From Enhanced Oil Recovery to Carbon Storage: Adapting Petroleum Engineering Skill Sets to CCUS

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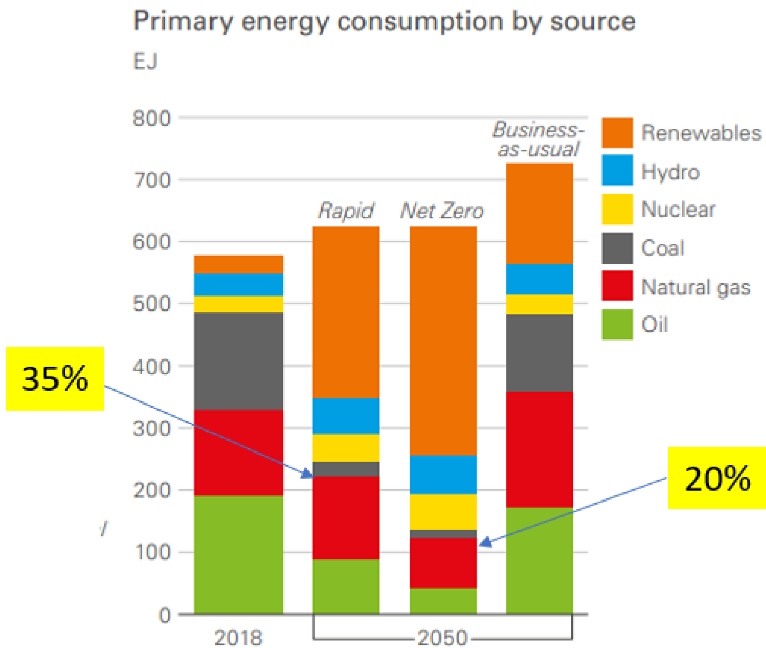
Global Energy Transition and the Role of Oil and Gas

(BP Energy Outlook Report, 2020)



Rapid: Significant increase in carbon price – carbon emission from energy falls by 70% by 2050
Net Zero: Carbon emission from energy falls by 95% by 2050 from policy and societal changes

- Global Energy Mix Will Shift Towards Low Carbon Fuels
- We are not Running Out of Oil and Gas in the Foreseeable Future
  - ***'Stone age did not end because we ran out of stones'*** *(Zaki Yamani)*
- Need to be Agile and Embrace the Transition

Grand Challenges

Earth Resources Engineering

- Make the Earth Transparent
- Understand, Engineer and Control Subsurface Coupled Processes
- Minimize the Environmental Footprint
- Protect People

