An Innovation Roadmap for Marcellus

Ben Franklin Technology Partners / Shale Gas Innovation & Commercialization Center
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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 …

	Markets	Technology	Operations	Functions
Oil & Gas	 Exploration	 Production	 Refining	 Distribution
Power & Mining	 Coal	 Generation	 Transmission	 Carbon
Renewables & Cleantech	 Biomass	 Solar	 Wind	 Geothermal
Chemical & Industrial	 Plastics	 Materials	 Auto	 Manufacturing

… Offering services that help clients understand markets, develop strategy, improve operations, and deploy technology

Market Research	Conduct in-depth research and analysis to identify new markets or segments, their size, profitability, growth, competitive landscape, client fit, and execution strategy
Investment Analysis	Build valuation models to analyze investments in capital projects, businesses, or capabilities to estimate economic value, ROI, NPV, IRR, risks, and other metrics
Business Strategy	Advise clients on competencies and improving them with organization and resource alignment to enhance competitiveness, entry barriers, and shareholder value
Scenario Planning	Develop and explore carefully drawn future scenarios to define medium-, long-term visions and pressure-test them through quantitative, analytical models
Competitive Benchmarking	Benchmark client capabilities, costs, and competitiveness against industry based on public information and rigorous modeling and suggest improvement ideas
Technology Assessment	Understand technologies including their business impact, cost, trends, competing options, deployment risk, and commercialization success
Innovation Strategy	Implement programs for ideation, portfolio development, stage-gate maturation, open innovation, IP management, functional excellence, and talent development
Process Design	Assess organizational goals and “as is” processes to identify gaps and design “to be” processes that fill gaps and achieve target goals

Our growing team brings experience in supporting blue-chip clients on various business and technical consulting projects

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

Select Clients

- U.S. Department of Energy
- National Institute of Standards and Technology
- Fortune 100 Oil and Gas Major
- FTSE 100 Oil and Gas Major
- Fortune 500 Coal Company
- Recent IPO Biofuels Start-Up
- Energy-Focused VC Firm
- Ben Franklin Technology Partners
- Fortune 500 E&P Company
- Energy Training Services Vendor
- Asian Chemical Conglomerate

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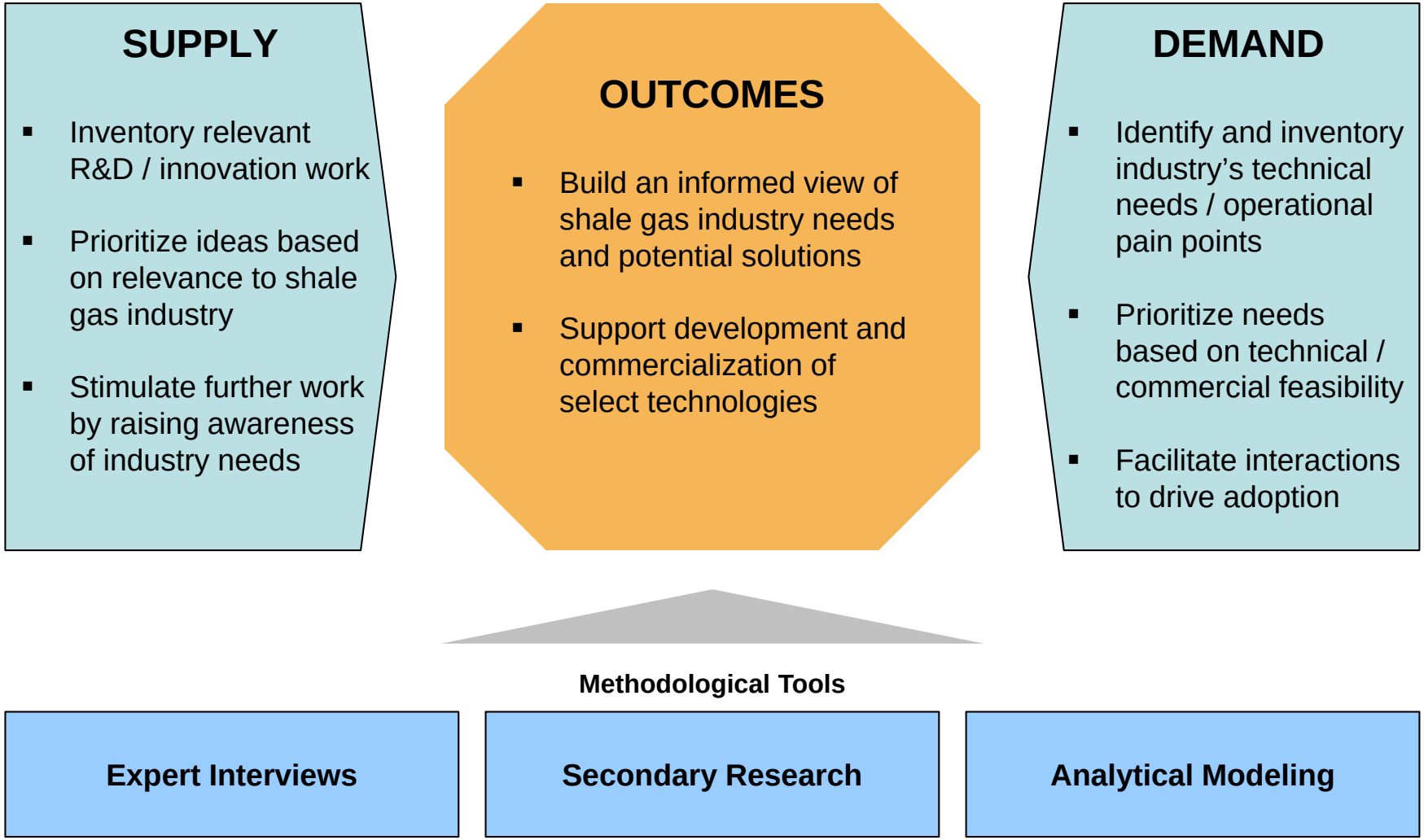
ADI Analytics is studying Marcellus' innovation needs to help Ben Franklin facilitate technology commercialization



