NATIONAL ENERGY TECHNOLOGY LABORATORY

DOE Traditional Research and NETL Complementary Research Portfolio

September 25, 2012

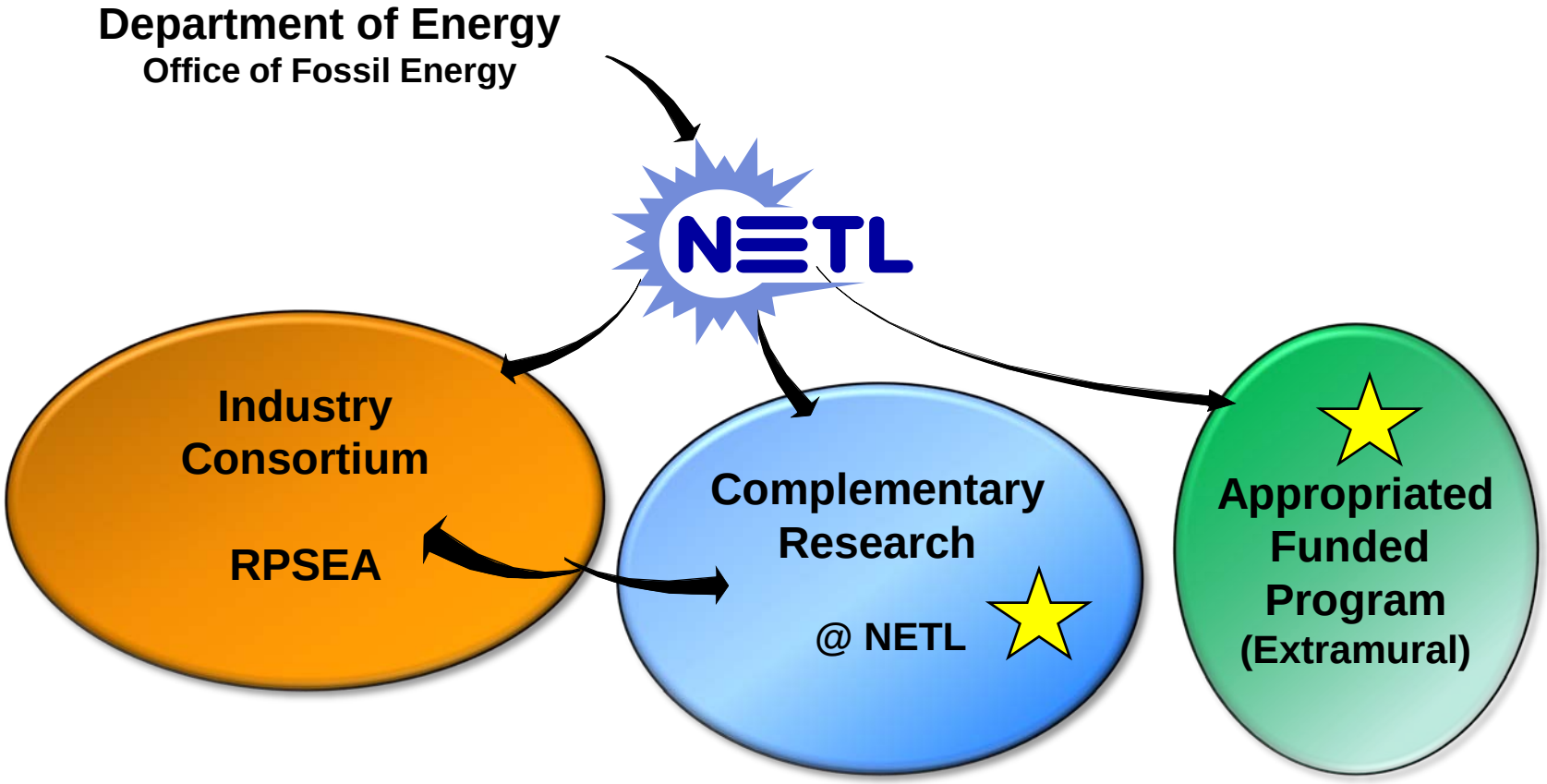
Alexandra Hakala

Technical Coordinator, Shale Gas

Office of Research and Development

National Energy Technology Laboratory

U.S. DEPARTMENT OF ENERGY



Maximizing Benefits

9 Projects Resource Characterization

12 Projects Production Optimization

Minimizing Impacts

10 Projects Water Treatment

4 Projects Water Resources Mgmt

2 Projects Impact Mitigation and Decision-making

Current Appropriated Program Drivers: Secretary of Energy Advisory Board - *Recommendations for Federal Agencies*

Secretary of Energy Advisory Board

Shale Gas Production Subcommittee
Second Ninety Day Report

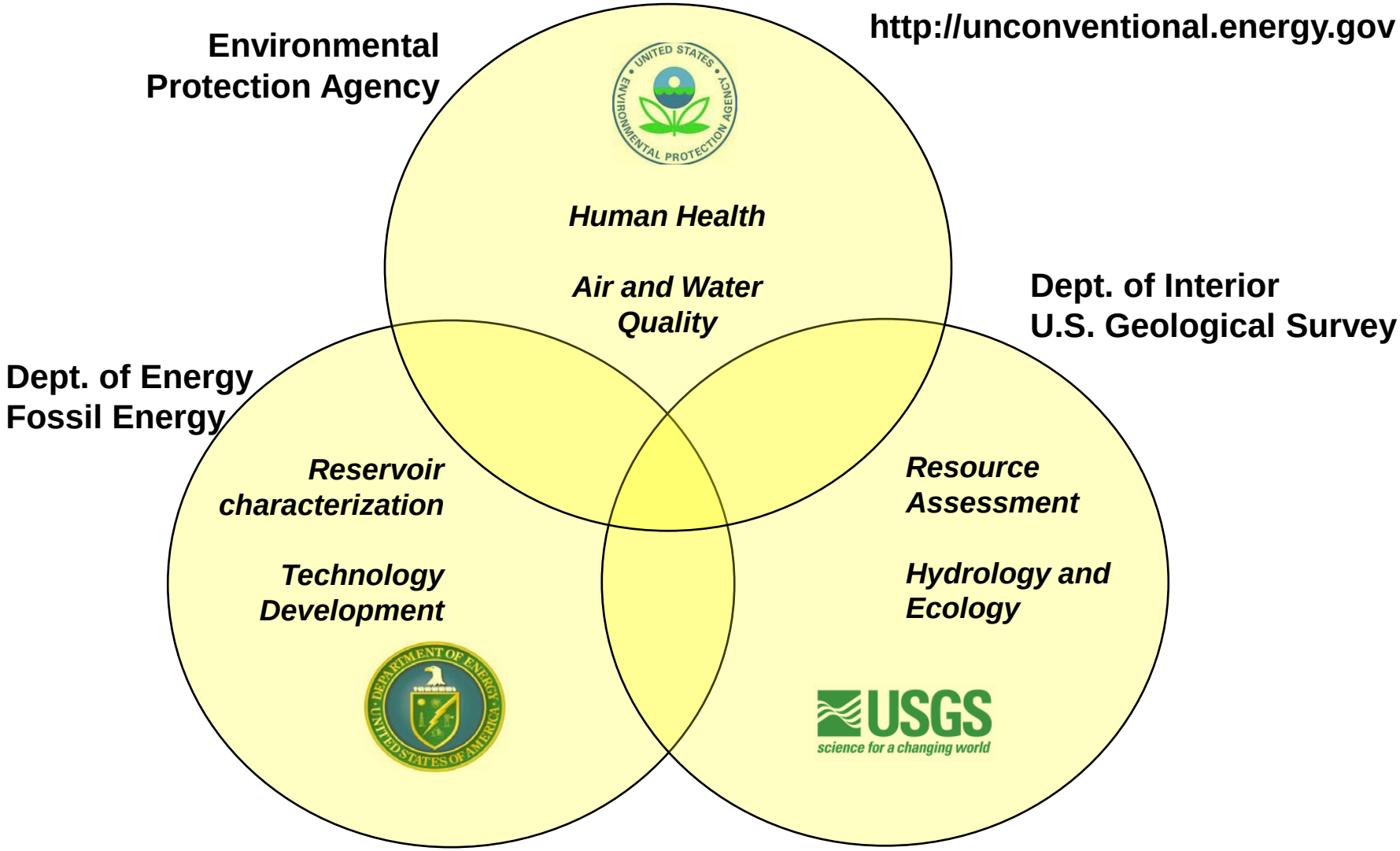
November 18, 2011

U.S. DEPARTMENT OF ENERGY

- Enhance the quality and quantity of public information
- Developing benchmark air emissions and monitoring related to gas operations
- Evaluate subsurface methane migration issues
- Water Quality Protection
- Fracturing Fluid Composition Disclosure
- Support the development of industry “best practices”
- Reducing safety risk and risk of environmental damage for shale gas operations

