The National Energy Technology Laboratory & The Strategic Center for Natural Gas and Oil R&D Program

Tribal leader forum: U.S. Department of Energy oil and gas technical assistance capabilities
Denver, Colorado

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SMTA
Strategic Center for Natural Gas & Oil
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Outline

- Review of Case History Technology Successes
- Review of Current Oil and Natural Gas Program
- Getting More of the Abundant Shale Gas Resource
- Understanding What is Going On Underground
- Reducing Overall Environmental Impacts

Four Case Histories

- Electromagnetic Telemetry
- Wired Pipe
- Fracture Mapping
- Horizontal Air Drilling

Development of Electromagnetic Telemetry

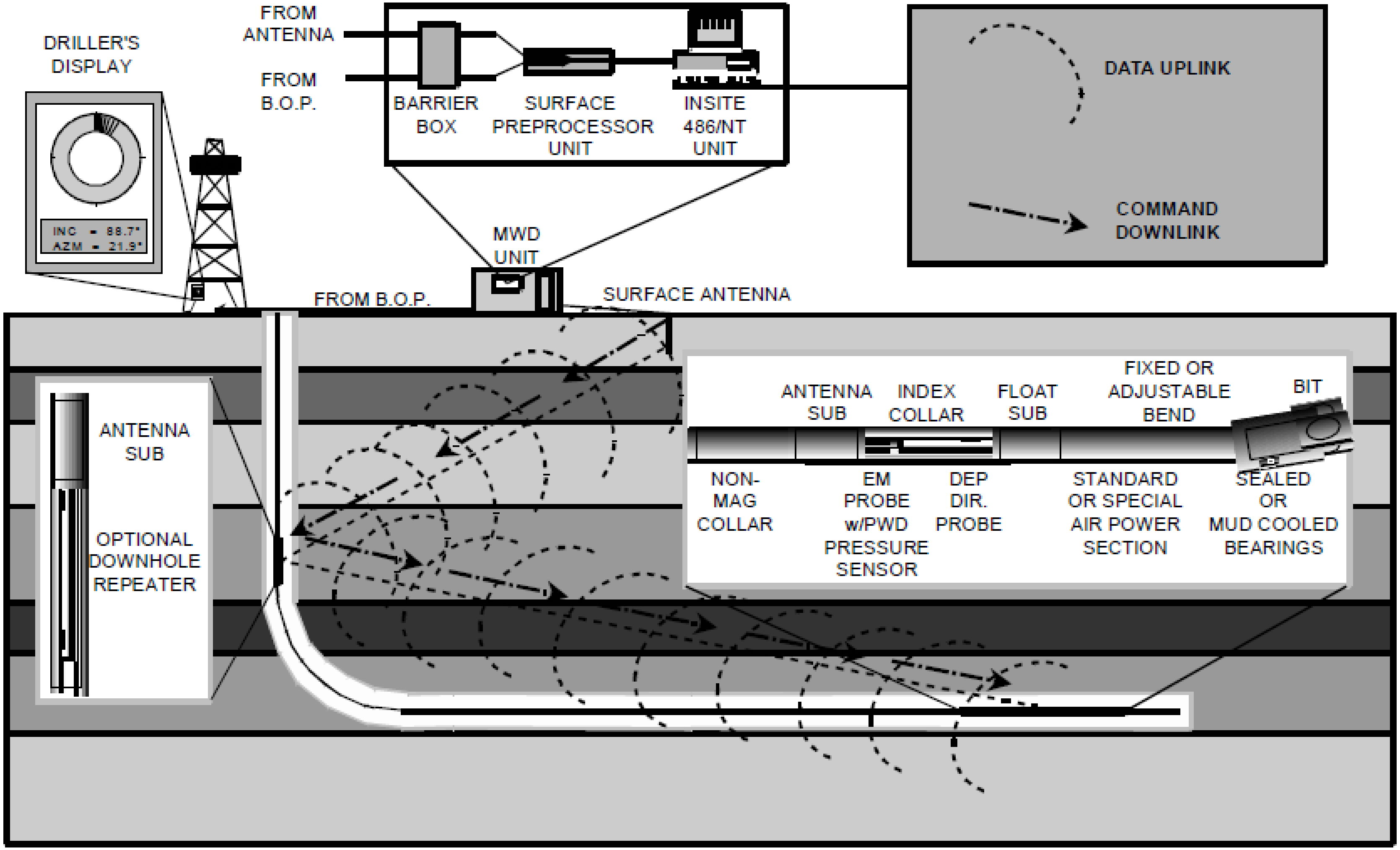
Problem

- In early 1980s, need for non-wireline, non-mud based communication system in air-filled, horizontal or high-angle wellbores grows.
- Problems with drillpipe-conveyed and hybrid-wireline alternatives sparked interest in developing a "drill-string/earth," electromagnetic telemetry (EMT) system for communicating data while drilling.
- Attempts to develop a viable EM-MWD tool by U.S.-based companies were unsuccessful.

DOE Solution

- Partner with Geoscience Electronics Corp. (GEC) to develop a prototype based on smaller diameter systems designed for non-oilfield applications
- Test the prototype in air-drilled, horizontal wellbores.
- Catalyze development of a U.S.-based, commercial EM-MWD capability to successfully compete with foreign service companies.

EMT System Schematic



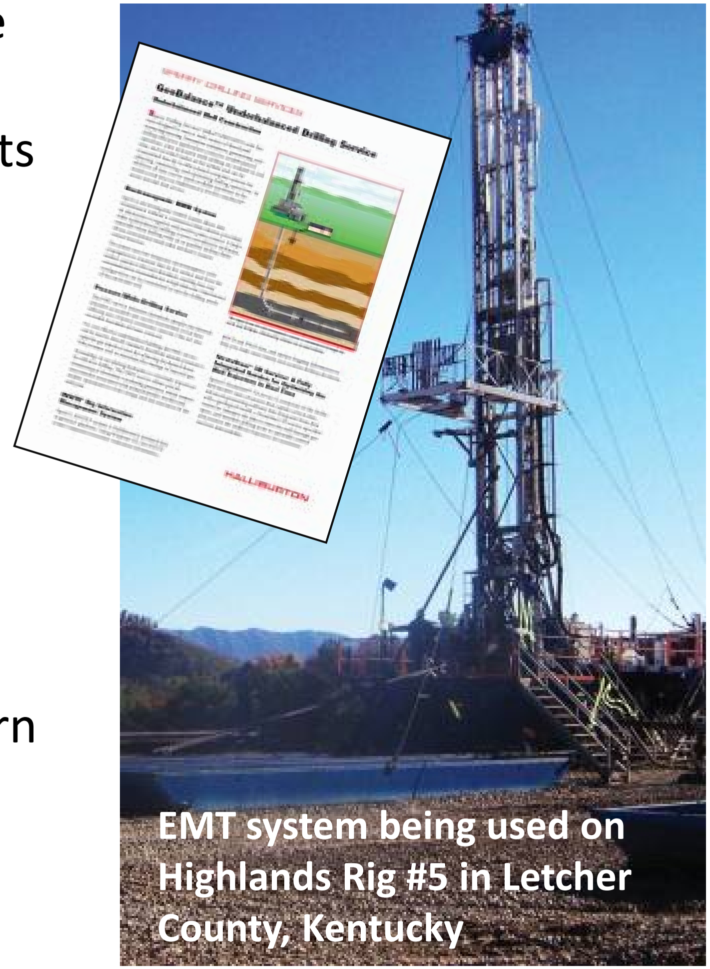
Source: Sperry-Sun, March 1997, Interim Report, DOE FETC Contract: DE-AC21-95MC31103

EMT Path to Commercialization

- 1986 – Initial test of GEC prototype tool at a DOE/NETL Devonian Shale horizontal drilling demonstration well in Wayne county, WV (10 hours on-bottom operating time).
- 1988 to 1993 – 13 DOE/GEC field tests resulted in a *hardened* prototype tool capable of operating 100 hours without failure in an underbalanced drilling environment. GEC sells prototype EM-MWD system to Sperry-Sun.
- 1995 – DOE partners with Sperry-Sun to develop an integrated underbalanced directional drilling system (EM-MWD and downhole motor combination).
- Sperry-Sun (now Sperry Drilling, a product service line of Halliburton) begins offering a commercial integrated system service to clients in the California and Saskatchewan underbalanced directional drilling markets.

EMT Today

- Sperry Drilling EMT service used by Equitable Gas in 2006 in the Appalachian Basin to significantly reduce horizontal air-drilling costs (~$100k per well) during development of Devonian Shale plays.
- EMT used to reduce operational time during air drilling in Barnett Shale wells; saves $52k per well.
- EMT used to reduce drilling time during air drilling of a deep, extended reach well with high downhole temperatures in Canada’s Horn River Basin Shale Play (17,536 ft. MD well at 8,530 ft. TVD).



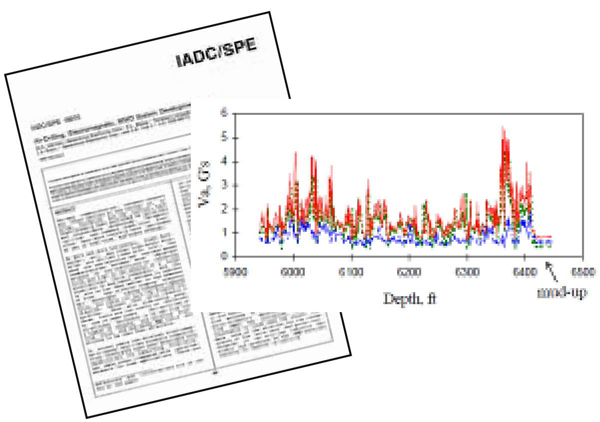
EMT system being used on Highlands Rig #5 in Letcher County, Kentucky

DOE Contribution

- **Identified a need and partnered with a technology innovator**
- **Provided funding and direction to field test a prototype**
- **Continued to support the integration of the technology into a service package that would meet commercial needs**

"In the early 1980s, the industry as a whole did not have a clear vision for producing gas from shales and benefited from DOE involvement and funding of EMT technology. While there were incremental improvements made by multiple parties over time, there is a clear line of sight between the initial research project with GEC and the commercial EMT service available today."

