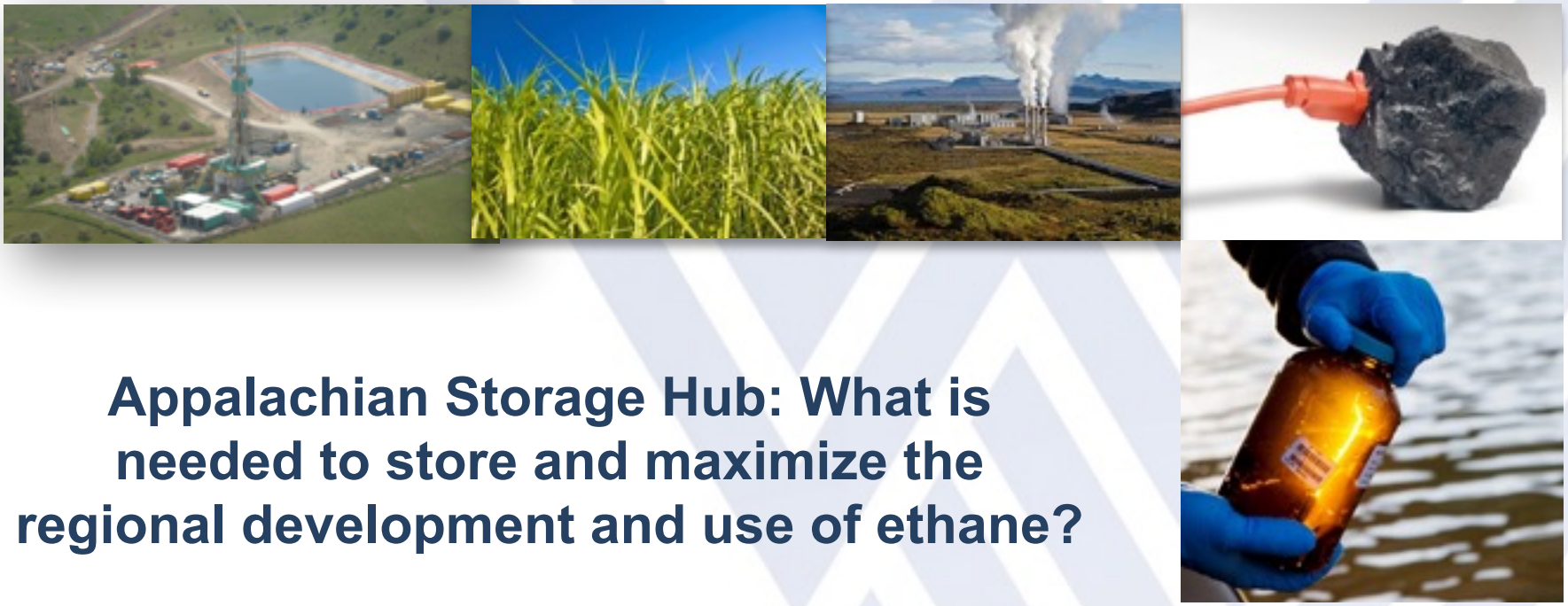


Appalachian Storage Hub: What is needed to store and maximize the regional development and use of ethane?

Brian J. Anderson
Director, The WVU Energy Institute
GE Plastics Material Engineering Professor
Chemical Engineering

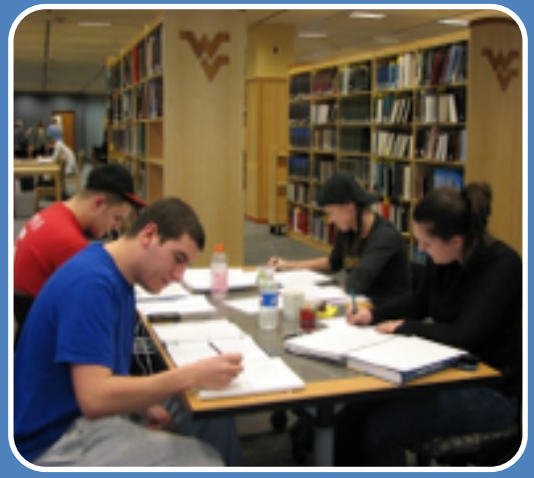
MARCELLUS & MANUFACTURING DEVELOPMENT CONFERENCE

March 23, 2016
Charleston, WV

Energy Institute Initiatives

Research

- Fossil
  - Coal, gas, oil
- Renewable
  - Biomass, solar
- Policy
  - Economic, regulatory
- Environment
  - Water, air



Education

- Energy graduate programs
- Energy minor and certificate programs
- General Education Curriculum
- Student energy club

Campus Sustainability

- Building efficiency
- Transportation services
- Campus energy services
- Student learning opportunities

Broad Areas of Energy Research

- **Fossil Energy**: Promote the efficient use of fossil resources, conversion, extraction, utilization, and environmental management

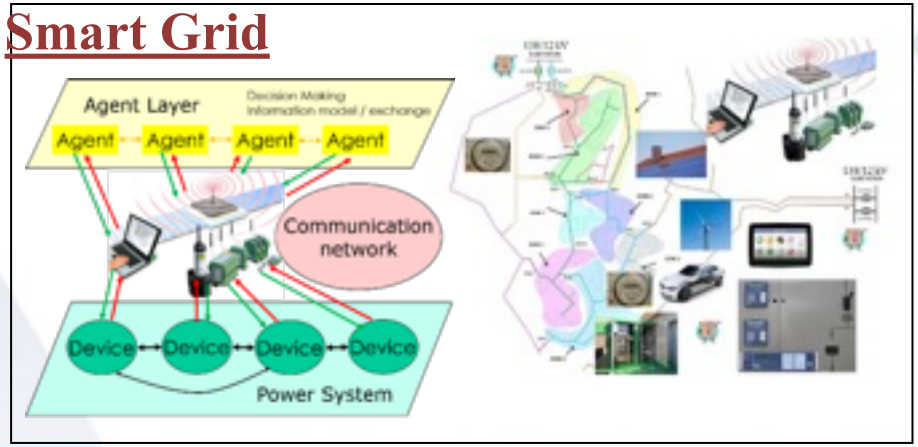
- **Sustainable Energy**: Promote energy efficiency, alternative fuels, conservation, renewable energy sources, geothermal, and sustainable and responsible development

- **Energy Policy**: Analyze energy policies, and their impact on use of these resources, carbon management, environmental, and infrastructure

- **Environmental Stewardship**: Ensuring that energy production is balanced with minimizing negative impacts to our air and water resources

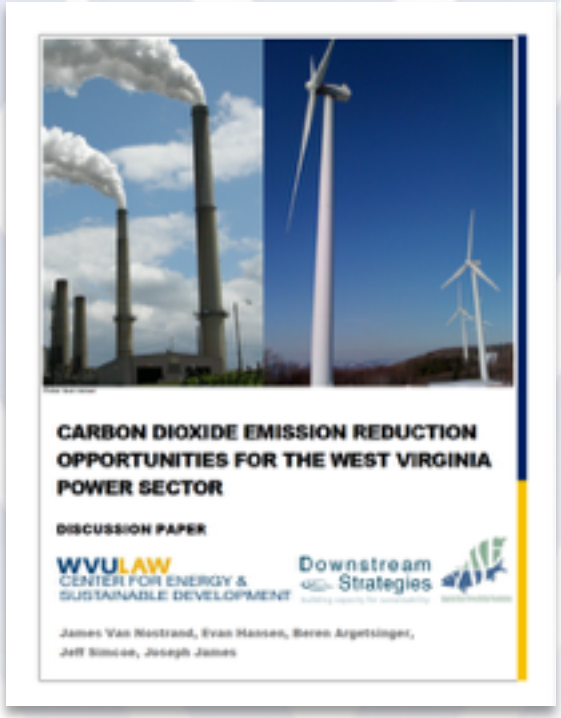
Sustainable Energy

- **Sustainable Energy**: Promote energy efficiency, alternative fuels, conservation, renewable energy sources, geothermal, and sustainable and responsible development
  - renewable energy; transitions from traditional to renewable energy sources:
  - geothermal energy
  - biomass conversion and utilization
  - biomass/coal conversion and co-firing
  - energy efficiency
  - conservation
  - sustainable design and development



Energy Policy

- **Energy Policy**: Analyze energy policies, and their impact on use of these resources, carbon management, environmental, and infrastructure
  - analysis and modeling of energy and environmental policy issues
  - analysis for the development of strategies for the management of carbon
  - analysis of energy infrastructure systems
  - data-driven policy assessment
  - community impact evaluation



Environmental Stewardship

- **Environmental Stewardship**: Ensuring that energy production is balanced with minimizing negative impacts to our air and water resources
  - developing tools to lower the carbon footprint of our energy portfolio
  - development of efficient water usage methods in energy production
  - evaluation of impacts of energy systems on air and water quality
  - sustainable use of water in energy production
  - life cycle assessment of energy systems

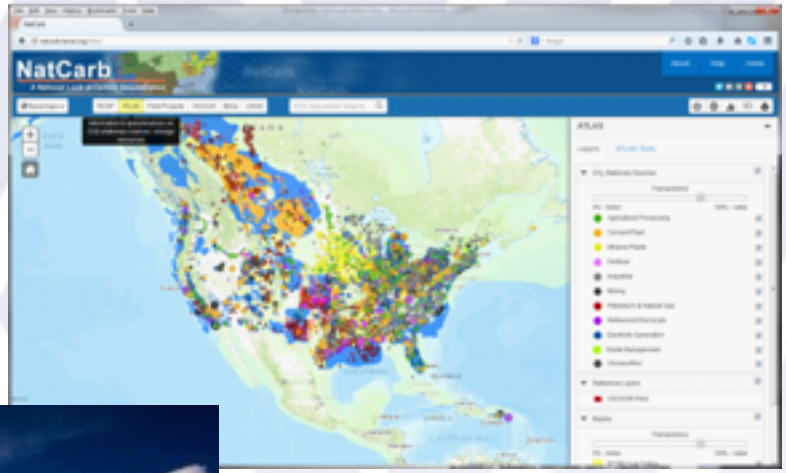
air emissions monitoring
CAFEE

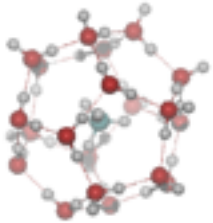
WEST VIRGINIA
WATER RESEARCH INSTITUTE

Fossil Energy

- **Fossil Energy**: Promote the efficient use of fossil resources, conversion, extraction, utilization, and environmental management
  - carbon capture and geologic storage
  - high-efficiency engine and vehicle technology
  - fuels production
  - clean power generation and distribution
  - extraction technology
  - utilization of coal for clean fuels and chemicals

NatCarb- Resource Assessments and Geospatial Resources





Shale Gas: From Supply to Demand

- Research at WVU spans the full range from upstream to downstream
- We have entered a strategic partnership with Ohio State University in five areas of shale-related activities
  - Subsurface
  - Utilization
  - Environment
  - Policy
  - Economics

"Father of Geology" *Israel C. White.*

POWERSOURCE

ENERGY NEWS. IN CONTEXT.
Pittsburgh Post-Gazette

Schedule a mammogram.

