sour Lake and on to the Humble oilfield near Houston. Houston emerged as the closest big city with good telegraph and rail connections, the economic development equivalent of today's internet and big airport.

Inside Houston's Oil Cluster

As any industrial cluster forms, the key actors are a group of decision makers. For Houston and the oil industry these are the oil producers, who decide whether to drill for oil or gas, where to drill, arrange the financing and share the profit or loss. These local producers can be large integrated oil companies like BP, Shell, Chevron or ExxonMobil, or independents like Anadarko, Apache, Burlington Resources or EOG.

Suppliers then join the cluster to be near the decision makers. Chief among Houston's local suppliers are the big three oil service companies of Baker Hughes, Halliburton and Schlumberger. The service providers work with the producers at the wellhead on each project, carrying out the geology, drilling, downhole testing and ultimately delivering hydrocarbons to wellhead. Houston has long been the heart of a global oil services industry. In the 1960s, when oil was discovered in the North Sea, for example, the British set a public policy goal of becoming a major oil-service provider. When the oil was gone, they could would carry these skills forward to future discoveries. Unfortunately for the British, the Texan lead in experience, patents and a history of work in frontier oil horizons simply could not be overcome.

Closely related to oil services, and often overlapping with services in many companies, is a large local machinery and fabricated metal industry that specializes in oil products. Howard Hughes, for example, patented the rotary bit in 1909, and founded the Sharp Hughes Tool Company on Houston's Second and Girard Streets. And Houston's "machine shop row" on Hardy Street was in full swing by the 1920s.

Cost Savings and the Power of Proximity

Whether it is oil, autos, finance, tech or the movies, economists call the glue that holds these clusters together economies of agglomeration. These economies are simply cost savings shared by every member of the cluster; they do not derive from the efforts of any one firm but accrue to all of them by virtue of mutual proximity. Every company inside the cluster gains substantial competitive advantage over any company located outside.

Once formed, these clusters set up a virtuous cycle that eventually draws in a major piece of their industry: the bigger the cluster, the greater the cost savings; the greater the savings, the more firms are drawn into the cluster; more firms mean more savings … and the industry concentration continues on. These cost advantages are powerful enough to (1) explain why only one large headquarters/technical center typically dominates each industry, and (2) why it is so hard for other cities to challenge these centers for a share of their work.

Proximity generates the cost savings that accrue to companies operating inside Houston's oil cluster, and these savings arise in three ways: access to many local companies specializing in oil; large numbers of skilled and specialized employees; and by generating company-specific intelligence on oil markets through its local knowledge loop.

- We have already seen how Houston's oil producers have immediate access to the major companies in oil services, machinery and fabricated metals. But dozens of such companies occupy a more modest niche, along with a wide variety of technical, engineering, legal, consulting and other industry-specific services. Because most such companies are heavily specialized, they must be constantly shopping across a large number of potential customers if they hope to drive down average cost. Houston's large cluster of firms eases the search.
- Companies operating in Houston have access to tens of thousands of potential employees. Table 3 offers insight into the remarkable concentration of Houston's cluster of key oil-related skills.

  If the concentration ratio in the table is greater than one, then the occupation is more heavily concentrated in Houston than in the rest of the nation. A ratio of 1.1 or 1.2 means that it is 10% or 20% more concentrated than the nation and can serve as a marker that something interesting is happening. Any ratio above two – doubling the national share – points to something extraordinary. And a ratio of 8 to 16 defines Houston a critical industry hub.

Augmenting the concentration ratios is the number of local employees working in each occupation, and Houston's rank by the number of workers across all 383 U.S. metropolitan areas. It is the combination of large numbers of oil workers and their concentration that sets Houston apart as you go down this list of petroleum engineers, geoscientists, chemical engineers, health and safety engineers, cartographers, etc. For example, the much smaller metro area of Midland is the only place with a higher concentration ratio of petroleum engineers than Houston, 66.3 versus 16.5. But Houston has 10,950 petroleum engineers versus 1,310 in Midland.

- Even among the relatively low concentration ratios for purchasing agents, logisticians and cost estimators, their raw numbers put Houston inside the top four metro areas as a major business center.

How does this concentration of oil skills lower cost? Normal turnover or industry expansion requires hiring, and the nearby workforce lowers the cost of search, hiring, relocation, and training. The concentration of local skills benefits employees as well, allowing them easy access to dozens of potential employers without relocation. Local workers are certainly paid better inside the oil cluster. We saw earlier in Table 2 that local oil-related compensation rates are much higher in Houston than elsewhere. Much of this difference reflects higher local skill levels, but companies also probably share part of their "agglomeration" savings with local employees as a bonus for proximity.

Table 3: Concentration and Number of Selected Oil-Related Occupations in Houston, 2017

Occupation	Concentration Ratio	Number of Workers	Metro Rank by No. of Worker
Petroleum Engineer	16.65	10,950	#1
Geoscientist	8.81	5,170	#1
Geological and Petro Tech	8.29	2,520	#1
Chemical Engineer	7.5	5,170	#1
Health/Safety Engineer	2.87	1,540	#1
Cartographer	1.91	460	#2
Mech. Draftsman	1.75	2,090	#2
Chemist	1.41	2,450	#3
Buyer/Purchasing Agent	1.34	11,360	#3
Logistician	1.34	4,380	#4
Mechanical Engineer	1.26	7,530	#4
Cost Estimator	1.22	5,280	#3

Note: Concentration ratio is the share of a local occupation in total employment divided by the occupation's share in the nation.
Source: Bureau of Labor Statistics, *Occupational Statistics*

- Finally, there is an important knowledge loop for the oil industry, and it is located in Houston. Proximity allows for the sharing of industry-specific intelligence from many sources, as local companies constantly seek to piece together additional data to form a better strategic picture. The intelligence sources can be local business meetings, industry-wide conferences or local professional meetings. Or they can be an informal lunch, an Astros' game or a round of golf at the local country club.

As an example, consider the Geophysical Society of Houston and the professional interaction that it generates. It is the largest chapter of the society in the nation with over 2,000 members; it conducts monthly technical meetings in three locations, has six special interest groups, presents an annual symposium, offers distinguished instructor short courses and forms liaisons with local universities. The Gulf Coast Chapter of Petroleum Engineers plays a comparable role in its profession, as do dozens of other local professional, technical and business groups. ■

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WHAT WILL PROTECT HOUSTON'S AIR FROM TRUMP'S EPA?

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To the extent that Houstonians breathe better air than they did 40 (or even 10) years ago, much of the credit must go to the EPA's dogged enforcement of the modern Clean Air Act, which was passed into law at the end of 1970.

Though there have been policy reversals under some EPA administrations that have slowed progress, and the air we breathe can still be unhealthful, air quality in Houston has generally improved over time.

Unfortunately, due to climate change and the Texas Commission on Environmental Quality's increasingly antagonistic stance with Obama's EPA and Harris County environmental enforcement, that progress started to stall in 2014. And the policies and priorities of Trump's EPA threaten to reverse Houston's hard-won gains. If that happens, some of our most vulnerable citizens will get sicker and die earlier. Economic growth will also take a hit and with it, Houston's vision of being a thriving city of the future.

Thank God for the rule of law.

Just last week, the D.C. Circuit Court of Appeals ordered Trump's EPA to stop delaying the implementation of the Chemical Disaster Rule, stating that the agency's delay was "arbitrary and capricious." That followed three other major court losses for the EPA the week before. And since Trump's attempt to make the EPA an agency that protects the coal industry, not the environment, the EPA has been on the losing side of multiple cases, including important air quality cases like implementing methane limits on the oil and gas sector.

Why is this happening? And can we continue depending on our courts to be a last bulwark against the actions of Trump's EPA?

The Clean Air Act and agency action

Understanding Trump's EPA's trouble in our courts requires a brief discussion of the role of agencies in government. Contrary to President Trump's apparent belief, neither the president, nor the agencies in the Executive Branch, have the unilateral power to change the law. No amount of tweetstorming or executive-order signing can alter the obligations of government agencies to follow laws as directed.

Under the Clean Air Act, the EPA is bound by its fundamental requirements: setting air pollution levels to protect public health, protecting vistas and visibility in our national parks, requiring pollution sources to install adequate pollution-control technology and enforcing these requirements on the states and pollution sources.

HIDDEN PROBLEM: How does air pollution make you sick?

While federal agencies, including the EPA, always have some leeway in how they choose to interpret and enforce laws, federal agencies cannot simply ignore legal requirements or change them for any reason. Agencies are required to follow proper procedures in all their actions, as required by the Administrative Procedures Act, a foundational law from 1946 which was designed to ensure fair process and public participation and influence over agencies. The Trump administration, perhaps more than any prior administration in history, doesn't understand or doesn't care about these limitations.

Scott Pruitt's deficiencies have helped protect us

While Trump's EPA has sometimes been compared to a bull in the environmental china shop, that would be an insult to the bull, which at least is acting predictably and without any intent necessarily to break anything. Trump's EPA, under Scott Pruitt in particular, hasn't seemed to act pursuant to any comprehensive plan beyond tearing down anything that was instituted by President Obama and throwing a sop to the coal industry.

Aside from his propensity for ethical scandals, Pruitt also came to the EPA without any expertise in environmental law, his sole qualification in Trump's eyes being his rejection of climate science and his history of repeated lawsuits against Obama's EPA. He then appointed senior staff who had little or no knowledge or experience in environmental law or policy or in requirements for agency action. Pruitt's focus seemed to be selling his own brand and currying favor with President Trump.

Not surprisingly, given the lack of expertise and attention, the majority of actions taken by Pruitt in the first year and a half of this administration were not legal or failed to follow proper procedure. Many of the things that Trump's EPA wished to do — roll back climate regulation, make it easier to operate coal-fired power plants or allow older dirty diesel engines back on the road — are simply not countenanced by the Clean Air Act. Without a change in the statute, these actions are simply illegal.

Understanding this reality, or simply out of ignorance, Trump's EPA plowed forward anyway, without even attempting to follow proper procedure or simply not enforcing requirements. Not surprisingly, the agency has faced multiple setbacks

The EPA attempt to derail requirements on Texas air polluters

An example of Trump's EPA's attempt to secure what it wants regardless of law is its approach to the requirements for Texas industry to clean up pollution that creates regional haze. After years of delays, and though required by a 2012 consent decree to propose a regional haze plan for Texas, Trump's EPA repeatedly tried to get the deadline waived or extended. When forced by a federal court to stick with its legally mandated requirements, the EPA filed a last-minute request to extend the deadline again, offering as a reason that the current administration (i.e. Trump's EPA) had a better relationship with the state of Texas than the prior one and wanted to reopen negotiations on a plan. The judge was unpersuaded.

"This is not the sort of significant change in circumstance that would warrant relief," Federal District Judge Amy Berman wrote. "Texas has been under the statutory obligation to comply with the Clean Air Act since at least 2007, and it has been on notice of EPA's finding that it had failed to comply with the requirement to submit a state implementation plan since 2009. ... So there has been quite a period of time during which 'cooperative federalism' could take hold."

Forced by the court to file the agreed-upon plan, the Trump administration simply filed a different plan, substituting the prior rejected Texas plan at the last minute, violating another legal principal that states that these plans have to go through notice and comment requirements before they can be implemented.

NO EQUITY: Why your health can depend on where you live

This action is, of course, being challenged in court, and the EPA's opponents will likely win, but this is a perfect example of the "win at all costs, the law be damned" approach that has gotten the EPA rebuffed time and time again by our federal courts.

What about the new EPA administrator?

Unlike Pruitt, the new Acting EPA Administrator Andrew Wheeler does not appear to have a propensity for ethical problems, and he has experience in the environmental and energy sectors. He reportedly has also reached out to reassure EPA employees that they are valued and that he will follow the rule of law. If he follows through with these promises, we should expect less nakedly illegal attempts to lessen environmental protections. In the face of another court loss, Wheeler pulled a Pruitt proposal that would have authorized the use of "glider kits" to reanimate older, polluting truck engines.

But we shouldn't expect the Trump administration to stop its efforts to favor polluting industries over the health of the public. While trying to follow the appropriate procedures for changing requirements could mean that these proposals are less vulnerable to attack, it is still true that much of the Trump agenda flies in the face of Clean Air Act core requirements.

Just this week, Trump's EPA came out with its proposal to rescind the Obama-era Clean Power Plan and replace it with a weaker rule to regulate greenhouse gas emissions from coal-fired power plants. But while the agency followed rote requirements of procedure, at least some of the proposal, such as waiving requirements that older coal-fired power plants upgrade pollution control equipment, appear legally shaky at best.

The rule of law will still prevail

While the shedding of Pruitt and his reckless, illegal style may have put some nice lipstick on the pig of Trump's EPA, the EPA will still be blocked from carrying out much of Trump's agenda. In many areas in this chaotic administration, our courts have shown themselves standing for the rule of law in the face of Trump's disregard for it. I expect that will continue to place some brake on the many dirty-air policies being pushed by the administration.

Last week's win for the Chemical Disaster Rule should help prevent massive toxic air releases during disaster, like Arkema's explosion during Hurricane Harvey that Houston experienced last year.

RESIDENTS AT RISK: Arkema, CEO indicted for 'reckless' chemical release during Hurricane Harvey

And ongoing lawsuits against Trump's EPA's attempts to weaken hazardous air pollution control and particulate pollution that impact health and visibility should be successful and help hold the line for Houston's air quality.

But as long as President Trump has pointed influence over the EPA, everyone has to remain vigilant and be prepared to fight dirty-air policies in court and keep the public informed of the were successful. Hopefully, Houston's air quality can survive the Trump administration, and our city can get back on the road to a better, healthier future. ■

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EXACTLY HOW MUCH HAS THE EARTH WARMED? AND DOES IT MATTER?

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The Earth is generally regarded as having warmed about about 1° C (1.8° F) since the beginning of the Industrial Revolution, around 1750. In 2017, two professional papers generated much debate in both the popular press and professional literature about whether this figure is correct. Schurer, et al. argued the rise is 1.2° C (2.2° F) and Millar, et al. claimed the rise is 0.9° C (1.6° F).

One might reasonably question why a few tenths of a degree would make much difference. Those making the argument for a higher number claim it is important because it shows we are already closer to the targets of 1.5° and 2.0° above pre-industrial temperatures established by the United Nations Framework Convention on Climate Change (UNFCCC), therefore greater cuts in future carbon emissions are necessary. Those supporting the lower figure believe the 1.5° target can be met with less stringent reductions.

The debate exists in part because the UNFCCC did not define pre-industrial when setting the targets. It is further complicated because there are uncertainties in both historical and recent global temperatures. Neither claim may have much impact.

What is the pre-industrial temperature?

The latest assessment (AR5) of the Intergovernmental Panel on Climate Change (IPCC) refers to a baseline of 1850–1900. This is a practical choice, since it includes the period of most reliable temperature records and less than 3% of total fossil fuel carbon dioxide emissions had occurred by that time.

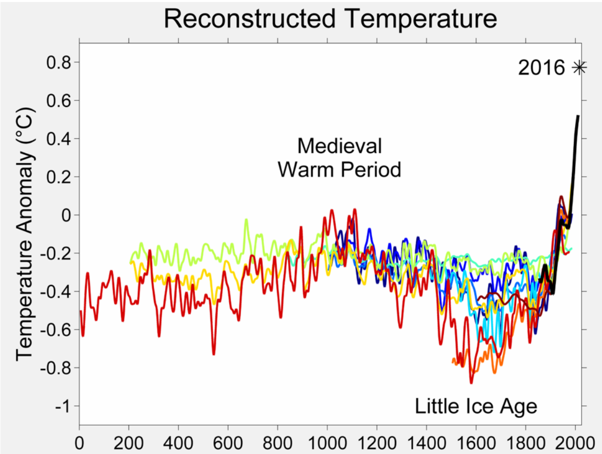
Presumably, this is the baseline intended by UNFCCC since they describe the IPCC reports as "the most credible sources of scientific information on climate change" and 1850–1900 is also referenced in the UNFCCC's Structured Expert Dialogue. However, other definitions of pre-industrial are used within the IPCC reports. For example, both "before 1850" and 1750 were used in the Working Group 1 report.

The primary argument of Schurer, et al. for using earlier time periods is that some human-caused warming may have taken place earlier, so pre-industrial should be defined as before 1850. Because temperature was lower for several centuries prior to 1850, their earlier baseline yields the additional two tenths of warming.

If the UNFCCC actually intended 1850–1900 as the base period, choosing an earlier interval is moving the goalposts. In addition, it raises the question of choosing the earlier period and determining the temperature of the new baseline.

The imprecision of pre-1850 temperature reconstructions

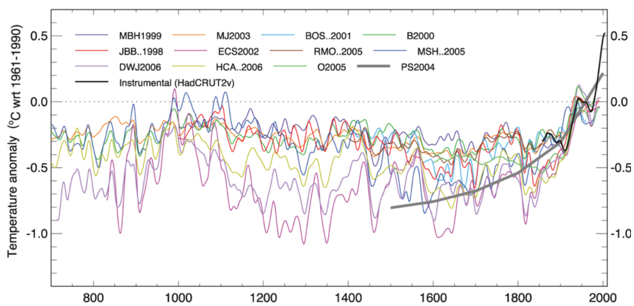
Since temperature measurements are sparse before 1850, temperature must be estimated by proxies, such as tree rings, ice cores, corals and pollens. These have known inaccuracies and do not agree. The graph below shows reconstructions from 11 different proxies. Each colored curve is a different reconstruction.



Source: Wikimedia Commons

Reconciling the various proxies involves numerous assumptions, corrections, and averaging techniques. Smerdon and Pollack call it a "problem of interpreting incomplete, inaccurate, and conflicting information."

Temperatures in the time frame of interest may also be estimated by pseudoproxy models, which combine climate models with proxy data. These also vary substantially, as illustrated in the sample of pseudoproxy models below. Schurer, et al. say "the estimation of pre-industrial temperature is far from straightforward."



Source: Modified from IPCC

Choice of pre-industrial

Although there is considerable difference between various reconstructions, most show a pattern of slow warming into the Medieval Warm Period, cooling into the Little Ice Age, and warming since about 1650. Which of these best represents pre-industrial?

Schurer, et al. suggest 1400-1800. This seems biased to showing the maximum amount of warming, since it brackets the Little Ice Age. One might as easily argue the Medieval Warm Period could be used. A better argument would be to use 750-1850 or 0-1850. The temperature over those intervals would not be greatly different from than IPCC's 1850-1900. Other authors have suggested different intervals.

Differences in present day temperature estimates

Although recent temperature measurements are far better defined than pre-industrial, they are not without uncertainty. Differences exist between different averaging methods and corrections, choice of land vs. land plus sea, etc. These can be on the order of a tenth of a degree.

The discussion here of ambiguities barely scratches the surface of defining the 1.5 and 2° goals. A well-written article by Rogelj, et al. discusses other questions in interpreting the intent of the UNFCCC. In a separate article, he and other authors caution against "shifting the [UNFCCC's] goalposts."

Limitations are not criticisms

This discussion of uncertainties is not meant as criticism of the science or the authors. It is a function of the current state of knowledge, which is well-described in mainstream peer-reviewed journals and discussed by respected climate scientists, many of whom are contributors to the IPCC reports. A recent example was correspondence in the journal Nature Climate Change between the authors of the Millar and Schurer papers, each of whom defended their conclusions.

Why an exact value doesn't matter

Although there are some out-of-the-mainstream views to the contrary, there is strong evidence the Earth has warmed about 1° C since pre-industrial times. Uncertainties in the data and lack of agreement on a reference date make it impossible to give a precise value.

If one subscribes to the belief that fossil fuels are the primary or sole cause of this warming, as do most climate scientists, it is urgent to reduce fossil fuel usage. The IPCC has been saying this since their First Assessment Report in 1990. Succeeding reports have described the situation as more urgent since inadequate progress in reducing fossil fuel emissions has been made.

It is hard to imagine that believing warming since pre-industrial is one or two tenths of a degree higher will change the urgency for fossil fuel reduction. This view has been expressed by Dana Nuccitelli, one of the most zealous emissions reductions advocates. In a Guardian article he says, "We're at the point where we need to cut carbon pollution as quickly as feasibly possible. That's true whether Earth has warmed 1.0 or 1.1 or 1.2°C above "pre-industrial" temperatures."

By the same token, the 57% of Americans who do not worry much about global warming are not likely to be influenced by a conclusion that pre-industrial temperatures are two tenths of a degree cooler than earlier thought. ■

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NEGATIVE EMISSIONS TECHNOLOGIES: HAS THEIR TIME ARRIVED?

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Amid the partisan rancor paralyzing U.S. politics and climate change policy, a surprising atoll of bipartisan consensus emerged earlier this year on carbon tax credits. On Feb. 9, Congress passed the FUTURE Act (the Furthering carbon capture, Utilization, Technology, Underground storage, and Reduced Emissions Act), which President Trump quickly signed into law. This statute essentially provides a tax credit to incentivize carbon capture, storage and utilization. The Act more than doubles the tax credits available for capturing and permanently storing carbon dioxide (CO^2) in geological formations and for CO^2-enabled enhanced oil recovery (EOR), and it extends the same support to industries that reuse carbon in other forms, including cement, chemicals, plastics and fuels.

The FUTURE Act has also for the first time allowed tax credits for negative emissions technologies (NETs) like direct air capture projects, thus creating opportunities for a systemic shift that can drive new partnerships between carbon management organizations and the energy industry. These technologies are advancing rapidly, their cost is dropping and the FUTURE Act would seem to signal that the time is right.

For now, however, these negative emissions technologies remain more novelty than mainstream, as a host of questions – from the impact on future use of fossil fuels to policies governing the use of public land and ocean resources – wait for answers.

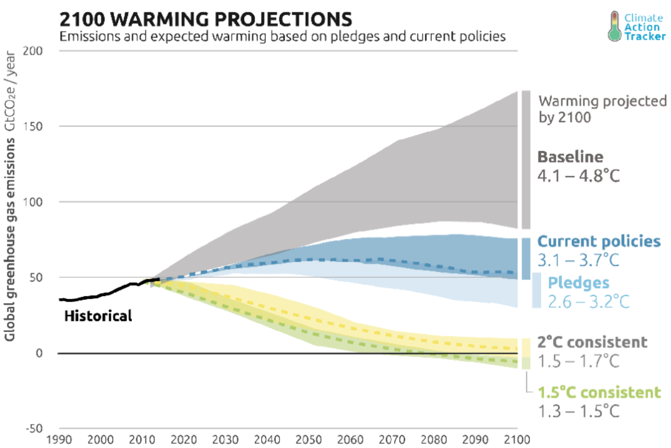
While these questions demand robust discussion from a wide-range of expertise, progress on these technologies continue.

