Welcome to the FORCES newsletter

Fall 2016

Welcome to the fall 2016 issue of the FORCES newsletter. This issue examines energy markets, a topic very near to FORCES researchers' interest. The topic is also relevant to this current moment in time, as new technologies push changes in the way we provide energy to populations worldwide. As markets in China, Europe, and the U.S. (including California, one of the largest economies in the world) move to create alternatives for consumers and investors, they must also ensure reliability and security for such an interconnected industry. One of the goals of FORCES is to understand how these changes operate in real time as well as ways to provide incentives that motivate users to make informed choices that not only benefit them but also promote the common good.

I'm also very pleased to include a commentary from FORCES industrial advisory board member Karen Fireman, who provides a unique analysis and history of recent boom and bust activity in oil energy markets.

Thanks very much for taking time to read the FORCES fall 2016 newsletter. As always, if you have feedback, comments, and suggestions I'd appreciate hearing from you.

S. Shankar Sastry
Professor and Dean of Engineering
University of California, Berkeley

RESEARCH SPOTLIGHT

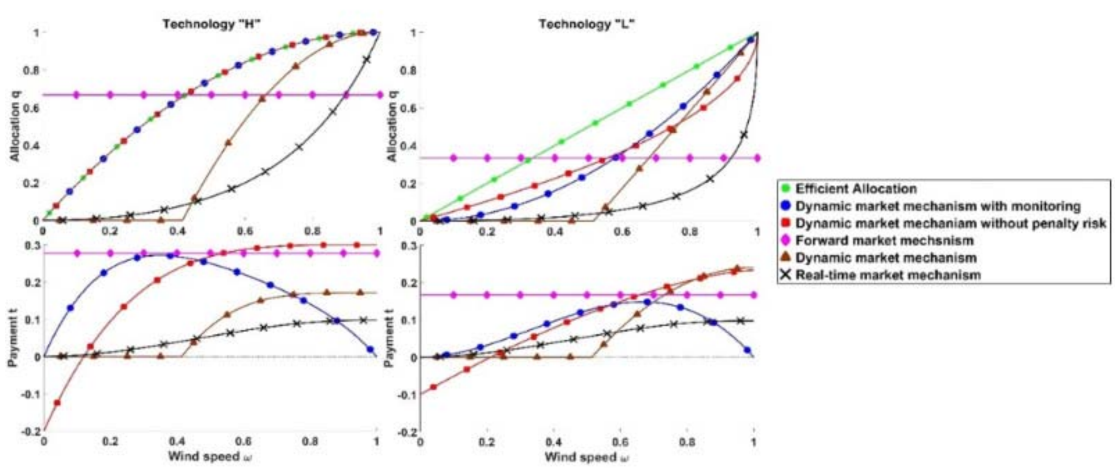
Dynamic Market Mechanisms for Wind Energy

by Hamidreza Tavafoghi and Demos Teneketzis (University of Michigan)

Wind generation is intermittent and uncertain. A wind energy producer does not have complete control over her generation in advance and dynamically learns about her generation capacity and wind condition over time. However, the current two-settlement market architecture, which consists of forward markets and real-time markets, is mainly designed for conventional generators assuming that they have (almost) perfect knowledge and control over their generation in advance. Therefore, the integration of wind generation into electricity markets is a challenging task due to the stochastic and dynamic nature of wind energy.

Currently, two common practices for the integration of wind generation is to include them either in real-time (e.g., the U.S. markets) or forward markets (e.g., the U.K. markets). However, each of these practices has its own limitations and drawbacks. Real-time markets were originally designed to compensate for the mismatch between load forecast and load realization in real-time. However, as real-time markets comprise just 3-5% of total electricity markets, the inclusion of wind energy in real-time markets is only feasible for a low share of overall wind generation, causing stability and reliability issues for higher shares of wind generation. The inclusion of wind energy in forward markets requires wind producers to make commitments without knowing their exact generation capacity, does not take into account the information that arrives after the forward markets close, and exposes the wind producers to penalty risks.