Dan Gleitman, Sr. Director – Intellectual Asset Management, Halliburton



Development of Wired Drill Pipe

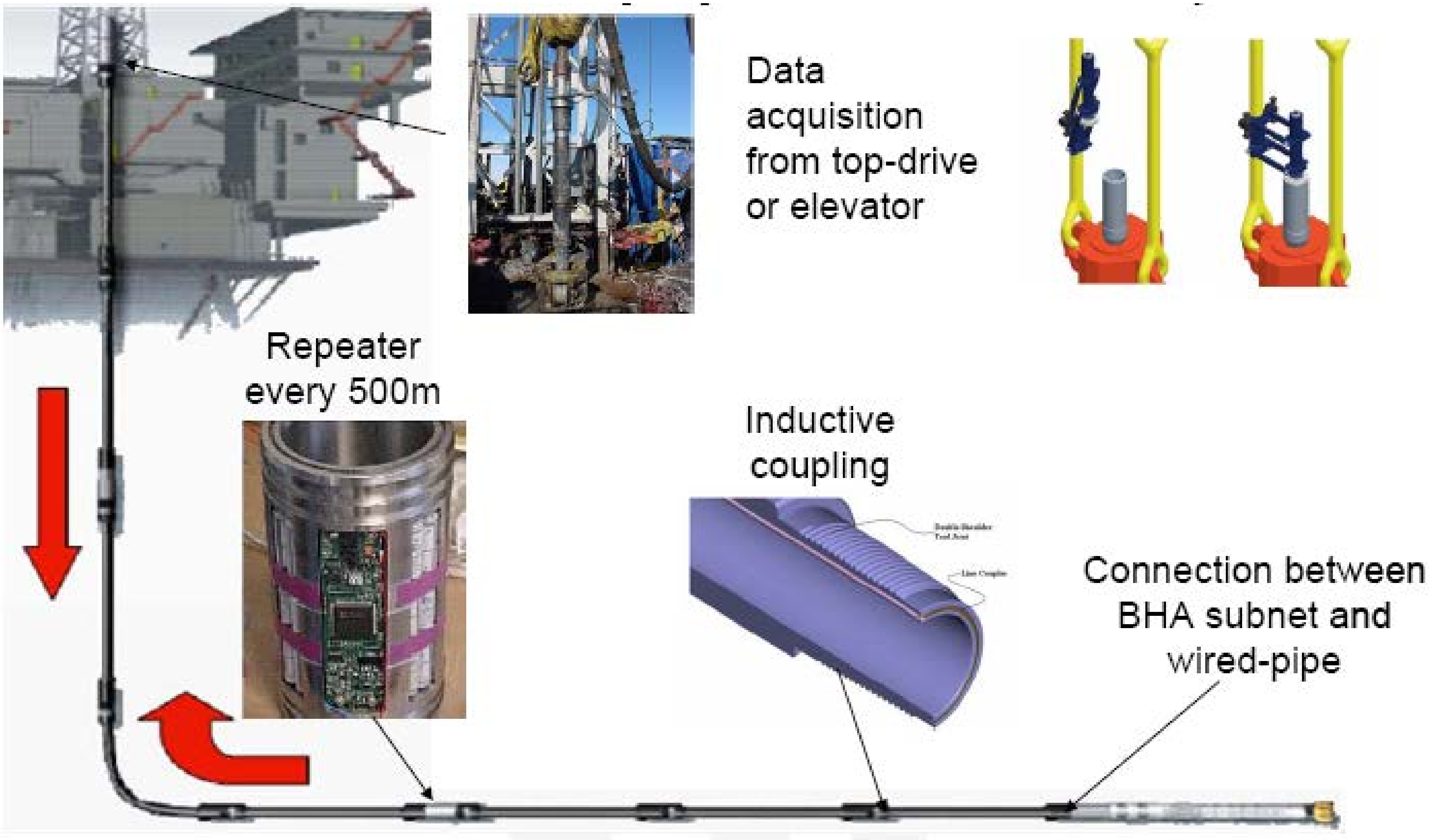
Problem

- There is a growing need for a high data rate communications system that allows high-resolution downhole drilling information to inform drilling decisions in real time.
- Conventional mud-pulse telemetry transmits at ~10 bits/sec, but rates of at least several 100,000 bits/sec are needed.
- Historical attempts to develop a technology to transmit data via the drill string have not been able to find a reliable way to bridge the tool joint connection.

DOE Solution

- Partner with Novatek to develop and demonstrate an economically feasible concept that would overcome the problems of tool joint connectivity.
- Demonstrate the operation of a bi-directional system in a 6,000 ft drill string under field drilling conditions.
- Demonstrate system in the field with a third party downhole tool.

Wired Pipe Telemetry



Wired Pipe Path to Commercialization

- 1998 – Original concept leveraged from Novatek's work with NETL in development of a hammer-based drilling system.
- 2001 – Phase 1 NETL/Novatek R&D developed economic means of placing data cable within drill pipe and successfully demonstrated communication through scaled string under drilling conditions.
- 2002 – Phase 2 R&D improved the coupler and demonstrated robustness of system over longer pipe string at field conditions.
- 2003-2004 – Phase 3 R&D demonstrated the utility of the transmission line with a third party tool and expanded the number of tools capable of interfacing with the system.
- 2004-2006 – Grant Prideco Inc. joins with Novatek to form a joint venture, IntelliServ®, to develop and market the drill pipe (Intellipipe).
- 2008 – Grant Prideco purchased by National Oilwell Varco (NOV)

Wired Pipe Today

- NOV™ IntelliServ® provides the oil and gas industry with the only high-speed, high-volume, high-definition, bi-directional broadband data transmission system.
- NOV IntelliServ has agreed to form a JV with Schlumberger to maximize the uptake of the technology.
- The program now has some 220 employees stationed in Utah, Texas, Aberdeen, Dubai and Mexico.

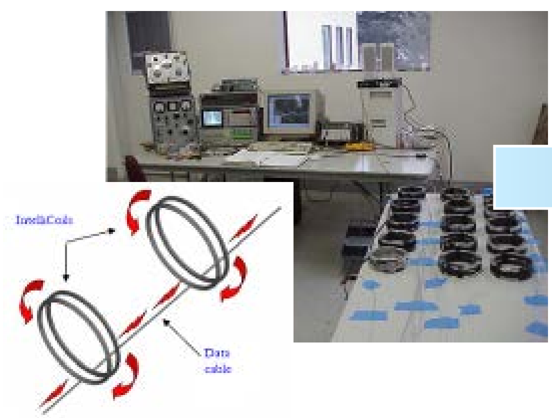
Recently, Statoil saved two days of rig time and two trips using Intelliserv in Norway's Visund Field

DOE Contribution

- **Identified a need and partnered with a technology innovator**
- **Provided funding and direction to field test a prototype**
- **Continued to support development of the initial technology into a system that attracted commercial interest**

"In my view, NETL's involvement in the development of networked drill pipe was absolutely essential. Novatek had limited resources and NETL provided critical funding that kept the project going. When dealing with a revolutionary technology … funding is very difficult to find in the early stages of development; where at the same time the new technology is unproven and it poses a threat to existing products that represent a substantial investment on the part of potential funding organizations."

David Pixton, VP, Mechanical Engineering, Intelliserve



Development of Fracture Mapping

Problem

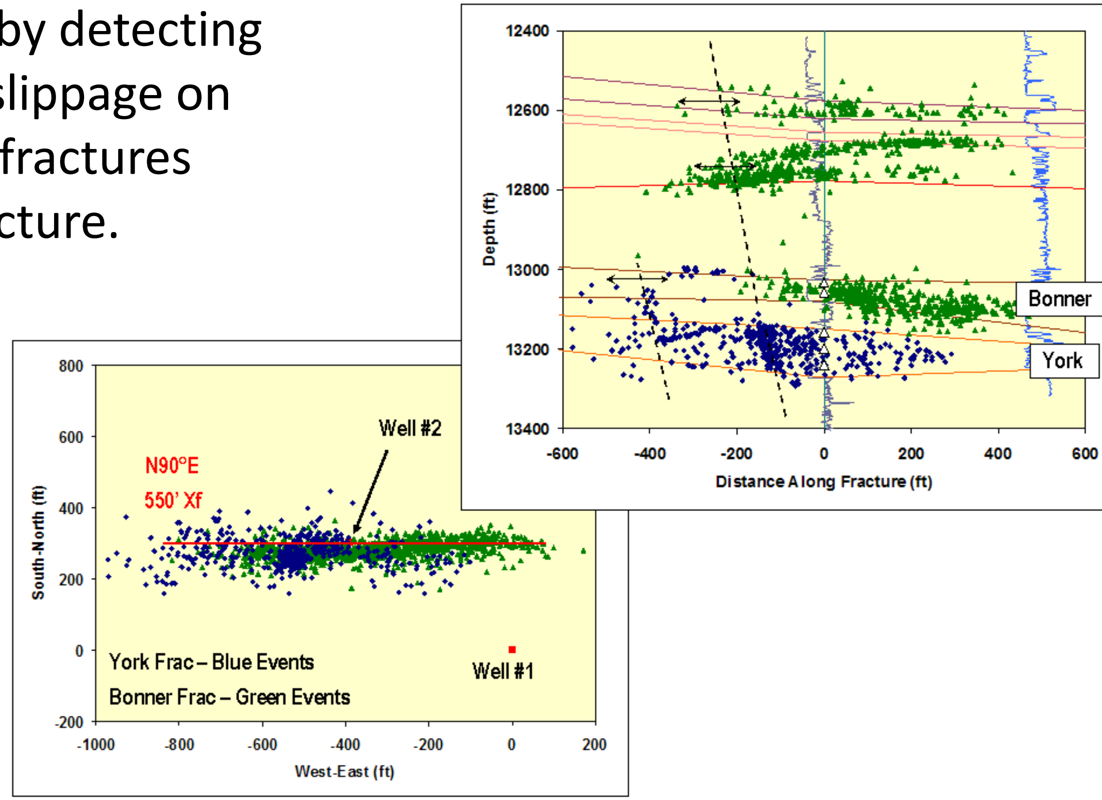
- During the 1970s, fracture simulation models and fracture diagnostic techniques are developed to *infer* the dimensions of a created fracture based on pressure and well performance, but there is no method for measuring the length and orientation of a propped hydraulic fracture.
- This lack of hard data as to the actual results of a fracturing treatment make it difficult to compare and optimize treatment designs.
- The need to design hydraulic fractures that will intersect natural fractures in unconventional gas reservoirs becomes increasingly important.

DOE Solution

- Fund early research through national labs to establish the basic science behind fracture mapping using microseisms and surface tiltmeters.
- Join with Gas Research Institute (GRI) to fund a field laboratory for studying hydraulic fracturing in a systematic, scientific manner.
- Team with technology providers to fund and develop tools and techniques that could lead to a commercial fracture mapping service.

Microseismic Monitoring

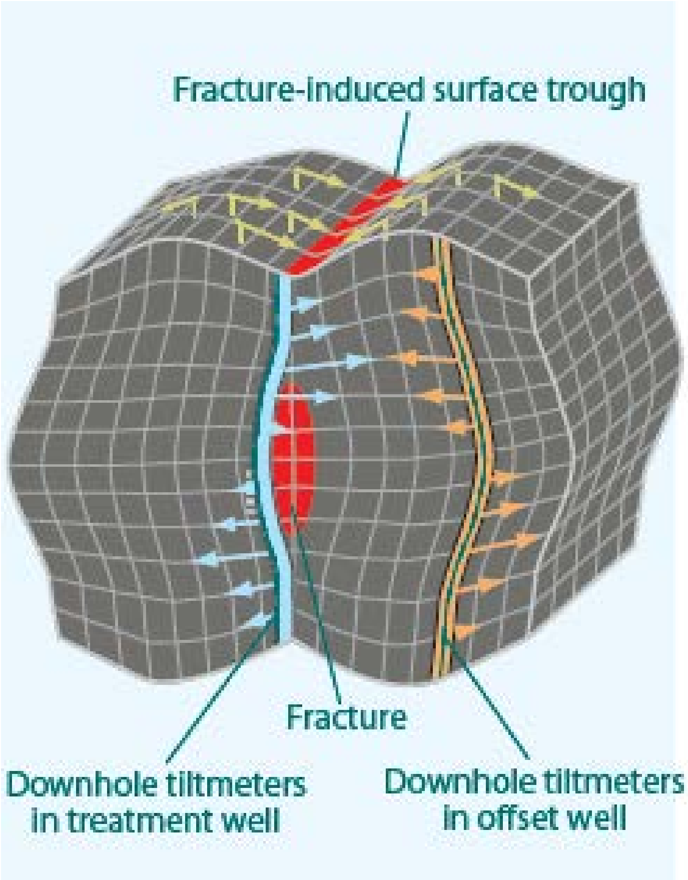
- Provides a fracture image by detecting microseisms triggered by slippage on bedding planes or natural fractures adjacent to a hydraulic fracture.
- Location of each microseismic event is obtained using a downhole receiver array positioned at the depth of the fracture in an offset wellbore.



- Alternatively, can be performed in the treatment well when an offset wellbore is not available.

Tilt Fracture Mapping

- Surface tiltmeter mapping measures the fracture-induced tilt at many points above a hydraulic fracture, and then determines the fracture parameters that would produce the observed deformation field.
- A typical hydraulic fracture treatment at 7,000 ft depth results in induced surface tilts of only about 10 nanoradians (10 parts in a billion).
- An array of 3 to 20 downhole tiltmeter instruments can be run into an offset well or the treatment wellbore prior to the treatment, to measure the subsurface deformation field. The tools are coupled to the wellbore with magnetic decentralizers.



Fracture Mapping Path to Commercialization

- 1970s – Early application of microseismic fracture mapping for geothermal research – Hot Dry Rock Project by Los Alamos National Lab with funding from DOE
- Late 1970s – DOE funded Sandia National Lab to build and deploy receivers for fracture mapping.
- 1980s – Sandia system used in the DOE Multiwell experiment (M-Site) in the southern Piceance Basin, where four out of five major fracture experiments were successfully monitored.
- Early 1990s – DOE funded joint Sandia and Oyo Instruments project that resulted in a multi-level receiver system that could be run on a fiber-optic wireline. DOE also funded early research related to tiltmeters, a second fracture mapping approach.
- 1992 – Surface tiltmeters become commercial fracture mapping technology. Pinnacle Technologies formed.

