An Innovation Roadmap for Marcellus

Ben Franklin Technology Partners / Shale Gas Innovation & Commercialization Center
November 18, 2011
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Outline

- Intro to ADI Analytics
- Background and Methodology
- Marcellus Innovation Needs
- Conclusions
ADI Analytics is an energy / chemical consulting firm that solves problems with a content- and data-driven approach

We use a Clear and Robust Approach …

Driven by hypotheses, data, and analytics

Grounded in industry expertise

Collaborative with client staff

… To Deliver Actionable Consulting and Insight

› Evaluate markets and opportunities to grow businesses

› Gather and analyze difficult-to-get information to address uncertainty

› Identify needs, ideas, and opportunities to optimize costs

› Design and implement processes to improve organizations
We specialize in energy, chemicals, and industrials with domain and functional expertise across the value chain ...

<table>
<thead>
<tr>
<th>Markets</th>
<th>Technology</th>
<th>Operations</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil &amp; Gas</td>
<td>Exploration</td>
<td>Production</td>
<td>Refining</td>
</tr>
<tr>
<td>Power &amp; Mining</td>
<td>Coal</td>
<td>Generation</td>
<td>Transmission</td>
</tr>
<tr>
<td>Renewables</td>
<td>Biomass</td>
<td>Solar</td>
<td>Wind</td>
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<tr>
<td>&amp; Cleantech</td>
<td></td>
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<tr>
<td>Chemical &amp;</td>
<td>Plastics</td>
<td>Materials</td>
<td>Auto</td>
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<tr>
<td>Industrial</td>
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</tbody>
</table>
... Offering services that help clients understand markets, develop strategy, improve operations, and deploy technology

<table>
<thead>
<tr>
<th>Market Research</th>
<th>Competitive Benchmarking</th>
</tr>
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<tbody>
<tr>
<td>Conduct in-depth research and analysis to identify new markets or segments, their size, profitability, growth, competitive landscape, client fit, and execution strategy</td>
<td>Benchmark client capabilities, costs, and competitiveness against industry based on public information and rigorous modeling and suggest improvement ideas</td>
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<table>
<thead>
<tr>
<th>Investment Analysis</th>
<th>Technology Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Build valuation models to analyze investments in capital projects, businesses, or capabilities to estimate economic value, ROI, NPV, IRR, risks, and other metrics</td>
<td>Understand technologies including their business impact, cost, trends, competing options, deployment risk, and commercialization success</td>
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<table>
<thead>
<tr>
<th>Business Strategy</th>
<th>Innovation Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advise clients on competencies and improving them with organization and resource alignment to enhance competitiveness, entry barriers, and shareholder value</td>
<td>Implement programs for ideation, portfolio development, stage-gate maturation, open innovation, IP management, functional excellence, and talent development</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario Planning</th>
<th>Process Design</th>
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<tbody>
<tr>
<td>Develop and explore carefully drawn future scenarios to define medium-, long-term visions and pressure-test them through quantitative, analytical models</td>
<td>Assess organizational goals and “as is” processes to identify gaps and design “to be” processes that fill gaps and achieve target goals</td>
</tr>
</tbody>
</table>
Our growing team brings experience in supporting blue-chip clients on various business and technical consulting projects

<table>
<thead>
<tr>
<th>U.S. Department of Energy</th>
<th>Assessed costs, economics, feasibility, and commercialization potential of several renewable energy technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream Independent</td>
<td>Identified strategic and technical needs to establish an unconventional business and designed a fit-for-purpose organization</td>
</tr>
<tr>
<td>Venture Capital Firm</td>
<td>Sized market, growth, and segment profitability of the oilfield services industry as groundwork to build investment fairway</td>
</tr>
<tr>
<td>Energy Equipment Vendor</td>
<td>Supported diversification strategy by sizing market and profiling customer willingness to switch vendors</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Select Clients</th>
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</thead>
<tbody>
<tr>
<td>U.S. Department of Energy</td>
</tr>
<tr>
<td>National Institute of Standards and Technology</td>
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<tr>
<td>Fortune 100 Oil and Gas Major</td>
</tr>
<tr>
<td>FTSE 100 Oil and Gas Major</td>
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<tr>
<td>Fortune 500 Coal Company</td>
</tr>
<tr>
<td>Recent IPO Biofuels Start-Up</td>
</tr>
<tr>
<td>Energy-Focused VC Firm</td>
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<tr>
<td>Ben Franklin Technology Partners</td>
</tr>
<tr>
<td>Fortune 500 E&amp;P Company</td>
</tr>
<tr>
<td>Energy Training Services Vendor</td>
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<tr>
<td>Asian Chemical Conglomerate</td>
</tr>
</tbody>
</table>
Outline

- Intro to ADI Analytics
- Background and Methodology
- Marcellus Innovation Needs
- Conclusions
ADI Analytics is studying Marcellus’ innovation needs to help Ben Franklin facilitate technology commercialization

SUPPLY
- Inventory relevant R&D / innovation work
- Prioritize ideas based on relevance to shale gas industry
- Stimulate further work by raising awareness of industry needs

OUTCOMES
- Build an informed view of shale gas industry needs and potential solutions
- Support development and commercialization of select technologies

DEMAND
- Identify and inventory industry’s technical needs / operational pain points
- Prioritize needs based on technical / commercial feasibility
- Facilitate interactions to drive adoption

Methodological Tools
- Expert Interviews
- Secondary Research
- Analytical Modeling
ADI Analytics is studying Marcellus’ innovation needs to help Ben Franklin facilitate technology commercialization

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Methodological Tools

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- Secondary Research
- Analytical Modeling

Focus of this talk
The shale gas industry value chain was assessed in a systematic fashion ...

