BIGSKYCARBON
SEQUESTRATION PARTNERSHIP

A New Energy Future for Montana, Idaho, South Dakota, Wyoming, the Pacific Northwest and the Nation

THE ECONOMICS AND IMPACTS OF CARBON CAPTURE, TRANSPORT & SEQUESTRATION

An Overview of the Big Sky Partnership Pilots and The Impacts of Carbon Sequestration and Transport on Siting

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Overview and structure

- Partnership Goal: **Develop infrastructure to support and enable future carbon sequestration field tests and deployment (regional orientation)**
- Phase II: Two focal areas: **geological** and **terrestrial** sequestration opportunities/pilots
  - Integrated with economic analysis and risk/liability assessment for scaling up potential (large-scale commercialization)
  - Using GIS carbon atlas for policy analysis and decision-making tool

Link Sources to Sinks

- GIS Component
  - Sources and Sinks Identification and Characterization (phase I efforts)
  - Carbon Atlas – static and interactive
  - National Mafic Rock Atlas
  - Pilot data integration
    - Site Specific Characterizations from geological pilots
    - Base Data/Infrastructure
    - Terrestrial and Economic Data Layers

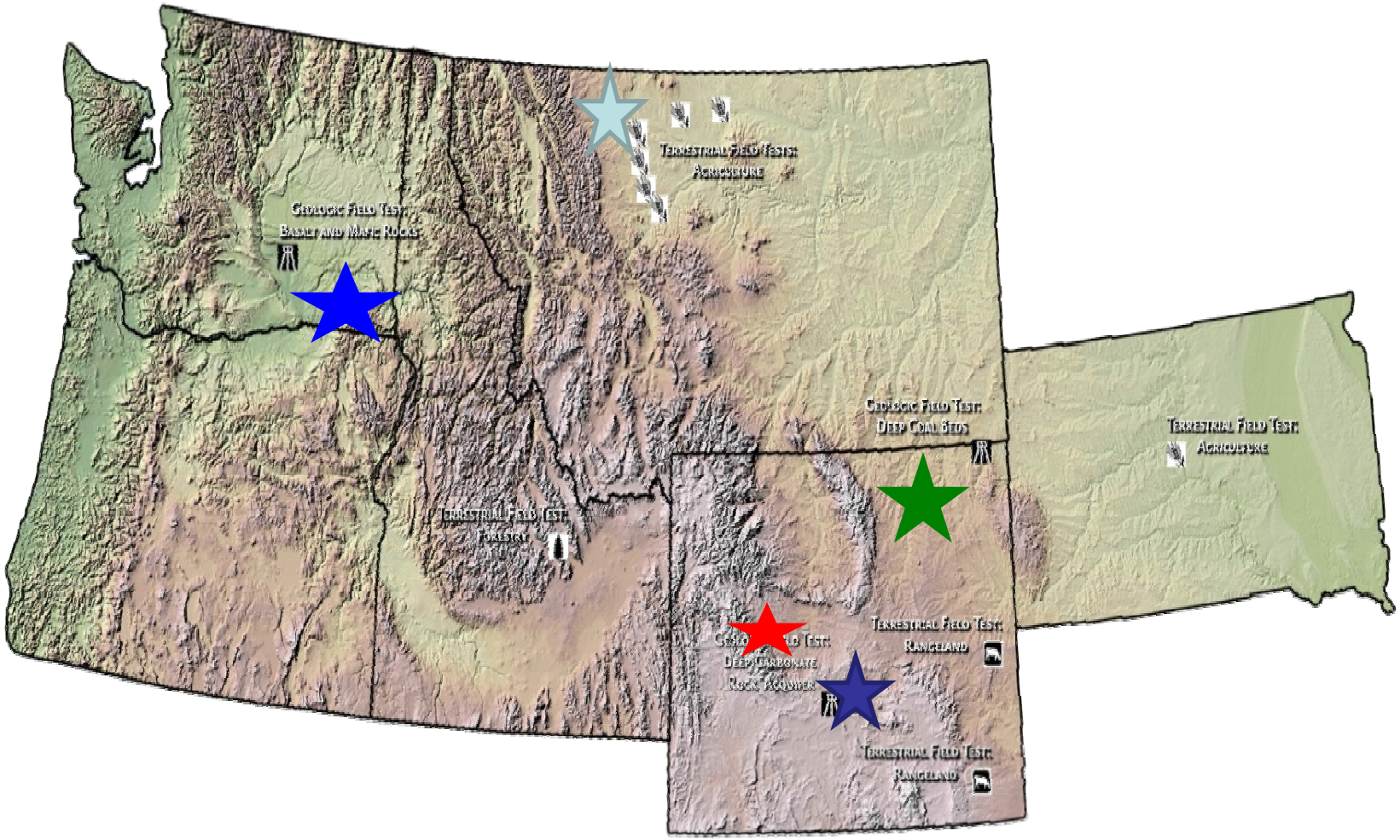
Geological Sequestration Efforts (technical lead: Bob Smith, UI)

Demonstration projects

- basalt/mafic pilot scale injection (form solid phase carbonates) – WA
- carbonate aquifer assessment (develop carbonate alkalinity) – WY
- deep saline aquifer pilot injection – WY
- Kevin Dome characterization study – MT
- deep coal bed exchange (separate and sequester from flue gasses)