NETL developing working lab to improve shale drilling

By Anya Litvak / Pittsburgh Post-Gazette

Most Read

MARCELLUS SHALE ENERGY AND ENVIRONMENT LABORATORY

MSEEL

The objective of the Marcellus Shale Energy and Environment Laboratory (MSEEL) is to provide a long-term collaborative field site to develop and validate new knowledge and technology to improve recovery efficiency and minimize environmental implications of unconventional resource development

PI: Tim Carr
Phone: 304.293.9660
Email: tim.carr@mail.wvu.edu

MSEEL Vision

- Demonstrate the Best Approach to Drill, Complete and Produce a New Horizontal Well That Minimizes Any Environmental/Social Costs While Maximizing Economic Productivity
- Monitor and Document Impacts in a Controlled Environment
  - Greenhouse Gas Emissions
  - Local Air Pollution
  - Water Supply and Quality
  - Noise and Activity
  - Societal Impacts
- Develop New Technologies
  - Microseismic Monitoring
  - Production Monitoring
  - Advanced Logging
- Develop New Scientific and Engineering Approaches to Apply to Multi-disciplinary and Multi-institutional Natural Resource Studies

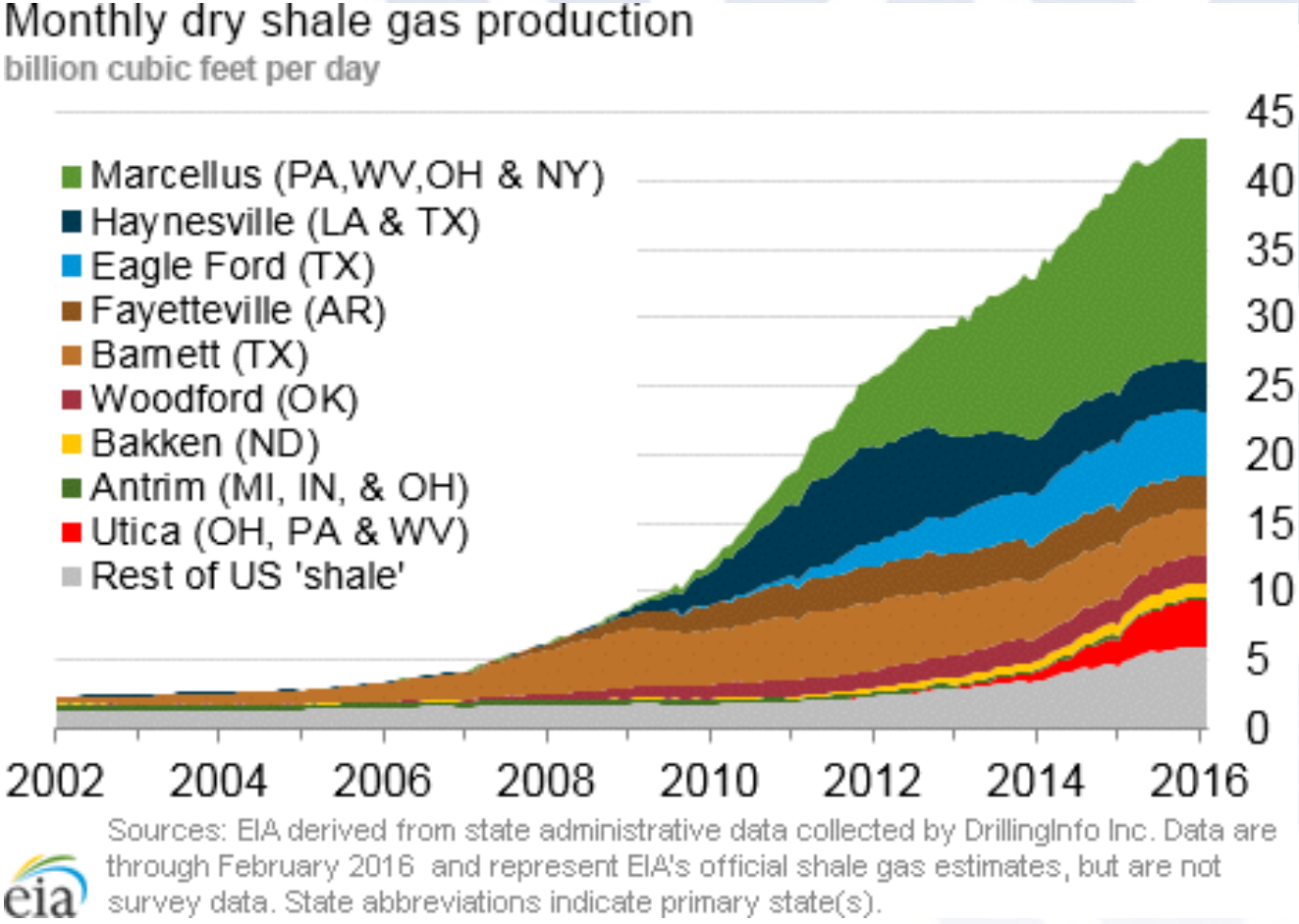
Marcellus Shale Energy And Environment Laboratory - MSEEL

MSEEL Science Well

MSEEL Research Areas

- Deep Subsurface Geochemistry
  - Characterization of Core, Fluids and Gases
- Database Development and Maintenance
  - Data portal will serve as central place to exchange and search for data
- Surface Environmental
  - Air Emissions
  - Water Supply and Quality
- Geologic Engineering
  - Analysis and Modeling of Well Drilling and Completion
  - Reservoir Simulation
  - Production Monitoring
  - Geostatistical Well Analysis
- Geophysical and Geomechanical
  - Microseismic Monitoring
- Economic and Societal

Marcellus (and Utica) are driving U.S. Gas production



WVU Mountain of Excellence in Shale Gas - Opportunities

- WV – a long history in NG to chemicals
  - Clendenin, WV: Site of the world's first commercial ethylene plant

- Union Carbide 10,000 lb/day ethylene plant online in 1921
- Driven by access to raw materials

- Upstream:
  - resource evaluation,
  - management, and
  - production
- Downstream:
  - use as an alternative transportation fuel
  - conversion to liquid fuels or chemicals
  - use in fuel cells

Natural gas utilization

The focus is on responsible demand-side research that emphasizes the technology needs to promote responsible growth of the shale gas industry and economic development in the State.

The focus must include economic, legal, and policy needs to inform the State and legislative decision makers.

The emergence of significant national natural gas plays, coupled with thermocatalyic pathways, provides the potential to decrease dependence on conventional petrochemical routes towards a variety of products, including gasoline, diesel, methanol, ethanol, ammonia, hydrogen, and a variety of oligomers and polymers.

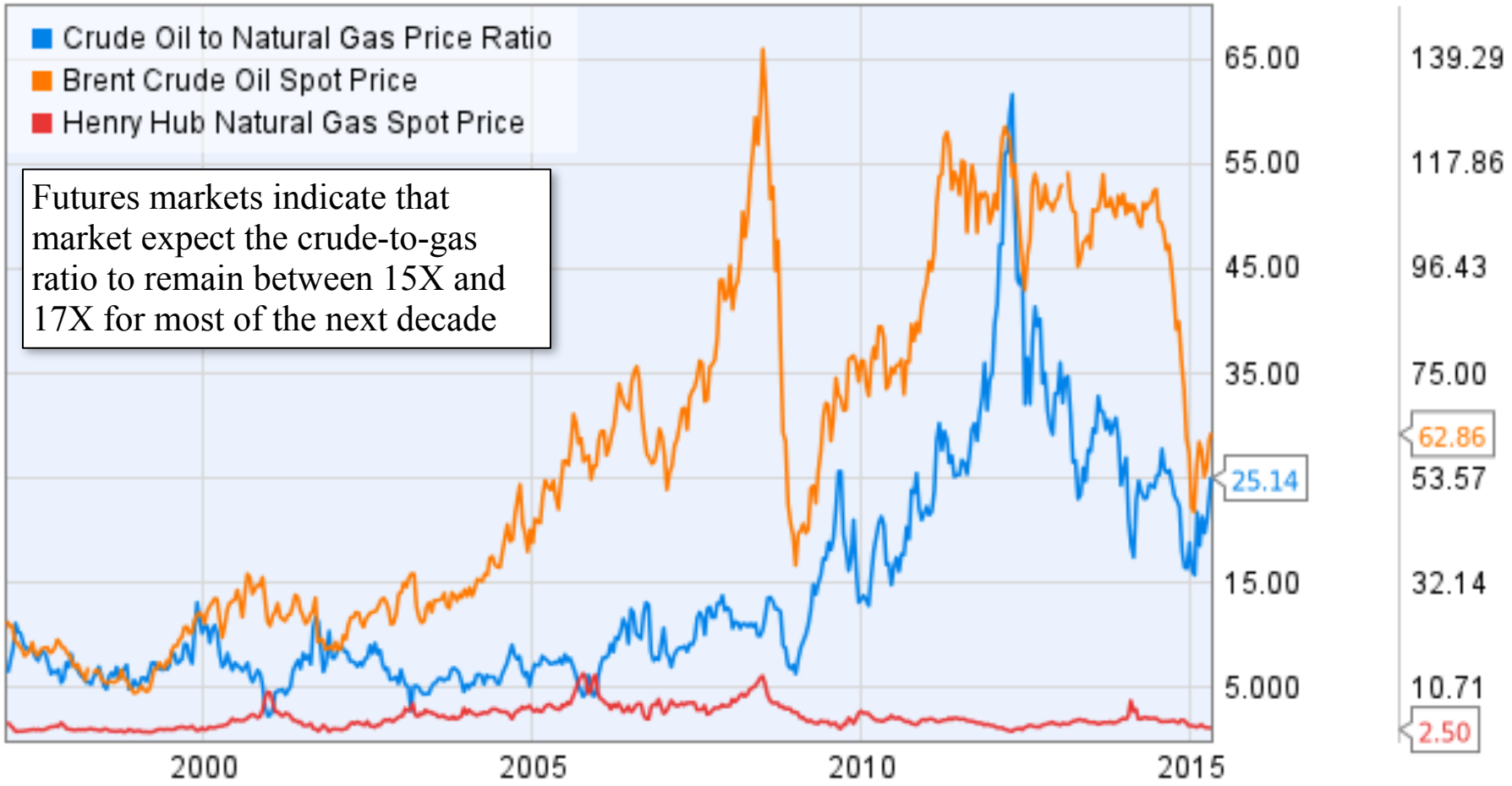
Statler Chair Lead
Shale Gas Utilization Initiative
(focus on STEM)

- **Demand & Utilization**
- **Finances**
- **Stationary & Mobile**

Natural gas utilization: around to stay?