A few months after Congress passed the FUTURE Act, a research paper was published predicting that mechanical direct air capture technologies would cost between $94 and $232 to remove one ton of CO^2 from the ambient air. While still pricey, this estimate constituted a dramatic reduction from the American Physical Society's 2011 estimate of nearly $600 per ton, which the Society used to brand direct air capture as not economically viable to mitigate climate change. Undeterred by this past estimate, progress on these technologies has advanced rapidly. A mere one month after the newly published estimate, the Canadian firm Carbon Engineering, Inc. announced it had raised 11 million Canadian dollars to commercialize its Air-to-Fuels technology. Based on its design estimates, Carbon Engineering said a fully commercial Air-to-Fuels facility could capture up to 1 million tons of CO^2 per year.

Yet as NETs have grown from a technology beset with daunting technical challenges into a potentially mainstream carbon removal process, they remain an outlier in most immediate policy discussions. What has prevented success so far?

The lack of confidence in NETs is especially puzzling because they have already evolved into an indispensable bulwark for any credible pathways to the targets set by the Paris Agreement. For example, most climate models that meet a 1.5 degrees C or 2.0 degrees C target rely on large deployments of some forms of CO^2 removal, in particular, biological energy production coupled with carbon capture and storage. But we remain nowhere close to defining potential NET implementation pathways that are feasible, economical, technically sound and socially acceptable. Skeptics argue that a premature focus on NETs will waste precious time and resources on technologies that have limited potential to solve our climate concerns. The bigger question is, whatever the mitigation potential of NETs might be, can we still afford to ignore them?

The average concentration of CO^2 in Earth's atmosphere hit an all-time modern high of 411 parts per million last May, considering the last 800,000 years for which reliable data is available. This elevated concentration threatens potentially vast damages from future severe weather events, rising sea levels, heat waves, droughts and other climate disruptions and effects.



Source: Climate Action Tracker

The urgency and magnitude of our climate problem belies the hope that any single solution in isolation can alleviate all potential health, safety and equity concerns. Given the need for a diverse suite of technological approaches, what should our mitigation timeline look like? So far we've evidently moved too slowly with the necessary decarbonization of modern economic activities; as a result, we likely have committed ourselves to the inevitable use of negative emissions technologies. Yet the current knowledge around NETs remains so incomplete and diffuse that an array of questions surrounds their present and future.

In the absence of strong climate policies and inconsistent governmental support, how can societies be convinced that NETs are beneficial? The foremost nemesis of all NETs is their economic and energy costs. Additionally, most NETs remain scattered at different stages of research and development: some in laboratories, some at demonstration scale, but they are all extremely expensive. How will the economics work, and what can be done to bring these technologies to scale? Lessons from CO^2 enabled EOR can be used as a successful base case to ensure scalability, along with an increased emphasis on energy efficiency, which in turn could reduce the risk involved.

In addition to cost concerns, NETs remain hobbled by uncertainty. The full-scale use of NETs could have the inherent potential to completely transform demand and supply of energy. Such a widespread transformation would raise key questions:

- If NETs transform the energy mix as we currently anticipate, would this lead to the resurgence of fossil energy sources such as coal? How would this transformation affect fossil-fuel geopolitics and the politics of energy?
- What are the socioeconomic, biophysical and environmental opportunities that could drive policy? How can this paradigm shift be encouraged and incentivized for risk absorption, and knowledge and resource sharing through international collaborations? How can we monetize this transition and acquire the required international finance flows, while ensuring that differentiation and over burdening does not limit economically weaker countries?
- How do we provide regulatory and financial immunity to first movers in this nascent and complicated space? How can we make entry less risky for additional players? On a business scale, most of the current risk is borne by private entities. Can the risk be shared equally with public entities through partnerships?

- Should the market be leveled for products to ensure broad success? Direct air capture, for example, faces competition from post-combustion or oxy-combustion technologies. These streams contains more concentrated CO^2, because the exhaust stream derives directly from combustion processes rather than the ambient air.
- For NETs that involve resources like air, clouds and ocean waters, what laws would govern international resource sharing? How do we account and plan for long-term resource requirements such as for land and water?
- Responsibility and accountability for novel technologies like NETs come with the tremendous pressure of what happens if they fail at scale? Are we prepared for the unknown consequences in case of failure? What are the indicators of success? How will performance be measured and monitored, and by whom?
- What other industries could NETs be connected with to create incentives and policy drivers? For example, combining technologies like direct air capture, water electrolysis and fuel synthesis to produce liquid fuel cells can potentially revolutionize the transportation industry, while cutting emissions from an industry that is responsible for 30% of total emissions. Making use of stranded assets – such as natural gas currently flared because the costs of capture and utilization are too high – offers the potential to provide massive energy and financial incentives to the development of NETs. Also, tapping renewable energy (which is sometimes dumped into the market at negative prices in the absence of storage solutions) will not only satisfy the demands of energy-intensive NETs but can offer a path to jointly develop these technologies, rather than pitting them against each other in the marketplace.

For now, negative emissions technologies are mired by these questions that are waiting for answers which can only be found when all stakeholders feel the same sense of urgency. An undertaking that initiates robust, all-inclusive, and unambiguous discussions amongst key participants – climate engineering researchers, climate scientists, leaders from the energy industry, experts in law, public policy, energy economics, ethics, philosophy, risk analysis and communication – will decide the future of negative emission technologies. Negative emission technologies need a fresh impetus, and now is the time. ■

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ON A KNIFE EDGE: BALANCING SUPPLY AND DEMAND IN A CHANGING WORLD

BILL MALONEY

Director, Energy Advisory Board Member, Trident Energy

Since November 2014, we have lived in a world where oil supply exceeded demand. Oil prices dropped below $30 a barrel. Companies took major defensive moves by cutting capital budgets, downsizing staff and some even lowered or cut their dividend.

Additionally, just about every company put massive efficiency programs in place with the goal of lowering the entire cost base of the energy industry. They succeeded in reducing the cost base, and the U.S. onshore industry has been able to remain cost competitive.

However all of this has come at a price. The industry, in general, has not invested in enough new projects to ensure there will not be a future supply shortage. So what's ahead? The picture is still murky, but here is what I see.

Supply and demand are in balance today, but on a knife edge, and it wouldn't take much of a supply shortfall to drive up oil prices. Brent topped $80 a barrel in early October, and West Texas Intermediate reached $75, and many analysts are pointing to a potential short-term risk for rising prices in this quarter and early into 2019. Why? The impact of U.S. sanctions against Iran are starting to take hold.

Iran, OPEC's third largest producer, produced 2.71 million barrels of oil per day in May 2018. That's close to 3% of global oil production. There will be a significant portion of that oil coming off the market in the fourth quarter of this year.

And it's not clear what will replace that Iranian oil. Outside of Saudi Arabia, OPEC has little spare capacity. Why do you think President Donald Trump called the king of Saudi Arabia recently? He would probably like to see Saudi Arabia raise its oil production. This is possible, but it couldn't happen immediately.

Russia, meanwhile, has stepped up its oil production to just over 11 million barrels per day, but is that enough? Venezuela, once a very strong OPEC contributor, is producing only half of what it did in 2016 as the government of President Francisco Maduro battles hyperinflation and escalating financial chaos. Can Libya and Nigeria maintain their current levels of production?

The United States, where the U.S. Energy Information Administration reports oil production for the week ending September 21, 2018, was 11.1 million barrels of oil per day, is often incorrectly called the new swing producer. Yet last week, the U.S. rig count for rigs targeting oil was down by three to 863 rigs, leading some to have at least a slight concern about whether the U.S. can maintain oil production at its current high level.

Demand, on the other hand, has continued to be quite strong globally. Yet there may be problems there, too, amid concerns that escalating tensions between the U.S. and China over trade could hurt demand. Add all of this together, and it is leading many people to look to the fourth quarter of 2018 and the start of 2019 as a time where dwindling spare capacity and an undersupplied market could become a reality. That being the case oil prices will rise. Is $100 oil possible? Maybe.

Costs remain low as a result of industry's efforts since 2014, prices are going up and the U.S. dollar is strong. Those factors should combine to make 2018 a good year for oil and gas companies, although results are still not so great for the service companies. Why mention this? Given that companies are now making money again, they are collectively talking about a large number of final investment decisions for 2019. New projects that were not approved in the period from November 2014 until today may be looked upon more favorably.

However, there is an issue there as well. Many people have left the oil and gas industry as a result of the recent downturn. The New York Times reported 163,000 U.S. jobs have been lost since the 2014 peak. Others have said up to 500,000 people have left the oil and gas industry globally. Will companies have sufficient capacity and quality in their human resources to deliver on these new projects? It's not certain they will.

If that isn't enough uncertainty, there is a lot of discussion about an energy transition, which is already underway. However, the transition won't follow a straight path. In fact, it will be a messy and tortuous trail as, without a major technological breakthrough, natural gas and oil combined will remain the dominant energy sources for the next 20+ years, with the natural gas share growing as it becomes the transition fuel to the future.

That should be good news for the U.S., as today North America is the largest gas producer in the world, with Russia and the Middle East as second and third. North America is likely to be the place where future natural gas projects have the lowest break even costs globally; as a result, abundant and low-cost natural gas will fuel a growing share of our global energy future. To close, we are in for a bumpy ride. Supply and demand are on a knife edge for sure, and we will see volatility in oil prices. Energy companies and producing nations need to replace the oil reserves that they have produced and maintain production. There will be challenges in meeting those objectives.

Lastly, our future energy usage will likely have a large component of natural gas and much of that will be produced in the North America. Fasten your seatbelts. ■

Published October 15, 2018, on Forbes.com

CLIMATE CHANGE AND CITIES: WHAT WE NEED TO DO

BRUCE RACE

Professor and Director of CeSAR, Gerald D. Hines College of Architecture and Design

On October 6, 2018, the International Panel on Climate Change (IPCC) released a special report in support of a global response to keep global warming to less than 1.5ºC above pre-industrial levels. Widely reported in popular media, the Summary for Policymakers (SMP) provided a clear warning - we need to act fast and decisively.

The October 2018 IPCC Summary to Policymakers indicates we must reduce our GHG emissions by 45% before 2030 and reach net zero emissions by 2075.

Climate Scientists' Projections

The IPCC scientific team's current projections indicate we have little over a decade to drastically reduce greenhouse gas emissions to avoid catastrophic climate change. We need to make a "rapid and far-reaching transition in energy, land, urban and infrastructure (including transport and buildings), and industrial systems" to avoid surpassing a 1.5ºC increase in global temperatures by 2050. Meeting the 1.5ºC or less target is critical for reducing climate impacts and reducing the costs for adaptation.

The latest report indicates we must reduce greenhouse gas (GHG) emissions 45% by 2030 and reach net zero emissions by 2075. Based on our current efforts, these seem like audacious goals. However, not meeting them means we can expect continued increase in extreme weather events and coastal flooding, impacts on food security and loss of biodiversity and unique ecosystems that also support people.

Meeting the goals is ambitious but not impossible. In fact, we already know a lot about what we need to do. Mostly, it will require rethinking the way we live, work and travel around the world's cities, which account for about 75% of global greenhouse gas emissions. Interesting efforts already are underway.

Four Broad Pathways to Net Zero

The report defines four broad "pathways" to reach that goal, along with the potential outcomes for each. These include (P1) lower energy demand, (P2) broad focus on sustainability, (P3) changing the way we produce energy and (P4) continuing a resource-intensive path. Pathways 1, 2, and 3 would require large-scale efforts, although they are not unprecedented in terms of speed. Pathway 4 requires very large investments in bioenergy with carbon capture and storage.

The mitigation strategies within the pathways include potential synergies or co-benefits when comparing the interrelationships between energy demand, energy supply and land use. For example, energy demand and supply strategies have synergies with responsible consumption and production, but there are tradeoffs when considering clean water and sanitation. While synergies like these seem logical, researchers continue to quantify co-benefits of relationships between climate actions and quality of life indicators.

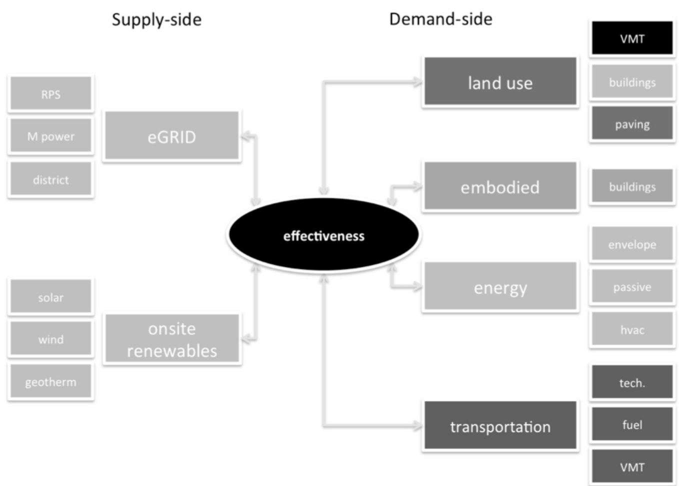
Pathways to Net Zero at the Local Level

Cities on every continent are setting aggressive GHG reduction targets that are changing their policies and investment in their operations, building stock and infrastructure.

The IPCC established protocols for assessing and measuring national GHG emissions. World Resource Institute, C40, and International Council for Local Environmental Initiatives collaborated with the World Bank and others to prepare a framework to allow cities to measure their GHG inventories in a consistent way in order to more easily align local climate protocols with those used by the IPCC. The Global Protocol for Community-Scale Greenhouse Gas Emissions has been piloted by 33 international cities. Other international networks, such as Resilient 100 Cities, C40 Cities, and EcoDistricts.org, are providing technical assistance and peer-to-peer mentoring.

Demand Reduction and Supply Strategies

Cities are pursuing broad community-scale strategies focusing on land use, energy used in the building sector, transportation, infrastructure (especially paving) and embodied emissions. These can be viewed as demand and supply-side strategies (below).



Source: Bruce Race

Land Use Strategies

The patterns in which cities are built contribute to their GHG emissions. Compact, connected and concentric walkable cities enable other reduction strategies. They more easily provide transportation options, more efficient infrastructure and building types that use less energy. They can also cut down on loss of farm and natural landscapes that store carbon and shorten farm-to-market supply chains.

Embodied Emissions

Building and infrastructure have embodied emissions. These are from the energy required to construct them, including that consumed to ship materials and equipment to the building site. Buildings that use locally sourced materials, as well as materials that do not require a lot of energy to manufacture and can be recycled or reused, have lower embodied GHG emissions. “Green infrastructure,” such as parks and open spaces designed as a continuous stormwater system, can serve a more compactly planned city reducing embodied emissions found in traditional concrete “gray infrastructure.”

Building Energy Strategies

In the United States, buildings account for 40% of all GHG emissions. Incorporating more energy-efficient technology into buildings and using locally developed renewable energy can dramatically reduce urban greenhouse gas emissions. In addition to incorporating new active technologies, better passive strategies including deliberate solar orientation, thermal insulation and ventilation can also improve building energy performance.

Cities need to define their own pathways to mitigate their GHG emissions by reducing the demand for energy, developing greener energy supplies, and supporting more sustainable lifestyles.

Transportation Strategies

The second highest source of global urban GHG emissions is the transportation sector. There are three general strategies for reducing emissions from transportation: reducing vehicle miles traveled, improving vehicle technologies and switching to cleaner-burning fuels. By developing “walk first” cities we can greatly reduce emissions. Well-connected and comfortable pedestrian systems enable intermodal transportation systems providing mobility options for residents.

Supply-side Strategies

Cities can employ green energy technologies and sources that reduce emission from the power sector. At the scale of the regional grid, cities can negotiate purchase of greener energy or benefit from national policies regarding reducing the amount of carbon dioxide and other damaging emissions in the power supply. Municipal power companies are developing greener portfolios by adding waste-to-energy, wind and solar technologies. At a local or site scale, cities and building managers/operators can employ smart micro-grid technologies or renewable technologies. These might include rooftop solar or ground source geothermal technologies. To meet net zero GHG emission goals, supply-side strategies are most cost effective when used in concert with demand reduction strategies.

Cities are Acting

We are at a serious tipping point in the earth's capacity to absorb additional heat. While the international efforts are discussed, local communities can take action, and many are. They are joining peer communities, learning from each other and developing polices that reduce their climate impact. They are developing GHG inventories to understand where reductions are needed, establishing reduction targets and goals, and pursuing strategies and supporting actions. They are following their own pathways to reduce emissions, developing greener energy supplies, and supporting more sustainable lifestyles.

In future blog posts I will share strategies cities are employing to reduce their GHG emissions and discuss their effectiveness. ■

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IS THERE A LINK BETWEEN A WARMING CLIMATE AND THE INCREASE IN SEVERE WEATHER?

ROBERT TALBOT
Director of ICAS, College of Natural Sciences and Mathematics

Hurricanes Harvey, Florence and Michael. Devastating tornadoes, droughts, flooding and wild fires. More than 400 months of increasing global temperatures, a significant reduction in Arctic sea ice, melting glaciers, rising sea levels and a constantly warming ocean.

What is going on?

The answer to this question is rooted in a fundamental understanding of how planet Earth functions.

What we know:

- Most of the heat reaching Earth from the sun (>90%) is being sequestered in the world's oceans.
- Earth is warming due to the greenhouse effect primarily attributed to carbon dioxide.
- Emissions of carbon dioxide and other greenhouse gases such as methane are still increasing globally in our atmosphere.
- Earth is rapidly moving toward a 1.5˚C temperature increase above pre-industrial levels , with potential catastrophic consequences driven by climate change.

What we don't know:

- What will happen if we exceed the 1.5˚C temperature threshold?
- How much will sea levels rise in the future?
- How much will severe weather continue to increase in both intensity and frequency in the future?
- Will mitigation steps be enough to offset the resulting changes in Earth's climate?
- What adaptations will be successful in offsetting future climate change? Or are we already too late?

These are serious questions facing planet Earth. The problem is, the processes and mechanisms are so complex that we do not understand them fully.

Most scientists agree that there is a correlation between a warming Earth and the occurrence of severe weather. However, the cause and effects are hidden to some extent by the complexity of Earth's systems. For example, there is no doubt that a warmer ocean will result in more intense and frequent hurricanes, as abundant heat is available in the tropical oceans. Hence, the most powerful storms usually occur in late summer and early fall, when ocean temperatures are at their maximum values. This is the time of greatest heat (or energy) transfer to the overlying atmosphere greatly facilitating storm formation.

A good example of this just occurred with hurricane Michael, which intensified overnight to a Category 4 hurricane once it moved over the very warm waters of the Gulf of Mexico.

What is lacking is a basic understanding of all of the processes and mechanisms involved. This will take time to unravel. Do we have the necessary time? ■

Published November 1, 2018, on Forbes.com

THE PARTY FOR OIL AND GAS

CHRISTINE EHLIG-ECONOMIDES
Professor, Cullen College of Engineering

Many U.S. residents and citizens work for companies that are in business because of domestic and foreign oil and gas production. Many more work for businesses that make money from the pull-through revenue related to water, land and air transportation, restaurants, hotels, consumer goods, taxes and much more. Is there a political party that so clearly favors oil and gas interests that voters can rightly consider ignoring their personal values when they go to the polls?

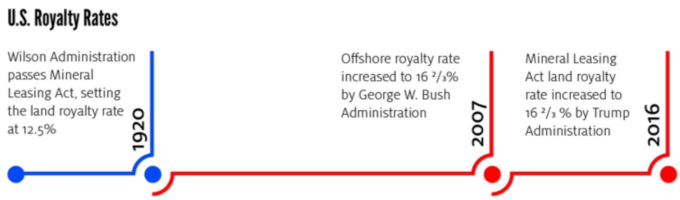
To answer this question, we consider criteria related to offshore and federal land development and royalty interests, energy price control, fuel economy, alternative energy competition, environmental restrictions and climate rhetoric. To make it easier to follow, I have underscored actions not favorable to oil and gas using bold type. Actions favorable to oil and gas are noted in italics.

The results might not be what you would expect.

The federal government controls oil and gas development access to about 28% of U.S. land and all offshore areas from beyond the three nautical mile limit controlled by a state to the 12 nautical mile territorial limit of U.S. jurisdiction, and charges royalties for lease of these areas where exploration and production (E&P) development is permitted. The U.S. land royalty rate was set to 12.5% by the Mineral Leasing Act passed in the 1920s under the Democratic Wilson administration and stayed at that rate for 90 years, until the current Republican Trump administration this year raised the minimum rate to 16%.

Red states Montana, Wyoming, North Dakota and Utah charge royalties at the 16% rate or higher, and Texas, with more than 95% of the land under private ownership, charges 25%. The federal government returns about half of the federally collected royalty in all states except Alaska, where 90% of royalty revenue is returned to the state and where every state resident receives an annual check from the Alaska Permanent Fund.

The offshore royalty rate was also 12.5% until it was raised in 2007 to 16% under George W. Bush leadership.

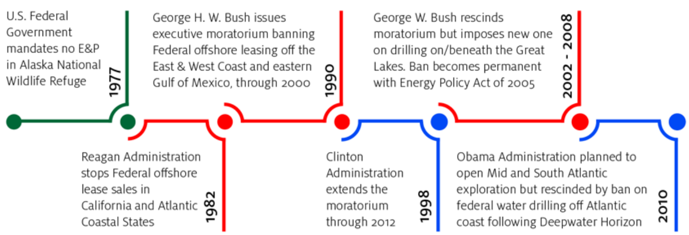


Source: Lauren Kibler

The federal government regulates onshore and offshore E&P access and has prevented E&P in the Alaska National Wildlife Refuge since 1977. The Reagan administration in 1982 stopped federal offshore lease sales in offshore California and Atlantic coastal states. The George H.W. Bush administration issued an executive moratorium restricting federal offshore leasing to Texas, Louisiana, Mississippi, Alabama and parts of Alaska. The moratorium banned federal leasing through the year 2000 off the East Coast, West Coast, the eastern Gulf of Mexico (offshore Florida Gulf Coast) and the Northern Aleutian Basin of Alaska. In 1998 Clinton extended the moratorium through 2012. In 2008, George W. Bush rescinded the executive order, but in 2002 the same Republican administration imposed a moratorium on drilling on or directionally beneath the Great Lakes, a ban that was made permanent by the Energy Policy Act of 2005.