Source: NAE Section-11 Newsletter

CCUS: Key Subsurface Technical Challenges

- How Much Storage Space is Available?
  - Capacity and Injectivity

Reserves and Resources Estimation

- Where is the Injected CO2 Going?
  - Monitoring and Verification

Reservoir Surveillance

- How do I Maximize CO2 Storage?
  - Operational Efficiency

Optimal Reservoir Management

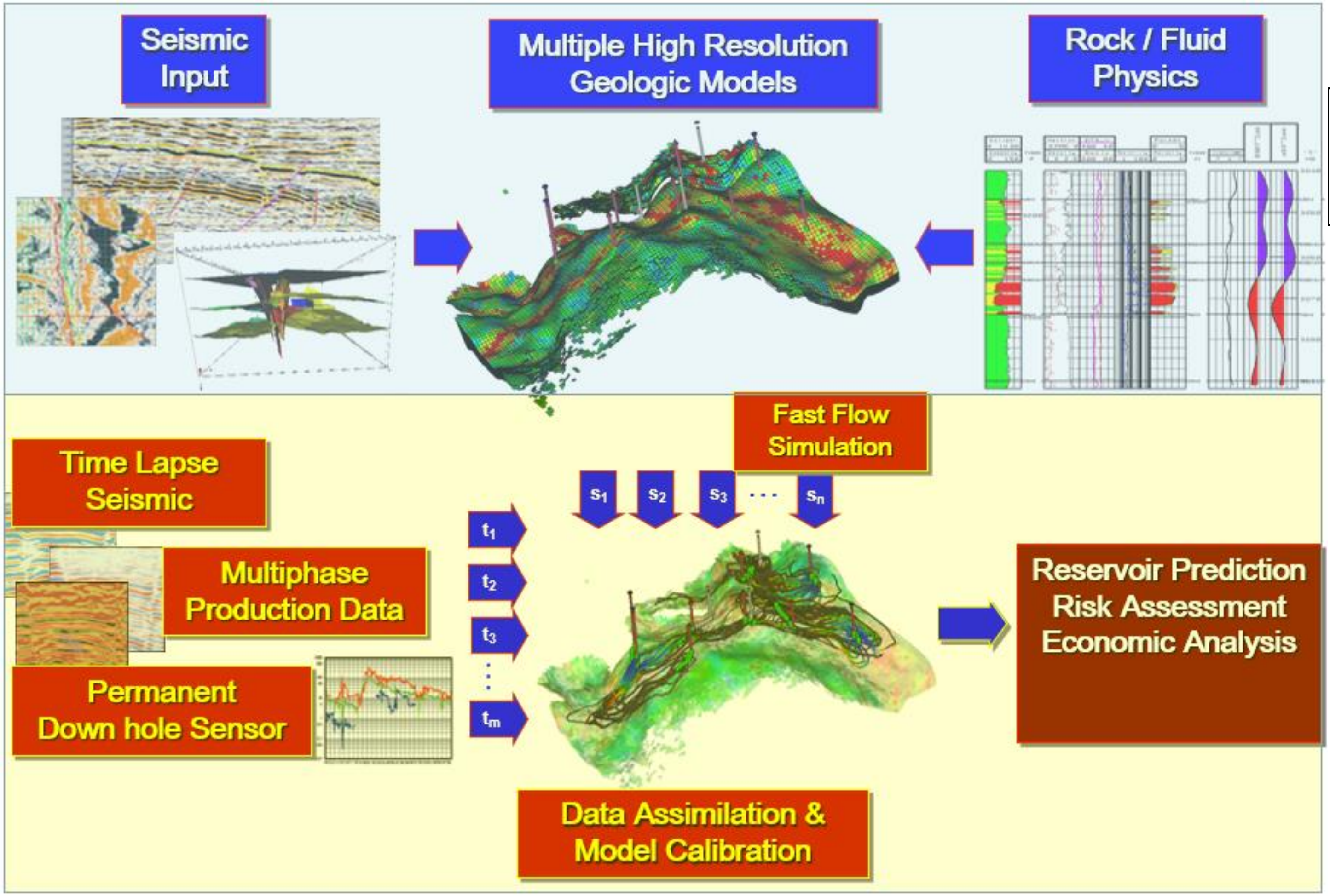
- Can CO2 be Utilized for Economic Benefits
  - Enhanced Oil Recovery (and other potential benefits)

Risk and Economics

- How Do I Ensure Safety of the Project?
  - Leakage and Induced Seismicity Concerns
  - Risks and Economics

