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The Shale Revolution:
What Do We Know Now and Where Are We Going?

Conference Report

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The Shale Revolution: What Do We Know and Where Are We Going?

A Conference Report

by

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I. Introductory Remarks

The energy industry is undergoing dramatic transformation due to the rapid development of unconventional energy resources, and over the past few years, the US has been one of the fastest-growing oil and natural gas producers in the world. The so-called "shale revolution" has transformed the US energy landscape, having major impacts on global energy markets and leaving policymakers grappling with new challenges. To explore and assess the impacts (both short- and long-term) that proposed and potential policy actions could have, the Center for Energy Studies (CES) at Rice University's Baker Institute for Public Policy has engaged in a study funded by the Alfred P. Sloan Foundation. Notably, the Sloan Foundation has a broad engagement ranging from the upstream through to the downstream across various aspects of the shale resource development. As such, the Sloan Foundation has also provided funding for researchers at The University of Texas's Bureau of Economic Geology, Resources for the Future, the Environmental Defense Fund, the University of Colorado-Denver, Duke University, and Rice University with the aim of contributing to a deeper understanding of the shale resource base and its potential long-term economic, political, and social impacts.

The conference organized by the CES at the Baker Institute on October 30, 2014, served as an opportunity for the various groups funded by the Sloan Foundation to present and discuss their respective research efforts, not only within the scope of each specific study but, more importantly, within the context of other studies. The conference, therefore, convened researchers across multiple disciplines from each of the aforementioned institutions and featured detailed presentations on topics such as research characterizing shale resources and recovery, the environmental impacts of shale development, public perceptions and policy motivation surrounding shale development, the local economic implications of shale development, and the broader economic impacts of various natural gas-related policy interventions. The lineup of speakers provided a natural progression in the analysis of factors that have been important for the US experience with shale, thereby shedding light on current and future opportunities and challenges. The conference program is included in an appendix.

II. The Role of Shale Gas in the US Energy Transition: Recoverable Resources, Production Rates, and Implications

Scott Tinker, John Browning, Svetlana Ikonnikova, and Gurcan Gulen
Bureau of Economic Geology at The University of Texas

The conference began with the Bureau of Economic Geology's research group presenting one of the most comprehensive assessments of shale gas resources to date. Researchers have explored in detail how to provide a deeper understanding of the physics of fluid flow in low-permeability, low-porosity formations so that well performance can be better characterized and more meaningful assessments can be made regarding the recovery and commercial viability of the resource. The group has examined data for thousands of wells in four major shale plays—Barnett, Fayetteville, Haynesville, and Marcellus—to better estimate the original gas-in-place (OGIP), porosity, thickness, pressure, depth, degree of natural fracturing, and clay content of the rock within the play. All of this information was then used to categorize opportunities within the plays according to productivity "tiers" and to discern the "white space" that remains viable for development within each tier. The picture that emerges is one of extraordinary heterogeneity both across and within shale plays, making any assessment of the scale and longevity of the shale revolution both difficult and complex.

The research underscores that we have witnessed an anticipated shale "evolution" rather than a "revolution." We have known about shale resources for a long time; we have simply been waiting for the technological advances and appropriate economic climate for unconventional exploration and development to occur and ultimately replace steadily declining conventional natural gas resources. Additionally, of the total resource in place, only about 20 to 25 percent is technically recoverable today, and only a modest fraction of that is economically viable. The research also highlights the nature of decline in shale gas wells. Specifically, the steep declines that are realized do not translate into a dearth of recoverable resources. Rather, the steep decline is followed by a very long tail with significant resources left to extract.

The geologic properties of each of the shales under study were then incorporated into a methodology to tier the wells by productivity. The well productivity maps that resulted from the

exercise highly correlate to OGIP and porosity maps, and they capture the notion that there is significant heterogeneity across a shale formation within a basin. Shale resources are categorized into 10 tiers, with tier 1 being the most productive and tier 10 being the least productive part of the shale. Importantly, high productivity does not necessarily mean that a well is a commercially viable prospect. Instead, one needs to consider the interplay of productivity, cost, price, and regulatory and other constraints that may be in place.