- Transfer results to the Nation
  - national mafic/basalt atlas

Geologic Field Activities



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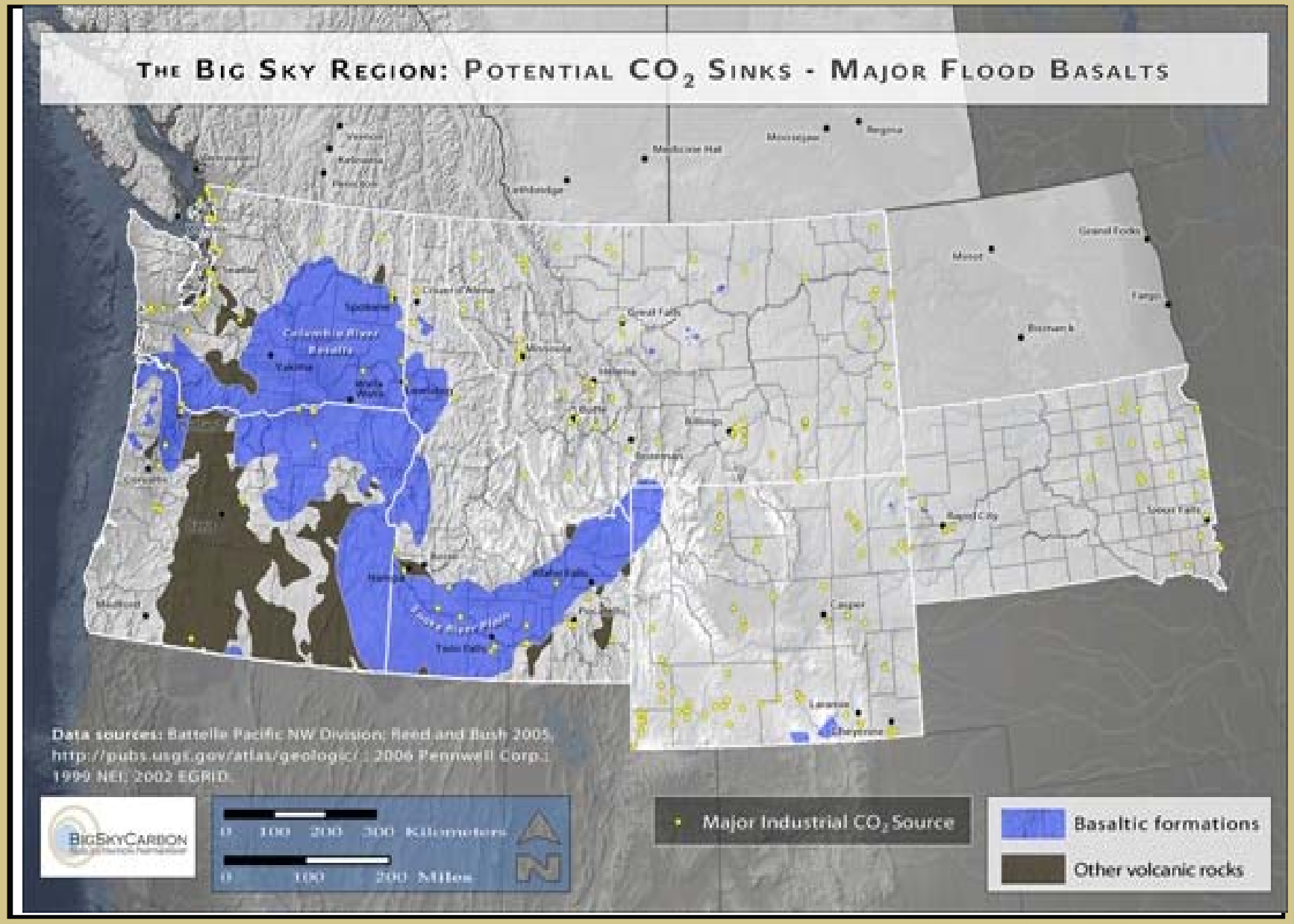

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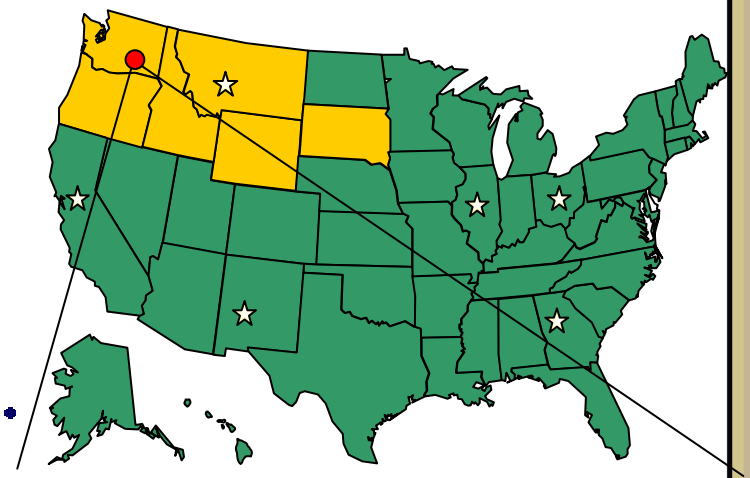
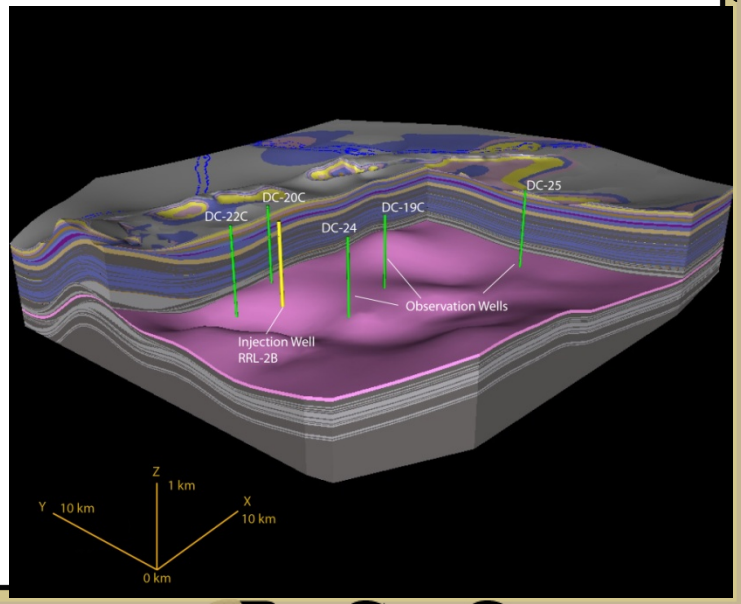
Basalt and Mafic Rock Field Validation Test

- 3000 MT of CO_2 transported by rail from refinery
- Utilize well to be drilled by industry partner in Phase III
- Target is Grande Ronde basalt formation (1,100 m depth)
- Post injection core sampling to verify mineralization reactions
- **Status:**
  - **NEPA CX application prepared for submission**
  - **Seismic site characterization to be completed 12/07**
  - **MMV plan complete**
  - **Will submit Class V injection well application in Q3 of 07**
  - **Injection to occur Q1 of 09**