Environment Health and Safety

Integrated Reservoir Modeling: Analogy to CCUS Workflow

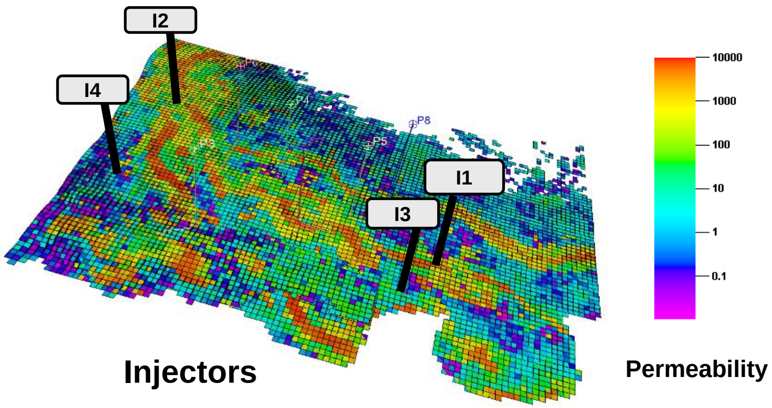


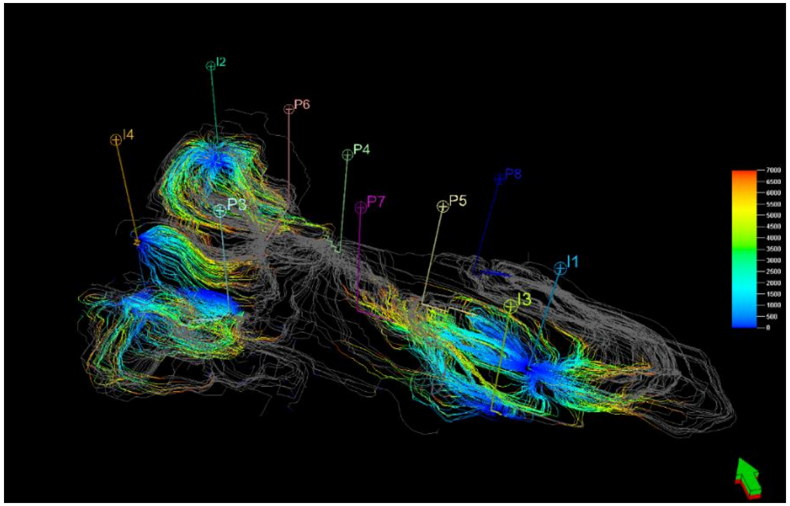
Capacity and Characterization

Modeling, Monitoring and Verification

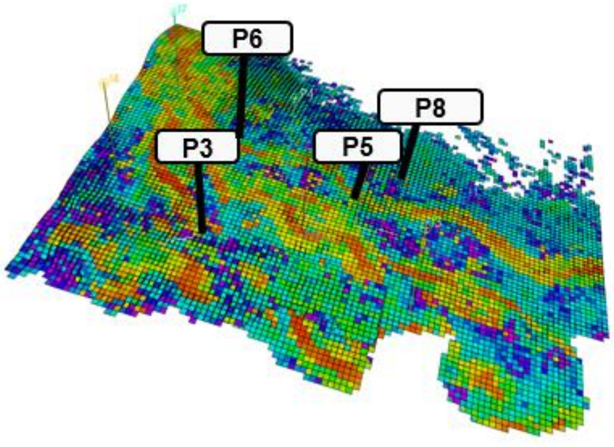
Source: mceri.engr.tamu.edu

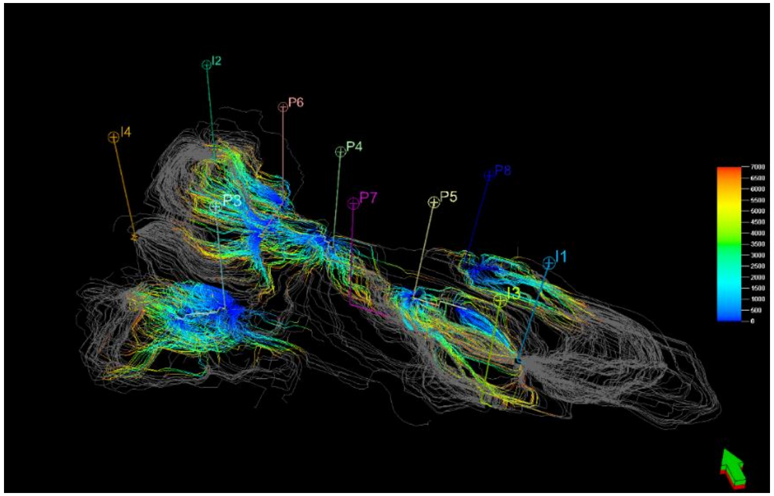
Where is the Injected Fluid Going?
Where is the Produced Fluid Coming From?





