Global Energy, Economy, and Security: A System in Transition



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THE ASPEN INSTITUTE
ENERGY & ENVIRONMENT
PROGRAM

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FOREWORD

The Aspen Institute Forum on Global Energy, Economy and Security was created to explore issues at the intersection of energy, economics, geopolitics, and security. Each summer a select group of US and international leaders and policy experts from energy producing and consuming industries, governments, and research organizations convenes in Aspen for a candid discussion of issues with national and global importance. The discussions are designed to encourage new, collaborative, cross-disciplinary thinking.

The 2016 Forum began with a deep dive into current trends and forecasts about global energy supply and demand and an examination of specific regional impacts followed. Then participants refocused and discussed the role oil and gas companies can take in a carbon restrained world. The final session sought to highlight specific technological innovations that will likely drive markets in the coming years. All sessions were kicked off by a few short frame-setting remarks by selected participants but the balance of time was reserved for moderated discussion.

We were sincerely honored this year to have Mary Landrieu, former Senator from Louisiana and currently Senior Policy Advisor at Van Ness Feldman, and Marvin Odum, the former Chairman and President of Shell Oil Company, serve as co-chairs. Their intimate knowledge and experience with all of the issues addressed during the Forum as well as their skill and grace as moderators added greatly to the discussion

The Institute acknowledges and thanks the Forum sponsors for their generous financial support. Without their support the Forum simply could not have taken place.

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EXECUTIVE SUMMARY

The energy world is now well into adjusting to one of the steepest oil price collapses in history, one which has caused shifts in global supply and demand. At the same time, previously growing levels of domestic natural gas production have slowed due to a glut of gas presently in storage and on the global market. Looking forward over the next couple of decades, global energy consumption is projected to continue to grow (mostly in emerging economies), and most forms of energy are expected to grow in absolute terms. The annual growth rate, however, is projected to be much slower than it has been, and market shares are projected to shift considerably, with coal losing to renewables and natural gas production. As with all forecasts, of course, there are uncertainties, as geopolitics, capital flows, and other global risks will affect energy's future.

Regional and national markets have both driven and been affected by these global energy trends. In Asia, Chinese oil demand (seen as unquenchable just a few years ago) could peak within the next decade or two, coal is still generally cheaper to use than natural gas in places like China and India (but not in the U.S.), and renewables and distributed energy resources could explode even further depending on financing. Russia, meanwhile, is facing unexpectedly competitive international energy trade markets, plunging oil and gas prices, a stagnant domestic economy (partially due to US and EU sanctions), and a huge domestic oversupply of gas, though Ruble devaluation has allowed Russian oil output and exports to grow modestly (at least in the short term). In the Middle East, where geopolitics have clear consequences for global oil and gas markets, Saudi Arabia and Iran see each other as existential threats, Saudi Arabia may or may not emerge as a swing supplier again (despite the big loss in revenues due to low oil prices), and Iraq may not be able to remain a unified state in the face of fiscal and political crises. In Latin America, the drastic drop in commodity prices has helped spur political unrest and economic hardship, and potential foreign investors are warily assessing the risks associated with investing in Latin American resource production.

North American oil production has been resilient in the face of low oil prices, thanks to impressive productivity and efficiency gains.

North American oil production has been resilient in the face of low oil prices, thanks to impressive productivity and efficiency gains. Supply is dropping, though, and shale drilling is basically taking place in only a few counties where the economics make sense at current prices. The reduced production, in turn, has reduced the throughput of midstream assets, creating challenges for North American midstream companies. While there is a base of US crude oil production that can come online quickly if prices start rising enough, there may never again be a world of stable $100 oil prices; instead, continuous cycles of rises and drops in price and production are likely for some time. There are also enormous US gas supplies in the $3-$4 range, though a lot of natural gas will be produced in the United regardless of price, due to the high profitability of gas produced in wet shale plays. In Canada, the existing oil sands projects have been economic even during the price downturn and should do quite well as prices go back up. The Canadian oil and gas industry has also been collaborating in addressing public policy challenges and technological opportunities, recognizing that its social license to operate has largely been provided by provincial governments' environmental policies. Mexico, meanwhile, managed to institute reforms in its oil and electricity sectors, introduce

private capital, slash electricity costs, and cut carbon, even though oil prices started to decline just as it opened its markets (which ended up helping the electricity sector). All of these developments, combined with many other factors, highlight the enormous opportunities to look at energy development, energy use, energy security, and environmental policy from a more integrated, North American perspective.

Maintaining the industry's social license to operate is inherently tied to public opinion, discourse, and education. Public opinion can shift strongly in the energy realm in ways that affect the ability to operate, as has been seen with nuclear power in Germany and hydraulic fracturing in the US. The climate issue influences a certain level of political pressure and public opinion around fossil fuels, at least in the US, as climate activists have turned to infrastructure fights and "keep it in the ground" in the absence of progress on national climate or energy policy. The national conversation on energy is propelled by hyperbole, ideology and misinformation, undermining the ability to find common ground and build public trust. Providing decision-makers with better, less bias information on energy issues is warranted, although many people do not want to be – or do not think they need to be – further educated.

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Even in a carbon-constrained world, most forecasts see fossil fuels as a big part of the energy supply for decades. Keeping warming below 2°C, much less 1.5°C, will require unprecedented improvements in the carbon intensity of the energy mix and in the efficiency with which energy is used in the economy. Every year of delay significant portions of the finite global carbon budget are 'spent' on emissions from burning coal, leaving less and less of the budget to spend on the less carbon intensive fuels like oil and gas. It is in the economic interest of business to put weight behind policies to rapidly reduce the carbon spend rate. In the US, prospects for a price or tax on carbon, hinge on those in Congress who think climate change is real, human-caused and economically feasible to manage.

Market dynamics and existing policies have already dramatically increased the role of natural gas in the US power sector, reducing that sector's emissions, and North American natural gas is now being liquefied and shipped around the world. Addressing methane emissions from oil and gas production and use, however, is key to capturing natural gas's potential environmental advantage. Carbon capture and sequestration (CCS) may also be essential – especially to deal with the gas and coal plants built over the past 10 years that are likely to operate for decades – but CCS is expensive and generally lacking policy supports. In addition, a transition to a lower carbon energy economy will likely require reassessing energy business models (e.g., moving away from the sole reliance on fossil fuels), making decarbonization policies less myopic (i.e., beyond renewables), increasing investment in low-carbon research and development, and figuring out the technology and human capabilities needed going forward.

Technological innovation has been and will continue to be a vital part of the energy system transition. The technology space in oil and gas is currently seeing new players, many startups, some venture capital financing, and lots of innovations, with a particular focus on digital disruption (e.g., machine learning, data analytics, mobile devices and services) to improve cost, simplicity, and speed. Companies will also have to leverage technologies to address needs such as low-carbon imperatives and remediation. In the transportation space, where the vast majority of oil goes, technological innovations involving improved fuel economy, vehicle electrification, and other areas have the potential to reduce oil demand, though policies and consumers will play huge roles in determining the future of transportation. The biggest uncertainty in the oil sector, as well as the electricity sector, is the rate of adoption of electric vehicles.

Major takeaways from the 2016 Aspen Institute Forum on Global Energy, Economy and Security included the following:

- **Global oil demand is projected to grow by 20 million barrels per day, or about 20%, by 2035. Demand falloff from fuel efficiency standards and other factors will be more than offset by growth in emerging economies.**
- **In the US, the cost of drilling for oil and gas is going down because of technology development, and some drilled-but-uncompleted (DUC) wells represent low-hanging fruit where production can ramp up relatively quickly in response to potential future price increases.**
- **The last two years have shown that era of Saudi Arabia as the world's swing producer, where they dial up or down production unilaterally based on market turbulence, may be coming to an end.**
- **US natural gas will continue to thrive despite relatively low prices, due to the fact that breakeven price for natural gas in dry shale plays is between $1-2.40 per mmbtu and in wet oil/gas plays is often negative. Cheap natural gas is here to stay for the foreseeable future and will continue to be used for power generation, continuing to displace both coal and nuclear, and potentially suppressing renewable deployment.**
- **The biggest uncertainty right now is the transportation sector. If the adoption curve of electric vehicles is steeper than it's been in the last few years, then demand for electricity may actually go up, instead of the current forecasts calling for flat or slightly decline demand, which has big implications for oil demand for vehicles, natural gas demand for power, and the transportation fuel mix.**

GLOBAL ENERGY TRENDS & FORECASTS

Energy has entered an era of price volatility, abundant supply, and changing geopolitics, with implications for global production and demand.

GLOBAL STATUS OF OIL & GAS

The oil world is in the midst of one of the steepest price collapses in history, though markets are starting to rebalance. In response to the price collapse, year-on-year global oil supply has fallen off, deepwater production is in trouble, capital expenditures have been cut back by around $1 trillion (likely setting up a future underinvestment cycle), and all while global demand for oil continues to increase. An obvious lesson of the price downturn is that price falls when supply increases faster than demand. It is conceivable that the recent market imbalance may have been caused as much by the failure of oil demand to live up to exuberant forecasts as by increased supplies from shale, oil sands, and other sources.

As for gas, there were predictions a few years ago about the golden age of gas, but that vision has stalled. There has been weak Asian demand growth, partly due to Chinese plans to meet air pollution challenges with coal retrofits and renewables. In addition, policy choices (e.g., in Europe) that focus not on carbon but on renewables have squeezed gas, as have rapidly falling renewables costs, market structures that do not work well (e.g., in India), limited market growth in sectors such as transport, and the political and public discourse about shale gas and social license to operate.

GLOBAL ENERGY FORECASTS

Looking forward, global energy consumption is projected to continue to grow, with virtually all of the net growth occurring in emerging economies. Accordingly, most forms of energy are expected to grow in absolute terms through 2035. Oil and gas are projected to have annual demand growth similar to what has been seen historically, while renewables could see a big acceleration in annual demand growth at the expense of coal. Aggregate oil demand is projected to grow by 20 million barrels per day by 2035, with declines from fuel efficiency standards and other factors more than offset by growth in emerging economies. Growth in oil demand around the world will come mostly from the transport sector, as well as from the industrial sector; electric vehicles (EVs) are not projected to work their way into the global fleet by 2035 at a scale or pace that would meaningfully affect this demand.