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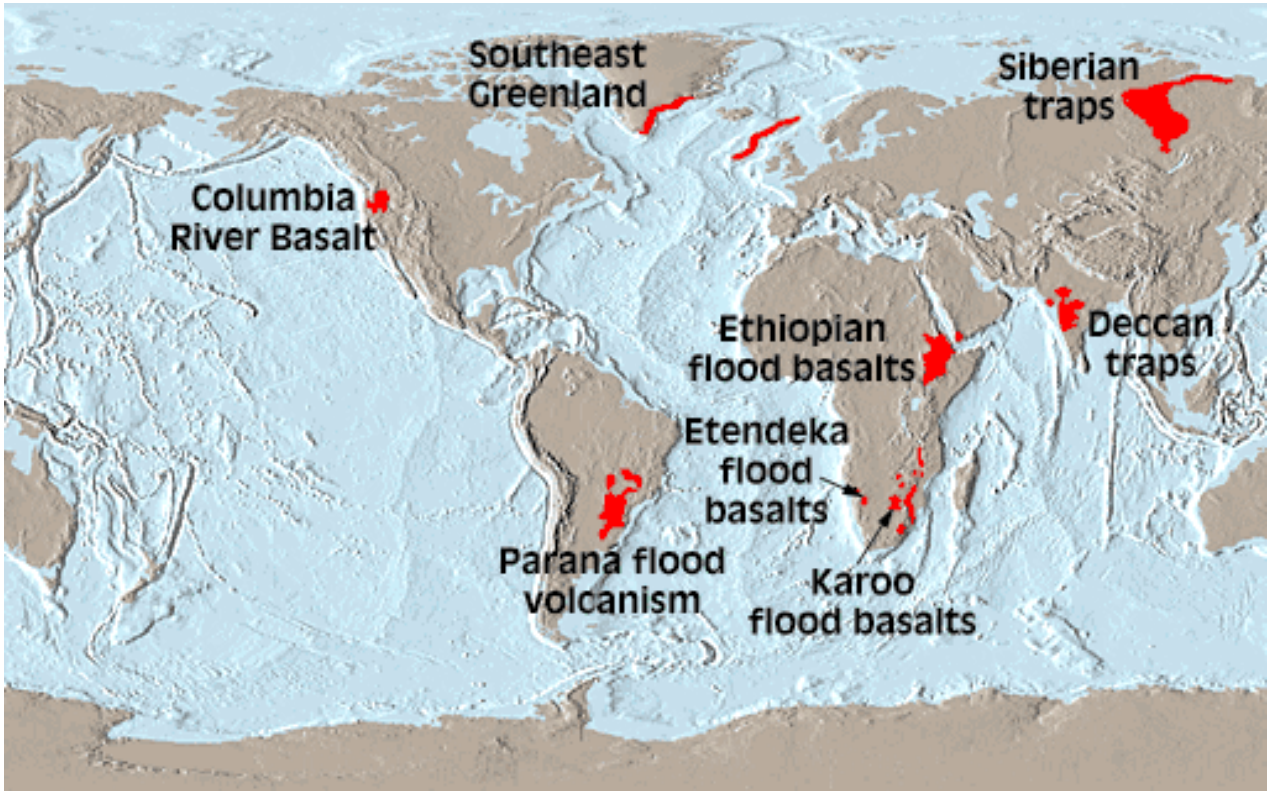
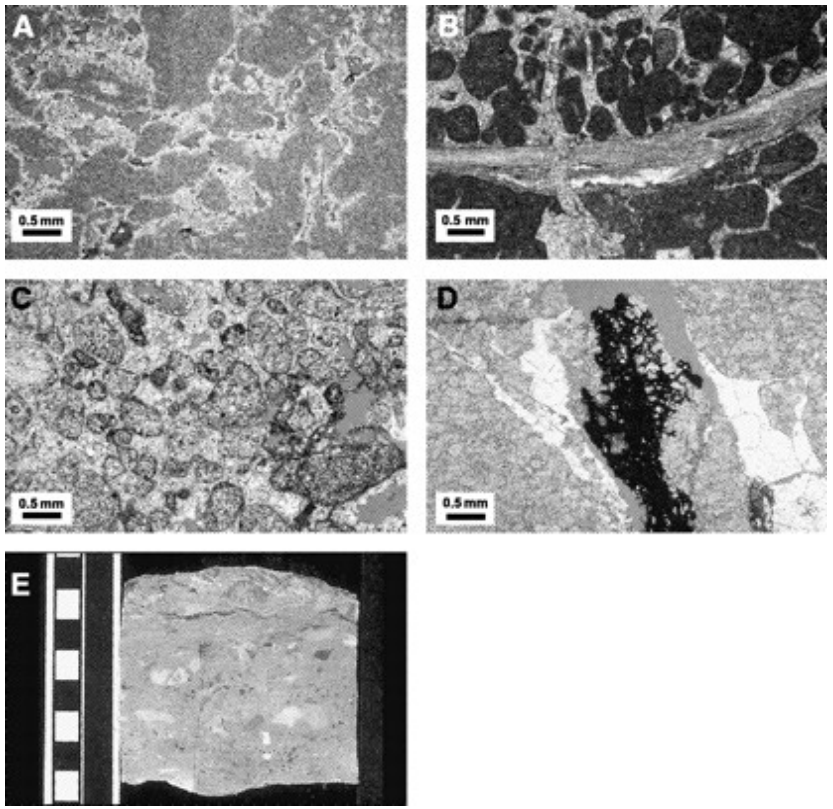
Conclusions: Sequestration in Basalts

- Large basalts provinces globally distributed: Five largest basalt provinces could sequester 10,000 years of world CO_2 emissions
- Economic opportunity costs of using basalts are minimal
- Conducive mineralogy for sequestration
- Rapid conversion of CO_2 to carbonate
- High porosity and permeability
- Big question: how does this compare to costs of other sequestration and mitigation options – relates to economic component of Partnership

