The Importance of Technology Integration and Collaboration

Mastering the Subsurface Conference

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DOE Office of Oil and Natural Gas

August 15, 2018

“Synergy is what happens when one plus one equals ten or a hundred or even a thousand! It's the profound result when two or more … determine to go beyond their preconceived ideas to meet a great challenge.”

Stephen Covey

DOE'S OIL & GAS PROGRAM AREAS

Unconventional Oil & Gas	*Developing technologies to maximize recovery and reduce environmental impact from unconventional oil & gas development (advancing fundamental shale, developing shales by conducting research* ex. *produced water mgmt)*
Offshore	*Minimizing the environmental impacts of deepwater and ultra-deepwater oil and natural gas production*
Methane Hydrates	*Unlocking the mysteries of methane hydrates and developing ways to tap their massive energy potential*
Natural Gas Infrastructure	*Developing technologies and practices to mitigate emissions from natural gas production and transmission infrastructure*
Crude By Rail	*Mitigate risks associated with frequent and large volume rail transport of crude oil in general and tight oil in particular*

KEY THEME AREAS

- Reservoir Management and Production Enhancement
- Real-Time Autonomous Sensing
- Induced Seismicity Characterization and Mitigation

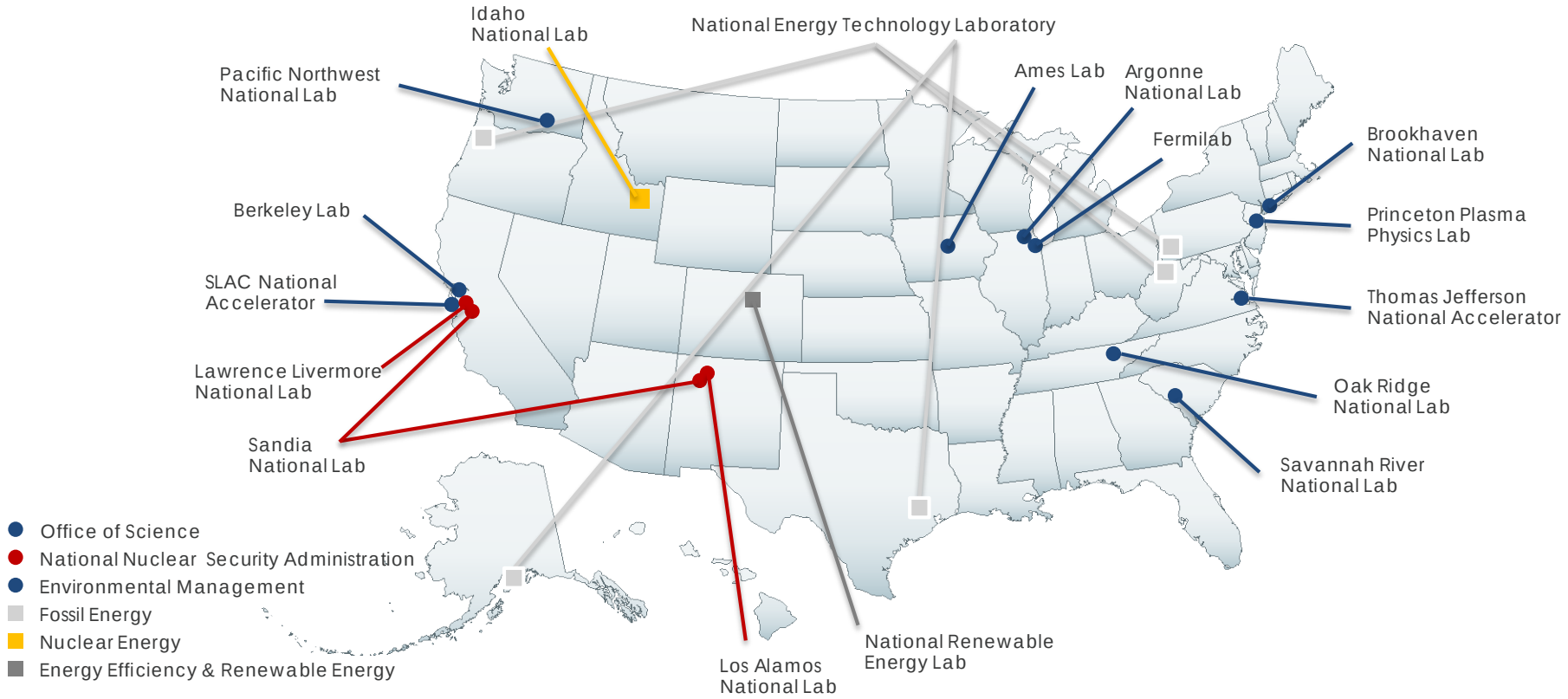
ENABLING TECHNOLOGIES

- Novel geochemistry measurements in the lab to be validated in the field
- Full physics, full chemistry multi-scale modeling
- Physics-based machine learning
- Advanced sensors and real-time data management

FE-32 INTERACTIONS

- Oil Industry
- National Labs
- Clean Coal Office at DOE-HQ
- Academia
- Professional Organizations
- Consortia
- Basic Research & Scientific Computing Office at DOE-HQ
- Others

THE NATIONAL LABORATORY SYSTEM



Fundamental Science at Nanopore scale (National Laboratory R&D)

LANL
--thermodynamics at nanopore scale
--fracture generation and hydrocarbon flow in heterolithic formations

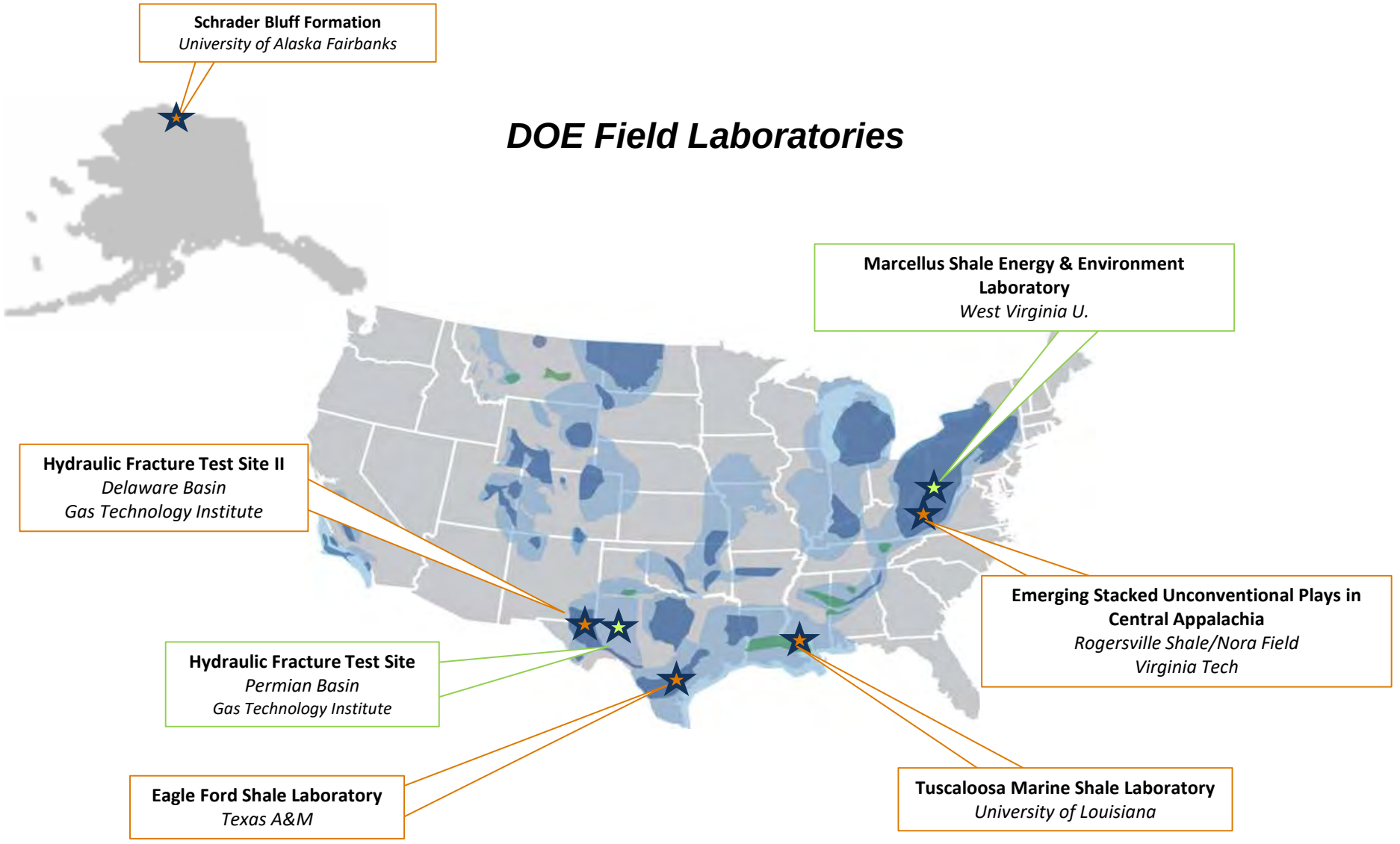
LBNL
--petrophysics of oil-rich shale
--petrophysics of water injection on shale gas mobilization into fractures
--geomechanics of fracture initiation and propagation and permeability evolution