While global energy consumption is projected to grow, the global annual growth rate is projected to be significantly slower than the recent historical norm, due to mature economies' plateauing energy demand and China's significant slowdown in energy consumption growth as its economy transitions away from energy-intensive development. For example, with the structural shifts in China's economy, the conversation about China has shifted from its unquenchable thirst for oil to the potential for oil demand to peak in the near future.

Market shares are also projected to shift considerably. Oil is expected to continue its 40-year erosion of market share, and coal is projected to lose market share as well. In contrast, renewable energy and natural gas are projected to gain significant market share, making particular gains in power generation to the detriment of coal.

To meet the expected increase in oil demand, the biggest growth in the world's oil supply is expected to come from the United States, which is projected to become a small net oil exporter by 2035. All net growth in oil supply outside of OPEC is projected to come from the Western hemisphere, including renewed investment in places such as Brazil and Canada. As for gas, about half of the growth in global gas supply is projected to come from shale, mostly (but not solely) from North America. Significant growth in production of conventional gas is also expected in emerging economies, particularly in the Middle East, Russia, and China. Global Liquefied Natural Gas (LNG) is projected to assume growing importance in the world's gas market, providing connectivity among what had been regionally disconnected gas markets and making the gas market look more like the oil market over time. However, by 2020, global LNG supply could reach about 50 billion cubic feet per day (bcf/d), but demand is only projected to be about 40 bcf/d, which means there could be 10 bcf/d oversupply.

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In any forecast, there are uncertainties – geopolitical risks, capital flows, and other global risks could all affect the future of energy. For example, there is likely to be more oil price volatility ahead, and it is unknown how producers will react to that volatility; some are more risk prone, others more risk averse. Volatility makes predictions hard. As another example, energy intensity has declined at a rate of about 1% per year over the past 50 years, but it has been faster than that over the past 20 years; projections need to account for that acceleration, as well as for the effect of policies after the Paris climate agreement that will push for more efficiency in energy use. Economic growth is another big area of uncertainty; if the Chinese economy, for instance, grows at a lower rate than expected, global energy demand growth will decline accordingly. Forecasts have also been notoriously bad at forecasting renewables (at least in power generation) and shale oil and gas, and it is possible they are understating the growth trajectory of electric vehicle adoption. Technology can surprise on the downside too, as evidenced by failures to rapidly develop next generation biofuels. The urgency of addressing climate change presents a further wild card for forecasts; the numerous projections for global oil demand all differ from the trajectory necessary for a carbon-constrained world.

REGIONAL IMPACTS

The trends in global energy have affected and been driven by regional and national markets.

CHINA AND EAST ASIA

The rapid changes in energy currently underway in Asia could upend conventional wisdom. For example, oil demand could peak in China within 10-15 years. Sourcing oil is a security threat for China and raises environmental issues. While car sales are still growing, oil demand will slow down within the next few years as per capita car ownership flattens out, cities restrict car purchases, fuel efficiencies improve, and alternative vehicles (including EVs) begin to spread. In addition, there are few trucking operators in China, and a large percentage of their trips are empty miles; using software to optimize trucking operations could slash oil demand, carbon emissions, and urban air pollution. The shifting of the country's economy towards lower energy intensity should further reduce demand for diesel and fuel oil. At the same time, in a world with no single swing supplier, there is a need for higher levels of storage and a greater ability to tap that storage, and China is building out its oil storage for both strategic and commercial stocks.

Oil demand could peak in China within the next 10-15 years.

Natural gas, despite the global oversupply, may not have great prospects in Asia due to economics. At higher gas prices (say, $6.50/MMBtu), financing new liquefaction facilities may be economic, but coal is cheaper than gas. At current gas prices (around $4.50/MMBtu), gas and coal are at parity, but new liquefaction facilities are uneconomic. In short, coal still wins on economics in Asia, and a number of countries are opting for it. Carbon prices may have to be on the order of $50/ton to make gas competitive with coal in Asia.

As for renewables and distributed energy resources, their adoption growth could increase drastically in Asia. Technology costs for solar power have already come down considerably, so the growth of solar in Asia now depends heavily on financing; the very low bids for solar power seen in various places around the world have had almost zero-cost financing. If the cost of solar financing comes down by 250 basis points, solar would be competitive with gas in Asia by 2020. Financing is incredibly important for the next wave of renewable energy in Asia. In addition, just as Asia leapfrogged the West in telecom by bypassing the fixed-line network to go right to wireless, it is possible Asia could leapfrog to having lots of distributed generation and other distributed energy resources (e.g., storage) tied together with software to form virtual power plants and grids. Singapore is already implementing a Smart City program.

Projections and expectations aside, there are wide open questions about what will happen in China and the rest of Asia. Much will be determined by the policy initiatives that are taken, whether and how they are executed, and what investments are actually made.

RUSSIA

The Russian energy story is one of disappointment. Ten years ago, Russia was announcing itself as an energy superpower, but the dynamic evolution of energy markets led to some surprises. Russia produces 10% of total primary energy in the world, consumes 5% of global primary energy, and accounts for about 15% of the total international energy trade (though Russia has never been a price-setter in the international oil and gas markets). Between 2000 and 2020, the number of big oil producing countries is doubling, the number of big gas producers is tripling, and the number of oil and gas exporting countries is increasing – so international trade markets are becoming very competitive. Russian leadership had not considered this, however, when crafting the country's energy and energy export strategies. The plunging oil and gas prices further exacerbate the unfavorable situation for Russia, aggravating a domestic context that includes stagnant energy demand and lack of access to financing (because of Western sanctions). The situation has negatively affected Russia's GDP, though the country has experienced far worse and survived.

To survive, the Russian government has chosen the simple tool of ruble devaluation, which has allowed oil and gas companies to offset the negative effects of the oil price decline (at the expense of the Russian population). Russia can survive for the next 10-15 years, if needed, on ruble devaluation; the country is rich enough to muddle through a stagnant (but not collapsing) economy, and the political regime is very popular. Following the devaluation, Russian oil output and exports are growing (though they are projected to decline in the long term). Oil companies now are maximizing their cash flow at the expense of future production.

A major global implication of the current Russian situation is that Russia appears to have completely lost control of Central Asia and the Caspian to China, which has become the most important energy power in the Eurasian space.

Even if Russian oil production declines, domestic oil demand is stagnant or declining due to the weak economy, which means Russian oil exports should remain pretty stable. Oil provides about half of Russian budget revenues, so maximizing exports is a government priority. Over the past few years, Russia has tried to diversify its export markets, and more than a quarter of Russian oil is now flowing to Asia (mostly China) – a figure that is expected to rise to around 40% by 2025.

The gas situation in Russia is less optimistic, as both production and exports are stagnating or declining. Russia has accumulated a huge domestic gas bubble, having overinvested in the upstream; spare gas capacity is more than 150 billion cubic meters and will exceed 250 billion by 2020 – nearly twice the level of Russian exports to Europe. The oversupply cannot be sent to Europe due to infrastructure bottlenecks, and most of Europe does not want more Russian gas due to energy security concerns. Domestic consumption cannot address the oversupply either, given the stagnant economy. The first Russian pipeline gas to China will not start before 2021, and the competitiveness of Russian gas in China remains a question mark; it is unclear if Russia will be successful in expanding contracts and making a strategic energy alliance with China. A major global implication of the current Russian situation is that Russia appears to have completely lost control of Central Asia and the Caspian to China, which has become the most important energy power in the Eurasian space.

Still, energy remains one (but only one) aspect of Russia's interests in the international arena. For instance, Russia has been very successful in reinjecting itself into the geopolitics of the Middle East, partly due to energy interests, but also out of concerns about security and radicalism.

THE MIDDLE EAST

Geopolitical issues in the Middle East have clear consequences for global oil and gas markets. Iran, Iraq, and Saudi Arabia have been big sources of supply growth the last few years, but the geopolitical landscape suggests that the region

may not be a great source of growth over the next 5-10 years; there is not a lot of upside potential in the Middle East over the short to medium term.

For example, there is questionable potential for renewed cooperation between oil producers in the region. Tensions in the Middle East are at a peak, with Saudi-Iranian and Sunni-Shia competition on the rise. Saudi Arabia and Iran see each other as existential threats and as challengers for dominance of the region, but neither country views oil prices that way, so the prospects for regional cooperation to limit supply growth are not good.

The Saudis are clearly having an impact on oil prices (and vice versa). Saudi Arabia may or may not emerge as a swing supplier again. Even if the Saudis were inclined to play the market management role, the flexibility of shale creates challenges in figuring out how to do so; Saudi Arabia miscalculated the rise if US shale production over the last few years, and the Saudis still may not have a good read future production changes. The Saudis also seem to expect no challenge to continued oil demand, which might be another miscalculation. In addition, the Saudis see no reason to cut production when other OPEC members will not, nor do they see a reason to prop up a high oil price that allows higher-priced supply options to grow. (OPEC may have made a mistake in letting the oil price stay high for so long, which brought on shale and spurred conservation efforts.) On the other hand, it may be too soon to declare the end of Saudi market management and OPEC's relevance; defending market share makes sense in the face of a long-lived shock, but that does not mean that Saudi Arabia or the cartel could not still come in during a temporary shock (e.g., a recession) to coordinate production cuts to support prices. The Saudis also have tended to take a longer-term view in terms of decisions about investment capacity, and it is possible they could decide to go above current capacity levels if they see that the demand exists and there are supply shortfalls from other areas; the decision to go beyond current capacity levels is an internal discussion that will happen over the next year or so.

The era of Saudi Arabia as a swing producer, who dials up or down oil production, may be a relic of the past.

In the short-term, the downturn in oil prices means Saudi Arabia is losing enormous purchasing power and revenue. The fiscal runway the Saudis have to keep oil prices low may be shorter than appreciated; it is hard for them to raise non-oil revenues to fulfill their bold Vision 2030 ambitions to privatize and diversify the economy. On the other hand, changes in the oil market that are seen as structural instead of cyclical could provide greater impetus to this effort. The new Deputy Crown Prince has commented that he wants to get Saudi Arabia off oil revenues by 2020 and plan for a future without oil, and there appears to be a lot of political will behind the transformation. It is hard, however, to imagine Saudi Arabia making it over all the hurdles in its path. Implementing the plan will require navigating Saudi culture, which means it is hard to contract out the implementation, but it is unclear that the Saudi government has the capacity to carry out the implementation itself. In addition, most working Saudis work for the government, while most private sector workers are foreigners; changing this will up-end the entire structure of the Saudi economy. A lot of the desired economic reforms will also require political and social reforms; for instance, it will be hard to bring women into the labor force without changing some of the restrictions on how people work and how men and women interact in society. It is unclear if the Saudi government will want to (or be able to) take on the religious establishment to loosen some of these restrictions. In fact, it is possible and perhaps likely that Saudi Arabia will instead become poorer, more repressive, and more radicalized, which could have dramatic implications for global energy markets.