Flood basalts cover more than 1 Million km^2 of the earth surface

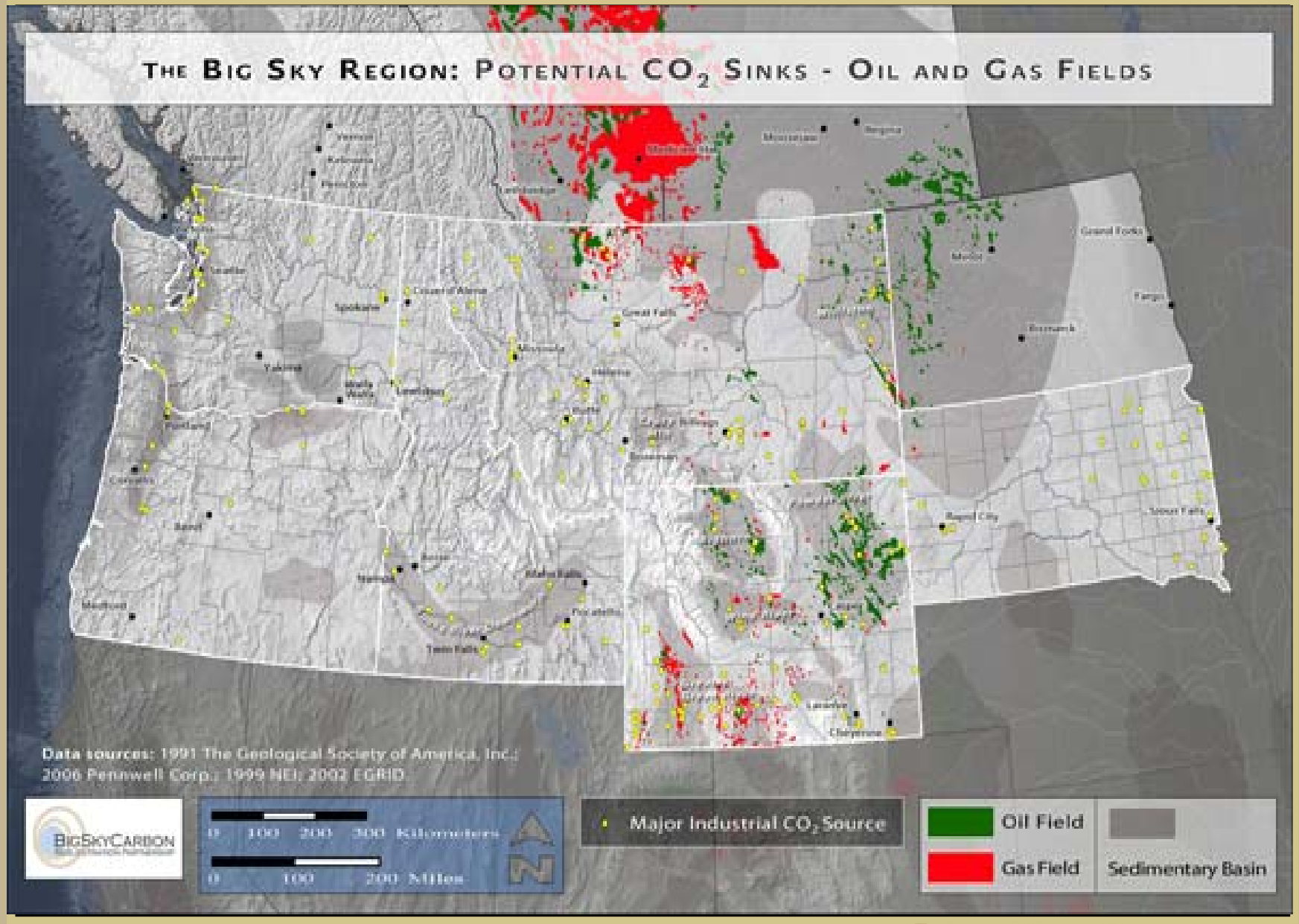


Reactive Carbonate Reservoir (Madison Formation) Field Validation Test



- The Madison Formation, a reactive carbonate reservoir, has regions that have been exposed to CO2 for millions of years in a naturally occurring gas reservoir
- Madison Formation: EOR operation for >20 years
- The objective of this field validation test is to determine changes in rock properties resulting from CO2 exposure and to conduct a geologic structural analysis that could provide the foundation for a Phase III demonstration to evaluate MMV performance.

- Update: EOR opportunities in the Region
  - High oil/gas prices make EOR attractive – (Gov offices in MT and WY)
  - Sources of CO2? IGCC?
    - Existing sources are anthropogenic (LaBarge Cr Plant – 240 MMcfd)
  - Infrastructure to deliver CO2 from existing and future point sources ($900k/mi pipeline cost)



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Proposed Wyoming Phase II Pilot

- **Objective:** Assess the viability and capacity of deep saline formation as a large-scale sequestration option
  - Inject 3000 tons of supercritical CO_2 into the target
- **Technical objectives**
  - Evaluate local and adjacent reservoir response to injection of supercritical CO_2
  - Track the migration and containment of the CO_2 and compare to modeling
  - Evaluate the rate of CO_2 sequestration and compare to laboratory predictions