NETL
--geochemical analysis of core from existing Field Labs
--air and water analysis at MSEEL

SLAC
--effects of chemical additives especially mineral precipitation

SNL
--equations of state for CH4, CO2, and H2O
--equations of state CO_2, and H_2O

FROM LAB TO FIELD: BASIN CENTERED STRATEGY (COST-SHARED R&D)



U.S. DEPARTMENT OF ENERGY | Fossil Energy
OFFICE OF OIL & NATURAL GAS

HFTS TEAM – SUCCESSFUL PUBLIC-PRIVATE PARTNERSHIP

Site Host

Sponsors and Participants

TECHNOLOGY INTEGRATION ENABLERS

- Oil and Gas Leadership Team spanning DOE-FE and 9 national labs
- Cross-lab Knowledge Management Team
- Big Data/Machine Learning Team
- Field labs with integrated industry, academia and national lab PI’s
- Coordination of subsurface technology across coal and oil/gas programs
- Frequent industry outreach meetings
- Leading-edge Integrated reservoir modeling project spanning several providers
- Physics- and chemistry-based machine learning involving at least six labs and industry
- Advanced sensor project spanning several institutions
- Shale KM platform and communities of practice – 175 plus users on recent prototype

Knowledge Sharing/Technology Integration

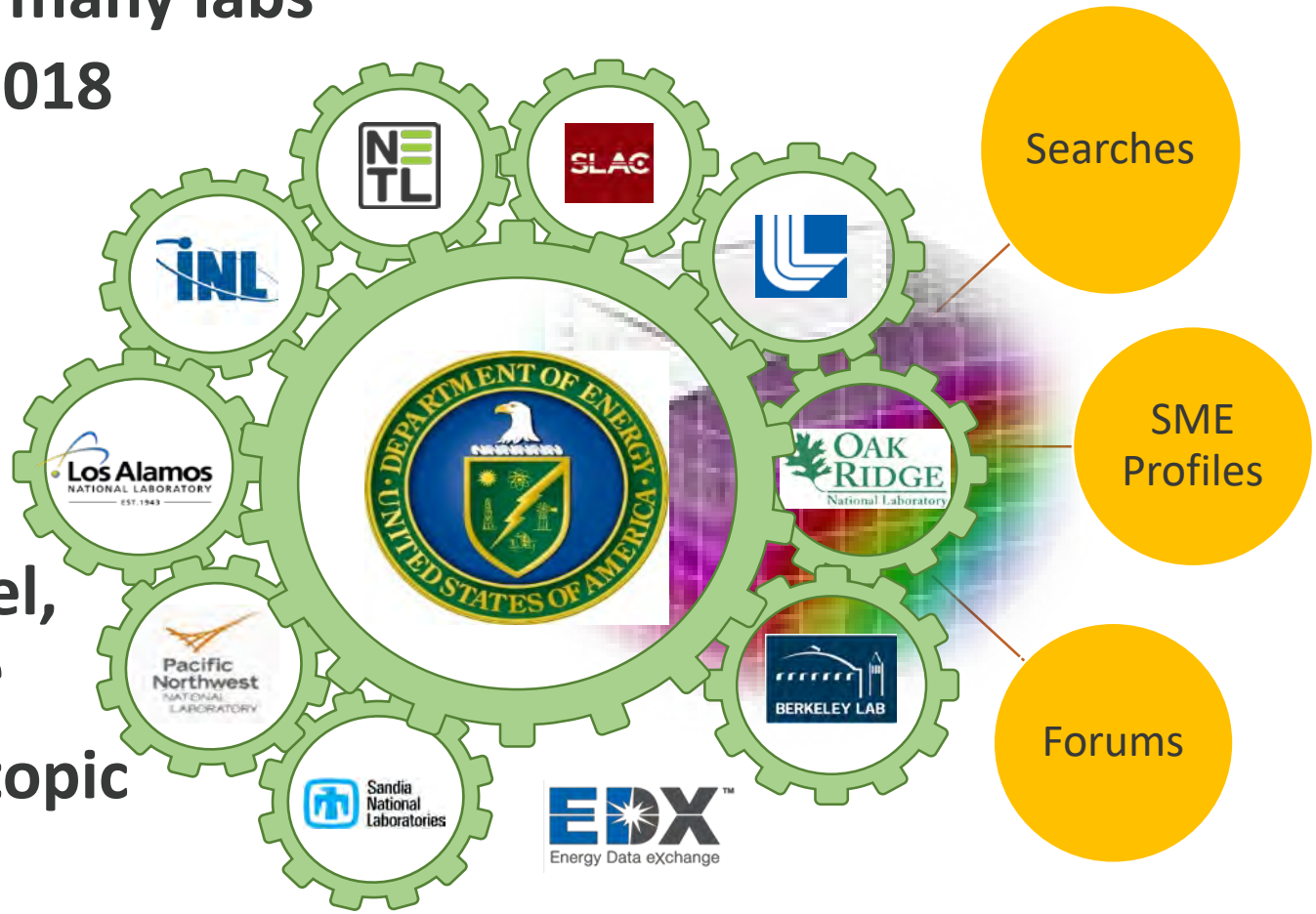
DOE Office of Fossil Energy engages many labs

Knowledge Management tool Aug 2018 with shale-focused community:

- User Dashboard
- Personal Profiles
- Technical Communities
- Knowledge Resources

Currently only involves lab personnel, but may be more open in the future

175 registrants to date and 4 shale topic areas (lab, field, modeling, ML)



A Tool for DOE FE Knowledge Management

Connecting FE-HQ and National Lab researchers for more efficient & effective **communication**, **coordination** and knowledge **curation**

DOE and National Lab personnel can join FE's KM community today
Email kmsupport@netl.doe.gov to find out how to join!

Any DOE/National Lab personnel are encouraged to **join the KM and contribute** to each technical Topic area to share:

- Questions, request info
- News, publications, and resources
- Upcoming conferences, workshops, meetings
- Solicitation news
- Seek partners, collaborators
- Discuss hot topics of the day

…all in an environment designed to facilitate information sharing, connection, and discovery