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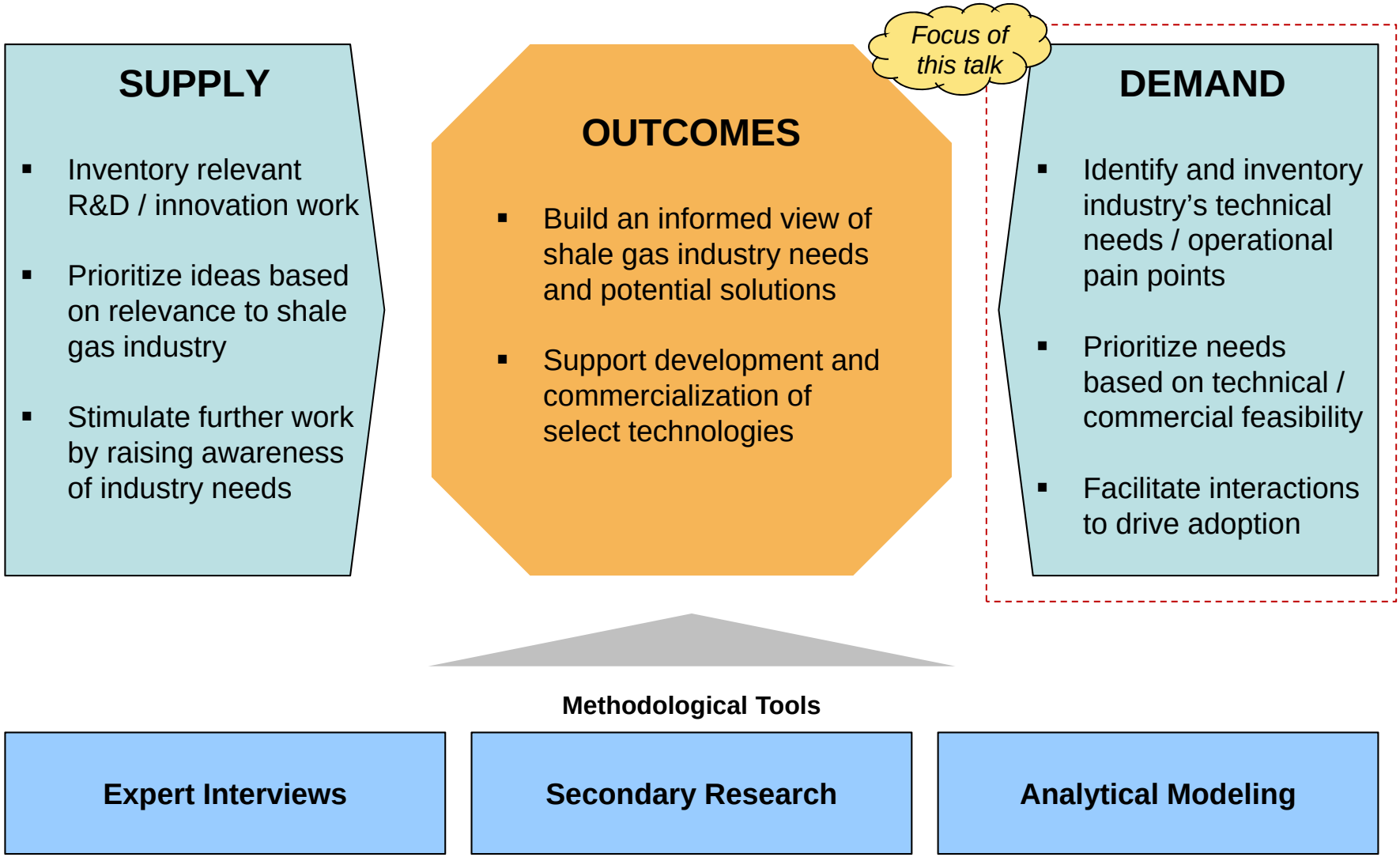