Challenges in the Middle East go beyond just Saudi Arabia, of course. For example, Iraq is at a critical existential juncture (as it always seems to be), and it may not be able to maintain itself as a unified state in the face of fiscal and political crises. Iraq falling apart would affect global oil production and market stability. The Iraqi government gets 90% of its revenues from oil, and its budget deficit is growing. It will have to spend more money on fighting ISIS, its cities are devastated, and it has billions of dollars' worth of reconstruction needs, but that money does not exist in the Iraqi system. While Iraqi oil production is increasing, it may not go much higher, as the government has asked companies not to make more investments in productive capacity (because contracts require the government to pay back company

costs). On the political front, energy used to be what tied Iraq together, with the Kurds receiving a portion of oil sales, but that has totally broken down in the low-price environment. The political crisis is further complicated by the fact that Kurds are taking over territory that ISIS claimed, and the Kurds see this as their window to create a new relationship – either federal or independent – with the rest of Iraq. The Iraqi government is very divided and overwhelmed, and the country is experiencing widespread violence due to ISIS. The Iraqi government is unable to focus on creating a legal, political, or security environment in which to grow oil production.

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Energy diplomacy can still have some beneficial effects on regional politics. The discovery of offshore gas in Israel created an opportunity for Israel and Jordan to work together on energy development, helping to transform that part of the Middle East. Still, economics rarely leads politics in the region. Israel is exporting gas to Egypt and Jordan – the only two countries there that recognize Israel. Gas is not being used as a diplomatic tool between Israel and the other Arab countries.

SOUTH AMERICA & THE CARIBBEAN

The drastic drop in commodity prices and the political risks associated with investing in Latin American resource production have led to a real shift in the region, from being exporters to importers of oil and gas (or at least reduced exporters). That dynamic may change again, though, given the material resources located in (and offshore of) countries such as Venezuela, Brazil, and Argentina.

Many Latin American countries lack the resources to develop their own oil and gas resources, so there is sporadic competition for foreign dollars. In Latin America as a whole, the pendulum swings left and then right regarding foreign investment, as has been seen in Venezuela, Ecuador, and elsewhere. For example, in the mid-1990s, there was an investment environment in Argentina very favorable to foreign direct investment, and dollars were flowing in. In the early 2000s, the country defaulted on its sovereign debt, devalued the peso, and went into an isolationist period that actively discouraged foreign direct investment. That period lasted until the elections in October2015. At this point, many investors are opening offices, looking around, and doing analyses in Argentina, but they are not writing checks, preferring to wait and see if the changes being implemented actually take hold. In general, potential investors have to weigh opportunities in any given Latin American country against opportunities elsewhere, and the worse the politics are in the region and the worse the price environment, the lower Latin America falls on investors' lists. In countries that lack a level playing field, such as Venezuela and Ecuador, there is very little direct foreign investment; instead, investment is almost entirely government-to-government, as can be seen in the investments China has made in the region.

The economic fallout of plunging commodity prices and the political unrest in many Latin American countries could have global ripple effects. For example, many countries dependent on oil for power generation depend on Venezuelan credit, and the collapse in Venezuela could lead to humanitarian crises and migration out of Haiti, Cuba, and elsewhere. The troubles in Latin America may not last, though, at least in some countries. For instance, Brazil has the potential to make a pivot like Mexico made; given its political, governance, and technocratic classes, Brazil could be back in a flash.

In the Caribbean, countries are beginning to switch from diesel and heavy fuel oil to natural gas for electricity generation; the numbers are not huge, but there is a clear trend. These countries are switching because they have electricity prices three times higher than in the United States, and they cannot make their economies run without affordable electricity. However, these high prices, along with abundant solar and wind resources, also make grid parity for renewables achievable in much of the Caribbean. Interest in clean energy has been growing throughout the region and several islands have completed projects or made commitments to renewables in recent years.

NORTH AMERICAN ENERGY

The North American region has in many ways been central to the changing global energy dynamics, particularly in terms of supply.

STATUS OF NORTH AMERICAN SUPPLY

North American oil production has been rather resilient in the face of low oil prices. A lot of independents were hedged, and there was a lot of momentum going into North American supply, so there was little reason to expect production to plunge. The resilience has been sustained as long as it has because of impressive productivity and efficiency gains, partly from high-rating of wells and largely from technological change and squeezed service costs.

It is conceivable that the new break-even cost in North American tight oil is $55, compared to $75 just a few years ago. In the oil industry, price drives cost, not the other way around.

Very few people would have thought a couple of years ago that the pace of productivity gains in tight oil and gas would accelerate even further from the breakneck pace it has been on for several years. Well improvements in some plays have been incredible; the technology utilized and knowledge gained on the rocks in 2015 has been very impressive, and the increased productivity and efficiency could bode well for long-term shale production. For example, when crude was at $100 in the spot market in 2014, there were 185 rigs drilling in the Bakken, and producers had an average investor rate of return of 37%. In 2015, there were still 76 rigs running at a 21% rate of return; it did not drop more than that because the cost of drilling a well dropped from roughly $9 million to roughly $6 million. In 2016, only 26 rigs were still drilling in the Bakken at a 12% rate of return, but the cost of drilling a well dropped even further. In response to economic signals, Bakken production dropped about 15% but did not drop further because of improving economics and improved productivity. In 2011, rigs in the Bakken could produce 222 barrels per day, a figure that has risen 260% to almost 800 barrels per day in 2016; other basins, including the Eagle Ford, the Niobrara, and the Marcellus/Utica, have seen even greater gains in production per rig. It is conceivable that the new break-even cost in North American tight oil is $55, compared to $75 just a few years ago. In the oil industry, price drives cost, not the other way around.

On the other hand, not all of the efficiency gains may be sustainable in the future. For instance, lots of service companies have gone out of business, which could slow the response time of the industry if prices increase. In the short term, entire supply chains may need to be recreated, sometimes with new suppliers because old ones disappeared. The surviving companies have lost many qualified people that are not coming back and will have to recruit and train new people. In addition, these companies have been waiting through cratering prices for the opportunity to make money again, and how quickly their prices come back up will affect operators' economics. These realities – combined

with the fact that higher oil prices will lead companies to start drilling again in less productive zones on a more speculative basis – create a real risk that there might not be such high productivity levels going forward.

While North American productivity gains have been impressive, supply is now dropping. In a single month in the summer of 2016, production in the Eagle Ford dropped 63,000 barrels per day; if extrapolated to other basins and other months, that is a significant decline. (The decline in the Eagle Ford actually started before the downturn, since the top ten producers were all in the condensate window, which was not faring well before the price crash.)

Production of gas from unconventional sources is about three times as high as from conventional sources (for oil it is about six times as high), but the shale revolution in 2016 is basically taking place in only 20 counties – a few in North Dakota, a bunch in the Permian, and a few in the Eagle Ford and Marcellus. That is where two-thirds of all rigs are. The economics of drilling everywhere else in the country are generally upside down at current prices, but the map will expand again as prices get higher. (Production is still happening in other counties, which drilled when prices were higher.) Most of the growth in US gas production has come from the Marcellus, where producers' capex is limited by cash flow and access to debt and securities markets.

OUTLOOK FOR NORTH AMERICAN SUPPLY

In January 2016, no one was prepared for oil to drop $1 a day, every day. By mid-February, people were pulling in dramatically, and cash flows plummeted. With the price trough in January and February, the service company activity drop and capex drop will likely be seen in the second and third quarters of 2016. US production should see steady and consistent decline in 2016, and balance between supply and demand should be achieved sometime around the fourth quarter of 2016 or the first quarter of 2017. (As a general rule of thumb, one can expect roughly a six-month lag between price changes and rig count responses – and another six-month lag between rig count responses and production data – though the lag may be even shorter.)

Drilled-but-uncompleted wells could represent low-hanging fruit where US production can ramp up quickly in response to price.

There is a base of US crude oil production that can come online quickly with a price signal of $60-$65, though the price range could be considerably wider. For example, some drilled-but-uncompleted (DUC) wells could represent low-hanging fruit where production can ramp up in response to price; some DUCs may not get completed until there are much higher prices, while others could get cleared at prices around $40-$50. In the Permian, meanwhile, productivity improvements have been incredible, so if the world oil price rebounds to, say, $75, there could be a very large amount of production out of the Permian Basin over the next few years. The likely reality is that there may never again be a world of stable $100 oil prices; instead, there may be continuous cycles of prices and production going up and down, though the pace and amplitude of those cycles remain unknown. These continuous cycles could mean more booms and busts, with impacts on companies' survival, local communities' budgets, school funding, and infrastructure development.

The rates of return for crude oil and natural gas are tied together more than many people realize, so while there are enormous US gas supplies in the $3-$4 range, there is a lot of natural gas that will be produced in the United States regardless of price. If crude is around $60, producers in different basins can make money at a range of natural gas prices. In the Haynesville, which has no crude, the breakeven price of natural gas would be $2.45. In the Marcellus Dry, where well costs are cheaper and productivity is higher, the breakeven price is around $2, whereas in the Marcellus liquid plays, producers would break even if gas is at $1.10. In the Eagle Ford, the gas price could be negative and producers would still be doing well; they would be making so much money on crude that they could afford to lose a little on natural gas. Likewise, crude oil plays could have gas prices be strongly negative for their associated gas.

Furthermore, if refracking wells can increase recovery from 10-15% to 20-25%, then there will be an immense amount of source rock out there that can be drained with higher and higher efficiencies. The jury is still out on whether refracks have a higher return on capital employed than fracking right the first time, and the science and technology for refracks may not quite be ready yet, but when that frontier is reached (which should not be long), it will allow refracking to be done very cheaply.

While the concept of "peak oil" now seems out of date, it may be that the easy oil has been discovered and that the world is on a long-run course towards higher marginal costs for petroleum production. The shape of the long-term production curve, however, will depend on the race between depletion and technology – and how that race will evolve is indeterminable. That being said, no more US money will be going into Arctic exploration until there is greater political will or some other driving force that would make companies want to go back. (Internationally, the story can be different; Russia is currently exploring in the Arctic.)