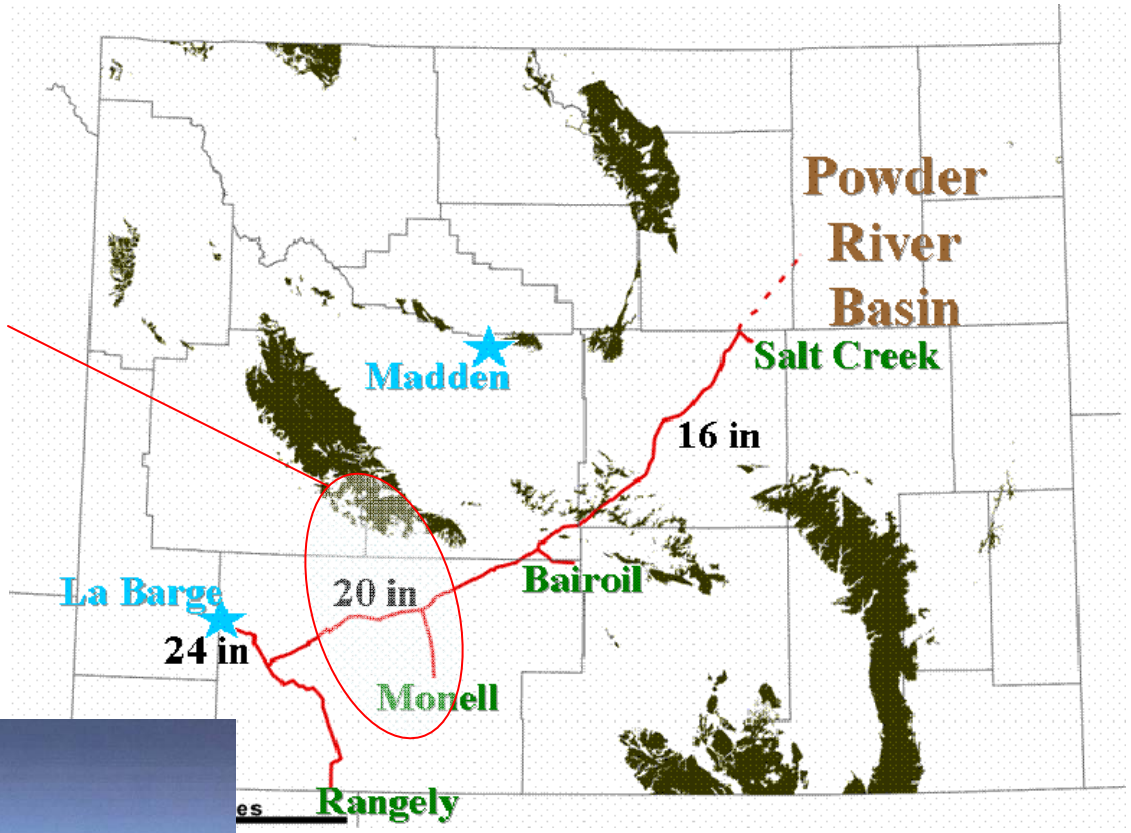
Wyoming Phase II Pilot site

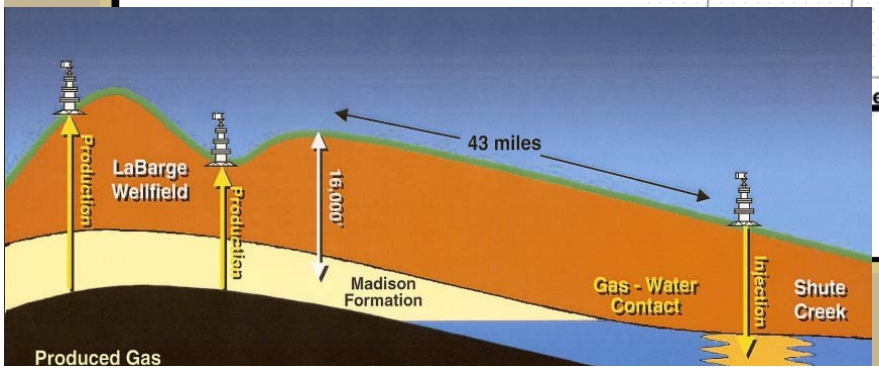
LaBarge Platform Location Map and CO2 Pipeline Infrastructure

Southwest Wyoming
Moxa Arch Structure

Large regional anticline