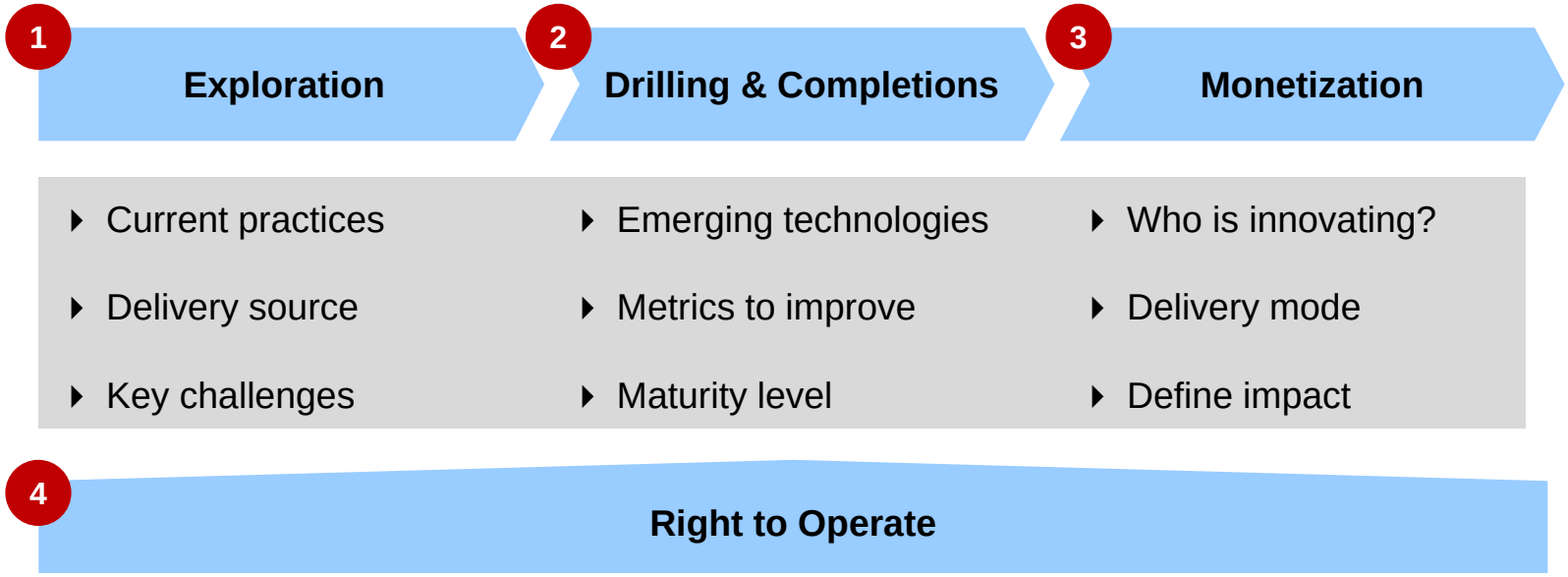
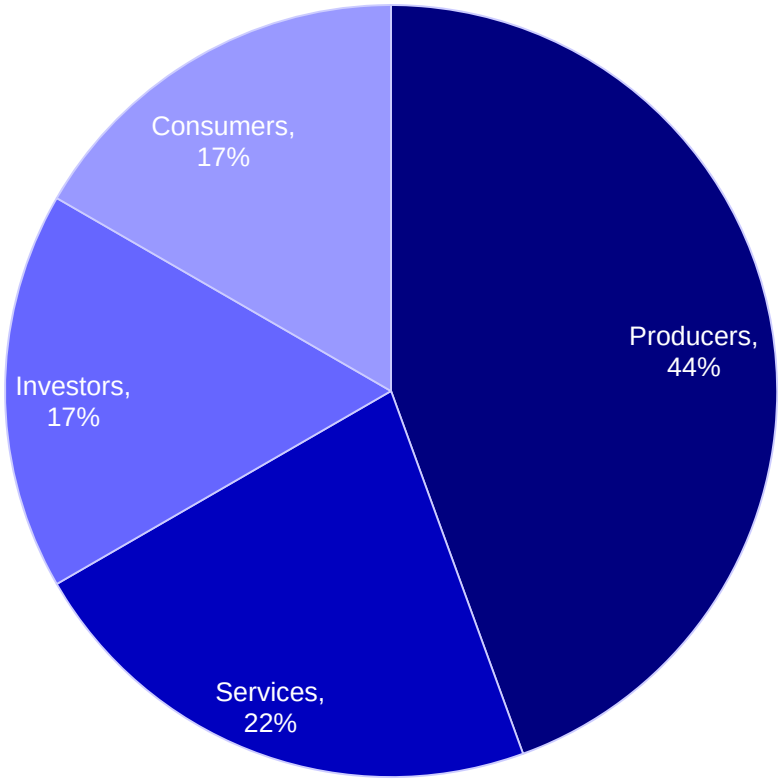