Interagency Collaboration

Focus on Environmental, Safety, and Health



NATIONAL ENERGY TECHNOLOGY LABORATORY

DOE Traditional Research Portfolio

September 25, 2012

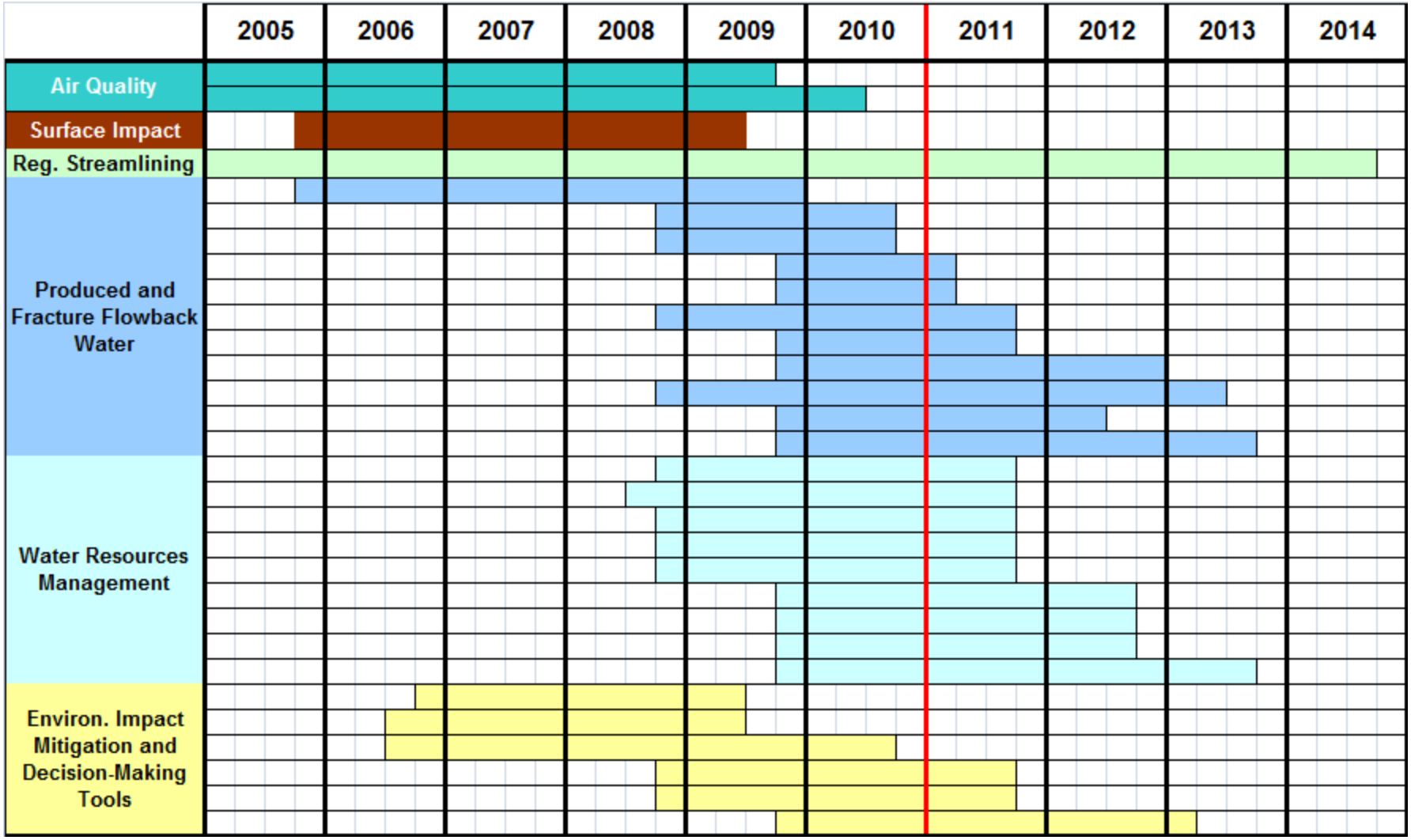
Alexandra Hakala, ORD

for Al Yost and Ray Boswell, SCNGO

U.S. DEPARTMENT OF ENERGY

Environmental Projects in Appropriated Program

Focus on water treatment and management since 2012



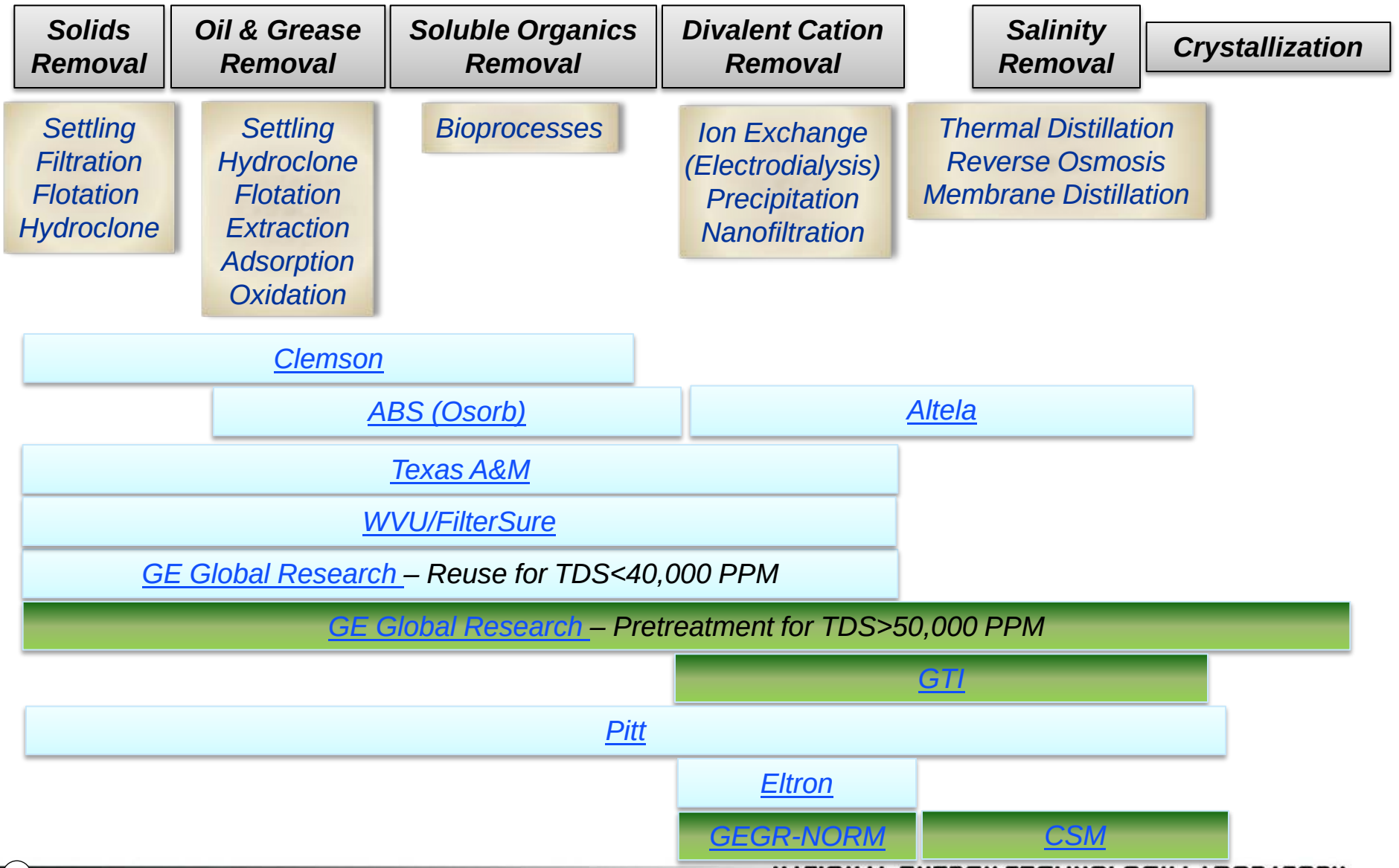
Recent Shale Gas Water Research Summary

- **2011-12 – Section 999 Consortium Program shifted focus to:**
  - **Novel treatment processes rather than incremental improvements in high-cost commercial technologies (focused on lowering cost of high salinity treatment)**
  - **Online water resource management tools that integrate options available to operators and provide decision support**
- **2011-12 – Section 999 Complementary Program shifted focus to:**
  - **Collecting data for risk assessments related to groundwater water contamination**
- **2011-12 – Appropriated Program not funded**

Water Treatment Objectives

- Reduce Fresh Water Demand
  - New treatments for frac water makeup
  - New treatments for alternative water sources
- Reduce Environmental Footprint
  - Minimize need to haul water
- Increase Beneficial Use Options
  - Investigate potential for treatment for arable use

Current Water Treatment R&D Portfolio Focus



Green = RPSEA Projects

Innovative Water Management Technology to Reduce Environmental Impacts of Produced Water

Clemson

- **Objective: To develop constructed wetland systems for treatment and beneficial use of produced water, and to conduct scientific studies to address ecological, environmental and regulatory concerns that limit options for managing produced water, including surface discharge water**
- **Timing: 2008 - 2013**
- **Current Results:**
  - Demonstration wetland treatment system constructed at coal bed methane field in northern Alabama (Clemson and partner Chevron)
  - Plants will acclimate before collected site water is passed through system
  - Target contaminants include metals, metalloids, oil and grease

Swellable Organosilica Materials to Clean Produced Water

ABS Materials (Osorb)

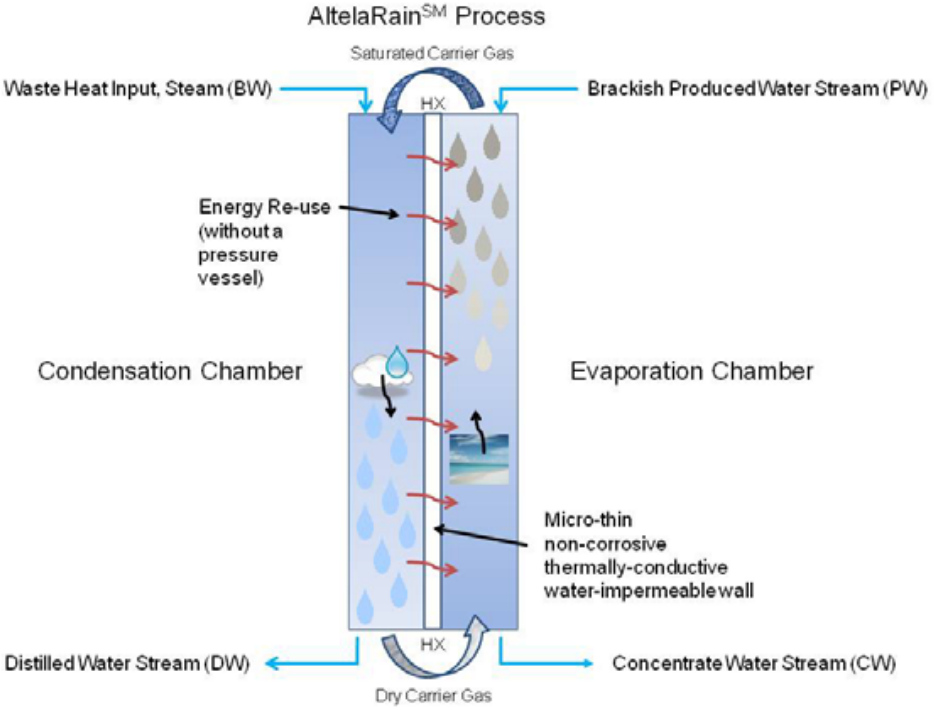
- **Objective: Develop and improve several water treatment technologies to remove dispersed and dissolved organic species from produced water with a focus on flowback treatment, and to develop a process to make these technologies commercially viable**
- **Timing: 2010 – 2013**
- **Current Results:**
  - Osorb can capture wide range of dissolved and dispersed organics from water
    - Adsorbed compounds can be removed with mild thermal treatment or rinsing
  - ABS completed build of PWU 1.5, a 65 gal/min fully-automated treatment system mounted on a 53 ft drop-deck trailer
  - Wet testing conducted late May/early June

Integrated Water Treatment Technology for Sustainable Water Resource Management in the Marcellus Shale

Altela, Inc

- **Objective: Demonstrate that the patented AltelaRain technology can be successfully deployed in a cost-effective manner to treat Marcellus Shale produced and flowback water, and that it can operate within state and federal regulatory requirements.**

- **Timing:** Oct. 2009 – Apr. 2011



DE-FE0000833

Pilot Test of Pretreatment Options to Allow Re-Use of Frac Flowback and Produced Brine for Gas Shale Development

Texas A&M University

- **Objective: Identify a reliable and cost-effective pre-treatment methodology for use in processes employed to treat and re-use field-produced brine and fracture flowback waters. Demonstrate technology in field operations using a trailer-mounted unit that will remove constituents in high salinity flowback water.**
- **Timing:** Oct. 2009 – Sept. 2011

Zero Discharge Water Management for Shale Development

West Virginia Water Research Institute , WVU, ShipShaper LLC, FilterSure, Inc.