In our recent FORCES work, we are studying the problem of market design for wind energy. We propose a dynamic market architecture that addresses the intermittent and dynamic nature of wind generation, and use that to determine a set of dynamic mechanisms for wind energy procurement that provides a coupling between real-time and forward markets over time. We show that the dynamic mechanisms outperform the real-time and forward mechanisms, and in this way we demonstrate the advantage of adopting dynamic mechanisms over static mechanisms for wind energy procurement. The proposed dynamic mechanisms provide a richer space of market allocations than forward and real-time markets, allow for flexible generation of wind energy, incorporate all the information that arrives over time, and provide forward commitment of wind producers.



An example of dynamic vs. real-time vs. forward market mechanisms

We also characterize the effect of wind monitoring and penalty risk on the market outcome. It has been shown in the literature that with an increase in the share of renewable generation, electricity markets become more susceptible to market manipulations. Therefore, it is important to analyze the effect of various market regulations and monitoring rules on market outcome. One of the main monitoring instruments for wind energy is monitoring wind condition over time. In our work, we show that wind monitoring reduces the incentive payment made to wind producers and improves the market outcome. Furthermore, we show that a market mechanism that shields the seller from any penalty risk results in a lower market outcome if the wind condition is not monitored.

Privacy-Differentiated Service Models and Optimal Privacy-Preserving Schemes

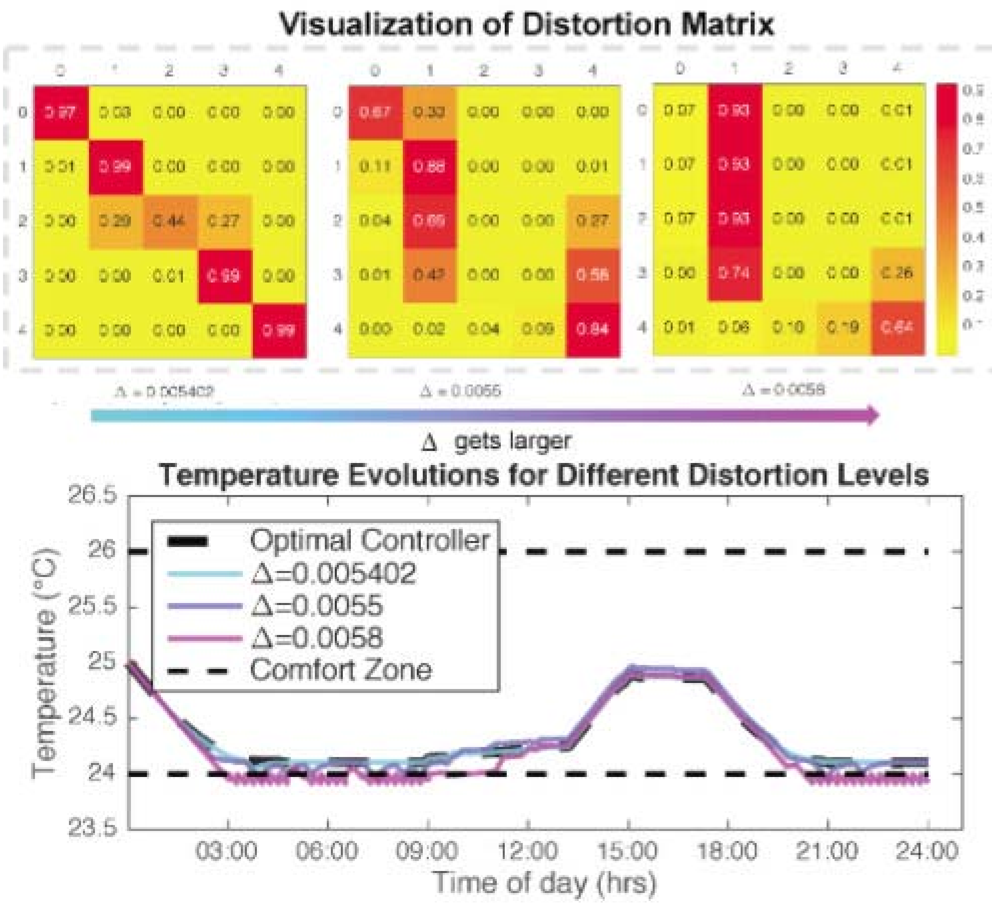
by Roy Dong (University of California, Berkeley), Ruoxi Jia (University of California, Berkeley), Lillian Ratliff (University of Washington), S. Shankar Sastry (University of California, Berkeley)

Advanced metering infrastructures (AMIs), smart appliances, and network-ready home automation devices have enabled entirely new forms of demand-side energy markets. These markets are facilitated by CPS connectivity, and, furthermore, derive most of their operational benefit from consumer engagement and awareness. To understand the effects of these new service models on the energy grid as a whole, we need to consider the incentive structure of these models.

