# Phase II-Task 10: Evaluation of Large-Volume Carbon Sequestration Test Sites in Central Appalachia

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# Phase II Update – Final Reports Submitted

- Task 2
  - Central Appalachian Basin Field Validation Test in Coal - 2009
    - (Host: CONSOL/CNX Gas)
  - Black Warrior Basin Field Validation Test in Coal - 2010
    - (Host: El Paso)
- Task 10
  - Evaluation of Large-Volume Carbon Sequestration Test Sites in Central Appalachia

# SECARB Coal Group - Research Team

- Southern States Energy Board
- Marshall Miller and Associates
- VCCER/Virginia Tech
- Geological Survey of Alabama
- Kentucky Geological Survey
- Advanced Resources International
- CONSOL Energy
- West Virginia University

# SECARB Coal Group – Phase II Partners (Cost Share, Data, Wells)

- Alawest
- Alpha Natural Resources
- AMVEST
- Appalachian Production Serv.
- Buckhorn Coal
- CCP2 Project
- CDX Gas
- Clean Energy Tech. Inst (MSU)
- CNX Gas
- CONSOL Energy
- Cumberland Resources
- Dart Oil & Gas
- Denbury Resources
- Dominion
- EPRI
- Equitable Production
- GeoMet
- International Coal Group
- McJunkin Appalachian
- Norfolk Southern
- Natural Resource Partners
- Oak Ridge National Laboratory
- Penn Virginia
- Pine Mountain Oil & Gas
- Piney Land
- Pocahontas Land
- Praxair
- RMB Earth Science Consultants
- Univ. British Columbia

# Task 10 Team Leaders

## Geologic Storage Options

| Devonian Shale | Depleted Oil & Gas Fields | Unmineable Coal Seams | ECBM | Saline Aquifers | Stacked Storage |
|---|---|---|---|---|---|
| KGS | MM&A | MM&A | VCCER | WVU | GSA |

## Technical Tasks

| Public Outreach | Legal, Permitting and Regulatory | Monitoring, Verification and Accounting | Modeling | Closeout |
|---|---|---|---|---|
| VCCER | CONSOL | VCCER | ARI | MM&A |

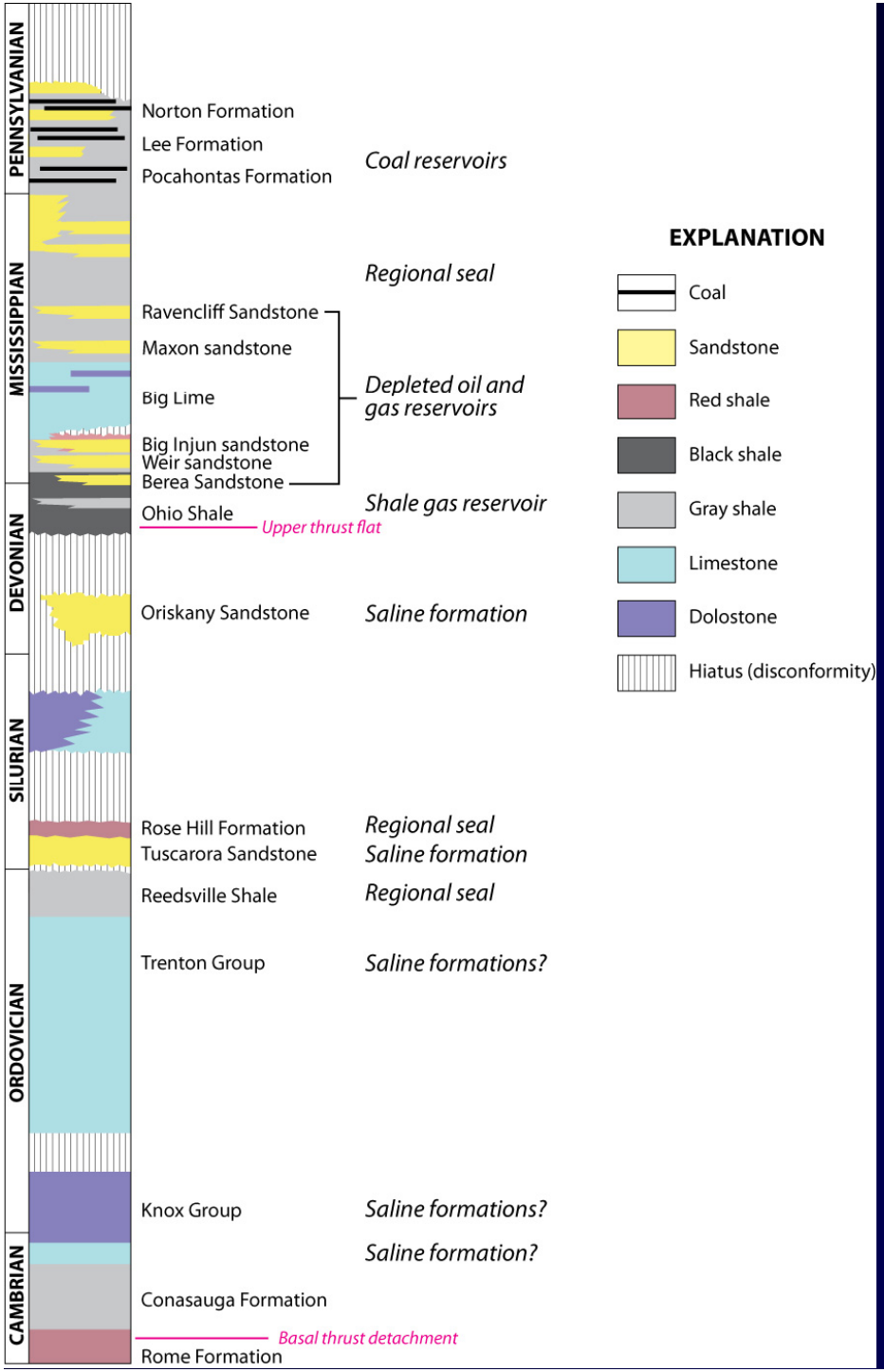
# Primary Objectives

- Characterize potential large volume test sites in Central Appalachian Basin for coal seam sequestration and ECBM recovery
- Identify depleted oil and gas fields that could support a large volume test
- Study saline formations to develop a secondary storage option
- Analyze the potential of shale reservoirs for sequestration