**Exploration**
- Current practices
- Delivery source
- Key challenges

**Drilling & Completions**
- Emerging technologies
- Metrics to improve
- Maturity level

**Monetization**
- Who is innovating?
- Delivery mode
- Define impact

**Right to Operate**
… Through a number of in-depth expert interviews

**Expert Affiliations**

- **Producers**, 44%
- **Investors**, 17%
- **Services**, 22%
- **Consumers**, 17%

**Representative Expert Titles**

**Shale Gas Producers**
- Exploration Manager, Independent
- Operations Manager, Super Major
- Reservoir Engineers, Various
- VP, Technology, Independent
- Chief Geologist, Independent

**Oilfield Service Companies**
- Water Technology Manager
- Field Development Manager
- Modeling Technologists
- Sales Manager

**Investors**
- VP, E&P-Focused Investment Bank
- President, Energy VC Firm
- Principal, E&P VC Firm

**Gas Consumers**
- Technical Fellow, Automaker
- Gas Buyer, Steel Company
- LNG Manager, Major
Outline

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  - Marcellus Innovation Needs
- Conclusions
We assembled 30+ technical / operational issues by value chain segment and distilled them into 9 innovation challenges

## Major Innovation Challenges

<table>
<thead>
<tr>
<th>Exploration</th>
<th>Drilling &amp; Completions</th>
<th>Gas Monetization and Right to Operate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ability to identify “sweet spots”</td>
<td>4. Develop faster, cheaper, and cleaner D&amp;C technologies</td>
<td>7. Increase attractiveness and adoption of natural gas-based transportation</td>
</tr>
<tr>
<td>2. Improve predictive modeling capabilities</td>
<td>5. Improve fracturing effectiveness with fewer non-performing fractures</td>
<td>8. Develop cheap and scalable natural gas conversion / utilization processes</td>
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<tr>
<td>3. Develop tools for hydrocarbon characterization</td>
<td>6. Increase hydrocarbon recovery or reduce shale gas well decline rates</td>
<td>9. Optimize water footprint through reduction, recycle, and treatment processes</td>
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</table>
### Ability to identify “sweet spots”

#### Key Reservoir Properties

<table>
<thead>
<tr>
<th>Rock Properties</th>
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<tbody>
<tr>
<td>Brittle rock</td>
</tr>
<tr>
<td>Stress regime</td>
</tr>
<tr>
<td>Over-pressure</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Well Productivity</th>
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</thead>
<tbody>
<tr>
<td>Local lithological variations</td>
</tr>
<tr>
<td>Faults</td>
</tr>
<tr>
<td>Water</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gas in Place</th>
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<tbody>
<tr>
<td>Porosity</td>
</tr>
<tr>
<td>Microporosity</td>
</tr>
<tr>
<td>Organic content</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thermal Maturity</th>
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<tbody>
<tr>
<td>Fraction of dry gas</td>
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<tr>
<td>Liquid content</td>
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</table>

#### Key Issues

- Initial thinking around the lack of “sweet spots” has now changed
- Identification of “sweet spots” is challenging and needs inter-disciplinary approaches spanning geomechanics, geochemistry, petrophysics, seismology, rock properties, and other areas

#### Technology Needs

- Cheaper and ultra-high density seismic imaging or equivalent subsurface diagnostic tools
- Better integration and modeling of various data sets coupled with subsurface measurements

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2 Improve predictive modeling capabilities

Key Modeling Challenges

- Nanodarcy permeability
- Fracture locations
- Shale Gas Models
- Adsorbed gas in organic media

Key Issues

- Existing models and modeling approaches are generally inadequate
- Fundamental research to develop underlying principles is still underway

Technology Needs

- Better integration and modeling of various data sets coupled with subsurface measurements
- Development of seismic search engines to interrogate increasing data volumes
Develop tools for hydrocarbon characterization

**Representative Biomarkers**

<table>
<thead>
<tr>
<th>Biomarker Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isotope Rollover</strong></td>
<td>Ethane isotope rollover in produced gas indicates in situ gas cracking, well pressure, and overall productivity</td>
</tr>
<tr>
<td><strong>Isotope Reversals</strong></td>
<td>Isotope reversals in mud gas indicates over-pressured shale gas basins</td>
</tr>
<tr>
<td><strong>Permeability Markers</strong></td>
<td>Differences in gas isotope compositions between free and adsorbed gases</td>
</tr>
<tr>
<td><strong>Other Biomarkers</strong></td>
<td>New biomarkers, e.g., diamondoids, can provide new insights and information to support exploration</td>
</tr>
</tbody>
</table>