Areas of Synergy Between Carbon Storage and Oil & Gas

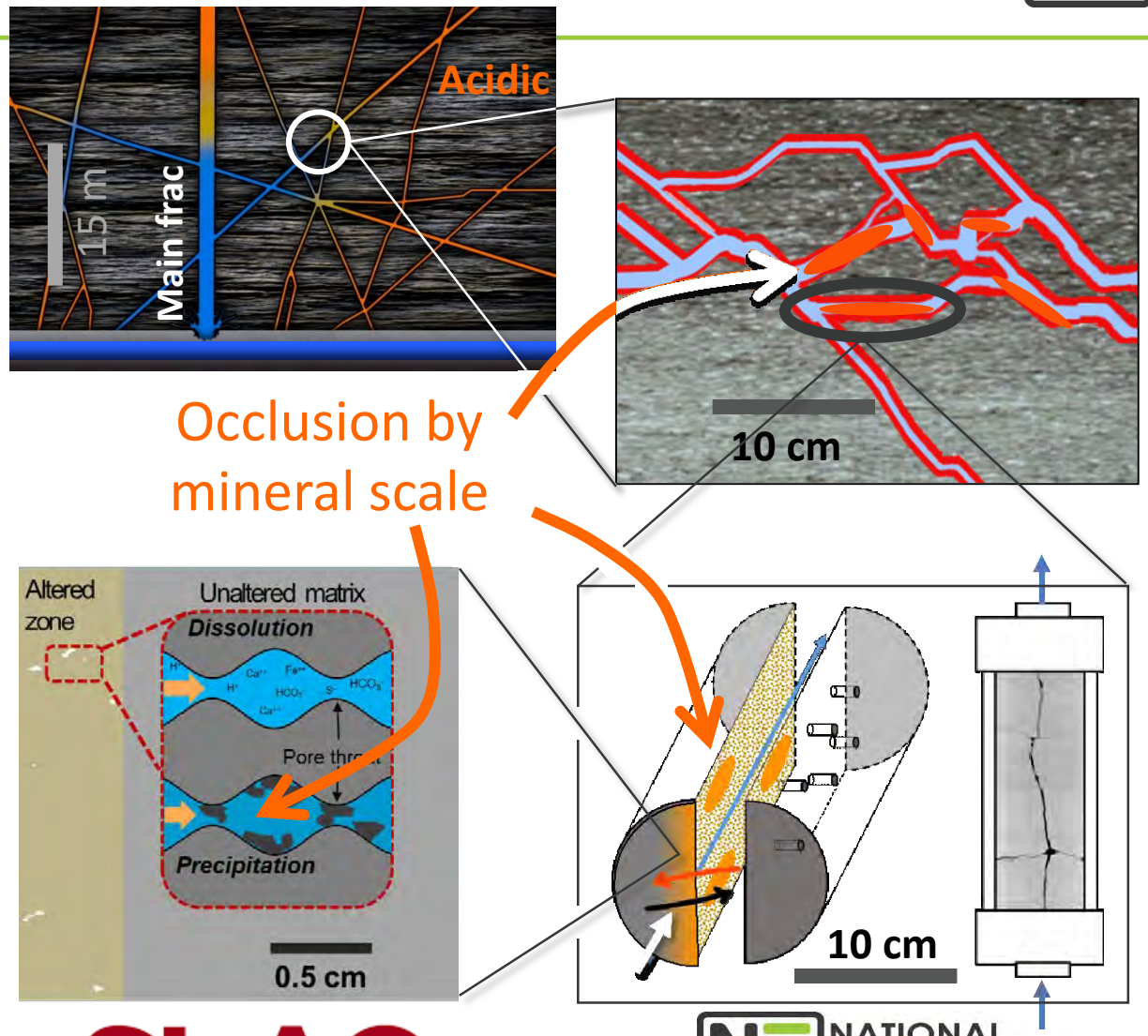
Common interests identified through crosswalk of respective research portfolios for 2018

- Storage and Recovery Efficiencies in Unconventional Oil and Gas Plays
- Market/Benefits Analysis
- Geomechanics Fundamentals
- Effects of Geochemistry on Porosity and Permeability Changes, and Hydrocarbon Production

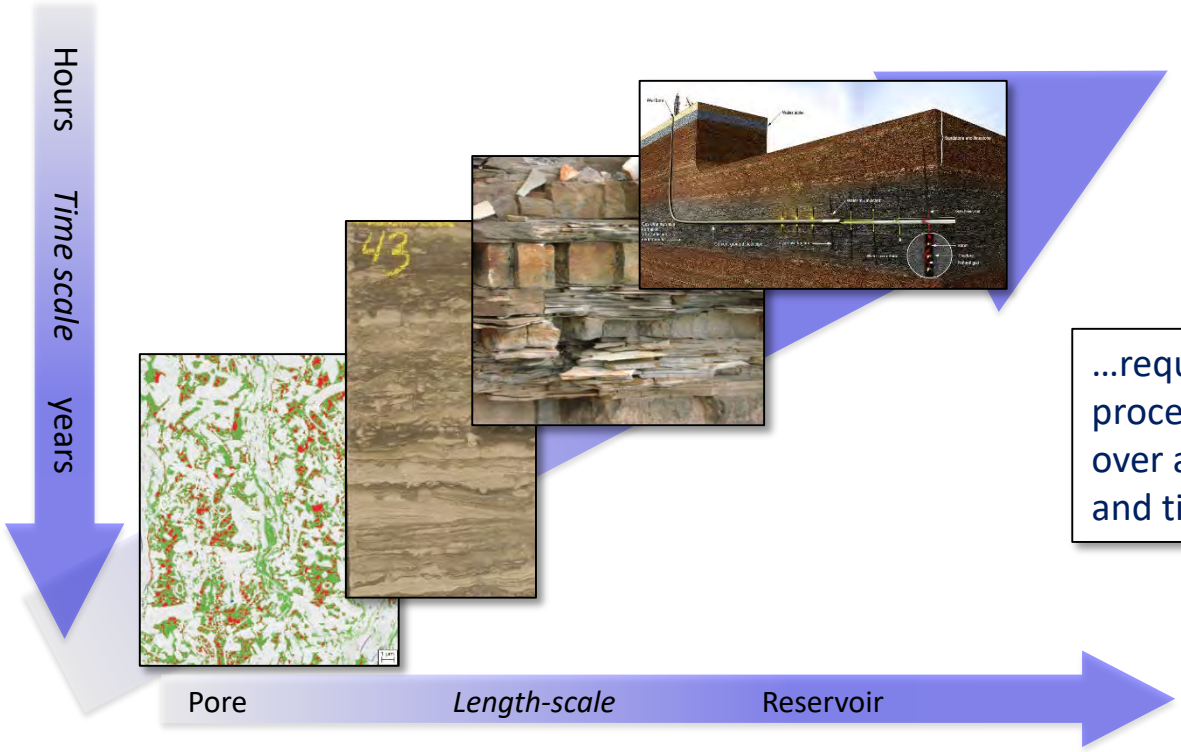
- Fundamentals of CO_2 Interaction with Geologic Materials
- Subsurface Microbial Ecology
- Wellbore Cement Integrity
- Geochemical Tracers
- Long Period, Long Duration Seismic Monitoring
- HPC/Machine Learning/Data Analytics

Benefits of integrated multi-lab geochemistry

- Enhanced efficiency
- Less damage
- More sustainable
- Improved water recycling



Controlling the mechanical and chemical response of the subsurface…



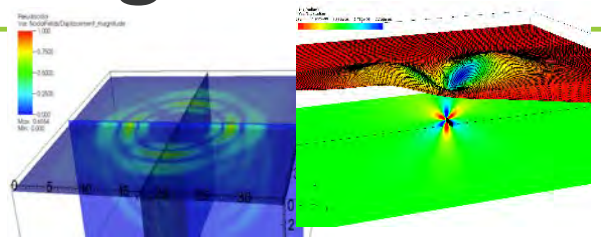
…requires integration of processes that take place over a broad range of length and timescales

Combining DOE sponsored expertise in modeling, experiments, and analysis with industry expertise and operations provides a unique opportunity for advancement

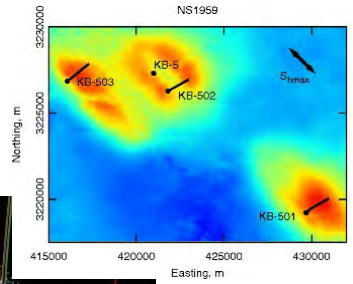
Leading edge multiscale coupled physics and chemistry based modeling