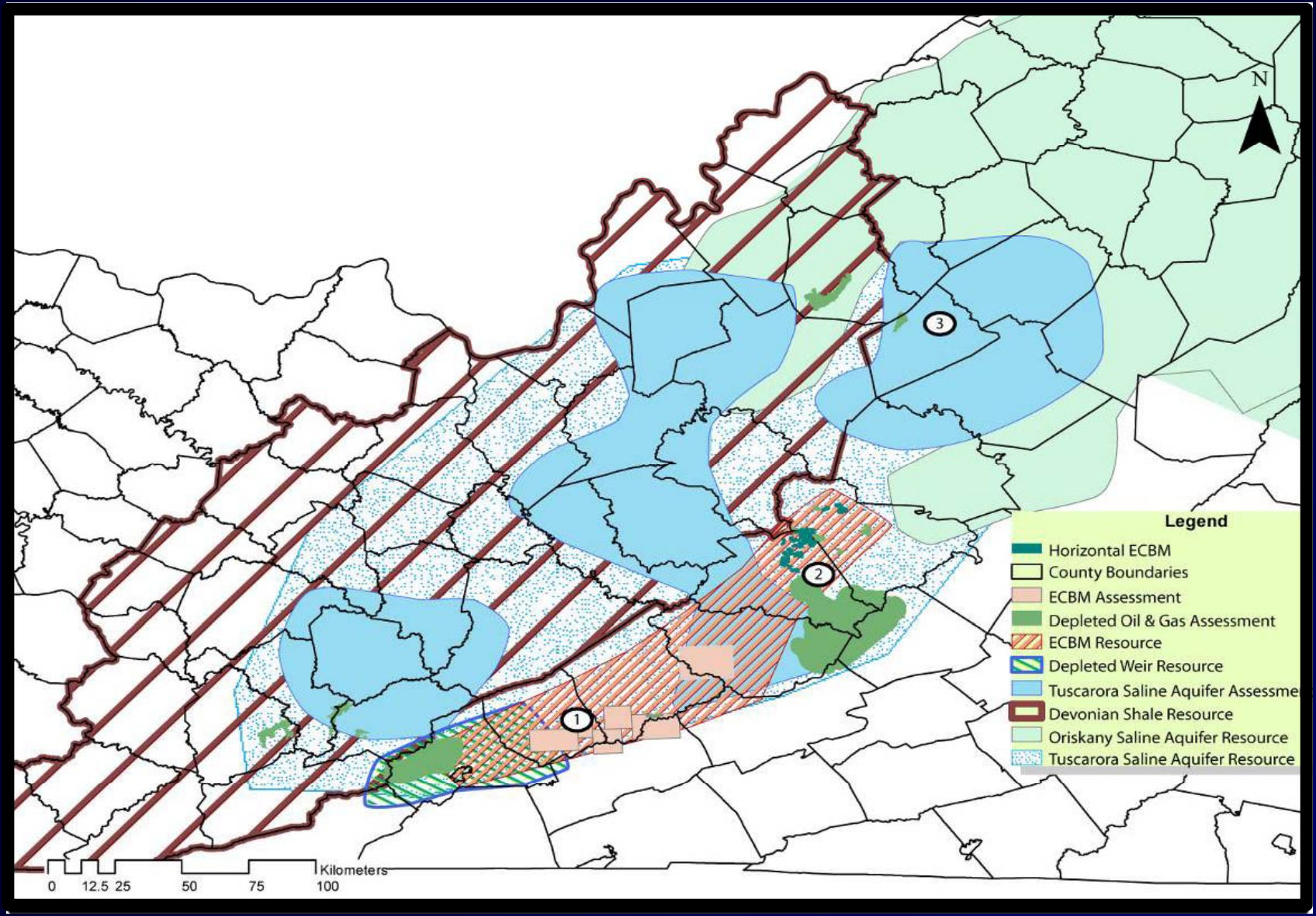
# Primary Objectives (cont.)

- Model potential $CO_2$ injection test sites and develop injection profiles for large-scale test
- Identify options for stacked storage reservoirs
- Select several test sites for a large volume sequestration project

# Stacked Storage Target Formations



# Target Formations



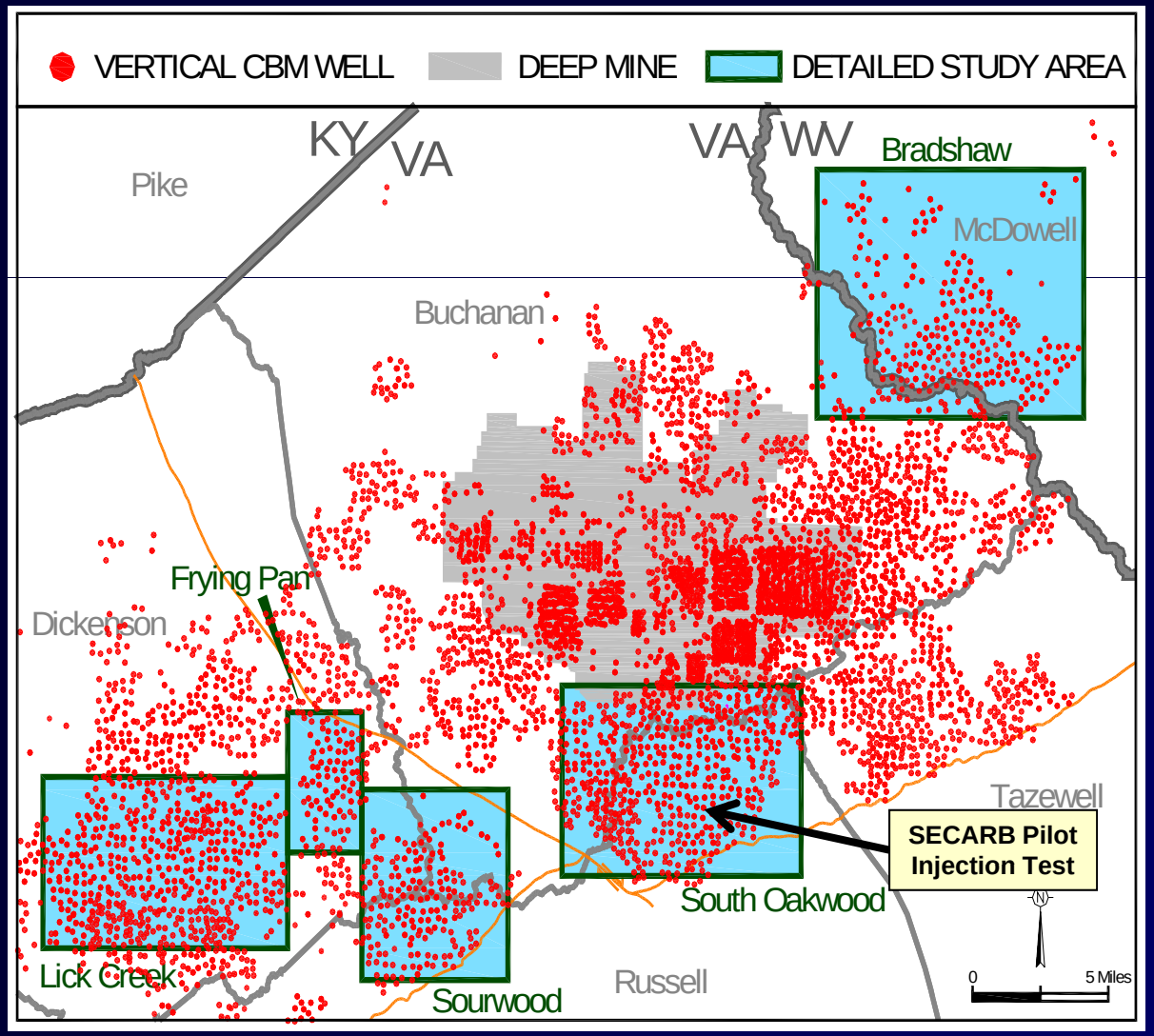
# Reservoir Characteristics of Targeted Sinks

| Stratigraphic Unit | Rock Type | Sink Type | Average Porosity (%) | Average Perm. (mD) | Average Pay Thickness (ft) | Average Depth (ft) | Reservoir Pressure (psi) | Reservoir Temp. (°C) |
|---|---|---|---|---|---|---|---|---|
| Norton, Lee and Pocahontas Formations | Shale, Sandstone, Coal | Coal | | 7.5 | 19 | 800 | 200 | 24.0 |
| Big Lime | Limestone, some Dolostone | Depleted conventional reservoir | 16 | | 50 | 2,947 | | 27.8 |
| Big Injun Sandstone (Price Fm.) | Sandstone | Depleted conventional reservoir | 16 | 6.3 | 38 | 2,050 | 507 | 25.5 |
| Weir Sandstone (Price Fm.) | Sandstone | Depleted conventional reservoir | 11 | | 38 | 4,157 | 73 | 37.7 |
| Berea Sandstone | Sandstone | Depleted conventional reservoir | 10 | 10.0 | 40 | 4,400 | | |
| Devonian Shale | Organic-rich Shale | Shale | | | 40 | 3,000 | | |
| Oriskany Sandstone | Sandstone | Saline formation | 8 | | 52 | | 2,612 | 45.3 |
| Tuscarora Formation | Sandstone | Saline formation | 10 | 10.0 | 82 | 6,496 | 3,074 | 50.6 |