The shale gas industry value chain was assessed in a systematic fashion …



… Through a number of in-depth expert interviews

Expert Affiliations
(n = ~30)



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

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We assembled 30+ technical / operational issues by value chain segment and distilled them into 9 innovation challenges

Major Innovation Challenges

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

1 Ability to identify “sweet spots”

Key Reservoir Properties

Rock Properties	▪ Brittle rock ▪ Stress regime ▪ Over-pressure
Well Productivity	▪ Local lithological variations ▪ Faults ▪ Water
Gas in Place	▪ Porosity ▪ Microporosity ▪ Organic content
Thermal Maturity	▪ Fraction of dry gas ▪ Liquid content

Key Issues

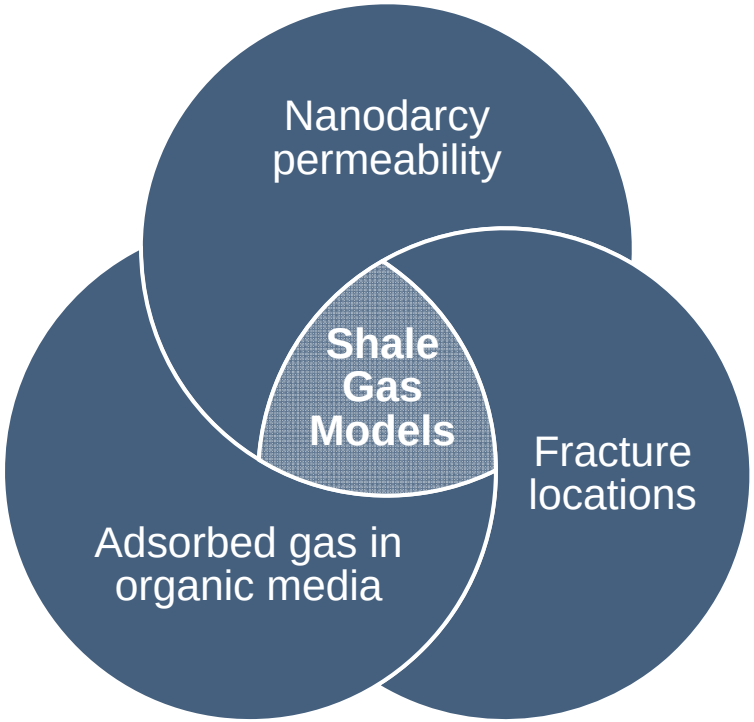
- Initial thinking around the lack of “sweet spots” has now changed
- Identification of “sweet spots” is challenging and needs inter-disciplinary approaches spanning geomechanics, geochemistry, petrophysics, seismology, rock properties, and other areas