A discounted cash flow model was then used to evaluate the commercial attractiveness of wells drilled in each tier based on the average profile of a comprehensive set of variables incorporating the local and federal tax regimes, regional prices, and coproducts (such as natural gas liquids [NGLs]). The model also incorporates information on oil and NGL prices, drilling costs, well attrition, and economic limits on production based on previous observables. The presence of NGLs, in particular, substantially affects a well's economic viability because liquids, which have been priced at a premium to natural gas, allow producers to considerably improve profitability. Indeed, liquids add extra value for wells in the northern counties of the Barnett shale, which are not high-tier wells on a gas production basis.

Drilling costs were also shown to impact well economics in a meaningful way. Highly productive wells in the Haynesville shale are economically challenged relative to wells in other shale plays due to costs. In particular, it was shown that wells in the Haynesville are commercially viable only in the most productive tier if gas prices are above $4, a result owing to the depth of the gas resources and the lack of any associated liquids. By contrast, the commercial viability of Marcellus shale wells is highly dependent on their specific location, as some regions are dry, others wet, and yet others super rich with high-value NGLs.

Once the economic and geologic parameters were defined, a production outlook was generated using a well simulation model that incorporates the productivity tier and economic viability of each opportunity. The outlook also factors in drilling "pace" parameters that constrain the speed of development given the inventory of wells and minimum/maximum completions by tier within a period. Accordingly, the model predicts well completions by tier and uses tier-specific type curves to calculate expected production. It was noted, however, that assumptions about

technology and infrastructure availability, not to mention the outlook for price and cost, present challenges to the overall exercise, as each of these things is taken as exogenously given. Moreover, each play has a unique set of features that underscore its development and contribute to the production outlook. For example, for the liquids-rich portion of the Barnett shale, the assumption on NGL prices and the percentage of accessible area that is allowed to be developed is much more important to the gas production outlook than the price of gas. All else equal, however, higher gas prices will induce more production, while lower prices will inhibit growth.

While the technical and economic advances that have driven the shale revolution are important, the economic benefits from shale development cannot be realized if the associated social and environmental risks are not addressed and reduced. Two important environmental issues associated with shale exploration were considered by two studies presented at the conference.

III. Risk Matrix for Shale Gas Development

Alan Krupnick
Center for Energy Economics and Policy, Resources for the Future

Research being conducted at the Center for Energy Economics and Policy at Resources for the Future (RFF) has considered the issue of potential water pollution related to shale gas development. In a survey of 215 experts from government agencies, industry, academia, and NGOs, a general consensus emerged that risks related to water (ground and surface water) need to be mitigated in the highest order of priority. Moreover, it was found that water quality concerns were more directly related to how produced water (or flowback) from shale-directed activity is handled.

With this information in hand, the risk associated with using pits versus tanks for onsite storage of produced water was underscored. The discussion underlined the paucity of rigorous studies on the matter, and, while some analyses show that there are more spills from pits than tanks, they do not provide information on the relative number of each storage medium, meaning the *rate* of spill is unknown. In addition, research on produced water characteristics in the Marcellus shale development has shown it contains very high amounts of barium, benzene, and other metals and

naturally occurring radioactive materials (NORMS). Moreover, the chemical composition of produced water varies considerably across wells, which presents an additional challenge for establishing an effective treatment and management regime with any homogeneity within and across states. In fact, a survey of 19 states identified extreme heterogeneity in pit regulations with 28 different regulatory elements, including pit classification type, treatment of pits located in a flood zone, and divergent permit, siting, construction, operation, and closure/remediation requirements. Indeed, one of the findings from the survey elements of the research is that companies are confused by the variety of regulations and often spend more on compliance costs than on water treatment. Consequently, there is an apparent need for a standard set of performance-based guidelines, as it may not be appropriate to consider one type of storage over another; rather, policymakers should consider how different storage types perform under different conditions. More research is needed to quantify the actual (versus perceived) risks to human and ecological health, as well as the degree to which different features of pits increase or decrease these risks. Such research would provide invaluable feedback to policymakers in establishing guidelines for the handling and storage of produced water.