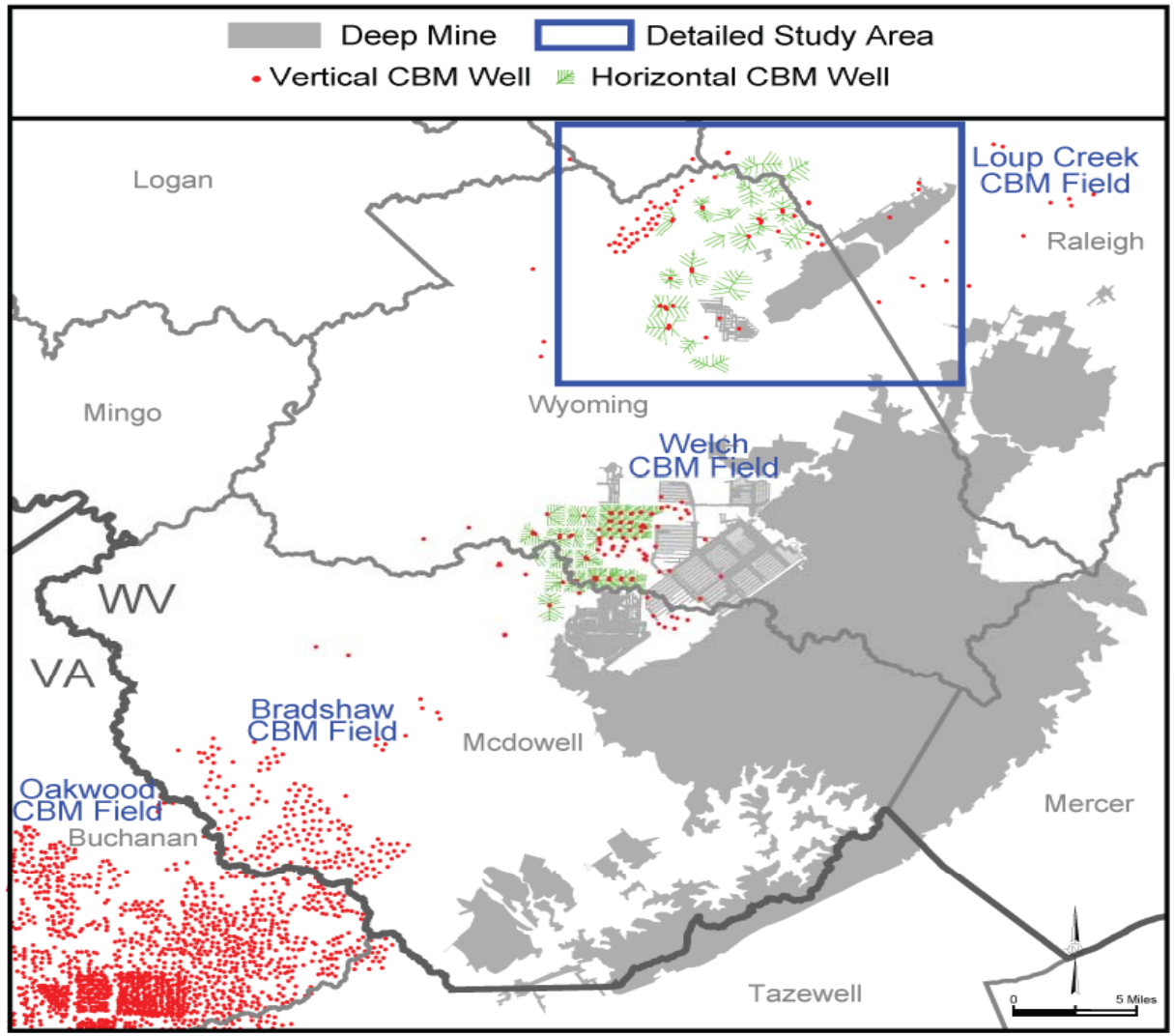
# CBM Fields in Study

- Bradshaw
- Lick Creek
- Sourwood
- Frying Pan
- Loup Creek
- South Oakwood

# CBM Characterization Study Area



# Loup Creek Study Area



# $CO_2$ Storage Estimate of CBM Fields

| Field Name | State | Cumulative Production (Bcf) | Ultimate Recovery (Bcf) | Current State of Depletion (%) | Current Storage Capacity (tonnes) | Total Storage Capacity (tonnes) |
|---|---|---|---|---|---|---|
| Frying Pan | VA | 17.1 | 35.6 | 48% | 1,613,000 | 3,360,000 |
| Sourwood | VA | 18.8 | 55.3 | 34% | 1,772,000 | 5,209,000 |
| Lick Creek | VA | 80.8 | 231.1 | 35% | 7,616,000 | 21,783,000 |
| South Oakwood | VA | 90.6 | 321.9 | 28% | 8,535,000 | 30,345,000 |
| Loup Creek | WV | 30.1 | 47.4 | 64% | 2,835,000 | 4,464,000 |
| Bradshaw | WV | | | | | 1,839,000 |
| **Totals** | **--** | **237.4** | **691.3** | | **22,371,000** | **67,000,000** |

# ECBM Estimates by Field

| Field Name | State | Recovery Factor | Ultimate Recovery (Bcf) | GIIP (Bcf) | Residual Gas (Bcf) | ECBM Potential* (Bcf) |
|---|---|---|---|---|---|---|
| Frying Pan | VA | 60% | 35.6 | 59.4 | 23.8 | 5.9 |
| Sourwood | VA | 60% | 55.3 | 92.1 | 36.8 | 9.2 |
| Lick Creek | VA | 50% | 231.1 | 462.2 | 231.1 | 57.8 |
| South Oakwood | VA | 50% | 321.9 | 643.8 | 321.9 | 80.5 |
| Loup Creek | WV | 85% | 47.4 | 55.6 | 8.3 | 2.1 |
| Bradshaw | WV | | | | | 5.4 |
| **Totals** | **--** | **--** | **691.3** | **1,313.1** | **621.9** | **160.9** |