In 2010 the Obama administration announced plans to open Mid and South Atlantic areas to oil and gas exploration, later rescinded by a ban on drilling in federal waters off the Atlantic coast after the disastrous Deepwater Horizon well blowout in the Gulf of Mexico. The state of Florida opposes offshore drilling in state waters and successfully negotiates bans on federal offshore leasing as well.

Alaska and Offshore Exploration & Production



Source: Lauren Kibler

Oil and gas price controls under Nixon and Ford administrations in the 1970s likely contributed to the increasing percentage of imported crude oil being consumed by Americans, because price controls inhibited profitable U.S. hydrocarbon production, especially unassociated natural gas. Fortunately the Carter administration began to liberalize price controls in the late 1970s, and the following Reagan administration accelerated this change, which favored increased domestic oil and gas production.

Harvard University economist Joseph Kalt concluded that while the 1970s price controls had saved consumers between $5 billion and $12 billion a year in gasoline costs, stifling domestic oil production caused an artificial domestic crude oil shortage of as much as 1.4 million barrels a day.

Corporate Average Fuel Economy (CAFE) standards were introduced by the Ford administration in 1975. Although U.S. passenger car fuel economy targets have increased by more than 12% since 2000 under George W. Bush and Obama administrations in succession, they are more than 12% less than European standards. The push to introduce ethanol as a replacement for methyl tertiary-butyl ether (MTBE) as an oxygenate promoting cleaner gasoline combustion was introduced by the George H.W. Bush administration in 1990 with the Clean Air Act. Under the George W. Bush administration in 2005, the Energy Policy Act required the use of 7.5 billion gallons of ethanol (from renewable resources such as corn) by 2012 under the Renewable Fuels Standard RFS). The RFS was later increased to 36 billion gallons by 2022 under the Energy Independence and Security Act (EISA) of 2007.

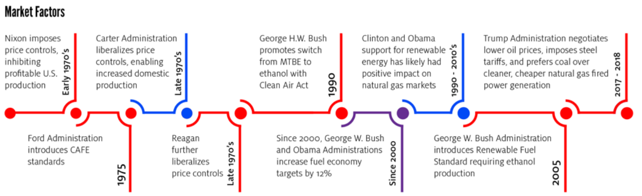
While natural gas would be a less expensive feedstock for ethanol production, American consumers pay higher costs for biofuel production, which also causes greater environmental damage.

Clinton and Obama administration support for wind and solar renewable energy resources has likely had a positive impact on natural gas markets because, unlike coal or nuclear power generation, natural gas electric power generation is readily dispatchable whenever the wind stops blowing or the sun goes down. Electric power generation has little or no bearing on the primary use for crude oil in transportation.

Environmental impacts from hydrocarbon E&P are generally overlooked in favor of well-paying jobs where the development occurs as long as those impacts are not excessive – as in the case of the Deepwater Horizon disaster. While the last Obama administration did interrupt hydrocarbon production in the Gulf of Mexico in the wake of this incident, the same Obama administration offered essentially no barriers to the most accelerated natural gas and then oil development from shale gas and tight oil that has ever occurred in the U.S. or elsewhere.

However, much of the American public is increasingly concerned about climate change that appears to be related to carbon dioxide release into the atmosphere as a result of hydrocarbon and coal combustion for electric power generation, along with oil-based transportation fuels. Climate change initiatives have occurred under both Republican and Democratic administrations. Until there are publically acceptable alternatives to transportation options currently dependent on crude oil, hydrocarbons will continue to dominate the energy supplied to the transportation sector.

Today the Trump administration negotiates to lower global oil prices and impose tariffs on steel, which makes up about 25% of well costs. This Republican administration also claims pipeline security risks for natural gas transport justify preferring coal-fired electric power generation over cleaner, cheaper and more efficient natural gas fired generation.



Source: Lauren Kibler

Based on this analysis, voters should not justify party affiliations on the basis of perceived negative impact on the oil and gas industry. In fact, we might all rather party with the Democrats. ■

Published November 13, 2018, on Forbes.com

A DISASTER THAT COULD HAVE BEEN MINIMIZED, BUT WASN'T

ROBERT TALBOT

Director of ICAS, College of Natural Sciences and Mathematics

Hundreds of barrels of crude oil per day have been spilling into the Gulf of Mexico since 2004 a largely unknown environmental disaster that is well on its way to becoming one of the worst offshore accidents in U.S. history.

The spill began when an oil production platform owned by Taylor Energy was damaged and sank into the Gulf, burying 28 wells under a mudslide associated with Hurricane Ivan. Fourteen years later, it threatens to make the 2010 BP Deepwater Horizon spill, the largest ever in U.S. waters, look small by comparison.

Despite more than a decade of lawsuits, studies and federal assessments, there is no resolution in sight. And unlike the explosion of the Deepwater Horizon oil rig – which killed 11 workers and leaked more than 3 million barrels of oil into the Gulf before it was capped – the Taylor Energy leaks have drawn little public attention.

The leaks continue, making this case a perfect example of why we need more rigorous enforcement – with real consequences – of U.S. and global regulations to protect our oceans. Oil pollution is not regulated by global conventions, but perhaps it should be. In any event, coastal states should establish regulations to protect their nearshore waters and maintain a clean area for recreation and fishing.

Taylor Energy sold its oil and gas assets and ended production in 2008, several years after the death of its founder. The company has declined to speak publicly about the spill and resulting damage, although it has stated in court filings that there is no evidence of leaks from its wells. It took a lawsuit from a consortium of environmental groups to force public acknowledgment of the leaking wells.

Even so, the majority of Americans have paid little attention to the slow-motion disaster perhaps because the spill originated more than a dozen miles offshore and away from their everyday activities.

The lack of attention, however, has done nothing to stem the damage racked up as the leaks continue. The toll oil spills take on wildlife is well-documented: Most spilled oil floats on the water surface, pushed outward by currents and wind and affecting diving birds, as well as fish and other marine life below. It also can affect human health.

This is indeed a sad story that is giving the oil industry a bad name, raising the question of why Taylor Energy failed to cap the affected wells. Was the company embarrassed by the accident, wanting to avoid bad publicity, or to limit the cost of a cleanup? It might be a combination of these.

Still, the responsibility doesn't fall solely on the company, which had reported the spill to the Coast Guard and established a multimillion-dollar trust to clean it up.

The oceans belong to everyone. They need to be taken care of, instead of being a dumping ground for unwanted materials.

The oceans are crucial to planet Earth and how it functions in a complex manner. They are a major food supply for people everywhere. Let us all be more responsible and take care of them! ■

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HOUSTON 2020: NATURAL GAS STILL DOMINATES THE ENERGY CONVERSATION

ED HIRS

Lecturer, College of Liberal Arts and Social Sciences

2020 is a year away, and we don't expect major changes in the energy markets. However, the forces already driving toward 2070 will be more entrenched - the displacement of coal by natural gas, liquified natural gas exports stabilizing the world market for natural gas and displacing oil in the developing world, and a growing confidence that evolving technology will accelerate the use of wind and solar. 2020 is an election year, and local and state governments across the nation — if not the federal government — will continue to implement policies for carbon reduction.

DEMOGRAPHICS 2020: A changing population raises challenges to future prosperity

DOWNTOWN 2020: Finally, an intentional design

ECONOMY 2020: Prepare for fundamental shifts

MUSEUMS 2020: Expect a Museum District transformed

PARKS 2020: Investments will start paying off

TRANSPORTATION 2020: From freeways to scooters, transit will get disrupted

In 2020, the volatile price of oil will still depend on geopolitical events and manipulations by OPEC in concert with Russia. The threat to Houston is that increased world oil production will again endanger offshore oil, shale plays and the Permian Basin. Sustained oil prices through to 2020 will require OPEC and Russia to continue to cede market share. Furthermore, with oil priced above the equivalent of cleaner natural gas, OPEC and Russia will cede oil's market share to cheaper natural gas around the world. By 2020, the costs of that strategy will be apparent, and lower oil prices will be in the offing.

For Houston in 2020, continued low-cost natural gas will produce the electricity to charge electric vehicles around the nation and provide the feedstock for continued growth of petrochemicals, plastics and fertilizers.

Electricity development in the United States and around the world will rely more on micro grids, which provide greater operational reliability for assimilating renewable energy and energy storage technologies. Even today, wind and solar electricity coupled with available energy storage techniques are on a trajectory to be cost-competitive with legacy electricity generation.

As the hub for energy technology research and development, Houston will continue to draw employment and energy investment capital in 2020.■

Published January 4, 2019, on Forbes.com

POLICIES OR TECHNOLOGY? THE KEY TO A SUSTAINABLE ENERGY FUTURE

CHARLES MCCONNELL

Energy Center Officer, Center for Carbon Management and Energy Sustainability

The chicken or the egg? The cart or the horse? Should policy or technology take the lead? It is not a reasonable question when it comes to deciding where the keys to a sustainable energy future lay – we need both.

Meeting that energy challenge is fundamental to maintaining our current way of life and fulfilling the growing energy needs of the rest of the world. About 1.3 billion people globally live in energy poverty – that is, they lack access to sufficient energy for basic needs and are forced to rely on the most primitive forms of energy such as wood burning and waste, as well as expending an excessive amount of time collecting these fuels. Another 2 billion or more people will be added to the world's population in the next 50 years, many of them in the developing world, compounding the difficulty of providing sufficient energy to meet their needs.

Creating a sustainable energy future – one that meets the demands of a growing population while addressing the challenges posed by concerns about a warming climate – is arguably the world's greatest challenge. Finding solutions will be difficult, and it won't happen unless we consider both the needs and concerns of the energy-intensive developed world and those of developing nations where the majority of population growth will occur.

Sustainable energy will require three components: Access and reliable supply; affordability and cost effectiveness in a competitive marketplace; and environmentally responsible production, transportation and consumption of energy. In the U.S. and other developed countries, we too often take the first two as a given and focus exclusively on the impact to air, land, water and communities as the keys to sustainable energy.

Much of the rest of the world is not as fortunate, a fact we must incorporate into any solutions for long-term sustainability. How do we get there? Policies, laws, business mechanisms and regulations can drive behavior and shape the operating landscape, but another key enabler cannot be ignored.

That is technology.

Today 80% of the world's energy is supplied by fossil fuels, and the International Energy Agency (IEA) has projected that demand for energy will double in 50 years. There will be an unprecedented amount of wind, solar and other renewable energy technologies deployed globally in that timeframe. Even so, IEA forecasts that the heightened demand will require that 80% of the world's energy 50 years from now will continue to be supplied from fossil fuels . Incredible global growth will demand it.

Technology will be key both to expanding access to renewable energy and to reducing the environmental impacts associated with oil, natural gas and other fossil fuels. It is the transformative key and investment in technology is a must.

Believing that we can solve the environmental issues simply by implementing policies to make some forms of energy less available and more expensive through taxation or policy is arrogant or, at best, naïve. We cannot grow by subtraction but by enabling all forms of energy to meet the challenge.

The developed world may complain of too many automobiles, too much CO^2 emitted to the atmosphere, far too much reliance on oil and gas and fossil fuels. But let's not forget that people in this world consume more energy per capita than anywhere else in the world by a wide margin.

Contrast that to the developing world, where the lack of access to affordable, reliable and safe energy for cooking, heating and other basic needs leaves people to burn wood and coal and suffer enormous personal health consequences as a result. Fossil fuels, relatively inexpensive and abundant, will be a requirement, even amidst global concerns about the impact on climate. That's why technology and investment in R&D for ALL forms of energy is a must.

We need policies, laws, business practices and regulations to address these issues, but we cannot assume those policies will magically produce the desired results, or that we will be better off for making energy less available and more expensive. We won't be.

Policies can be very effective at driving behavior, but they must work in concert with enabling technology to realize the outcomes we desire, including increased energy efficiency and reduced emissions.

Environmental policy does work as the United States has made incredible progress in reducing automobile emissions, improving efficiencies in electric power production and ensuring our manufacturing facilities are best in class globally. We enacted policies to drive such outcomes—but we also invested in technology to achieve it.

The world should expect the U.S. to continue to lead the technology transformation for the future, both lifting the impoverished people of the world and building a broad and expansive network for our technology to enable our energy transformation globally. That transformation will include fossil fuels for the foreseeable future, and those fuels must be made environmentally responsible to use. We have to evolve beyond a simple denial of fossil fuels in our future and to focus on the realities of reducing the emissions and other environmental impacts.

Let's solve problems and grow, not create a world of have and have nots by narrowing the energy choices available to people. Policies AND technology will ensure our sustainable energy future. ■

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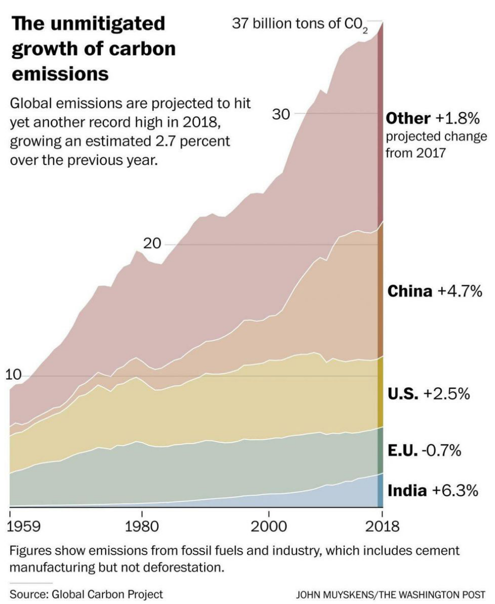
CARBON EMISSIONS STILL CLIMBING. HISTORY SHOWS US WHAT WE NEED TO DO

ROBERT TALBOT

Director of ICAS, College of Natural Sciences and Mathematics

2018 was not a good year for carbon emissions into the Earth's atmosphere. Global emissions were up nearly 3% from the previous year. Leading the pack was China, with the U.S. in second place.

As a matter of fact, emissions from all countries that signed the Paris agreement in 2015 had increased emissions last year (see figure). To put it simply, repeated similar performance will not keep Earth's temperature from rising above the critical 2 degrees C mark.



Source: Global Carbon Project

In the words of United Nations Secretary General António Guterres, "the effects of global warming will only intensify in the absence of aggressive international action." Higher emissions are linked to that increased warming, with consequences ranging from rising sea levels to more severe heat waves, floods and drought. It is clear that we need to act now and quickly, with unlimited perseverance. The global community did this once in the past, and this is the time for a repeat performance.

In 1974, Mario J. Molina and F. Sherwood Rowland demonstrated that the upper atmosphere was a sink for chlorofluromethanes, more commonly known as chlorofluorocarbons (CFCs), by destroying ozone, and thus creating the so-called "ozone hole." These were the compounds used in refrigeration at the time.

Finally, in 1985 the ozone hole was observed above Antarctica by British scientists for the first time. The Montreal Protocol in the late 1980s subsequently banned the production and use of these compounds, and the world complied. Ozone in the upper atmosphere protects living things on the Earth's surface from harmful UV radiation. Although the ozone hole still exists today, its size has been contained and the danger to our planet reduced.

Molina and Rowland, along with Paul J. Crutzen, were awarded the Nobel Prize in Chemistry in 1995 for their work in atmospheric chemistry, particularly for their work on the formation and decomposition of ozone. It is the type of action that is required to save Earth from catastrophic climate change. Both problems seriously held our planet at hostage. We can minimize the risk if we act now. Do it! ■

Published January 24, 2019, on HoustonChronicle.com

ANY GREEN NEW DEAL MUST INVOLVE THE OIL INDUSTRY

CHARLES MCCONNELL

Energy Center Officer, Center for Carbon Management and Energy Sustainability

The Green New Deal sounds great — a United States fully powered by renewable energy sources within a decade or so. Everyone should embrace the low-carbon future now, right?

But hard things are hard, and making that transition, especially on a global scale, will be no different. That's why we must strive to reduce fossil fuel emissions while also making our entire energy supply more efficient, reliable and cost-effective, as well as environmentally responsible. This change cannot happen overnight, no matter how much we might wish.

The world's population is projected to grow by nearly 3 billion people over the next 50 years, and most of the growth will occur in what is now the developing world. Those people will need energy to enable economic growth and a rising standard of living. In the meantime, the Western World is becoming more energy intensive every day. Worldwide energy demand is projected to double in 50 years.

Global forecasts project that fossil fuel consumption will hold steady at 80 percent of the energy supply over the next half-century due to this growth in demand. Renewables will grow significantly, particularly in the United States and other developed nations, but much of the developing world will choose fossil fuels such as coal, oil and gas because they are the most accessible and affordable. Their first order is providing access to energy, not preventing climate change.

This may sound like a cop out to people calling for an end to fossil fuel use. It isn't. It is a recognition of the challenges to powering the world into the future.

But clearly it can't be business as usual, and the industry has begun to recognize that. Concerns about climate change, including emissions of carbon dioxide and methane, pose a serious risk to a sustainable future. In releasing its State of American Energy report earlier this month, the American Petroleum Institute acknowledged the risks and touted industry's voluntary efforts to reduce emissions.

It's not just talk. Sami Al-Nuaim, president of the Society of Petroleum Engineers, recently addressed members of industry and academia at the University of Houston, discussing the organization's initiatives to protect the environment.

Technology is a big part of the solution. This includes carbon capture, utilization and storage, as well as nascent technologies to turn carbon emissions into fuel and chemicals. Industry and the public sector must commit to investing significantly in technology R&D and demonstration facilities and creating the pathway for transformation. Technology must inform policy to drive change.

New regulations, including tax credits, are needed to encourage investment. Carbon taxes and cap-and-trade schemes are being discussed, and methane emissions controls from oil and gas development are integrated into traditional regulations. But more importantly, companies must shift from thinking about reducing emissions as an added expense to valuing carbon management as an asset to the bottom line.

Companies are beginning to see sustainability as critical for their shareholders, their employees and the countries where they do business. Investment in renewable technology development is part of that, from solar farms to wind, algae, biomass and other forms. But they must also aggressively address their own existing carbon footprints. It's good for business because it is good for the environment.

In fact, we won't be able to reduce global emissions and address the goals of the United Nations International Panel on Climate Change without the active involvement of the oil and gas industry. That's because the scale and capability of the industry is essential to the solution. Transformation will be enabled by research partnering with universities and the support of the state and federal government, but these industries hold the key to energy sustainability.

No amount of government intervention and "stick" will be as effective as the "carrot" of a sustainable future and a position as leaders in the global market.

Houston is the energy capital of the world. Its leadership, from industry to academia and public policymakers, must embrace our future and enable the transformation of our energy reality. That reality requires that we don't choose either/or but use all forms of energy to make our future bright. ■

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FACT CHECKING THE CLAIM OF A MAJOR SHIFT IN CLIMATE CHANGE OPINION

EARL J. RITCHIE
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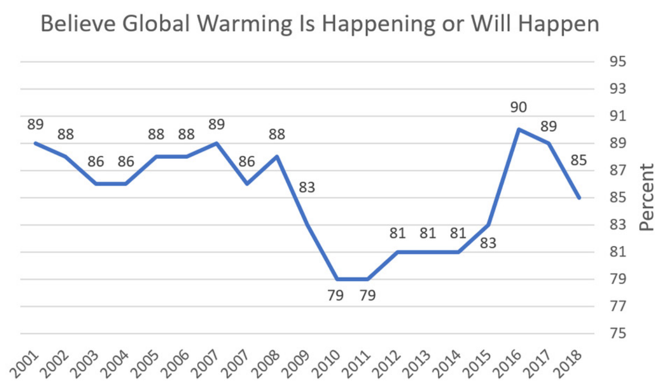
One frequently sees articles announcing a watershed moment in public concern over climate change. A recent CNN article said "A growing number of Americans, including most Republicans, believe that climate change is happening, a shift in public opinion from three years ago."

By contrast, a Gallup headline says, "Global Warming Concern Steady Despite Some Partisan Shifts." Which is true? Is climate change belief increasing? The answer is yes and no. Overall, the change is minor; in some segments it has changed greatly.

Polls show little change in belief in climate change

Belief in climate change is a much-studied subject. It has long been surveyed by Pew, Gallup, Yale/George Mason and others. It is periodically surveyed by various researchers, survey firms and news organizations. Reported change over time varies with the polling organization and specific question. The graph below shows that roughly 80% to 90% of those polled by Gallup believe the Earth has warmed or will warm. This has not changed greatly in the past 20 years.

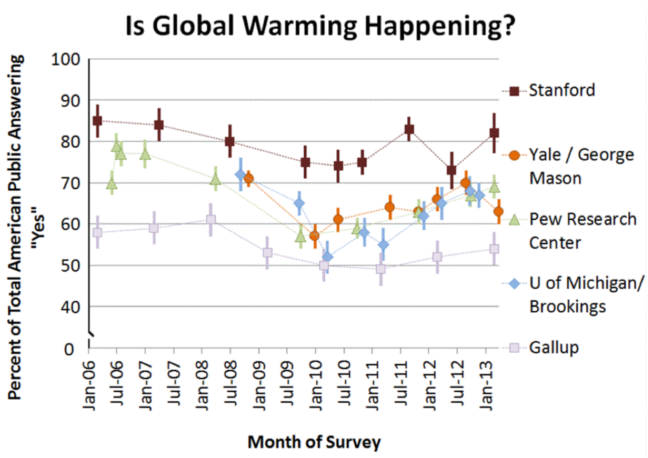


Source: Data from Gallup

The Yale and ABC/Stanford polls show belief about 10% lower but also show little change over time.

It depends on the question

Survey results vary because questions reported similarly in headlines are not actually the same. For example, Gallup asks when it will happen, with an option to say it will never happen; Monmouth asks whether there is a change that is causing extreme weather and sea level rise; Yale asks simply whether it is happening; University of Michigan and Muhlenberg College ask whether there is solid evidence. The somewhat dated graph below shows that difference among surveys is much greater than the difference over time in any individual survey. This is hardly surprising, given the differences in methodology.



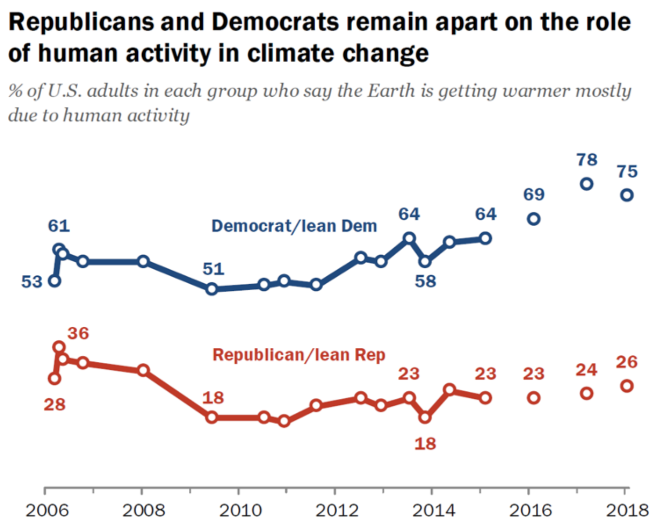
Source: American Geophysical Union

It is not reasonable that the Gallup results of about 55% and the Stanford results of about 80% can both represent the actual level of public belief. The discrepancy is due in part to question wording.