Source: EIA

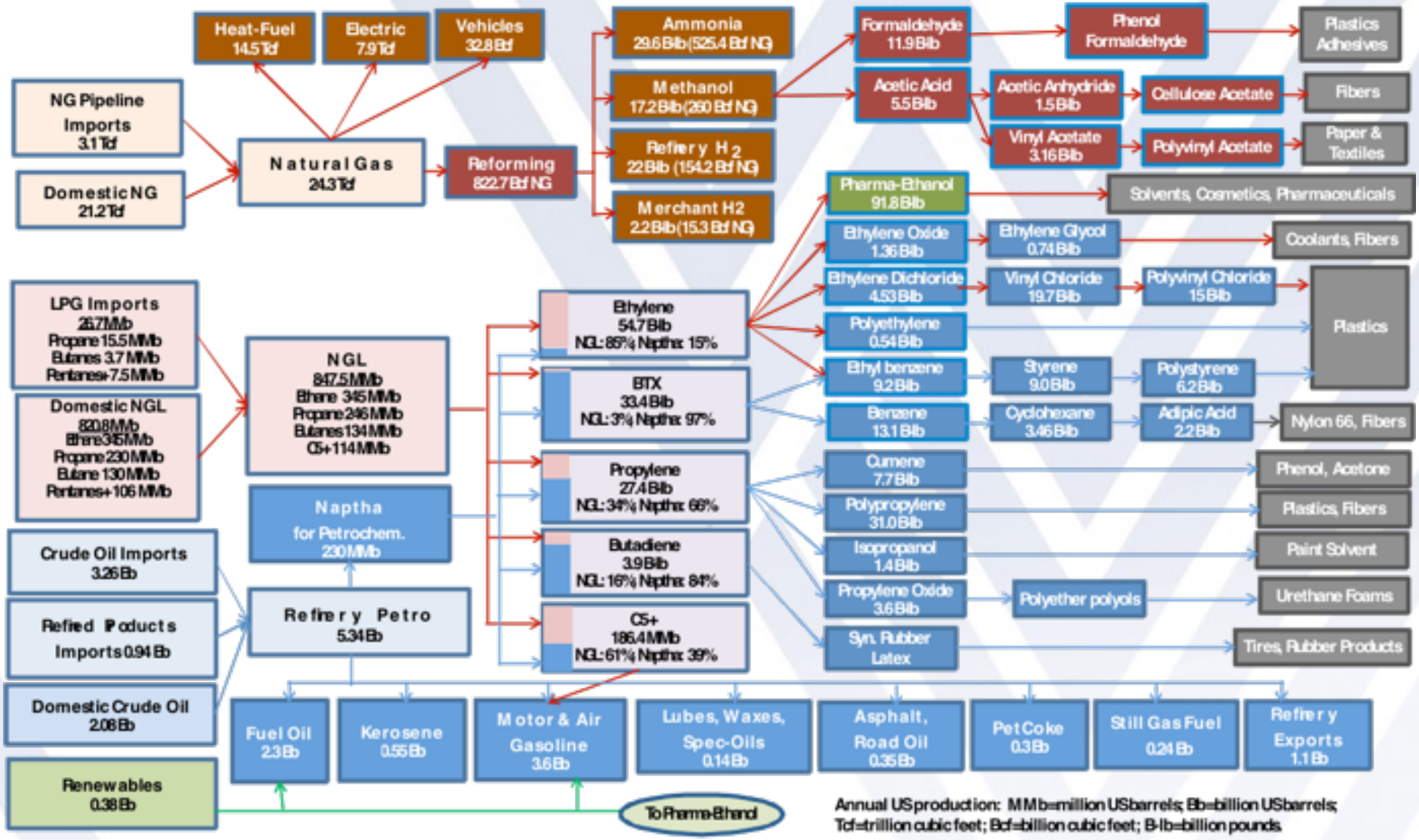
Natural gas utilization: around to stay?



Source: EIA

The "true" BTU ratio of WTI crude to natural gas of 5.8 MMBtu/Bbl

Natural gas utilization: many options



Natural gas utilization: pathway toward a natural gas economy?

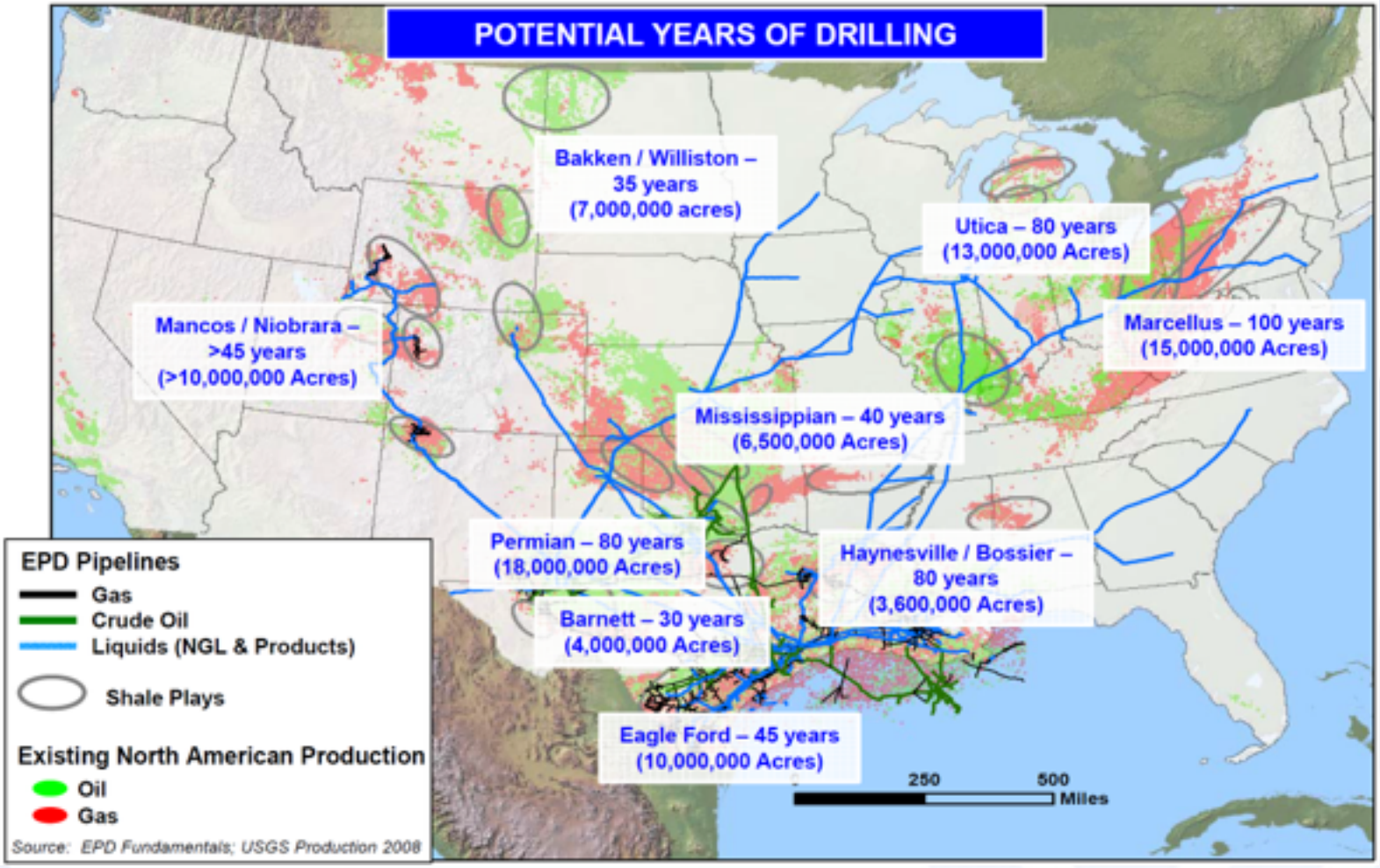
Significant R&D needs remain:

- Process Synthesis:
  - development and utilization of advanced algorithms to synthesize and model processes tailored for a specific characteristic
- Reaction Engineering:
  - leveraging scientific innovation, leveraged by technology pull and push, to develop processes (thermal, catalytic, photo, etc.) tailored for natural gas feeds.
- Grand Challenges:
  - exploit advances in fundamental computational and experimental sciences to rapidly identify optimum structure-function relationships
  - overcoming grand challenges associated with natural gas utilization (C1 activation, H-cleavage, coking, etc.).