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

2 Improve predictive modeling capabilities

Key Modeling Challenges



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

3 Develop tools for hydrocarbon characterization

Representative Biomarkers

Isotope Rollover	Ethane isotope rollover in produced gas indicates in situ gas cracking, well pressure, and overall productivity
Isotope Reversals	Isotope reversals in mud gas indicates over-pressured shale gas basins
Permeability Markers	Differences in gas isotope compositions between free and adsorbed gases
Other Biomarkers	New biomarkers, e.g., diamondoids, can provide new insights and information to support exploration

Key Issues

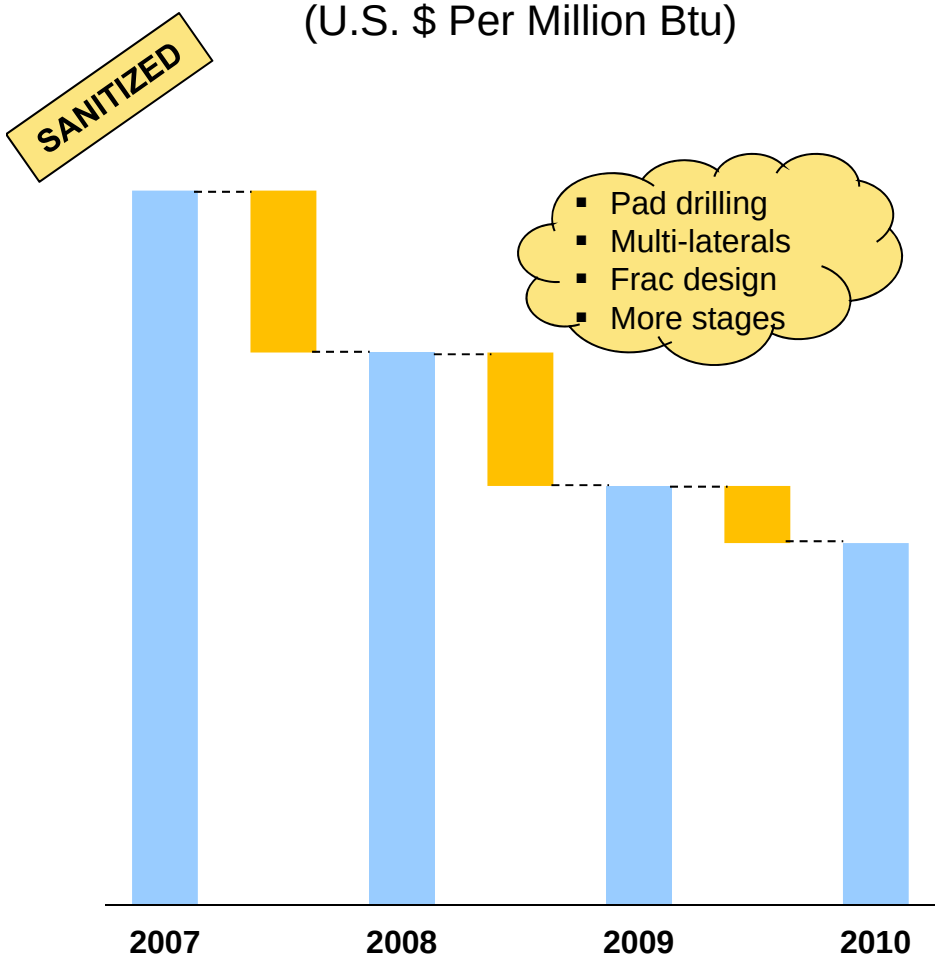
- Biomarkers such as diamondoids indicate crude oil maturity and are present in higher amounts in deeper, mature oils as a lot of oil has cracked into gas
- Better geochemical analyses using biomarkers can help find sweet spots