Questions may include "explainers," nominally to give some understanding of the subject. These explainers are often biased, usually in favor of climate change belief. Not surprisingly, this skews poll results. One study found a 40% increase in overall results and a 100% difference among Republicans as a result of explainers and question structure. Despite claims of margin of error of 5% or less, differences among surveys show that poll results are not that accurate.

Whether it's caused by humans is divided

Although the media routinely treat climate change as synonymous with anthropogenic climate change, the public is much less convinced that human activity is the cause. Per recent Pew poll results, approximately half of Americans believe climate change is caused by human activity. However, this belief differs greatly by political orientation. The graph below shows an increasing majority of Democrats believe warming is due to human activity, but the belief by Republicans is low and little changed.

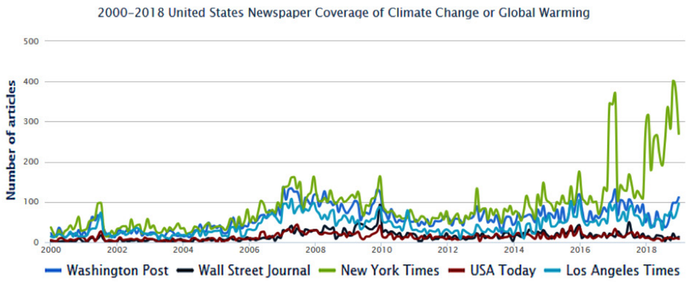


Source: Pew Research Center

There are differences by age, gender, location and education level. These are small compared to political affiliation and ideology.

More coverage in the liberal media

There has been increasing coverage of climate change in U.S. newspapers. Consistent with the political split on climate change concern, the increase in has been primarily in publications that tend to be rated as liberal or left of center. In tracking of five newspapers by the University of Boulder, the largest increase has been in the New York Times, with significant increases in the Washington Post and Los Angeles Times. All three are rated liberal by numerous groups including AllSides and Boston University. Coverage is much less in USA Today and the Wall Street Journal, rated moderate and conservative, respectively. A similar study of US television found mentions are dominated by CNN, also considered a left-leaning source.



Source: Earl J. Ritchie

Hyping minor changes

As in other politicized issues, proponents make a big deal out of any news that favors their viewpoint. The CNN article quoted at the beginning of this article was based on a Monmouth survey. Monmouth's own announcement was more subdued but touted dramatic increases in climate change belief: an 8% change overall, and a 15% change among Republicans.

If real, those changes are indeed significant. However, the overall belief level was consistent with levels reported for the past several years in other polls and the Republican belief level is considerably higher than reported in other recent polls.

Perhaps the shift in Republican belief reported by Monmouth is real; perhaps it's a random variation, perhaps it's the result of the question's wording. Given the differences between surveys and a degree of year-to-year variation, it's premature for a single survey result to be taken as proof of a major shift.

How important is climate change to the public?

Climate change does not rank high on the list of public concerns. A 2018 Pew poll listed it 22nd of 23 issues. It ranked similarly low in earlier surveys. However, like all aspects of the debate, it is strongly politically divided. It was tied for fifth place among Democrats/lean Democratic in the 2018 poll.

It was not included in the 2018 Gallup poll of most important problems. In their global warming poll, 91% of Democrats and 33% of Republicans expressed worry.

The facts

There is considerable debate over the exact level of climate change belief; however, some conclusions are clear:

- A strong majority of Americans believe climate change is happening
- Roughly 50% believe human activity is a significant contributor
- Democrats are largely believers that human activity is the cause of climate change; Republicans are not
- Change in belief has been slow

A broader perspective

One can get too concerned about differences of a few percentage points in poll results. A bigger issue is what people are willing to do. Support for renewable energy and elimination of fossil fuel cars is high, but the amount people are willing to pay to accomplish it is low. Poll results vary, but, commonly, 30% to 40% say they are not willing to pay anything. Few seem willing to pay over $200 per year. This compares with an estimated carbon tax cost of $1,000 per year or more needed for U.S. residents to meet a goal of keeping warming below 2 degrees Centigrade.

However, these are very imprecise numbers. I'll talk about it in a later post. ■

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NOT ENOUGH TALENT FOR THE ENERGY WORKFORCE? ENERGY'S DIVERSITY PROBLEM MAY BE THE SOLUTION

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HAYLEY BROWN Founding Partner, Impact Diversity Partners LLC

There is much talk about the shortage of talent to fill jobs in the energy industry. Known as "The Great Crew Change," over half of the energy workforce will be retiring in the next seven years. Even as hiring has slowed in the face of moderating oil prices, companies have only been able to hire one new employee for every two exiting the workforce. Who will fill these positions? Perhaps not young people.

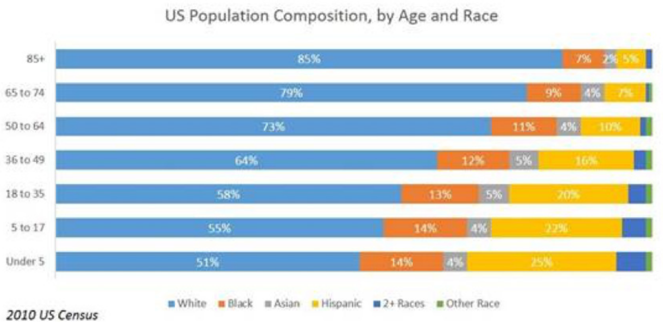
An EY poll reveals that only 18% of Millennials and 6% of Gen Zers found a career in oil and gas to be very appealing, with many young people viewing the industry as dangerous, unstable and bad for the environment. This has resulted in, among other things, companies such as Statoil actively rebranding to alter their organizational attractiveness. As jobs requiring STEM degrees skyrocket, more industries are competing with oil and gas for STEM candidates. Many of these industries offer more work-life balance and inclusivity than oil and gas, which are more attractive to younger employees than a large paycheck (which the competition also offers).

If the energy industry hopes to improve its labor shortage problem, it must take steps now to embrace practices that have been shown to create environments that attract talent.

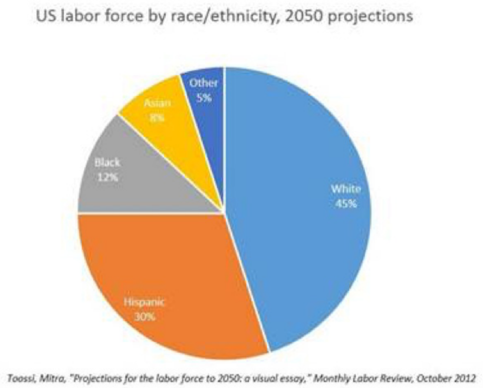
Source: Christiane Spitzmueller

How is gender and ethnic diversity impacting the talent shortage in the energy industry?

Young talent and diverse talent are increasingly becoming one and the same. Therefore, in order to court young talent, energy companies must embrace the full breadth of diversity in the workforce, something which most have failed to do so far.

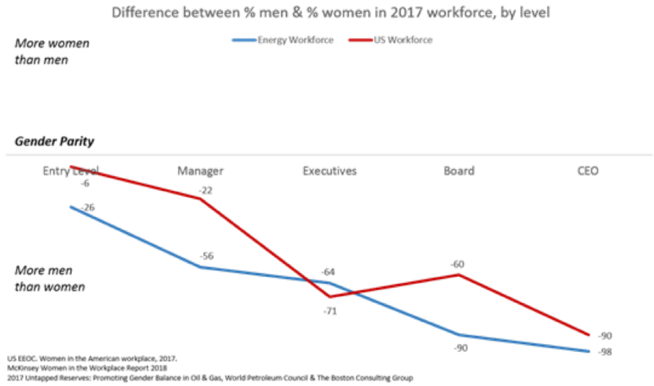


Source: 2010 US Census



Source: 2010 US Census

For example, African Americans account for only 6.7% of the current energy workforce, compared with 12% of the US workforce. The workforce disparities are even greater when it comes to women. In 2015, women constituted 47% of the US workforce, but made up only 17% of the energy industry. A 2017 collaboration from the World Petroleum Council and The Boston Consulting Group stated that "women [in oil and gas] account for a significantly smaller share of the workforce than they do in almost any other sector."



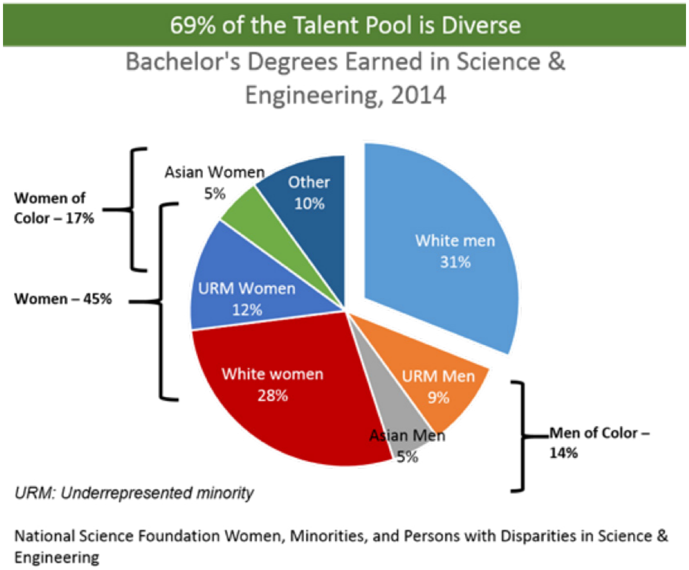
Source: US EEOC. Women in the American Workplace, 2017

In fact, at a recent event hosted by the International Association of Drilling Contractors in Galveston, TX, an energy company manager told the room that "offshore rigs and makeup just don't go together." The energy industry must act swiftly and strategically if it hopes to catch up to its competitors' efforts to attract an increasingly diverse talent pool.

Here's How:

1. Acknowledge there is a problem and measure its magnitude and price

Each energy company experiencing talent shortages needs to take a critical look at its workforce demographics. Are women, African Americans and Hispanics represented in newly hired cohorts in percentages that resemble their representation at the institutions from which they are recruited?



Source: URM: Underrespresented Minority

Are organizations losing talented women and employees from historically underrepresented groups because they are less likely to be promoted or recognized for high performance? Is there representation across all types of executive ranks? What are the costs associated with your talent shortages?

Research suggests the economic benefits of highly diverse teams are significant and that there is indeed a cost to a lack of diversity. However, organizations cannot measure the full extent of their problem or the impact of any progress made without rigorous metrics and analytics. Companies must go beyond simple diversity snapshots to discover exactly where the problems and successes are occurring. In the words of Peter Drucker, "What gets measured gets managed."

2. Promote an inclusive envrionmnt through diversity ally traning

Recruiting more diverse employees will have limited impact in organizations that lack inclusive cultures. In order to retain those employees, organizations must educate their current workforce on the value of diversity and how their behaviors can contribute to an inclusive climate.

Trainings that hope to improve culture by increasing awareness of implicit bias are commonly used but not universally effective and may even result in diversity backlash. If increased awareness, on its own, were enough to eradicate bad behavior, smoking would have died out long ago. Based in research on behavior change, diversity ally trainings focus on teaching actionable behaviors that create change as well as on the value those behaviors produce – the why and how of inclusion.

3. Focus on organizational and systemic changes that benefit everyone

Sustainable inclusivity can only be gained by ensuring transparency and accountability in policies, practices and organizational systems. For instance, determining whether organizational policies impact diverse employees differently from the remainder of the workforce is critical. Are recruitment practices truly evidence-based, with the goal of predicting job performance while maintaining access for candidates from varied backgrounds? Are systems in place to secure equal access to career development networks and opportunities?

If energy companies are to compete for future top talent, they must commit to action now. Organizational change takes time, and time is not a luxury that the energy industry can afford it if plans to be ready for the nation's first majority minority workforce. Or for the great crew change. ■

Published February 8, 2019, on Forbes.com

WHAT YOU SHOULD KNOW ABOUT THE GREEN NEW DEAL(S)

EARL J. RITCHIE
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The first thing you should know about the Green New Deal is that there is no single Green New Deal. Recent media attention has been focused on the proposal supported by newly elected Congresswoman Alexandria Ocasio-Cortez. However, there are multiple proposals using the name Green New Deal, which vary tremendously in their scope and intent.

Green New Deal proposals fall into two categories: proposals which focus on improvement of the environment, especially reducing the risks of climate change, and proposals which combine the former with broad societal and governmental changes, such as income redistribution and reduction of the U.S. military.

The original Green New Deal

Per Wikipedia (and Friedman himself), the phrase was originally used by Thomas Friedman in a 2007 New York Times op-ed. Friedman's proposal was an exhortation to action on climate change. It was weak on specifics and did not include the social agenda included in other proposals.

Friedman's version is simply an all-out effort to combat climate change. As such, it is no different from actions championed by proponents of the theory of anthropogenic climate change, such as James Hansen, Michael Mann, the United Nations Framework Convention on Climate Change (UNFCC) and numerous others.

Popularization of this concept is usually attributed to James Hansen's 1988 speech to Congress; however, the concern dates back at least to the 1960s and was the subject of a comprehensive report by the National Research Academy in 1977. Warnings have become increasingly urgent since there has been little reduction in the growth of greenhouse gas emissions.

Green New Deals with a social agenda

The Green New Deal introduced by Alexandria Ocasio-Cortez is an example of an environmental program combined with a social program. In addition to having the U.S. become carbon neutral, it envisions a "national, social, industrial, and economic mobilization on a scale not seen since World War II and the New Deal era" and providing all people of the United States with high-quality health care; affordable, safe, and adequate housing; and economic security.

Another example of the social democratic version was published by the Green Party U.S. and remains part of their platform. It includes "a WPA-style public jobs program," a single-payer medical system, tuition-free college, forgiveness of all existing college debt, repeal of the Patriot Act, somewhat vague voting reform, and various other liberal agenda items. They adopt Stanford University scientist Mark Jacobson's estimate of $13.4 trillion as the total cost of a renewable energy conversion. It would be paid for by a 50% cut in military spending, a very high carbon tax and higher taxes on "the wealthiest Americans."

Other Green New Deals

A number of other organizations have proposed Green New Deals. Examples include the Green New Deal Group, Data for Progress and Elected Officials to Protect America. Most often, these include a social agenda, although the nature and extent of social measures varies among proposals. Sometimes the Green New Deal is used as a generic term, without reference to a specific plan.

Someone has to pay for it

It is entirely reasonable, even commendable, that a proposal include the means to fund it. After all, the $13.4 trillion estimate of the Green Party US is more than half the existing US national debt. The Green Party proposes taxing the rich, cutting military spending and a carbon tax.

The proposal by Alexandria Ocasio-Cortez does not include specific funding. However, she has earlier advocated taxing the rich and carbon taxes.

Bundling a package of social reform measures with emissions reduction creates a false dichotomy. Either one could be done independently.

Media coverage is often misleading

It is very common for articles, such as this New Yorker piece, to leave out the social agenda. This is incomplete and misleading. The social agenda is a major part of the proposal by Ocasio-Cortez and others.

Many commentators in the right-wing media emphasize the social agenda of the Green New Deal, some going as far as to call it a "Trojan horse for socialism." I had a hard time finding such articles that didn't include a rant against Alexandria Ocasio-Cortez, Bernie Sanders or the Democratic Party generally. Regardless of rhetoric, their point is correct: most versions of the Green New Deal are not just about protecting the environment. Balanced coverage would not leave out the significant social measures included in these plans.

Make sure you know what you're supporting

A recent Yale poll reported 81% support for the Green New Deal among American voters. However, it also reported 82% of voters knew nothing about it. Furthermore, the question was prefaced by an "explainer" that described the promised benefits with no mention whatever of the associated social democratic measures.

As I said in an earlier post and others have reported, "explainers" of this type can bias poll results. I doubt that all survey participants, who were told the Green New Deal would produce jobs, strengthen the U.S. economy and generate 100% of the nation's electricity from clean, renewable sources within the next 10 years, would necessarily have supported it if also told of tax increases, universal health care and other social agenda items not disclosed in the "explainer."

Yale says, "our description of the Deal accurately provided details about the proposal." I encourage you to compare the explainer (it's the first paragraph of the link to the poll) to the Select Committee proposal to see whether it "accurately provided details."

In this era of fake news and the echo chamber, it is important to look behind the promises of proponents of any proposal. If you're polled or voting for someone the basis of the Green New Deal, make sure you know what you're supporting. ■

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MERKEL SALVAGES NORD STREAM, BUT IS PUTIN LOSING RUSSIA'S GAS MONOPOLY?

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Cullen Distinguished Professor of Economics, College of Liberal Arts & Social Sciences

The European Union took a first step with its February 8 vote towards turning Russia's gas monopoly, Gazprom, from an instrument of Russian power politics into a regulated utility, deprived of its monopoly power. In an odd twist, Germany, the self-proclaimed guardian of European unity, found itself politically isolated from the rest of Europe, which sided with U.S. President Donald Trump. A bitter pill for Germany to swallow.

Meanwhile, Putin and Germany complained that U.S. intervention was exclusively for its own plans to sell its expensive LNG to Europe.

As the European Union (EU) permanent representatives gathered in Brussels on Friday, February 8, to vote on the EU's Gas Initiative of the Third Energy Package, Russia's Nord Stream 2 (NS2) undersea pipeline project was in jeopardy. Even Germany's reliable ally France had declared its intent to vote against the German-Russian project. Without France, Germany could not block an anti-NS2 vote, and an alarmed Angela Merkel swung into diplomatic overdrive. In hasty negotiations, Merkel and France's Emmanuel Macron reached a compromise agreement that allows all parties to fight again another day.

Eastern and Central Europe and Ukraine strongly oppose the Russian-German project being built by Gazprom in conjunction with five European energy giants. Their objections: NS2 will bypass the Ukrainian and other pipelines that currently transport about half of Russian gas to Europe through their territories. NS2 will make Germany the hub of gas trade and distribution, and a new gas transport infrastructure must be built for economies east of Berlin. Although supporters claim NS2 will not increase Europe's dependence on Russian gas (because of competition from LNG), NS2 combined with Gazprom's proposed Turk Stream pipeline would semi-circle Europe's energy market from both the south and the east at a time when North Sea production is waning.

Moreover, at present prices, LNG is not competitive with piped-in Russian gas.

Merkel's counterattack revealed her deep commitment to NS2. She pressured NS2-opponent Romania, which chaired the February 8 meeting, to bring forth an alternative proposal for a vote. Phone lines between Paris and Berlin buzzed as Merkel sought a compromise that would gain France's support. Indeed, when the commissioners met on Friday, they passed with only one "no" vote (Bulgaria) the compromise worked out by Merkel. The next step will be expected approval by the European parliament, presumably before the May 2019 parliamentary elections.

The main point of contention was whether the EU would subject pipelines originating outside of the EU, such as NS2, to EU regulation as spelled out in the EU's Third Energy Package. EU rules require pipelines operating in the intra-European market to unbundle transportation from production. For NS2, this means that Russia's natural gas monopoly, Gazprom, would have to sell its pipeline to a third party to separate production from delivery. The application of EU guidelines to NS2 would also subject Russian gas sold in Europe to regulation by Brussels. Such regulation would outlaw Gazprom's past ban on reselling its gas to other countries and would prevent Gazprom's giving favorable rates to friends and punishing foes with higher prices.

The compromise is that Germany would be in charge of insuring that Gazprom honor the EU rules on unbundling, price regulation and access by third parties to its pipeline network.

Putting Germany in charge of NS2 regulation may be like putting the fox in charge of the hen house. Although Merkel has vocal opponents of NS2 in her own party, her coalition partners, the Socialist party of Germany (SPD), has been throughout an avid supporter of NS2, the chairman of which is former German chancellor Gerhard Schroeder. Merkel's shaky coalition with the SPD constrains her. If she were to come out against NS2, her "grand coalition" government would fall, and new elections would have to be called with quite uncertain results.

The United States under President Trump has taken a strong anti NS2 position, Trump raised his objections to NS2 at the NATO summit in July. The U.S. ambassador to Germany, Richard Grenell, threatened the five European partner companies with sanctions if they cooperate on the NS2 plan. Russia and supporters of NS2 in Germany complain that the U.S. is simply trying to force its expensive LNG on Europe and opposes Nord Stream 2 for selfish commercial gain.

In its editorial, the influential Der Spiegel, criticizes Merkel for failing to gauge the depth of European opposition to increasing commercial entanglement with Russia. Germany's argument is that Nord Stream 2 is just a commercial undertaking between two consenting powers, but Germany's support of Nord Stream 2 has been a political disaster that has isolated Germany from the rest of Europe.

Sober voices in Europe are basically questioning whether Europe should tie itself even more to a pipeline that depends on the good behavior of a country that illegally annexed Crimea, started a war in East Ukraine, denied shooting down a passenger plane, intervened in Syria to save a client and brazenly violated the law of the seas by seizing Ukrainian war ships and sailors, and engages in relentless hybrid warfare and propaganda against the Western world. Is it coming close to the time that Europe and the rest of the world punishes a rogue state, in the heart of Europe, for its many violations of international law and norms? ■

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IT'S NOT JUST THE PERMIAN. SUPER BASINS ARE A GLOBAL PHENOMENON

CHARLES A. STERNBACH

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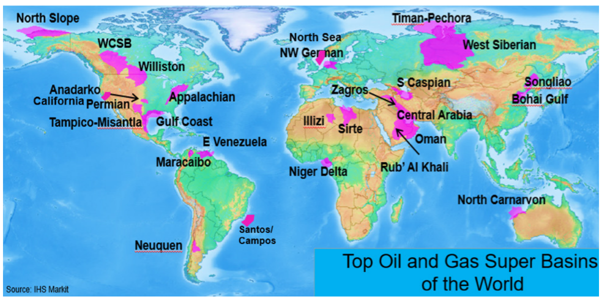
Forget what you may have heard. Fossil fuels aren't going anywhere.

There is a lot of excitement, and deservedly so, about renewables, but the foundation of our energy supply is and will continue to be hydrocarbons for at least the next few decades.

There are several reasons for that, but an important part of the story is that advances in seismic imaging and other new technologies have shown that these fuels are in abundant supply, both in the United States and globally, including massive offshore deposits.