Model results

Predict Observables

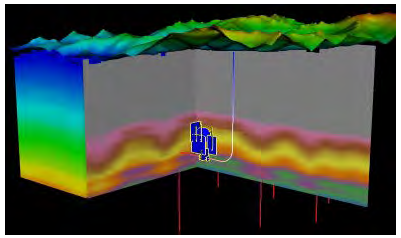


Field Observation

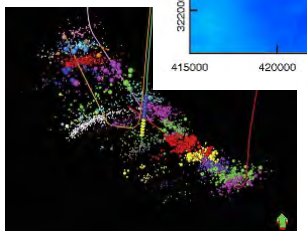


Geophysical and pressure measurements

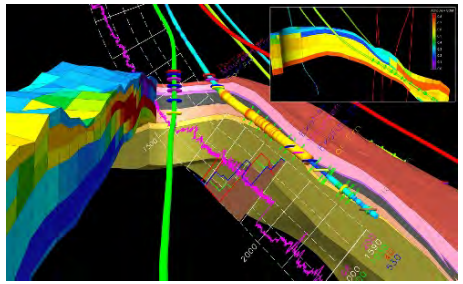
Geomechanics and flow modeling



Revise Physical Models

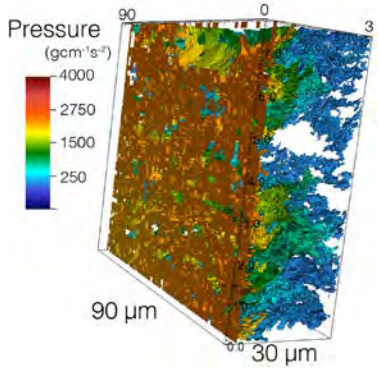


GEOS-TOUGH Simulation



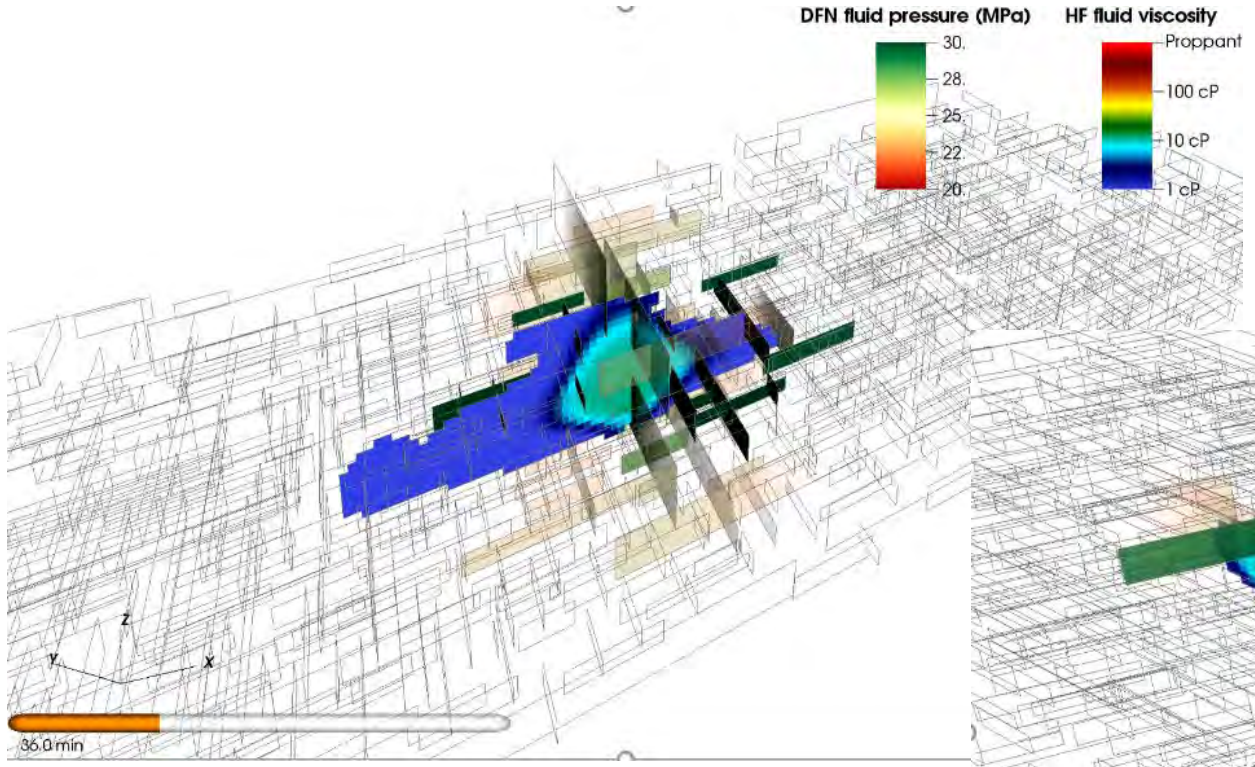
Site Model

Pore-Scale Behavior



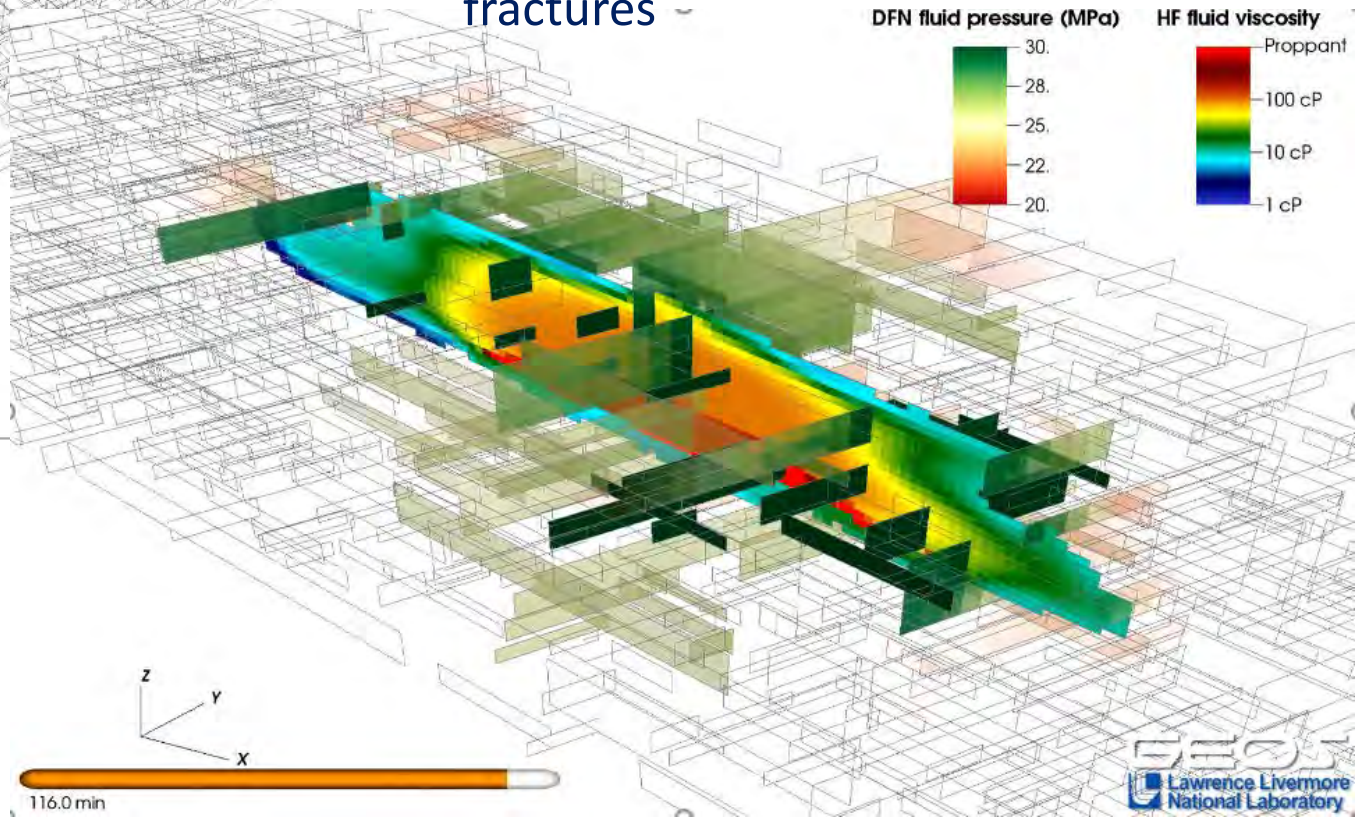
Incorporating chemistry at scale

Simple illustrative example…



- Slurry rheology influences the partitioning of proppant between hydraulic fractures and DFN

- Studies indicate strong ***3D*** interactions among hydraulic fractures, stress barriers, and preexisting natural fractures



Intelligent Subsurface Engineering Initiative

- **DOE and Labs perspective**

  Enable continued American energy dominance

  Generate and transfer cutting-edge technologies to industry that enable increased recovery

  Combine distributed sensing and real-time data analytics for early warnings and improved subsurface control