- **Objective: Develop and demonstrate a process for treating hydraulic fracturing water returns from Marcellus wells that will allow an increased recycle rate while decreasing makeup water and disposal requirements.**
  - Test mobile, on site treatment options
  - Evaluate volumes, chemistries and disposal options for byproducts
  - As filtration is optimized, employ laboratory studies to evaluate filter systems and electocoagulation at bench scale
  - Test with “real” frac water at the scale of 2 to 6 gpm
  - Field test mobile systems upscaled to 150 gpm
- **Timing: Oct. 2009 – May 2012**

WVU/Filtersure Prototype Performance

2GPM Filter Unit

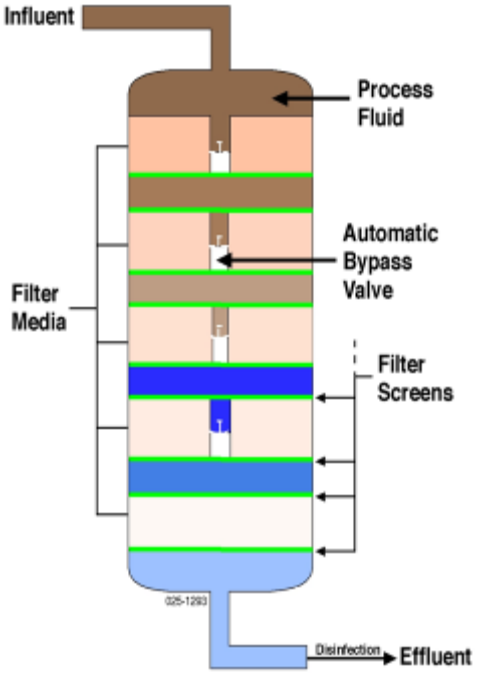
Measured Water Chemistry	Actual Frac Return Water (mg/L)	2GPM prototype Mobile Treatment Unit (mg/L)	% Reduction
TDS	112,000	81,400	27
SO_4	414	101	76
Cl	65,000	51,000	22
Na	32,800	19,500	41
Ca	10,600	7,830	26
Mg	1,200	786	35
Fe	16	8	50
Ba	201	93	54
Sr	1,340	1,090	19

2 GPM Filter Unit

Mobile Treatment Unit Constructed for Planned Field Test

Planned Field Test

- Two Filter Units running in parallel to treat 5,000 bbl/day (Rate 150GPM)
- Media selected to reject greater than 20 micron sized solids
- Focus on Sulfate reduction – current test show 76% reduction in SO_4



Mobile Treatment Unit Constructed for Planned Field Test

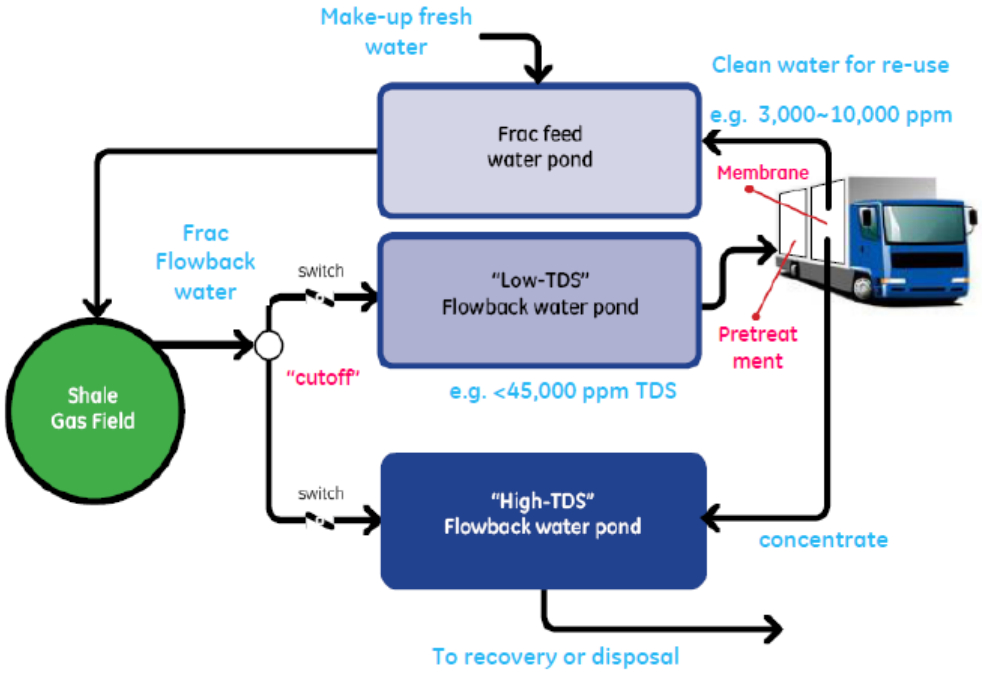
Planned Field Test

Cost Effective Recovery of Low-TDS Flowback Water for Re-use

GE Global Research

- **Objective: Design a low-cost, mobile process to treat the low- total dissolved solids (TDS) portion of the flowback water from hydraulic fracturing operations in order to reduce the cost of shale gas production.**

- **Timing:**
  Oct. 2009 – Mar. 2011



Sustainable Management of Flowback Water during Hydraulic Fracturing of Marcellus Shale for Natural Gas Production

University of Pittsburgh, Carnegie Mellon University

- **Objective: Develop an approach that will allow the use of flowback water from one well as a hydraulic fracturing fluid for subsequent wells in the Marcellus Shale.**
  - Evaluate the potential to combine and treat two waste streams (flowback water and acid mine drainage)
  - Identify a separation technology which is suitable for high-TDS, high-flowrate flowback water, which stabilizes and removes undesired divalent cations
  - Develop novel viscosity modifiers that are stable under extreme salinities to enable reuse of flowback as fracture water on site

- **Timing:** Oct. 2009 – Sept. 2012


Marcellus frac in PA

Unconventional High Temperature Nanofiltration for Produced Water Treatment

Eltron

- **Objective: To develop unconventional high temperature nanofiltration membrane technology for removing salinity and mineral content from produced water resulting in greater utilization of domestic fuel reserves.**

- **Timing: 2010 – 2012**
- **Current Results:**
  - Phase I (2009 – 2010) demonstrated feasibility of high temperature nanofiltration membranes for produced water treatment
  - Polymer formulations deposited onto microporous alumina tubes, and performance evaluates
  - > 60% $MgSO_4$ rejection; ~50% NaCl rejection

Standard thin film composite membrane, cross sectional SEM image (50µm scale)

Water Management Objectives

Provide:

- **Tools for developing and evaluating best practices**
- **Tech Transfer of R&D results, available treatment technologies, and region specific water treatment needs**
- **Public sources of data and tools to enable sound science for regulatory decision making**

Current Water Management Projects

Water Management Objectives:

- **Tools for developing and evaluating best practices**
- **Tech Transfer of R&D results, available treatment technologies, and region specific water treatment needs**
- **Public sources of data to enable sound science for regulatory decision making**

Project DE-FE0000888: Water Management Strategies for CBM in the Black Warrior Basin – Geological Survey of Alabama

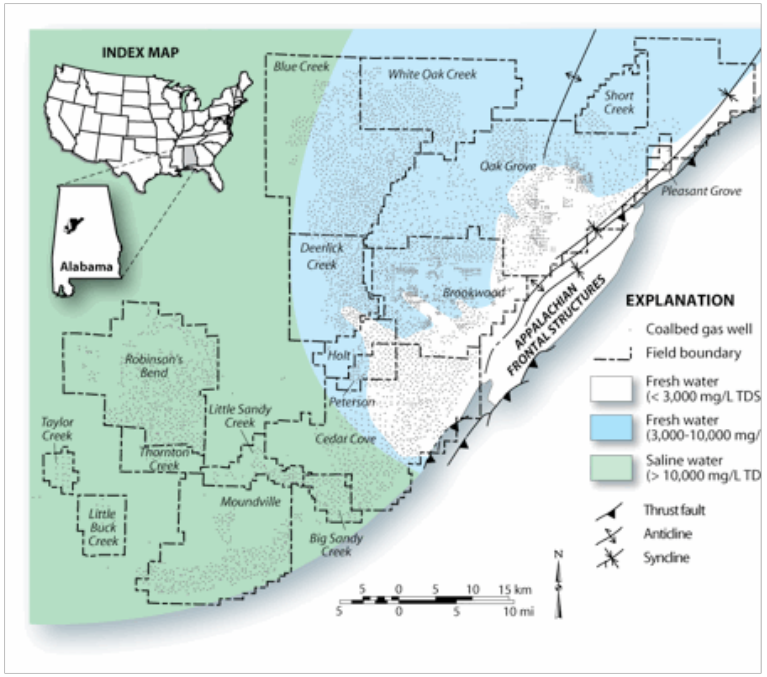
Project DE-FE0000880: RBDMS with FracFocus – GWPC

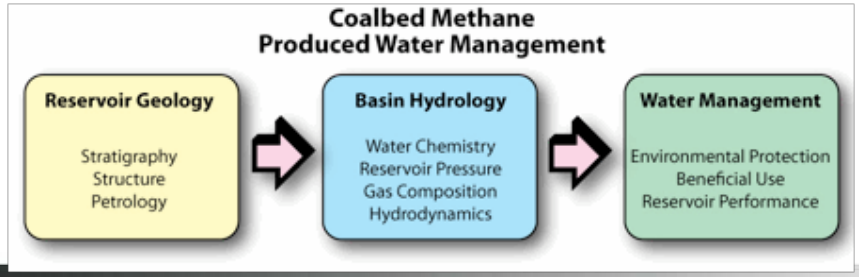
Project DE-FE0000804: Fayetteville Shale Decision Support System – U. Arkansas

Water Management Strategies for Improved Coalbed Methane Production in the Black Warrior Basin

Geological Survey of Alabama

- **Objective: To analyze and develop strategies for water resource management within the coalbed methane (CBM) reservoirs of the Black Warrior Basin**
- **Timing: 2009 – 2013**
- **Current Results:**
  - **Completion of organic analysis from samples collected to date**
  - **Bulk geochemical analysis of water samples completed**
  - **Databases on gas production complete**





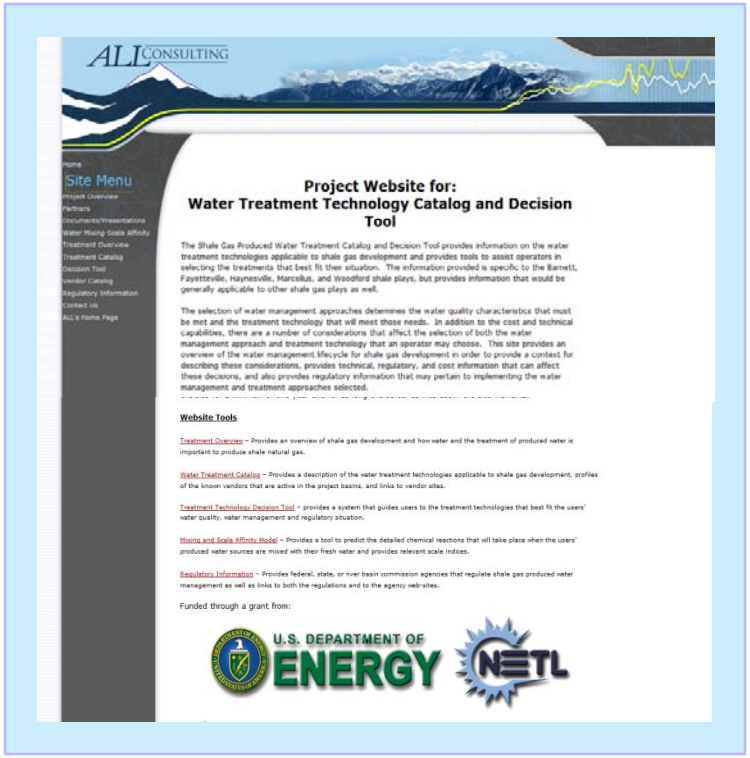
Produced Water Treatment Catalog and Decision Tool

ALL Consulting, Ground Water Protection Council (GWPC)

- **Objective: Create an Internet-based Water Treatment Technology Catalog and Decision Tool that will pair an operator's water treatment cost and capacity needs to optimal water treatment technologies.**

- **Significance:** Oil and gas production will increase as cost-effective approaches to meeting water use and discharge requirements allow permits to be issued in areas that have been off limits due to regulatory requirements. These new approaches will also enhance environmental protection.

