Outline

• Overview of the Systems Engineering and Analysis Directorate at the National Energy Technology Laboratory (NETL)
• Energy Market Modeling Overview
• The NETL Capture Transport Utilization and Storage - National Energy Modeling System (CTUS-NEMS)
• Benefits Evaluation of CCUS RD&D Using CTUS-NEMS
• Other Analysis Focus Areas/Capabilities at NETL
• Conclusions
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NETL Enduring Core Competencies

Effective Resource Development
Efficient Energy Conversion
Environmental Sustainability
The Systems Engineering & Analysis Directorate’s vision is:

• To become the world’s premier resource for the development and analysis of innovative advanced energy systems

• To provide unprecedented breadth of integrated modeling and optimization capability to support decision making and analysis across multiple scales

• This competency will support identification, evaluation and prioritization of R&D concepts at earlier stages
Energy Systems Analysis

Resource Availability and Cost Modeling
- CO2 storage (saline and EOR)
- Fossil fuel extraction
- Rare earth elements
- General subsurface technology evaluation and support

Grid modeling and analysis

Environmental Life Cycle Analysis

Energy Markets Analysis

Energy Economy Modeling and Impact Assessment
- Enhanced fossil energy representation
- Multi-model scenario/policy analysis
- Infrastructure, energy-water

- Economic impact assessment
- General regulatory, market and financial expertise

- Process synthesis, design, optimization, intensification
- Steady state and dynamic process model development
- Uncertainty quantification
- Advanced process control

Design, optimization, and modeling framework to be expanded to all SEA “systems”
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Models are Representations of the Physical World
With Scales that Vary from Holistic to Specific

- World-wide model incorporating energy, land use and climate impacts
- National or state-level model integrating economy, environment and energy
- Specific energy system, such as pipelines, electricity transmission, etc.
- Modeling at the power plant, reservoir or smaller level
Assessing Program Portfolio Impacts:

Coal Program Example

Baseline Data & Model Development → Set R&D Goals → Develop Scenarios → Project Technology Deployments → Estimate Potential Benefits of RD&D

NETL Cost and Performance Baseline for Fossil Energy Plants

- Detailed, transparent account of plant information
- Key resource for government, academia and industry

NETL CO2 Saline Storage Cost Model (onshore and offshore)

Borehole bottom locations mapped by play name

NETL CO2 Prophet Model

- CT Bearing Formation
- Gas Cap
- Oil Zone
- Aquifer/ROZ

NETL CO2 Capture, Transport, Storage and Utilization - National Energy Modeling System (CTUS-NEMS)

- Adopted by EIA; used in AEO’s Since 2014
- Facilitates and encourages agency interactions

U.S. DEPARTMENT OF ENERGY
Assessing Program Portfolio Impacts:

- Scenario design is a crucial step in the assessment of impacts
- Assumptions about economic growth, policy, electricity demand, etc. will typically drive results
- These assumptions are often the most sensitive and vulnerable to debate
Assessing Program Portfolio Impacts:

Baseline Data & Model Development → Set R&D Goals → Develop Scenarios → Project Technology Deployments → Estimate Potential Benefits of RD&D

U.S. Benefits of the Program, Cumulative through 2040

<table>
<thead>
<tr>
<th>Benefit Area</th>
<th>Metric</th>
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</thead>
<tbody>
<tr>
<td><strong>Economic Growth</strong></td>
<td>Total Electricity Expenditure Savings</td>
</tr>
<tr>
<td></td>
<td>Employment</td>
</tr>
<tr>
<td></td>
<td>Income</td>
</tr>
<tr>
<td></td>
<td>Gross Domestic Product (GDP)</td>
</tr>
<tr>
<td><strong>Environmental Sustainability</strong></td>
<td>CO₂ Captured at Coal and Gas CCS Facilities</td>
</tr>
<tr>
<td><strong>Energy Security</strong></td>
<td>Additional Domestic Oil Production via EOR</td>
</tr>
</tbody>
</table>

R&D Success
CCS Tax Credit
High growth
Reference Case

Total Coal Capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
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<tr>
<td>GW</td>
<td>350</td>
<td>300</td>
<td>250</td>
<td>200</td>
<td>150</td>
<td>100</td>
</tr>
</tbody>
</table>

Baseline Data & Model Development & Model Development & Model Development
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EIA-NEMS and FE/NETL CTUS-NEMS