Fracture Mapping Path to Commercialization

- 1990s – GRI joins with DOE in funding fracture mapping R&D at M-Site, and eventually partner with Pinnacle Technologies to help commercialize microseismic technology.
- Late 1990s – Downhole tiltmeter mapping validated at M-Site and Pinnacle develops first downhole wireline tiltmeter system.
- 2002 – CARBO Ceramics buys Pinnacle Technologies.
- 2004 – DOE continues to partner with Pinnacle to develop a single microseismic tool combining geophones and tiltmeters.
- 2008 – Halliburton buys Pinnacle Technologies from CARBO Ceramics in deal valued at $137 MM.

Fracture Mapping Today

- At least five companies now offer some form of fracture mapping service, worldwide.
- In U.S. shale plays (Barnett, Fayetteville) and tight gas plays (Bossier, Cotton Valley, Piceance and Green River Basins), microseismic monitoring has had a direct impact on both hydraulic fracturing strategy and well spacing.
- Pinnacle Technologies, which has monitored more than 12,000 hydraulic fracture treatments, was purchased by Halliburton in 2008.

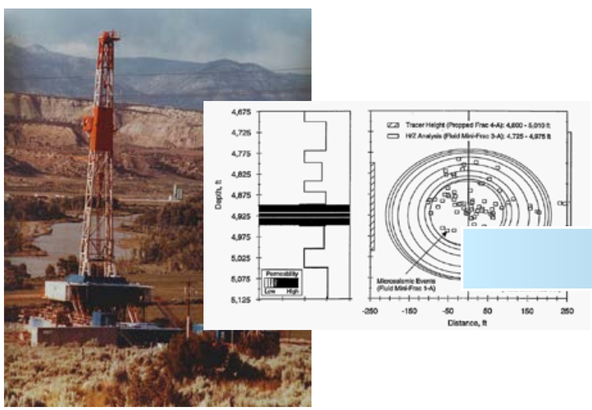
Pinnacle operators deploying downhole tiltmeter tools prior to a fracture treatment

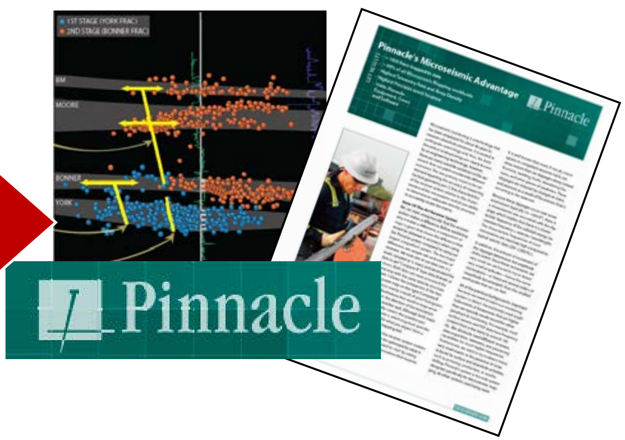
DOE Contribution

- **Identified a need and funded early basic science at National Labs**
- **Provided funding and direction to field test technology**
- **Partnered with technology developer to help develop the technology into a service package to meet commercial needs**

"It is important to recognize DOE's very significant historical role in fracture mapping's development. It took over two decades to make fracture mapping workable for normal oil and gas activities, and the DOE's long-term support was critical."

Norm Warpinski, Chief Technology Officer, Pinnacle Technologies





Development of Horizontal Air Drilling

Problem

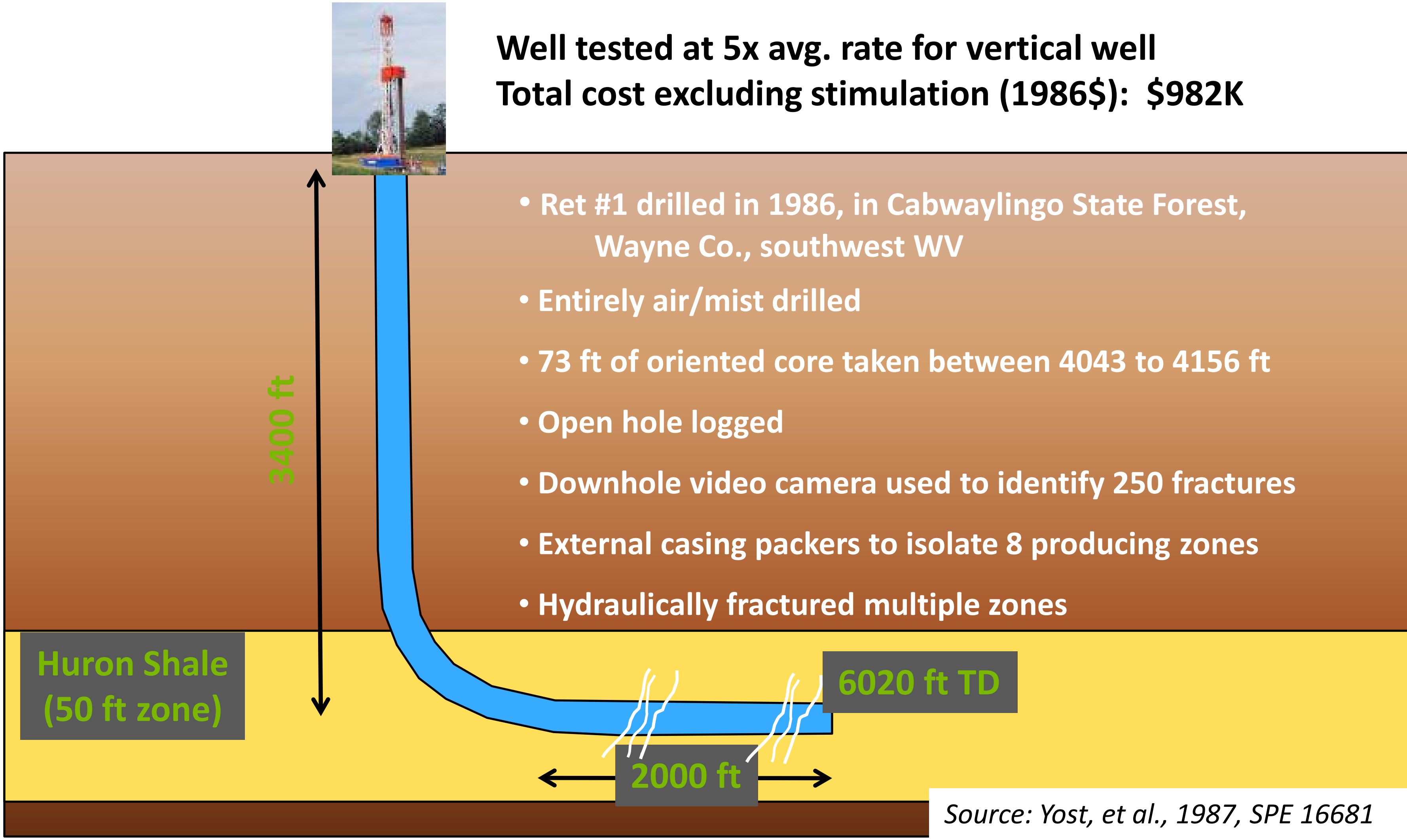
- In the 1970s, producers are searching for ways to improve the performance of low productivity Appalachian Devonian Shale wells.
- Despite the recognized potential for utilizing horizontal wellbores with multiple hydraulic fracture treatments to intersect natural fractures in these shales, a lack of reliable and affordable equipment and inadequate well siting technology inhibit its application.

DOE Solution

- Research and develop a site selection and well design technology that would maximize the chance of success
- Site and drill a horizontal well and perform multiple hydraulic fracture treatments.
- Demonstrate the practicality of widely applying cutting edge drilling and completion technologies to enhance productivity from Appalachian Shales.

Horizontal Air Drilling

Well tested at 5x avg. rate for vertical well
Total cost excluding stimulation (1986$): $982K



- Ret #1 drilled in 1986, in Cabwaylingo State Forest, Wayne Co., southwest WV
- Entirely air/mist drilled
- 73 ft of oriented core taken between 4043 to 4156 ft
- Open hole logged
- Downhole video camera used to identify 250 fractures
- External casing packers to isolate 8 producing zones
- Hydraulically fractured multiple zones

Source: Yost, et al., 1987, SPE 16681

Horizontal Air Drilling: Important Firsts

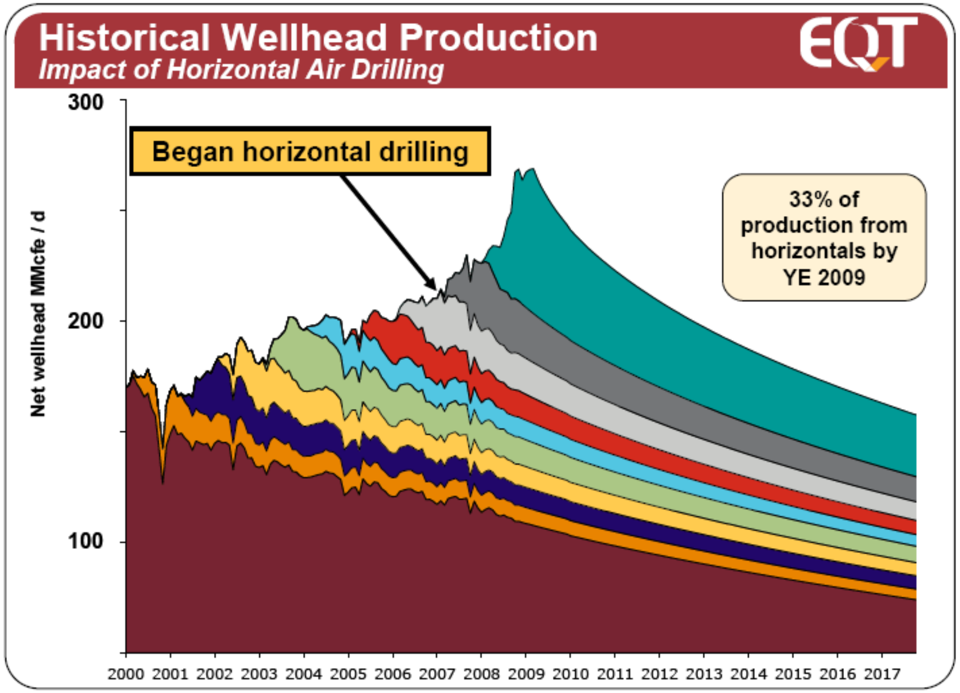
- First well to test concept that multiple horizontal fractures from horizontal air drilled well could be used to enhance productivity of Devonian Shale.
- First use of drill pipe-conveyed logging system to log horizontal air-drilled shale well.
- First use of downhole television camera to identify fractures and wellbore flow.
- First use of external casing packers in a horizontal air-drilled shale well.
- Demonstrated importance of site selection based on knowledge of regional fracture network.
- Three subsequent horizontal shale wells drilled in 1989 and 1990 confirmed and expanded on lessons learned.