MIDSTREAM STATUS

The midstream part of the oil and gas sector is not immune to industry cycles and low prices. From the 1940s through 2000, there was a steady buildout of midstream North American infrastructure, followed by a boom in infrastructure buildout through 2014. Billions of dollars have been invested in midstream projects over the past few years, during times of high prices and drilling exuberance. Low prices, however, reduce production, which in turn reduces the throughput of midstream assets; the trend in barrels per day carried in pipelines is declining. The result has been some bankruptcies, rejected contracts, and reduced cash flows for North American midstream companies. Midstream companies that focused too much on the upstream and lost sight of the marketplace found themselves with too much debt and questionable business models, leading to changes in corporate structure. Companies entirely levered to the upstream are finding the dam either broken or leaking, and many of those companies will not exit the difficult part of the cycle in the same form, if at all.

A lot of discussion in the trade press has focused on the need to build out more gas infrastructure, because some regions (e.g., the Marcellus) have serious capacity constraints. While there is a shortage of capacity in some places, though, there is excess infrastructure capacity in others (e.g., Colorado). A lot of the new infrastructure being built is financed by long-term take-or-pay contracts with utilities.

During the midstream infrastructure buildout boom, producers signed take-or-pay deals for pipelines that ended up overbuilt and oversized for what was actually produced. Midstream companies that keep those contracts in place might see short-term cash flow benefits but might forfeit relationships and long-term growth and profitability; attempts to shift that risk onto producers could jeopardize midstream companies' throughput, as producers are already overburdened with financial commitments. Midstream companies will likely have to take on more risk, which requires a better understanding of supply and demand fundamentals; not every company, though, is in a position to do that.

CANADA

Even during the price downturn, the economics of existing Canadian oil sands projects have been acceptable, and those projects should do quite well as prices go back up. The oil sands assets in Canada are likely to be producing for decades to come.

The Canadian population (more than the American population) generally recognizes the connection between the health of the country's economy and the health of the oil and gas business. Vibrant provinces transfer money to less vibrant provinces, so when the oil and gas industry declines, so do the transfers. There are also only 35 million

people in Canada, representing a much smaller education challenge than in the United States. The message that the Canadian government and industry took from the Keystone XL pipeline fight was not to rely on the United States as Canada's market in the future and to try to get product to the coasts to ship to markets in Europe and Asia. While efforts to get product to the coasts tend to meet the same fate as Keystone XL – none get approved due to First Nation, environmental, or other opposition – deals could potentially get made with First Nations and among provinces to facilitate such projects. That being said, Canadian producers are not pushing as much for a new pipeline given changes in the market; producers are more hesitant to commit to capacity when they do not know if the growth will be there.

In Canada the oil and gas industry is collaborating in a remarkable way to address public policy challenges and technological opportunities.

The oil and gas industry is collaborating in a remarkable way in Canada in addressing public policy challenges and technological opportunities. The industry is sharing technological developments that can advance the environmental characteristics of oil and gas development; the productivity improvements and cost reductions in the Alberta oil sands have been dramatic. The industry's engagement on public policy is important because the social license for continued growth of oil and gas development in Canada has largely been provided by provincial governments in their environmental policies. For example, British Columbia and Alberta have a carbon tax, while Ontario and Quebec are (or will be) aligned with California's cap-and-trade system. These policies create room for growth and development of oil sands, mostly on the backs of power generators; Alberta, for example, has a provincial plan to phase out all coal generation no later than 2030.

MEXICO

Mexico has instituted significant reforms of its energy sector, the success of which hinge on the private sector driving it and on North American linkages. If the private sector does not lead, the Mexican economy will not be liberalized. As a manufacturing country, Mexico was always at a disadvantage because of its expensive gas and electricity; freeing itself from those constraints could change everything.

Mexico's future will see strong competition between the state productive companies and private companies. A key element of the reform was breaking up the Pemex monopoly on oil and gas, converting Pemex into a special state productive enterprise – a hybrid state-private entity. The minister of energy sets policy, the minister of finance sets the finance terms, and there is a new safety ministry and self-funded regulators. Pemex got to keep a chunk of its existing assets, as a basis for joint ventures and farm-outs. The reform at Pemex, however, has been disappointing; it did not make the cuts it was supposed to, and reforms are not getting done. The first licensing round did not work well, with misjudged values for every project, but there was willingness to listen to industry's concerns, and subsequent rounds have gone better. Deepwater is the big prize for Mexico, but if companies do something wrong, the government can take the project away, which is a big risk – and every element of risk goes into the price. Given the risk, as well as the reporting burden, it is an open question whether Mexican deepwater can compete.

The Comisión Federal de Electricidad (CFE) (English: Federal Electricity Commission) also became a state productive enterprise that is supposed to compete and make a profit like any other company. CFE was divided into different companies, with walls between the different generation subsidiaries. Transmission and distribution will still be a public service, without competition, and CFE remains the only entity providing basic electricity service to consumers under 1 MW, but supply of electricity to users above 1 MW is open to competition. CFE had been reliant on fuel oil (purchased from Pemex) for electricity generation, but as a competitive company trying to make a profit, it is aggressively shifting the fuel mix to substitute natural gas and renewables for fuel oil. There are thousands of miles of new gas pipelines being developed in Mexico and across the US border. Over the next couple of years, CFE alone will

have the capacity to import 8 bcf/d just from Texas; that kind of import capacity could move the market. Costs of power generation in Mexico are also coming down significantly; in 2012, the gap between electricity rates in Mexico and the United States was 84%, whereas in 2016 the gap is 8%. In addition, the first long-term auctions resulted in the most competitive price for solar PV worldwide.

In a short period of time (about 2-3 years), Mexico managed to institute energy reforms, introduce private capital, slash electricity costs, and cut carbon, even though oil prices started tanking just as Mexico opened its markets (which ended up helping the electricity sector). The change from fuel oil to gas and renewables has been driven largely by a desire to make the economy more competitive and to attract investment – and it is working, due in part to an excellent technocratic class. It is an open question whether the Mexico example can be replicated elsewhere; knowing what has to happen and having the political capability and mastery to execute the pivot are different things.

Mexico's future will see strong competition between the state productive companies and private.

This is not to say the Mexican reforms were easy. There were challenges as Mexico instituted and executed its energy sector reforms, including industry resistance, union resistance, and corruption. The Mexican reforms also are not guaranteed to stick. Russia, for example, similarly pursued energy reforms, liberalization, privatization, and private capital in the 1990s, but as a political framework and not a real competitive market framework, the result was concentration and nationalization; the government decided energy was a strategic industry for the state and did not want to allow control of it to leak out to foreigners. Mexico has to make sure it gets the implementation of the reforms – the bureaucracy and rules – right. In addition, the violence issues along the border have been a real negative for people and companies interested in doing business in Mexico. There is also a question about the resilience of the reforms in the face of elections and party changes. If the current party in power remains in power after the upcoming elections, any problems with the reforms will likely be fixed through regulation. If another party takes power, implementation of the reforms may be more uncertain.

NORTH AMERICAN INTEGRATION

The future may involve considering energy on a North American basis. Talk about energy independence and self-sufficiency of any individual country may be myopic. There is already one economic market because of the 1994 North American Free Trade Agreement (NAFTA), so harmonization makes sense.

The "Three Amigos" agreement made in June 2016 among the leaders of Mexico, the United States, and Canada largely sought to harmonize environmental policy in North America, but these days, environmental policy is leading energy policy, and harmonization of energy policy can only improve efficiency. The summit of North American leaders reflected the increasingly integrated infrastructure (e.g., pipeline flows, electricity grids) on the continent and the interest in leveraging the competitive advantages of an integrated North American economy. It also reflected an emerging North American climate and energy partnership, including significant joint commitments on clean energy and reducing methane emissions from the oil and gas system across the value chain.

Integration is driven by both policy and markets. There has been ongoing and long-term integration of energy between the United States and Canada, at least on a regional basis, and there are increasing connections between the United States and Mexico as well. With international borders to cross and infrastructure to regulate and permit, policy (both statutory and regulatory) will have a big role in how an integrated North American energy and environmental approach will work. The United States lifted the crude export ban, and the Federal Energy Regulatory Commission (FERC) has been doing a good job on permitting. Electricity, oil, and gas are crossing borders.

There is enormous opportunity to make energy development and use in North America more efficient for the economy and more beneficial for the environment. Importing clean hydro from Canada into the northern tier of the United States would obviate the need to build many power plants in that area for years. States willing to take Canadian or Mexican renewable energy (e.g., to meet Renewable Portfolio Standards) can reduce their costs and foster greater integration. The short-run answer to the lack of infrastructure to get Marcellus gas to New England could be to transport LNG from the Gulf Coast to New Brunswick, gasify it there, and then transport it in a pipeline that already exists from New Brunswick to Massachusetts (though Jones Act restrictions prohibiting any foreign built or foreign flagged vessel from engaging in coastwise trade within the US would likely have to be addressed). North American integration is an opportunity, but the Three Amigos meeting rhetoric has to translate into action. Structurally, there still is not a North American focus within the US federal government writ large.

The G7 energy ministerial has defined a set of 21st century energy security principles that focus on transparent markets, fuel diversity, greenhouse gas reductions, modernized and more resilient infrastructure, and continued investments in development of energy technologies.

NORTH AMERICAN ENERGY SECURITY

Relatedly, there is a need to broaden the thinking about what North American energy security means in the 21st century. In the 20th century, access to energy supplies was prominent in America's military strategy (whether overt or not), and energy security was basically equated with oil supply security. In the 21st century, energy needs can be met in an increasing variety of ways, with an abundance of North American resources and technologies made possible by decades of innovation, including oil, natural gas, renewable energy, and energy efficiency. This change lets North America ask different questions about security and engage the world in a different way.

Around the globe, the G7 energy ministerial has defined a set of principles on energy security that is focused on transparent markets, fuel diversity, greenhouse gas reductions, modernized and more resilient infrastructure, and continued investments in development of energy technologies (particularly clean energy technologies). Especially for European allies worried about reliance on Russian gas, the principle of energy diversification is key, in terms of both geographic locations of supplies and types of sources and technologies. The lack of diverse supplies is not only a problem for Europe, however. In a connected world, the vulnerability of North American allies translates to North American vulnerability. Energy security underpins national security.