In our work, we consider privacy-differentiated energy programs, which allow users to vary the granularity of energy consumption data collected by AMIs. This mirrors several privacy-differentiated service models already emerging in other infrastructures: car insurance companies are offering different plans to users who attach an accelerometer and GPS sensor to their vehicle, and Internet providers are offering lower rates to users who allow their Internet packets to be examined and used for targeted advertising.

We have shown that the naive design of these new service models may not provide any operational benefit if the users have hidden preferences and behave strategically. The contract design must take into account incentive compatibility and individual rationality constraints. In our work, we design incentive compatible contracts, and can quantify the economic loss compared to the socially optimal case, where all users are altruistic.

Building on this research direction, we consider the design of optimal privacy-preserving schemes. Research has shown that the occupancy of buildings has a significant effect on the temperature and air quality: heating, ventilation, and cooling (HVAC) of buildings can be greatly improved when occupancy estimates are provided to the controllers. However, building occupants may have different preferences for the privacy of their location traces, which can often be inferred from occupancy estimates.



Temperature fluctuations correspond to distortion levels

In our recent work, we analyze how to optimally trade-off between privacy and control. In particular, we consider how the performance of HVAC controllers vary for different privacy-preserving occupancy distortions. We are able to design this noise to maximize the privacy of users, as measured by mutual information between a private variable and the public observables, subject to a control performance constraint. Our methodology allows us to provide optimal privacy-preserving schemes that minimize negative effects on the operational efficiency.

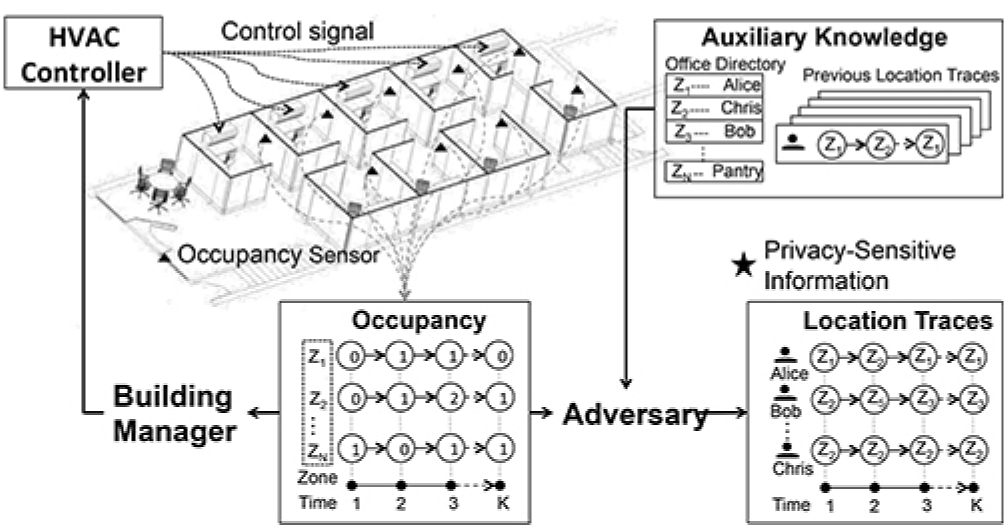


Illustration of HVAC control influenced by occupancy data and variable privacy concerns

Energy Markets for Electric Vehicles

by Ian Hiskens (University of Michigan)

Vehicles that connect to the electricity grid to recharge, referred to generically as electric vehicles (EVs), offer a range of potential benefits, including reductions in reliance on liquid fuels and in pollutant emissions, and increased energy efficiency. It is therefore anticipated that EV sales will substantially increase over the next few years. If such growth does happen, it will become necessary to account for EV charging patterns in grid operation.

Accommodating large numbers of vehicles on the grid will require coordination of EV charging so that their power and energy requirements can be optimally and robustly satisfied. This is a challenging control problem. Work on analyzing EV charging schedules, and their effect on utilities, began in the 1980s. Recent work is extensive and includes development of EV dispatch algorithms that are consistent with day-ahead electricity markets.