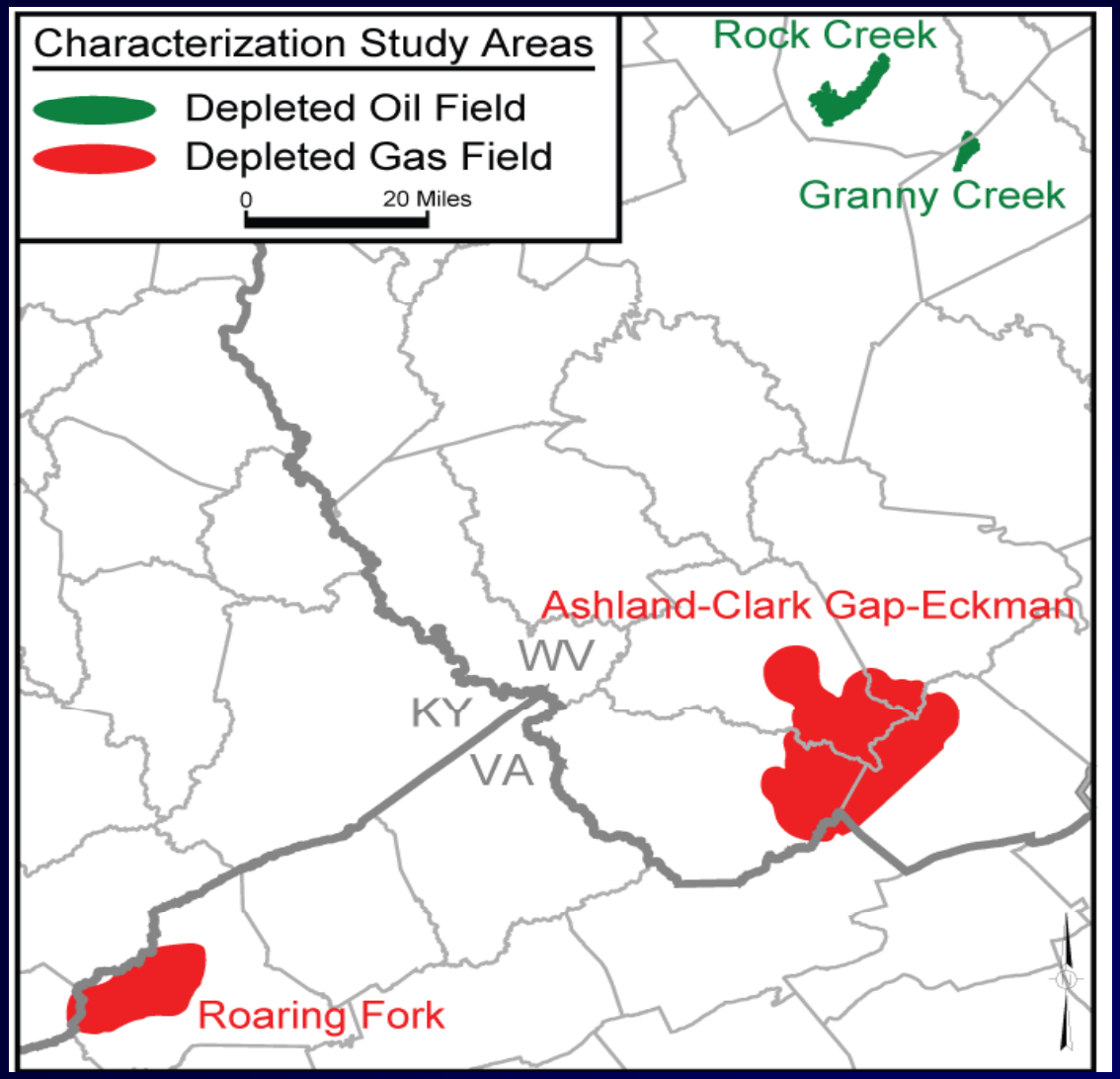
# Depleted Oil &Gas Fields in Study

- Weir Formation – 2 Fields
- Big Injun Formation – 2 Fields
- Big Lime Formation – 10 Fields

# Weir & Big Injun Fields in Study

- Roaring Fork
- Ashland – Clark Gap – Eckman
- Granny Creek
- Rock Creek

# Weir & Big Injun Study Area



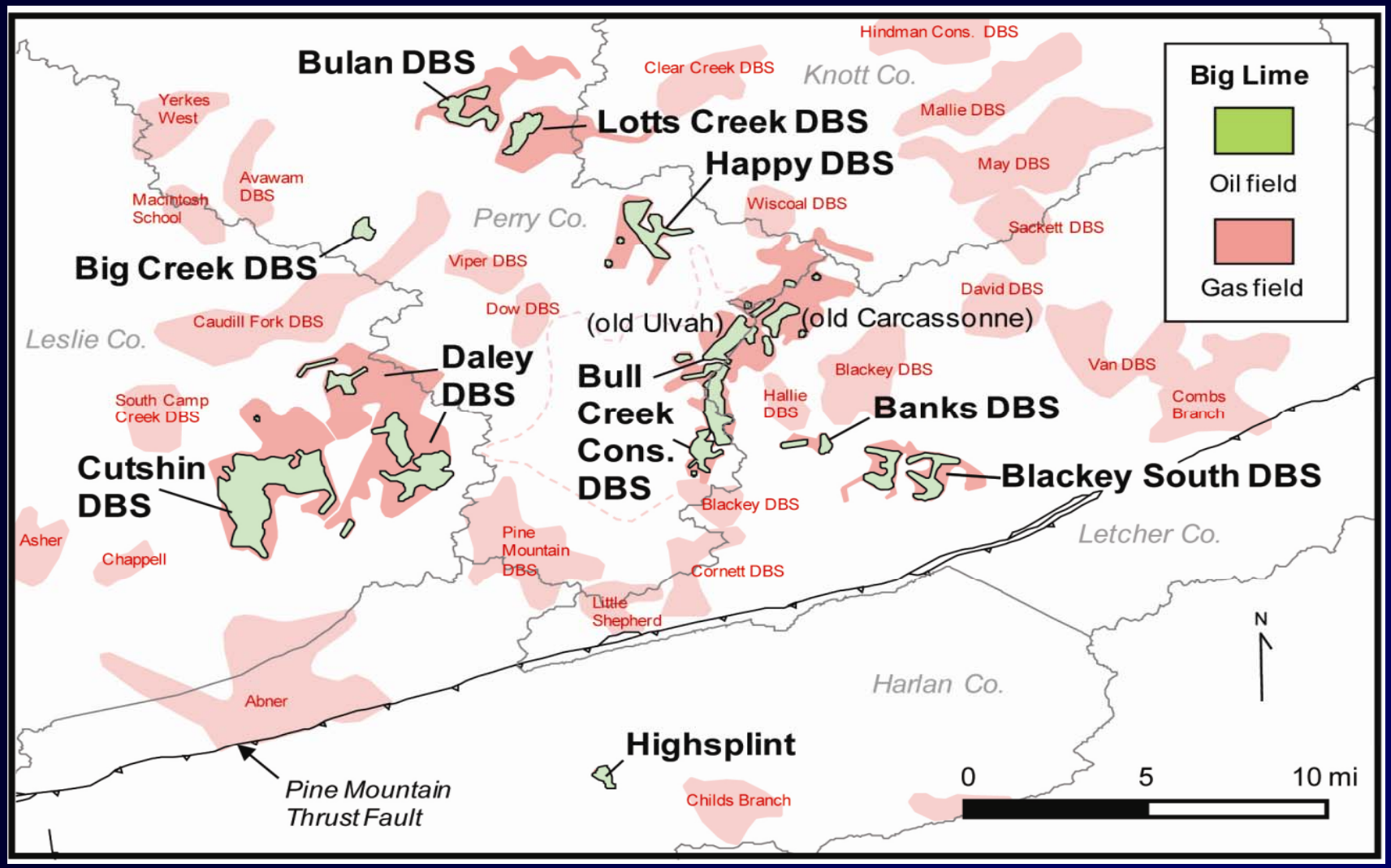
# $CO_2$ Storage Estimate in Weir and Big Injun Fields

| Field Name | Mid-Point Depth (ft) | Estimated Ultimate Recovery | Storage Capacity (tonnes) | Enhanced Oil Recovery (bbls) |
|---|---|---|---|---|
| Roaring Fork | 4,550 | 157.9 Bcf | 27,773,165 | -- |
| Ashland-Clark Gap-Eckman | 4,210 | 411.5 Bcf | 29,043,433 | -- |
| Granny Creek | 2,050 | 11.9 MMbo | 149,792 | 84,597 |
| Rock Creek | 2,029 | 25.5 MMbo | 311,333 | 162,369 |

# Big Lime Fields in Study

- Banks
- Blackey South
- Bull Creek Consolidated
- Daley
- Highsplint
- Big Creek
- Bulan
- Cutshin
- Happy
- Lotts Creek