IV. EDF's Scientific Efforts to Quantify Natural Gas Methane Leakage

David Lyon
Environmental Defense Fund

Research being conducted by the Environmental Defense Fund (EDF) reveals that while there is no shortage of research on methane emissions associated with upstream shale development, the results are highly divergent. For example, the EPA has generally assessed the methane leakage rate at 1.3 percent, while other studies have found leakages as high as 9 percent in Uinta Basin. This type of difference is by no means trivial, and if the leak rates are on the high end, upwards of 7 percent, then natural gas is not much better than coal with regard to climate change.

To provide a consistent, rigorous, and multifaceted assessment of methane leakage, the EDF embarked on 16 studies with over 100 collaborators over the period 2012–2014. The studies have employed three different methods for quantification, including direct measurement of components, near-field measurements of plumes, and regional open air measurements. The work

has included a methane-mapping project where a Google Street View car was given a methane sensor to assess the level of methane leaks in Boston, Minneapolis, and Staten Island, as well as a comprehensive assessment of the Barnett shale region that used all possible methane quantification methods. In addition, gap-filling studies have been conducted to assess the contribution of methane content in the air by potentially missed sources such as abandoned wells and a number of super-emitter sites. EDF has concluded that the best way to decrease methane leakage is early detection, but the best detection equipment on the market is also very costly. Thus, EDF initiated a Methane Detector Challenge and selected five proposals for further exploration.

V. Understanding the Political Fractures and Seams around Hydraulic Fracturing

Tanya Heikkila and Samuel Gallaher
University of Colorado-Denver

Researchers at the University of Colorado-Denver are examining the perceptions of policymakers and influencers on hydraulic frac'ing practices and regulation. In doing so, they have conducted surveys among government officials, NGO and industry representatives, consultants, and academics in the states of Texas, Colorado, and New York. Importantly, these states have very different histories with regard to oil and gas activity, making them prime for comparison.

The survey revealed a general difference in opinion regarding hydraulic fracturing across the various groups, with the exception of opinions pertaining to public distress, water competition, and public nuisance regulation by local governments. In addition, greater polarization between survey respondents was evident in New York than in Texas or Colorado. But regardless of the respondent's position on hydraulic fracturing activity in practice, there is a general consensus that there is an insufficient capacity to regulate and monitor field activity, resolve conflicts between the mineral rights owner and landowner in a timely manner, and that there is a general public distrust toward the oil and gas industry, which is evident in anti-frac'ing demonstrations. Interestingly, this research also reveals that the preference for the regulating authority differs across the extremes of the groups surveyed. Specifically, those opposed to frac'ing activity

generally prefer a federal government regulatory presence, while those supportive of industry generally view state and local regulatory authority as more appropriate. In addition, the differences across the groups indicate that more technical and scientific information is not always the solution to resolving differences, and reaching a consensus can be impossible until the issue becomes a "hurting stalemate." Thus, it may be more appropriate to look for conflict-mitigating strategies in addressing the differences among groups with regard to hydraulic fracturing activity.

VI. Policy Outcomes and Political Venues: The Case of Hydraulic Fracturing

Robert Stein and Marvin McNeese
Baker Institute and Department of Political Science, Rice University

Researchers at Rice University are applying punctuated equilibrium theory to assess whether or not a significant increase in news coverage of issues related to shale development has any indication of a policy intervention. Coding over 7,000 articles covering a period of six years in national and local newspapers reveals a steady and massive increase in articles on hydraulic fracturing beginning in January 2010. Moreover, the articles demonstrate a clear direction toward a negative tone.