PUBLIC OPINION & EDUCATION

Maintaining the industry's social license to operate is just as important as any technological or policy development and requires attention to both public opinion and education.

THE ROLE OF PUBLIC OPINION & DISCOURSE

There is a very broad range of public opinion in America with regard to energy. Most people are relatively disengaged on energy issues, so long as energy is available and affordable. A significant portion of the American public thinks energy policy ought to be driven by domestic jobs, affordability, and domestic content – period. Others want sources that are affordable, available, reliable, clean, and safe.

Public opinion plays a crucial role in companies' ability to operate – especially in the energy industry. Bland reassurances from corporate spokespeople of the fossil fuel industry that everything will be fine tend not to play well with the public, particularly since the persistent public perception of the industry is that it is greedy, destructive and malevolent. There have been ballot initiatives in US states to restrict oil and gas development, with arguments about protecting kids' health and keeping operations away from people. The Macondo Gulf spill, the Gasland movies, and apparent industry supported attempts to manipulate public opinion have all spurred further shifts in public attitude. Public opinion on energy can also turn quite suddenly as happened with nuclear power following the Fukushima disaster, which was so strong that the German government changed its energy mix policy.

Conversations on energy issues are often driven by hyperbole and rhetoric, and it has gotten worse over the past few years.

Conversations on energy issues are often driven by hyperbole and rhetoric, and it has gotten worse over the past few years. People in academia, industry, the environmental community, and elsewhere that are actually trying to solve for climate change, energy security, economic growth, and the range of other interconnected issues are finding it harder and harder to have a rational conversation with good, trusted sources of information. Industry publications seemingly never acknowledge a problem that a government regulation might need to address. Industry rhetoric (e.g., that environmentalists want everyone to go back to living in caves) is worrisome, and rhetoric from green groups is rarely better. Gas pipeline protestors have started showing up at people's homes, making protests on these issues essentially a moral crusade. The environmental community seems to be coalescing around the "keep it in the ground" mantra, while the energy industry and most Republicans in Congress are still denying the reality of climate change. The rhetoric and polarization undermine the ability to find common ground and build public trust on these issues.

When it comes to fossil fuels, there are three dimensions at play in the world of environmental advocacy: community impacts, climate change, and "keep it in the ground." These dimensions overlap, but they are not identical, so when the industry engages with environmental advocates, it should try to figure out where the conversation and concerns

are coming from. For example, for some development, local community impacts are the primary concern (e.g., truck traffic). Operators in areas that have not seen drilling in a long time have not been sufficiently attentive to community concerns, and their inattention is recruiting supporters to the cause of opposing increased oil and gas production.

A lot of what is driving the politics and public opinion around fossil fuels is the climate issue. Absent real progress on national climate policy (e.g., national cap-and-trade), climate activists have turned to opposing every pipeline and every permit; infrastructure fights and "keep it in the ground" have become the proxy. From a global carbon management perspective, it makes sense to insist on analysis of the compatibility of government-approved infrastructure investments with the global greenhouse gas abatement objectives to which the government has committed. (In addition to climate concerns, the "keep it in the ground" activists are partly driven by broader philosophical theories of social justice, how the economy should be structured, and the like.) The combination of climate and "keep it in the ground" concerns results in significant uncertainty around infrastructure permitting, which could really change the energy outlook. For example, while some view natural gas as a wonderful, abundant fuel that is continually underappreciated and misperceived, growing local and regional opposition to fracking is leading to decisions and policies that the industry is going to have to live with, even if they are based on misperceptions.

The rest of the world, outside of the United States and the OECD countries, may be less bothered by climate change than by energy access or other issues. By 2040, India's population will increase by about 900 million people. Africa's population will increase by more than 1 billion people, and the average age of the population will be 19. Picture a continent of teenagers without food or energy, and the current migrant crisis could end up being remembered with nostalgia. Electricity was a big part of the Arab Spring protests in some countries, and energy access challenges could destabilize the world if unaddressed. Other places, such as China, experienced limited opposition to fossil fuels until the air pollution got really bad and people moved to more of a middle-class existence; even then, to the extent people care about pollution (as opposed to economic survival and growth), scrubbers can solve those problems. The public in Russia is totally ignorant of the climate change issue, and concerns about carbon dioxide or methane emissions are non-existent. The public in Latin America is more concerned about economic burdens and political unrest, though NGOs in some countries are seeking to protect sensitive, biodiverse areas, potentially affecting companies' license to operate.

THE NEED FOR EDUCATION

The level of energy illiteracy in the country is frighteningly high. Most people's formal educations do not encompass energy issues, and they get little (useful or accurate) information on energy from the news or social media. The public value of experts and data is also at low ebb, as has been evident in the Brexit decision and in some of the US political discourse; in some ways, this is a post-factual world. If the goal is to have people make informed energy decisions, they have to be educated about how energy is produced and used and about the pros and cons of energy options. As a democracy, it is important for people to have at least a basic understanding of certain key areas so they can make good decisions.

There are numerous stakeholders engaged in the energy arena, including resource owners, local communities, consumers, environmental protection interests, industry, and government. One or more of them being misinformed can inhibit the thinking needed to make important decisions. The stakeholders with the most responsibility to make sure that correct information is relayed to the rest may be government, the energy industries, and environmental protection interests. These stakeholders should not create artificial walls between each other such that they do not understand the real workings of the energy system. Ideally, the three can agree enough to allow resource owners, consumers, communities, and other stakeholders to make decisions based on information and institutions they can believe in.

Clearly, greater education of the public and decision-makers on energy issues is required. This could include basic literacy on energy as part of the K-12 school curriculum, a citizen-level education effort about fundamental choices

involving energy, and education of decision-makers on energy issues. It is conceivable that some sort of initiative encouraging regions to achieve energy goals could force necessary conversations based on real facts about the energy resources available in regions and about potential paths forward.

Education is needed for the energy sector as well – on how to educate others. When people ask whether fracking causes earthquakes and the industry answers with a categorical "no", that is a technically correct but worthless answer. The industry has also done a poor job of making the moral argument that the world is a better place today because of energy sources such as oil, gas, and coal; the industry may want to consider trying to educate the public more on the moral level than on the technological level.

The level of energy illiteracy in the US is frighteningly high.

Education on energy, however, is a struggle for many reasons. For one thing, a lot of people do not want to be educated on energy, as they have many other things on their minds, including raising their kids, their jobs, other interests, and other issues. Throwing facts at people also may not be an effective solution. Facts tend to be a means to an end, to support some conclusion or interpretation, and they are often offered and received with biases. It is hard to come up with a set of facts on energy that everyone agrees on. There is also a huge trust deficit; people do not trust industry or government – or even the media. Furthermore, many people feel they are already educated on energy, with firm grounds for their positions, so further "education" will have minimal effect. For example, many activists supporting "keep it in the ground" are motivated by the view that every additional dollar spent on fossil resources is going to crowd out at the margin some investments in energy efficiency or renewable energy. Activists opposing fossil fuel infrastructure as a proxy in the climate fight likely cannot be "educated" about the benefits of any particular project, as that misses the bigger issue they are trying to address. Activists who are more on the fringe and are anti-everything will never be educated. People in cities suffering every day from air pollution feel they have already gotten a firsthand education about polluting fuels.

FOSSIL FUELS IN A CARBON-CONSTRAINED WORLD

Most forecasts still see fossil fuels as a substantial part of the energy supply for the next few decades, even in a 2°C scenario. The fossil fuel industry, policymakers, and others have to figure out the role of fossil fuels in a carbon-constrained world.

CARBON GOALS & BUDGETS

Climate change is a global problem, requiring action from all major emitters in a cooperative fashion. Any single country taking action to reduce fossil fuel use (and the associated emissions) is unlikely to be effective. Global fossil fuel demand means emissions will get into the atmosphere somehow. For example, if the United States acted alone and reduced its use of natural gas, that would mean more gas gets exported to, say, China, except then it would have been shipped thousands of miles, adding to its carbon footprint. If, however, that gas is kept in the ground in the United States, then Russia has an oversupply of gas it would sell to China, who will burn it. That is why cooperative global action is required – and why the Paris agreement coming out of the COP21 meeting in late 2015 holds such potential. In the Paris agreement, the countries of the world agreed to try to keep global warming to well below 2°C, and to limit it to 1.5°C if possible. Each country pledged actions to reduce their greenhouse gas emissions and to revisit those pledges every few years.

The route to achieving meaningful emission reductions looks like a double black diamond ski slope, which humanity will have to navigate quickly and cautiously.

Countries have agreed on global goals before without actually meeting them (e.g., the Millennium Development Goals), leading to some skepticism about whether the world is truly heading for a 2°C target. This skepticism is heightened by how challenging it will be to achieve that target, much less a 1.5°C target. To have a two-thirds chance of hitting a 1.5°C target, global emissions have to be zeroed out in six years. That is not going to happen. To have a 50% chance of hitting the 2°C target, some suggest that emissions basically have to be zeroed out in 28 years, which will be hard. Others, such as the International Energy Agency, suggest that to have a 50% chance of achieving 450 ppm and a 2°C scenario, the hydrocarbon budget is 1140 Gt CO2 from 2016 to 2100, more than 60% of which is used up by 2040, leaving 415 GtCO2 between 2040 and 2100; carbon dioxide emissions from fossil fuels have to plummet steeply after 2040 to near zero by 2100. Either way, the route to achieving meaningful emission reductions looks like a double black diamond ski slope, which humanity will have to navigate quickly and cautiously.

That is not the slope humanity is currently on, however. Some current projections for carbon dioxide emissions show the growth rate falling by half by 2035, and some aggressive cases see emissions starting to decline, but all of them fall short of solving the climate problem; to do that, there will have to be unprecedented improvements in the carbon content of the energy mix and in the efficiency with which energy is used in the economy. Many energy forecasts note the growth in energy efficiency, the dramatic improvements in the economics and penetration of renewables, and the like, but they tend not to include the persistent gap between projections and the needed emission reductions.