As super basins gain attention – basins that already have produced five billion barrels of oil and contain the potential to produce an additional five billion barrels (IHS Markit)– a mood of optimism has replaced fears of shortage and "peak oil" declines. The potential for this reset in thinking at a global scale offers profound opportunities regarding energy, environment, economics, and security.



Source: Charles A. Sternbach

What's ahead?

Predicting future energy supply and demand is a mix of art and science, balancing the need for more energy as the global economy grows – developing countries are still trying to ensure their populations have sufficient energy to participate in rising standards of living – with concerns about climate change and demands for a lower-carbon future. The growth of electric vehicles is surging. But the electricity to power those vehicles has to come from somewhere, and we have to look at the all-in costs of electricity, creating it in responsible ways and eliminating, not just redistributing, emissions. That's no trivial task.

The International Energy Agency (IEA) predicts energy demand will double over the next 50 years, with historic levels of solar, wind and other renewable technologies deployed during the coming decades.

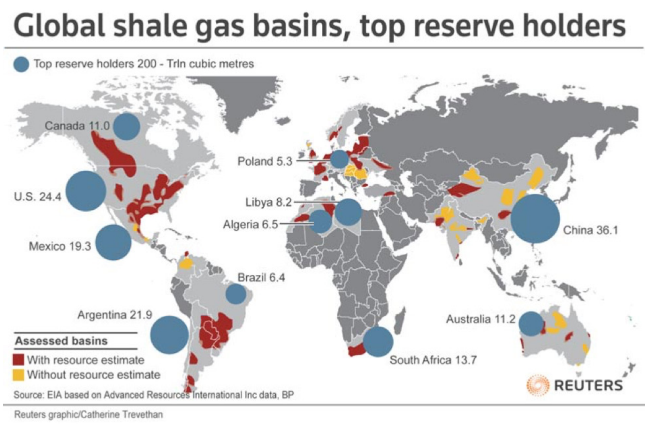
But fossil fuels make up about 80% of the global energy supply today, and IEA forecasts show that percentage will be unchanged in 2040. Increasingly, we expect that natural gas will make up a large and growing share of that category, with climate concerns contributing to a drop in the use of coal, at least in the United States. Global coal use actually rose last year, making the potential for producing vast amounts of clean-burning natural gas even more important

That's where the new emphasis on technology and super basins comes in. Onshore basins with unconventional resources are benefitting from engineering breakthroughs in stimulation and recovery. Offshore basins with conventional resources are being revitalized below salt and other barriers by enhanced seismic imaging.

In addition to past production and the prospect for future production, these basins include many pays and plays, along with substantial infrastructure. In contrast to rank frontier exploration, super basins are well established basins where new technology is the game changer. Super basins combine geoscience architecture, commerciality, infrastructure and above-ground issues in a holistic review.

The Permian Basin is the prototype onshore unconventional super basin . It possesses key geological fundamentals in abundance. In addition, the Permian Basin and other North American basins are a fertile cradle of technology. They possess critical factors for innovation: private mineral ownership, a strongly networked community, service company partnerships and immediate rewards for risk taking. The Permian offers hard won lessons from more than a decade that include: addressing needs for energy transport, water handling, sand usage and variations in gas/oil ratios. Building on this experience, other basins can leapfrog ahead.

That is important, because the super basin phenomenon isn't just about the Permian, or even the continental U.S. In the global energy conversation, geoscience matters and prosperity is a choice.



Source: Reuters

So where will the super basin renaissance go next? That will be largely driven by above-ground issues. Drilling began in South America's Neuquen Basin in 2018, and with favorable regulations and government support, it is one of the few basins outside the U.S. where producers are pursuing horizontal drilling and hydraulic fracturing with commercial results.

Mexico, too, is home to potentially ripe basins, while offshore basins in the North Sea, Brazil and the Gulf of Mexico (and other areas) are benefiting from geophysical enhancements.

The industry takes seriously our mandate to provide affordable and environmentally sustainable energy. As past-president of the American Association of Petroleum Geologists and an adjunct professor at the University of Houston, I often talk with students about their future plans. Despite what you may have heard, many want to go into the energy field. Their reasons? They want to work with teams of smart people. They are drawn to the challenge, adventure and the high-tech aspect of the industry. And students have a strong sense of social responsibility. We encourage them to help industry do a better job and to be a part of the energy solution.

The super basin renaissance is just beginning. Providing energy prosperity for the world is a noble pursuit and hydrocarbons have a key role to play. ■

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CONNECTING PEOPLE TO THE GRID IN INDIA ISN'T ENOUGH

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The United Nations has called for universal access to electricity by 2030 as part of its Sustainable Development Goals. India has been a leader in this effort, declaring in April 2018 that every Indian village had been electrified and committing to ensuring every household was connected by March 2019. There is little doubt that, at least on paper, India will reach that goal. As famed management expert Peter Drucker pointed out, "What gets measured gets done."

The corollary to Drucker's famous quotation, however, is also true – what goes unmeasured is often left undone. Ensuring that the electricity being provided is of a high quality remains a critical challenge for the expansion of Indian infrastructure, without blackouts, brown-outs or other disruptions of service. India suffers from rampant electricity theft and heavily indebted electricity distribution companies (DISCOMs), and poor quality electricity has resulted in damaged equipment, losses of productivity and lower investment. Moreover, some recent studies have suggested that electrification will have little impact on household welfare if that access is poor quality.

It turns out that electric connections alone are not enough. Improving the quality of connections is critical to improving access.

In a study forthcoming in Energy Policy, Johannes Urpelainen (Johns Hopkins School of Advanced International Studies), Aseem Mahajan (Harvard University) and I demonstrate that there is an additional cost to the lack of power quality – those who observe low power quality are not willing to pay as much for electrical connections. Thus, poor quality may hinder efforts to expand access and make the DISCOMs solvent, since unelectrified households are less likely to purchase connections or will not be willing to pay as much for those connections.

While this link should seem intuitive, demonstrating it is not completely straightforward. The reason is that there is a selection problem – if people in areas with high quality access are willing to pay more, then they are more likely to have already purchased a connection. This means that, among our unelectrified households, differences in willingness to pay for electricity might be suppressed because those in higher quality areas have already purchased connections and are excluded from the sample. And indeed, when we simply compare perceptions of quality to willingness to pay, we find little connection.

We address this issue by leveraging policymakers' incentive to emphasize the quality of electricity to larger habitations (the equivalent of neighborhoods in India). Using this as an instrument, we are able to estimate the effect of selection in our results and estimate the impact of quality on willingness to pay. We find that quality of supply has a large impact on willingness to pay – increasing the amount respondents reported being willing to pay by 13% to 48%, depending on the measure of quality used. This translates into roughly 70 cents to $2.70 more dollars per household per month.

Our results should increase the focus on effectively measuring the quality of access. This is somewhat more difficult than measuring access, since it can be more difficult to verify and there are limited incentives for both the government and electricity distribution companies to publicize the quality of access – electrifying a village produces immediate good press, improving the reliability of that access does not produce the same headlines.

There are also definite political obstacles to improving quality. Electricity theft, for example, is rampant in India, but cracking down on this theft is not very popular politically – indeed, some studies have suggested that leaders actively ignore theft during election campaign seasons to improve their chances of re-election.

Some efforts at monitoring quality of access are beginning in India. A group out of the University of Michigan has been trying to develop a monitor of access quality using satellite night time imagery of lights. Prayas (Energy Group) has also sponsored an Electricity Supply Monitoring Initiative (ESMI), where they use electricity monitors on the ground to examine the quality of supply.

All of these efforts need to be substantially expanded. In order for the scale and costs of the quality issue to come to public attention and be adequately addressed, we must create a better accounting of its impact. ■

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DUAL USE LNG SHIPPING: A GAMECHANGER FOR CARBON MANAGEMENT?

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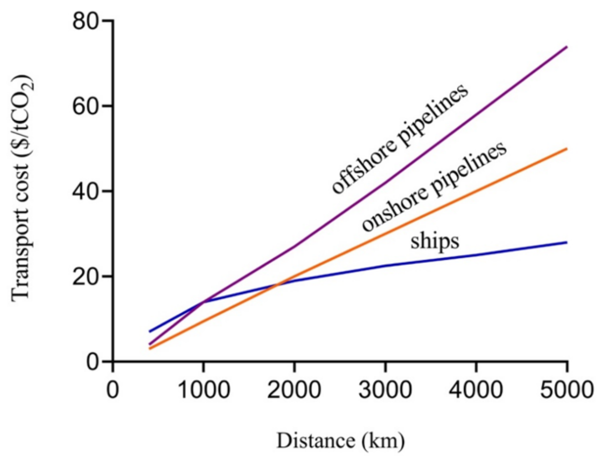
Finding ways to not only capture carbon emissions but use or store the carbon presents both a challenge and an opportunity for the industry in our increasingly carbon-constrained world. Doing so in a way that is both cost-effective and practical will be key to a carbon neutral world. Part of the solution may involve taking advantage of another growth industry: Shipping of liquefied natural gas (LNG) and liquefied petroleum gas (LPG).

Carbon capture, utilization and storage, or CCUS, has been established as one of the few mitigation strategies that can be relied on for safe and scalable management of carbon. Fundamentally, it consists of three stages: the capture of CO^2 from a source, such as an industrial plant; its transportation for use or storage; and its long-term isolation. However, the sources of carbon aren't typically close to the sinks, thereby raising the cost and making it challenging to scale up operations. Pipelines have traditionally been used to bridge this gap, but high capital expenditures and the threat of sunk costs present a significant financial risk for distances over 100 miles, often rendering projects infeasible, especially in the case of offshore pipelines.

This is where shipping comes in. Transporting CO^2 via dual-purpose ships presents an opportunity for both eliminating the cost of operating an empty vessel on its return trip and providing a cost-effective way to move CO^2 from where it is produced and captured to where it can be used or stored.

Carbon capture, utilization and storage has been repeatedly written off as not financially viable. However, an International Energy Agency estimate for the 2°C scenario – that is, for efforts to keep warming at or below 2°C above preindustrial temperatures – has determined that CCUS must account for sequestering about six gigatons of CO^2 per year by 2050. To sequester this quantity of carbon we would require a sink that is 6,000 times the area of the North Sea's Sleipner gas field and a pipeline network 120 times longer than current enhanced oil recovery pipeline capacity in the US. Transportation costs for such an effort would be between \$11 to \$23 per ton of CO^2.



Source: Ramanan Krishnamoorti and Aparajita Datta

The flexibility of ship transport provides an opportunity for CO^2 capture from multiple clusters, allowing parallel development of projects of different scales and terms and more importantly, from low-cost high-purity capture sources such as ammonia plants, hydrogen production facilities and refineries. CO^2 can be transported economically over long distances using ships while retaining the flexibility to route the delivery to different locations . This can be especially beneficial for CO^2-based enhanced oil recovery, where uncertainties often exist around the timeline for deploying capture technologies and the need for CO^2 at the sink depends on the lifetime of the well.

Several small dedicated CO^2 ships currently serve enhanced oil recovery and other industrial applications. However, significantly larger carriers will be required to transport greater volumes for CCUS to work at scale. CO^2 shipments, interestingly, have similar cargo conditions to that of the semi-refrigerated liquefied petroleum gas (LPG) or liquefied natural gas (LNG) carriers operating today. An excellent business opportunity presents itself in the form of dual-purpose carriers: ships that transport hydrocarbons could carry captured CO^2 on their return journey, allowing the CO^2 to be used for enhanced oil recovery at the original production site.

Like other carbon management processes, a key difference between conventional transportation of LPG or LNG vs. that of CO^2 lies in the commercial profitability; while the former are valuable products, CO^2, despite its industrial value, is largely considered a waste product. By using it for enhanced oil recovery, carbon gains an end-of-use business value and at the same time provides a use for the vessel on its return journey when it would have otherwise returned empty. This makes the transportation cost of the CO^2 delivery almost free.

With fuel costs making up about 60% of operational expenses, an empty vessel on the return journey is unquestionably a lost economic opportunity, as charter costs, port charges, insurance, wages, canal costs and brokerage fees have to be paid nonetheless. Fuel consumption for a cargo-free vessel is only about 25%-30% less than that for a laden vessel. Consider a 250,000 m3 LNG vessel that consumes about 220 tons of fuel per day. If we were to use this vessel and forgo the 30% reduction in fuel consumption by loading it with CO^2 – at \$440 per ton for bunker fuel and assuming a one-way journey of two weeks – we could be transporting more than 300,000 tons of CO^2 at \$1.4 per ton. Moreover, from a logistical perspective, CO^2 is often produced at points close to LNG offloading (at refineries or chemical plants in close proximity) and the CO^2 demand for enhanced oil recovery is close to sources of natural gas. At this transportation price, logistical convenience and with the added value of enhanced oil recovery, we are looking at a radical turning point for CCUS.

Previous scoping studies have analyzed potential shipping routes across the world and have provided estimates for the economics of dedicated CO^2 shipping (without dual-purpose ships). A study by the IEA Greenhouse Gas R&D Program estimated the cost of ship transport over 125 miles-7,500 miles at between \$18 and \$58 per ton of CO^2. Studies elsewhere have found similar costs – from between \$8 and \$14 per ton in the United Kingdom for pre-pressurized CO^2, and \$42 per ton from Norway to the North Sea. However, these estimates do not take into account the cost implications of the sulfur content cap enforced by the International Maritime Organization starting in 2020. These studies have also demonstrated that for low volumes of CO^2 (up to 10 million tons/year) shipping becomes competitive with pipelines at distances between 93 miles and 435 miles, while the breakeven distance is approximately 900 miles for higher volumes (about 30 million tons/year).

The introduction of dual-fuel diesel electric vessels altered the landscape for maritime transport in the early 2000s. With a 20% increase in efficiency compared to conventional steam turbine vessels, these reduce fuel costs considerably. Other advantages include lower maintenance costs, minimum hull space requirements that allow more room for revenue-earning cargo and the high flash point of diesel, which reduces the risk of accidents. Some of the above-mentioned cost ranges for dedicated CO^2 shipping also take into account the cost advantage of dual-fuel diesel electric vessels. Although these estimates are founded on project-specific assumptions and conditions, it is evident that CO^2 transport via ships becomes cost competitive over long distances and low volumes. In some cases, even shorter distances are cost efficient depending on the scale of transport.

Using the experience of a mature industry with a fairly unblemished safety record and leveraging acquired industry experience along with existing port infrastructure and services, transporting CO^2 over long distances in combination with LNG gets rid of two crucial CCUS bottlenecks: high costs over the large source-to-sink distances and the need to develop dedicated infrastructure.

However, the need to optimize the entire supply chain, address the lack of regulatory support for ship transport of CO^2 and establish focused incentives for transportation all need urgent attention. In addition, environmental legislation to check that carbon continues to be produced as a byproduct and not a feedstock, storage regulations, insurance mechanisms and monitoring and reporting health and safety issues in the work environment will need to be tackled. Overcoming infrastructural challenges that may be imposed by existing ports, along with the readiness of LNG facilities to handle CO^2 without corrosive damage or elaborate infrastructural overhauls, will be crucial to scale up projects.

To address each of these, several demonstration projects will be required before ship transport of CO^2 can be mainstreamed. When developing a CO^2-LNG transport fleet, the shipping industry's environmental footprint will need to be assessed and minimized, since maritime emissions contribute about 3% of global emissions, and if left unchecked, could multiply 250% by 2050.

In the U.S., tax code 45Q provides a credit for CO^2 sequestration: $50 per ton credit for geological storage, and $35 per ton for enhanced oil recovery. Can a dedicated transportation tax credit recognizing the distinction between the volume and scale of CO^2 that can be profitably transported by ship vs. pipelines transform the landscape for carbon capture and utilization? Outside the U.S., regulations under the London Protocol, the European Union Emissions Trading system and international laws such as the United Nations Convention on the Law of the Sea, the International Maritime Organization's Safety of Life at Sea and IGC code that currently limit or prohibit ship-based CO^2 transport for CCUS will need considerable amendments.

Policy development will prove particularly challenging for countries like China and India, whose carbon emissions are expected to accelerate rapidly in the next few years. However, if incentives are dedicated toward early and rapid implementation of ship-based CO^2 transport, CCUS deployment will boost emissions reduction for these high emitters.

As the momentum for carbon management builds, there is a distinct window of opportunity provided by the transport of CO^2 via ships. Will a policy overhaul get us on board? ■

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THE GLOBAL WARMING HIATUS: MAKING A MOUNTAIN OUT OF A MOLE HILL

EARL J. RITCHIE
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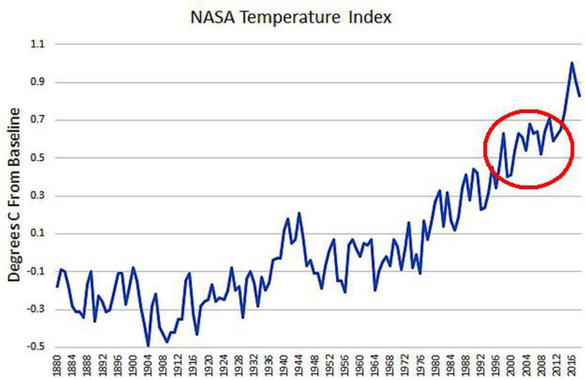
Let's start with the bottom line: you can't judge climate over a 15-year interval. Climate is almost universally defined as weather averaged over a long period, usually 30 years or more. Therefore, a deviation from trend of 15 years or less, including the so-called global warming hiatus, may be the beginning of a possible change, but it is not proof of a change in trend. This is true whether it's a few colder years or a few hotter years.

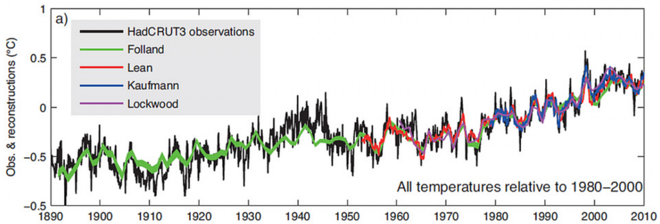
What is the global warming hiatus?

The hiatus is usually defined as 1998-2012 or 1998-2013, an interval during which the rate of global surface warming decreased or temperature actually declined. Various analyses disagree on the amount of decrease. The temperature curve below is based on data from NASA. The hiatus is circled in red. Other temperature reconstructions differ but would not be greatly different in trend.



Source: NASA

There is a great deal of up and down in the curve. It is obvious that there are numerous other short intervals that could be chosen to show declines or accelerations. They are easily seen in the graph below of measured temperatures and several reconstructions from the Intergovernmental Panel on Climate Change's Fifth Report. Despite these short-term fluctuations, the overall trend has been upward since the early 1900s.



Source: IPCC

Is the hiatus real?

Some have claimed the hiatus never existed. Arguments to support this include that arctic warming was underrepresented in the temperature data, and that improper corrections to the data made the increase appear less than it really was.

The discussion in the technical literature is arcane. Some papers delve into semantic argument about what constitutes a pause. Others redefine the hiatus interval to drop the anomalously warm starting point or add subsequent warmer years. Some argue that it is not statistically significant.

Despite these mental gymnastics, the preponderance of data shows there was a decrease in the warming rate from 1998 to 2012. A 2016 analysis by Lewandowsky, et al. concludes this period is not statistically significant but shows it to have the slowest warming rate of any 15-year period since 1981.

The fact that it is not statistically significant does not mean the hiatus doesn't exist. However, it does support the main premise of this article: that it is not meaningful in assessing the long-term trend.

Technical explanations for the hiatus

According to one count, over 200 peer-reviewed papers have been written to explain the hiatus. Explanations include the El Nino/La Nina phenomenon, the Atlantic Multidecadal Oscillation, greater transfer of heat to the ocean, lower sunspot activity, volcanic eruptions and warming occurring in the upper troposphere rather than at the surface. Some of these are short-term effects and some are partitioning of heat between the lower atmosphere and other parts of the Earth system.

To the extent these explanations are correct, they explain why surface warming was lower. However, they do not negate the longer upward trend.

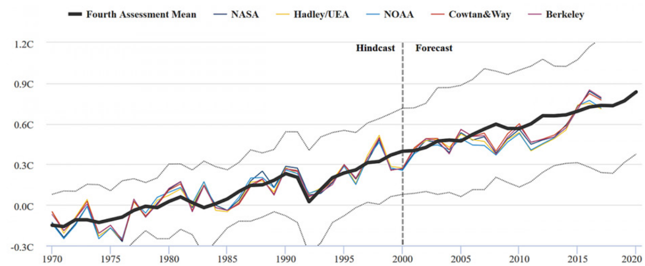
Are the models wrong?

The hiatus has been used to argue climate models are wrong. In a nutshell, this conclusion is wrong. However, it is a more complex question than whether the hiatus is real.

One cannot simply say "the models" are wrong. There have been published projections from numerous different models using numerous different assumptions. In order to validate a model, one must compare a projection based on assumptions that match the actual conditions that have occurred since the projection was made. In practice, this means a projection based on assumed CO^2 concentration that is closest to observed.

Zeke Hausfather has done such comparisons for a number of published models, including those of the IPCC reports.

His illustration below for the models in the IPCC's Fourth Assessment Report is typical.



Source: Zeke Hausfather

The matches on the order of a few years are not very good and the model overestimates temperature during the hiatus, but the gross fit is pretty good. Other comparisons differ, but are generally similar.

This is a rather simplistic look at a complex subject; however, it is fair to conclude that most models do a reasonable job of forecasting intermediate-term temperatures, on the order of 20 to 40 years.

We should know better

It doesn't matter whether the global warming hiatus did or didn't exist because data from 2014 to 2018 show warming has resumed. It should have been known at the time, and should be known in the future, that a few years deviation from a longer-term trend does not prove the trend has ended. It is an indication of the emotion involved in the subject of climate change that the "hiatus" generated so much controversy.

We all want to know the answers to questions, and we want the answer right now. But we have to make decisions on the best information available to us at the time. That includes keeping new information in perspective.■

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SELF-DRIVING AUTOMOBILES: TWO VISIONS OF THE FUTURE

EARL J. RITCHIE
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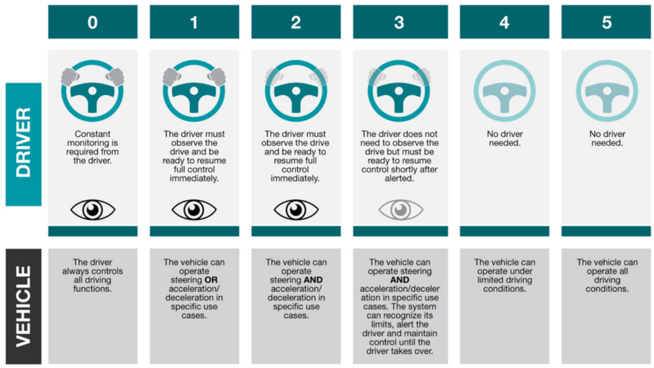
Some predictions of the effect of self-driving automobiles, or autonomous vehicles (AVs), include that they will virtually eliminate personal car ownership, cause people to travel by Uber-like ride hailing services and Zipcar-like car-sharing, and have no need for garages. They will save cost and time, and will reduce air pollution and greenhouse gas emissions.