The research also finds that the shift in media attention has not resulted in the emergence of a single dominant image. As a result, according to the theory, a major policy change at the federal level is not expected. However, an exploration of various policy venues indicates that anti-drilling policy changes are more likely to be implemented at the local level—for example, by municipalities—while pro-drilling interests are more likely to be instituted at the state level. In sum, the research indicates a greater propensity for local policy interventions than broad, sweeping ones.

The discussion evolved to one of discerning the likelihood of local policy interventions under different conditions. For example, if robust shale development has already occurred in a locality, is the likelihood of policy intervention reduced? Indeed, the places where local policy action to prohibit shale development has occurred have not been directly impacted by robust shale

activity. This raises questions about the overall impact of local policy intervention if it is forthcoming, particularly if it does not impact production in a material way.

VII. Shale Public Finance: Local Government Revenues and Costs Associated with Oil and Gas Development

Richard Newell and Daniel Raimi
Duke University Energy Initiative

Researchers at Duke University provide a possible explanation for why municipal governments may be more likely to legislate against hydraulic fracturing while state-level policies are more likely to embrace the shale revolution. The researchers interviewed local officials in eight different states as well as experts from government, industry, and academia. They also analyzed financial documents and relevant tax and revenue data from various localities. The study reveals that municipalities tend to experience smaller net fiscal benefits than state governments. This is especially true in North Dakota where the costs associated with shale development outweigh the fiscal benefits that come from sales and property taxes, "impact fees," or in-kind agreements.

More generally, some of the local costs observed in Texas, Pennsylvania, and North Dakota have been associated with road maintenance and with increased staffing requirements by local government and regulatory authorities. In North Dakota, where local governments cannot directly levy property taxes on oil and gas production and where local populations have grown exponentially, the associated costs outweigh new revenues for counties and municipalities. Even in Texas, where municipalities and counties generally experience positive financial impact, some counties have had trouble with costs associated with road upkeep. In general, the research underscores that while the effects of shale development are positive for state governments, the impact is not uniformly distributed through local governments, and municipalities in particular are often disadvantaged. In sum, the research reveals that taxes and fees levied on shale production have important implications for the local regions and, possibly, public attitudes toward drilling.

VIII. The Market Impacts of Shale Gas-Directed Policies in the United States

Kenneth B. Medlock III
Center for Energy Studies, Baker Institute, Rice University

What is the impact of shale-directed policies on the market? And, do policies need to be directed specifically at shale to affect its development? For example, what is the impact of environmental policies requiring implementation of emission reduction technologies, or policies restricting international trade?

Research at the Center for Energy Studies at Rice University's Baker Institute for Public Policy indicates that changes in *local* taxes on production can impact local production activity, but have a minimal impact on the overall market. The deep interconnectedness of the North American gas market and highly varied supply portfolio allows for relatively easy substitution among resource opportunities as relative costs change. In other words, the perturbations triggered by policy interventions in one locality can be smoothly arbitraged by new resources in other regions.

More generally, as policy interventions become more localized, their impacts on the US natural gas market diminish. However, as policy interventions move into the federal domain, their impacts grow substantially. For example, when considering bans at the local or federal level, a federal ban has a dramatic impact on the US market, whereas localized bans generally do not.

Importantly, there are a host of other policies that affect shale development indirectly by influencing demand for domestically produced gas, including LNG exports and environmental policies targeting emissions in the power sector. According to the research presented, the impacts of policy interventions generally decreased in severity as one moved from a federal ban, to a ban on US LNG exports, to local policy interventions. Regardless of the case, however, it was emphasized that when examining the future of shale development, it is crucial to employ an integrated market assessment that takes into account demand, supply, and the ability to trade across the entire market.