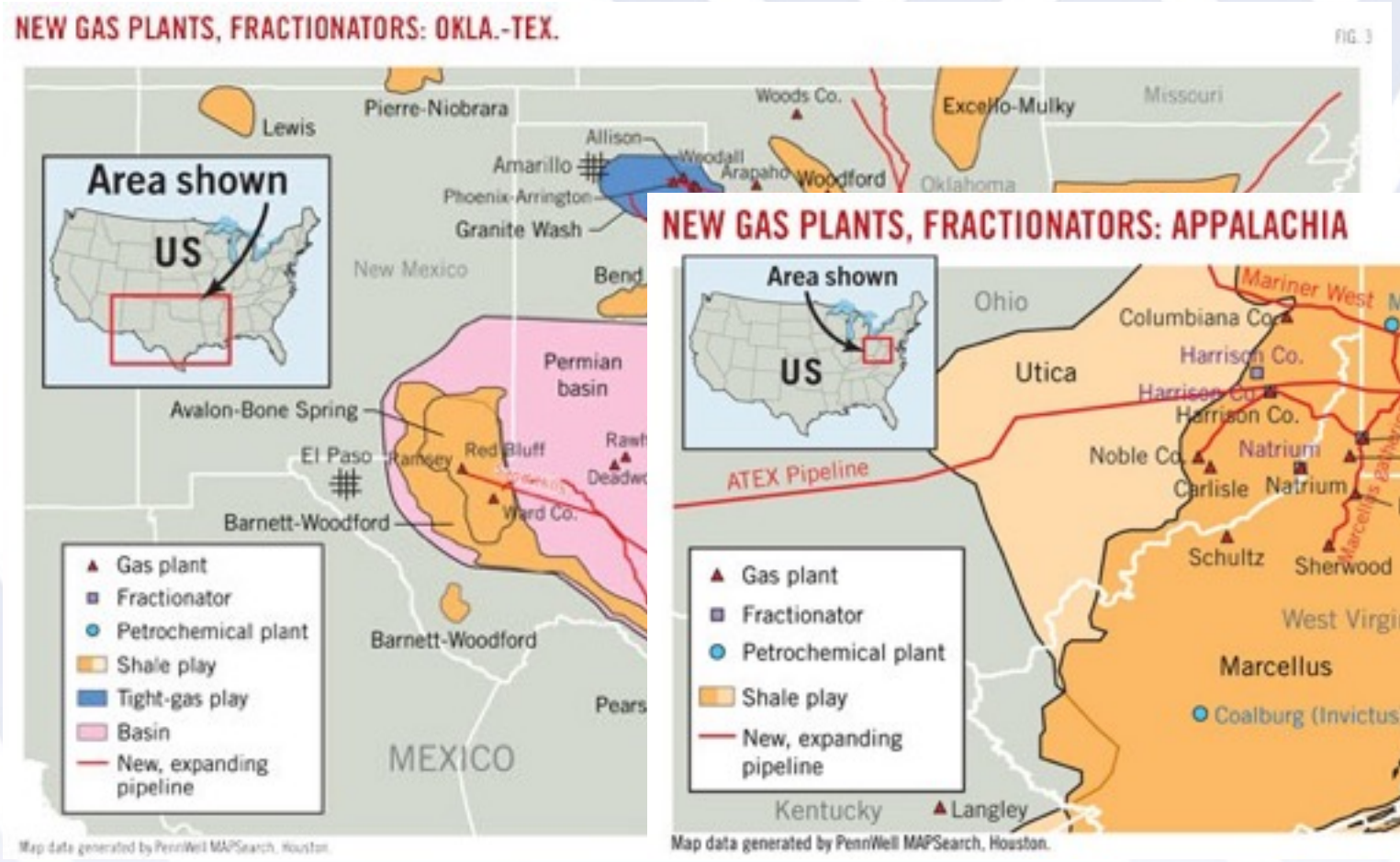
Natural gas utilization at WVU

- Topic areas
  - Gas to liquids (GTL)
    - Catalytic approaches
    - Non-catalytic approaches
  - Direct-use NG fuel cells (FC)
  - NG combustion (NGC)
    - Stationary
    - Vehicular
  - Gas to chemicals (CTC)
    - Alkanes
    - Aromatics
- Basic science needs
  - Catalyst and chemical pathway development (GTL, GTC)
  - Fundamental SOFC material development (FC)
  - Reactive CFD modeling (NGC, FC)
  - Computational chemistry (GTL,GTC,NGC,FC)

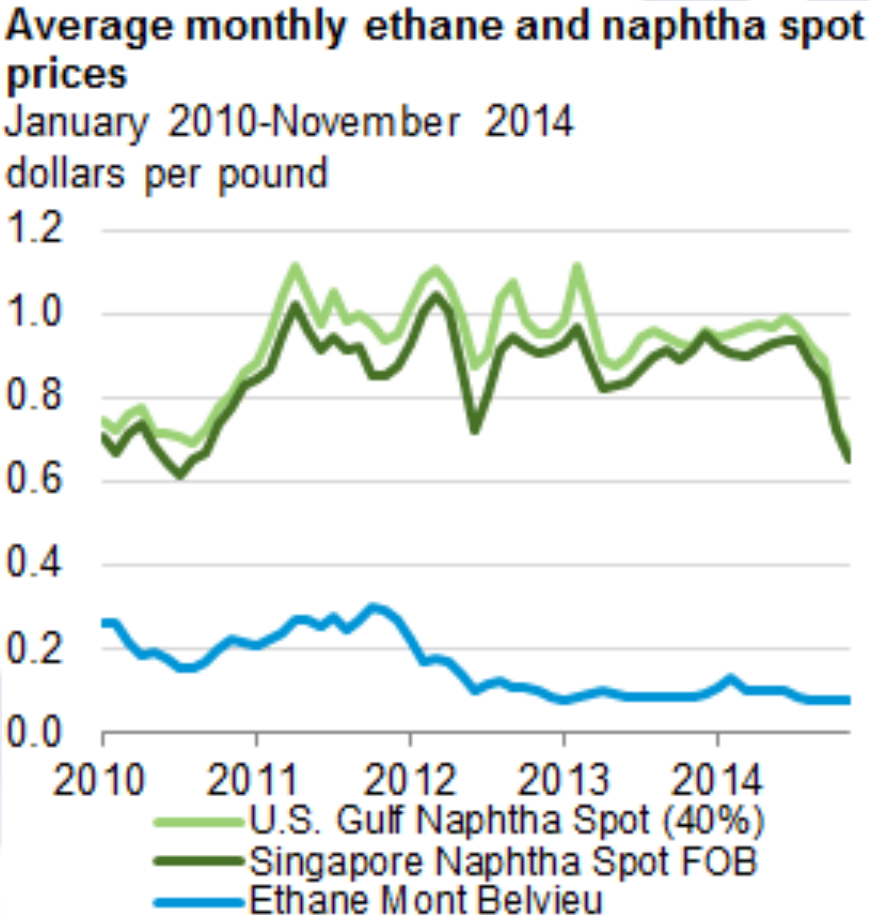
Potential lifetime of North American Gas

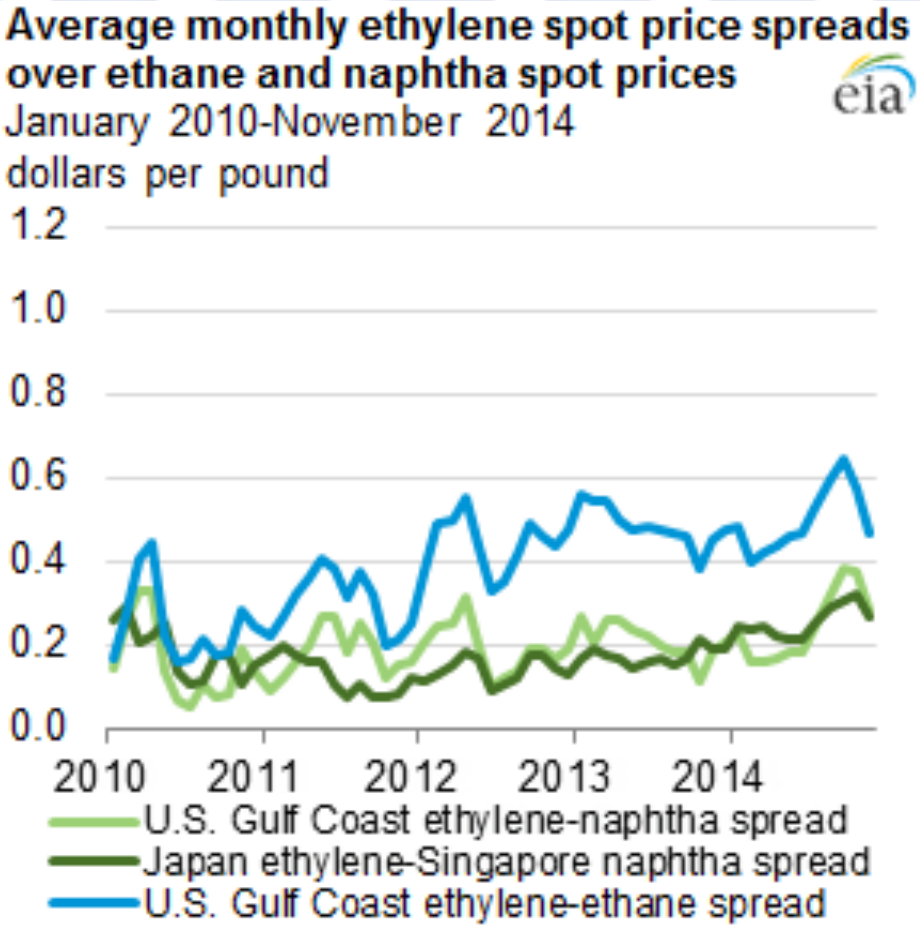


New Fractionation Capacity in the U.S.



The U.S. has become long on ethane



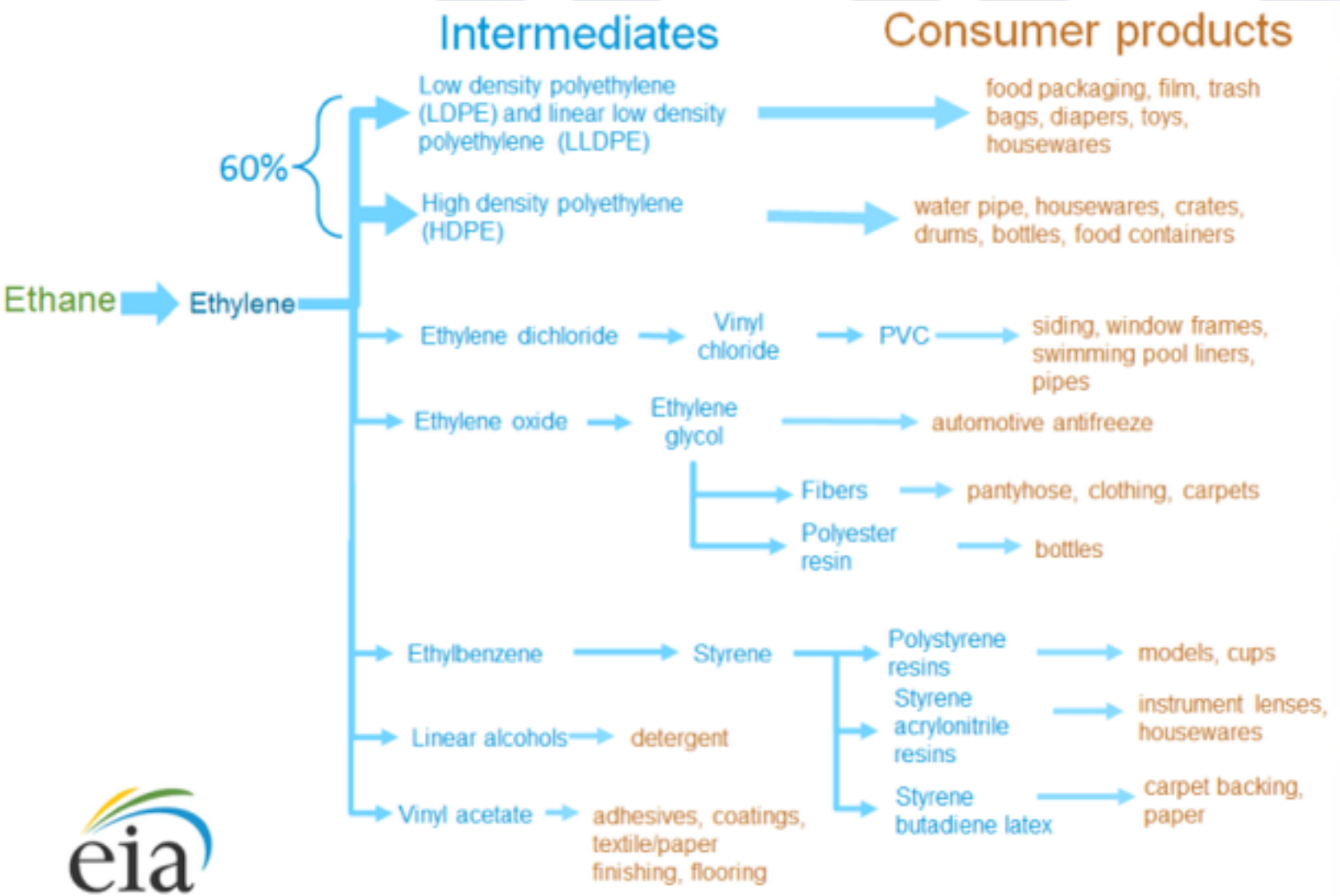


Why focus on ethane?