In this model, transportation practices will be revolutionized. This is a dramatic change that makes for eye-catching headlines. However, it is not the only possible future. It is equally plausible that the convenience of AVs will encourage suburban growth and increase miles driven.

Before we examine these arguments, we need to understand what a self-driving vehicle is.

What is an autonomous vehicle?

The popular impression of a self-driving car is that you get in the car, tell it where to go and it takes you there, no matter where that might be. This would be Society of Automobile Engineers Level 5 automation (Level 4 would be capable within a limited area). At least Level 4 is required for most of the envisioned benefits.



Source: Electronic Component News

The most advanced commercially available AVs today are Level 2. They have adaptive cruise control and will keep you in the lane. A few will change lanes upon command. Some "self-driving" cars from Apple, Uber and Google that you read about are Level 4. They are in an experimental or trial phase.

The utopian model

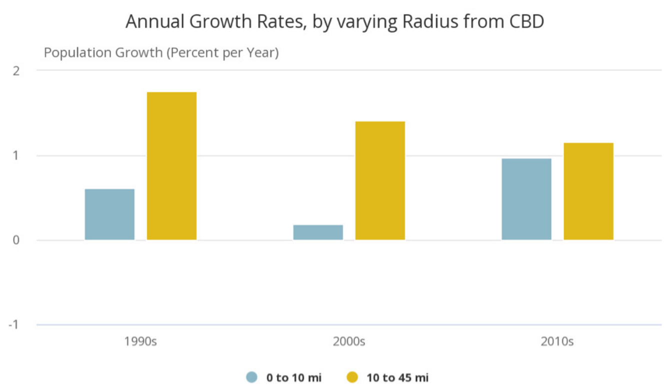
Let's call the demise of personal car ownership the utopian model. The predicted benefits depend upon a number of assumptions beyond the availability of self-driving technology. These include that the cost of AVs will come down dramatically, they will be electric and people will adopt a high-density lifestyle that makes for short commutes. Many versions of this model also assume ride-sharing among strangers, a practice that has not been popular except where it allows use of HOV lanes.

The first two assumptions do not necessarily favor the utopian model. Decreasing cost will favor both private ownership and ride hailing at the expense of mass transit. It is virtually certain that future autos will eventually be electric, so environmental benefit will depend primarily upon miles driven rather than whether the vehicle is shared or privately owned.

The third assumption is crucial. You have to believe AVs will cause a reversal of current housing trends, with the majority of the population choosing to live in high-density housing.

Proponents of the ride-hailing model point to recent increases in center-city living and decreases in car ownership by millennials. There is debate whether this is a preference change or the economic consequences of low income growth and high student debt.

You will see varying numbers for the rate of suburban growth vs. urban growth, due to differing definitions. The graph below is one example. None of these definitions are perfect, but most show suburbs continuing to grow faster than city cores. Even millennials are buying mainly in the suburbs.

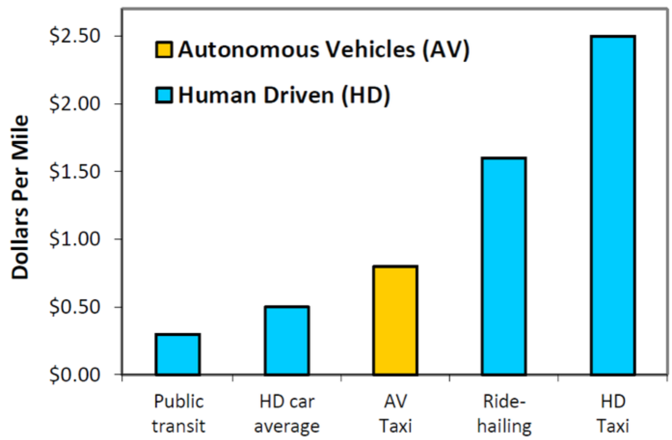


Source: Source: Harvard University

Reasons to give up your car

Let's examine whether the benefits of AV ride hailing are likely to overcome personal car ownership.

A primary argument is that the AV ride-hailing model will be cheaper. However, cheaper doesn't mean people will use it. As seen in the chart below, public transit is already much cheaper than travel by personally owned car. Few people use it, except in New York and a few other high density cities. According to the American Community Survey, over 75% drive to work alone and only about 5% use mass transit. The same can be said of carpooling, which also reduces cost and is used by only about 9% of the population.



Source: Modified from Victoria Transport Initiative

Given the amount of hype about Uber, it may surprise you that ride hailing and AV ride hailing are more expensive than private car ownership. This is shown in the chart above and by others, such as a Credit Suisse report which says ride-hailing services "are not cost effective at present either for average car owners or even for infrequent/low-usage drivers." Credit Suisse predicts driverless ride hailing may eventually be cost effective for a "significant minority" of drivers.

A second reason is convenience. The degree of convenience depends upon a number of factors, including the type of trip. In the ride-hailing model, you will be picked up at your door and dropped off at your destination. However, you may have a wait, and in the privately-owned model, the car is already at your door. So, there may or may not be time savings, depending upon the availability of the hailed ride vs. parking time for the privately-owned vehicle.

A third reason is environmental benefit. As mentioned, privately owned vehicles will likely be electric and will have per-mile emissions reductions comparable to ride-hailing vehicles. Various capabilities and design parameters of AVs aid in reducing energy use and emissions, but far and away the most important factor is miles driven. Significant reduction beyond what comes from electrification will require we share rides and stop moving ever further out in suburbs.

However, we could already be doing this and have not chosen to do so. Experience has shown that the vast of majority people are not willing to suffer much inconvenience for the sake of the environment.

In the utopian model, car ownership will plunge. This will disrupt the auto industry and associated businesses. Parking lots, auto repair shops, auto price websites and similar related businesses will become the buggy whip manufacturers of our time. There is good reason to believe this may not happen.

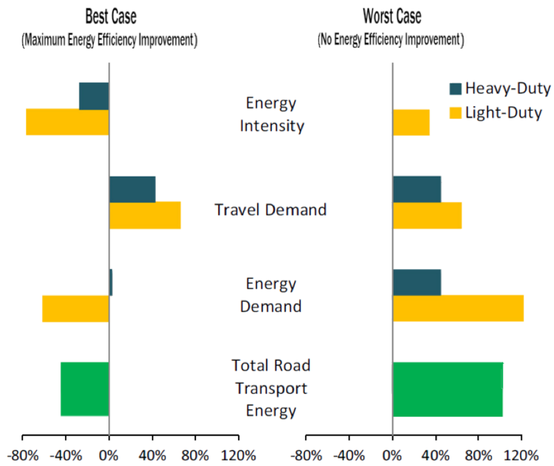
The dystopian model

There are several reasons why the convenience and potentially lower-cost of self-driving vehicles might increase travel and number of cars rather than decrease them. In fact, most studies predict miles traveled will increase around 15% to 25%; some are much higher.

The most significant reason for the predicted increase is that travel will become a pleasant rather than unpleasant experience. A 30- or 45-minute slog in traffic will become an opportunity to use a laptop, text, chat with friends or just enjoy the scenery.

The graph below shows the best and worst of four hypothetical scenarios from a 2016 study. Both cases represent unlikely endpoints.

Energy savings in the best case are due in part to the widespread adoption of single passenger and two passenger vehicles. Energy demand increases substantially in the worst case due in part to higher speeds and larger vehicles.



Source: Modified from Wadud, et al

Many benefits claimed for the ride-hailing model, such as more efficient driving to save energy, elimination of fossil fuel use by electrification and fuel savings due to smaller vehicles, also apply to the dystopian model. It is misleading to attribute these to ride hailing.

The full benefit of ride hailing depends upon shared (multi-passenger) rides. A recent study of the effect of AV ride hailing in Massachusetts concluded it did not have a net economic benefit unless the amount of ride pooling was over 40%.

How soon will it happen?

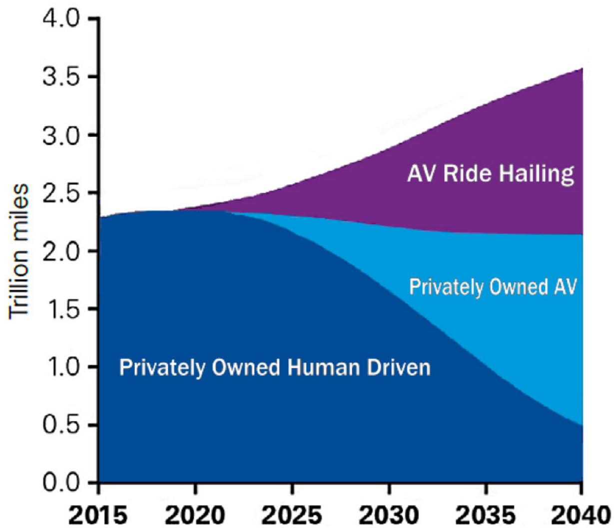
Various manufacturers are expected to offer the first level 4 cars to the public in 2020 or 2021. That's nice, although such predictions have a track record of being optimistic. And when will they be available in meaningful numbers?

IHS Markit estimates 51,000 AVs worldwide in 2021 and 1 million in 2025. This will make for an interesting technological experiment, but it's a drop in the bucket. There are over 260 million cars and trucks in the U.S. alone.

Longer-term predictions vary widely. In 2040, Credit Suisse has

AVs as 14% of production; IHS Markit has U.S. sales at $7.4 million, about 40% of current sales. However, sales forecasts do not speak to the relative share of miles traveled in ride-hailing and privately-owned vehicles.

Predictions of ride-hailing travel share have even wider ranges, with the more optimistic often being given as scenarios that "could happen." This aggressive forecast from KPMG shows a 50% increase in total miles driven by 2040, with 85% being in AVs. AV travel is split roughly equally between privately-owned and shared vehicles.



Source: Modified from KPMG

Which model of the future will prevail?

No one knows yet what the transportation revolution will bring. Despite predictions that self-driving vehicles will reduce suburban sprawl, traffic congestion and miles driven, there are equally good reasons to believe they will have the opposite effect.

In all likelihood, there will be both effects. In high density cities some people will give up automobile ownership and increase ride hailing and car sharing. People will also continue to live in the suburbs. Suburban sprawl and miles driven will increase. The relative strength of these two effects remains to be determined.■

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ENERGY AND CYBERSECURITY: WHAT A DIFFERENCE A DECADE MAKES...

CHRIS BRONK
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While it's hard to ascertain what event represented the tipping point on the perception that cybersecurity issues in the energy industry are serious, that is indeed the case today. After Stuxnet, Shamoon, WannaCry, NotPetya, and a host of other incidents, commercial firms and government are unable to keeps their heads in the sand on the cybersecurity issue. This was one of the key lessons to emerge from a recent Cybersecurity in Energy Symposium at the University of Houston.

There were other lessons to learn as well. First off, the energy sector is many different industries: electricity distribution and generation; oil and gas production; petrochemical production; pipeline operations; and nuclear power top the list. These businesses are similar in some respects and different in others, but one element is shared between them: the application of interconnected information and computing technologies in plant and infrastructure operations.

In the cybersecurity world, some of us call this area Operational Technology (OT), and security efforts surrounding it OT security. What does that mean? Well, it's probably easier to think of what it isn't. Much activity in cybersecurity over the last two decades has been aimed at the desktop or laptop PCs, servers and mobile devices that we label generic Information Technology (IT). IT security is about stopping phishing emails, defeating rapid-moving malicious software and defeating data ransom or deletion attacks.

OT security is all about protecting the devices that make assembly lines, medical imaging equipment or mass transit systems run. These are the computers all around us that make the infrastructure of our society work. Increasingly these systems have made their way into all aspects of activity. Consider stoplights. Once electro-mechanical systems that turned the lights on a pre-configured pattern, traffic signals now are increasingly programmed for coordinated control. This facilitates the movement of traffic based on known patterns that may vary across the time of day. In active control scenarios, traffic managers can trigger lights during peak traffic patterns not regularly seen, like after an Astros game.

The bad news is that traffic signals have been found to be eminently hackable. Unfortunately, so are systems in other industrial and infrastructure applications all around us. Jet engines, subway trains and even automobiles have been found to be vulnerable to subversion of their operation via computer hacking. We fear the same to be true of systems used in oil drilling operations, petroleum refining, pipelines, electricity generation and even gas station pumps. Worse, these computers are increasingly interconnected, often via Internet protocols. The people who built these systems didn't design them to be connected in a contested environment like the Internet. Oops.

As corporate boards and government leaders have recognized this problem, change has come. Action is afoot. Work with my colleagues at the Baker Institute, the University of Houston and in the oil and gas industry at the beginning of the decade led to the creation of an information sharing body for the oil and gas sector, the Oil and Natural Gas Information Sharing and Analysis Center, an intelligence clearinghouse focused on sharing cyber threat data. This was a good step, but far more activity is now underway and has become a revenue center for leading firms. One of the takeaways from our recent symposium is that firms in the energy sector, and particularly oil and gas, are open to studying the OT security problem and collaborating on finding solution. While these companies may be the fiercest of competitors, they are willing to work on cyber issues collectively, much as they have handled safety issues.

While OT security is likely still in an early phase of development, the immediately apparent risks to operations and the commercial activity that derive from them is quickly apparent to anyone able to read a balance sheet. There are lots of nasty adversaries for the United States and its allies out there – China, Russia, Iran and North Korea among them – and they have learned how to play offense on cyber extremely well. This makes our national response, codified in policy and adopted by firms around the country, as critical as the infrastructure that we are trying to protect. ■

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THE PLASTICS RECYCLING CONUNDRUM: TECHNOLOGY, ECONOMICS AND HUMAN BEHAVIOR

RAMANAN KRISHNAMOORTI Chief Energy Officer, UH Energy

The recent announcement by the industry group Alliance to End Plastic Waste that it will commit over $1 billion to eliminate plastic waste has focused scientific and commercial attention on creating a sustainable path for the use of plastics.

Since the mid-1950s, when commercial plastics production began in earnest, over 8 billion metric tons of primary plastics have been produced, principally from hydrocarbon feedstock. Almost one-third of these plastics remain in use, mostly in infrastructure, buildings, transportation vehicles and industrial machinery. Only 500 million tons or about 6% of the produced plastics have been recycled; the majority has been discarded (55%) or incinerated (8%).

The very qualities that make plastics attractive – their durability and stability – also make it difficult to dispose of them when their usefulness comes to an end.

About 2% of that plastic waste, or 8 million tons – predominantly from China, Indonesia, Philippines, Sri Lanka and Vietnam – ends up in the oceans and other marine ecosystems each year. It gets there in a variety of ways, in both visible and microscopic form, through accidental spills, airborne and water borne microplastics and microfibers, careless dumping and runoff from landfills, among other routes.

The challenge is clear. Reducing the amount of plastic waste would mean less plastic makes it to the world's waterways. There are several ways to address that:

- Increased recycling; with less material discarded as intact plastics, there is less opportunity for synthetic plastics to make it into the marine ecosystem.
- Switching to bio-based materials that can degrade in the ecosystem.
- Incorporating sustainability into polymer manufacturing.

All three are needed, but that last idea offers perhaps the most exciting promise, even offering the potential to convert plastic waste from a problem to a solution.

At the least, we clearly should do better than recycling only 10% of all discarded one-time use plastics, but that will require meeting challenges and opportunities that are technological, economic and most importantly, behavioral.

Technologically, in most cases reusing plastics leads to a degradation of the material properties, resulting in downcycling the materials to lower value products.

That downcycling through traditional recycling routes, along with the intrinsic costs of collecting, cleaning and sorting prior to remanufacturing of the plastic materials, makes plastics recycling cost-prohibitive and an unattractive proposition. One potential solution is finding ways to use the embedded energy in those discarded plastics without the challenges of downcycling, while managing the costs of handling the plastics from consumer to recycled material.

Currently, such upcycling technologies are in their infancy and are largely exploratory.

Economically, the most significant challenge is the collection, sorting and cleaning of plastic waste for recycling. Recently, I wrote about demonstrations of improvements in last-mile technologies, and those technologies have raised significant excitement in the public. Advances in the last-mile solutions that incorporate digital technologies are hard to scale up, and they intrinsically are site-specific. Nevertheless, these last-mile solutions are becoming more and more important as each community grapples with the challenge of increasing plastic recycling rates.

Solving the technical and economic issues will require that we understand human behavior and attitudes about plastic waste, and the cultural and societal nuances that come into play. For instance, increased recycling efforts have made people feel freer to use more plastics and therefore, have led to significant increases in the consumption of single-use plastics. Similarly, the development of bio-based plastics – made from renewable biological resources including plant waste – has resulted in increased use of plastics. These non-intuitive responses indicate that we ought to pay close attention to human behavior and how people respond to proposed changes.

Plant- or bio-based plastics that could replace those produced from fossil fuels is often touted as a sustainable solution. Many bio-based materials are seen as drop-in replacements for fossil-based materials by replacing at the molecular building block level a fossil fuel derived material with a bio-derived material; while reducing our dependence on fossil energy, however, this solution does not address the environmental and especially the marine impacts of plastics.

Beyond that, bio-based plastics that perform comparably to the synthetic plastics they aim to replace, composed of building blocks which degrade naturally at their end of use, are still a long way off.

Even if high-performance bio-based plastics do become a reality, they won't automatically solve the problem of plastic pollution in the marine ecosystem. The challenges of large objects and single-use plastics, as well as finely dispersed plastics accidentally being delivered directly or indirectly to waterways, such bio-based plastics do not address the environmental issues resulting from the physical characteristics of the plastic objects.

The direct discarding of waste, while visually upsetting and the most often discussed issue, is only a small part of the challenge we face in protecting the marine ecosystem. The proliferation of microplastics and other plastic waste that we cannot easily discern is perhaps the bigger challenge. While most research to date suggests that microplastics have not been proven to cause toxicological issues, the smaller fragments are nevertheless more easily absorbed by both humans and wildlife.

Amid all these challenges, we do, however, have opportunities. The most attractive involves designing sustainability and inherent recyclability directly into the plastics manufacturing process.

Today a rubber tire or wind turbine blade has to be incinerated or degraded all the way to their fundamental building blocks through the use of energy-intensive depolymerization. Vulcanization or irreversible chemical cross-linking confers these materials with outstanding properties such as strength and resilience, but these materials can't be recycled by simple mechanical means. What if we were instead to design and develop a rubber or epoxy material in such a way that the links between molecules can be easily unlocked by either heating or exposure to a chemical or microwave radiation, allowing the material to be easily reprocessed? These technologies are rapidly developing and moving from the realm of science fiction to everyday applications.

For such a process to work, we would need to redouble our efforts to recycle plastic waste, perhaps by focusing on it as a product supply chain rather than a waste disposal paradigm. Then last-mile solutions might indeed become the first-mile opportunities. This would fundamentally revolutionize the world of plastics and their impact on our environment. ■

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IS RUSSIA PREPARING A GAS NUCLEAR OPTION?

PAUL GREGORY

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Vladimir Putin is noted for taking surprise action, which confronts his victims with a fait accompli. They must then either accept the new unfavorable status quo or react in a way that they would consider too risky. Putin has employed this playbook in Georgia, Crimea, East Ukraine, Syria, on Ukrainian naval vessels in the Black Sea and to prop up the Maduro regime in Venezuela.

Putin's potential targets should put themselves inside Putin's head to anticipate his next hostile move in order to avoid again being caught off guard with few good options.

Putin loves the unexpected; so beware. On paper, this would be the worst time for Russia to act up in its European gas market. Russia's Gazprom just narrowly saved its key project – the undersea Nord Stream 2 pipeline directly to Germany – despite almost universal opposition in Europe. Gazprom faces new unfavorable (unacceptable) regulations: On April 5, 2019, The European Parliament and European Commission adopted a new gas directive that requires Gazprom to unbundle delivery from production. Moreover, Germany's Angela Merkel has promised Ukraine that, Nord Stream 2 or not, Russian gas will continue to flow through Ukraine. That's not all: With the threat of competition from American LNG, Russia would strive to emphasize the reliability of its deliveries to its massive European market. Finally, LNG competition would surely constrain Putin from taking hostile action that jeopardizes Russia's European gas revenues.

We can add one more factor that should temper Gazprom's behavior with respect to its European gas market: According to Gazprom's own reports, the Nord Stream 2 pipeline will not be completed as planned by the start of 2020. Denmark has not issued construction permits and has requested that Nord Stream change its route. According to European authorities, the delays could be substantial.

With Nord Stream 2 delayed (its capacity is 85 percent of Ukraine's transmission capacity into Europe), Russia would seem to have no choice but to make substantial use of Ukraine's pipeline.

Despite these factors, Ukraine's gas company, Naftogaz, worries that Putin is preparing to launch what amounts to a "nuclear gas option" that will push Ukraine into recession and create gas shortages throughout Europe. Russia's move, they think, will take place on or around Jan. 1, 2020.

Here is how it would work:

Ukraine gas experts point with some alarm to Gazprom's accumulation of gas in European storage facilities. As they fill up, Gazprom leases more storage facilities. The gas in storage, the Ukrainians think, is being accumulated to meet Russia's minimum contractual deliveries to Europe while bypassing Ukraine's pipelines in total.

If Gazprom were not planning to bypass Ukraine, it would be negotiating a transit contract with Naftogaz, but Ukraine sees no move by Russia in this direction. In fact, Ukraine has yet to receive the relatively small volume of Russian gas for which it prepaid. Russia's Gazprom, in addition, continues to refuse to pay Ukraine a $2.6 billion fine levied by Stockholm arbitration.

Consider the effects of such a nuclear option: With no gas coming through Ukraine, Gazprom will only be able to meet its minimum contracts to Europe, even with the gas in storage. Gas prices, in such a scarcity situation, will increase, compensating Gazprom in part for the smaller volumes of sales. Ukraine, which has been buying Russian gas from Europe, will literally be left out in the cold. Europe will not have enough gas supply to back flow it into Ukraine. With a struggling economy and Azov seaports quasi-blockaded by the Russian navy, Ukraine would lose the $3 billion in transit revenues, which constitutes some 3% of its GDP. Deprived of these revenues, Ukraine could slip into a recession, in new President Volodymir Zelensky's first year in office. Russia could hope the besieged Zelensky will cave and seek accommodation with Russia on Crimea and East Ukraine.