Important for optimal utilization of pore space

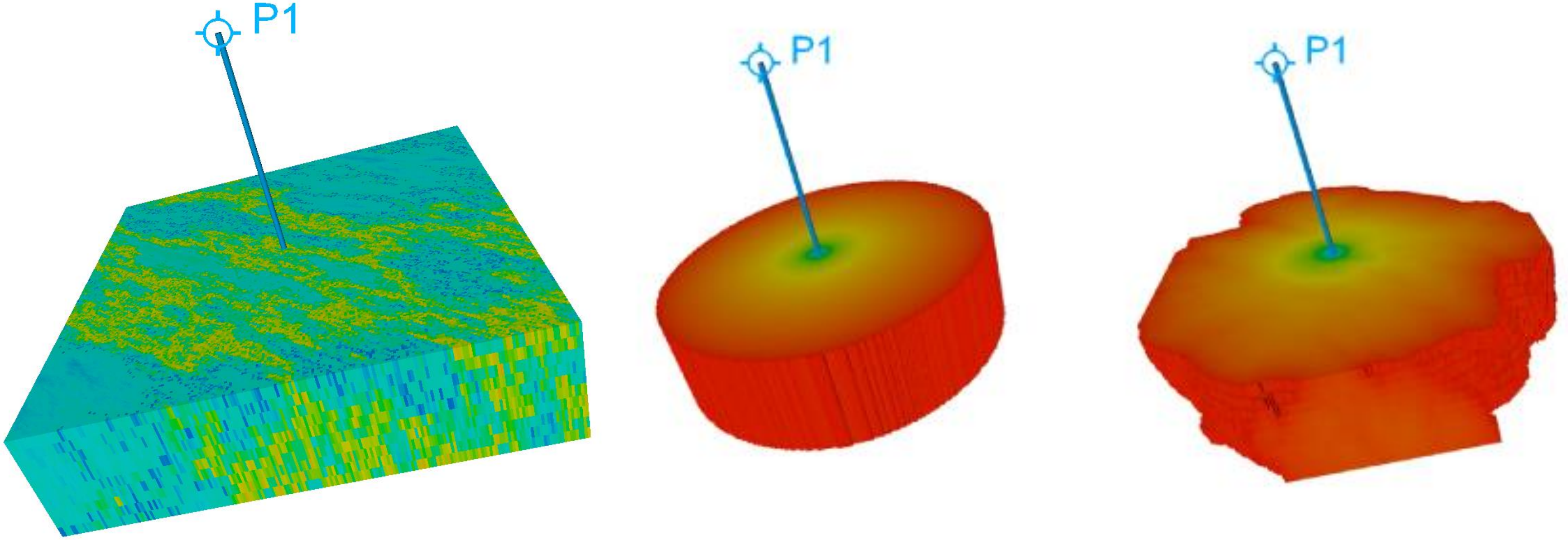




Producers

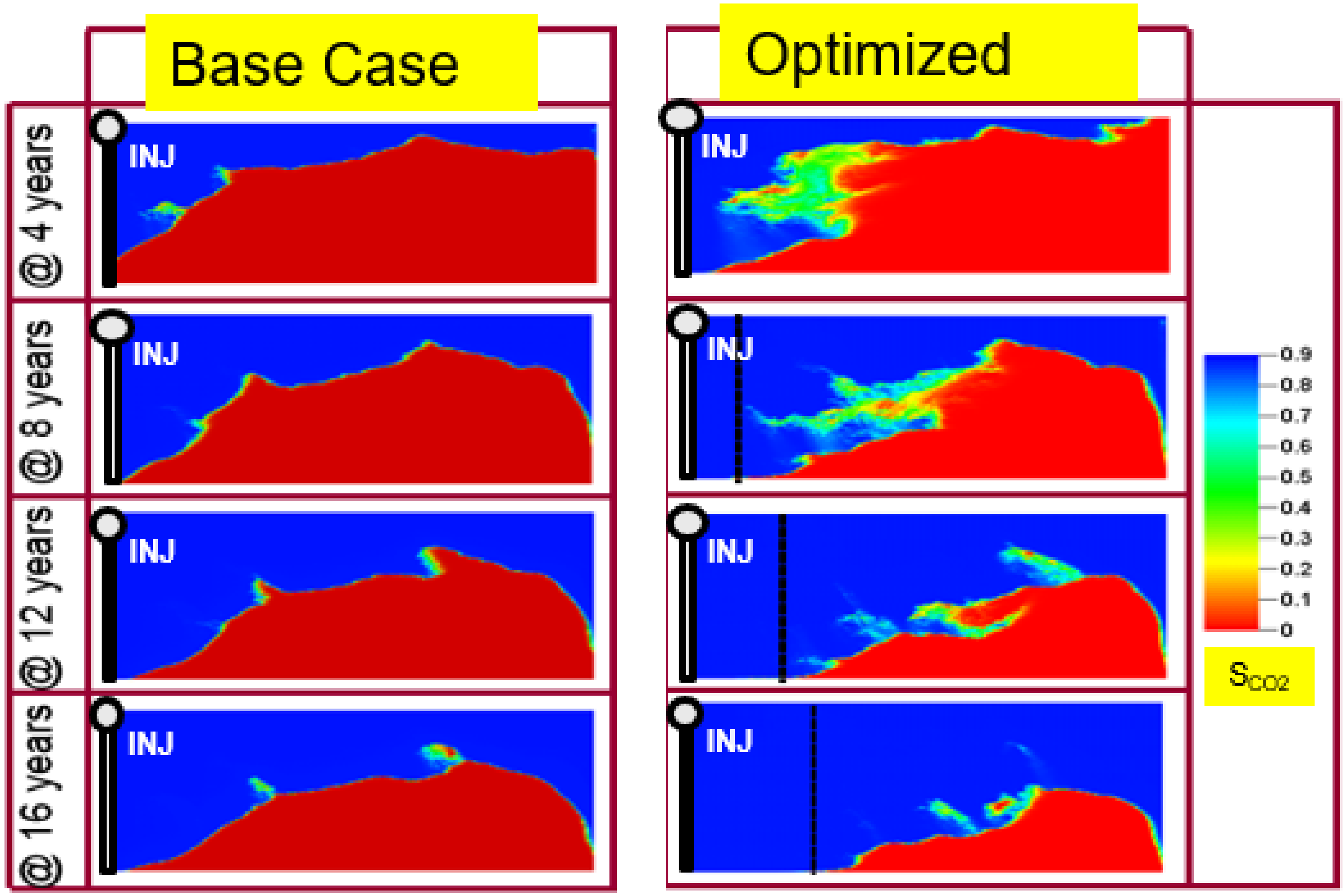
Important for pressure management

Pressure 'Front' Propagation and Implications on Dynamic Injectivity



Important for Area of Review determination

CO2 EOR: Maximizing Vertical Sweep via Rate Control



Important for maximizing storage efficiency

Numerical Modeling and Calibration : Challenges

- Expensive Multiphase Flow Simulations
  - Large scale, compositional and coupled flow/geomechanics/reactive transport
- Time Consuming Model calibration
  - Requires repeated flow simulations
  - Depleted oil and gas reservoirs with long histories, hundreds of wells and often lacks sufficient data
- Uncertainty Quantification
  - Sparsity of data in deep saline aquifers
  - Must examine multiple scenarios for risk assessment