# Big Lime Fields in Study



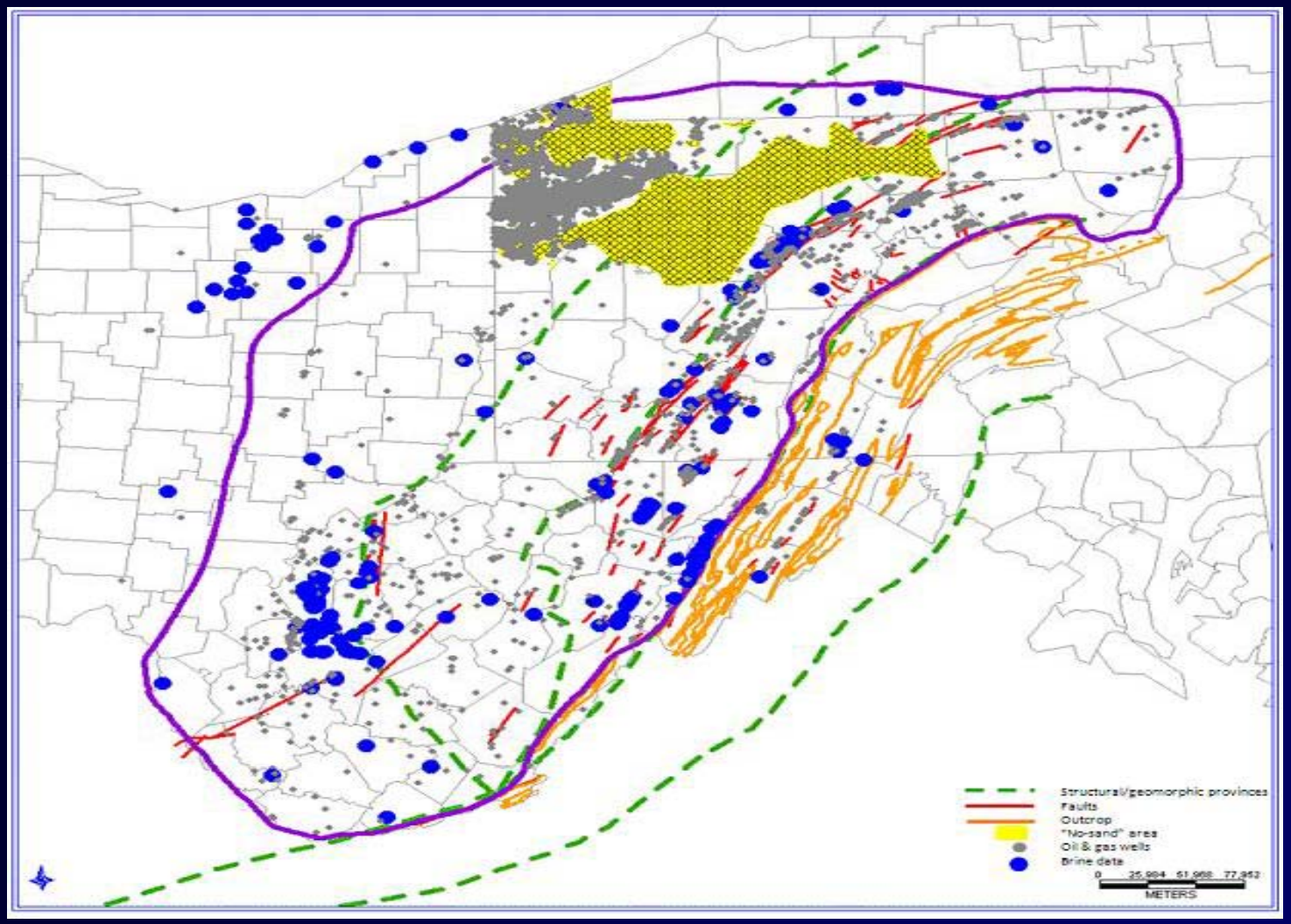
# $CO_2$ Storage Estimate in Big Lime Fields

| Field Name | Recovery factor | Estimated $CO_2$ Storage Volume (tonnes) | | | |
|---|---|---|---|---|---|
| | | Case 1 | Case 2 | Case 3 | Case 4 |
| All 10 Fields | 100% | 397,175 | 2,717,650 | 17,516,542 | 32,264,296 |
| | 40% | 158,870 | 1,087,060 | 7,006,617 | 12,905,718 |
| | 20% | 79,435 | 543,530 | 3,503,308 | 6,452,859 |
| | 10% | 32,497 | 265,060 | 1,748,217 | 3,220,904 |