EQT Air Drilling Horizontal Shale Wells

- Equitable's Huron/Berea program is the first, large scale, horizontal, air drilling program in the Appalachian Basin. More than 800 horizontal Huron/Berea wells have been drilled and development costs are projected to be less than $0.90 per Mcfe

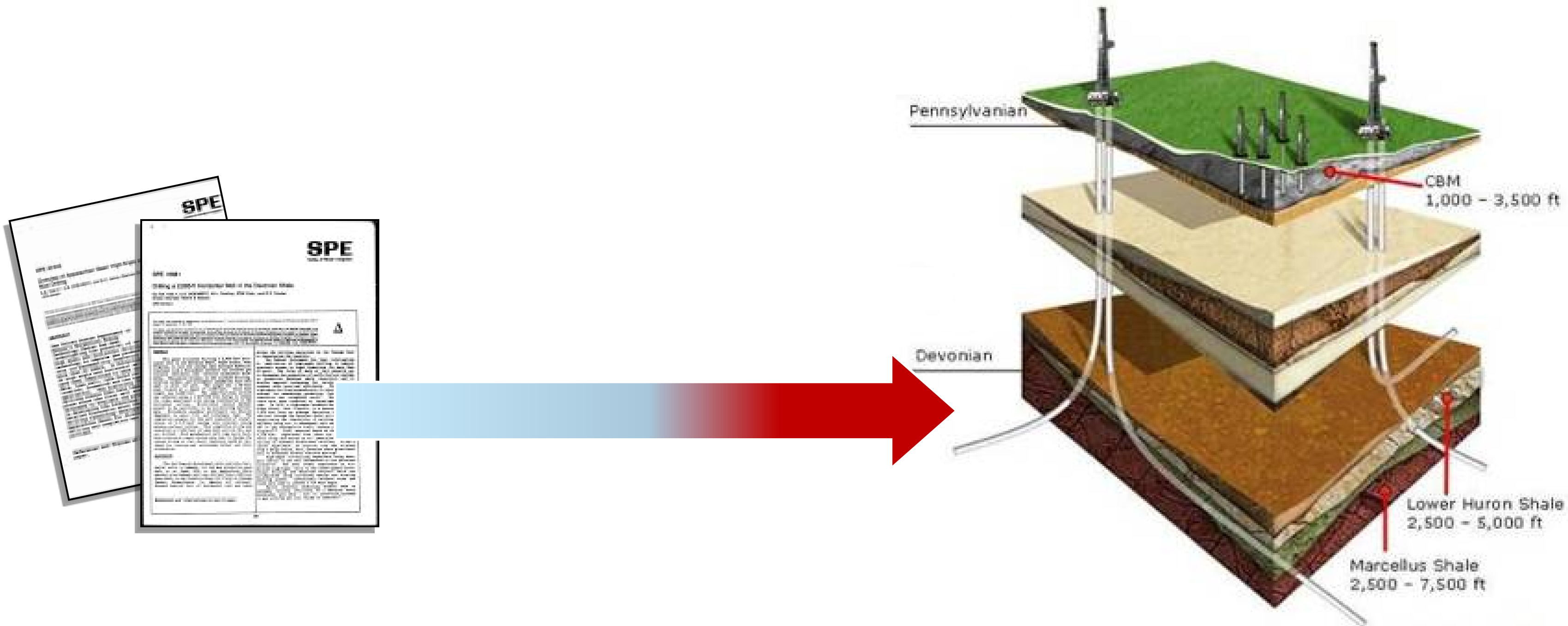
- EQT has tested air drilling Marcellus wells based on its success in the Huron/Berea. *"… horizontal air drilling works … and is being extended to multiple formations …"* - Murry Gerber, Chairman and CEO.

- EQT plans to continue to experiment with multi-lateral and extended lateral wells.

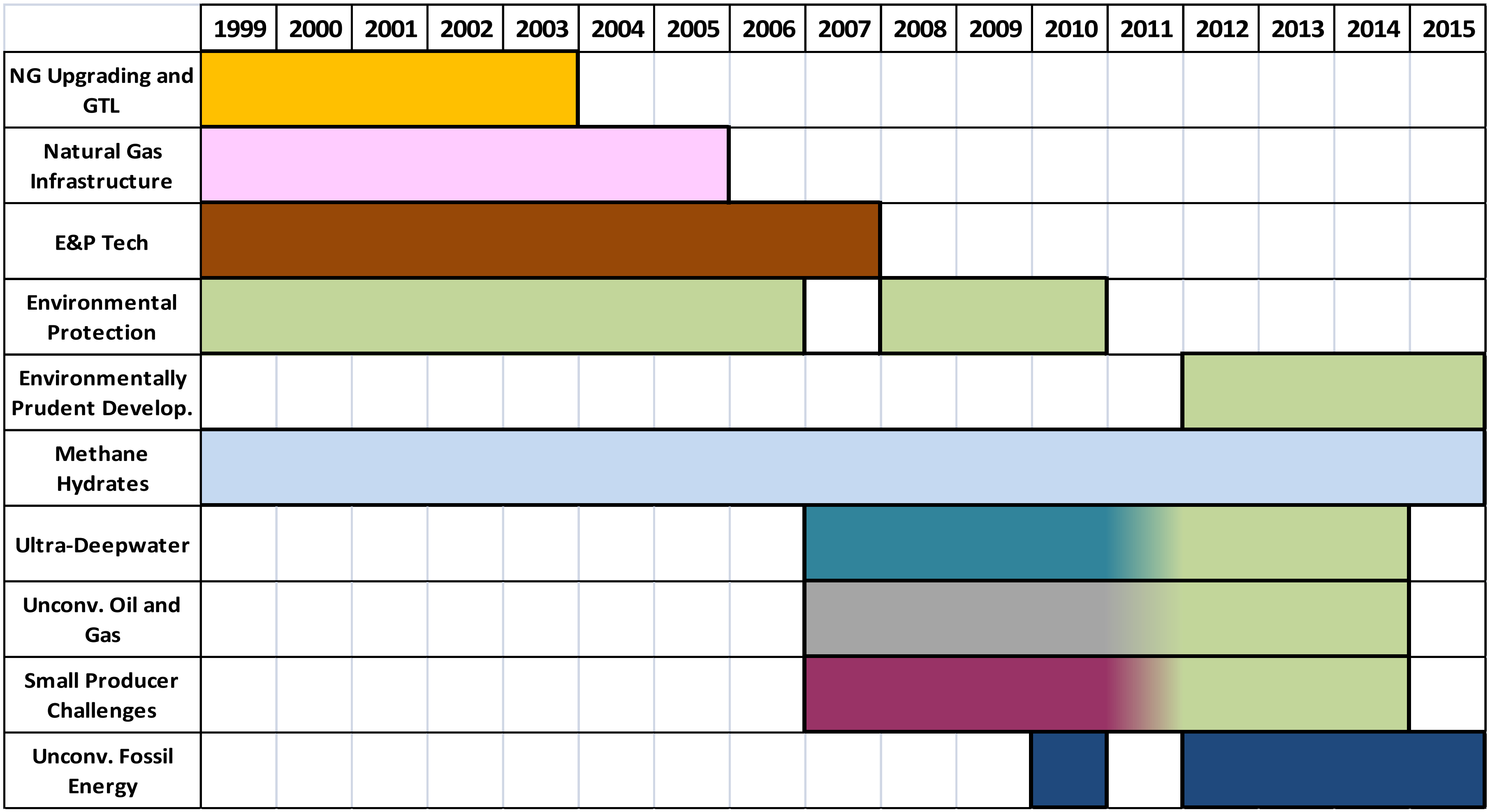


DOE Contribution

- **Identified potential for new technology to enhance performance**
- **Provided funding and direction to develop and demonstrate new technologies for the first time in Appalachian Basin.**
- **Published findings and supported efforts to apply elsewhere.**



NETL-SCNGO Oil and Gas R&D Timeline



******Methane Hydrates Program Existed 1983-92, 1999+; E&P Tech and NG Infras. Prgms. started in 1994, NG Upgrading and GTL started in 1991; Environmental Protection Program Started in 1983*

DOE Oil and Natural Gas Research Program

- 123 projects with a total value of more than $422 million
- 93 projects remain active, with expected completion dates through September 2019
- Major focus has been unconventional resources (primarily shale gas), including hydraulic fracturing technologies and water treatment/management technologies, accounting for about half of projects and funding
- NETL-ORD in-house research is focused on risk assessment and basic science

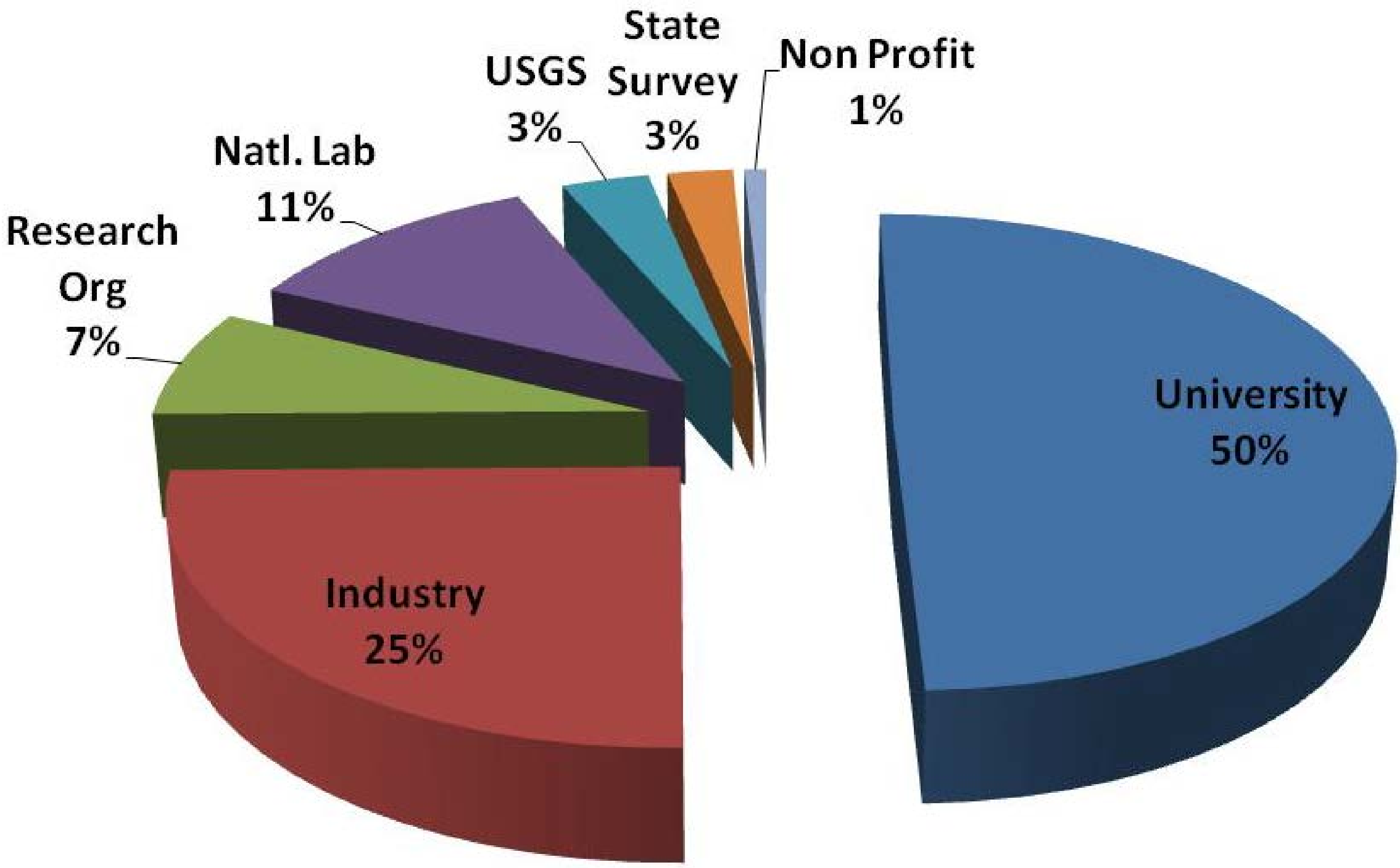
DOE Oil and Natural Gas Project Categories

Category	Number of Projects	Active* Projects	Total Value** (MM$)
Enhanced Oil Recovery	4	2	11.2
Methane Hydrates	25	20	69.5
Offshore Ultra-deepwater Technology	26	19	98.5
Small Producer Challenges	13	8	17.4
Unconventional Resources	55	44	225.9
	123	**93**	**$422.4**

** Project end date prior to August 2015*

*** Average partner cost share is about 27%, DOE funding about 73%*

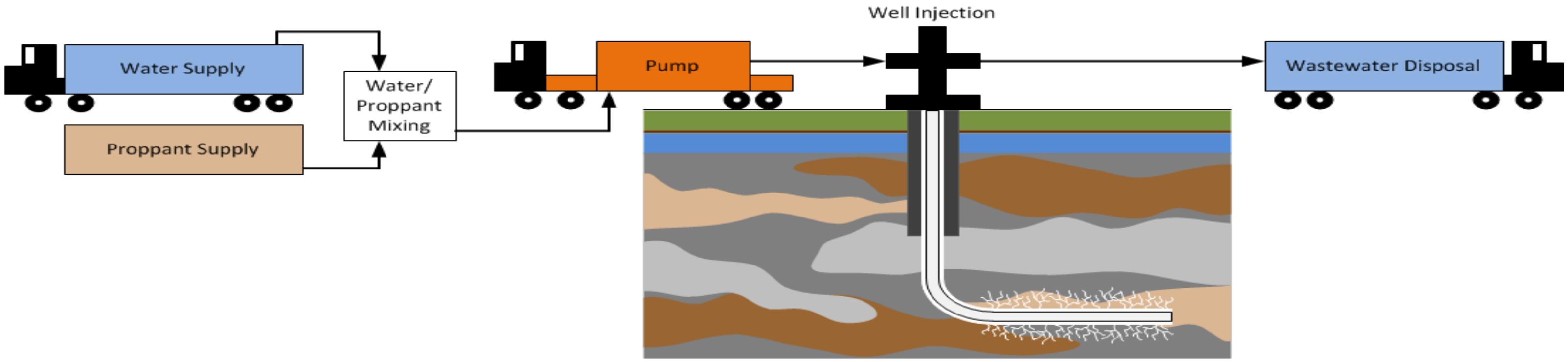
DOE Oil and Natural Gas Project Performers