- **Benefits for operators**

  Engage National Labs to work on YOUR use cases

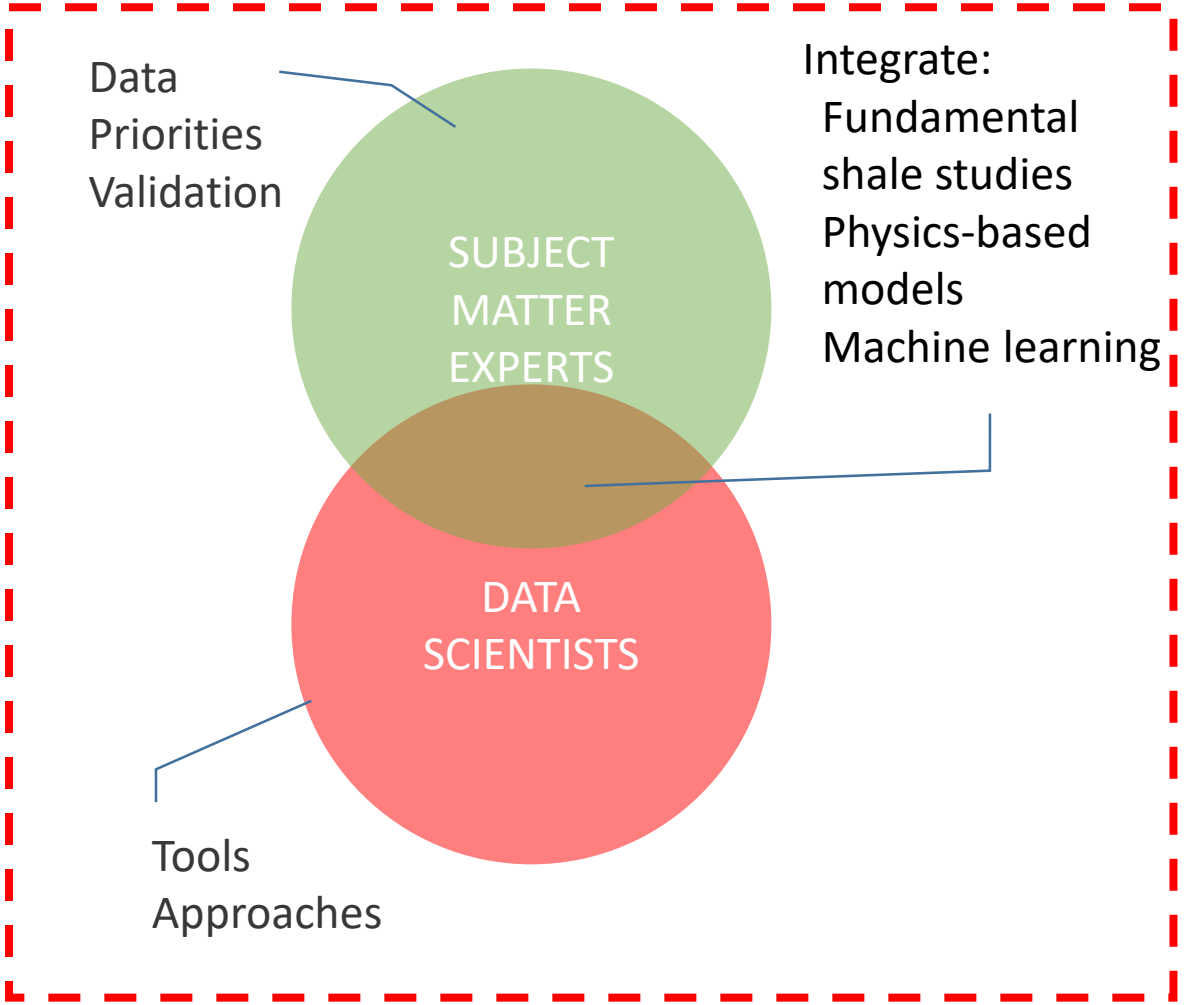
  Assemble sufficiently big data to apply cutting-edge machine learning approaches

  Early access to new machine learning technologies

  Combine fundamental understanding of shale resources with machine learning and distributed sensing

Integrate organizations and technical skill sets

- Industry has primary domain expertise
- Labs have both SMEs and data scientists
- Labs can engage academia and other research organizations
  - Pipeline for data scientists with domain expertise



National Lab Capabilities in ML

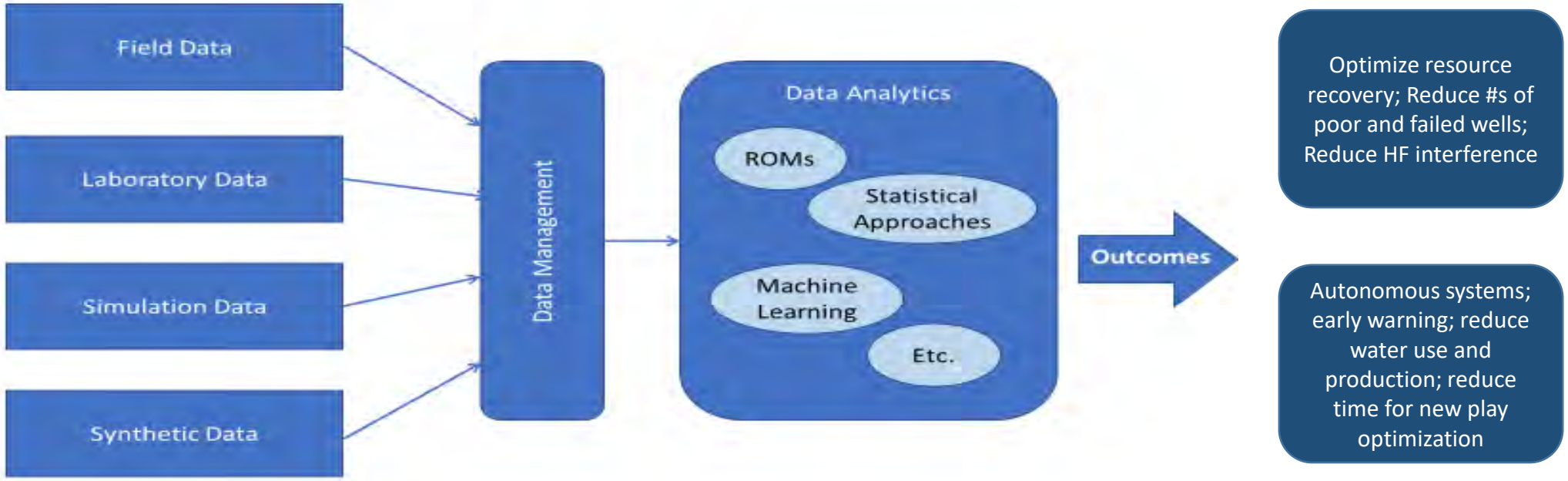
- Over 1000 data scientists many with subsurface experience – more than just Random Forest users
- Fundamental shale studies and leading-edge advanced physics-based modeling from pore-scale to reservoir-scale as part of ML
- Advanced geochemistry that we can measure on oil company cores and cuttings and include in the big data studies
- Experience in managing and working on large datasets (EDX platform)
- Ability to keep data secure
- Strong integrated approach involving NETL and several other labs (one-stop shopping)

Move beyond current data analytics approaches

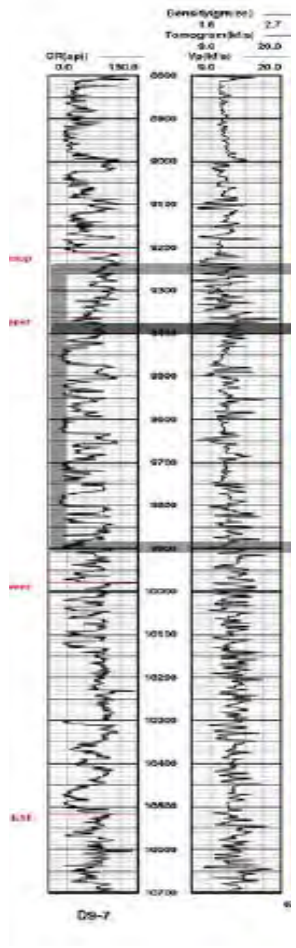
- **With access to supercomputers, NETL and other labs can train machine learning algorithms with cutting edge simulation capabilities**
- **Combined with distributed sensing (e.g., fiber optics), this can enable:**