• NEMS projects the production, consumption, conversion, import, and pricing of energy
• The primary use for NEMS is to produce the Annual Energy Outlook
• NEMS is also used for evaluating the energy generation and landscape under a variety of scenarios including policy and regulatory constraints
• Scenario analysis performed, primarily at the request of the U.S. Congress
• A modified version of NEMS, the NETL CTUS-NEMS Model, is developed and maintained by NETL
• The CTUS-NEMS Model is used to assess the impacts of DOE Fossil Energy RD&D by NETL
General NEMS Structure

- Oil and Gas Supply Module
- Natural Gas Transmission and Distribution Module
- Coal Market Module
- Renewable Fuels Module
- Macroeconomic Activity Module
- International Energy Module
- Residential Demand Module
- Commercial Demand Module
- Transportation Demand Module
- Industrial Demand Module
- Electricity Market Module
- Liquid Fuels Market Module

Supply | Conversion | Demand
CTUS-NEMS Comprehensive Model Structure

Integrates Multiple Project Databases and Models

- Competing Prices for CO₂ By Source
- Available CO₂ By Source
- Demand for CO₂ By EOR

OGSM

- Potential Revenue Stream from EOR
- CO₂ Supplied by CTL to each OGSM Region
- Price of CO₂ From CTL to each OGSM Region

EMM

- Pipeline Infrastructure to Support CO₂ Flows
- Cost of transport from source to sinks (EOR and/or Saline Storage)
- Cost of Saline Storage

CTUS

- Potential Revenue Stream from EOR
- CO₂ Supplied by CTL to each OGSM Region
- Price of CO₂ From CTL to each OGSM Region

LFMM

- Cost of transport to sinks
- Cost of Storage

- P and Q CO₂ for EOR

- CO₂ captured for EOR and/or Storage

CTSSavr.gdx
CTSSoln.gdx
CTSSavr.gdx
CTSSoln.gdx
New Variables in Restart

CO₂ Capture Cost Model
NETL-V2

CO₂ Transport Cost Model
CD2 Saline Storage Cost Model, NETL-V1

CO₂ Saline Storage Cost Model
FE/NETL CO₂ EOR Modeling System Drives CTUS-NEMS

Spreadsheet Input Files

Python Scripting Tool

Reservoir Data
User Control Data
FE/NETL CO₂ Prophet Model

User Control Data
Cost Data
CO₂ Prophet Results
FE/NETL Onshore CO₂ EOR Cost Model

Spreadsheet Output Files

Graphic Output

FE/NETL CO₂ EOR Modeling System Drives CTUS-NEMS

User Control Data

Cost Data

Graphic Output
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• **Benefits Evaluation of CCUS RD&D Using CTUS-NEMS**

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Publicly Available CCUS Benefits Study on CCUS RD&D


- Used to generate a two part series in Public Utilities Fortnightly, Oct. 2017 and Mid Oct. 2017

- Evaluates the economic and job impacts of implementation of a successful FE/NETL R&D program and enactment of the enhanced version of 45Q
  - Assumes that 45Q has no sunset provision per vintage of proposed language

- Results indicate that implementation of both successful FE/NETL R&D program in conjunction with an enhanced 45Q will result in (scenario dependent):
  - Achieving DOE R&D goals will create 500K - 3.3M additional jobs
  - CCUS tax credits will create 4.3M - 6.1M additional jobs
  - Achieving DOE R&D program goals in conjunction with CCUS tax credits will create ~ 5M - 10M additional jobs
Public CCUS RD&D Benefits Study Cont’d

- 7 scenarios were evaluated in the CTUS-NEMS Model

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>O&amp;G Prices</th>
<th>Economic Growth</th>
<th>Electricity Demand</th>
<th>CCS Tax Credits</th>
<th>CCS Technology</th>
<th>EOR O&amp;M</th>
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<tr>
<td>1. No CPP Reference Case</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
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<td>Low Costs</td>
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<td>Low Learning</td>
<td>Low Costs</td>
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<td>3. High Growth, CCS TC Case</td>
<td>Reference</td>
<td>Low Learning</td>
<td>Low Costs</td>
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<td>Low Costs</td>
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<td>4. High Growth, CCS TC, PG Case</td>
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<td>Low Learning</td>
<td>Low Costs</td>
<td>Yes</td>
<td>R&amp;D Program Goals</td>
<td>Low Costs</td>
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<tr>
<td>5. High O&amp;G Prices Case</td>
<td>High</td>
<td>Low Learning</td>
<td>Low Costs</td>
<td>No</td>
<td>Low Learning</td>
<td>Low Costs</td>
</tr>
<tr>
<td>6. High O&amp;G Prices/CCS TC Case</td>
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<td>Low Learning</td>
<td>Low Costs</td>
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<td>Low Learning</td>
<td>Low Costs</td>
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<tr>
<td>7. High O&amp;G Prices/CCS TC/PG Case</td>
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<td>Low Learning</td>
<td>Low Costs</td>
<td>Yes</td>
<td>R&amp;D Program Goals</td>
<td>Low Costs</td>
</tr>
</tbody>
</table>