Centralized coordination faces numerous difficulties, from computational complexity to the loss of EV decision-making autonomy. Many distributed coordination methods have been proposed to address those challenges. In a general sense, that work is structured around individual players determining their optimal charging strategy over the charging horizon with respect to either the total demand of the other players, or the system (clearing) price, which is based on the total system demand. In numerous cases a hierarchical structure has been considered for scheduling EV charging. Each EV determines its preliminary charging (load) profile by solving an individual optimization problem with respect to the latest forecast of the system clearing price. The clearing price is then updated to take into account the latest charging profiles of the individual EVs. With a carefully designed update process the resulting strategies asymptotically approach a Nash Equilibrium (NE) as the EV population increases to infinity. The resulting NE is nearly socially optimal.

Most of the distributed methods are quite distinct from the economic generation dispatch that underpins deregulated day-ahead electricity markets. To economically dispatch generation, auction mechanisms, such as uniform market-clearing-price and pay-as-bid, have been widely adopted in electricity markets around the world. Each generating unit submits to the Independent System Operator (ISO) their bids over the forward market period (typically 24 hours), with bids consisting of pairings of minimal selling price and maximum supplied electricity for each market subinterval. The ISO dispatches the generation requirements among units based on their submitted bid profiles. However, these auction mechanisms do not achieve incentive compatibility and provide no guarantee of attaining the efficient (centrally optimal) solution. In contrast, recent work has studied EV charging coordination over multiple time intervals under an incentive compatibility mechanism. This work utilized a progressive second price (PSP) auction mechanism designed by Lazar and Semret and initially applied in the allocation of network resources.

In a single divisible resource allocation problem under the PSP auction mechanism, each player only reports a two-dimensional bid. This bid is composed of a maximum amount of demand and an associated buying price, and is used to replace the player's complete (private) utility function. Under the PSP mechanism, the money transfer (or payment) of a player measures the externality that they impose on the system through their participation. The PSP auction mechanism is a VCG-style auction. Therefore incentive compatibility holds, ensuring that all players submit truth-telling bids, and resources are allocated efficiently. Under this mechanism, in the context of single-unit network resource allocations, the efficient bid profile is a NE.

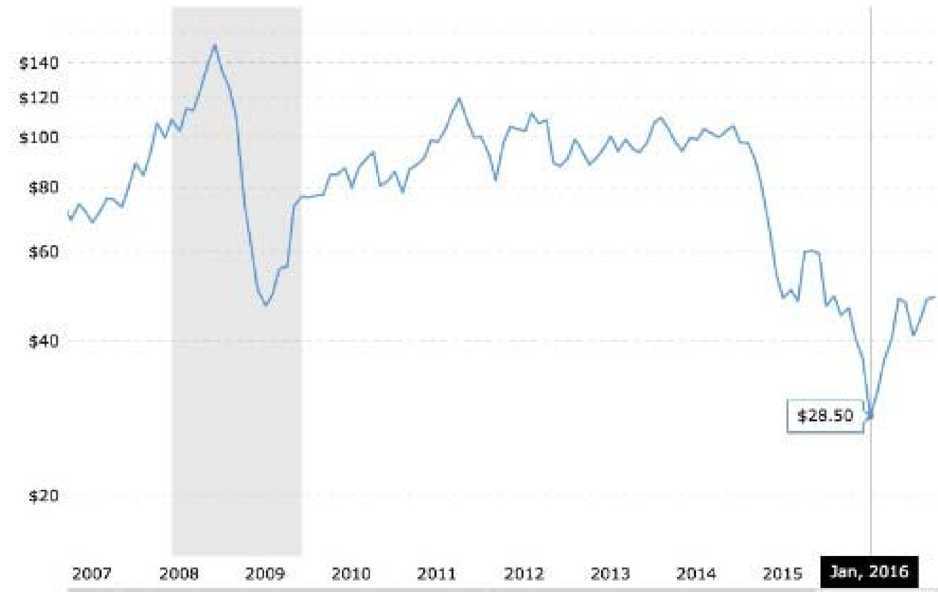
In formulating their bids, EVs must consider tradeoffs between energy costs that vary over the charging horizon, the benefit derived from the total acquired energy, and battery degradation. Individual EVs are therefore inter-temporal, cross-elastic loads. This results in an auction-based allocation of a collection of divisible resources, where electric energy at each time-step of the horizon is a separate divisible resource. Consequently, each EV must submit a bid that has dimension double the number of divisible resources to be shared (equivalently double the number of time-steps in the charging horizon). Such auctions have received limited attention in the literature. Recent work has shown that a player's marginal valuation for electric energy at a particular time is dependent upon both the amount of energy requested at that time and the total energy request over the entire charging horizon. Importantly, this work has concluded that the efficient set of EV bids over the charging horizon is a NE of the underlying auction game. In other words, the EV charging schedules achieved through this distributed auction-based process will match the solution given by centralized coordination.