The physics of climate change require a cumulative emissions budget that will be enforced one way or another. The longer humanity continues its current burn rate, the less space left in the budget there will be. Delay favors the coal industry in the competition for that finite space, as coal is the most carbon-intensive and is used in the longest-lived facilities; every year of delay locks in big chunks of the finite budget for coal, to the disadvantage of the oil and gas industry. (The optimal use of the budget for burning hydrocarbons, for example, is probably to use gas, which can generate 250% more electricity than coal within the same carbon budget.) It is strange that there is not more of an effort in the industry to embrace its role in the energy future and incentivize competition to engineer the lowest-carbon fossil fuel complex possible; it seems like a missed opportunity not to have some kind of carbon intensity competition within the industry. In addition, although the oil and gas industry's climate strategy for decades has been to delay climate policy for as long as possible, the industry may need to recognize that it is in its interests to put some political weight behind policies to rapidly reduce the carbon burn rate, preserving space in the carbon budget and advantaging its fuels versus coal.

CARBON TAX PROSPECTS

Some fossil fuel companies have internal prices on carbon that they use to rank projects and investment. They may need to start meeting more with their members of Congress and saying publicly that putting a price on carbon is important for the development of free enterprise, the economy, and their companies. It is also possible that a national carbon price (and other climate policies) could extend the industry's social license to operate.

Republicans who think climate change is real and human-caused may be the most important people on the planet. The left in US politics has gone about as far as it can go; there is a need for conservatives to act on climate. The environmental left does not understand the amount of rejection it faces on the political right. The left thinks it is being nice and helpful, but its members are perceived as being guilt-trippers who want everyone to walk and eat bugs. Climate change has come up in the US conversation in the worst possible way for conservatives: the UN got together with godless scientists, government bureaucrats, and intellectual elites. Conservatives want no part of that. There is such distrust that even when the military – generally revered by conservatives – asserts that climate change is real and a threat to the country, conservatives perceive the military as kowtowing to the White House. Apocalyptic narratives and big government solutions turn off half of the potential audience. Each side totally underestimates how locked down the other is. Social science indicates that people will cherry pick science and information to support their pre-existing values and ideologies, which means it is important to look to social science for ways to create common ground and a bigger tent.

A carbon price is necessary and useful, but it is not a universal elixir.

Polling suggests that big majorities of Republican Millennials take climate change very seriously, but politicians tend to be trailing indicators; American politicians are still stuck on old talking points on climate change. Some Republicans have said climate change is hooey simply because Al Gore was for it. The question now put to Republican members of Congress is whether they believe in climate change (as if it is a question of belief, not data), but if they answer yes, they cut themselves off from the current Republican base. It may be better to ask a different question, such as whether free enterprise can solve climate change. A message focused on internalizing negative externalities and revealing hidden costs could appeal to conservatives, especially if a carbon price could get rid of policies such as renewable energy subsidies. (Some argue that it may be possible to achieve 2°C, and perhaps 1.5°C, at a cost trillions of dollars lower than business as usual, driven by cheap efficiency and renewables; this could allow for an easier climate conversation focused not on cost, burden, and sacrifice, but rather on profits, jobs, and competitive advantage.)

Some conservatives (outside of government) are promoting a revenue-neutral, border-adjustable carbon tax. Revenue-neutral means cutting taxes somewhere else or giving money back to the people via dividends. Border adjustable

means the tax would be removed on exports and imposed on imports if the country of origin did not have a similar price. The United Nations would not have to do anything; this would be unilateral American action that could be winnable if challenged under the World Trade Organization (as a content tax). Other countries would likely follow suit, preferring to have the tax remitted to their capitals than to DC. According to some working to achieve progress on Capitol Hill, there could be a dozen or more Republican Senators and perhaps 50 Republican members of the House who would support a revenue-neutral carbon tax if given enough political cover to be able to withstand whatever backlash may come. They need well-known conservative media figures and companies in their districts to express their views that it is good to have a price on carbon.

A carbon price is necessary and useful, but it is not a universal elixir. Even if there is a price on carbon, there will continue to be a need for companion policies that work to address problems that are not easily addressed by a price. There are so many market conditions and market failures that unless the carbon tax is huge, it may not incentivize much innovation or change in investment. In addition, the track record so far suggests that regulations, performance-based measures, tradable credits, vehicle standards, and many other types of policies are turning out to have more impact on reducing emissions than a carbon price. The United States, for instance, focuses on regulations and incentives. The Production Tax Credit for wind in 2014 had a rough value of around $60/ton. Net metering in California is equivalent to a carbon price around $90/ton. These other measures may not be the most economically efficient way to proceed, but they are more politically acceptable (because the price is more hidden) and – so far – more effective.

NATURAL GAS IN A LOW-CARBON POWER SECTOR

Natural gas has been rising in power generation, largely at the expense of coal. In 2015, about 31% of natural gas went to residential and commercial users, about 30% to industrial use, and about 39% (a big jump) to power generation. Around 2015 or 2016, natural gas became the leading source of electricity generation in the United States, helping to spur tens of millions of tons of carbon dioxide emission reductions in the power generation portfolio; natural gas has begun displacing coal globally as well. Projections are that natural gas will grow to account for 40% of power generation by the middle of the next decade.

It may be unrealistic to think that fossil fuels will not be a big part of the power industry going forward, but this is the most conservative, risk averse industry in US economic history, and events are sweeping past it. Natural gas may or may not end up as the king of the new power system; market trends, non-market forces, and public concerns could keep gas from being the dominant fuel of the century.

Projections are that natural gas will grow to account for 40% of power generation by the middle of the next decade.

For example, power load growth in the industrialized world is basically flat, due in part to energy efficiency, demand response, and grid optimization. The existing infrastructure involves power lines and power plants designed to meet the needs of the hottest summer day in any particular location, but decreases in the cost of wind, solar, and storage will lead to greater proliferation of renewables and distributed generation, a much more decentralized grid, and a materially different shape of power load than in the past. Already, more than half of all incremental generational capacity in 2015 was renewable energy, which is competitive and getting more so. The role of natural gas power plants in the power sector may therefore be changing. In states with lots of solar covering mid-day loads, natural gas plants will need to ramp steeply to address loads as solar goes offline later in the day. (Batteries can play a role in addressing that load as well.)

Gas can be a bridge to the low-carbon future, but it is possible the bridge may not be as long as once thought. The US Environmental Protection Agency's Clean Power Plan (CPP), which will likely be effective starting in 2022 (if upheld by the courts), was projected to be great for gas in the US fuel mix, but in combination with the renewable

energy tax extenders passed by Congress at the end of 2015, gas is projected to get crushed. The competitiveness of gas in the United States (and elsewhere) is highly price sensitive, and the subsidies for solar and wind make a huge difference in the amount of gas versus renewables involved in CPP compliance. (The CPP will likely have little real impact on coal plants, which are already shutting down due to cheap shale gas and pre-Obama EPA regulations such as the NOx emissions standards). Even given these dynamics, the CPP has a long enough glide path that it will not jeopardize reliability.

LNG

The ways North American natural gas might help address climate change need not be confined to North America. Cargoes of North American LNG have been shipped all over the world in 2016, and a lot of countries have or are considering LNG import facilities. LNG exports allow the world to access the efficiency, pricing, and fuel-switching benefits that the United States has experienced, and a large build-out of US export capacity is underway, mostly along the Gulf Coast. In addition, floating gas capacity is starting to be brought online around the world, which allows for quick responses to market needs and reduces the risk of stranded assets, as it is scalable and flexible and can be redeployed to other parts of the globe as needed.

The industry, however, needs to work to better present LNG as part of the climate and environmental solution set. The same environmental groups that supported LNG several years ago are now resisting it at every turn, and the activists fighting fossil fuel infrastructure include development of LNG export facilities among their targets.

Even with low gas prices, there is a global market for US LNG, but it is a tight market. Small changes in gas prices have a big impact on US gas demand and on global demand for US LNG exports. The LNG community is banking on Pakistan, Egypt, Jordan, and other countries for demand. LNG proponents, however, may be underestimating how difficult it could be to create global demand for natural gas. Other governments want natural gas, but they are starting to see how complicated, messy, and historically unpredictable natural gas markets are, as well as how much infrastructure is needed. The US natural gas system – the gathering, transmission, processing, and storage systems, as well as sophisticated participants in wholesale and spot markets – developed over decades, and there is nothing else like it on the planet. Many countries have small governments with small energy teams, and they may lack understanding of natural gas markets. It is difficult for them to build new infrastructure to receive and distribute the fuel, implement tariffs, and generally build the entire system necessary. Natural gas may very well have a bright future globally, but it may be challenging to develop the demand pool for it.

ADDRESSING METHANE

Addressing methane emissions from oil and gas production and use is key to capturing natural gas's potential climate advantage, and companies increasingly are seeing methane as a reputational issue.

Natural gas is composed mostly methane – a greenhouse gas many times more powerful than carbon dioxide. About a quarter of the warming the planet is experiencing today is associated with methane emissions, and the oil and gas industry is a big source of them. Big leaks, such as from the natural gas storage facility at Aliso Canyon, may get headlines, but small leaks in the system can add up to big climate impacts. A leak rate of 2.7% across the entire natural gas supply chain, from well to burn, might undo all the climate benefits of coal-to-gas substitution (though the precise leak rate that would have that effect is somewhat disputed).

There is a debate in the United States about how much methane is currently being lost in the oil and gas value chain. Some studies show the national leak rate to be between 2% and 2.5%, and studies have shown that official government statistics are understating the problem. The EPA restated the official inventory in April 2016, raising it by 34%,

and it may still be understated. Measurements can be done at the field level and via aircraft with methane detection equipment. Field measurements have made clear that many facilities have no evidence of leaks at all – illustrating that zero leakage can be achieved – and that a relatively small number of sources are responsible for a relatively large fraction of emissions. Older equipment in the field can be problematic.

Companies often think they do not have a problem, as they do not manage what they do not measure. As a practical matter, though, equipment malfunctions occur in the natural gas system, the technologies and practices to address methane issues are readily available, and low-cost programs to go after low-hanging fruit make sense. Problems (e.g., malfunctioning valves) are only found if companies go look for them, such as with infrared cameras that can detect hot vapor (which may or may not be methane, but the cameras at least identify the need to fix the system's integrity). Retrofitting some facilities and finding and fixing leaks could have a major impact on slowing the rate of warming in the near term. Regulations to change out older equipment and do systematic leak detection and repair can spur improvements and present opportunities for technological innovation. (It can be challenging to wrap methane into a carbon tax, though, as it is hard to precisely monitor, measure, and verify the reductions.)

The Obama Administration has committed to a 45% reduction in oil and gas methane emissions by 2025, but this is not just an American concern. Canada and Mexico have now made commitments as well. More work also has to be done to engage Russia and Europe on these issues, address flaring in Nigeria, and tackle other related challenges around the globe.