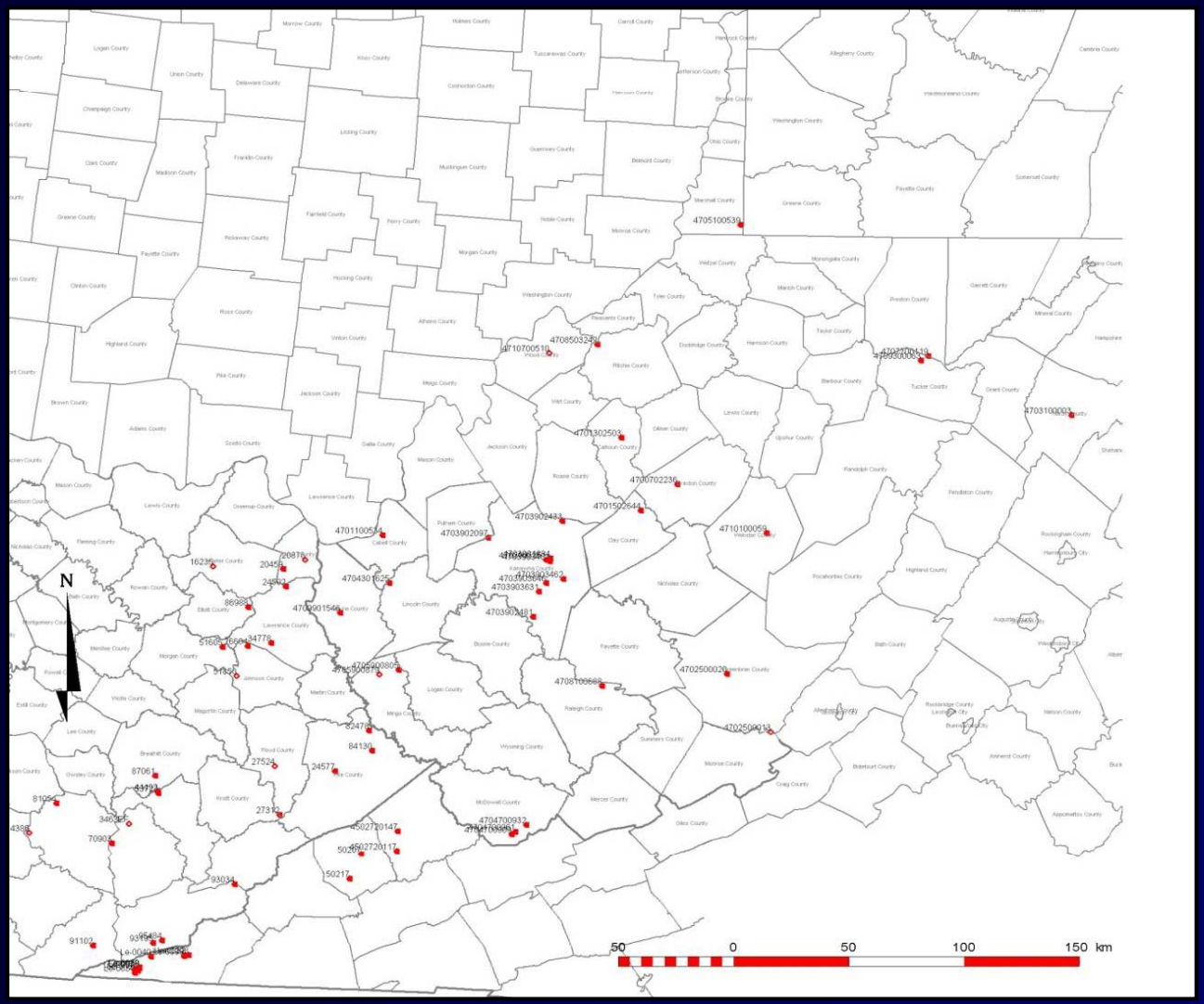
# Saline Reservoirs in Study

- Oriskany Sandstone
- Tuscarora Sandstone

# Oriskany Sandstone Potential Sequestration Area



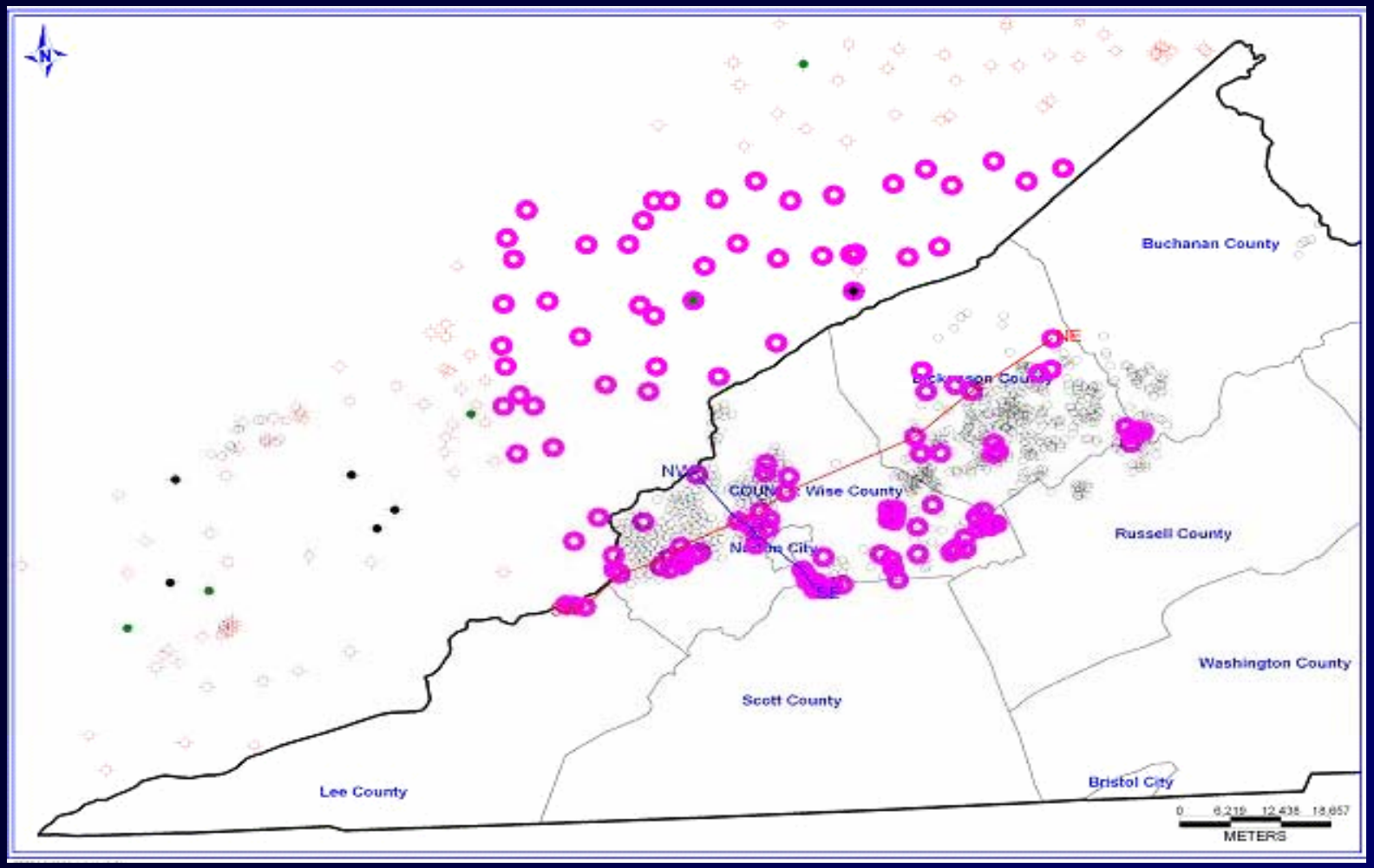
# Tuscarora Study Area



# $CO_2$ Storage Estimate in Oriskany and Tuscarora SS

| Formation | High Estimate E=0.04 (tonnes) | Low Estimate E=0.01 (tonnes) |
|---|---|---|
| Oriskany | 4,983,000,000 | 1,246,000,000 |
| Tuscarora | 423,069,942 | 105,767,485 |

# Devonian Shale Study Area



# $CO_2$ Storage Estimate in Shale in SW Virginia

| Area | $CO_2$ (tonnes) |
|---|---|
| Buchanan Co. | 2,043,906 |
| Dickenson Co. | 7,215,155 |
| Lee Co. | 575,206 |
| Norton City | 352,267 |
| Russell Co. | 154,636 |
| Scott Co. | 158,958 |
| Wise Co. | 16,921,749 |
| **Total** | **27,421,877** |

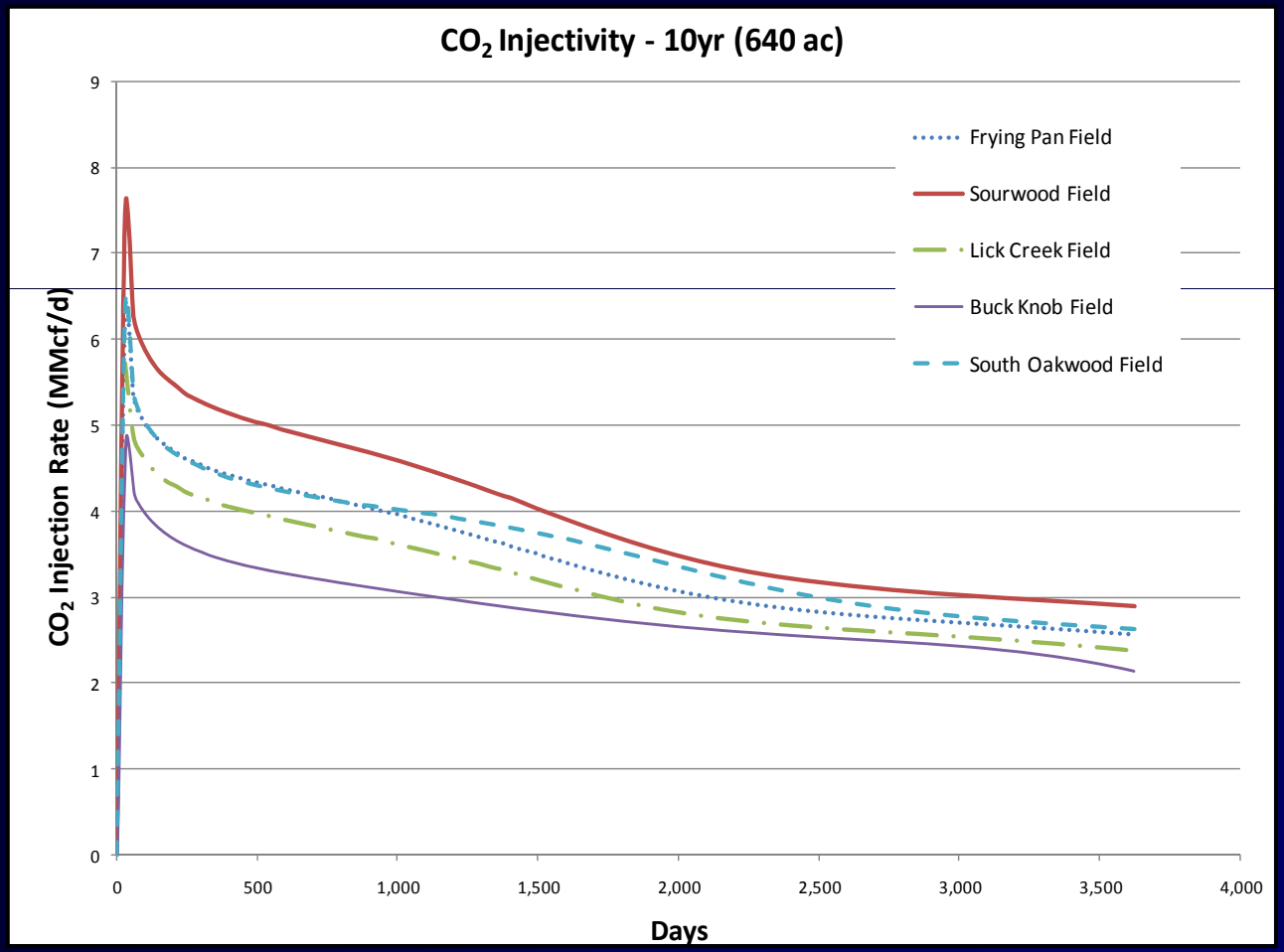
# $CO_2$ Storage Estimate for Geologic Sinks

| $CO_2$ Sink | Estimated $CO_2$ Storage Capacity (tonnes) |
|---|---|
| Unmineable Coalbeds | 453,408,000 |
| Depleted Oil & Gas Fields | 89,542,019 |
| Saline Reservoirs | 5,406,069,942 |
| Organic-Rich Shales | 27,421,877 |
| **Total** | **5,976,441,838** |