Energy Markets: The Recent Boom and Bust

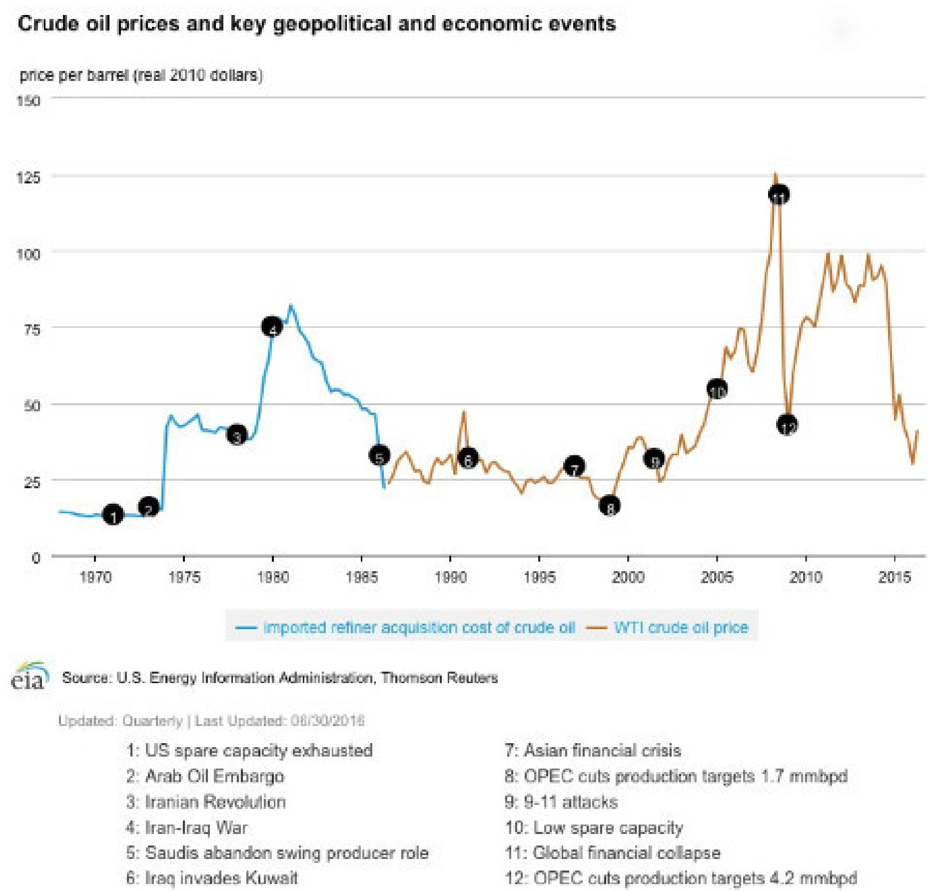
by Karen Fireman, CFA (Fireman & Associates)

When the FORCES team considers the resilience of U.S. energy, they tend to think of preventing accidental or malicious intervention or cyber terrorist attacks. When FORCES asked me to write this article, I wondered if the unfolding story of energy boom and bust would resonate as a threat to energy resilience.

Here are the key players: the oil and gas industry, the banks and Wall Street, non-OPEC producers, OPEC and Russia, retail and commercial consumers; and here are the indicators which also become drivers: price of oil and gas, inventory, number of rigs, capital expenditures (CAPEX), production levels and changes in millions of barrels per day (mbd), defaults on debt, bankruptcy filings, and layoffs. The list goes on as everyone wants to enter the arena. Other catalysts include renewable pricing and production, government tax incentives, weather, and natural disasters.