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

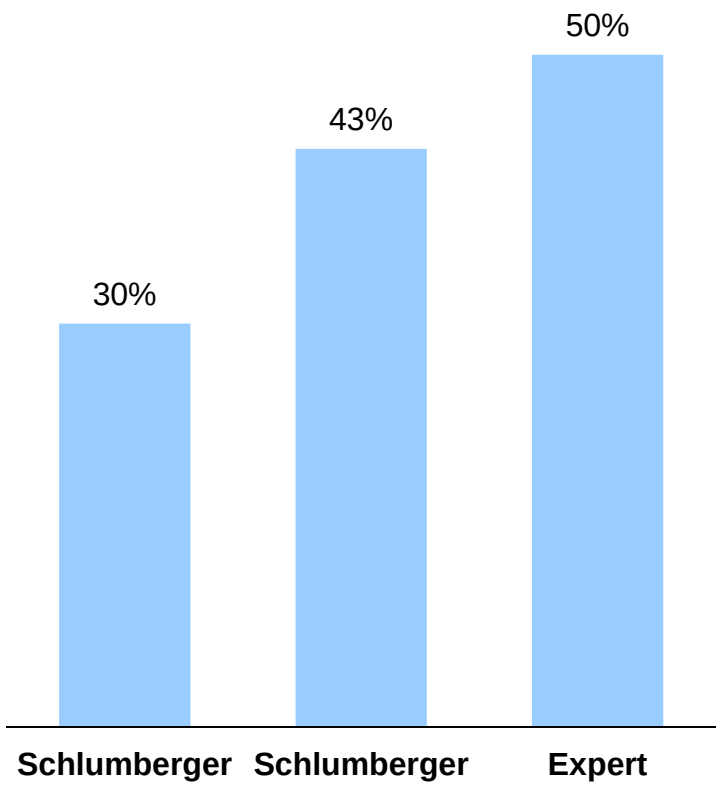
Technology Needs

- 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

5 Improve fracturing effectiveness with fewer non-performing fractures

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



Key Issues

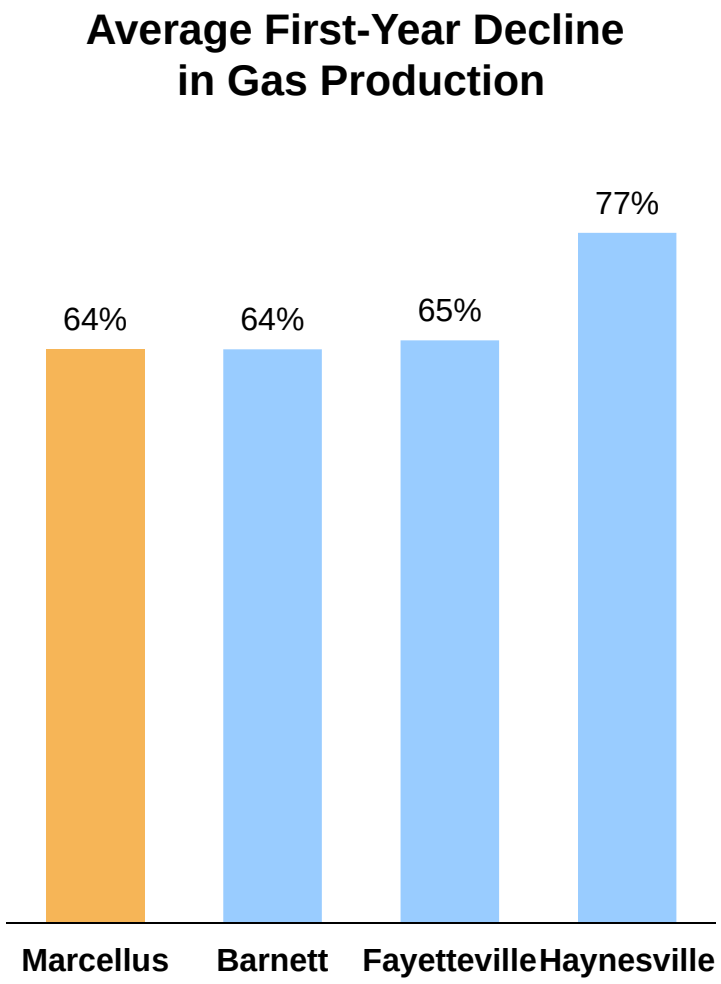
- Growing realization that production per cluster of fractures is not uniform in shale gas reservoirs
- Nearly 30% - 50% of fractures contribute less than 1% to 5% of gas production