Top Shale Gas Research Needs

- Getting more out of the abundant domestic shale gas resource
  - Understanding how alternative fracturing fluids could increase recovery
- Understanding what's happening underground
  - HF diagnostics to optimize process for cost and productivity
- How to reduce overall environmental impacts
  - Reduce water use through re-use of flowback water
  - Reduce risks of gas migration from poor zonal isolation
  - Reduce level of methane emissions
  - Reduce risk of induced seismicity from waste water injection

Current Hydraulic Fracturing Process



- Total water usage 3 to 7 million gallons per well
- Competes with other fresh water demands in drought areas
- Flowback water treatment and disposal challenges

Alternatives to Water Based Fracturing Fluids

- **Nitrogen-based Foam Fracturing**
- **CO_2-based Foam Fracturing**
- **CO_2/Sand Fracturing**
- **Straight Nitrogen or Straight CO_2 Based Fracturing**
- **Gelled LPG Fracturing**
- **LNG Fracturing**
    - Challenges for the Future

LNG Project Objectives

- **Develop a rugged, mobile, and economic system that can take unprocessed natural gas from a wellhead and prepare it for use as a fracturing fluid, significantly reducing water usage**
- **Identify the optimal process for bring the wellhead gas to injection pressure (10,000 psi) and temperature (+/-20 deg F)**
- **Complete a laboratory scale test to validate the fracturing concept**
- **Complete a field test to validate the capability of the system design to operate at field conditions**

Testing to be conducted at SwRI facility in San Antonio, TX

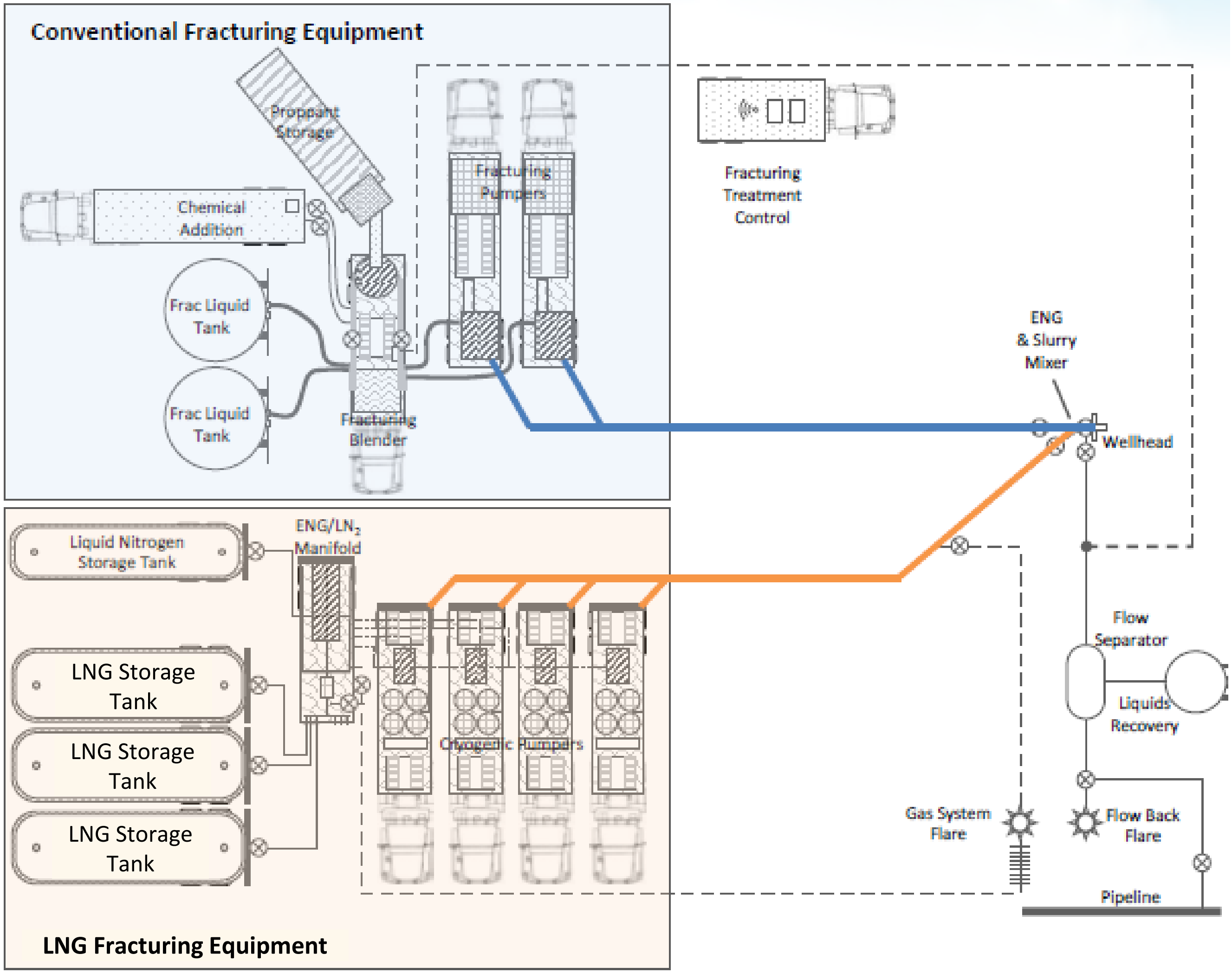
LNG Fracturing Fluid Concept

- **Liquefied natural gas (LNG) is stored at -162 deg C and atmospheric pressure**
- **LNG is then pressurized and heated to 15 deg C**
- **LNG is combined with a conventional fracturing fluid stream**
- **The mixture is used to hydraulically fracture the reservoir.**

LNG Fracturing Fluid Concept

Conventional equipment prepares the fracturing slurry stream with proppant and chemical additives

LNG is added to the fracturing slurry fluid stream at the wellhead



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Do We Know What's Happening Downhole?

Group	Fracture Diagnostic Method	Main Limitations	Ability to Estimate							
			Length	Height	Asymmetry	Width	Azimuth	Dip	Volume	Conductivity
Far field, during fracturing	Surface tiltmeter mapping	• Cannot resolve individual and complex fracture dimensions • Mapping resolution decreases with depth (fracture azimuth ± 3º at 3,000 ft depth and ± 10º at 10,000 ft depth	May determine	May determine	May determine	Cannot determine	Can determine	Can determine	Can determine	Cannot determine
	Downhole tiltmeter mapping	• Resolution in fracture length and height decreases as monitoring-well distance increases • Limited by the availability of monitoring wells • No information about proppant distribution and effective fracture geometry	Can determine	Can determine	Can determine	May determine	May determine	Cannot determine	Can determine	Cannot determine
	Microseismic mapping	• Limited by the availability of monitoring wells • Dependent on velocity-model correctness • No information about proppant distribution and effective fracture geometry	Can determine	Can determine	Can determine	Cannot determine	Can determine	May determine	Cannot determine	Cannot determine

Can determine   May determine   Cannot determine

Source: After Cipolla, C.L. and Wright, C.A. 2000. State-of-the-Art in Hydraulic Fracture Diagnostics. Presented at the SPE Asia Pacific Oil and Gas Conference and Exhibition, Brisbane, Australia, 16–18 October. SPE-64434-MS.

Do We Know What's Happening Downhole?

Group	Fracture Diagnostic Method	Main Limitations	Ability to Estimate							
			Length	Height	Asymmetry	Width	Azimuth	Dip	Volume	Conductivity
Near wellbore, after fracturing	Radioactive tracers	• Measurement in near-wellbore volume • Provides only a lower limit for fracture height if fracture and well path are not aligned		May determine		May determine	May determine			
	Temperature logging	• Thermal conductivity of different formations can vary, skewing temperature log results • Post-treatment log requires multiple passes within 24 hours after the treatment • Provides only a lower limit for fracture height if fracture and well path are not aligned		May determine						
	Production logging	• Provides only information about zones or perforations contributing to production in cased-hole applications		May determine						
	Borehole image logging	• Run only in open hole • Provides fracture orientation only near the wellbore		May determine		May determine	May determine	May determine		
	Down hole video	• Run mostly in cased holes and provides information only about zones and perforations contributing to production • May have open hole applications		May determine						
Model based	Net-pressure fracture analysis	• Results dependent on model assumptions and reservoir description • Requires "calibration" with direct observations	May determine	May determine		May determine			May determine	May determine
	Well testing	• Results dependent on model assumptions • Requires accurate permeability and reservoir pressure estimates	May determine			May determine				May determine
	Production analysis	• Results dependent on model assumptions • Requires accurate permeability and reservoir pressure estimates	May determine			May determine				May determine

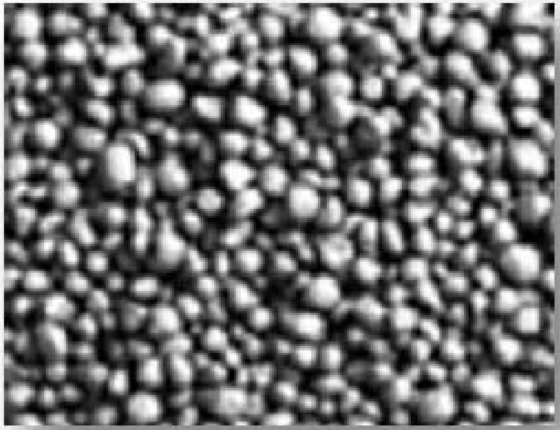
Can determine | May determine | Cannot determine

Source: After Cipolla, C.L. and Wright, C.A. 2000.

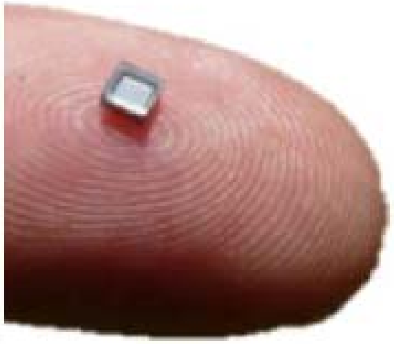
Getting the Most out of Hydraulic Fracturing

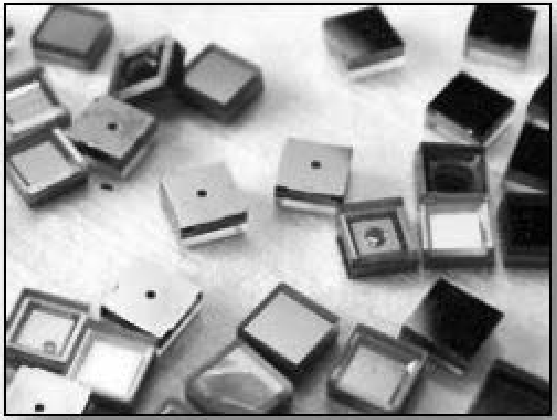
Problem: Need to know where fractures are propagating, their number, width, extent.