- **Timing: Oct. 2008 – Sept. 2011**



DE-FC26-09NT0005680

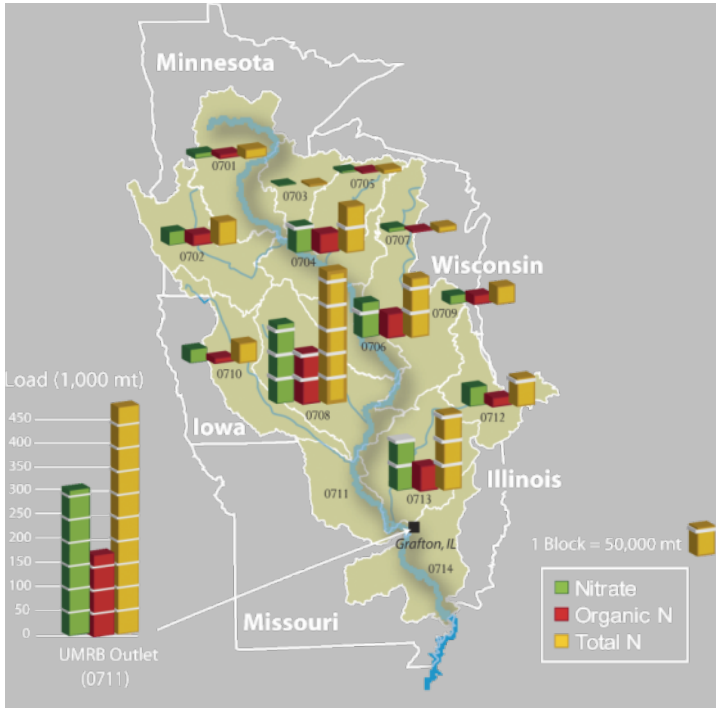
Integration of Water Resource Models with Fayetteville Shale Decision and Support Systems

University of Arkansas, Texas A&M University

- **Objective: Develop a water management decision support system by modifying and integrating a state-of-the art water resource simulation model with a modern enterprise geographic information system.**

- **Approach:**
  - Add watershed-related information to Fayetteville Shale Information Website
  - Develop new water resource models in the Soil and Water Assessment Tool (SWAT)
  - Develop new Fayetteville Shale Decision Support System (FSDSS) spatial layers to support SWAT models
  - Advance knowledge of how ground and surface water withdrawal affects water availability and water quality in a watershed

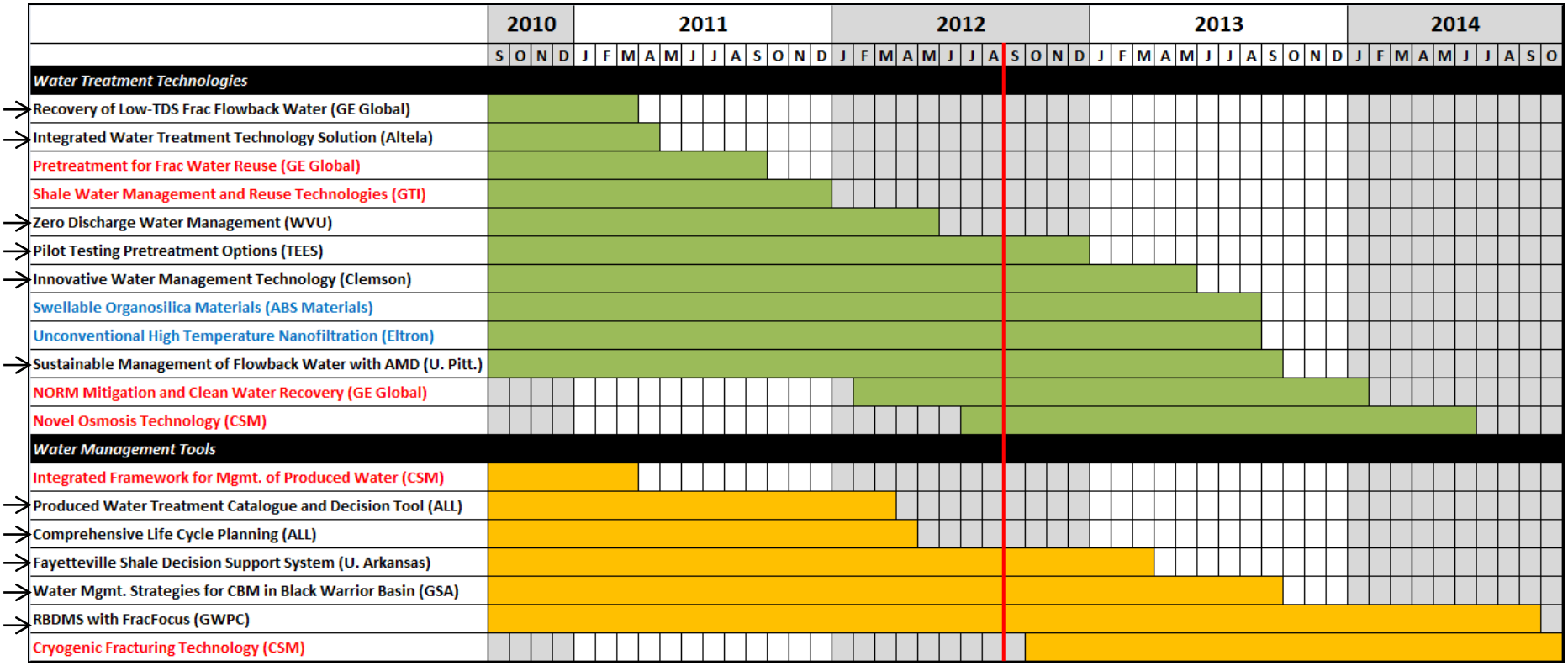
- **Timing: Oct. 2009 – Sept. 2011**



Typical SWAT output- Chemical loads at watershed level at watershed discharge points

DE-FE0000804

Water Portfolio Timeframe



Red = RPSEA Administered Section 999 Projects
Black = Appropriated Program Projects
Blue = SBIR Phase II Projects

Information

- **Website (www.netl.doe.gov/technologies/oil-gas/index.html)**

- ***E&P Focus* newsletter (http://listserv.netl.doe.gov/mailman/listinfo/epfocus)**

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DOE Complementary Research Portfolio
EPAct Section 999

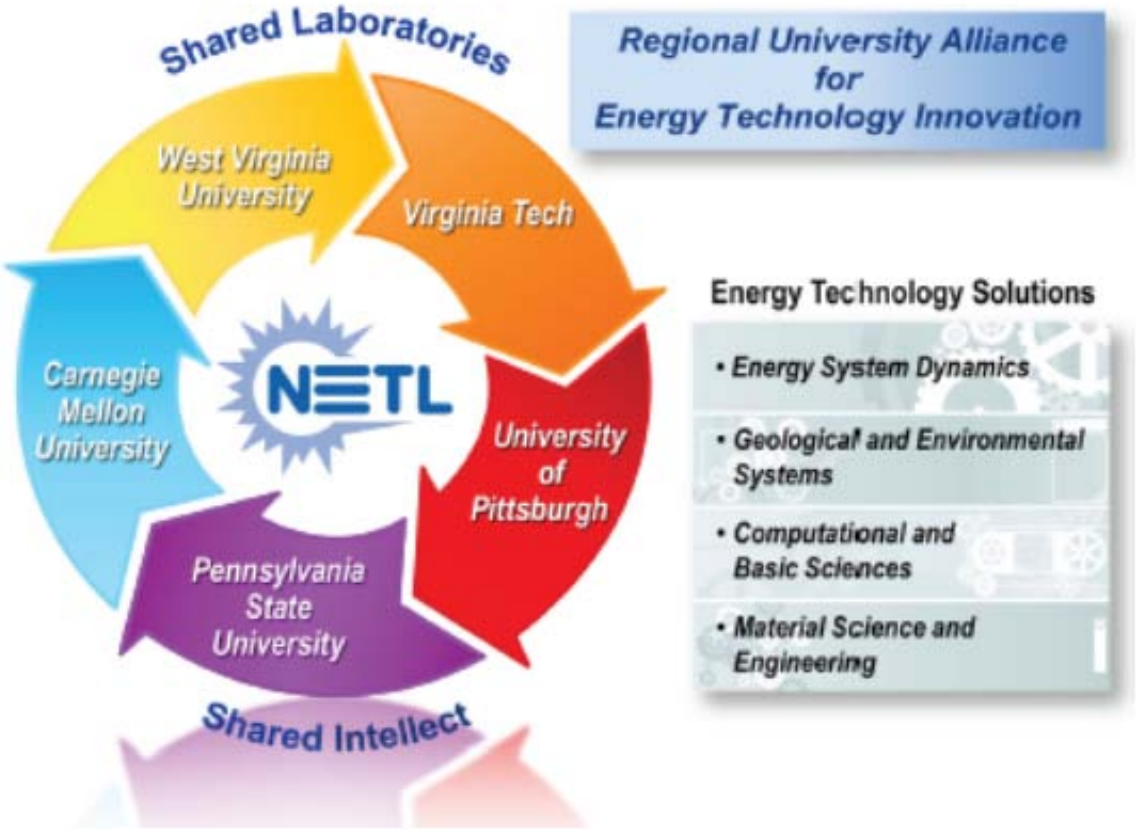
September 25, 2012

Alexandra Hakala, ORD

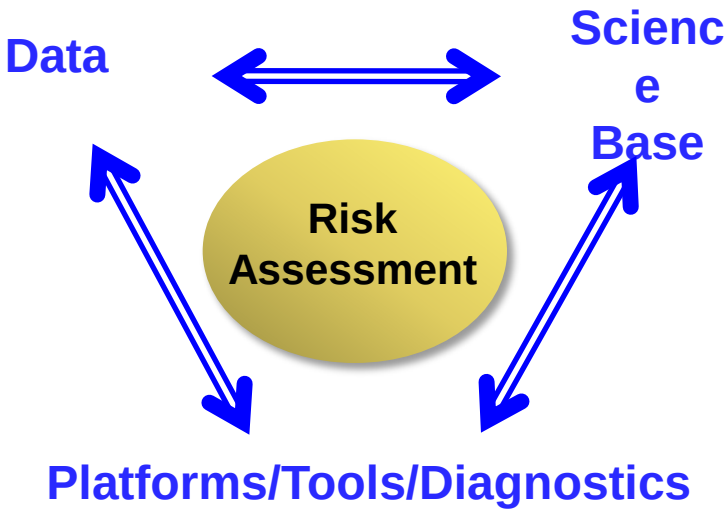
U.S. DEPARTMENT OF ENERGY

NETL-Regional University Alliance

- **NETL's Office of Research and Development**
- **URS**
  - Carnegie Mellon University
  - Pennsylvania State University
  - University of Pittsburgh
  - Virginia Tech
  - West Virginia University