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

6 Increase hydrocarbon recovery or reduce shale gas well decline rates



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

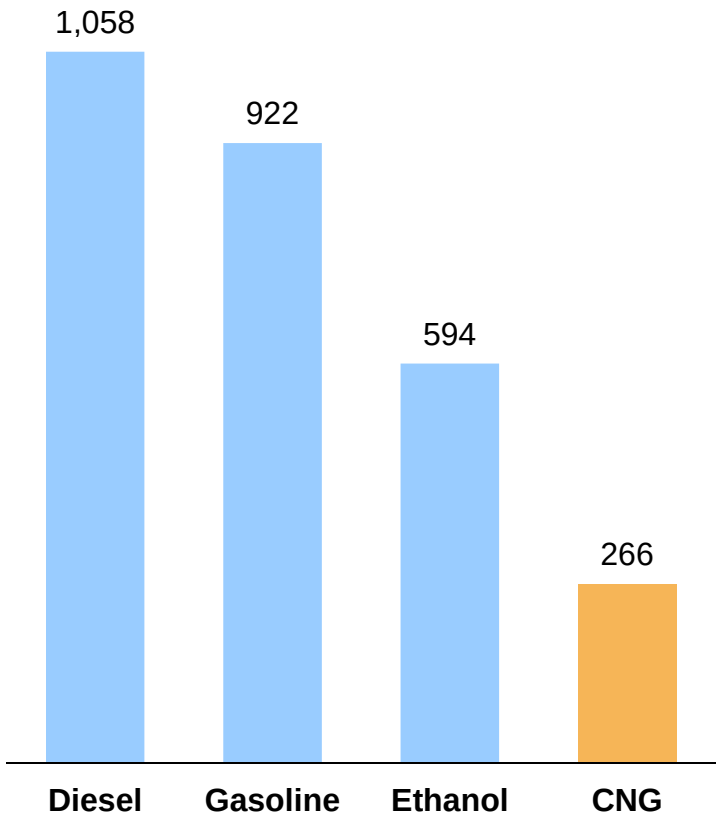
Technology Needs

- 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)



Key Issues

- CNG vehicles suffer from lower compression ratio and efficiency …
- … Emit high unburned CH_4 emissions
- Low population of CNG vehicles and lack of fueling infrastructure