Broad Range of Models are Needed

- Traditional reservoir engineering workflow is too time consuming to facilitate rapid decision making
  - Can take days or weeks
- Need fit for purpose modeling tools
  - Early project developments, regulatory approval, risk assessments and predictive modeling
- Broad range of predictive tools available for development planning and forecasting
  - Streamlines, fast marching, reduced order models
- Model calibration is by far the most time-consuming aspect of the workflow
  - Needs substantial speed up to facilitate real time decision making

Monitoring and Verification: Why

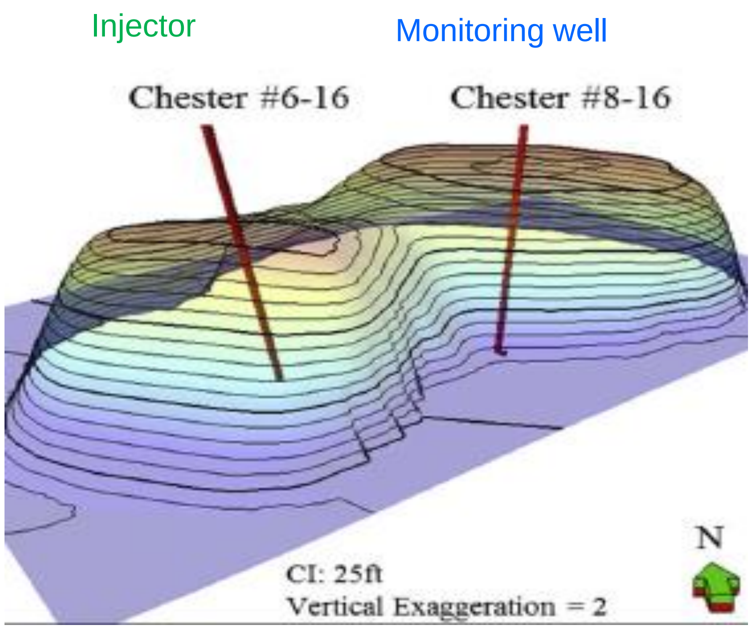
- Spatio-temporal evolution of the CO_2 plume
- Pressure buildup and its active management
  - Induced seismicity mitigation
- Containment of CO_2 in target formation
  - Leakage of CO2 through preferential paths/abandoned wells
- Storage efficiency optimization
- Groundwater contamination

Monitoring and Verification: How

- Broad Range of Monitoring and verification tools
- Challenge is engineering integration of diverse data in a timely fashion

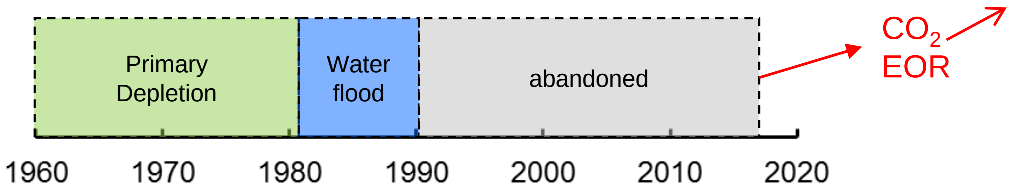
- Downhole Pressure
- Distributed T and P Surveys
- Geochemical Sampling
- Well Logging (PNC, Image, Cement Bond Log, etc.)
- Gravity Surveys
- Vertical Seismic Profiles
- 3D Seismic
- 3C/4D Seismic
- Microseismic Monitoring
- Satellite monitoring