Risk assessment requires predicting the potential for a deleterious event as well as its consequence

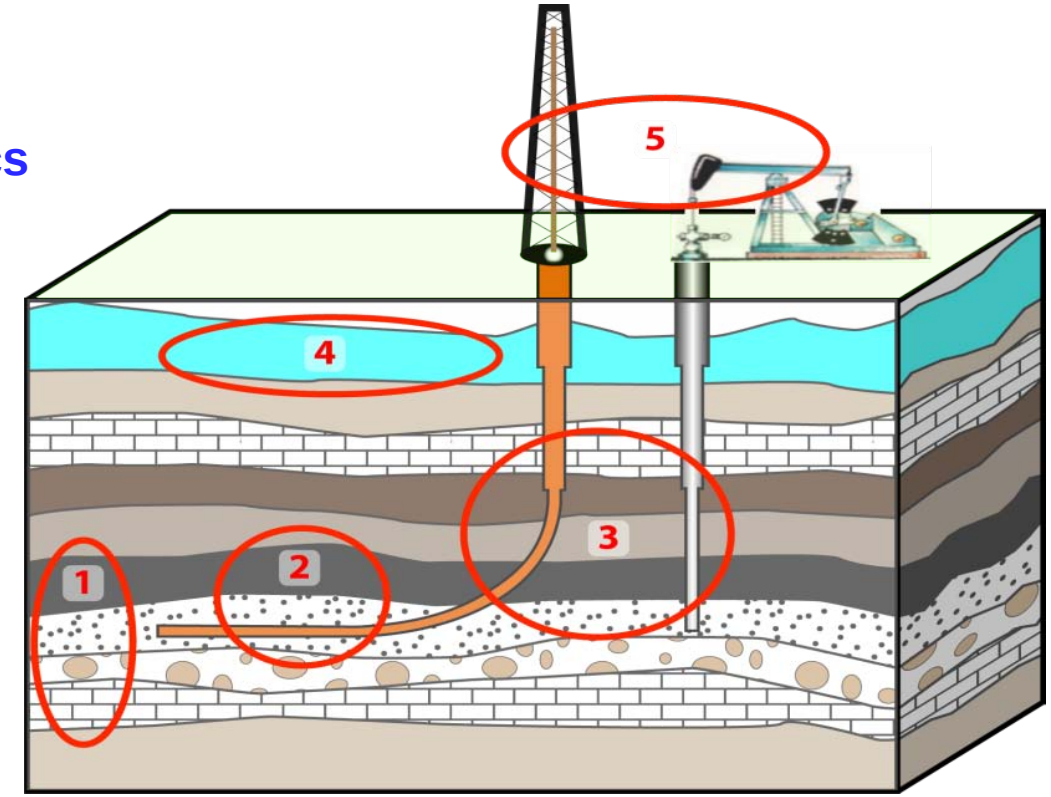


Risk = probability X consequence

site performance

impact of event

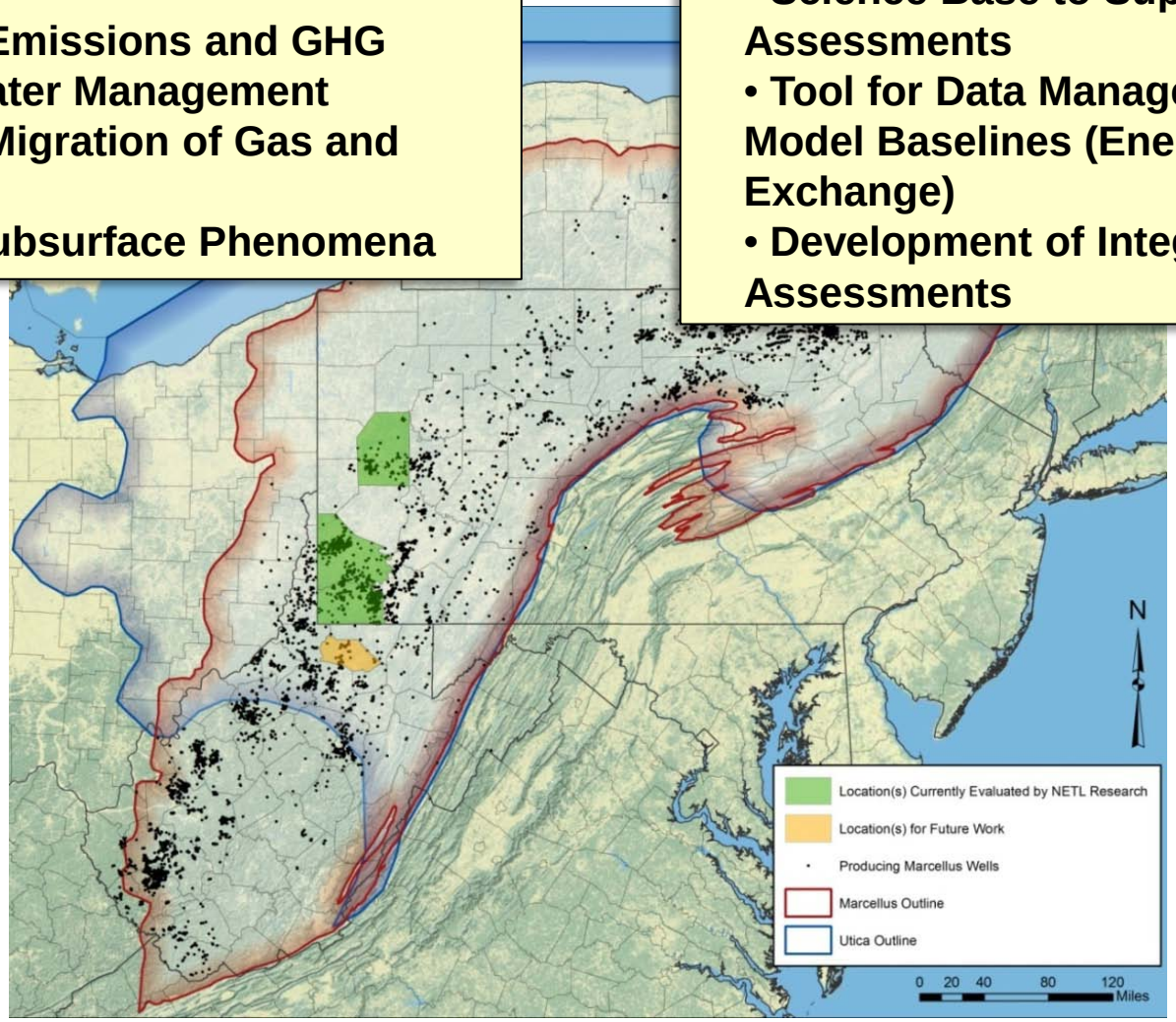
- Field Data to establish baselines and impacts of processes
- Laboratory Data for simulations and confirmation of field data
- Computational Tools to characterize and predict system baselines and behavior



Safety and the Environment for Responsible and Sustainable Shale Gas Development

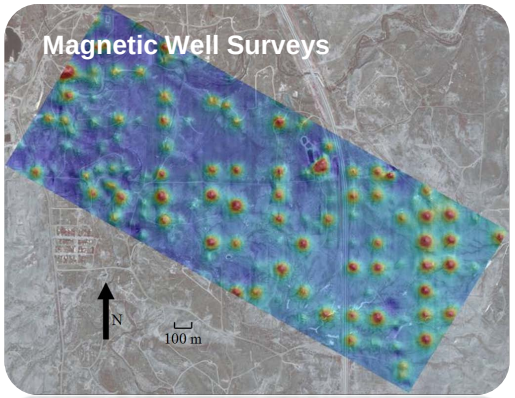
Goal: Deliver Integrated Assessments for
- **Fugitive Air Emissions and GHG**
- **Produced Water Management**
- **Subsurface Migration of Gas and Fluids**
- **Predicting Subsurface Phenomena**

Research Plan Organization
- **Science Base to Support Assessments**
- **Tool for Data Management and Model Baselines (Energy Data Exchange)**
- **Development of Integrated Assessments**



Field-based monitoring to evaluate the environmental integrity of sites undergoing oil and gas development

- **Historical Successes (2005 – 2011)**
  - Air Quality
    - Development and permitting of NETL Air Quality Monitoring Trailer
      - Novel and portable tool for comprehensive ambient air quality monitoring with remote data collection capabilities
    - Deployment of NETL Air Quality Monitoring Trailer in the Allegheny National Forest to evaluate air quality downwind of oil and gas operations
  - Water Quality
    - Electromagnetic surveys demonstrated the efficacy of subsurface drip irrigation as a reuse strategy for coalbed methane produced waters in response to a request for an neutral assessment from the WY Dept. of Environmental Quality
      - Results informed development of discharge permit requirements
    - Demonstrated use of strontium isotopes as natural indicators for distinguishing difference between AMD and Marcellus Shale produced waters
      - Established science base for launching widescale development of new analytical chemistry protocols for geologic fluids analyses
  - Existing Wellbores
    - Airborne magnetic surveys detected the location of unknown wells in an active CO_2-EOR field and led to solutions to fix problem of unwanted CO_2 leakage from unknown wellbores (2005 – 2007)



Development of integrated modeling, monitoring and information-based tools for subsurface processes in oil and gas development

- **Historical Successes (2005 – 2011)**
  - Fracture Modeling
    - Developed top-down “intelligent modeling” process (FRACGEN/NFFLOW) for simulating fractured reservoir systems (e.g., the Bakken oil-bearing shale)
      - Opened the door for some developers in the Marcellus Shale, and improved production and well placement
    - FRACGEN/NFFLOW multi-layer version was released to the public and is being used by small- to mid-size operators to design production operations
  - Information Tools for Rapid Assessments
    - Assemblage of 3-D geologic framework model for the Marcellus Shale using commercial software (EarthVision)
      - First necessary step for providing quantitative input for reservoir models used for developing well designs, completion techniques, and efficacy in producing hydrocarbon resources; also a key foundation for risk assessment modeling of shale gas operations
    - Comprehensive petrographic and geochemical data compilation – foundation for regional assessments of overall shale gas productivity and potential environmental issues (e.g., sources of metals and contaminants)