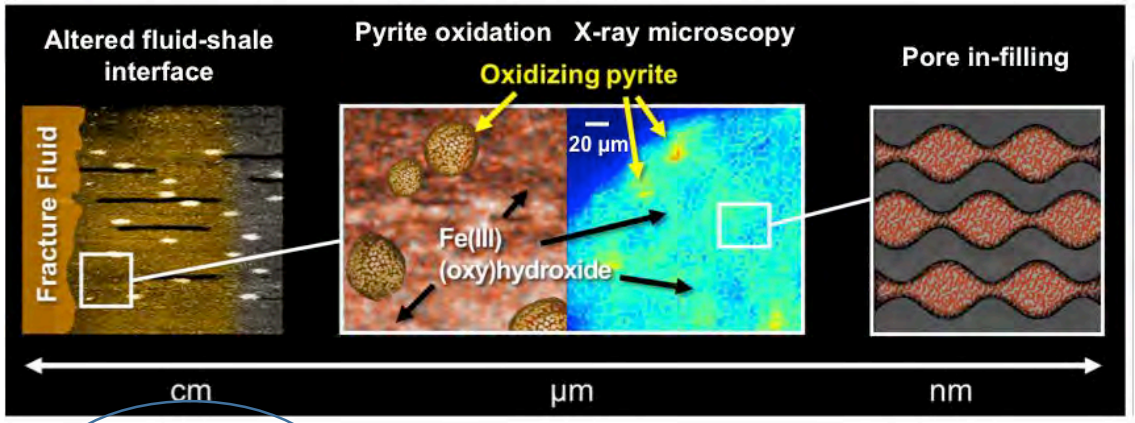
  Improved HF design, well placement, and operations to optimize recovery and reduce costs

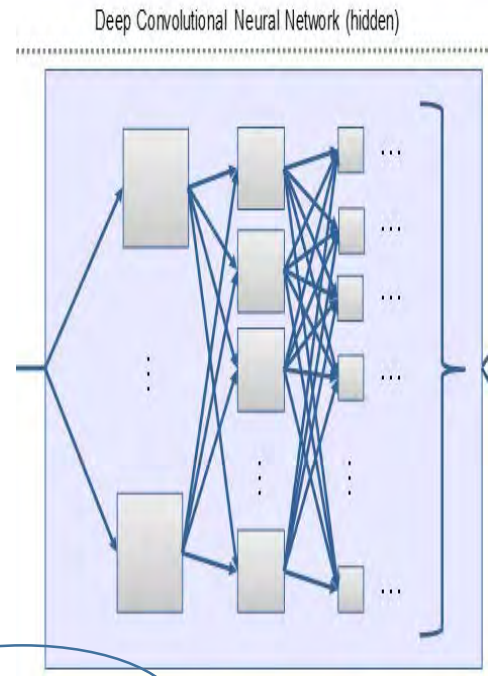
  Real-time automation to substantially increase recovery, reduce cost, and reduce failures



Integrate fundamental studies, field labs and machine learning to achieve better results.







Core and cuttings experiments

Physics-based models

Fundamental Shale Studies

Industry collaborations

Machine Learning

Model Validation

Reduced order models

Field Laboratories

Data-Driven Approaches

"Big Data"

Academia

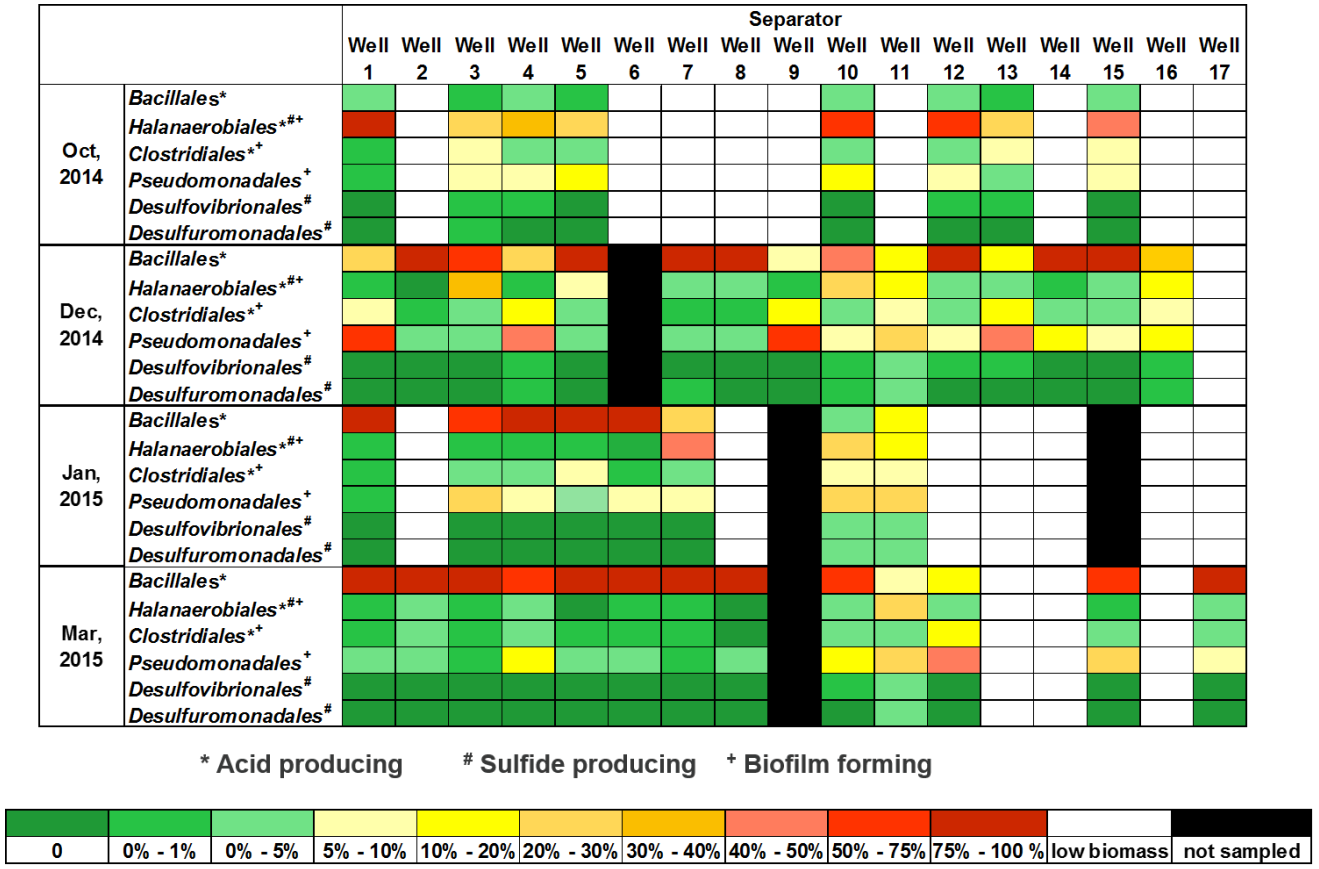
HPC

Shale Microbial Ecology Affects Reservoir Performance

Classifying how microbial ecology may affect geomechanical and geochemical properties of fractures, well integrity, or biofilm formation.