# Other Tasks

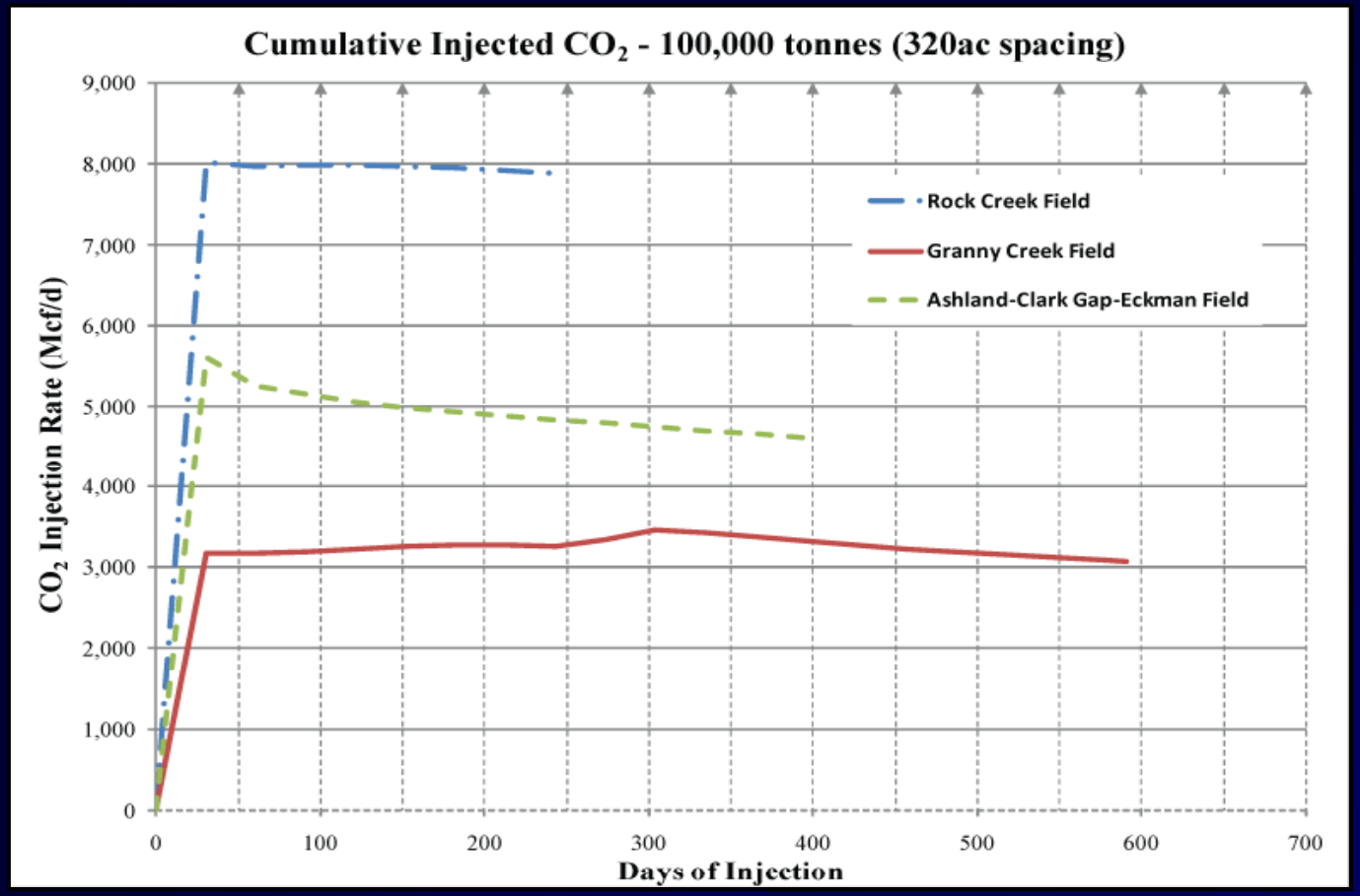
- Reservoir Modeling
- Monitoring, Verification, and Accounting
- Permits
- Public Outreach and Education

# Modeling Results of Injectivity of CBM Fields




*Compares favorably with characterization results.

# Modeling Results of Injectivity of Depleted Oil and Gas Fields




*With a developed area of 15,360 acres (62.2 square kilometers), the Rock Creek field may be capable of accepting nearly five million tonnes of $CO_2$ in the first year.

# Reservoir Modeling Results

| Reservoir Type | Field Name | Reservoir Name | Injection Spacing | Injection Duration for 100,000 metric tonnes |
|---|---|---|---|---|
| | Frying Pan | Lee and Pocahontas | 640 | 396 (13 months) |
| | Sourwood | Lee and Pocahontas | 640 | **335 (11 months)** |
| Coal Bed Methane | Lick Creek | Lee and Pocahontas | 640 | 441 (14 months) |
| | Buck Knob | Lee and Pocahontas | 640 | 517 (17 months) |
| | South Oakwood | Lee and Pocahontas | 640 | 381 (12.5 months) |
| Depleted Oil and Gas | Rock Creek | Big Injun Sandstones | 320 | **240 (8 months)** |
| | Granny Creek | Big Injun Sandstones | 320 | 584 (19 months) |
| | Ashland-Clark | Weir Sandstones | 320 | **383 (13 months)** |
| Gas Shale | Big Sandy | Devonian Lower Huron | ~40 | 21,900 (720 months) |
| Deep Saline | N/A | Tuscarora Sandstones | N/A | 1,460 (48 months) |
| | N/A | Oriskany Sandstones | N/A | 3,106 (102 months) |