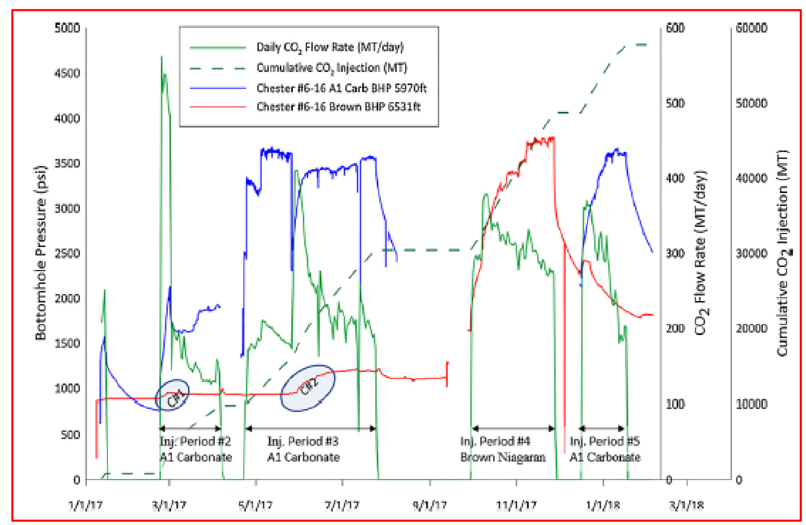
CO2 Plume Delineation at Chester-16 CCUS Project



- Chester-16 Pinnacle Reef located in Otsego county, Michigan
- Large scale CO2 storage test, Midwest Regional Carbon Sequestration Partnership (MRCSP)
- CO_2 arrival tracked at the monitoring well via DTS
- Infer distribution of CO_2 inflow at different zones using Pressure and DTS

Field Development History

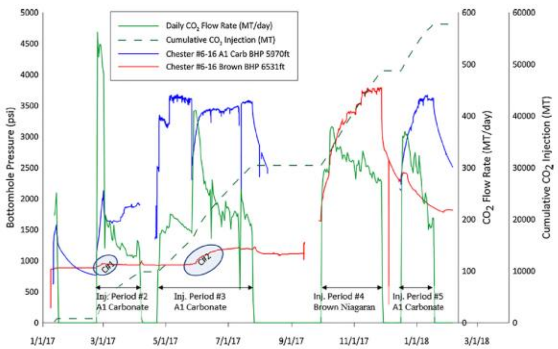




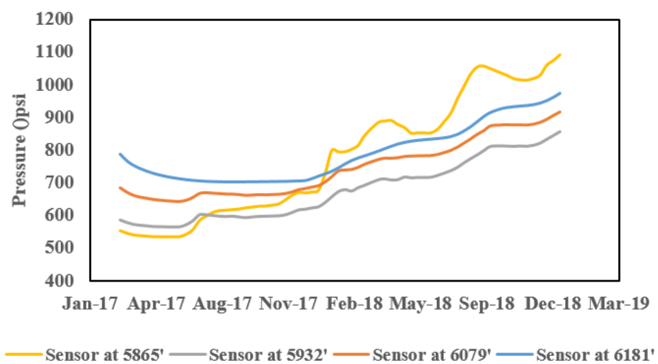
Courtesy: Battelle

Chester-16: Monitoring Data (Pressure and DTS)

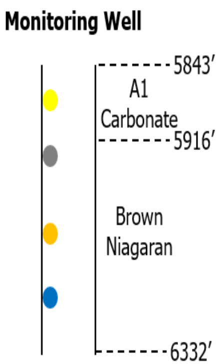
Pressure



Bottom-Hole Pressure of Injection Well

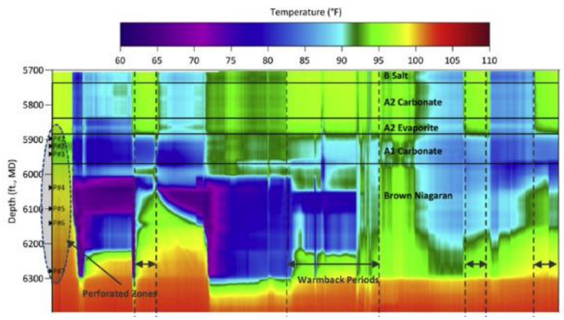


Behind-casing Pressure of four sensors at Monitoring Well

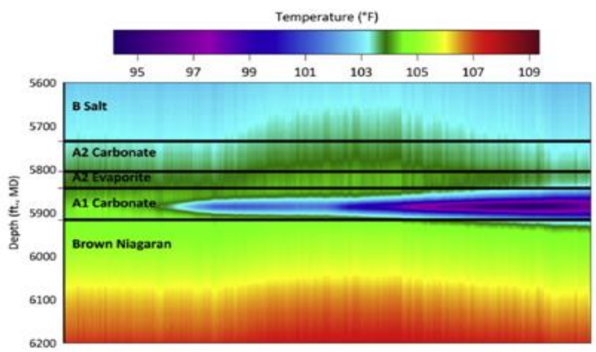


Location of behind-casing sensors

Temperature

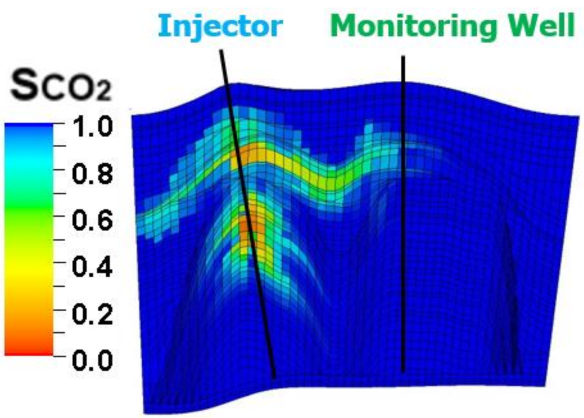


DTS (Injection Well)