Purity product	Conversion factor (Mcf/bbl)	Application	End-use product	Primary sector
Ethane	1.558	Ethylene for plastics production, petrochemical feedstock	Plastic bags, plastics, antifreeze, detergent	Industrial
Propane	1.499	Propylene for plastics/solvents/ petrochemicals, residential/ commercial heating, cooking	Plastics, solvents, LPG for home heating, stoves, BBQ, engines	Industrial, residential, commercial
Normal butane	1.288	Petrochemical feedstock, gasoline blendstock	LPG, synthetic rubber for tires, lighter fuel	Industrial, transportation
Isobutane	1.245	Petrochemical feedstock, gasoline blendstock	Alkylate for gasoline, aerosols, refrigerants	Transportation
Natural gasoline	0.940	Gasoline blendstock, ethanol denaturant, diluent for bitumen	Motor gasoline, Canadian crude oil imports	Transportation

Source: U.S. Energy Information Administration.

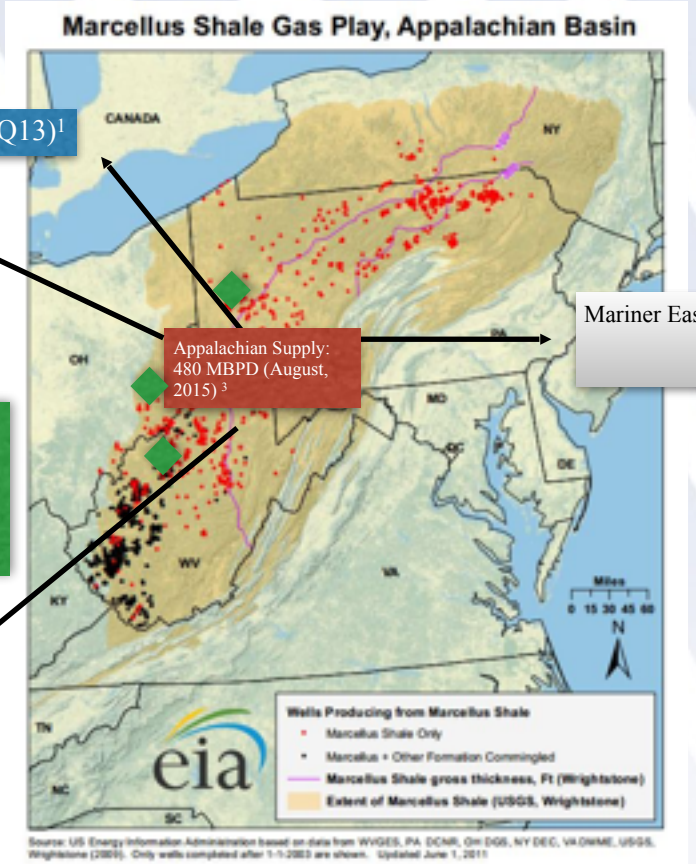
Why focus on ethane?



Regional Advantage

Product	Price Unit	Gulf of Mexico	Europe	Asia	Appalachian Basin
natural gas	$/MMBtu	2.50	6.30	8.20	0.87
ethane	$/gal	0.19	0.49	0.60	0.04
propane	$/gal	0.41	0.72	0.87	0.10
isobutane	$/gal	0.66	0.64	0.93	0.40
n-butane	$/gal	0.66	0.64	0.93	0.25
gas condensate	$/gal	1.06	1.25		0.90

Estimated Ethane Supply and Announced Demand



Mariner West (MW): 50 MBPD (4Q13)[1]

KM Utopia (MW): 18 MBPD (1Q18)[1]

Appalachian Supply: 480 MBPD (August, 2015) [3]

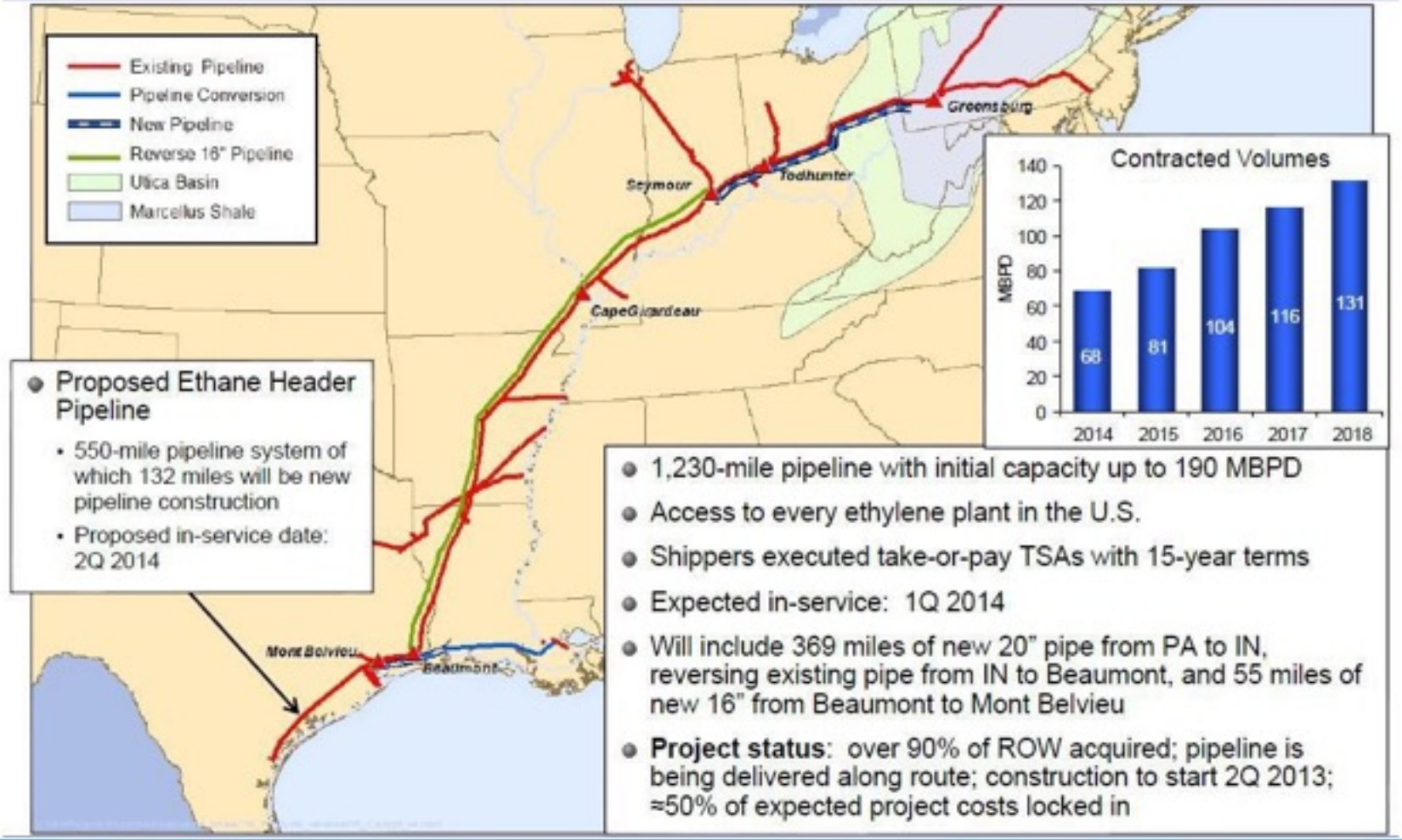
Mariner East (ME): 23 MBPD (4Q15)
91 MBPD (1Q17)
Total: 115 MBPD [2]

Steam Crackers [5]
Shell: 65 MBPD (2019)
PTTGC: 65 MBPD (2020)
Braskem: 65 MBPD (2021)
Total: 195 MBPD

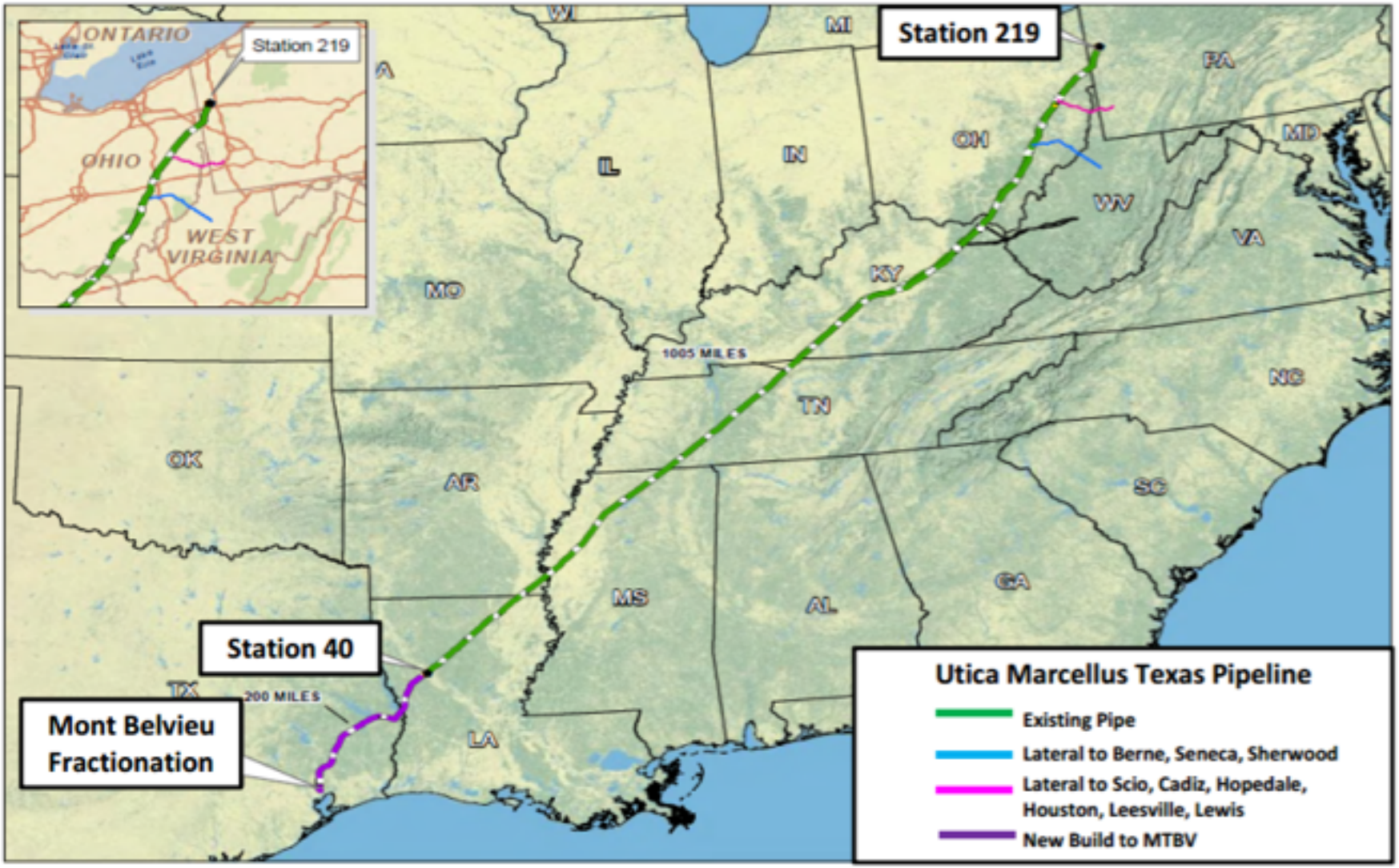
ATEX (AX): 65 MBPD (1Q14)
60 MBPD (Future)
Total: 125 MBPD [4]