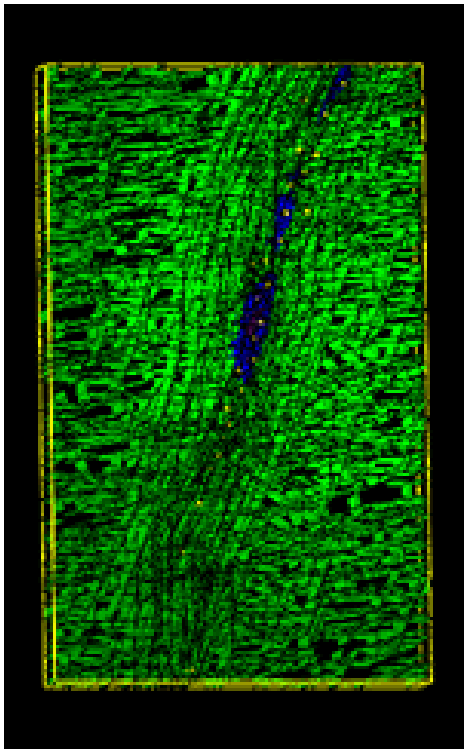
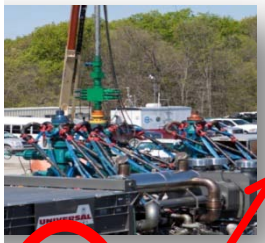


Image from fracture simulation tool

Integrated assessments for emissions life cycle estimates

- Applying field measurements of fugitive methane to reduce uncertainty in life cycle greenhouse gas emissions of unconventional natural gas

Uncertainties in LCA inform sampling locations and necessary measurements

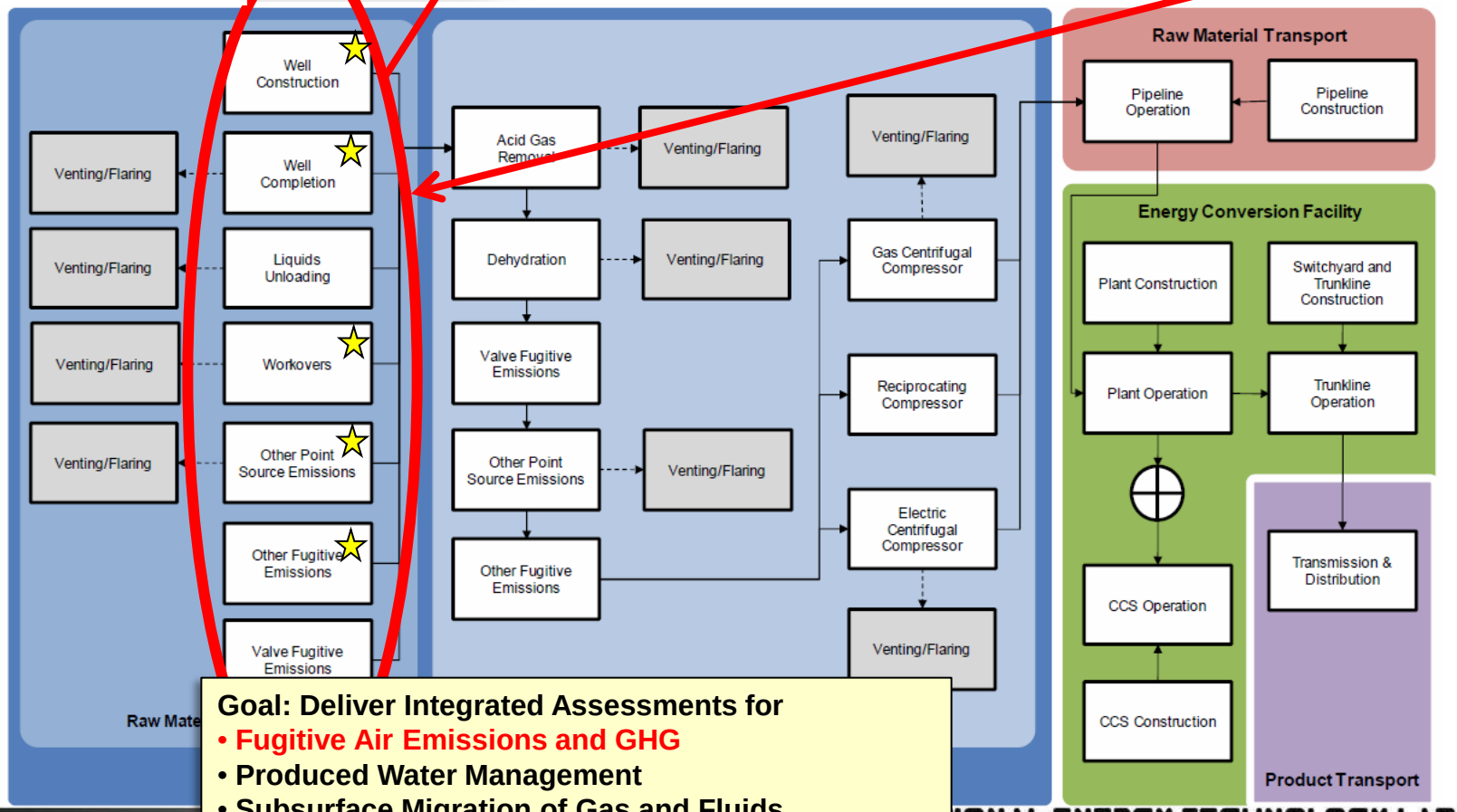


Air Quality Monitoring Trailer: CH_4, Ozone, NOx, SO_2, NH_3, VOCs, PM_{10}, $PM_{2.5}$

Leak-Detection System (mobile): CH_4, CO_2, bulk (C_1-C_{15}) hydrocarbons

Infrared Cameras and Toxic Vapor Analyzers for point-source measurements

Processed and QA/QC-ed data used to improve values AND associated uncertainties



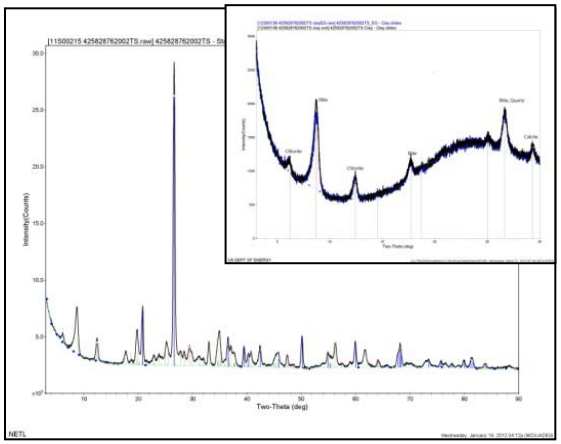
Goal: Deliver Integrated Assessments for
- **Fugitive Air Emissions and GHG**
- **Produced Water Management**
- **Subsurface Migration of Gas and Fluids**
- **Predicting Subsurface Phenomena**

Source: Skone, et al. 2011

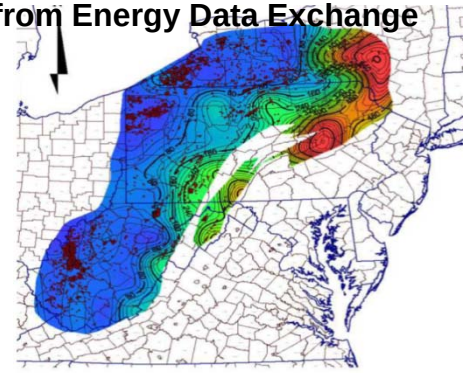
Integrated assessments for predicting produced water composition

- Develop capability to predict the volume and composition of flowback water as a function of reservoir, stimulation, and fluid properties

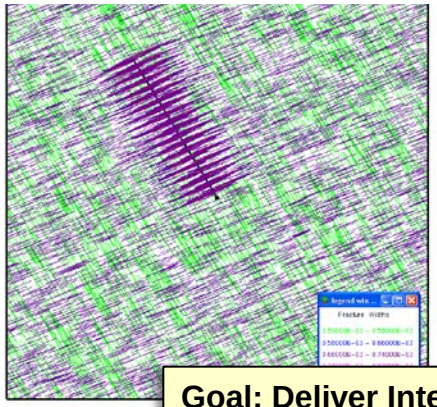
Rock Geochemistry/Mineralogy



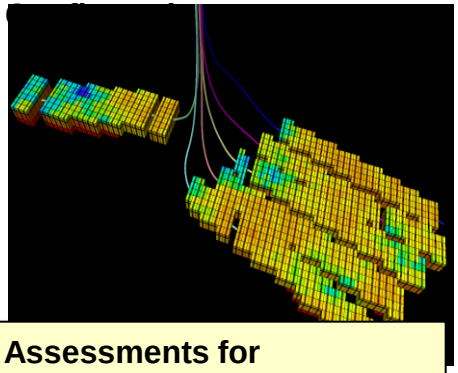
Formation-Scale Geospatial Data from Energy Data Exchange