Whether or not Putin deploys the nuclear option depends on his calculation of short and long-run costs and benefits. In the short run, the nuclear option could destabilize the Ukrainian economy, a top priority for Putin. He would deprive Ukraine of essential transmission fees and create gas shortages during Ukraine's bitter winter. He might be able to convince Ukraine's new political leadership to play ball with their powerful neighbor. With a general shortage of gas in Europe, Putin might be able to split Europe by playing favorites and punishing enemies. Maybe he could even force those countries that are delaying Nord Stream 2, either through permits or gas directives, to get behind completion of the project.

Clearly, a nuclear option would risk long-term damage to Russia's gas business with Europe. It would promote the construction of LNG terminals throughout Europe and drive European buyers into the clutches of American LNG. Europe could not afford to gamble with Russia's unreliability as a supplier of such a key resource. But the nuclear option carries with it tempting short-run gains. It would remove Ukraine from the gas delivery business. Russia could destabilize the new administration of a young and popular president. Russia could again play king of the hill and split Eastern Europe from Western Europe, not only with cyber-attacks but with the more potent weapon of energy.

Let's wait for Putin's move. ■

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HOW TO MAKE HOUSTON THE SUSTAINABLE ENERGY CAPITAL OF THE WORLD

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The global demand for a low-carbon future is undeniable. Scientific research, opinion pieces, political speechmaking and the global marketplace are all speaking loudly. The question is how? At what pace? At what cost?

And despite all the talk, the real leadership will be shown through actions to reduce greenhouse gas emissions while also meeting the growing global demand for energy.

Houston and Texas must embrace a new mantle - Sustainable Energy Capital of the World, the place where new technologies and new policies are put into practice. This only makes sense: Texas not only produces the oil, natural gas, transportation fuels and plastics that allow the nation to thrive, but Texas also has the infrastructure in place - pipelines, transmission lines, storage tanks, rail and port access - that will be required if we are to transform carbon emissions into viable commercial products.

Texas contributes significantly to the energy mix and products demanded by modern life. Globally the economic uplifting of entire countries and the continued growth of population and prosperity means that demand for energy and material goods will continue to grow, and we must ensure that these products remain affordable and become more environmentally friendly. The solution will largely fall to the energy industries in the states and countries that produce energy to embrace this future as an opportunity.

That means Houston, and Texas, will be critical to success. And we have the good fortune to have forward-thinking, global energy companies that recognize this coming change. Virtually all of them have a strong presence in Houston.

Texans know renewables are important, today and for the future, as the state produces more wind-generated electricity than all but six countries. The amount of solar is growing rapidly. We must strategically integrate all sources of renewables and promote electrification via clean sources of energy. This is not simply good for the environment - it will offer benefits to consumers and create value for the industries.

Texas also consumes twice as much oil, gas and coal as any other state, by virtue of our large manufacturing base, so it falls to us to create this transformation to a low-carbon future.

This transformation will require more than the efficient and lower carbon production and generation of energy. For example, Texas has led the country in the integration of industry with infrastructure and demonstrated how to reduce and capture CO^2 emissions in a way that is both cost-effective and useful, storing carbon dioxide in geologic formations and using it for enhanced oil recovery.

Carbon Capture Utilization and Storage (CCUS) has been practiced for over 50 years in Texas, used both in the Permian and East Texas for enhanced oil recovery with great success. There are challenges and opportunities for methane, as well. The primary component of natural gas, methane is also a valuable fuel and feedstock for petrochemicals.

We must invest in transformative technologies that will allow us to view carbon and methane as not simply a waste to be disposed of, but an opportunity to lead the nation in both eliminating emissions and creating value.

That won't happen on its own. It will require new policies promoting investment and restructuring of the marketplace. We must all work to create a new energy ecosystem, not just new technologies to capture emissions, but to also produce lower-carbon fuels and products that can be differentiated and compete globally. It is not about choosing the "right" technology or product, but about incorporating all forms of fuels and technologies for both renewable and hydrocarbon-based energy while also lowering emissions.

Texas must embrace this immense opportunity to leverage our universities, energy companies and marketplace to take advantage of our world-leading energy infrastructure. If we get it right, we can become a playbook for the rest of the world. We can walk the talk here and accelerate the transformation that will benefit everyone.

There is no more important global challenge, no more important time and no more important place than Houston. Real sustainability requires meeting the growing global demand for energy and reducing greenhouse gas emissions significantly, as well as assuring energy is affordable and reliable for all. Houston and Texas must become the Sustainable Energy Capital of the World.■

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SELF-DRIVING AUTOMOBILES: HOW SOON AND HOW MUCH?

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Based on the wide range of published forecasts of when autonomous vehicles (AVs) will be on the street and how much they will cost, you can believe almost anything you want. By 2030, they will only cost $5,000. There will be a significant price premium until the 2030s. There will be a million robotaxis on the road next year. Fully autonomous vehicles are more than a decade away. Some predictions do not have them on the road in significant numbers until the 2040s.

Aside from pure hype, the main difference for these extremes is different definitions of self-driving. In the popular imagination, a self-driving vehicle is one that you get in and it takes you where you want to go, with no limitations. Many predictions of imminent implementation are based on vehicles with significant restrictions: trolleys operating on fixed routes, delivery vehicles operating in limited areas and super cruise controls that drive the car on a freeway but still require a driver for part of the trip. These limited applications are significant advances but fall far short of a transformation in mobility.

A special case is the argument that robotaxis are, figuratively speaking, just around the corner. I'll discuss that separately.

What they will cost

Most current versions of AV technology use lidar, a laser mapping technology. It's expensive but commonly predicted to decrease rapidly, to perhaps $2,000 by 2030. Breakthroughs in solid-state devices may bring the system price to the low hundreds of dollars. However, you still have to build the rest of the car.

The average cost of a new car in the US is over $30,000. For the past two decades, the price of the average car sold has increased at slightly less than the rate of inflation. There's no reason to believe that will change in the near future. AVs will still sell at some premium to conventional vehicles and will have an average nominal price over $30,000.

Tesla and some smaller firms are working on lower-cost systems that do not depend on lidar. This is a controversial approach; however, even if it works, the self-driving system is not free. The hardware and software will still add to the cost of the vehicle. Some models of the future envision costs will be brought down by a shift to "pods" or small urban commuters, similar to the currently available Smart Fortwo pictured below. This would require a major shift in US driving habits. No car in this size class is presently even in the top 25 sellers. And conventional versions of these cars will still be cheaper than self-driving ones.

Misleading definitions of self-driving

There is an unambiguous understanding of Level 5 automation, as defined by the Society of Automotive Engineers, or SAE: The car can do anything a human driver could do. SAE Level 4, called self-driving by most, is less clear. In Level 4, the system fully controls the car under specific conditions, called the operational driving domain (ODD). Level 4 automation is ambiguous because the car could be self-driving within a geographic area (geofenced) or on a specific road type, such as a freeway. These are very different capabilities. In the first instance, the vehicle could function as a robotaxi or driverless delivery vehicle within the defined area, say a city center.

In the second instance, a driver must get the vehicle to and from the freeway or other operational driving domain.

Most announcements of the near-term release of self-driving cars are models with road-specific capability. Ford claims they will have geo-fenced vehicles for fleet use by 2021.

How soon will you be able to ride one?

This depends upon your definition. According to the European Road Transport Research Advisory Council (ERTRAC) 2019 Roadmap, you can ride automated shuttles and buses on dedicated roads now; you'll be able to ride them in mixed traffic backstopped by remote control centers by 2024; and they will be fully automated within defined urban conditions by 2030. This says nothing about how widely available they will be.

ERTRAC has a similar forecast for passenger cars: they predict "Highway Autopilot," the road-specific form of Level 4, will be available in 2020, fully automated (Level 5) sometime after 2030. It's worth noting that their 2015 Roadmap had full automation in 2026. Predicted implementation dates tend to slip.

Of course, ERTRAC's forecast is only one of many. If Ford's geo-fenced Level 4 vehicle is actually available in significant numbers by 2021, it will be a major accomplishment. They will be initially available only in some cities with favorable weather conditions. Ford is vague about how soon their AVs will be available for personal purchase.

Ancillary issues

Predictions tend to focus on technology and cost; however, other considerations, often called "barriers," are likely to delay implementation. These include legislation, liability, safety and consumer acceptance. These will be resolved, but they will not be resolved tomorrow.

Two of the most dramatic predictions, AVs accounting for 95% of passenger miles by 2030 and one million robotaxis next year are accompanied by caveats that seldom make it into the headlines. These are "within 10 years of regulatory approval" and "I'm confident we will have regulatory approval at least somewhere," respectively.

The robotaxi model

I have previously written about the robotaxi, also called AV ride hailing or transportation-as-a-service. Briefly, several studies question the economics as presented by champions of this model, and they face the same barriers as passenger cars. The timelines of the more aggressive predictions seem wildly optimistic.

The bottom line

The adoption of AVs is intertwined with the concepts of ride hailing, automated deliveries, environmental concern and housing density. However, potential changes depend upon the availability and cost of door-to-door driverless vehicles. You can make your own guess from the wide range of available forecasts. However, I would make two final points:

Given the issues remaining to be resolved and the failure of numerous earlier forecasts of availability, predictions of the widespread availability of fully autonomous vehicles, even operating within limited areas, within the next few years are probably wrong.

The premise of a wholesale shift to robotaxis based primarily on cost savings is not valid. People do not make their transportation choices solely on cost. Otherwise, the best-selling vehicles in the United States would be compacts and subcompacts at prices below $20,000 and fuel economy over 30 miles per gallon, rather than pickup trucks with an average price of almost $50,000 and fuel economy around 20 mpg. ■

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A NOVEL APPROACH TO LNG CONTRACTING

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A year ago, researchers with UH Energy proposed a complex contracting system to expand LNG markets by providing incentives for new buyers to switch from coal and oil to LNG, explaining the details in a research paper.

This system, described in "LNG Projects Have Stalled. A New Business Model Could Help," recognized that large natural gas producers had a compelling interest in the development of new LNG projects to access new international markets for their growing production. However, the next generation of projects had stalled due to low international spot LNG prices and the unwillingness of traditional LNG consumers to commit to long term supply contracts at prices adequate to allow developers to attract debt capital.

A recent announcement by Apache and Cheniere is a step in the right direction, but it risks resulting in highly volatile netback prices to Apache. A June 3 press release described the benefits of the new contract:

Cheniere Energy, Inc. ("Cheniere") LNG, +1.48% announced today that its subsidiary, Cheniere Corpus Christi Liquefaction Stage III, LLC ("Corpus Christi Stage III"), has entered into a long-term gas supply agreement ("GSA") with Apache Corporation ("Apache") (NYSE, Nasdaq: APA). Under the GSA, Apache has agreed to sell 140,000 MMBtu per day of natural gas to Corpus Christi Stage III for a term of approximately 15 years. The LNG associated with this gas supply, approximately 0.85 million tonnes per annum ("mtpa"), will be marketed by Cheniere. Apache will receive an LNG price, net of a fixed liquefaction fee and certain costs incurred by Cheniere, for the natural gas delivered to Corpus Christi Stage III under this agreement. The LNG price is based on international LNG indices.

"This first-of-its-kind long-term agreement with Apache represents a commercial evolution in the U.S. LNG industry, as it will ensure the continued reliable delivery of natural gas to Cheniere from one of the premier producers in the Permian Basin, while enabling Apache to access global LNG pricing and receive flow assurance for its gas," said Jack Fusco, Cheniere's President and CEO. "This commercial agreement, which is expected to support the Corpus Christi Stage III project, reinforces Cheniere's track record of creating innovative, collaborative solutions to meet customers' needs and support Cheniere's growth."

"Apache's agreement with Cheniere is part of the company's long-term strategy to leverage the scale of our assets in the Permian Basin and diversify our customer base and cost structure by accessing new markets for natural gas produced at Alpine High. We are pleased to partner with Cheniere in this innovative marketing agreement," said John J. Christmann IV, Apache's Chief Executive Officer and President.

This agreement will provide a steady cash flow to Cheniere from the agreed liquefaction fee and recovery of "certain costs," which should allow the company to finance construction of its Corpus Christi Stage III LNG project. However, Apache may be exposed to high price risk if Cheniere is unsuccessful in marketing its LNG or is obliged to accept low market prices. This may occur if international LNG markets grow more slowly than developers add LNG capacity.

Apache and Cheniere will have a shared interest in expanding the LNG market by encouraging industrial and power generation companies currently burning diesel, coal and fuel oil to switch to natural gas. As we pointed out in our 2018 paper, this should include loan guarantees and other incentives to companies that agree to switch fuels in favor of LNG.

The alternative would be to allow LNG prices to collapse as abundant supplies exceed existing consumption and let the low prices stimulate market growth and raise prices in a recurring price cycle. It would seem prudent for Apache to act as an aggressive partner to keep the pressure on Cheniere's marketing strategies and plans with the intent of mitigating the volatility of Apache's achieved netback prices.

In our view, a robust business development strategy should include:

- Research on companies currently burning oil products or coal, with the goal of creating a portfolio of dedicated prospective customers;
- Long term LNG supply agreements with industrial and power generation companies;
- End use LNG pricing that is competitive with the displaced fuel, possibly with some ceiling and floor provisions, and recognizing the environmental benefits of LNG;
- Financing for the end user investment in plant and equipment needed for switching to LNG.

It is appropriate that U.S. natural gas producers should shoulder the price risk endemic in trading their commodity, but they would be wise to also take steps to dampen the price volatility that would accompany reliance on spot LNG markets. ■

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ALBERTA REPEALED ITS CARBON TAX. WHAT NOW?

BRET WELLS

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Alberta repealed its highly controversial provincial carbon tax this week, and so it is a good moment to think about what this may portend for pricing carbon more generally.

In many areas of law, design questions often center on whether nudges (like Section 45Q's tax credit for carbon sequestration in the United States) are better than sticks (like carbon taxes). Both nudges and sticks, from an economic perspective, can correct a market imperfection where the negative cost of an externality – a consequence of commercial activity that affects people not directly involved in that activity – has not been adequately built into the market.

An economist may well be indifferent as to whether the pricing of an externality is done through a tax subsidy or through the imposition of an added Pigovian tax, which can serve as an added fee to internalize the cost of the unwanted externality. Politically it seems to be more acceptable to deal with the negative effects of CO^2 emissions through tax subsidies than through affirmative pricing of carbon via additional carbon taxes.

This week's decision by Alberta adds further evidence for that point of view. Tax breaks for reducing emissions appear more palatable than increased taxes for producing them in the first place. Nevertheless, this is unfortunate, because one would expect that an "all of the above strategy" is likely to be needed if one truly wants to fully internalize the negative CO^2 externality cost of global warming so that market decision-makers adequately price-in the impacts of the negative CO^2 consequences of their actions.

Those interested in market efficiency should argue in favor of efforts to ensure that markets efficiently and fully account for all negative consequences, thereby encouraging participants in the market to reach rational outcomes that achieve maximum public good. In the case of carbon emissions, that "maximum public good" means economic decisions that accurately consider the impact of cleaner air and a healthier environment.

Perhaps the upcoming U.S. presidential election will provide a forum to move the public discourse towards understanding the need for both nudges and sticks, or at least to see how those two approaches work from an economic perspective. From that point, the public needs to understand that the best choice depends not on dogma, but instead on which choice actually is most effective in covering the cost in the most efficient manner, without spill-over costs.

Certainly there is precedent for that to happen. When the U.S. wanted to build the interstate highway system, the Highway Trust Fund was established in 1956 and then funded by the imposition of excise taxes on the sale of diesel and gasoline. That helped to spread the cost among the highway users who, on a macro level, benefitted from the resulting interstate highway system.

So we have priced carbon to account for a different public policy reason in the past. That prior effort – in order to internalize the cost of highway usage to the consumer who benefits from the highways – has stood the test of time and has had broad political acceptance for decades. Of course, we haven't had the political will to raise excise taxes on gasoline or diesel since the early 1990s to fully fund the highway trust fund.

Any system of internalizing an externality will need to be carefully done to minimize the consequences to competitiveness. But, even so, simply relying on tax subsidies as a means to address the negative consequences of CO^2 emissions is unlikely to be adequate on a stand-alone basis.

Tax subsidies can motivate some industries to clean up the cost of CO^2 emissions created by others, but tax subsidies leave the original polluter as a "free-loader" who shifts its costs to others to manage. Thus, a thoughtful policy response should also envision pricing mechanisms that motivate the original CO^2 emitter to find efficient means to fully price-in the cost/benefit analysis of minimizing CO^2 emissions, and on that metric a Pigovian tax can be an important means to ensure that this occurs. Thus, nudges and sticks are likely both needed to create market responses that consider climate change externalities. ■

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WE HAVE TO CHANGE HOW WE TEACH SCIENCE FOR THE FUTURE ENERGY WORKFORCE

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Scientific literacy – the understanding of scientific concepts and processes – is a major goal of K-12 schooling. The National Science Education Standards, established to guide science education in primary and secondary schools, say the knowledge is necessary "for personal decision making, participation in civic and cultural affairs, and economic productivity."

Ensuring that today's students gain that knowledge is certainly crucial to energy leaders, who are preparing for what is known as "The Great Crew Change," as more than half of the current energy workforce is expected to retire within a decade. Whether their replacements will be making policy or working with conventional fossil fuels or with alternative energy sources, these future workers need to be grounded in science and technology. And as U.S. schools educate the most diverse student body in the nation's history, that will include an understanding that there isn't just one way to approach science. Indeed, a diversity of viewpoints can strengthen our scientific and technical skills.

The rewards of that won't be limited to energy, of course. In order for the U.S. to remain competitive in a wide range of scientific and technological fields, we must prepare and support all students' interest and engagement in science, including girls and underrepresented minorities.

We already know a lot about how to achieve this. A future challenge for science education will be to ensure that students are prepared to address not only the questions facing today's energy workforce but those that will have to be answered tomorrow.

One way to increase student interest and engagement in science is to make sure classroom work authentically reflects the many ways scientists explore and learn about the natural world. This can be difficult because of the misconceptions people have about science. For example, traditional science teaching involves having students complete scientific experiments by following the scientific method, which is a prescribed and linear process. This usually includes asking a question, doing background research, constructing a hypothesis, testing hypothesis with an experiment, analyzing data, drawing a conclusion and reporting results. But scientists don't actually follow a linear process when they are working, and teaching science in this way gives the impression that science is stagnant and prescriptive.

Another example is the notion that science is objective, with no role for personal beliefs and creativity. This is inaccurate. Scientists around the world hold many different points of view that influence how they pursue their work. It is not realistic to believe that backgrounds do not influence how we see the world. That's especially important to remember as the nation's student body becomes more diverse.

With so many common misconceptions about science, it is critical that we all have a better understanding in order to give the future workforce a more complex and realistic view of science, including an understanding of what we call the nature of science, a term describing what science is, how it happens and how scientific knowledge develops.

According to Norman Lederman, professor of mathematics and science education at the Illinois Institute of Technology, there are seven things all students should know about the nature of science:

- There is a difference between observations and inferences. Observations are descriptions of scientific phenomena through the five senses of touch, smell, sight, sound and taste. Inferences are explanations and conclusions we form about phenomena based on observations, prior knowledge, experiences, etc.
- One of the most commonly held misconceptions is that scientific theories become laws after repeated experimentation. In fact, laws and theories are distinct forms of knowledge, and one does not become another. Scientific laws describe the relationship between observable phenomena. Scientific theories are explanations inferred from observable phenomena.
- Science involves creativity and imagination. Science is not completely objective because the entire scientific process includes creativity from generation of questions, development of methods, and explanations and conclusions from data.
- Scientific knowledge is subjective, because scientists each have their own point of view, influenced by their knowledge, education, training, experiences and beliefs. These points of view influence what scientists investigate, how they investigate, what they observe and how they interpret their work.
- Science is practiced in a larger culture, including societal expectations, socioeconomic components and religion, and it influences how we see the world.
- Science is never absolute or certain. You never "prove" in science, since scientific knowledge can change due to new evidence and/or reinterpretation of old evidence.
- Nature of science is not the same as scientific processes or inquiry. Scientific processes, such as observations and inferences, are tools to engage in inquiry. Scientific inquiry is more complex and occurs in a cyclical pattern.

Whether the future energy workforce is engaged in policymaking or designing technologies to produce energy or to mitigate the environmental hazards of fossil fuels, it needs to understand the underlying scientific processes.

That will happen when students have the opportunity to engage in scientific inquiry activities that are authentic to the fields of science. To portray science as linear, objective and elite prevents all students from believing they can be the innovators of tomorrow.

Science education faces another test, as well. The energy landscape is changing, both in the growing demand for cleaner, affordable forms of energy and the need to provide more energy as standards of living rise globally. Scientific education must be flexible enough to ensure that future generations are ready to address those changing needs.

That last point is especially important for today's diverse student population. If the energy sector is to remain competitive in a fast-paced world, it must recognize that different points of view, from a diverse set of future workers, will enrich the questions, methods and conclusions needed to create the energy innovations of tomorrow. ■

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A PERSONAL VIEW OF THE TRANSPORTATION REVOLUTION

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I love the idea of autonomous automobiles (AVs). I have a vision that I can get in my self-driving car and tell it to take me to the grocery or work, then sit back, use my laptop, text, chat with friends or just enjoy the scenery. It will be an upscale version of the Johnny Cab of the 1990 movie Total Recall, without the cheesy robot driver.

I also like the idea that it will reduce accidents, improve traffic flow and pollute less. However, unlike some writers, I don't expect it to cause me to drive less and not own an automobile. In fact, I am likely to drive more because I will be able use the time productively and traveling will become less tedious and stressful.

The best choice is dependent upon circumstances

It is easy to understand that the appeal of transportation options is different under different circumstances. Congested high-density cities with limited and expensive parking favor mass transit and ride-sharing. Sprawling suburbs with car-oriented shopping and offices favor private ownership.

Like most Americans, I have primarily commuted by driving to work alone. However, at various times I have carpooled, used mass transit, bicycled and walked. I have ridden buses, light rail, heavy rail, jitneys and taxis. In each case, I used the best, and sometimes only, available mode.

The important considerations are time, cost and convenience. Here's what I've found from living in several mostly car-centric Southern and Western US cities.