August 2015 it is estimated that 350 MBPD was rejected — the announced demands/off takes will provide a relevant "frac" spread for the Appalachian Basin with the majority of ethane leaving the region (Europe, Texas, Canada)

Appalachia to Texas (ATEX) Express Pipeline



Utica Marcellus Texas Pipeline (UMTP)



New Outlets Needed for Appalachian NGLs

- Appalachian growth projections exceed planned local fractionation capacity by 2016
- Achieving MTBV pricing, liquidity, and connectivity for all products can only be achieved on UMTP

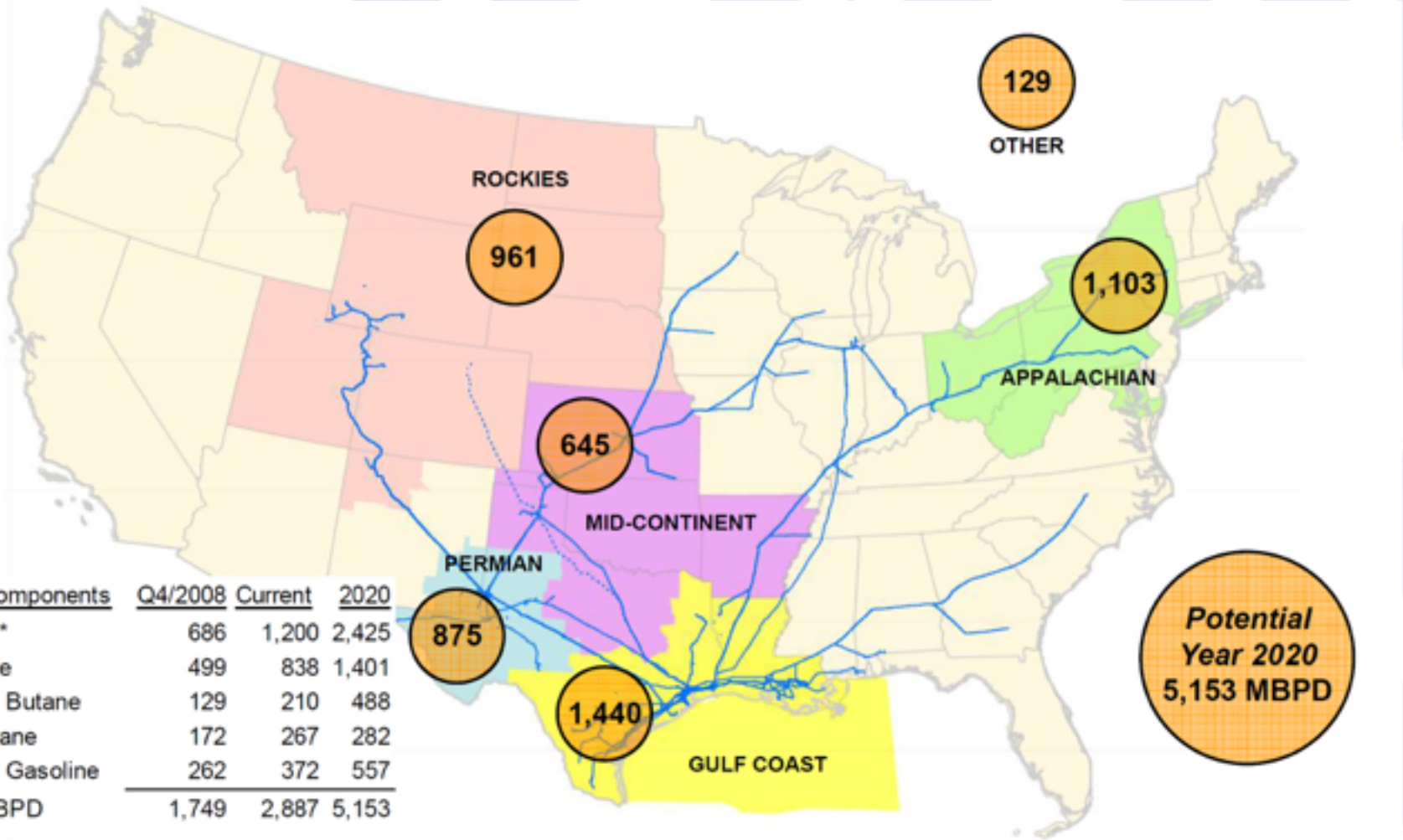
C3+ Analysis	2014	2015	2016	2017	2018	2019	2020
Supply	169	263	332	378	427	463	496
Fractionation	300	300	320	335	335	335	335
C3+ Available	------	-------	**12**	**43**	**92**	**128**	**161**

- Producers will only recover ethane to the extent they:
  - Reach the ethane spec limits on the gas pipelines
  - Achieve value higher than gas price (rejection economics)
  - Have contractual obligations to ethane pipes
- Appalachian producers can only achieve Mont Belvieu pricing for ethane via ATEX, UMTP

C2 Analysis	2014	2015	2016	2017	2018	2019	2020
Supply	177	278	350	400	452	490	525
Takeaway	118	131	154	236	301	301	301
C2 Rejection	**59**	**147**	**196**	**164**	**151**	**189**	**224**

From: Kinder Morgan

U.S. NGL Supply Potential Assuming Sufficient Markets (MBPD)



NGL Components	Q4/2008	Current	2020
Ethane*	686	1,200	2,425
Propane	499	838	1,401
Normal Butane	129	210	488
Iso Butane	172	267	282
Natural Gasoline	262	372	557
MBPD	1,749	2,887	5,153

** Current is increased by 200–250 MBPD for estimated ethane rejection*

Source: EPD Fundamentals

Tri-State Shale Summit

- WV, PA, and OH
  - Governors signed collaboration agreement
    - Infrastructure
    - Research
    - Workforce Development
    - Publicity and Marketing
  - http://www.tristateshalesummit.com/

Vision Shared

Team NEO

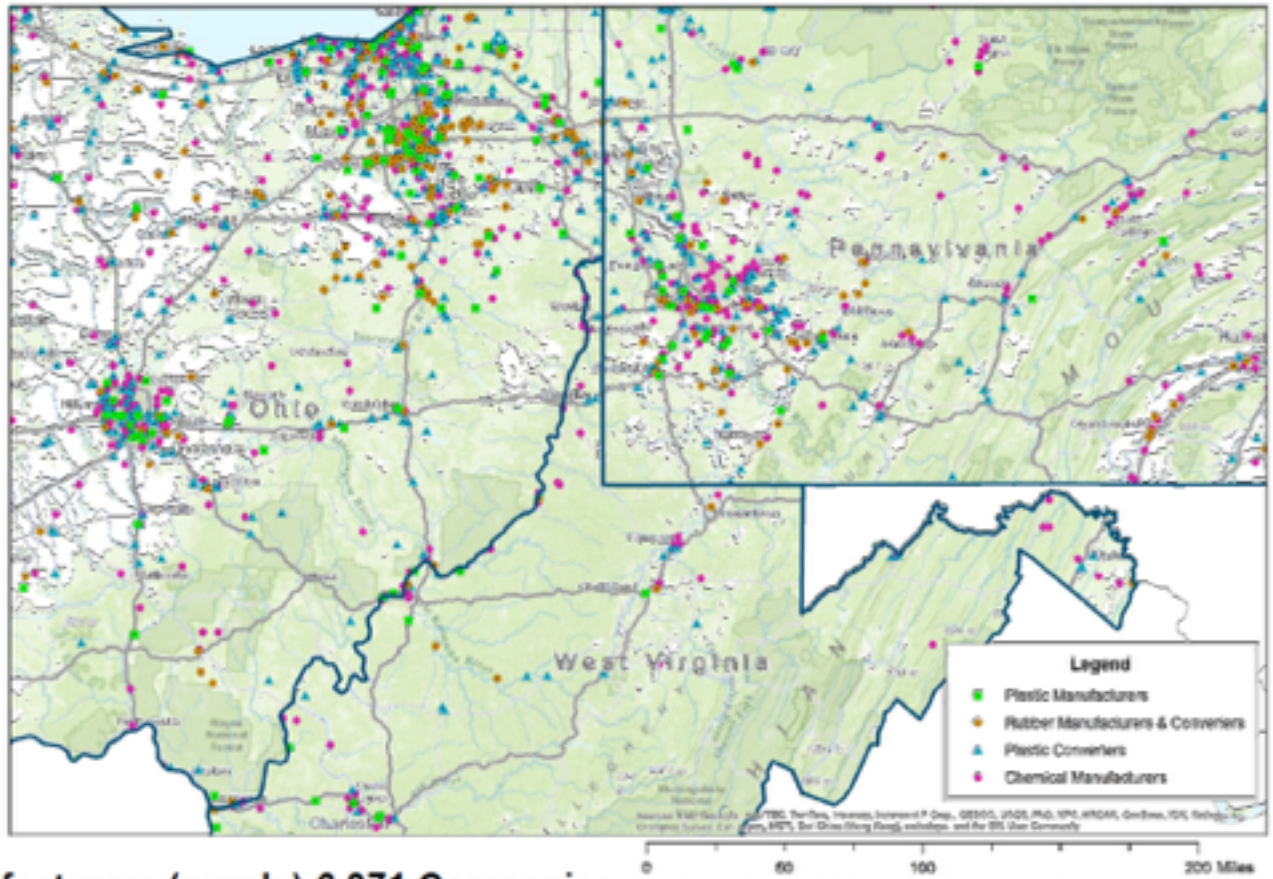
Allegheny Conference on Community Development