Given the likelihood of various types of policy action, it was asserted that demand-side policies are likely to have the largest impact on the US gas market in the coming years. Modest shifts in local taxes and wellhead costs due to regulatory intervention induce changes that are relatively small because they shift the marginal source of supply on a highly elastic supply curve. Moreover, there are varying responses across scenarios in Canada and Mexico that tend to mitigate the impacts of any singular policy change in the US, which highlights the importance of the highly integrated nature of the North American gas market.

IX. Concluding Remarks

In sum, the conference provided a forum for researchers with varied backgrounds from diverse disciplines to provide an update on the state of their research into the current geologic, economic, and political state of shale in the US. The conference participants were given a multidimensional view of the factors that can influence shale gas development under different scenarios. The collection of research presented underscores the heterogeneity that is inherent to many aspects of shale—including geologic heterogeneity, heterogeneity in productivity and economic viability, heterogeneity of state and local regulations, heterogeneity of public sentiment, and heterogeneity of impacts on local economies and infrastructures. This, in turn, makes shale an interesting and challenging transformative phenomenon that requires study by experts in diverse areas—including geology, engineering, economics, and policy—if one wishes to fully understand the potential future of shale in the US.

Appendix I. Conference Agenda

The Shale Revolution: What Do We Know and Where Are We Going?

Rice University's Baker Institute for Public Policy

October 30, 2014

9:00 am – Welcome and Study Design

Kenneth B. Medlock III, Ph.D., James A. Baker III and Susan G. Baker Fellow in Energy and Resource Economics, and Senior Director, Center for Energy Studies, Baker Institute

Resources and Recovery

9:15 am

"The Role of Shale Gas in the U.S. Energy Transition: Recoverable Resources, Production Rates, and Implications"

Overview and Geology

Scott Tinker, Ph.D., Director, Bureau of Economic Geology, and Allday Endowed Chair of Subsurface Geology, John A. and Katherine G. Jackson School of Geosciences, The University of Texas; and State Geologist of Texas

Well EUR and Technically Recoverable Reserves

John Browning, Senior Research Fellow, Bureau of Economic Geology, The University of Texas

Well Economics and Production Outlook

Svetlana Ikonnikova, Ph.D., Research Associate and Energy Economist, Bureau of Economic Geology, The University of Texas

Sensitivities and Economic Differences

Gürcan Gülen, Ph.D., Senior Energy Economist, Center for Energy Economics, Bureau of Economic Geology, The University of Texas

Environmental Impacts

11:00 am

"Risk Matrix for Shale Gas Development"

Alan Krupnick, Ph.D., Director, Center for Energy Economics, and Senior Fellow, Resources for the Future

1:00 pm

"EDF's Scientific Efforts to Quantify Natural Gas Methane Leakage"

David Lyon, Scientist, Environmental Defense Fund

Policy and Public Sentiment

2:00 pm

"Understanding the Political Fractures and Seams around Hydraulic Fracturing in Texas"

Tanya Heikkila, Ph.D., Associate Professor and Director, Doctoral Program, School of Public Affairs, University of Colorado-Denver

Samuel Gallaher, Ph.D. Candidate, School of Public Affairs, University of Colorado-Denver

2:30 pm

"Policy Outcomes and Political Venues: The Case of Hydraulic Fracturing"

Robert Stein, Ph.D., Fellow in Urban Politics, Baker Institute; and Lena Gohlman Fox Professor, Department of Political Science, Rice University

Marvin McNeese, Ph.D. Candidate, Department of Political Science, Rice University

Economics and Market Response

3:15 pm

"Shale Public Finance: Local Government Revenues and Costs Associated with Oil and Gas Development"

Daniel Raimi, Associate in Research, Duke University Energy Initiative

4:00 pm

"The Market Impacts of Shale Gas-Directed Policies in the United States"

Kenneth B. Medlock III, Ph.D., James A. Baker III and Susan G. Baker Fellow in Energy and Resource Economics, and Senior Director, Center for Energy Studies, Baker Institute