- Marcellus and Bakken investigated
- Links to operational and geochemical factors that affect biocide composition, well age, and total dissolved solids concentrations.
- Microbial communities have similar functions but exhibit differences in their relative abundance across formations

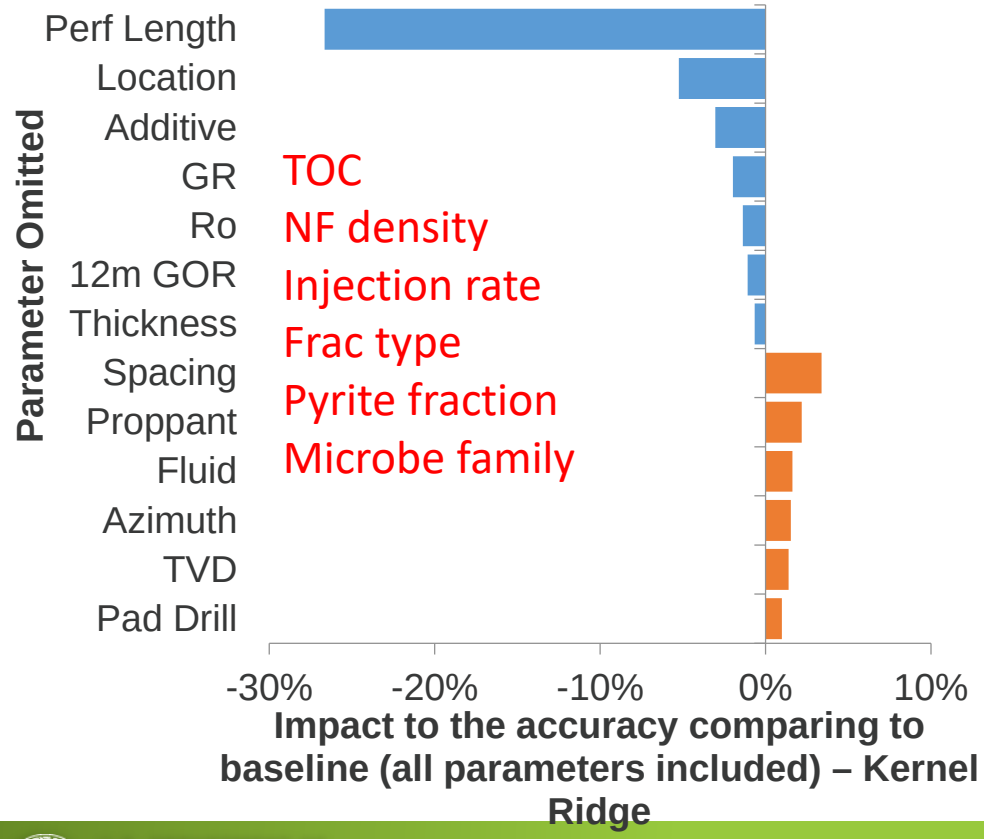
Bakken Petroleum System

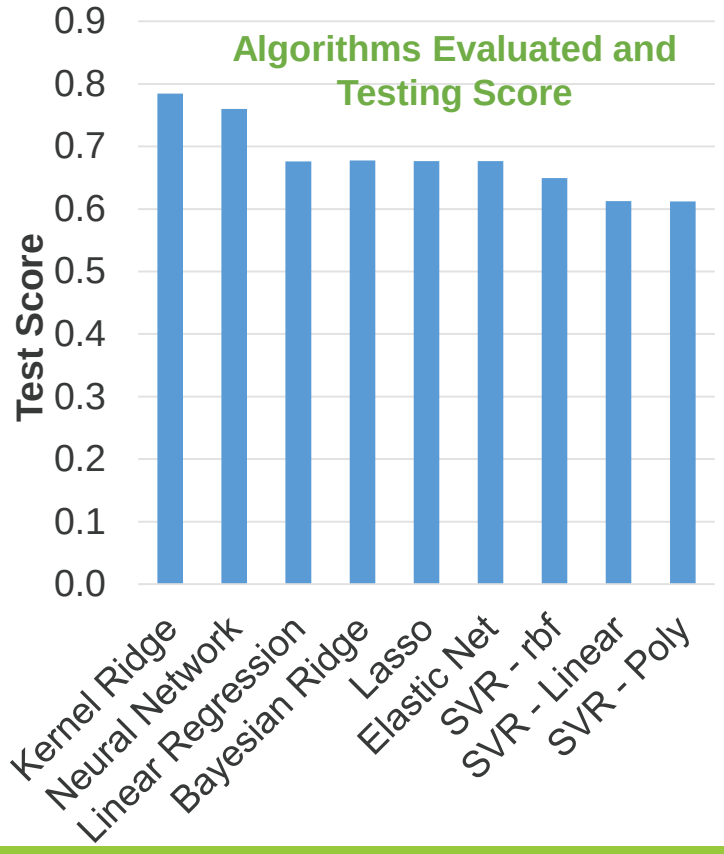


Better decisions for HF and well operations with data analytics

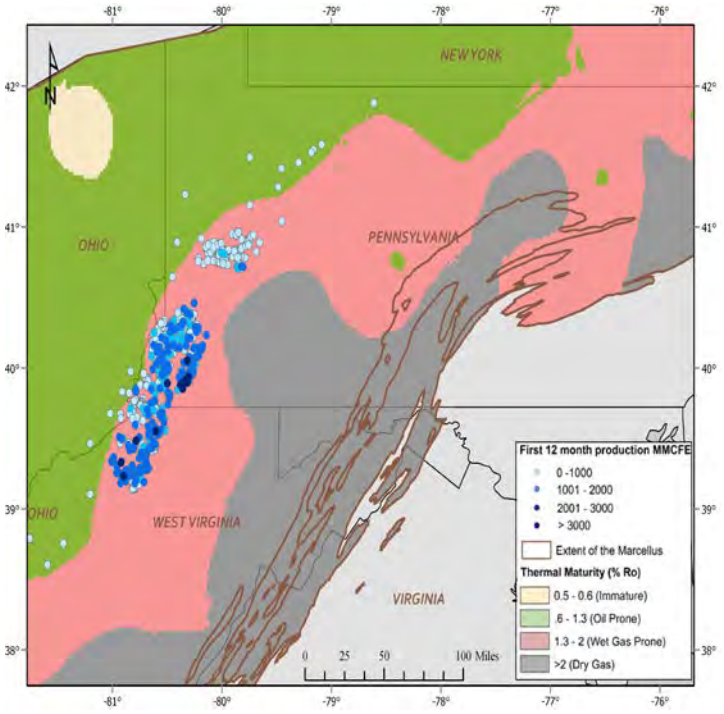
Western Marcellus Predictive Model

- Non-linear algorithms performed better indicating the problem complexity
- Perforated Interval Length has substantial impact to the model accuracy





Thermal Maturity and Western Marcellus Wells



Capabilities for securely maintaining data

- Maintain confidentiality of all data coming from industry partners
- Only use work product for sharing outside of group
- Enable access to computational resources for partners

NETL assembling stacked system for machine learning applications

Carnegie Mellon University

Future Sensor Technology Development
(plus real-time data mgmt., lossless data compression, Raspberry Pi, and ML)

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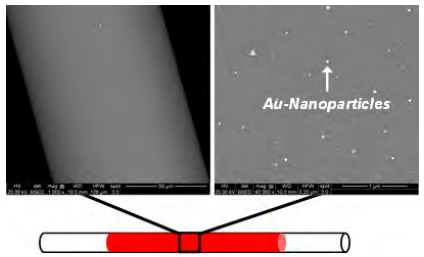
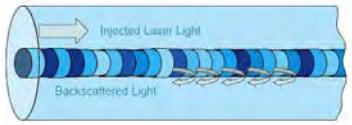
NATIONAL ENERGY TECHNOLOGY LABORATORY

Functional Coatings to Enable Distributed Chemical Sensing

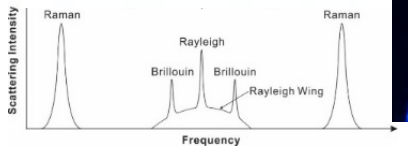


Advanced Interrogation Techniques and Methods Leveraging Physics of Scattering

Imperfections in fiber lead to Rayleigh backscatter:

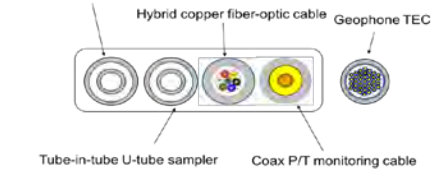


Rayleigh backscatter forms a permanent spatial "fingerprint" along the length of the fiber.