Answer: Embedding smart microsystems within standard proppant formulations



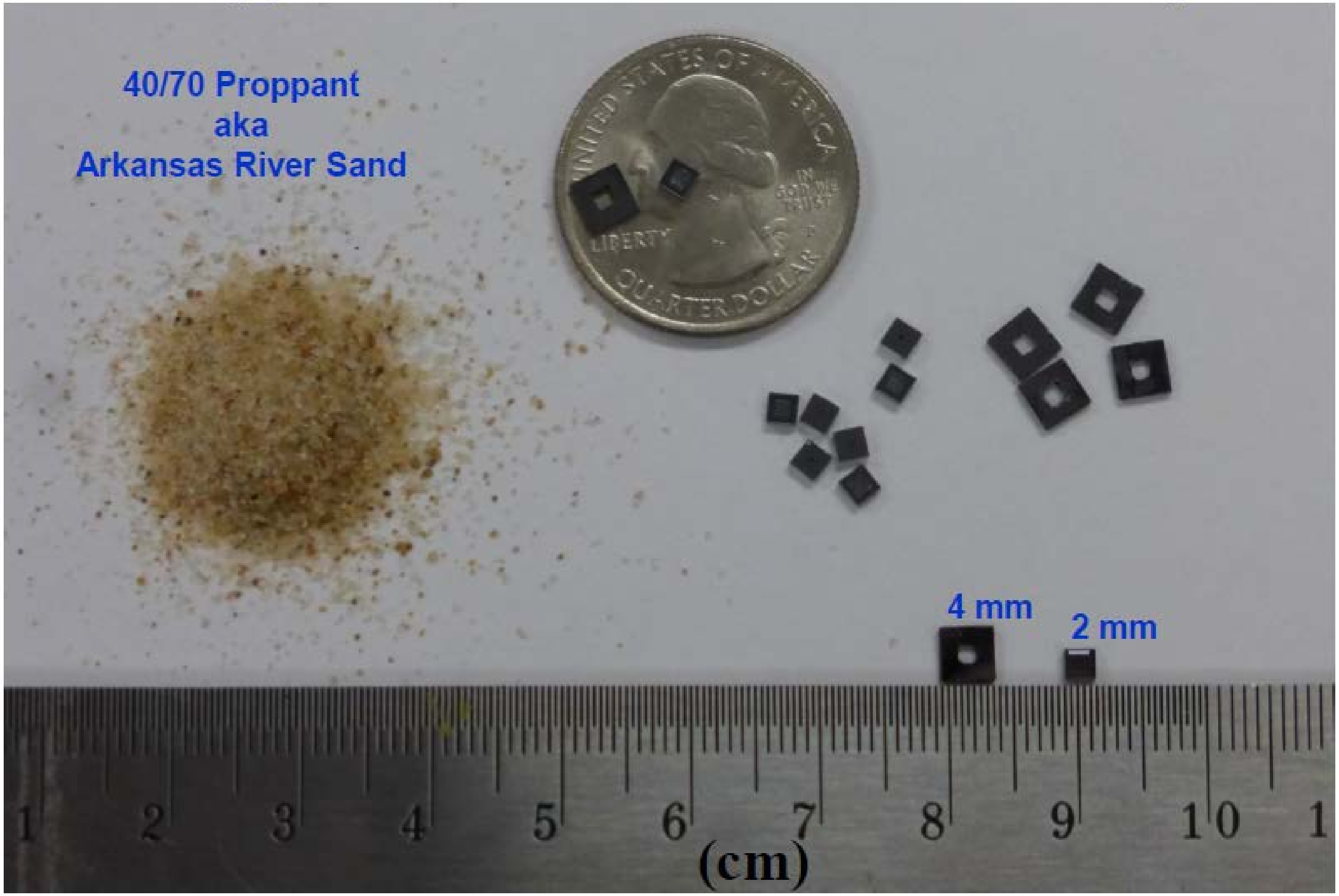
Typical ceramic proppant 20/40



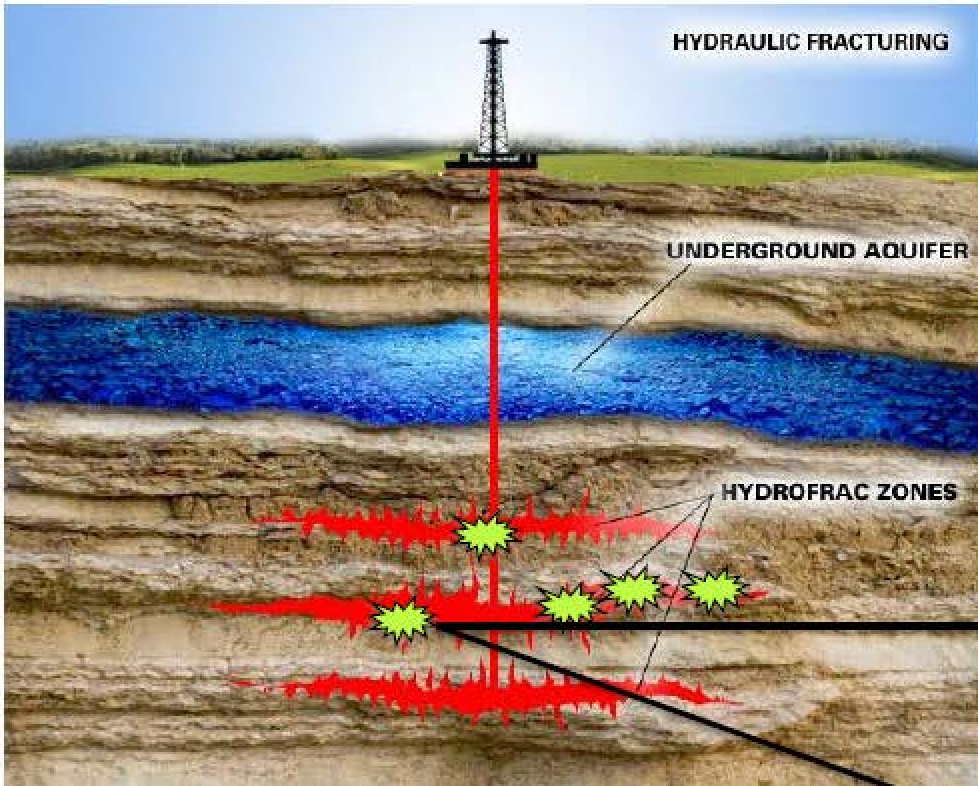


fluidion smart micro-emitter (prototype stage)

40/70 Proppant Vs. Acoustic Micro Emitters

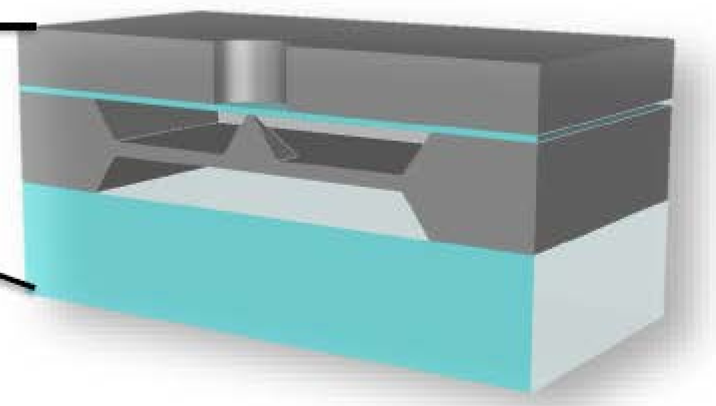


Using Smart Acoustic Micro Emitters (AME)



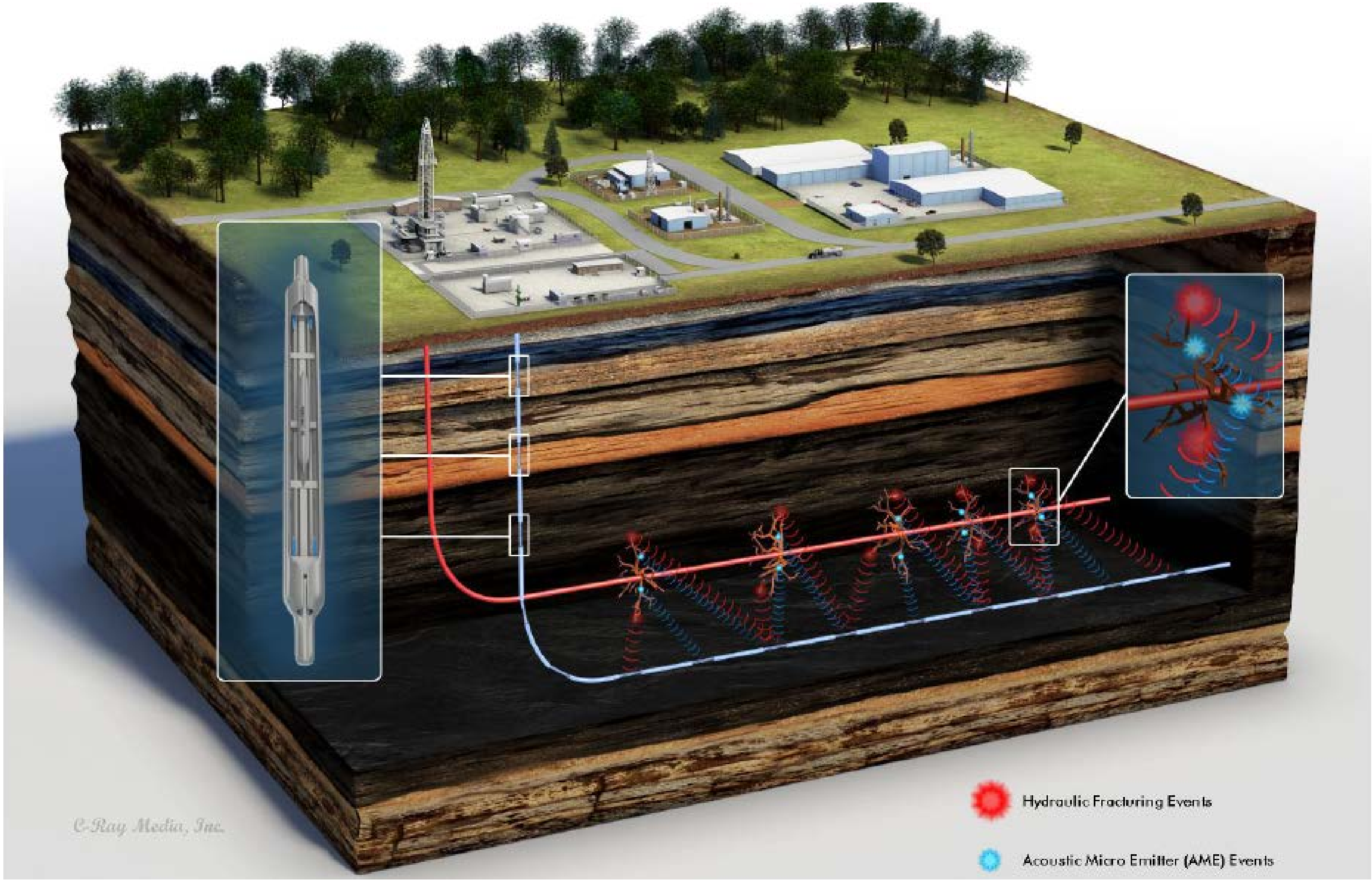
<u>Simple logistics:</u>

1. Injected in well along with proppant
2. Detected using fiber optic sensor array



Advanced Borehole Monitoring System

Incorporating Acoustic Micro Emitters



Smart Acoustic Micro Emitters - Summary

- **Advances state-of-the-art beyond standard micro-seismic monitoring**
- **Can produce valuable information on:**
  - fracture dimensions
  - fracture orientation
  - number of fractures created per treatment
- **Advanced system enables more effective fracture optimization**