170 TCF of gas in Madison formation

Mostly CO_2, with some H_2S, CH_4 and He





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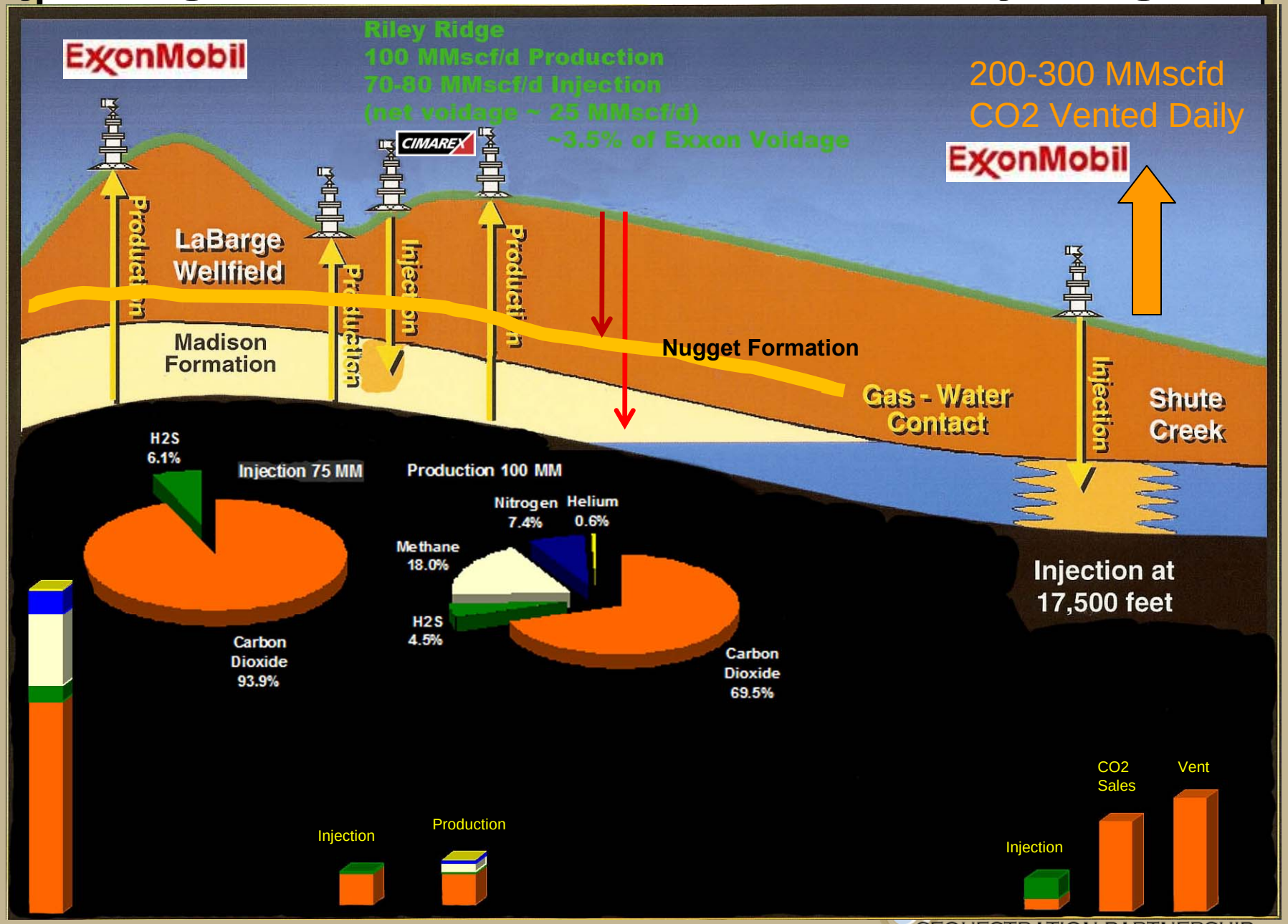
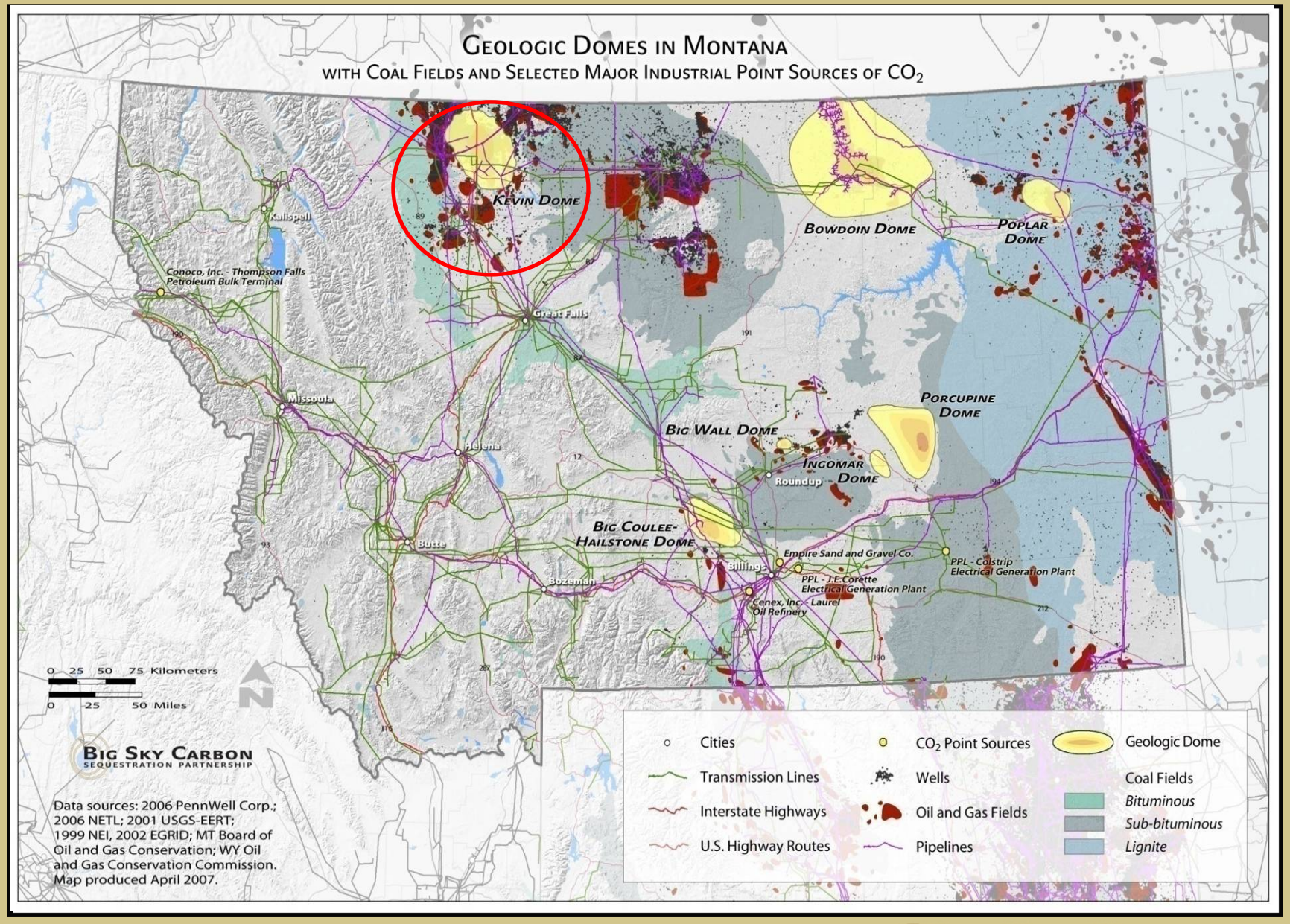
Wyoming Phase II Schematic – With Riley Ridge POD