Source: BoAML



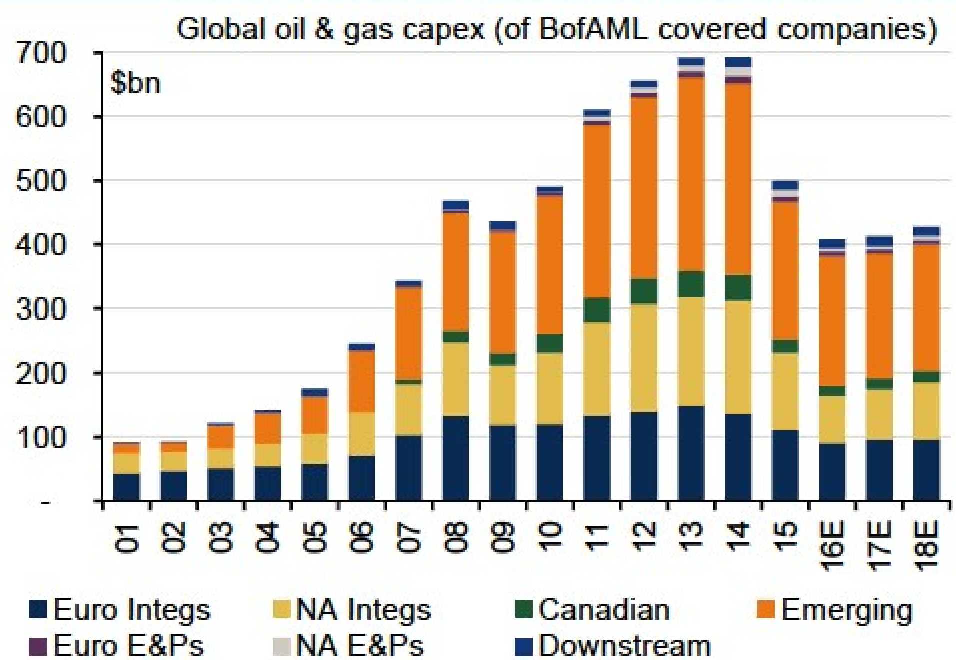
Source: U.S. Energy Information Administration; Thomson Reuters

In 2008, oil prices had steadily risen to all-time highs ($151/bbl). During the financial crisis of 2008-2009, oil retrenched from $125/bbl to $42/bbl. From 2011-2014, oil prices largely traded in a range between $95 and $105. In January of 2014, many factors had contributed to a severe supply overhang. While the U.S. reduced production by 1.08mbd to lessen the supply/demand imbalance, OPEC and Russia sometimes met the demand with their cheaper production. U.S. fracking, horizontal drilling, and technological innovations led to significantly increased production. In addition, the 2015/16 El Niño created the warmest winter in years, reducing heating energy demand. This growing supply/demand (S/D) imbalance precipitated the quick fall of oil prices.

By February of 2016, natural gas fell to $1.66/MMbtu, its lowest level since the bust of 1999. However, in a sudden reversal, excessive temperatures increased demand, and a massive fire during May and June in Canadian oil fields lost 1.1mbd of production. Together these caused a drop in peak inventories, ushering in a strong summer rally, with natural gas prices rising +83% (from $1.66 to $3.05/MMbtu). Hello, volatility.

Companies have become cautious about reacting to good news. Price volatility, waffling Federal Reserve statements, and unknown election results have added to uncertainty. Most companies are not planning to add rigs, and most are cutting capital expenditures (i.e., -25% worldwide, but US CAPEX has seen 40-50% cuts.) The production decline was fast but restoring it is slow; companies are waiting until they believe there is sustainable improvement.

Chart 1: Capex in the global oil and gas industry has tumbled, with total spend falling from $690bn in 2014 to just $410bn this year...