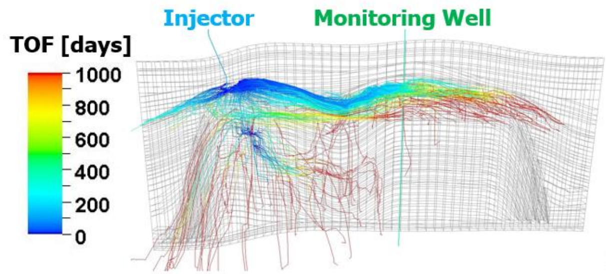


DTS (Monitoring Well)

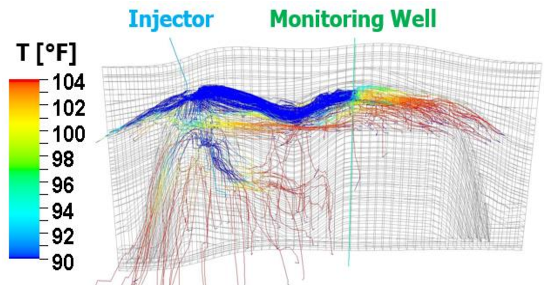
CO2 Plume Tracking at Chester-16



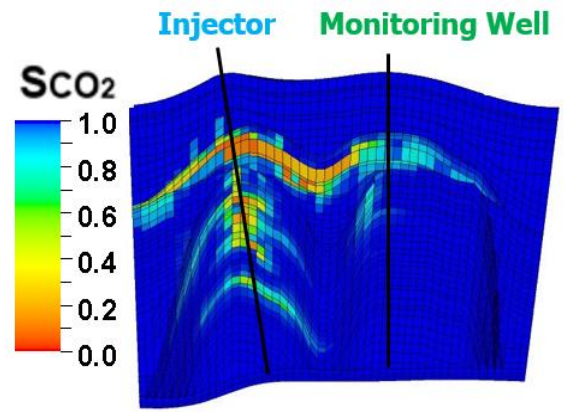
Initial



Streamline Time of Flight



Temperature along Streamlines



Pressure + DTS Match

- CO_2 moves further after model updates with pressure and DTS data
- Vertical movement of CO2 is limited and CO2 mostly stays in the zone of injection
- Confirmed by independent warm-back analysis of the DTS data

DOE- SMART

(Science-informed Machine Learning for Accelerated Real-time Decisions in Subsurface Applications)

- Multiorganizational effort to transform our understanding of the subsurface through real-time visualization, forecasting and virtual learning

Real-Time Visualization
"CT" for the Subsurface

Enable dramatic improvements in the visualization of key subsurface features and flows by exploiting machine learning to improve speed and enhance detail.

Rapid Prediction
Virtual Learning

Transform reservoir management: perform rapid analysis of real-time data to inform operational decisions.

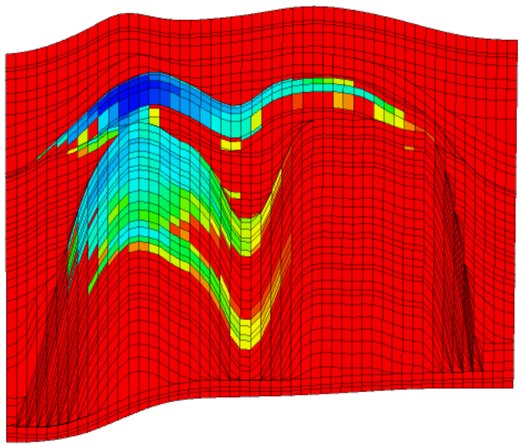
Real-Time Forecasting
"Advanced Control Room"

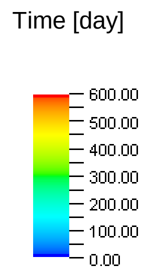
Develop a computer-based experiential learning environment to improve field development and monitoring strategies.