Proposed Montana Study at Kevin Dome

- **Objective:** Assess the viability and capacity of a deep saline formation located within a geologic dome as a large-scale geologic sequestration and storage option
  - Evaluate the efficacy of EOR using produced and stored CO_2 from the dome.
  - Characterize Kevin Dome's potential as a temporary storage site for CO
- **Technical objectives:**
  - Detailed subsurface geological characterization
  - Determine volume of natural CO2 in dome and potential volume for CO2 seq.
  - Regionally characterize other large-scale domes
  - Evaluate the potential for expanded EOR efforts

Kevin Dome Location



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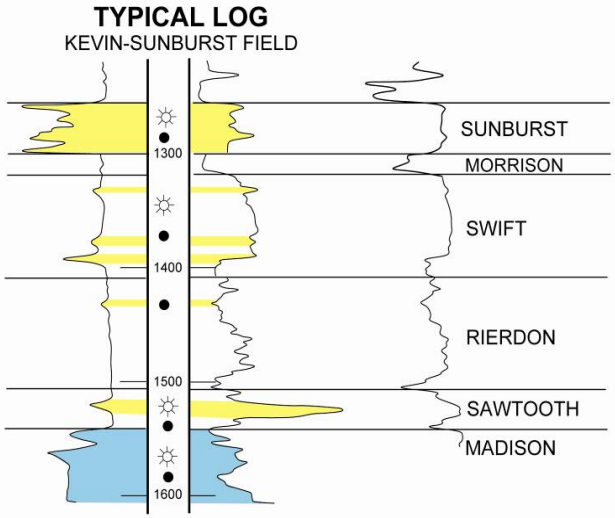
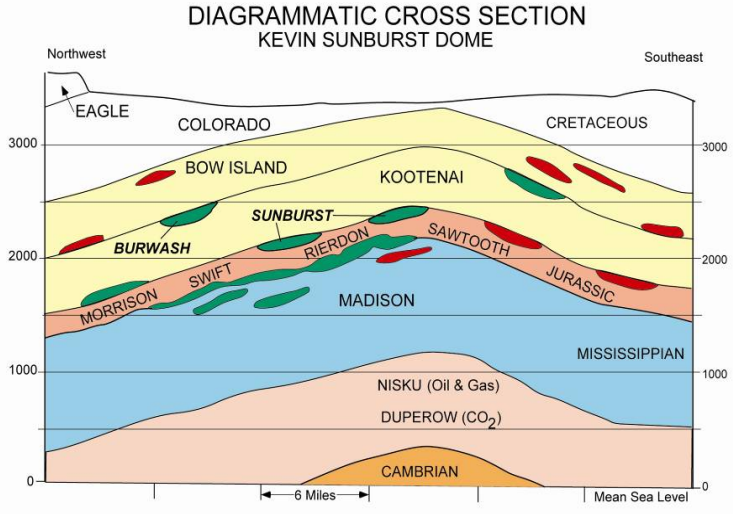
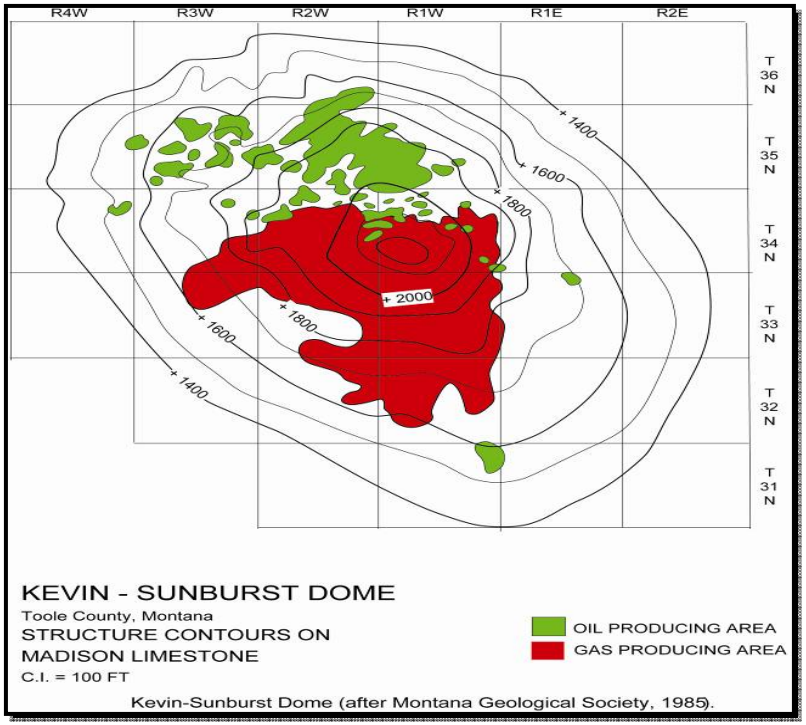
Kevin Dome Project





Typical log, Kevin-Sunburst Field and diagrammatic cross-section. Shows both the Karst-related (Madison) distribution of sandstone reservoirs and development of channel-related (Cretaceous) sandstone horizons (from Montana Geological Society, 1985).

- Evaluate potential to inject in Duperow (dolomite) off flank of dome below the CO_2 gas water contact
- Conduct petrographic analysis of exposed dolomites to supplement seismic data
- Allows simultaneous study of natural analog



Kevin-Sunburst Dome (after Montana Geological Society, 1985).

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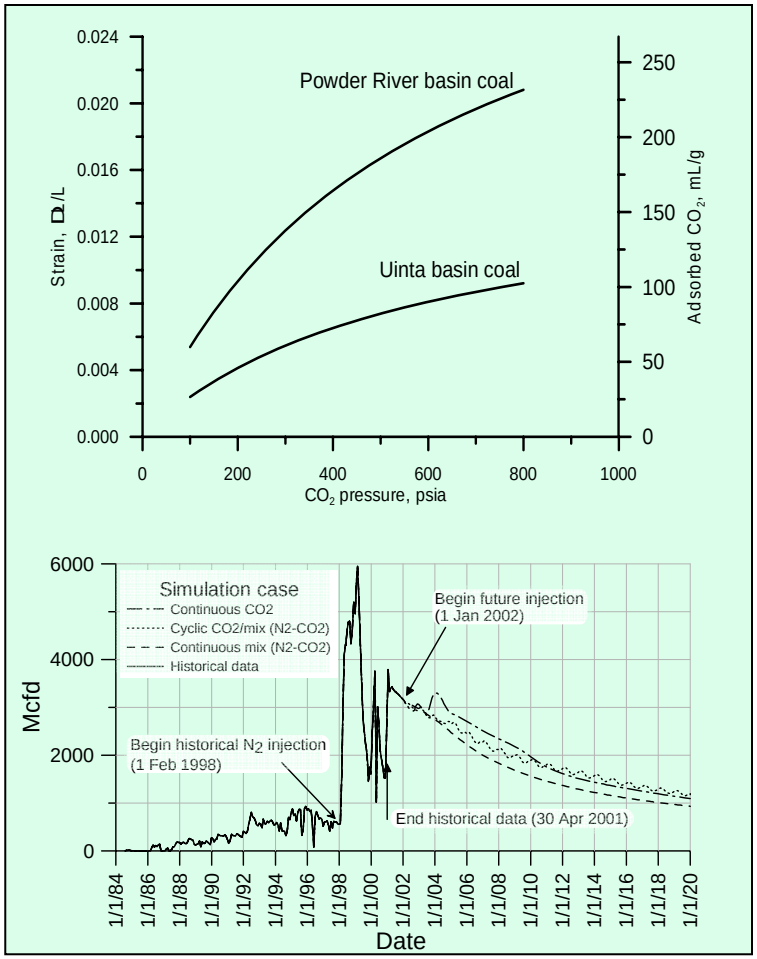
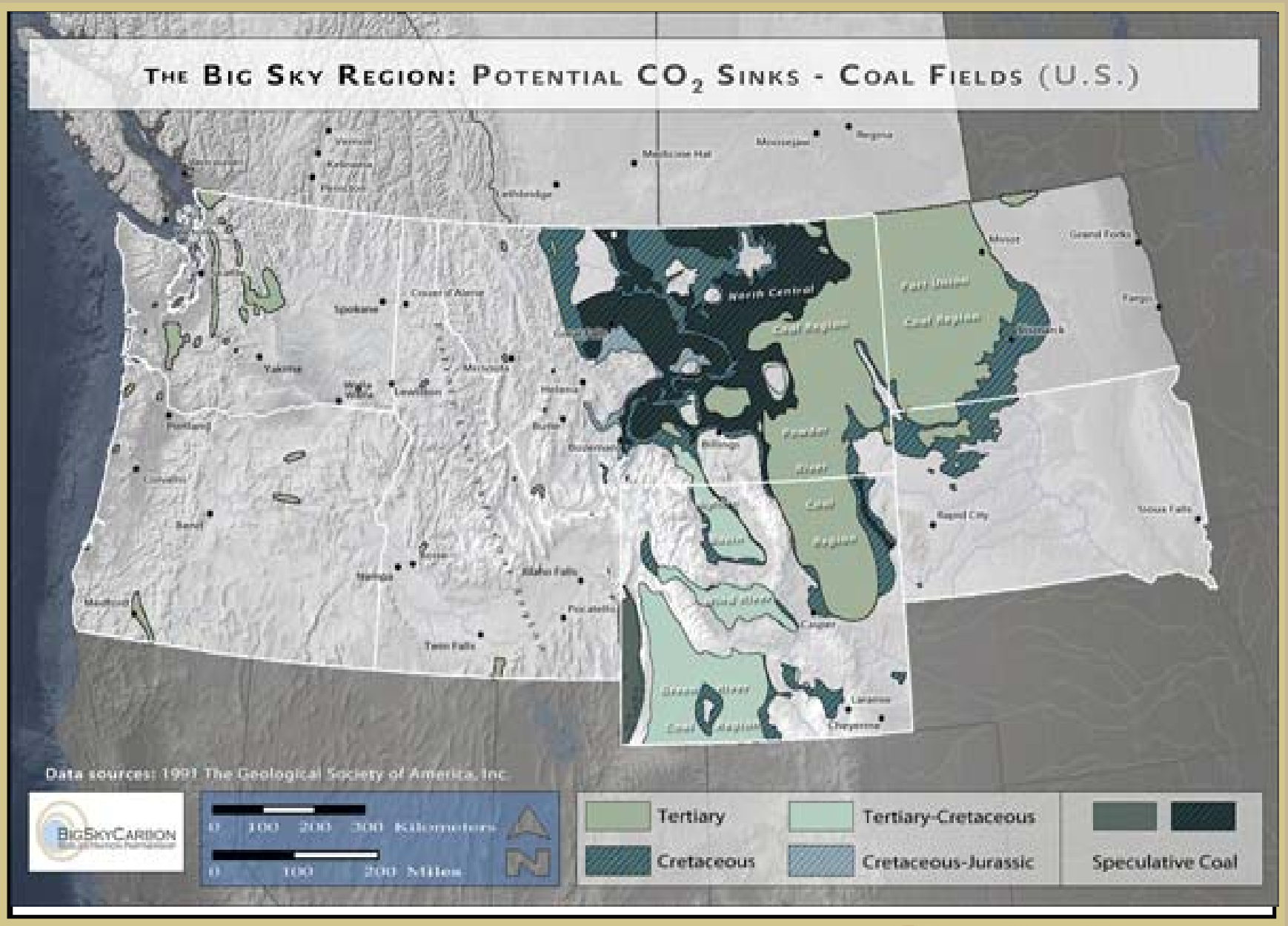
Pilot Design: Enhanced Coal Bed Sequestration (collaboration with SW)