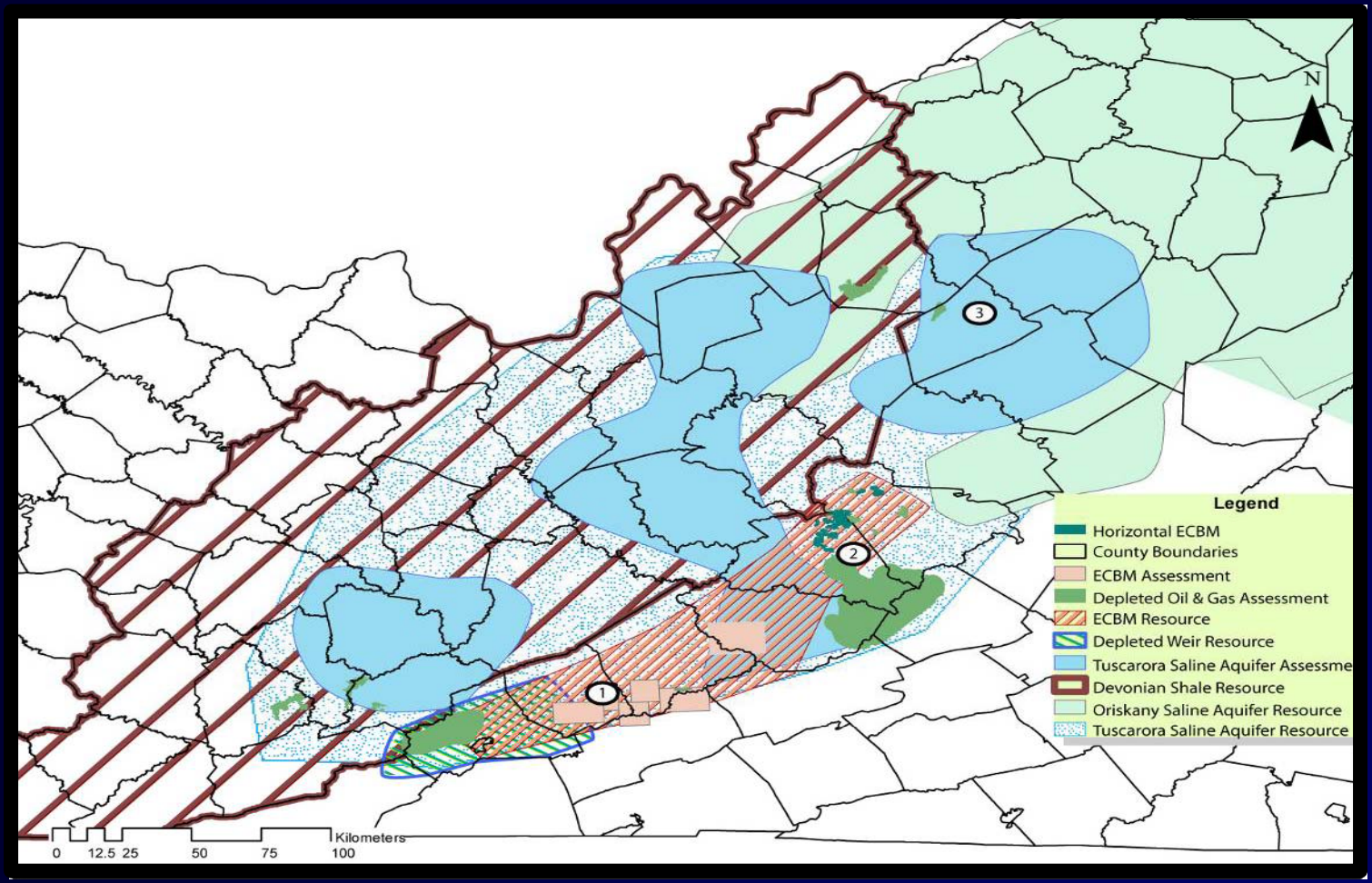
# Site Selection Parameters

- Footprint - storage capacity (tonnes/acre)
- Modeled injectivity (tonnes/day)
- Confinement characteristics
- Target depth range (m)
- Storage reservoir availability
- ECBM-EGR potential
- Storage risks
- MVA challenges
- Distance to large $CO_2$ emitters

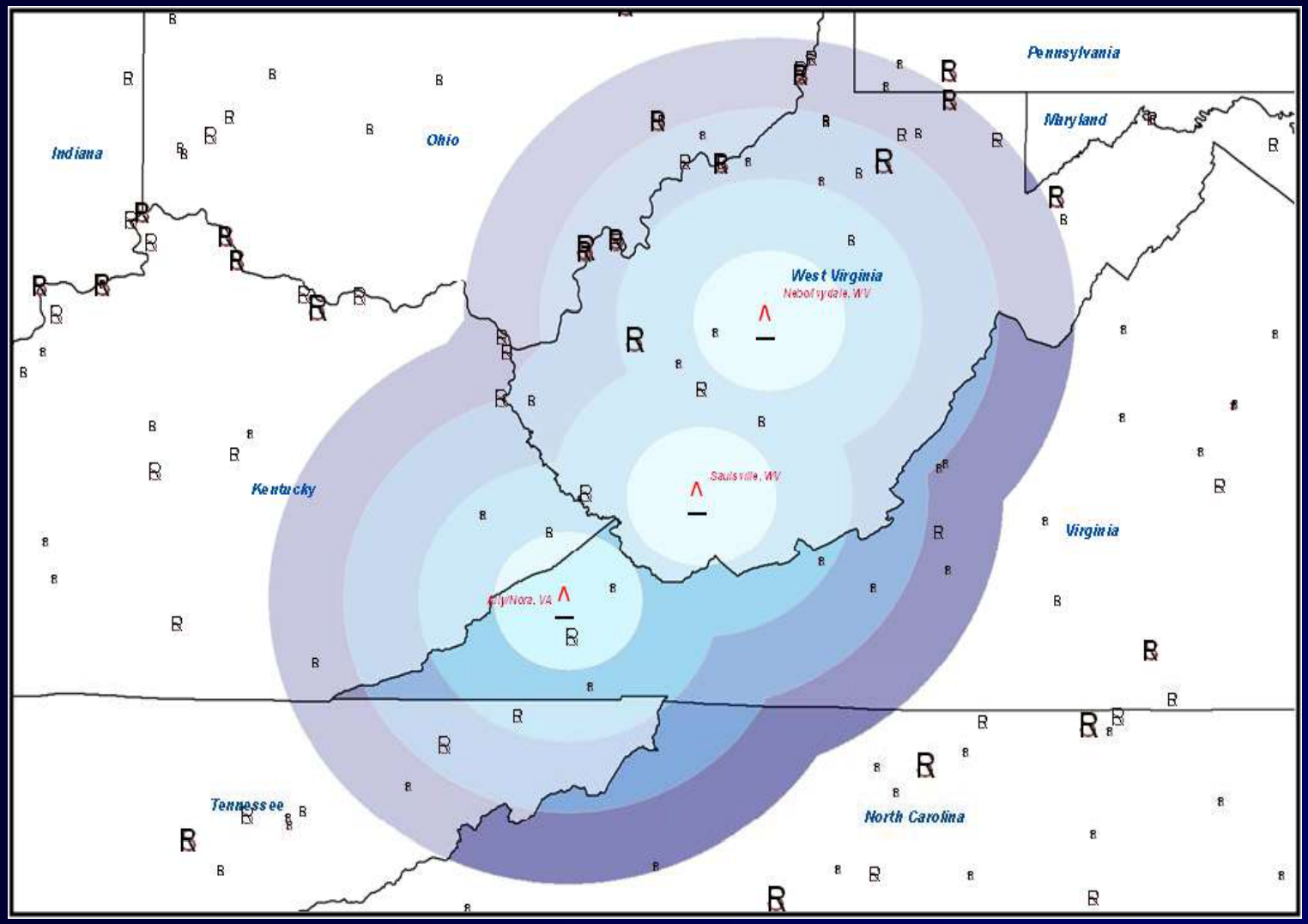
# Selected Sites

- Site 1 – Southwestern Virginia
  - Unmineable coal seams, depleted gas reservoirs and Devonian Shale
- Site 2 – Wyoming County, West Virginia
  - Horizontally developed coal seams, depleted gas reservoirs and Tuscarora saline reservoir
- Site 3 – Clay County, West Virginia
  - Oriskany and Tuscarora saline reservoirs

# Potential Sites for Large-Volume $CO_2$ Injection and Sequestration



# Sources and Sinks




* Dominion Hybrid Energy Center currently under construction

# Conclusions

- 3 sites identified for large volume $CO_2$ testing in Central Appalachian Basin
- Significant potential exists for long term commercial-scale storage of $CO_2$
- Sites are close to $CO_2$ sources
- Good geological characterization and vast number of wells in region

# Recommendations

- 3 year pre-injection engineering study
- Complete storage system design and cost analysis
- Conduct 3D seismic study at site
- Drill shallow and deep test wells
- Inject moderate volume of $CO_2$ to confirm commercial potential