Source: https://edx.netl.doe.gov/smart/about-smart/

CO2 Plume Imaging: Physics Informed Machine Learning vs. Traditional Approach

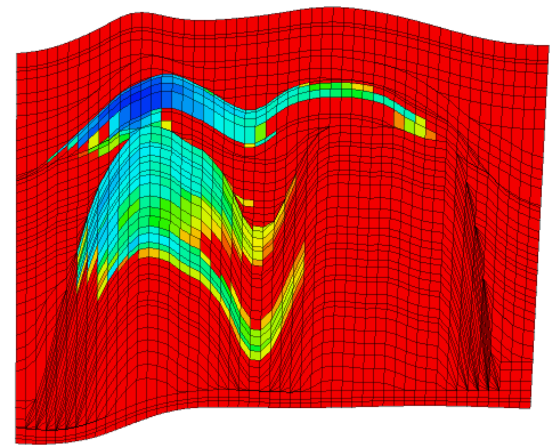
Traditional Model Calibration





Hours/Days

ML-based update



Minutes

Machine learning uses a combination of autoencoder-decoder for image compression and deep learning for regression

What I Left Out

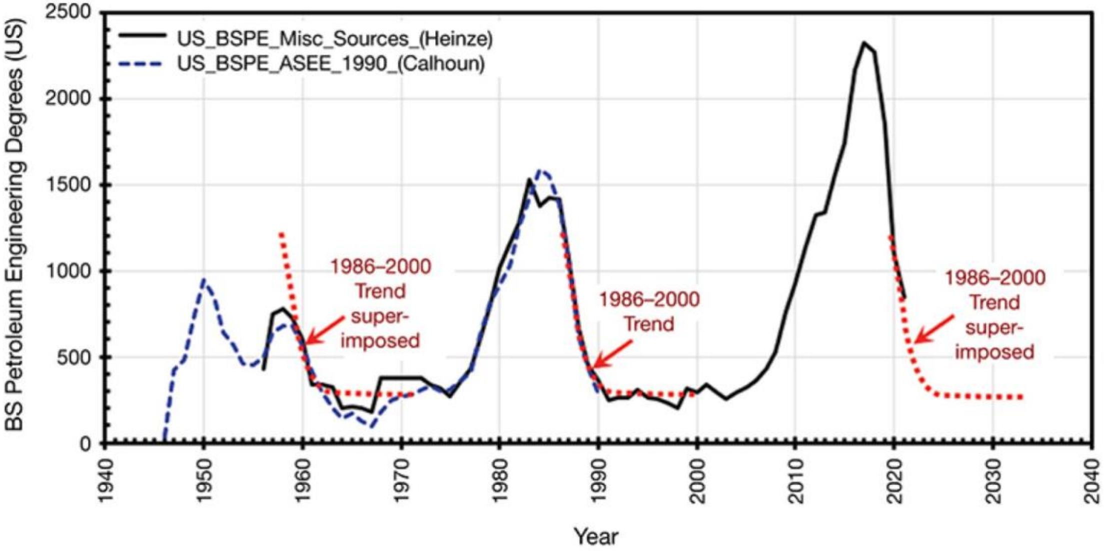
- Capacity and Characterization
  - Characterization process similar to O&G exploration (for storage reservoir + caprock integrity)
  - Data sparsity is a major issue, particularly for regionally extensive deep saline aquifers
  - Detailed fault characterization and fault slip potential calculations
- Risks and Economics
  - Risks generally well understood
  - Primary focus is on adverse impacts from potential loss of CO_2 storage integrity
  - Capture costs can be significant and 45Q tax credits provide incentives
- Non-technical Considerations
  - Public confidence that CO_2 storage is safe and socio-environmental impacts
  - Trustworthy GHG accounting and verification approaches
  - Development of cost-effective regulatory regimes

CCUS: Opportunities and Challenges

- Uses (mostly) proven technology with no major surprises from existing projects
- Relatively easy transition of many petroleum engineering technologies
- CO2 EOR provides important bridge technology
- Needs rapid scale-up to meet net-zero targets
  - Storage capacity requirements (roughly 150% of the space evacuated by oil production each year, JPT March 2022)
  - 70-100 new capture facilities each year until 2050 (Loria and Bright, 2021)
- Capture costs can be significant
  - Gulf coast region has clusters of concentrated emission sources, potentially providing economies of scale
- Stakeholder engagement is critical

Petroleum Engineering and Energy Transition

US Petroleum Engineering Degrees



Broadening of Curriculum

- Carbon Storage
- Water Management
- Hydrogen Storage
- Methane Hydrates
- Geothermal

- CCS Offers Exciting New Opportunities for Petroleum Engineers to Participate in Low Carbon Energy Transitions

- Many Major Petroleum Engineering Schools are in the Gulf Coast Region and can be a Valuable Source for the CCUS Workforce