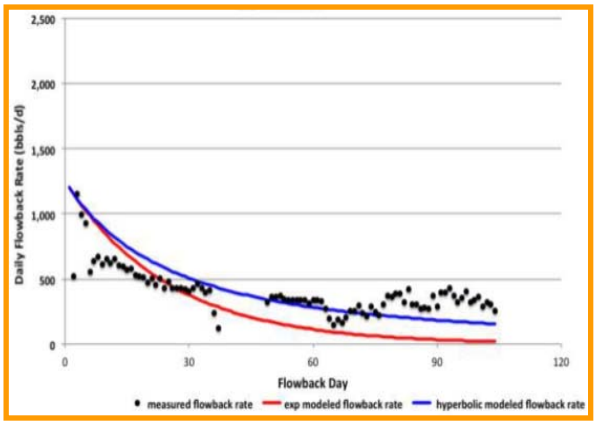
Fracture Network Properties



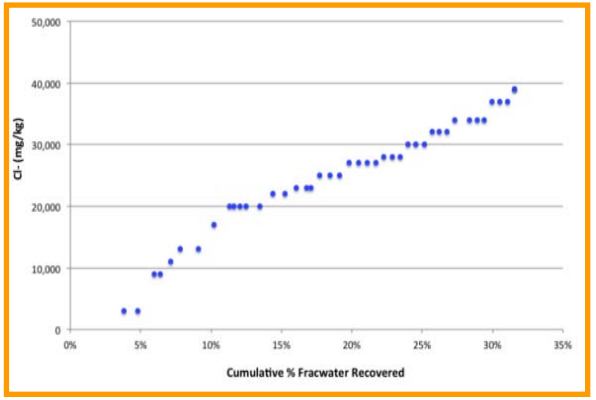
Well Stimulation Details and



Flowback Volume



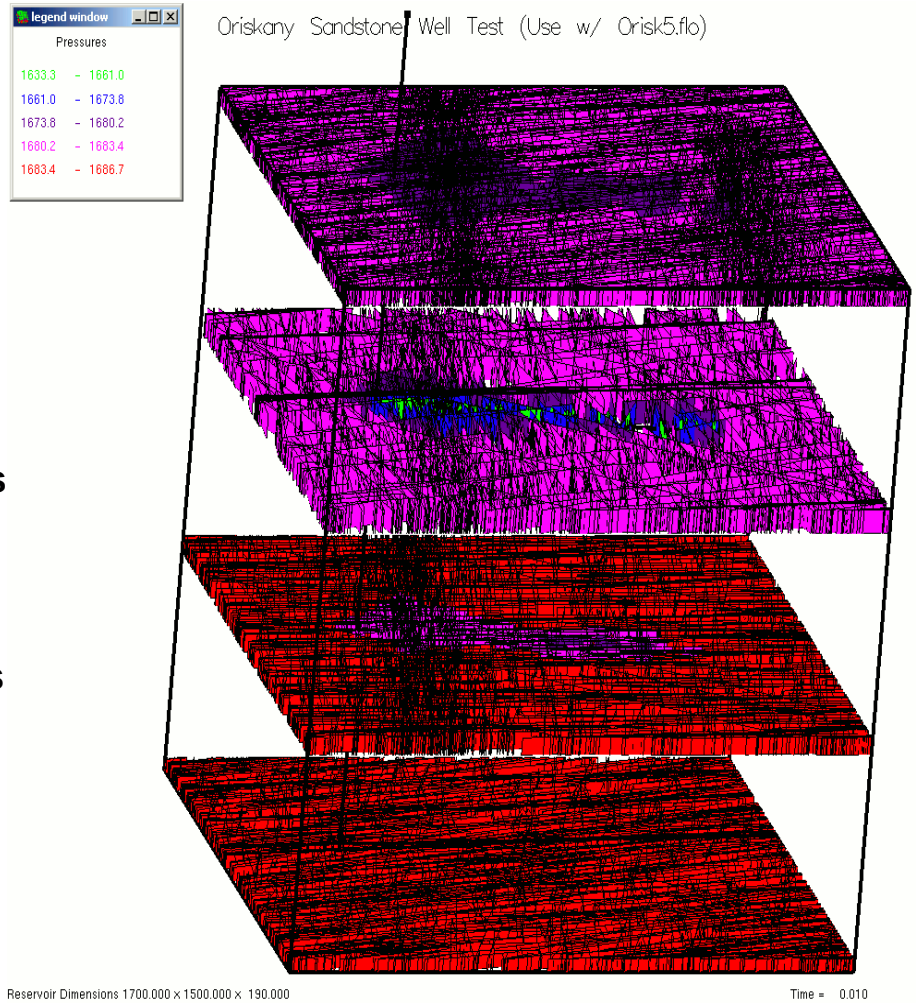
Flowback Composition



Goal: Deliver Integrated Assessments for
- **Fugitive Air Emissions and GHG**
- **Produced Water Management**
- **Subsurface Migration of Gas and Fluids**
- **Predicting Subsurface Phenomena**

Developing predictive capabilities to determine the potential for gas and fluids to migrate along existing pathways to shallow systems

- **Impact and Relevance**
  - Location and integrity of existing wells may affect the integrity of shallow systems (e.g., USDWs) overlying target unconventional reservoirs if gas or saline fluids leak into shallow systems
- **Current understanding and approach**
  - Developing specific knowledge of the density and state of abandoned legacy wells in unconventional resource plays
  - Determining whether NETL's seal leakage reduced order model can adequately represent the potential for deep saline fluids to leak into shallower systems



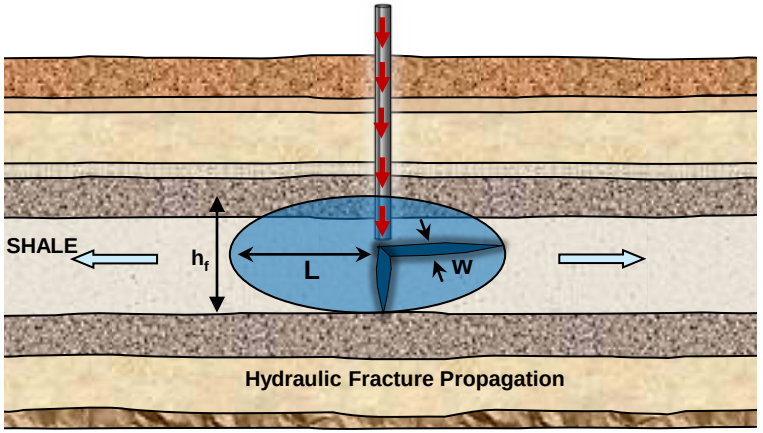
Goal: Deliver Integrated Assessments for
- Fugitive Air Emissions and GHG
- Produced Water Management
- Subsurface Migration of Gas and Fluids
- Predicting Subsurface Phenomena

Developing predictive capabilities to determine extent of fracture development, fluid migration, and induced seismicity due to fracturing and waste injection.

- **Impact and Relevance**
  - Fracturing events may result in fluid and gas migration to other reservoirs, and also may result in induced seismic events
  - The potential for contamination of USDWs, and felt seismicity (M>2) or damaging seismicity (M>4+), needs to be understood in order to design potential mitigation tools
- **Current understanding**
  - Fracture flow models and associated reduced order models can predict vertical migration of fluids within a fracture network (NETL work)
    - Industry standard fracture growth models assume fractures stay within the Marcellus, but data has shown that associated microseismic events occur above the Marcellus (recent field results)
  - Induced Seismicity from hydraulic fracturing believed to be low, but multiple examples exist worldwide; Induced Seismicity from water disposal operations of much greater concern

Energy technology	Number of Projects	Number of Felt Induced Events	Maximum Magnitude of Felt Events	Number of Events M≥4.0[d]	Location of M≥2.0 Events
Secondary oil and gas recovery (waterflooding)	~108,000 (wells)	One or more events at 18 sites across the country	4.9	3	AL, CA, CO, MS, OK, TX
Tertiary oil and gas recovery (EOR)	~13,000	None known	None known	0	None known
Hydraulic fracturing for shale gas production	35,000 wells total	1	2.8	0	OK
Hydrocarbon withdrawal	~6,000 fields	20 sites	6.5	5	CA, IL, NB, OK, TX
Waste water disposal wells	~30,000	8	4.8[c]	7	AR, CO, OH

From NRC Report on Induced Seismicity (2012)



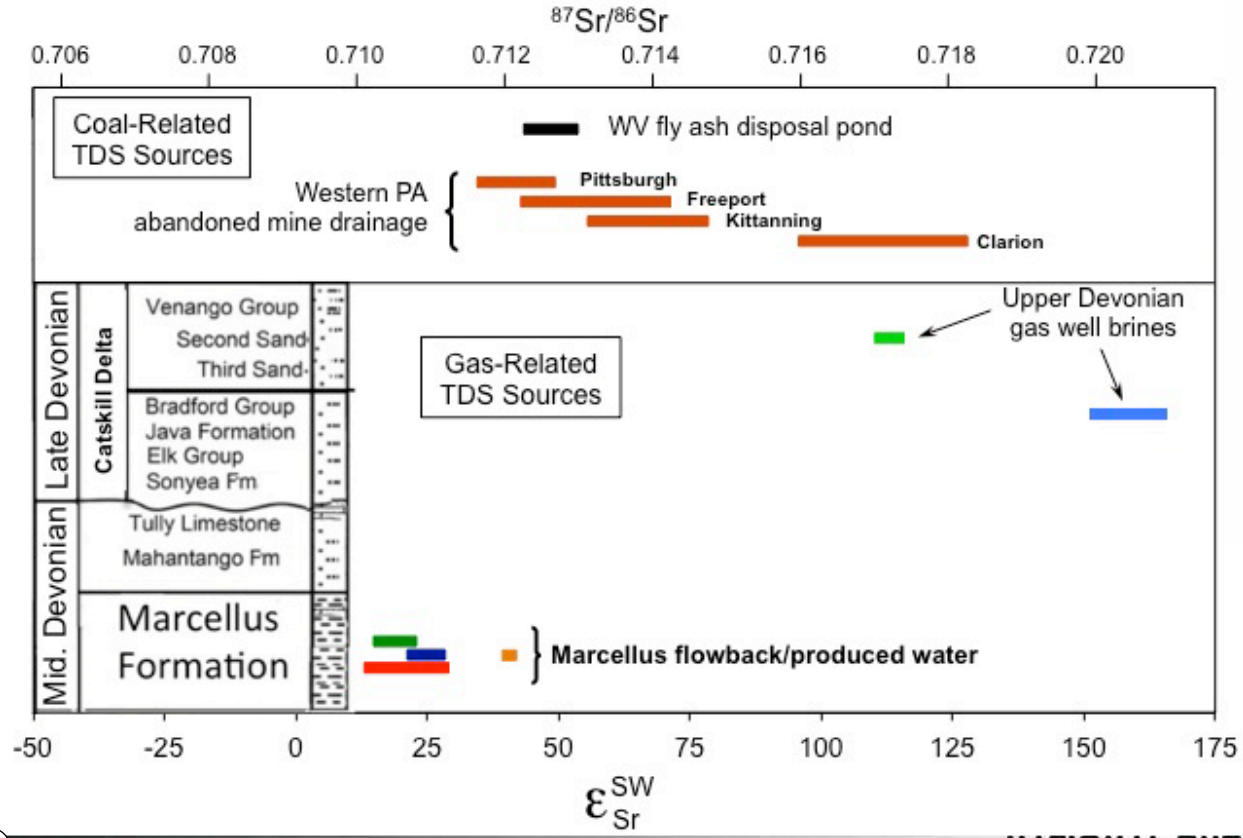
Previous work relied on analytical models for fracture growth

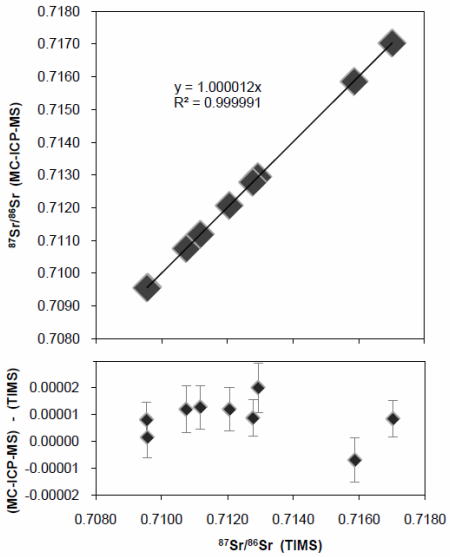
Goal: Deliver Integrated Assessments for
- **Fugitive Air Emissions and GHG**
- **Produced Water Management**
- **Subsurface Migration of Gas and Fluids**
- **Predicting Subsurface Phenomena**

UNC Portfolio Accomplishments

Next wave water quality analysis tools demonstrated with application of new technique

- **Natural Geochemical Tracers for Monitoring**
  - Documented temporal changes in water chemistry and isotope ratios during flow-back and into production and developed method for rapid analysis of Sr ratios
    - *Manuscript in preparation, scheduled for completion during Q4*
  - Showed significant differences between isotope ratios for Marcellus waters and other waters in the region – ***new monitoring tool using natural signals***