Top Shale Gas Research Needs

- Getting more out of the abundant domestic shale gas resource
  - ➢ Understanding how alternative fracturing fluids could increase recovery
- Understanding what’s happening underground
  - ➢ HF diagnostics to optimize process for cost and productivity
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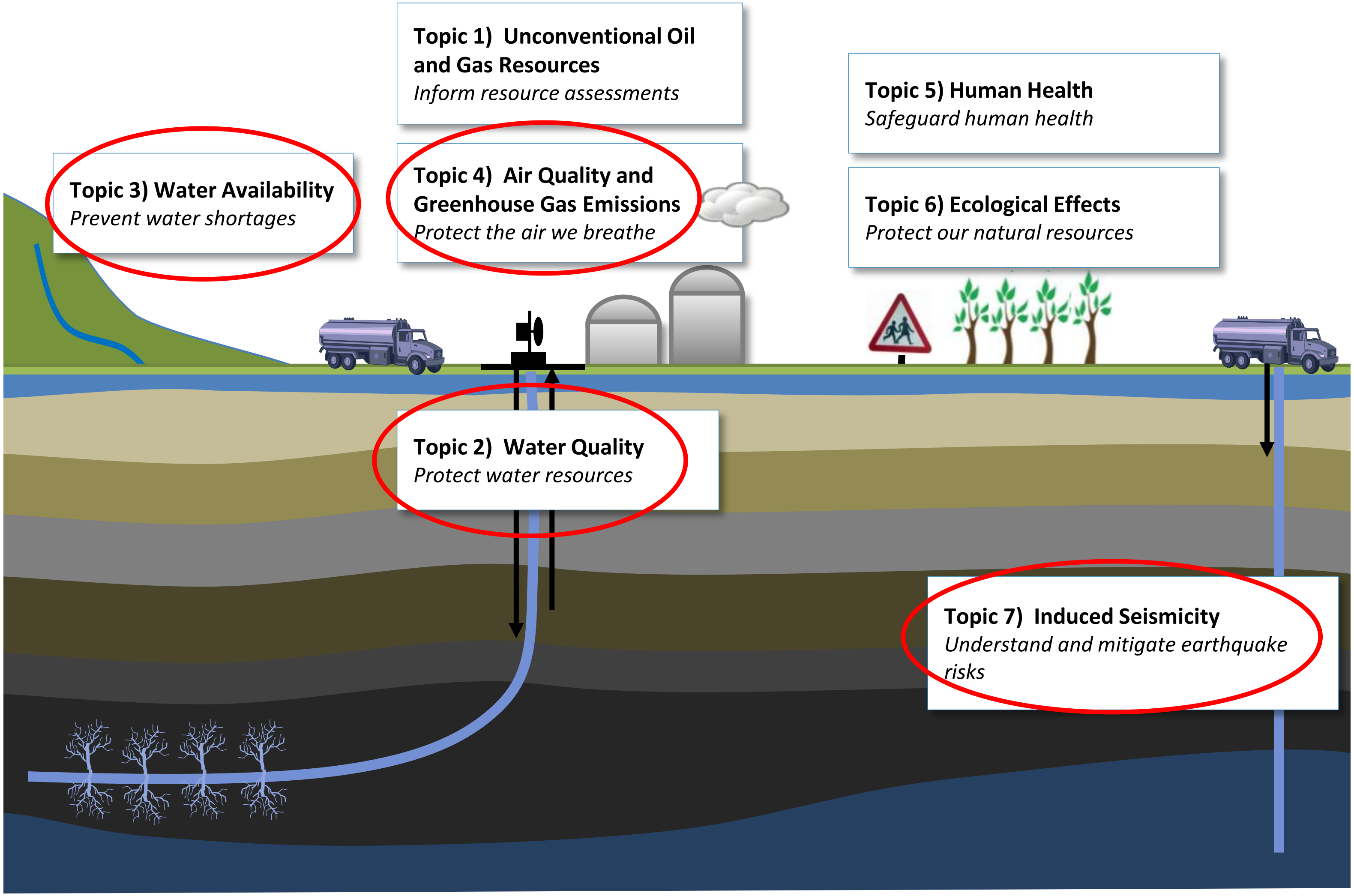
Unconventional Oil & Gas: U.S. Federal Multiagency Collaboration on Research



DOE Oil and Gas "Water" R&D Program

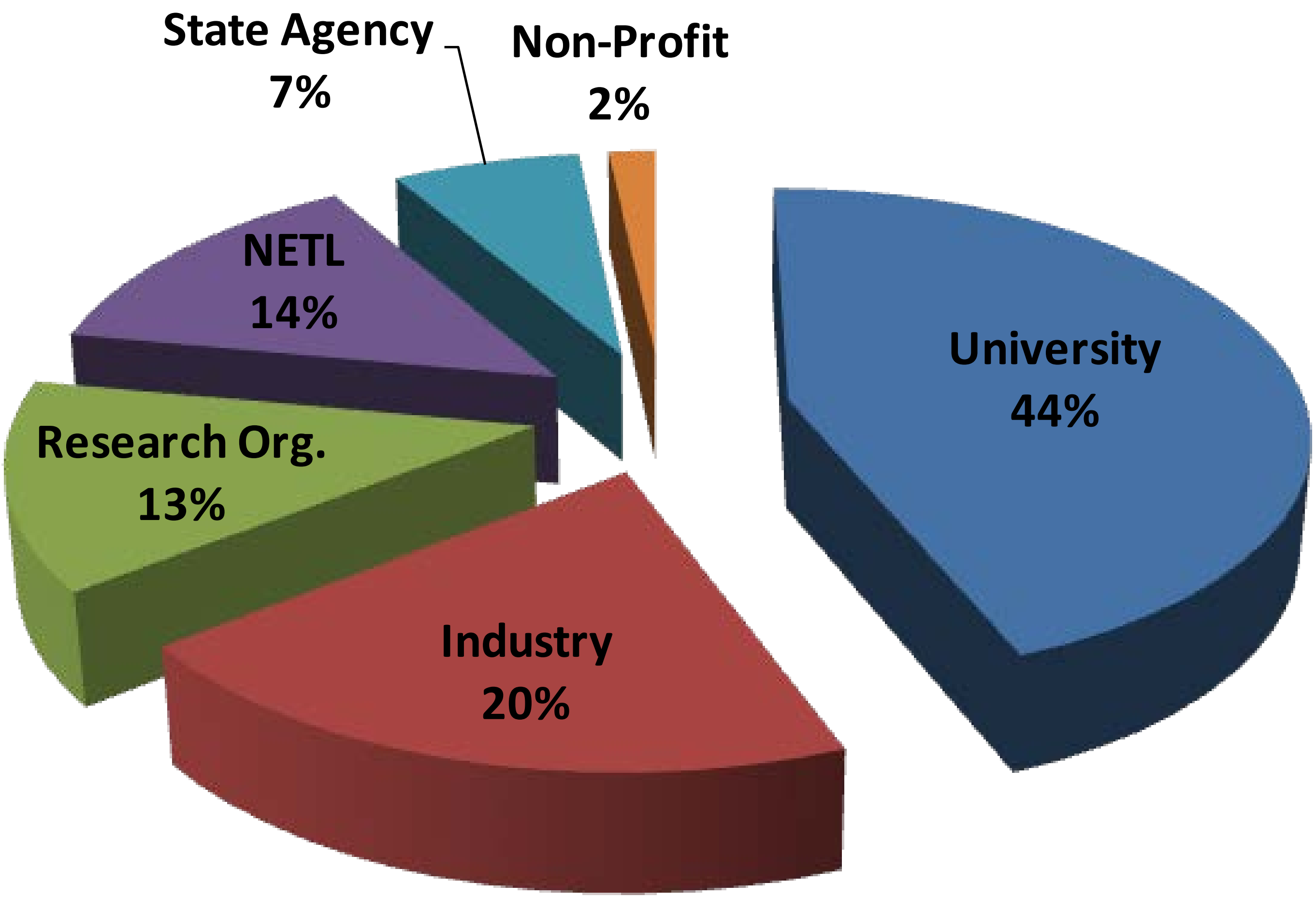
- 59 projects initiated since 2008 with a total value of more than $104 million
- 34 projects remain active, with expected completion dates through September 2017
- Major focus has been water treatment technologies, accounting for about 40% of projects and a third of funding
- Program covers a broad range of water-related issues (e.g., improved cementing technology to protect aquifers)
- NETL-ORD in-house research is focused on risk assessment and basic science surrounding a host of water issues

DOE Oil and Gas Water Project Categories

Category	Number of Projects	Active Projects	Total Value* (MM$)
Water treatment technology development	25	14	33.4
Basic science and risk assessment (NETL ORD in-house research)	8	5	na
Water management tool development	6	2	8.4
Improved annular isolation	5	4	19.2
Environmental impact reduction	3	2	14.3
Alternatives to water as fracturing fluid	3	3	7.6
Enhanced water disposal options	2	0	2.1
Other (e.g., beneficial use, water chemistry, induced seismicity, volume reduction)	7	4	19.4
	59	**34**	**104.4**

** Average partner cost share is about 30%, DOE funding about 70%*

DOE Oil and Gas Water Project Performers



Oil and Natural Gas "Water" Challenges

Fracturing Water

- Find Non-Freshwater Alternatives
- Reduce Freshwater Requirements
- Lower Treatment Costs
- Ensure Safe/Economic Disposal

Produced Water

- Reduce Produced Water Volumes
- Lower Treatment and Disposal Costs
- Support Beneficial Reuse

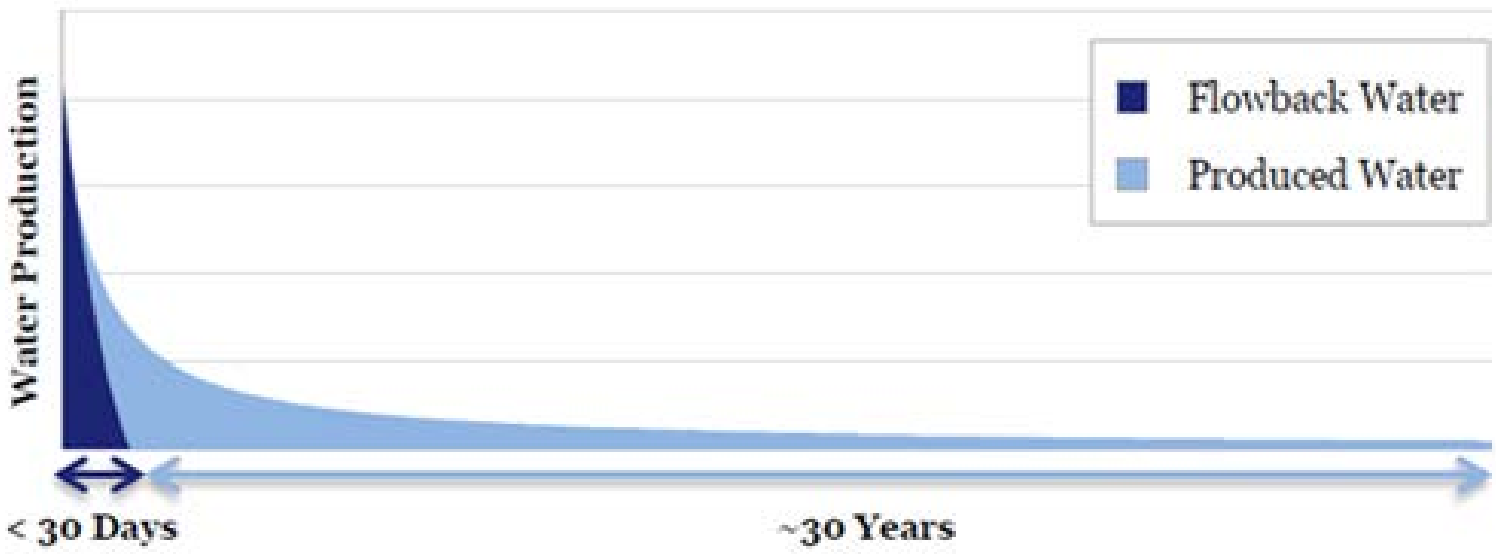
Fresh Water Protection

- Follow Drilling and Well Completion Best Practices to Protect Fresh Water Sources
- Improve Methods for Locating and Plugging Abandoned Wells

Water Disposal

- Reduce Risk of Induced Seismicity

Shale Well Flowback vs. Produced Water



The portion of injected frac fluids that return to surface *before production*. Typically 10-20% returns quickly in 7-14 days with a rapid decline in quality and quantity

Recycle Treatment Options

Technology	Bag Filtration	Physical/Chemical Separation	Electro-Coagulation	Chlorine Dioxide Treatment	Evaporation/ Distillation (MVR)	Crystallization
Total Suspended Solids (TSS)	✖	✖	✖	✖	✖ With pretreatment	✖ With pretreatment
Metals		✖	✖	✖	✖ With pretreatment	✖ With pretreatment
Bacteria		✖	✖	✖	✖	✖
Barium		✖			✖ With pretreatment	✖ With pretreatment
Hardness (Ca)					✖ With pretreatment	✖ With pretreatment
Total Dissolved Solids					✖	✖
Limitations	Disposing of spent filter bags. Can be costly$	Can have large chemical usage and solids processing / landfilling $	Requires very consistent/stable raw water quality; Can have high ($) electrical requirements	Danger handling and generating chlorine dioxide. Can be costly. Have to pay close attention to system performance.	High Energy. High Cost. Rigorous Pre-Treatment.	High energy. Requires very consistent/stable raw influent water quality. High Cost.