Claude Worthington Benedum Foundation

TRI-STATE SHALE SUMMIT

October 13, 2015

Petrochemical & Downstream Manufacturers within 400 Miles: 17,477 Companies



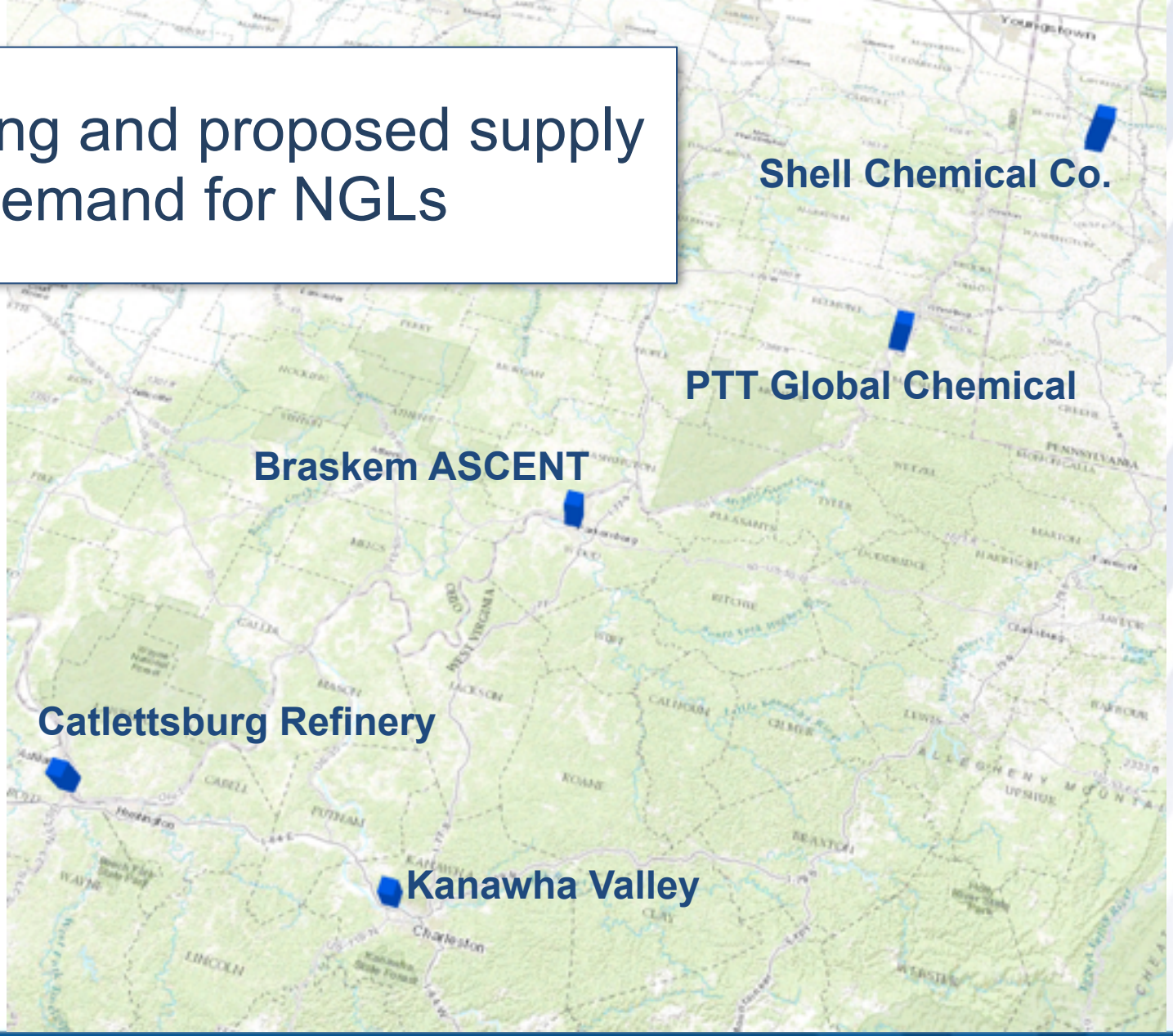
Chemical Manufacturers (purple):6,371 Companies

Plastic Converters (blue): 8,147 Companies

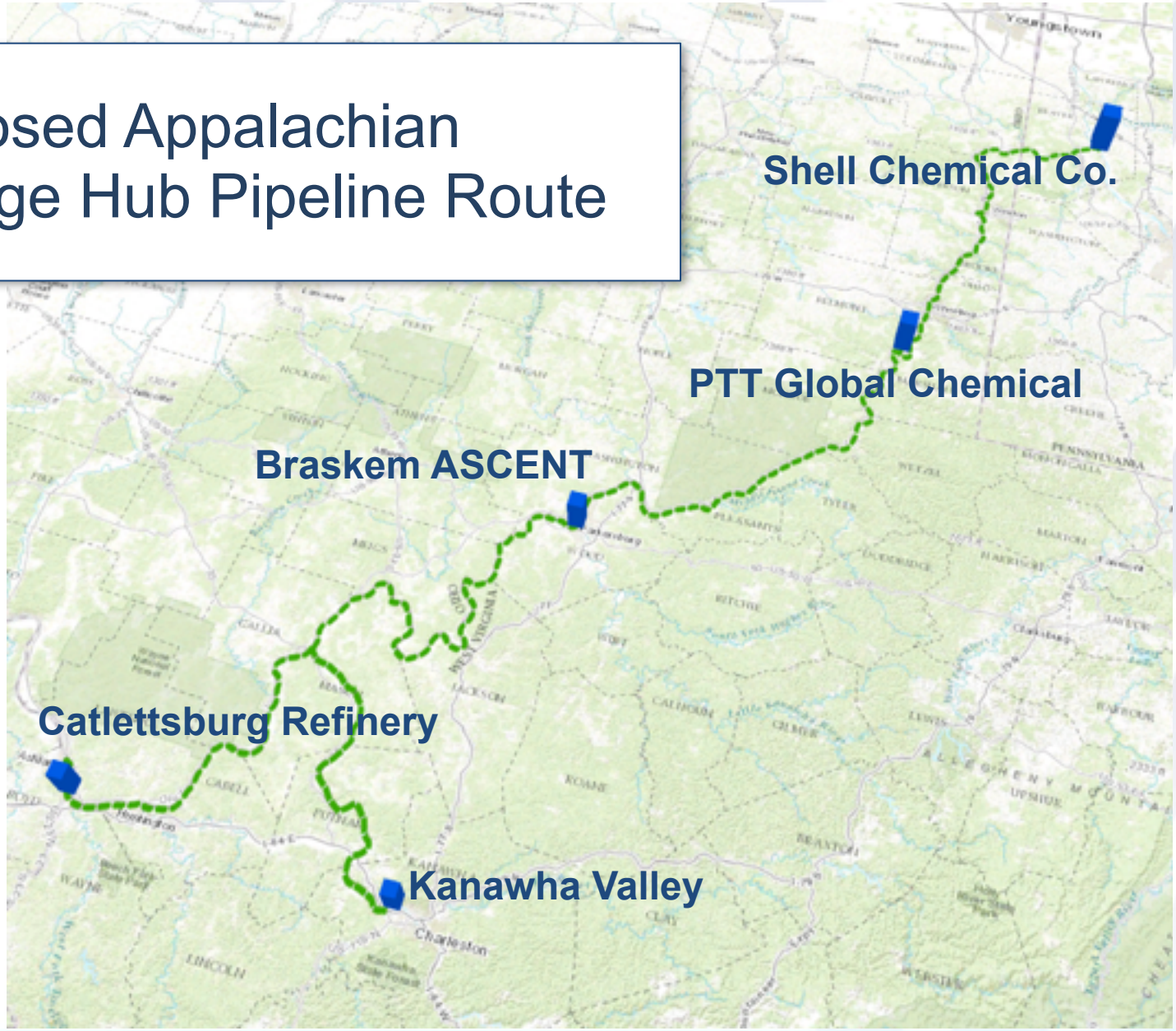
Rubber Mfg. & Conv. (brown): 1,812 Companies

Plastics Mfg. (green): 1,147 Companies

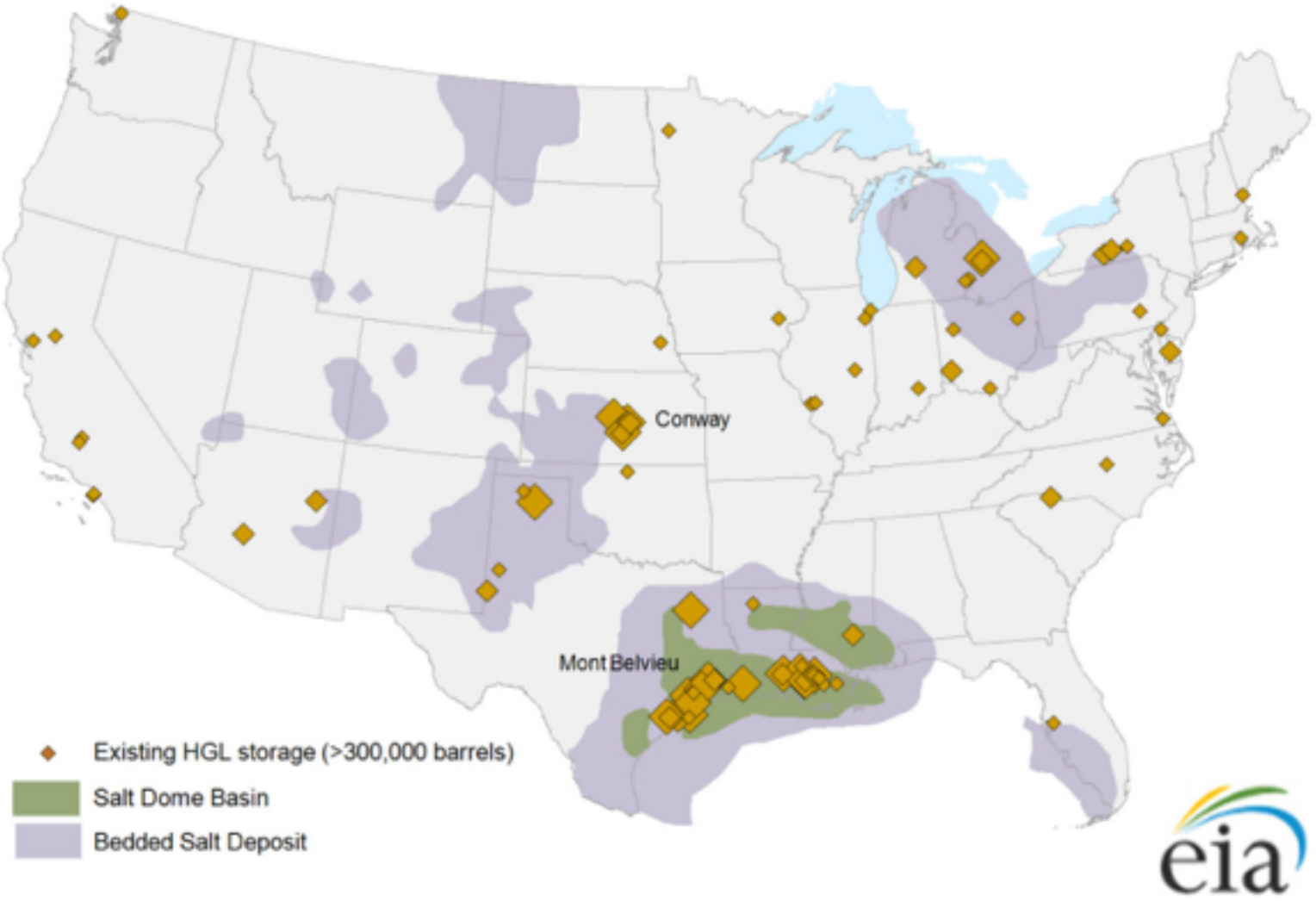
Existing and proposed supply and demand for NGLs



Proposed Appalachian Storage Hub Pipeline Route



Operating underground and aboveground U.S. HGL storage facilities



Source: U.S. Energy Information Administration, compiled from Sulpetro LPG Almanac and U.S. Department of Energy, National Energy Technology Laboratory, Cavern Roof Stability for Natural Gas Storage in Bedded Salt, with permission.