**Key Issues**

- Biomarkers such as diamondoids indicate crude oil maturity and are present in higher amounts in deeper, mature oils as a lot of oil has cracked into gas
- Better geochemical analyses using biomarkers can help find sweet spots

**Technology Needs**

- Identify relevant biomarkers
- Correlate biomarkers to key reserve, productivity, and performance metrics
4 Develop faster, cheaper, and cleaner D&C technologies

Marcellus Production Costs
(U.S. $ Per Million Btu)

Key Issues
- The share of drilling and completion costs continue to be high notwithstanding significant cost reductions
- Problem accentuated by large number of wells required

Technology Needs
- Advanced drilling technologies, e.g., at high pressures, lasers, and spallation
- Engineering system optimization of drilling operations to further reduce costs
- Optimized and environment-friendly drilling muds and fracking fluids

Source: ADI Analytics Research
Improve fracturing effectiveness with fewer non-performing fractures

Share of Low-Performing Fractures (Fractures contributing 1-5% of production)

Key Issues

- Growing realization that production per cluster of fractures is not uniform in shale gas reservoirs
- Nearly 30% - 50% of fractures contribute less than 1% to 5% of gas production

Technology Needs

- Better fracture imaging and siting, e.g., with cheaper micro-seismic, alternative diagnostic tools such as ultrasound, and better data interpretation
- Advanced proppants and optimized proppant delivery mechanisms

Sources: A. Gatti, Schlumberger, December 2010; ADI Analytics Research
Increase hydrocarbon recovery or reduce shale gas well decline rates

Average First-Year Decline in Gas Production

<table>
<thead>
<tr>
<th>Location</th>
<th>First-Year Decline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marcellus</td>
<td>64%</td>
</tr>
<tr>
<td>Barnett</td>
<td>64%</td>
</tr>
<tr>
<td>Fayetteville</td>
<td>65%</td>
</tr>
<tr>
<td>Haynesville</td>
<td>77%</td>
</tr>
</tbody>
</table>

Key Issues

- Liquid hydrocarbons and water can impact gas production from wells by reducing permeability
- Gas sorbed on clays and organic matter versus free gas can impact first-year declines

Technology Needs

- Advanced proppants and optimized proppant delivery mechanisms
- Separation of liquid hydrocarbons and water from gas downhole
- Microbial enhanced hydrocarbon recovery

Sources: D.M. Jarvie, Worldwide Geochemistry, 2010; ADI Analytics Research
7 Increase attractiveness and adoption of natural gas-based transportation

### Energy Density of Various Fuels
(Thousand Btu Per Cubic Foot)

- **Diesel**: 1,058
- **Gasoline**: 922
- **Ethanol**: 594
- **CNG**: 266

### Key Issues
- CNG vehicles suffer from lower compression ratio and efficiency …
- … Emit high unburned CH₄ emissions
- Low population of CNG vehicles and lack of fueling infrastructure

### Technology Needs
- Low-cost vehicle retrofit and fuel distribution technologies
- Evaluation of CNG blends with other fuels for fleet-based transportation
- Conversion to DME as diesel substitute

Sources: J. Eberhardt, DEER, 2002; A.L. Boehman, Penn State University, April 2011; ADI Analytics Research
Develop cheap and scalable natural gas conversion / utilization processes

Key Issues
- Various natural gas conversion processes have high capital costs …
- … Driven primarily by the cost of generating syngas and …
- … Limited number of commercial plants

Technology Needs
- Cheap and scalable syngas process
- Modular GTL, MTG, and MTO plants
- Cost-effective air separation units
- Other C1 activation routes
Optimize water footprint through reduction, recycle, and treatment processes

Key Issues
- Flowback (low salinity, high organics) produced initially is reused by 20-30%
- Produced water is low-organic, high-salinity effluent
- Varies a lot across wells/basins/time

Technology Needs
- Drilling muds, fracking fluids, and proppants compatible with used water
- Water treatment options that cost no more than $2-$5 per barrel
- Cradle-to-grave water management solutions

Intra-Basin Produced Water Variability (Total Dissolved Solids, mg/l)

Sample 1: 252,000
Sample 2: 160,000
Sample 3: 144,000
Sample 4: 33,300
Tap water: 440

Sources: D. Sarkar, Halliburton, 2010; ADI Analytics Research
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Conclusions

- The shale gas industry has **grown rapidly and significantly** in the Marcellus basin …

- … But **continues to need new technologies and innovations** to address their technical challenges and operational pain points

- These industry needs are a **significant opportunity for researchers, innovators, and entrepreneurs** to develop step-change solutions for industry

- In addition, **talent and workforce development, supply chain growth, stakeholder engagement, and interactive policy development** can help Pennsylvania tap **additional economic development value** from the Marcellus

- Finally, technology development and commercialization can be challenging but the oil and gas industry has a proven track record of evaluating and integrating new innovations