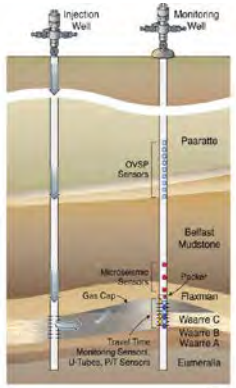


Extreme Environment Optical Fiber Fabrication Through Single Crystal Growth Processes

DAS, DTS Field Deployment

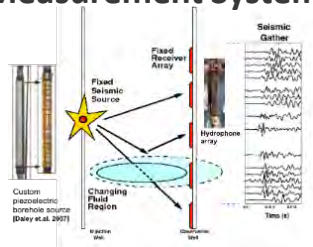


Monitoring CO_2 Storage at 2 km (Otway)

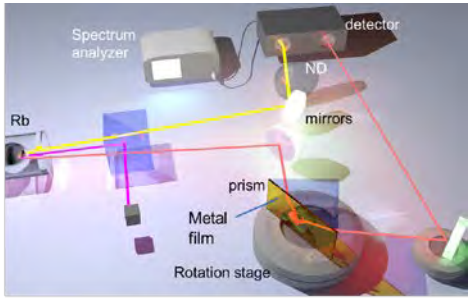


BERKELEY LAB
Lawrence Berkeley National Laboratory

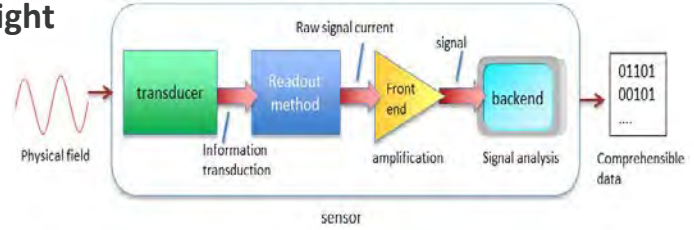
Unique Geophysical Measurement Systems

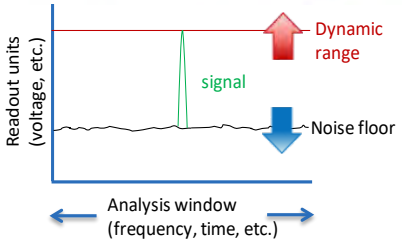


Quantum Sensing Techniques Including Entanglement and Squeezed Light



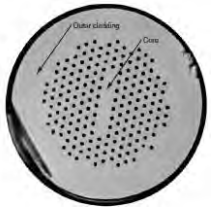
OAK RIDGE National Laboratory



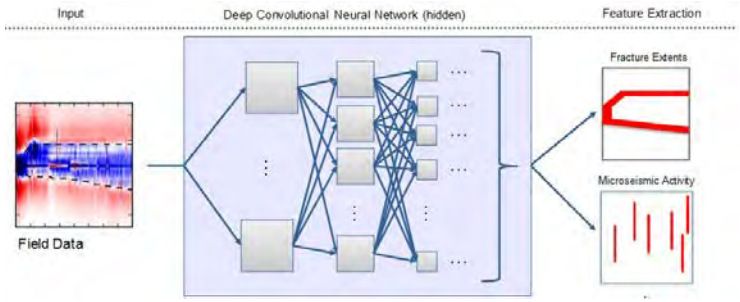


Quantum Noise Reduction to Measure Signals Beyond the Classical Limits

Custom Fiber Optic Cable Design, Modeling, Fabrication, and Processing



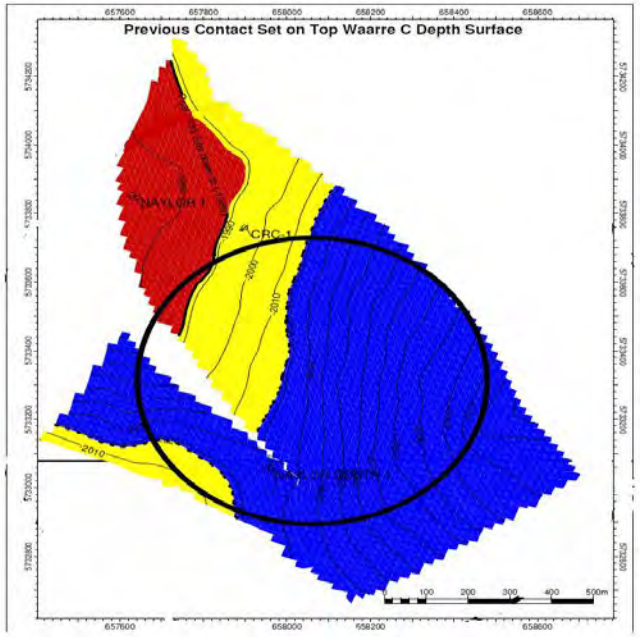
Data Analytics for Rigorous Feature Extraction From Large DTS, DAS, DSS Datasets

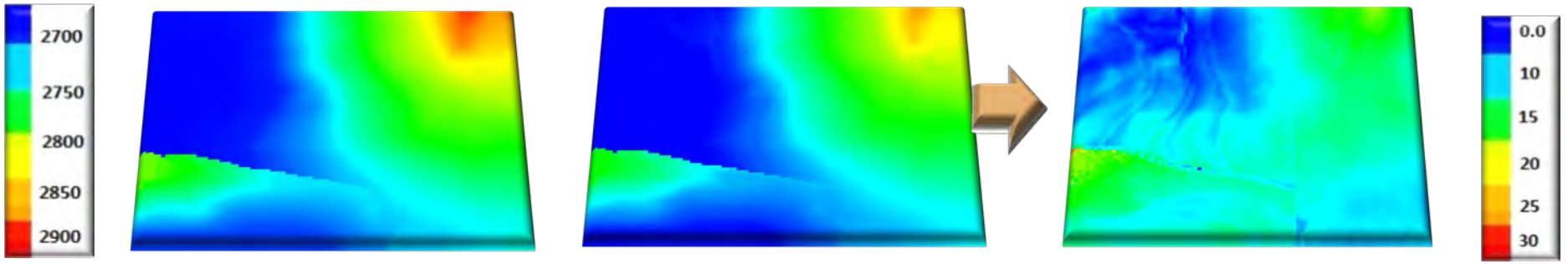


Lawrence Livermore National Laboratory

Surrogate reservoir modeling uses machine learning for faster reservoir simulations

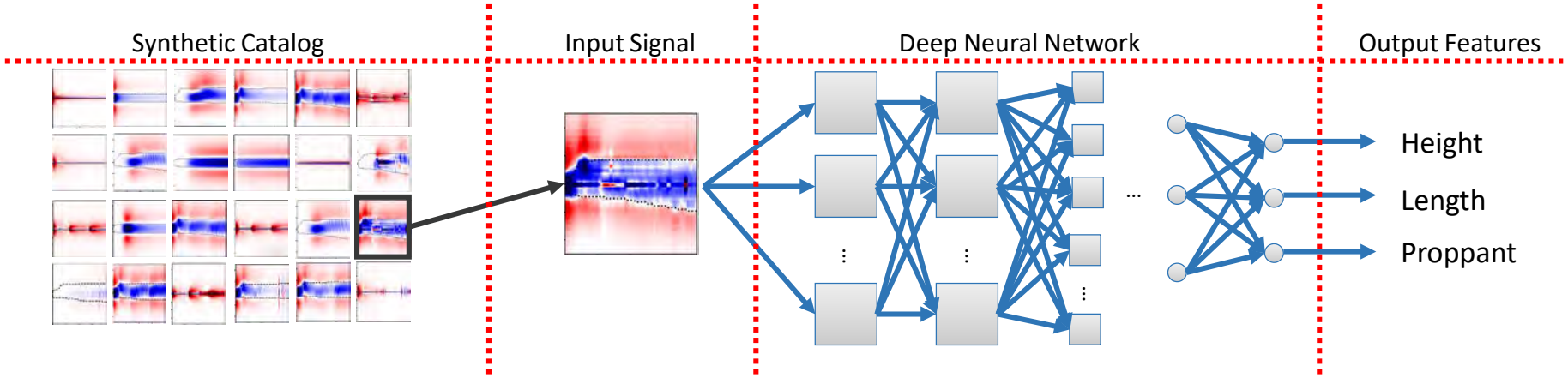
- **Utilizes data mining and neural networks to predict reservoir behavior**
  - Pressures
  - Saturations
- **Can be trained with a relatively small number of reservoir simulations**
- **Allows for spatial heterogeneity and operational variability**
- **Shrinks time for reservoir simulation from days and hours to minutes and seconds**





Towards adaptive control with machine learning - DAS

- The goal is to develop automated, near-real-time characterization of fracture development to allow for adaptive control and optimized production.
- Machine learning requires large training sets.
- We are generating a catalog of synthetic DAS measurements to serve as a training set.
  - Provides known results for validation and benchmarking.
  - Targets: fracture height, length, proppant distribution.



Courtesy of LLNL

Thank You!

- Questions?
- Alan.cohen@hq.doe.gov

Acknowledgements: Leaders and PI's from our national labs and DOE-HQ