Uber doesn't work for me

Let's look first at ride hailing. The cost of car ownership is highly dependent on personal circumstances: what you pay for your car, how long you keep it, how many miles you drive, your parking costs and other factors. I buy moderately priced vehicles, keep them more than five years, drive about 7,000 miles per year and have negligible parking costs. My all-in cost, including insurance and depreciation, is less than $7,000 per year or $1 per mile.

Costwise, Uber is a losing proposition for me. Most of my driving is short trips to grocery stores, retail stores, libraries, private homes and similar locations. The average cost of an Uber trip is $2 per mile, but is higher for short trips due to fixed fees, and that doesn't include tips. A two-mile trip to my local grocery would be $2 in my car or about $10 with UberX, Uber's lowest-cost non-sharing service. Uber's cost disadvantage is less for longer trips but is still there. Including tips, UberX is about $17 for an eight-mile trip downtown and $35 for a 27-mile trip to the suburbs.

My ride-hailing economics are typical for those not living in high-density cities. Nerdwallet found car ownership cheaper for commuting in 12 of 20 cities. The biggest savings from Uber were in San Francisco, New York and Chicago. Seventy percent of Uber and Lyft trips are in nine large, densely-populated metropolitan areas.

Uber is often justified on convenience. That also doesn't work for me. Most of my destinations have convenient free parking. Parking time is, at worst, about equal to waiting for Uber to arrive. My errands often have multiple stops, which are neither convenient nor cost-effective on Uber. I also like to leave things in my car for convenience: an umbrella, sunglasses, a flashlight, a cooler for refrigerated groceries. Sure, I could tote them around on Uber, but it's a hassle. You might say this is carping, but convenience is worth something.

When ride hailing makes sense

If you're going drinking, Uber (or a taxi) makes sense. If you're going where parking is expensive or inconvenient, Uber makes sense. If you hardly travel at all, Uber makes sense. None of these apply to me.

Riding the bus

When I rode the bus to work, the bus stops were close to my house and work. The fare was reasonable, about the same as paying for parking. The buses were reasonably clean. The route didn't take me through any dangerous neighborhoods. I could read, daydream or do a limited amount of work.

There were disadvantages. It took some time to walk to the bus stop. The schedule was not completely reliable, so I had to be there early. Waiting in bad weather was unpleasant. Because of stops, the commute took longer than driving. I had no way to conveniently run errands at lunch time or on the way home. Nonetheless, I was completely happy to ride the bus. However, if you take away some of the advantages, say by raising the fare or having the bus stop farther away, it would no longer be attractive.

Other modes of transportation

In my limited exposure to high-density cities, I traveled by subway, called a taxi or walked. None of these were ideal. Subways were often the fastest but had some of the disadvantages of buses and were uncomfortably crowded; taxis were expensive and often dingy; walking was slow and unpleasant in bad weather. However, driving a car was worse. Parking was expensive and often inconvenient; traffic made travel slow and frustrating. Subway, taxi and walking were the best options despite their disadvantages. During the energy crisis of the 1970s, I and many of my coworkers carpooled. It saved gasoline cost and wear and tear on your car, relieved you from having to drive the car yourself every day, and allowed you to socialize during the trip. If you anticipated needing to run errands, you could choose to drive that day. The disadvantages were primarily longer travel time due to gathering and occasional friction between riders. I didn't find the disadvantages significant, and I'm surprised it is not more popular.

Walking is OK, but it's slow, you're exposed to the weather and you can't conveniently carry very much. I like it in pleasant surroundings, such as college campuses. Studies show that most people don't want to walk more than a half mile. That's about my personal limit for commuting, although I walk much farther for exercise. Less than 3% of the population walks to work.

I bicycle recreationally and have tried it for commuting. It hasn't worked for me. You're at risk from traffic, you get sweaty and you have to find a place to park the bicycle. Arguably, this could all be corrected by dedicated bike lanes, shower facilities at work and safe parking for bicycles. However, none of these currently exist for me and there would still be disadvantages if they did. Some may say bicycling works for them. That may be true, but it doesn't appear to work for the vast majority of the population. Well under 1% of the U.S. commutes by bicycle.

What about the transportation revolution?

It was probably obvious to you before reading this article that the most appealing way to get around depends upon circumstances. And not everyone in the same circumstances will make the same choice. Will cheaper and arguably more convenient transportation increase the appeal of living in the center city? Probably so. Those who are already attracted to that lifestyle will find it a little more appealing. But, it's hard to imagine that people will move en masse to high-density housing to save a few thousand dollars a year in commuting costs. They could already save a few thousand dollars a year by buying cheaper cars, riding mass transit or carpooling, and they aren't doing it.

There's a reason why twice as many people live in suburbs as in city centers. People move to suburbs for lower crime, better schools, less noise, cheaper houses and other advantages. In the future, people may travel in electric self-driving cars, but they probably won't stop living in the suburbs. ■

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NO MORE BUSINESS AS USUAL FOR OIL AND GAS COMPANIES

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There may not be a national consensus on how, or even if, the United States should deal with a changing climate, a state of uncertainty exacerbated by President Trump's decision in 2017 that the country would not participate in the 2015 Paris Accord on climate change mitigation.

However, it is increasingly clear that the conversation is not over. The public is becoming more skeptical of companies that produce fossil fuels, including oil, gas and coal, a trend seen most clearly in young people. That has implications not just for action to mitigate climate change but also for the industry's ability to recruit workers to replace retiring baby boomers.

A study commissioned by the advocacy group Union of Concerned Scientists and released last week found that 57% of Americans said oil, gas and coal companies bear at least some responsibility for the damages caused by global warming. They also said the companies should pay for at least a portion of the damage caused by carbon pollution, from rising sea levels to extreme weather events.

The pollsters said that even in Texas, 56% of residents support holding the companies accountable for the costs of adaptation.

That wasn't a surprise. Energy companies, and specifically oil and gas companies, remain a major force in the Houston economy. Yet when the Hobby School of Public Affairs at the University of Houston, working with the Environmental Defense Fund, surveyed UH students in energy-related disciplines, they told us a company's environmental stewardship will play a role in their decisions about employment.

Specifically, we found:

- A majority of respondents said a company's environmental stewardship practices and its corporate social responsibility program will factor into their decisions about working in the oil and gas industry.
- There were no differences in attitudes toward corporate social responsibility and environmental stewardship between students in technical fields, such as petroleum engineering, and those in social science, business and the humanities.
- A majority of respondents said the United States should participate in the Paris Accords.
- A majority said the United States should use more renewable energy and fewer fossil fuels in the future.

"The company's environmental footprint is a major factor in where I'm looking for employment," one student, an industrial engineering major, said. "I'm looking for energy-related jobs, whether that be renewables or offshore oil and gas. Not all fossil fuels are terrible at this moment, but we need to be looking toward the future."

Despite efforts to diversify its economy, Houston is still known as the "energy capital" of the world, home to about 5,000 energy companies. Many people either work in the industry or know someone who does. But the industry is undergoing a transformation known as the Great Crew Change, an industry-wide gap in middle-level managers stemming from the oil bust of the 1980s. Older workers are retiring, and younger workers must decide whether to take their place.

UH, situated in the heart of Houston, is the training ground for a large proportion of the industry's workforce. Although our findings may not generalize to the entire U.S. population, they do provide insights into how the next generation of energy sector employees think about corporate social responsibility and environmental stewardship.

The survey relied upon three complementary strategies: 1) It directly asked students about their attitudes toward corporate social responsibility and environmental stewardship; 2) Respondents were randomly assigned to one of three informational conditions, allowing us to identify how information about environmental practices affects perceptions of environmental issues and initiatives; and 3) It used an empirical strategy that presented respondents with a choice of two job hypothetical job profiles that varied by pay scale, energy sub-industry and environmental stewardship. Through analysis, that allowed us to determine to what extent respondents were willing to trade income for a firm's reputation as a leader in environmental stewardship.

What we found, coupled with the public opinion poll released by the Union of Concerned Scientists, suggests many of the issues facing the industry – both in recruiting and retaining younger workers, as well as in its interactions with society at large – are rooted in concerns about the climate.

We found strong support for the idea that global warming is real (88.3%) and caused mostly by humans (80.1%). Almost three out of four said the U.S. should participate in the Paris climate agreement. And about 94% said the U.S. should use renewable sources of energy – wind, solar and geothermal – much more or somewhat more than we do today. About as many said we should rely less on fossil fuels than we currently do.

More than 82% said they are "moderately," "very" or "extremely" concerned about the environment.

It isn't so much that the students disapproved of fossil fuels. But strong majorities said they would consider how a company handled environmental issues as part of their calculations about working in the industry . Almost 57% said their top priority would be the company's attitude toward environmental responsibility; almost two out of three said they would take a lower salary or lesser role at a company with strong environmental policies.

Companies are aware of these attitudes, and most of the major oil companies support a carbon tax or some other mechanism to offset the damages caused by CO^2 and other harmful emissions. They also have begun to ramp up both environmental programs and the broader corporate social responsibility efforts, both for international and domestic operations.

They are investing in technology, both to expand access to renewable energy and to reduce the environmental impacts associated with oil, natural gas and other fossil fuels.

Environmental concerns demand that, but so does the future workforce. ■

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TRANSFORMING ENERGY EDUCATION IN THE DIGITAL AGE

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In this era of information sharing and building collaborations through social technologies, learning environments are more "open" than ever before. The idea of openness as sharing and expanding resources has brought about a paradigm shift in many parts of society and especially in higher education. The last 10 years have seen significant advances, including such innovations as open educational resources and massive open online courses abound.

The movement has launched innumerable projects, with global implications.

George Siemens, a professor at the University of Texas at Arlington, created the idea of "connectivism," a theory of learning that explains how internet technologies have opened up new opportunities for people to learn and share information across the web and among themselves. He argues we should pay more attention to managing knowledge and learning and emphasizes the importance of understanding where to find what we need to know rather than memorizing or otherwise attaining specific knowledge. Learning, connectivism says, is about connecting specialized nodes or information sources, and Siemens describes the flow of information within an organization as the equivalent of "the oil pipe in an industrial economy."

Despite the analogy, the energy industry hasn't embraced that flow of information. Across sectors – traditional oil and gas, electric generation and distribution, alternative and renewable energy and energy storage – the industry continues to treat its data as prized, and proprietary . It has not necessarily embraced the concept of data sharing.

And energy is increasingly a data-intensive industry, reliant upon advances in artificial intelligence, robotics, data analytics and other techniques and technologies for everything from seismic analysis and subsea safety to carbon management and grid management.

With the proliferation of digital devices and sensors, IoT, or the internet of things, and devices across the value chain, data is being collected at an astounding rate in all aspects of the energy industry. For instance, a single producing oil or gas well generates over 3 terabytes, or 3000 gigabytes of data a day.

Sharing that data, in some form, could lead to increased efficiencies, improved safety and other benefits across the industry.

That's not to say there aren't legitimate business, regulatory and litigation risks associated with broad sharing of data. There are, and they have to be addressed. But an industry-accepted agreement about best practices from affiliated high-risk industries – including aerospace, automobile and health, in addition to energy – could identify mechanisms to share data without compromising the corporate entity.

Education and training is an obvious place to start. A recent report from DNV GL, an international risk-management company working in the global oil industry, found that the biggest challenge the energy industry faces in the coming digital transformation will be to find employees with domain expertise and digital skills.

So far, however, aside from a smattering of niche corporate-owned training systems, education and training in the energy field remain separate from the advancements in open educational resources

(OER) and the proliferation of massive open online courses (MOOCs). Clearly, we need to bridge that disconnect, creating an alternate paradigm to advance education in energy-related topics that can rely on real-world examples and data.

That applies to in-house training, as well as both industry-specific certificates and general STEM disciplines delivered in universities and other institutions of higher education. As STEM educators get on board with data-sharing and open educational resources, or OERs, they can begin to develop a new cadre of digital native workforce, who will not only transform the energy industry but also be charged with advancing sustainable energy development globally.

That includes ensuring graduates have a broad understanding of how data is used, with deeper dives into discipline-specific areas.

As these digital natives rise through the ranks, perhaps their natural affiliation for open sourcing will influence company attitudes toward data-sharing and other data challenges facing the industry.

In the meantime, these future workers and leaders are at the vanguard of a critical step in the OER movement: the high cost of college textbooks remains a persistent barrier for many students. STEM textbooks – the basis for learning in many energy-related fields – are often the most expensive.

The need is huge. A recent survey conducted by the University of Houston Student Government Association found that more than 37% of respondents had not purchased a required textbook due to the cost.

Lawmakers have started to respond. A bill introduced earlier this year in Congress, the Affordable College Textbook Act, seeks to expand the use of open textbooks. The Texas Legislature in 2017 approved a bill supporting open access resources in Texas public colleges and universities, requiring schools to give students the ability to easily search for classes that use open resources, allowing them to take classes using free or low-cost textbooks.

Those efforts are a good first step. Education and training crucially depend on connecting textbook learning with real-world examples, and that has become a major emphasis for academic programs training the world's future engineers, geoscientists, policymakers and other energy leaders. Data plays a key role there: think about the learning opportunities within that 3 terabytes of data originating every day from a producing oil or gas well.

For now, that is largely off limits, both to students seeking to enter the industry and to the world at large.

Remaking that paradigm – determining how to share the reams of data produced throughout the industry without jeopardizing legitimate corporate interests – won't be easy.

It may, however, be inevitable. The movement toward open-source resources is sweeping through other areas of society, and the energy industry is unlikely to be spared.

And that's OK. The knowledge we develop from such a paradigm shift will ultimately make the industry smarter, safer and stronger. ■

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ENERGY INNOVATION REQUIRES CRITICAL THINKING. HERE'S HOW TO BUILD THAT.

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In science, energy is loosely defined as the ability to do work. It exists in a number of forms – chemical, mechanical, thermal – and is an important scientific concept because it plays a role in all branches of science, including biology, chemistry and physics. That scientific concept – included in science classes from kindergarten to grade 12 – and the skills students must develop to understand it also play an important role in our efforts to build a science-literate energy workforce.

Understanding energy as a scientific concept is a pre-requisite to understanding the demands that will be required to work on innovations ranging from self-driving cars to micro electric grids and zero-emission fuels.

We're not there yet. Many children hold misconceptions about energy. For example, children often believe energy is "used up", and once it is used, it disappears. Another misconception is that an object at rest has no energy or is not under any forces. Research also show that older students often have difficulty developing a deep understanding about the basic energy concepts and applying those ideas to everyday situations. A previous study revealed that over half of high school seniors held misconceptions about fundamental ideas regarding energy.

There are several reasons for that: students' don't have a deep conceptual understanding of the topic, partly because scientific curriculums tend to focus on established knowledge, and classroom activities emphasize students' confirmation of this knowledge. The focus on standardized testing, which largely emphasizes scientific facts instead of engaging in the scientific process, pressures teachers to prepare students for fact-focused assessments. This can result in more teacher-directed instruction, which is in opposition to research that calls for providing time for students to experiment and participate in authentic scientific processes leading to discovery of both scientific facts and the scientific experience.

While the emphasis on scientific fact may lead to students' knowledge of discrete information, it also results in a reduced understanding of scientific phenomena. For example, students may know Newton's laws of motion, but they may not understand how or why the laws work.

What does all this have to do with today's energy demands and the needs of a skilled workforce that can lead us into the future? It comes down to critical thinking. Students who can't understand energy as a scientific concept will be less prepared to lead the technical and policy transformations required to power a growing world.

Already the industry is grappling with demands to produce more energy for an energy-hungry world while also looking for new and better ways to reduce the harmful emissions from that fuel. Policymakers and financiers are considering the tradeoffs of nuclear energy – emission-free but burdened with high costs, safety concerns and the lack of permanent storage for spent nuclear rods – and other potential ways to power modern life.

Even people who don't work in the industry need to understand these concepts in order to make smart choices about the cars they drive, the appliances they purchase and, in states with deregulated energy markets, the electricity providers they choose to power their homes. The need for a scientifically literate population has never been greater. Luckily, we know a lot about what works to give students these skills.

Providing students with inquiry-based experiences that foster critical thinking can help. That type of active learning engages students in questioning, planning and implementing investigations, analyzing data and generating conclusions using critical thinking. Scientific inquiry promotes opportunities for students to think and act like scientists, to relate evidence with explanations, formulate scientific arguments and defend scientific conclusions.

Critical thinking is crucial if we are to prepare students to be energy innovators of tomorrow. According to the late Richard Paul, research director of the Foundation for Critical Thinking, critical thinking involves considering multiple perspectives, scrutinizing implications, engaging in arguments to justify claims with evidence and reasoning, and re-examining findings or conclusions when new data emerges.

To nurture future energy innovators and develop critical thinking in science classrooms, Jonathan Osborne of Stanford University recommends that:

- Students engage in questioning, analysis and critique to develop their science understanding and reasoning skills.
- Space and time is provided to challenge or assess scientific knowledge.
- Students critically compare evidence with predications and observations through argument to remain as objective as possible.
- Teachers and peers reveal and respond to students' preconceptions, and misconceptions, of scientific topics.

Students also should participate in scientific argumentation, a process that helps scientists cultivate better explanations of phenomena through debate, modified to develop consensus for scientific ideas based on evidence. One way to do this is by having students engage in Claims, Evidence, Reasoning and Rebuttal (CERR). Students make claims, which are statements that answer a scientific question or problem, with evidence and sufficient scientific data to support the claim. This is all tied with reasoning, which is the justification that connects the evidence with the claim. Reasoning must also show why the data is appropriate to support the claim by using scientific ideas and principles to support the connection between the data and the evidence. Additionally, students can include rebuttal. According to Katherine L. McNeill of Boston College, the rebuttal is when students propose an alternative claim and provide counterevidence and reasoning for why the initial claim is inappropriate or inaccurate. Rebuttal requires critical thinking to consider evidence from different perspectives and frames-of-mind in order to formulate the best claim that fits the evidence with reasoning.

This isn't just educational theory, of interest to teachers and other educators. It has major implications for the future.

To develop the energy innovators of tomorrow, we must prepare students with increasingly sophisticated knowledge about the concept of energy and the energy industry. It is critical for students to be involved in authentic scientific experiences that foster the critical thinking skills and habits-of-mind that can create, analyze, scrutinize issues and propose solutions to the energy needs of our world. ■

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THE PERMIAN IS BOOMING. NOW WHAT?

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The shale revolution has demonstrably increased the production of crude oil from the U.S. and given the country the title of the world's largest oil producer, even if it lasted only briefly. The increased output from the Permian Basin, located in West Texas and Southeastern New Mexico, has been the biggest contributor to this growth.

We conducted a recent study on the rapidly growing production from the Permian Basin and the attendant consequences on the energy business in the U.S. The key findings were validated through conversations with members of industry, government and infrastructure leaders. The key implications of this work are summarized here.

A major point: There is no significant domestic customer for the incremental crude projected to come out of the Permian Basin over the next five years. The Permian Basin produced 3.2 million barrels per day in 2018. That production is expected to grow by 1 million barrels per day each year for the next four years, to about 7 million barrels per day in 2022. Permian production was already up to 4 million barrels per day midway through 2019.

For comparison, the U.S. Energy Department reported earlier this month that U.S. oil production had surpassed 12 million barrels per day in April, meaning more than one of every three barrels produced in the United States today comes from the Permian.

U.S. refineries already are buying all the light crude they can use from domestic suppliers; Gulf Coast refineries have not imported significant quantities of light crude since 2015. Most of the additional 4 million barrels per day of crude coming out of the Permian Basin over the next five years will have to be exported .

Pipeline capacity for the crude produced in the Permian has been a major bottleneck, but it will move back into balance with demand by the middle of 2020, if not before. The shortage of pipeline capacity, and the resulting inability for producers to transport oil from the region, has caused a significant discounting of the produced crude oil in the Permian and has also resulted in increasing the inventory of drilled but uncompleted wells.

Plans to build pipelines from the Permian to the Gulf Coast – several to the ports at Corpus Christi, Houston and Beaumont – have been announced in recognition of the need for additional pipeline capacity to move the oil from the Permian, and most are planned to come online between now and 2022. The announced pipeline capacity and timing will be more than adequate for the evacuation of the additional crude oil that will be produced in the Permian.

However, new supply chain bottlenecks will emerge further downstream as the export terminals in Corpus Christi, in particular, are unlikely to be ready to handle the volume, even though the port expansion is being developed for the operation of very large crude carriers (VLCCs). Currently the Louisiana Offshore Oil Port (LOOP) is the only port along the Gulf Coast capable of handling VLCCs, which can carry 2 million barrels of oil.

The remaining ports along the Gulf Coast will be capacity constrained for the foreseeable future.

But getting the oil out of the Permian and delivering it to the ultimate customer aren't the only challenges facing the basin. The major operators, including ExxonMobil, Chevron, BP and Shell, are increasingly consolidating production and resources in the Permian, as well as the supply chain leading to domestic refiners. The announced acquisitions of acreage in the Permian by the majors, along with their part ownership of the pipelines and the downstream assets along the Gulf Coast, means the smaller independent producers still operating in the Permian will have to look for options to export their crude.

That won't be easy. Independent producers are relatively inexperienced with the complexities of exporting oil, and they are likely to face business challenges in the absence of appropriate intermediaries stepping into the market. If the independent producers don't – or are unable to – build their export capabilities, they could become targets for acquisitions.

Independents also face additional pressures because of the flight of capital from the Permian because of relatively weak return on investment.

Consolidation by majors and increased pressure on the independents will lead to the gradual erosion and ultimate destruction of enterprise value among many oilfield services companies due to the lack of pricing power.

Nevertheless, there is significant uncertainty regarding when the pipeline and export terminals will be completed, especially the planned expansion of the Port of Corpus Christi, and the ancillary facilities that must be developed alongside the terminals. Some of the uncertainty arises from a significant "not in my backyard" movement in Texas towards the building of pipelines and large-scale infrastructure. There is also the likelihood of a significant shortage of skilled workforce for construction and operations for both the significantly expanded operations focused on exports and new downstream operations being planned along the Gulf Coast.

Lastly, two notable challenges, both for the majors and the independent producers, must be resolved soon to ensure the resources of the Permian can continue to be produced:

- The poor consistency of crude quality exported to Asia due to the mixing of different grades (API) of crudes, and
- The continued environmental footprint especially from the flaring of associated natural gas that is produced in conjunction with oil.

Overall, we found a bright future for the likely continued growth of production from the Permian Basin. That future, however, won't happen without continued planning, infrastructure growth and adjustments to market conditions.

Independent producers, especially, must adapt to market realities and become adept at maneuvering through the export process . Gulf Coast ports and the ancillary infrastructure will have to learn to manage the additional congestion and technical obstacles posed by increased crude oil and LNG exports. ■

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