Industry Approach Has Changed Over the Past 5+ Years

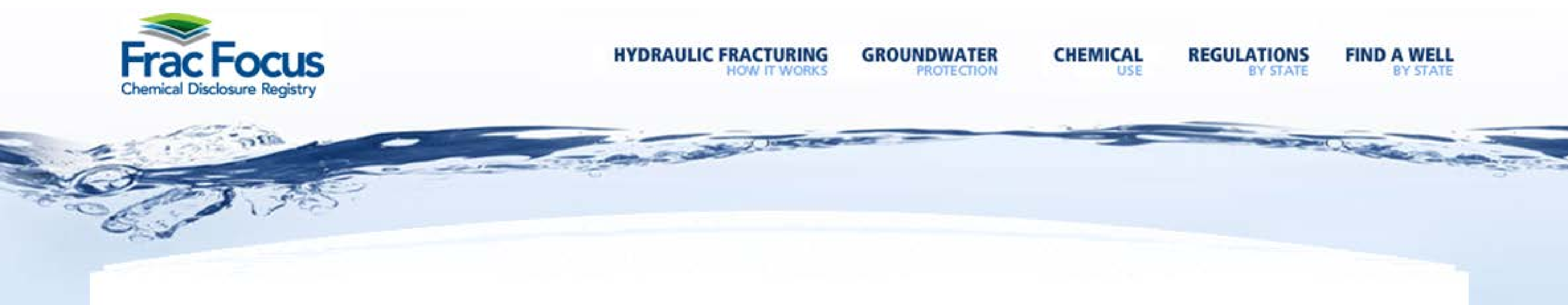
- **Advances in fracturing additive chemistry** have enabled the industry to replace freshwater sources with fracturing flowback, brackish groundwater, produced water, and other non-potable sources.
- **Treatment technology innovations** continue to make reuse of flowback and produced water more technically and economically feasible.
- **Improvements in water conveyance** have reduced truck traffic and associated environmental impacts.
- **New water storage designs** are flexible, reliable, leak resistant and exhibit low evaporation loss.
- **Water monitoring innovations** for tracking water use enhance transparency.
- **Evolved company organizational structures** now often include water management teams that focus on managing the full water cycle from sourcing to use, recycling, and disposal.

Two Marcellus Wastewater Treatment Facilities Open with DOE-Tested Technology

- Located in Clarion County and McKean County, Pennsylvania
- Energy-efficient AltelaRain® thermal distillation process captures heat from condensation, uses it during evaporation
- Capacity = 12,000 barrels of wastewater per day per plant
- Discharge water exceeds Pennsylvania Department of Environmental Protection requirements

FracFocus Website Developed and Maintained via DOE Funding to GWPC

- **Contains publically available data on fracturing treatments for more than 93,000 wells fractured after Jan 1, 2011**
- **1109 companies have contributed data as of Feb 26, 2015**
- **New websites features will facilitate data downloads and analysis by any interested stakeholder**
- **Many producing states are incorporating FracFocus into reporting requirements**



Well Integrity Diagnostic Challenges

- **Measuring the integrity of multiple well casing and cement annuli at intermediate-to-surface depths across aquifers**
- **State-of-the-art acoustic imaging cannot resolve multiple annuli in the intermediate zone above 10,000 ft. where there are 2 to 5 stacked casing/cement rings**
- **Ultrasound-based techniques do not operate in gas filled wellbores**
- **Electromagnetic tools are sensitive only to damage in casing**
- **Internal pipe strings magnetically shield external pipes and significantly reduce sensitivity/spatial resolution**

Well Integrity Research Project Objectives and Benefits

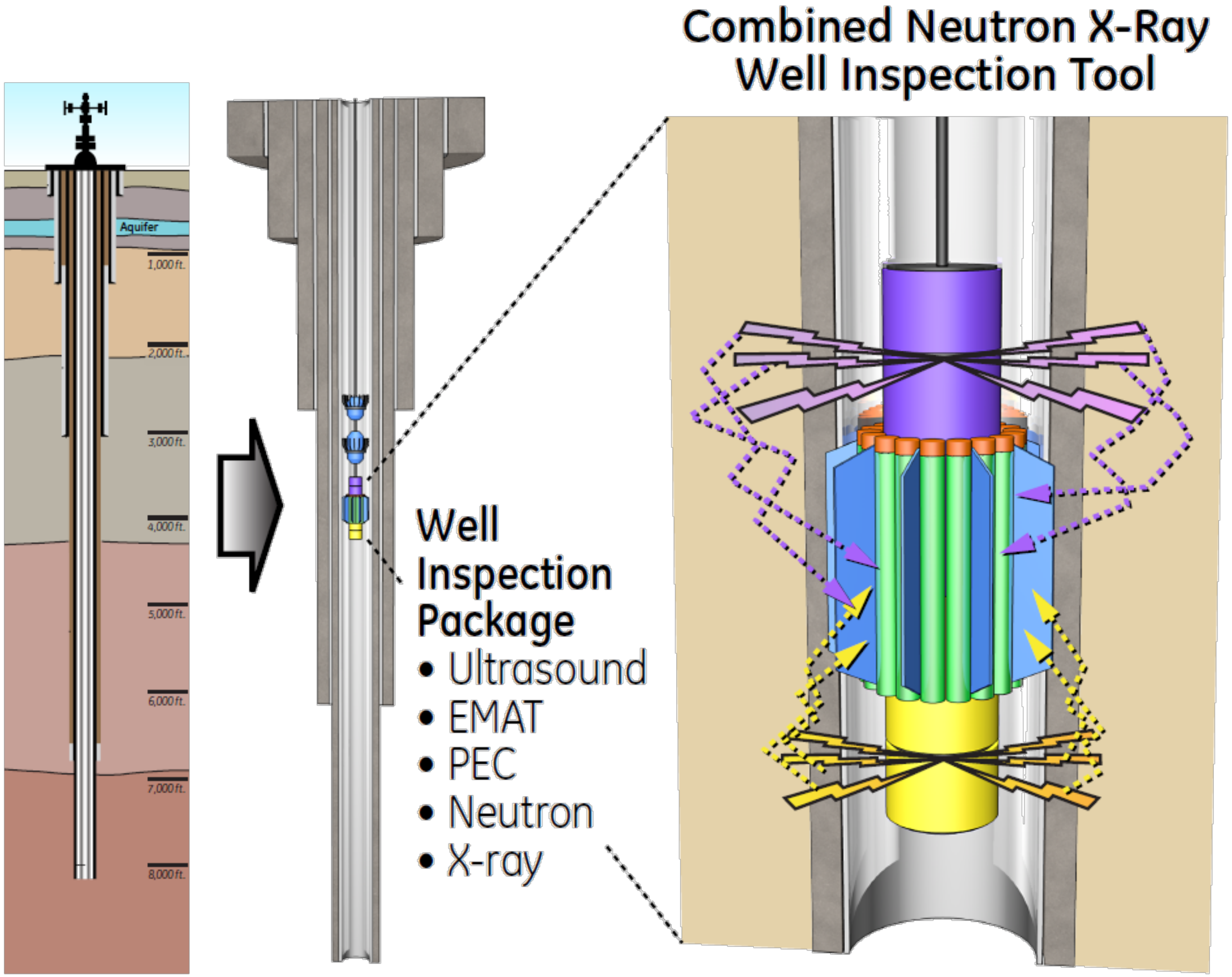
Objectives

- **Combine high energy x-ray and neutron based detection**
- **Incorporate conventional methodology (ultrasound (EMAT), Eddy current and magnetic flux leakage)**
- **Achieve penetration and inspection beyond first casing string using novel combination of x-ray and neutron techniques**
- **Develop small diameter sources and detectors; reduced size electronics**
- **Ensure high temperature operation of sources and detectors**

Benefits

- **Reduced environmental risk thru enhanced long term integrity of wells**
- **Detection of defects, fractures leaks, corrosion/material loss, annular cement gaps, contaminated cement, and formation or pipe bonding flaws**

Develop New Combination Logging Tool to Address Challenges



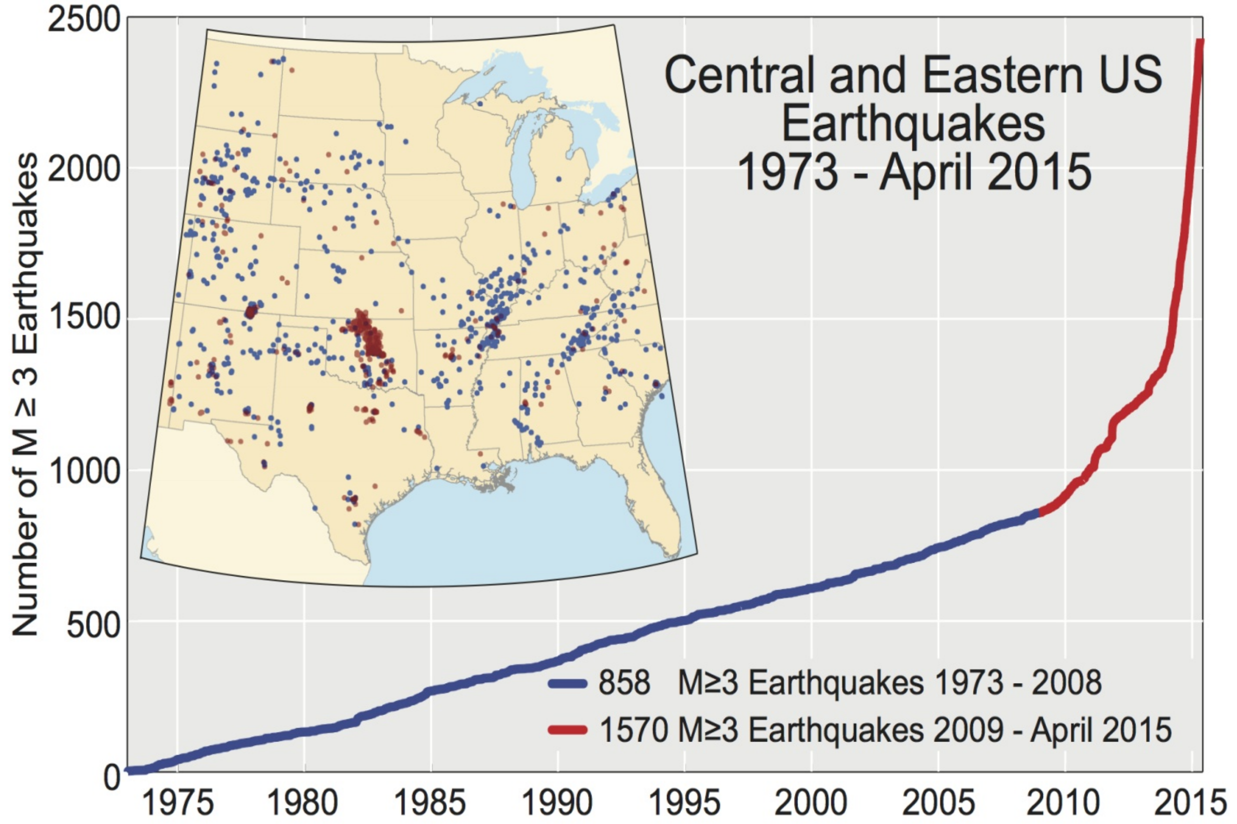
Methane Emission Reduction

Multiple Efforts to Estimate O&G Production Methane Emissions

- Environmental Defense Fund Studies in progress
  - UTexas - Production - Phase 1 (published Sept. 2013)
  - UTexas - Production - Phase 2
  - Colorado State U. - Gathering/Processing
  - EPA/HARC - Production
- Various "top down" studies
  - Brandt, February 2014
  - Petron, June 2014
  - Miller, December 2013
  - Karion, August 2013

Understanding Induced Seismicity

- **Wastewater disposal is primary cause of increase in quakes in central U.S.**
- **Current R&D focused on understanding the physical processes involved**
- **Collecting data on injection timing and volumes, seismicity, subsurface geology**



- **Developing models that can relate intensity to injection characteristics and enhance understanding of how deep and shallow faults are affected**

Information

- Website (www.netl.doe.gov/technologies/oil-gas/index.html)
- *E&P Focus* newsletter (http://listserv.netl.doe.gov/mailman/listinfo/epfocus)
- Natural Gas Program Archive - 2 DVD set (2007) (www.netl.doe.gov/publications/cdordering.html)