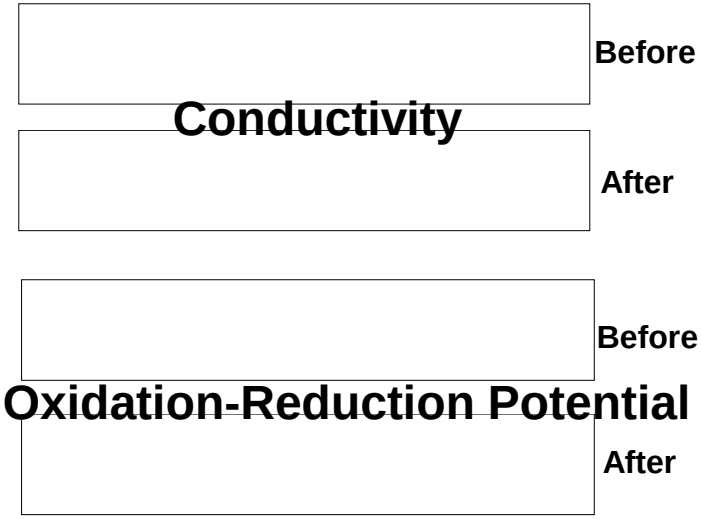
UNC Portfolio Accomplishments

Improved strategies for re-use of produced waters and management of potential health risks

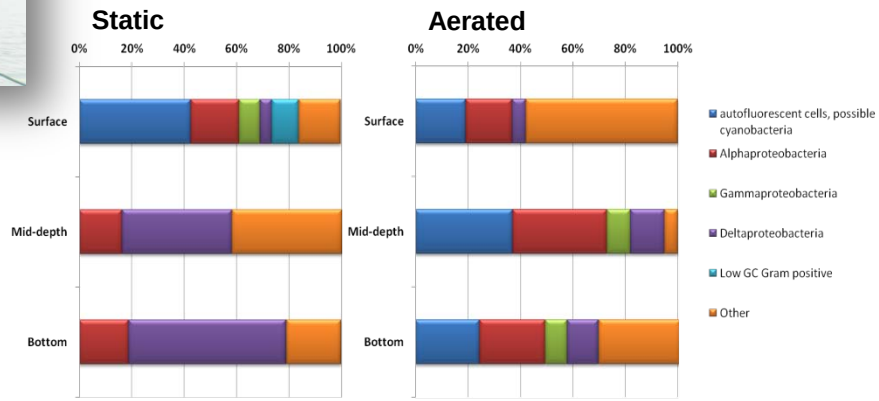
- **Produced Water Management and Treatment**
  - Stable and uniform chemistry of produced water holding ponds is possible with aeration treatment
    - Demonstrated through study of microbiology and chemistry of pond pre- and post-treatment
    - Avoidance of unfavorable microbial reactions with aeration
  - NETL Technical Report in progress & NETL-RUA technical manuscript on microbiology

Sampling Produced Water Impoundment

Chemistry



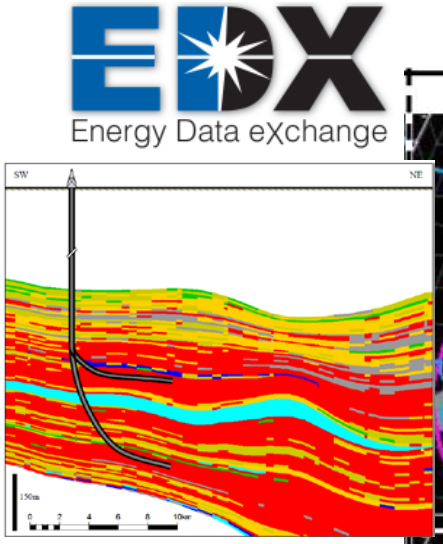
Microbiology



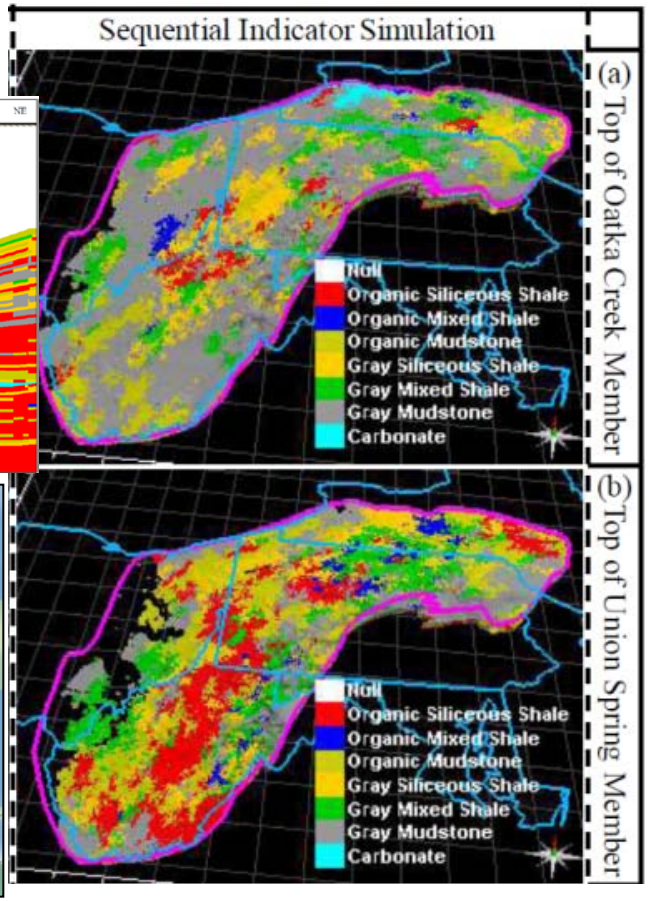
UNC Portfolio Accomplishments

New resource for public outreach and integrated risk assessments for Appalachian Basin shale gas and liquids plays

- **Spatial-Analysis Tool for Risk Assessment**
  - **Developed & released live online** 6/2012, **NETL-EDX** full v. 1 slated for release 7/29/2012
    - https://edx1.netl.doe.gov/
  - MOU initiated with GWPC to incorporate RBDMS data within EDX
  - Completed catalog of previous research (NETL-ORD, EGSP)
  - ***3D geomodel for Marcellus Shale units*** (structure, stratigraphy, organic content, brittleness variability)
    - Publication submitted to AAPG Bulletin with 2 additional manuscripts on this work under development.
  - Development of "Natcarb-like" atlas & online viewer of North American Shale Basins, preliminary deployment 9/30/2012, draft version underway



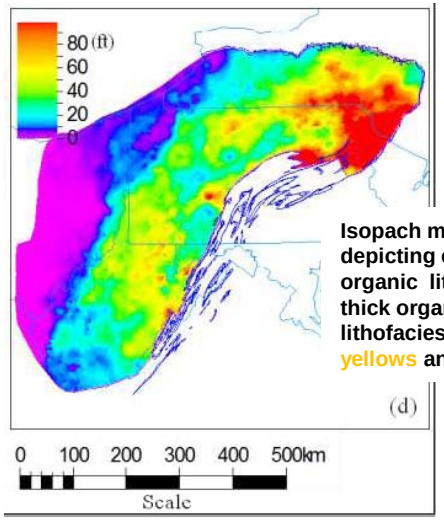
NA Shale Basins (pink shading), active drilling regions outlined in red



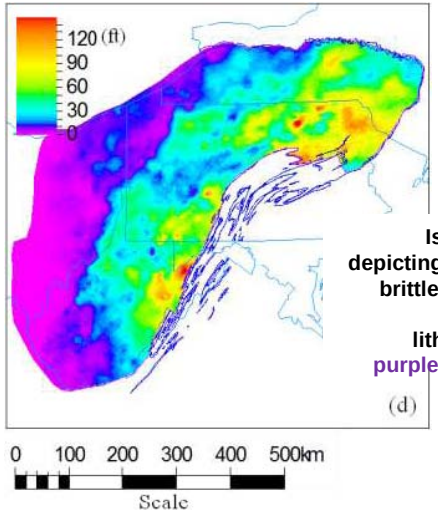
Marcellus lithofacies geocellular model (2D representation of 3D interpretation)

UNC Portfolio Accomplishments

New resource for public outreach and integrated risk assessments for Appalachian Basin shale gas and liquids plays



Isopach map depicting composite organic lithofacies, thick organic-rich lithofacies are yellows and reds

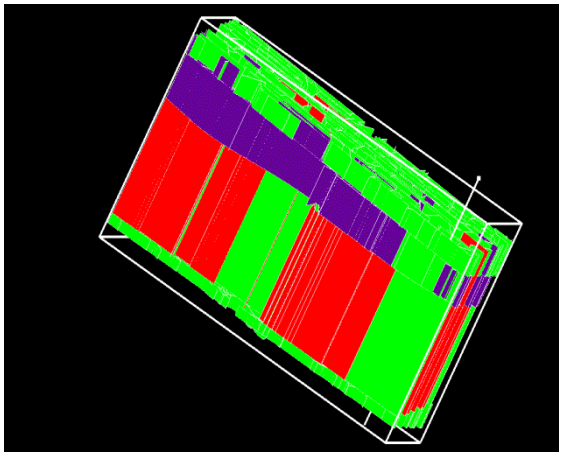


Isopach map depicting composite brittle lithofacies, thin brittle lithofacies are purples and pinks

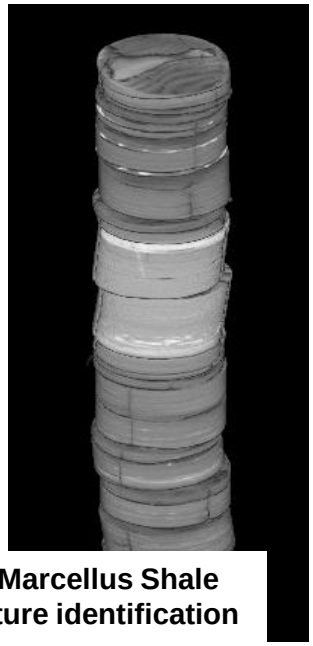
National Gas Shale Viewer

Additional Preliminary Results
UNC Portfolio (August 2011 – Present)

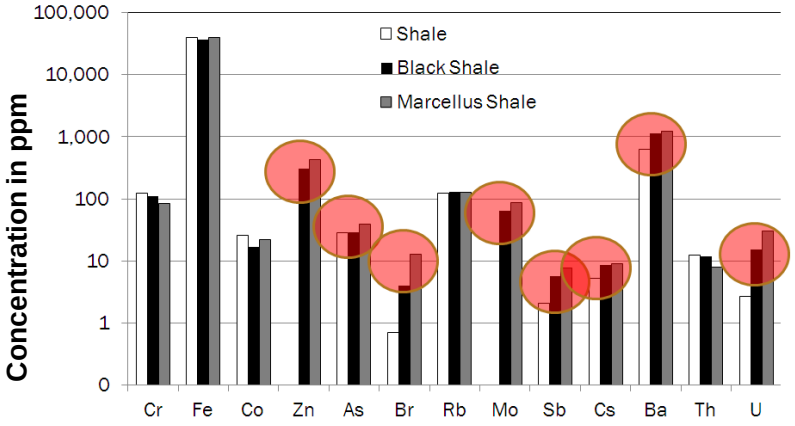
- **Improving risk predictions and reducing costs for sustainable shale gas development using science-based strategies**
  - Models for reducing uncertainties in shale gas GHG life cycle assessments and produced water management strategies
  - Geomechanical and geophysical data to develop ***predictive capabilities for induced seismicity and gas migration***
  - Biogeochemical data to develop ***predictive capabilities for produced water composition***



Fracture network generated by simulator



CT image of Marcellus Shale core for fracture identification



Questions?

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