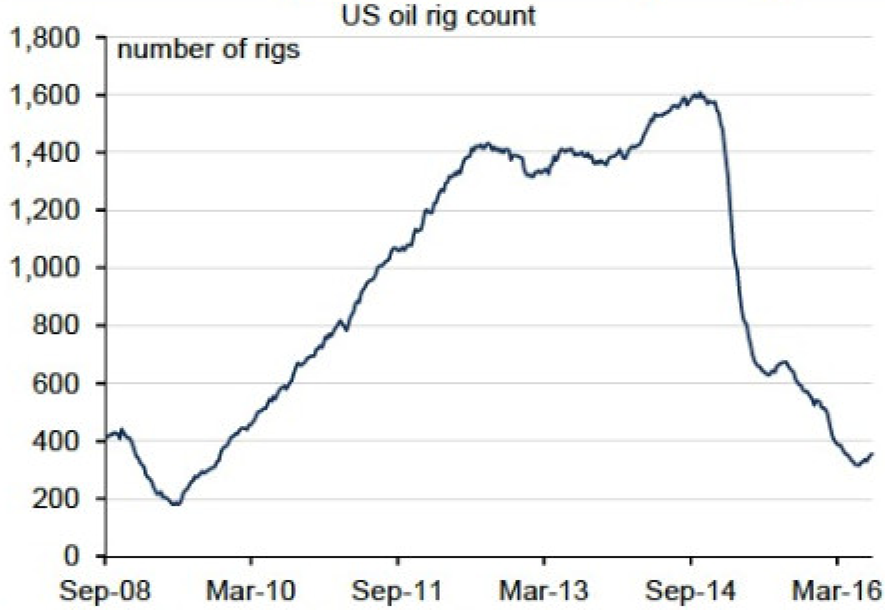


Source: BofAML Global Research

Rigs

In February 2016, US rigs hit their low at just under 400. In May 2016, in preparation for the Houston annual Offshore Technology Conference (OTC), Baker Hughes oilfield services reported that while the number of US Rigs were down, Middle East rigs had *increased* 5%. Currently, the US has 522 oil rigs, compared with 809 a year ago, and a peak of 1600 oil rigs in Sept of 2014.

Chart 7: Decline rates have been most pronounced in the US, given its reliance on fast-declining type curve, and a 78% drop in the rig count



Source: Baker Hughes, BofAML Global Commodities Research

In Texas, rigs were down more than 75% from peak to trough. Companies are working to be more efficient, as well as cherry-picking the best crews and drilling the best plays. Many of these efficiencies are probably not sustainable at higher future rig levels. With fewer rigs, and a desire to minimize CAPEX, companies are idling rigs, reducing rig maintenance, and even cannibalizing their rigs for spare parts. These equipment-related reductions hurt energy service and operations company performance and induce layoffs in that sector. FuelFix reported that since the start of the oil bust in 2014, 150,000 employees have lost their jobs in the oil and gas industry.

Meeting last week in Algiers, OPEC announced an agreement in concept to reduce production for the first time in eight years. This news led to swift increases in oil of +3.2% to $45.93/bbl and by Friday oil was up 8% to $48.24/bbl for West Texas Intermediate (WTI). However, OPEC put off until next month the difficult part of determining how much each country must reduce its output.

The imbalance is affecting every part of the energy supply chain: exploration, operations, pipelines, shipping companies, refineries, etc., resulting in lower prices, lower cash flow, lower capital expenditures, and lower oil and gas production.

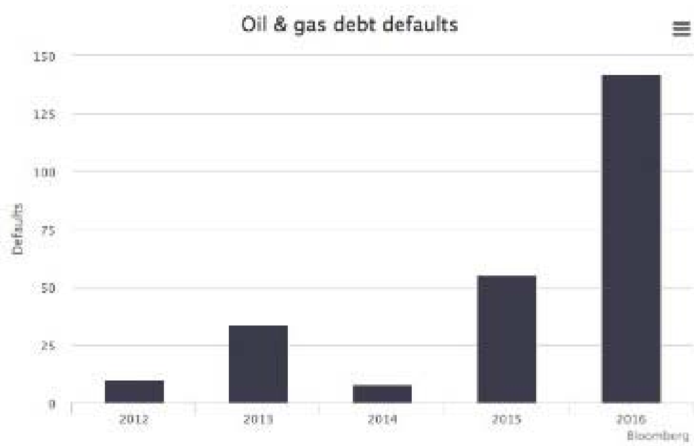
Even before companies lowered production, their cash flow was suffering from reduced prices. Then, their efforts to rebalance the S/D via production decreases further exacerbated negative cash flow.

In June 2008 at the height of the market with WTI oil prices at $151/bbl, credit was easy; it was still easy in June 2014, with WTI at $105/bbl. Often smaller firms used bank "reserve-based lending." However, with depressed oil and gas prices, the reserves lost value, ratios sank and threatened to not meet debt covenants, banks began calling in debt, and new loans became scarce.