INCREASED JOB-YEARS GENERATED 2020-2050
COMPARSED TO REFERENCE CASE

U.S. COAL PRODUCTION UNDER EACH SCENARIO

Final version of 45Q Differs from Modeled Version

• **Credit 2008-2018:**
  - $20 per metric ton in secure geologic storage
  - $10 per metric ton used for EOR or EGR in a qualified manner
  - Available credits: 75 million Tons

• **Updated Credit (included in the February 2018 “Bipartisan Budget Act of 2018”):**
  - Credit available to qualified facilities for 12 year period and awarded on an annual basis
  - Applicable Amounts for projects placed in service on after the date of enactment
    - $50 per metric ton for secure geologic storage, with the credit increasing annually until the full value is reached in 2026
    - $35 per metric ton for EOR, EGR, or utilization with the credit increasing annually until the full value is reached in 2026
  - Defines qualified Carbon Oxides (CO or CO\(_2\))
    - Captured from an industrial source or the ambient air
    - Measured at point of capture and verified at the point of disposal/injection/use
    - Excludes gases recaptured during EOR process
  - Qualified facilities
    - **Construction must begin by Jan 1, 2024**
    - Original planning and design includes carbon capture equipment
    - 500,000 t/CO\(_2\) captured/yr for electric generating facilities (for facilities that emit less than 500,000 t/CO\(_2\)/yr, credits available for up to 25,000 t/CO\(_2\) captured and used)

• **Utilization**, including Photo- or chemo-synthesis, chemical conversion, other purposes for which commercial markets exist

• **Credit can be claimed by owner of capture equipment or transferred to disposal/use entity**
The scenarios re-evaluated thus far are as follows (plan to do complete benefits assessment that mirrors original):

- **High Growth Base Case (“HG Base”):** High economic growth with 2.6% per year increase in GDP and high electricity demand of 2% per year, lower EOR O&M costs, and CCS technologies reflecting no federal R&D

- **45Q Tax Credit with Sunset Case (“45Q Sun”):** High Growth with CCS Program Goals Case combined with a 45Q sequestration tax credit that provides $35/ton for captured CO₂ used for EOR and $50/ton for captured CO₂ sent to geologic storage. Credits are available for power and industrial CCS projects that start construction by January 1, 2024

- **45Q Tax Credit Extended Case (“45Q Ext”):** High Growth with CCS Program Goals Case combined with a 45Q sequestration tax credit that provides $35/ton for captured CO₂ used for EOR and $50/ton for captured CO₂ sent to geologic storage. Credits are available for power and industrial CCS projects indefinitely
• The 45Q Tax Credit Scenarios Significantly Impact Volume of CO₂ Sequestered
• The 45Q Tax Credit Scenarios Result in Significant Displacement of Naturally Sourced CO$_2$ for EOR
CCUS Capacity – 45Q Sunset vs. Extended

- New Coal with 90% Capture is Dominant CCUS Technology under 45Q Tax Credit Scenarios
• Coal Generation and Consumption could see a Resurgence under 45Q Tax Credit Scenarios
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NEMS Water Energy Model (NWEM)

- Integrate water availability into energy-economy projections

- Forecast energy-water shortages under various drought scenarios

- Evaluate impacts of water conservation under these scenarios
Marginal Cost Supply Curve for Water in HUC 12070103 – Navasota, Texas

Forecast cost of water from alternative sources in this HUC8 region.

*Retrofits are unit specific

Surface

RC retrofit*

Appropriated

Agriculture

Waste water

Brackish

DC retrofit*

Billion Gallons

$ per 1,000 gallons

2 DC retrofits* (+100)
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Conclusions

• The Department of Energy Office of Fossil Energy/National Energy Technology Laboratory have developed unique capabilities to assess the impacts of fossil energy related RD&D through various detailed and higher level energy-economic models.

• Efforts are also underway to assess technologies applicable to the existing fleet of coal fired power plants in order to estimate benefits of increased efficiency/tolerance to cycling, etc.

• These assessments are important to enable the most efficient allocation of public resources toward technologies with the highest impact and probability of success.