Overall, the industry is tilting toward being more responsible and better stewards of the environment, though some operators do a better job than others. There are also environmental impacts beyond methane and climate change to consider. For example, the impacts of natural gas development on water are critical. In addition, there are clear air quality benefits from substituting gas for coal. Climate change may have taken too much of the spotlight within the environmental movement, as opposed to improving the environment in terms of all pollutants and all impacts.

CCS

Carbon capture and sequestration (or carbon capture and storage, CCS) technology matters because of the climate change math. There is not much left in our carbon budget, and humanity is burning through it quickly. Humanity needs to start reducing emissions a lot faster than it will stop using fossil fuels, so CCS may be essential – especially to deal with the coal and gas fleet built over the past 10 years that is likely to operate for 40-50 more. It is also hard to scrub carbon emissions from some parts of the economy, such as steel, cement, and heavy industry, and CCS is good for those parts; the industry should push ahead more on industrial CCS. Without CCS, the chance of hitting a 450ppm target is less than 50%, and if the target is hit, the cost would be more than double. CCS can substantially reduce the rate at which humanity is spending its carbon budget.

There are already 15 CCS projects in operation around the world, and 7 more are under construction, which means 22 operating by the end of the decade, capturing 40 million tons per year. That is more than most people are aware is occurring, but it is nowhere near enough. There is a need for 100 times more than that in the next 25 years, mostly in non-OECD countries.

The prospects for CCS are dim because it is not the cheapest carbon mitigation option on the table today.

The most familiar CCS project for many Americans is the Kemper plant, which is radically over budget. The things that have gone wrong with Kemper have almost nothing to do with carbon capture itself and more to do with proceeding on a project without having the requisite engineering done in advance, but it is still bad publicity for CCS. The prospects for CCS are dim not because every project will have cost overruns like Kemper, but rather because CCS is not the cheapest carbon mitigation option on the table today. This is a classic

challenge in carbon mitigation: if one focuses only on what is cost-effective within the next five years or so, the gains in reductions will only be incremental, falling short of the long-term deep decarbonization goals. There is a need for a clear sense of the target and what is needed to get there.

While CCS is not the cheapest carbon mitigation option, it also is not the most expensive. The levelized cost of energy for CCS with coal or with natural gas combined cycle plants is already price competitive with or cheaper than some other options, including offshore wind, utility solar thermal, nuclear plants, and rooftop solar. CCS has not advanced, however, because it has no Investment Tax Credit, Production Tax Credit, low-carbon portfolio standard, or other substantial policy support. Many organizations, including the UN, have called for policy parity and support for CCS, but there are no political consequences for saying no to CCS (unlike renewables, gas, and others). While the oil and gas industry has shown leadership on CCS, making substantial capital and technological investments, its response to reports, Presidential budgets, or proposed bills that call for substantial tax credits for CCS has been non-existent; the industry has to come forward and say these are good ideas. (CCS is not alone in being a climate solution lacking support; nuclear power plants in competitive markets are not getting the price signals or policy support needed to stay open.)

Progress has been made on CCS, but liftoff is needed – and that requires spending money. Whenever one looks at infrastructure that has to be put in place, scale must be considered. Deploying hundreds of millions of dollars is difficult and takes a long time, whereas millions or tens of millions of dollars (e.g., for low-cost solutions such as energy efficiency) can find their way to market faster. As was learned with FutureGen, when it comes time for the big check, the government determines that it has higher priority uses for half a billion dollars and pulls the plug. The high capital costs of CCS slow deployment and the rate of innovation; CCS does not look like a substantial, cost-effective contributor to carbon reductions in most near- or mid-term projections. Getting the costs down may require focusing on modular systems that can ship anywhere in the world and take advantage of economies of scale from mass production.

If the industry does not make this kind of progress, it risks following what happened to coal, which lost 95%-98% of its market capitalization in about three years because the assets were overvalued. With CCS deployment, the runway for fossil fuels is extended.

THE LOW-CARBON TRANSITION

Some big oil and gas companies are starting to assess what will be needed to accomplish a 2°C scenario, but not enough are thinking about adjacent businesses they can move into or what aspects of their businesses require wholesale changes in culture and operation.

The transition in the energy sector, though, is already well underway, with disruptions taking place across the globe. Looking at decades-long scenarios makes the transition look smooth and orchestrated, but the reality of transitions in specific places and in shorter timeframes is that they are very rocky and disruptive, with winners and losers along the way.

Transitioning to a low-carbon energy future will involve overcoming some significant disconnects that currently exist. For example, demand projections will have to fix faulty assumptions, such as failing to take into account fossil fuel demand destruction due to energy efficiency, demand response, renewables policies, carbon pricing, or other factors. Business models will also have to be reassessed; major oil and gas companies still spend the vast majority of their budgets on oil and gas projects, but the model of focusing on reserve replacement ratios and finding and proving up as many reserves as possible will not work in a carbon-constrained environment. If humanity even gets close to achieving its climate targets, vast fossil reserves may be stranded. At some point, Wall Street will have to stop rewarding companies for replacing reserves, and climate change risks will have to be assessed in credit ratings, factoring in the increased costs, policy and regulatory uncertainty, and necessary business model adjustments for companies in

a world with materially reduced greenhouse gas emissions. By the time climate change becomes a defining issue for financial stability, though, it may be too late.

Making the low-carbon transition may also require decarbonization policies to become less myopic. Many policies are focused on spurring renewables but not on, say, increasing the efficiency of fossil fuel power generation. The question ought to be how to achieve deep cuts in greenhouse gas emissions while sustaining economic growth, enhancing energy security, and bringing modern energy to the billions who lack it. If natural gas can be a solution in that framework, it ought to be considered, but the industry has to give people reason to believe natural gas is an answer. Policies should also provide signals to say that the industry ought to be investing in low-carbon energy solutions as a service; the industry could make more money if it thought of energy efficiency in the industrial area as a well it wants to drill, funding machinery upgrades in joint ventures with industrial companies. To accomplish these types of policy changes, the industry has to work closely and proactively with policymakers – something it tends to assiduously avoid.

If humanity even gets close to achieving its climate targets, vast fossil reserves may be stranded.

In addition, the low-carbon transition will require increased investment in low-carbon research and development. The day before COP21, President Obama and 19 other leaders announced Mission Innovation, an agreement to double clean energy R&D spending over the next five years. This would mean greater availability of patient at-risk capital to invest in the early stages of technologies; these are long bets, only some of which will pay off. On the same day, Bill Gates and a group of private investors announced the Breakthrough Energy Coalition, pledging billions of dollars in R&D support over the same time period.

An essential part of the low-carbon energy transition for the energy industry (and for agencies) will be getting the human capability right. There are a lot of retirements happening, and it is hard to ensure the continuation of an educated, knowledgeable workforce that has the particular skills needed as the industry evolves. Attracting people is even harder when, due to low prices, the industry is not paying as much as it did years ago. Individual companies and the industry as a whole need to have forethought about the organizational capabilities they will need as the transition occurs – what they can accomplish with the capabilities they have now, which capabilities they can buy, which can transition, and which cannot go along into the future.

TECHNOLOGY & INNOVATION

Technological innovation in power, transportation, and other areas may well have been more impactful over the last few years than geopolitical or regulatory developments, and innovation will continue to drive a rapidly changing energy system transition. Companies will have to leverage technology to deal with plummeting and volatile prices, major capital projects, crew changes, low-carbon imperatives, safety, remediation, and much more.

TECHNOLOGY & INNOVATION IN OIL AND GAS

Technology adoption in the oil and gas sector tends to be slow, as operators that have been doing the same thing for decades tend to resist adopting new technologies. The longer prices stay low, however, the greater the appetite will be to adopt new technologies. The technology space in oil and gas currently is seeing new players, many startups, some venture capital financing, and lots of innovations targeting industry, many of which focus on cost, simplicity, and speed – things that are not usually industry strengths.

Some innovations in the oil and gas space involve chemistry, materials, downhole tools, water technologies, and basic process improvements, but a lot of entrepreneurs are heavily focused on digital disruption. Machine learning has become mainstream, data analytics has become huge, and mobile devices and services are a key focus. Entrepreneurs are not cracking the nut on any one thing so much as they are pulling different pieces together and bundling them into digital oilfield offerings. There are innovations, for instance, related to remote monitoring and remote assistance for operators; companies cannot afford to have experts in the field all the time, so having remote dial-an-expert capability is a way to bring costs down while becoming a more reliable operator. Drone companies are also offering to fly relatively inexpensive camera-equipped drones within derrick structures to check for safety problems. In addition, there are software companies helping drillers drill more efficiently by training software, through machine learning, to better guide a directional bit through different types of rocks and parameters. Other startups are providing digitized business-to-business connections for oilfield companies. As digital and data analytic solutions keep coming into oil and gas, there will be continued innovation and improvement in costs.

There are numerous other technological needs within the industry. For instance, many companies are going out of business and abandoning wells, which means there are many places with very large remediation costs; technologies to clean up old wells and facilities in responsible ways for the environment could reduce billions of dollars in remediation costs for industry. (Some innovations are indeed trying to push the envelope on abandoned wells, such as companies promoting use of expanding metal instead of concrete to plug wells.) It will also be important for the industry to identify and pursue technologies that will allow it to thrive in a low-carbon energy future. New technologies could include advances in energy conversion (e.g., solid oxide fuel cells), products that create markets for natural gas beyond combustion (e.g., graphene production via chemical vapor deposition), and new processes to make existing products (e.g., going directly from methane to ethylene and liquids).

When getting into a new business or deploying new technologies, companies have to understand their competitive advantage and timing. Companies may need to buy wisely from vendors, jointly develop technologies, or acquire other companies. When technology innovation happens faster or slower than forecast, however, there can be winners and losers; companies can get in the game at the wrong time. Furthermore, to make a difference, innovation generally has to think about systems change (which can be really slow) as opposed to single widgets. Companies need to have portions of their organizations dedicated to thinking through all pieces of the system and the various timing issues involved in deploying new technologies.

Regulations can pose additional obstacles to technology adoption in the sector. For instance, the Federal Aviation Administration's caution about drones is understandable, but it inhibits potentially beneficial uses of drones in the industry. Regulations restricting uses of produced water are another example, as they hinder deployment of technologies that can help with water purification. These regulations too, however, are understandable. There is a great deal still unknown about what the contaminants are in produced water, what public health standards should be for those contaminants, and how to treat them. There is much more science needed on these questions before a permit for discharging produced water to agriculture can assure protection of public health and the environment.