In addition to banks tightening credit, bond and equity market funding also dried up. For example, during early 2015, monthly energy debt issuance was $6.5B. By August of 2016, monthly issuance was down 75% to $1.7B.

The U.S. Energy Information Administration (EIA) recently reported that on average, 83% of energy cash flow is being used to service company debt. Balance sheet strengthening has become a necessary, high priority.

Furthermore, FuelFix reported that 135 companies are on the verge of bankruptcy, in addition to the 175 companies that have already filed for bankruptcy. Other firms are being merged or sold.



The number of defaults among oil and gas related bond issues spiked in 2016 as the decline in oil prices drove many lenders in the bankruptcy. Year-to-date, there have been 142 defaults, mostly among issues not rated by the major agencies. The number of defaults represent 56% of all defaults among bonds issues since 2009, with the majority of the defaults occurring in bonds issued between 2013 and 2015.

— Contact Charles McGrath at cmcgrath@pionline.com

McGrath reports that in 2016, more than 140 companies in the oil and gas industry have defaulted on debt, most of which was issued in 2013 and 2015, and many of which were not rated.

Merrill Lynch reported the outlook from oil and gas companies: The highest priority use of cash flow for most companies is debt service (i.e., paying interest on their enormous debt load), followed by strengthening the balance sheet (by either paying down debt principal or selling assets or both).

Companies were asked about price levels for various stages of recovery: sustainability, adding to rigs, adding CAPEX, and growth. Responses were mixed, but it is believed by some analysts that it would cost $25 from every barrel of oil produced by the U.S. to have enough cash flow to pay for 425 more rigs. Consequently, oil would have to be $25 higher than today in order to support this without negative cash flow. So, $50/bbl would barely be sustaining; $70-$75/bbl would provide money for rigs; $80/bbl would allow growth.

Renewables

Renewables are cheaper to create than ever before, adding to the glut. The Houston *Chronicle* reports that the U.S. Department of Energy indicates there is a cost improvement of 41% and 54%, for onshore wind turbines and rooftop solar panels, respectively. Last year, renewable energy accounted for 66% of the power generation installed in the U.S. In 2000, there was effectively *none.* Energy Secretary Moniz recently spoke to Congress reiterating the importance of low-carbon energy production, yet foreshadowed 2020 phase-out of renewable energy tax subsidies. Additionally, consumers are using more energy efficient lighting (such as LEDs), efficient buildings are being created to an LEED v5 standard, and companies are improving electric car efficiencies. While these lower demand, there is a surge of large gas guzzling vehicles because gas prices are down.

Nuclear
The low-cost, surging production of renewables is creating doubt for the need of government financial subsidies for nuclear energy. Yet nuclear is efficient, clean, unaffected by weather, and runs approximately 24/7. Nuclear energy is expensive but FERC is revisiting rate-making policy and cost allocations. Additionally, newer nuclear reactors cost half as much as older ones to operate. Lastly, the labor market for nuclear is aging and will soon retire. Nuclear currently comprises over 60% of clean non-carbon-emitting fuel. We cannot afford to eliminate our key "green" energy source. We have approximately 100 reactors in the U.S., but five were recently retired and several more have accelerated their retirement. In the U.S. some states are subsidizing their nuclear power plants, while others are prematurely decommissioning/retiring them. These reactors were expensive to build during times of energy shortages, and people were investing in nuclear power. While reactors are now comparatively expensive to run, this author worries that hasty decommissioning decisions during cheap energy years will be a costly mistake in the long and even medium term.

In summary, the energy bust is in its second year. The supply overhang continues to depress prices. Macro events are adding uncertainty. Funding sources are extremely limited in an industry that has been overbuilt, oversubscribed, and loosely monitored by lenders. Cash flow is going almost entirely to debt service. Rigs and CAPEX are down, and the entire supply chain is being impacted. Companies are defaulting and many are going bankrupt. The solution is not likely to be quick, but hopefully we are on the right track for recovery.

Sometimes, the biggest risk is right in front of you.

PROJECT NEWS

Upcoming Events

2016 NSF CPS Principal Investigators' Meeting
October 31-November 1, 2016
Renaissance Arlington Capital View
Arlington, VA

FORCES NSF Review Meeting
January 25-26, 2017
Westin Arlington Gateway
Arlington, VA