The Appalachian Basin Ethane Storage Study

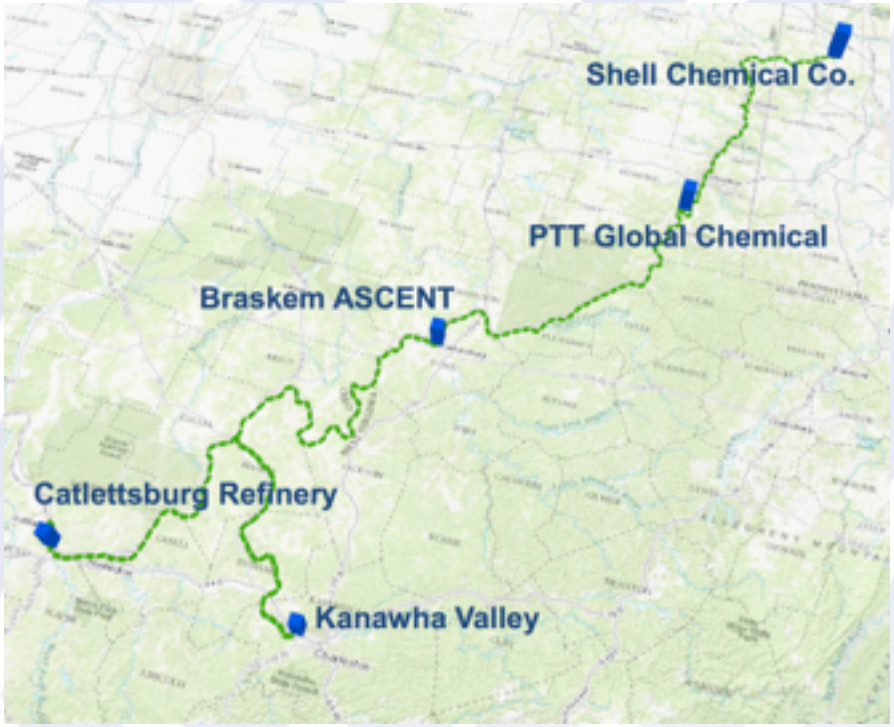
A Project of the Appalachian Basin Oil & Natural Gas Research Consortium

National Research Center for Coal & Energy, West Virginia University
State Geological Surveys in Ohio, Pennsylvania and West Virginia

With thanks to the conditional support from the Claude Worthington Benedum Foundation

Appalachian Basin Ethane Storage Study

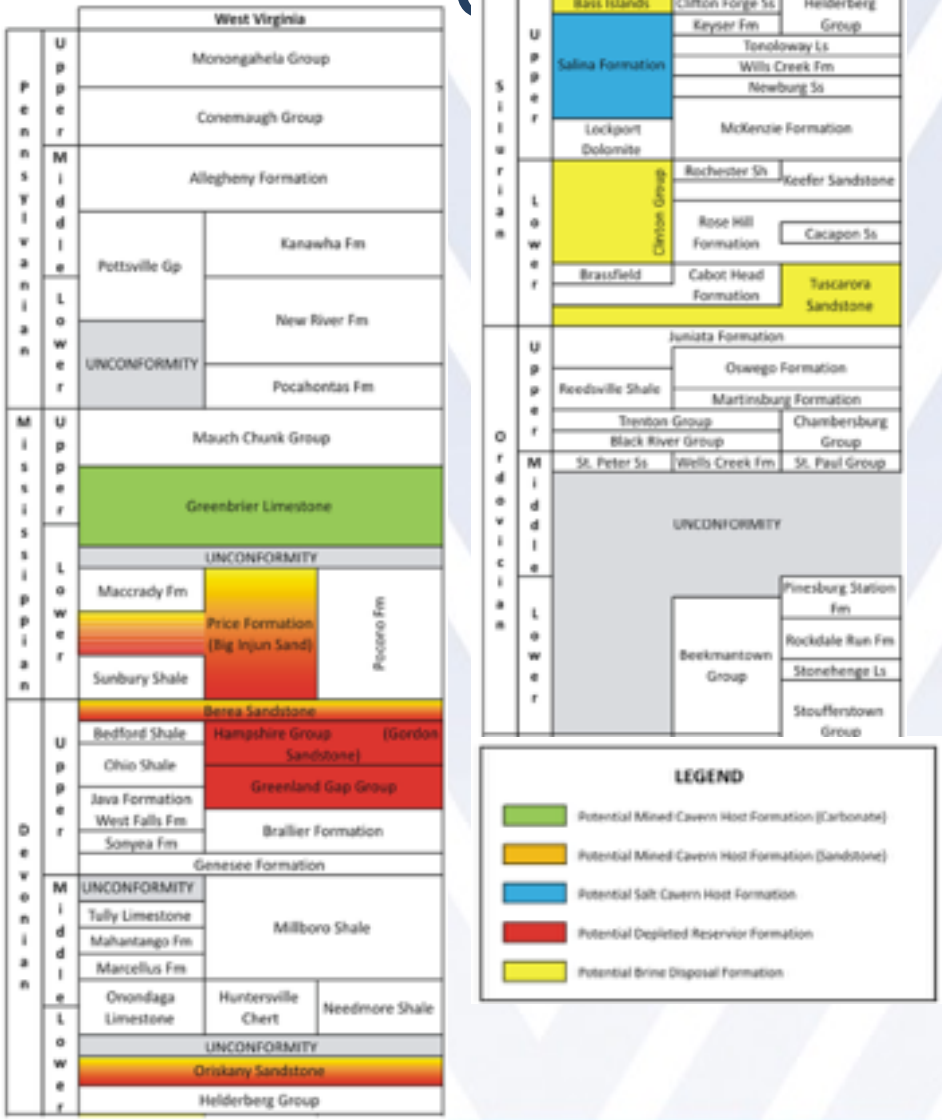
- Geologic investigation of potential subsurface storage options for liquid ethane in a broad geographic area
- Study area is essentially along the Ohio River, starting in Pennsylvania and ending in southern West Virginia and eastern Kentucky
- Proposed project is a critical step in the overall process to build a subsurface storage facility adjacent to a “6-pack” pipeline, one to transport liquid ethane



- The goal of this project is to provide essential data to support of the development the chemical manufacturing industry, promoting economic development

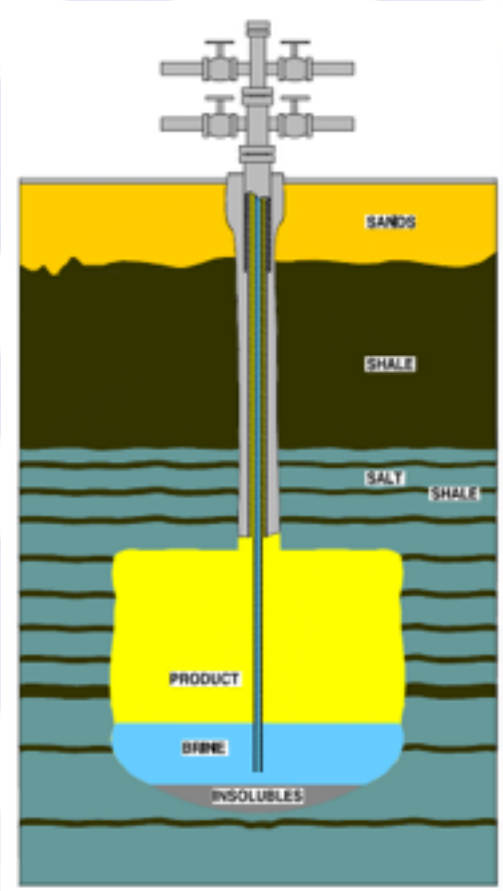
Stratigraphic Units to be Investigated

- Greenbrier Limestone
- Salina salt beds
- Mississippian sandstones (Keener to Berea)
- Upper Devonian sandstones (Bradford, Venango, Elk)
- Oriskany Sandstone
- Clinton – Medina through Tuscarora Sandstone
- Upper Sandy Member of the Gatesburg Formation
- Rose Run Sandstone



Types of Potential Ethane Storage

- Solution mining to create large cavities in Salina salt beds
- Subsurface excavation to create large mines in Greenbrier Limestone
- Injection into depleted gas fields with good porosity & permeability
- Vertical & lateral seals essential for each option



Schematic Illustration of a Solution-Mined Storage Cavern in Bedded Salt

Appalachian Storage Hub Work Plan

- Data collection (well logs & cores); database creation
- Stratigraphic correlation of key lithologic units
- Map the thickness, extent & structure of key lithologic units
- Conduct studies of reservoir character and storage potential of key lithologic units
- Develop ranking criteria for potential storage zones
- Make final recommendations for the ethane storage hub location

Generalized distribution and thickness of Salina salt beds (modified in part from Fergusson and Prather, 1968; Griggs, 1958; Sanford, 1965; and Rickard, 1969

Conclusion

- There is an abundance of natural gas (containing NGLs) in the shales of WV, PA, and OH
- The Appalachian Basin provides 1) access to markets, and 2) a competitive pricing advantage due to the abundance of valuable (yet currently underpriced) hydrocarbons
- Ethane storage is key to the development of a robust NGLs trading post, i.e. a spot market essential to further development of the chemical manufacturing industry in this region
- Businesses developing Marcellus, Utica, Rogersville will benefit from significant infrastructure investments in the region
- A storage facility will be tied into the overall play via massive piping infrastructure
- Would tie Monaca, PA, through the Ohio River valley, to Catlettsburg's refinery, with a tee to the Kanawha Valley
- Would include main trunks for methane, ethane, ethylene, propane, propylene, and chlorine
- The region would benefit from infrastructure development to satisfy the feedstock and offtake requirements for world scale and/or distributed manufacturing elements





The WVU Energy Institute

The Institute's mission is to coordinate and promote University-wide energy research in engineering, science, technology, and policy.

With an emphasis on

- **Fossil Energy**
  - Coal, Oil, and Natural Gas
- **Sustainable Energy**
  - Biomass, Geothermal, Wind, and Solar
- **Energy Policy**
  - Energy and Environmental Policy
- **Environmental Stewardship**
  - Protecting our Air and Water Resources

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