TECHNOLOGY & INNOVATION IN TRANSPORTATION

Three-quarters of all oil goes to transportation. On a systems level, there was almost no innovation in the transportation sector for decades, but there are now dramatic innovations and changes occurring with the potential to transform transportation demand and the transportation system. The three biggest such innovations are vehicle electrification (including both electric vehicles and hydrogen vehicles), shared mobility (beyond Uber and Lyft), and automated vehicles (which could have large positive or negative impacts, but likely not for a while). These three innovations have the potential to revolutionize the transportation sector, but their success or failure will be heavily influenced by policy.

The fuel economy of vehicles, particularly in the United States, was flat for decades, but that started changing around 2008-10. New internal combustion engine vehicles have seen about 4% improvement per year in fuel economy, and the 2025 vehicle standards make it likely that new vehicles' fuel consumption will basically be cut in half over a 15-year time period. Those savings are all with gasoline, not with electric vehicles or biofuels; the savings will come from lightweight materials, better combustion, better transmissions, and the like. Beyond 2025, the 4% annual improvements will probably continue but will come from a gradual transition in vehicle technologies toward electrification, including gasoline hybrids, plug-in hybrids, pure battery electric vehicles, and fuel cell vehicles. This trajectory will likely occur not just in the United States, but in all OECD countries and much of the rest of the world.

The three biggest innovations in the transportation sector are vehicle electrification, shared mobility, and automated vehicles. These three innovations have the potential to revolutionize the transportation sector.

Battery costs are dropping sharply. Not too long ago, batteries were around $1000-$1200 per kWh, but will soon be around $200, which is a dramatic change. At the same time, there has been steep growth in global EV sales, though EVs still make up only about 1% of sales. While EV sales in the United States have been relatively flat for the last couple of years (though starting to rise again), EV sales in China have gone way up; China sold more EVs in 2015 than the world did in 2012.

Energy forecasts have underestimated EVs so far, and they may be underestimating the future of EVs as well. Forecasts have to be humble on how technology will evolve; technology can move faster or slower than expected. It is possible, for instance, that there could be huge annual growth in EVs, yielding significant oil savings within the next few years, driven by policies and technological gains. EV adoption could potentially be driven even faster by a range

of other factors, including ultra-lighting, fee-bates (where those buying inefficient cars pay a fee that funds subsidies for those buying low-carbon vehicles), monetization of the grid services EVs can provide, shareable autonomous mobility services, and India and other countries considering massive EV deployment by 2030. Historically, fuel substitution can happen rather quickly. For instance, diesel dominated new sales of trucks in the United States within 20 years, and the same basically happened with diesel-powered locomotives in North America. Since transport is basically the one place that oil still has a monopoly, a surprise regarding EVs could certainly be very consequential.

As noted earlier, technology can surprise on the downside too, as in the case of advanced biofuels, which have underperformed. The policies developed to promote biofuels did not incentivize or require oil companies to invest in biofuels – though oil companies may be the only ones with the capital and expertise to truly make advanced biofuels work – so while the companies dabbled in biofuels, they decided they did not need to do it. There are niches where biofuels will make sense, and niches where they will not. There likely will not be much use of biofuels in light-duty vehicles, but if carbon concerns are to be addressed, advanced biofuels may be needed in aviation and long-haul trucking. (Similarly, natural gas is expected to be a niche fuel in the transportation sector, used a bit in heavy-duty vehicles.) Advanced biofuels are likely to be more expensive than fossil fuels for a long time, which means interest in them really comes down to greenhouse gas emissions.

Energy forecasts have underestimated EVs so far, and they may be underestimating the future of EVs as well.

Projections aside, spurring greater efficiency and alternative fuels at a time of low oil prices is a big challenge, and policies and consumers will play huge roles in determining the future of transportation. When the gap between the market and regulatory programs is large, problems arise, and fuel economy standards are currently getting out of alignment with markets and consumers. Americans are currently buying SUVs as if they have no idea (or concern) about the potential for oil prices to explode as markets adjust. Fuel economy standards are averages for different vehicle footprints, so if consumers shift to bigger cars, that could undermine the rules' effectiveness. Similarly, if consumers do not choose EVs, whether because of cost, range anxiety, or other reasons, the future could look very different than some are projecting. If the regulatory goals are to be achieved, something is needed to align the price and market signals with the regulations. Carbon taxes alone will not be enough to achieve that alignment, but feebates might align market signals, though they will be politically challenging to enact.

APPENDICES: AGENDA

WEDNESDAY, JULY 6

9:00 – 9:30 AM	**Introduction**	**David Monsma**, Executive Director, Energy and Environment Program, The Aspen Institute
	Co-Chairs Welcoming Remarks	**Mary Landrieu**, Senior Policy Advisor, Van Ness Feldman, and **Marvin Odum**, Former Chairman and President, Shell Oil Company
	Global Forum Look-back	**Bill White,** Chairman, Lazard Houston, Lazard Freres & Co. LLC
9:30 – Noon	**SESSION I: Global Energy – Trends and Forecasts, Supply and Demand**	
	Presently the global price for crude oil has risen slowly for several months, as demand continues to increase, supply disruptions escalate, and storage appears to edge ever closer to capacity. How have low oil and natural gas prices impacted production and demand and what do projections for future supply and demand look like?	
	Moderator: Marvin Odum	
	Discussants:	
	Global Energy Outlook	**Mark Finley,** General Manager, Global Energy Markets and US Economics, BP
	Emerging Trends in Global Energy Markets	**Jason Bordoff**, Professor, Professional Practice in International and Public Affairs, Founding Director, Center on Global Energy Policy, Columbia University
	Overview of North American Midstream and Storage	**Jim Teague**, Chief Executive Officer, Enterprise Products Partners LP
	Where the Rubber Meets the Road: The Convergence of Power and Gas	**Pat Wood**, Principal, Wood3 Resources
	The Future of Energy Use: Insight to Stakeholder Response	**Dan Domeracki,** Vice President, Government and Industry Relations, Schlumberger

1:30 – 4:30 PM **SESSION II: Regional Impacts**

The impacts of regional and national issues impact energy markets around the world. What will the impacts of low Chinese GDP growth, decreased energy demand growth in China and elsewhere, and continued lower oil and gas prices mean for the world markets?

Moderator: Jack Riggs, Senior Fellow, Energy and Environment Program, The Aspen Institute

Discussants:

The Utility Business Model – The Future is Now	**Sue Tierney**, Senior Advisor, The Analysis Group
The Future of the Utility Industry	**Stuart Hemphill**, Senior Vice President, Customer and Operational Services, Southern California Edison
East Asian Energy Demand	**Anthony Yuen**, Global Energy Strategist, Commodities, Citi Research
Russia	**Tatiana Mitrova**, Research Scholar, Center on Global Energy Policy, Columbia University
The Middle East	**Meghan O'Sullivan**, Professor, Practice of International Affairs; and Director, Geopolitics of Energy, Harvard University's Kennedy School of Government
Mexico Energy Reforms	**Eugenio Herrera**, Chief of Staff of the General Director, Federal Electricity Commission
South America and the Caribbean	**Steven Crowell,** President and Chief Executive Officer, Pluspetrol Resources Corporation

THURSDAY, JULY 7

9:00 – NOON **SESSION III: The Current State of the North American Oil and Gas Industry**

Two years of lower oil and gas prices have caused lower rig counts and decreased production. What is the long term impact of the current pricing downturn on exploration, production, and supply of oil and natural gas? What are the traits of companies that could emerge stronger as prices begin to increase?

Moderator: Mary Landrieu

Discussants:

Capacity of the North American Oil Field Service and Midstream Industries To Recover	**Bill White**, Chairman, Lazard Houston, Lazard Frères & Co. LLC

Canada – Production and Exports	**Gordon Giffin**, Partner, Dentons LLP
Venture Capital in Oil & Natural Gas	**Adam Lasics**, Senior Director, GE Ventures
Mexico	**David Goldwyn**, Chairman, Atlantic Council Energy Advisory Group

8:30 – 11:30 AM **SESSION IV: Fossil Fuel in a Carbon Constrained World**

What are ways that global energy companies, particularly oil and gas companies, can contribute to the low carbon future. How will carbon pricing and partnerships on issues such as methane reduction, impact fossil fuels? What is the likelihood of a carbon price in the US in the coming years, and what might that look like?

Moderator: Marvin Odum

Discussants:

The Prospects for a Carbon Tax	**Bob Inglis**, Executive Director, republicEn.org
Finding Common Ground: NGO/Industry Partnerships	**Mark Brownstein**, Vice President, Climate and Energy Program, Environmental Defense Fund
The Launch of CCUS	**Julio Friedmann**, Senior Advisor, Energy Innovation, Lawrence Livermore National Laboratory
LNG for Efficient and Cleaner Power	**Anatol Feygin**, Senior Vice President, Strategy and Corporate Development, Cheniere Energy, Inc.
Implementing Paris	**Paula Gant,** Principal Deputy Assistant Secretary, Office of International Affairs, Department of Energy

FRIDAY, JULY 8

8:30 – 11:30 NOON **SESSION V: The Energy System Transition - Looking into the Future**

Technological innovation, combined with policy decisions and markets, have resulted in a rapidly changing energy system transition. The cost of low-carbon alternatives, both for electricity and transportation, have dropped faster than forecasts in recent years. What drivers of supply and demand could result in surprises in the next decade? What will the global energy market look like in 10 years? In 30 years? Who is well positioned for the future – who is not – and why? What are the breakthrough technologies on the horizon that could pave the way for the energy system transition?

Moderator: Mary Landrieu

Discussants:

Industry Technology and Innovation	**Barbara Burger,** President, Chevron Technology Ventures

The Future of Oil and Gas Markets	**Rusty Braziel,** President and Chief Executive Officer, RBN Energy
Natural Gas in a Low-Carbon Energy World	**Mark Boling**, President, V+ Development Solutions, General Counsel and Secretary, Southwestern Energy
Trends in Vehicles and Fuel Use and the Future of Transportation	**Daniel Sperling**, Founding Director, Institute of Transportation Studies and Professor, Department of Civil and Environmental Engineering, University of California, Davis

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