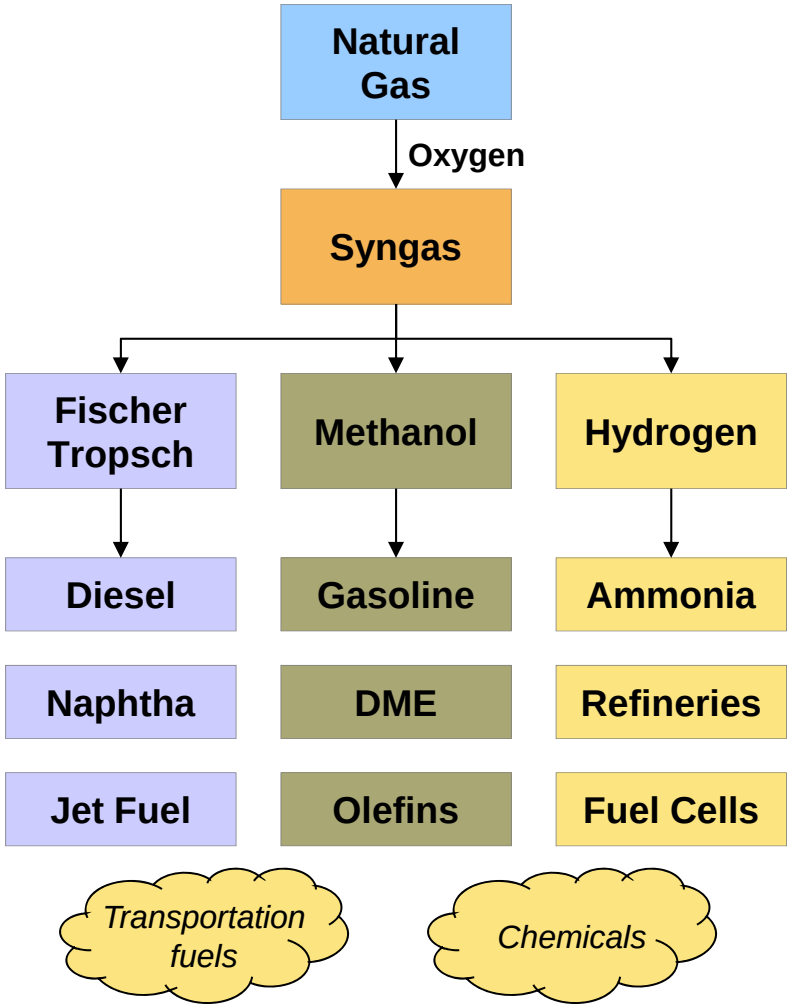
Technology Needs

- 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

8 Develop cheap and scalable natural gas conversion / utilization processes

Gas Conversion Processes



Key Issues

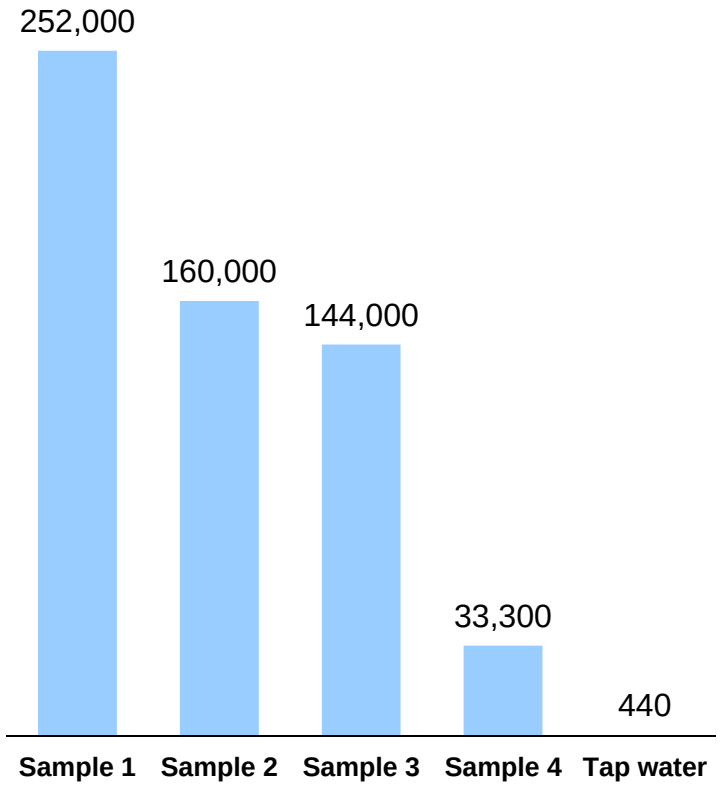
- Various natural gas conversion processes have high capital costs …
- … Driven primarily by the cost of generating syngas and …
- … Limited number of commercial plants

Technology Needs

- Cheap and scalable syngas process
- Modular GTL, MTG, and MTO plants
- Cost-effective air separation units
- Other C_1 activation routes

9 Optimize water footprint through reduction, recycle, and treatment processes

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



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 then $2-$5 per barrel
- Cradle-to-grave water management solutions

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