- Recent work shows Powder River basin coals can adsorb twice as much CO_2 as Uinta basin coals
- Study various gas injection strategies
  - Economic evaluation
  - Reservoir simulation
- Attention will be given to impact of coal swelling on permeability changes
- Planned pilot in Phase III





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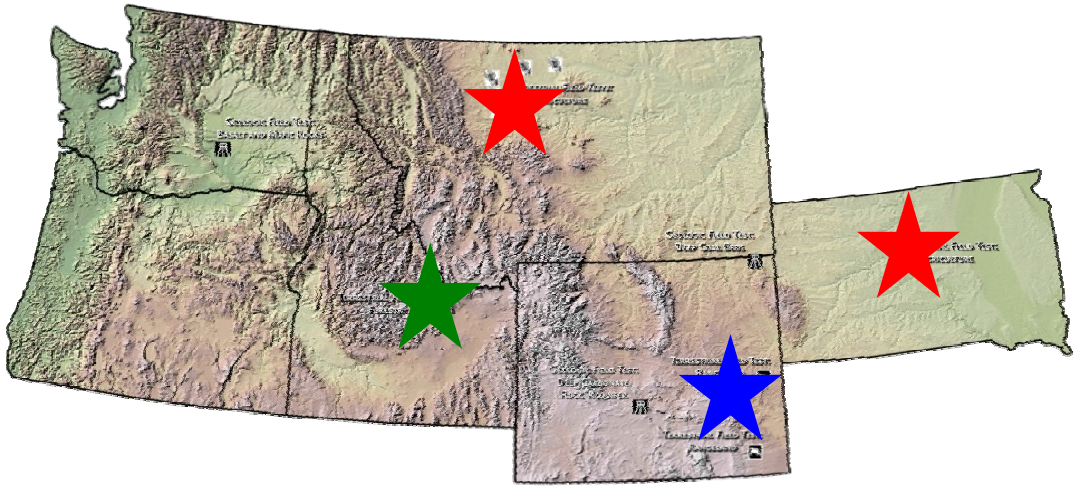
Terrestrial Sequestration Efforts

(technical lead: Dave Brown, MSU/WSU)

- Carbon Markets
  - Market-based storage and verification protocols
  - Design carbon portfolios in conjunction with industry, tribal members, and landowners
- Terrestrial Pilots
  - Agriculture
  - Forestland
  - Rangeland



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Terrestrial Sequestration Efforts status

- Market–based storage and verification protocols:
  - submitted materials to NATSOURCE via CCX, (later presentation)
  - design carbon portfolios in conjunction with industry, tribal members, and landowners
  - Develop portfolios for carbon markets

- Terrestrial Pilots and Activities:
  - Cropland: continuing to enroll producers' lands
  - Forestland: starts up in Year 3
  - rangeland field test sites
  - Design plans for cropland and rangeland field test sites have been submitted – focusing on cost effective MMV for eventual carbon markets

Carbon Market Explorations - Overview

- **Development of Carbon Market Portfolios**
  - Establish enlistment criteria
    - Sequestration potential of different cropping, tilling and grazing practices
  - Create contracting documents and work w/potential buyers
    - Document enrollment, verification, and transaction costs
- **C-Lock and Terrestrial Carbon Credits**
  - Goal: reduce overall transaction costs for carbon trades
  - Evaluate results of other carbon-based models and user acceptance of the graphical user interface for encouraging landowner participation in establishment of carbon markets

Monitoring and Verification of Carbon in Croplands, Rangelands and Forests

Objectives

- Quantify and determine management practices to optimize C sequestration
- Develop MMV protocols that can establish sequestration rates for different management practices
- Develop MMV protocols that reduce verification costs

Activities

Soil Sampling and calibration
MMV methodologies
Planning Handbook

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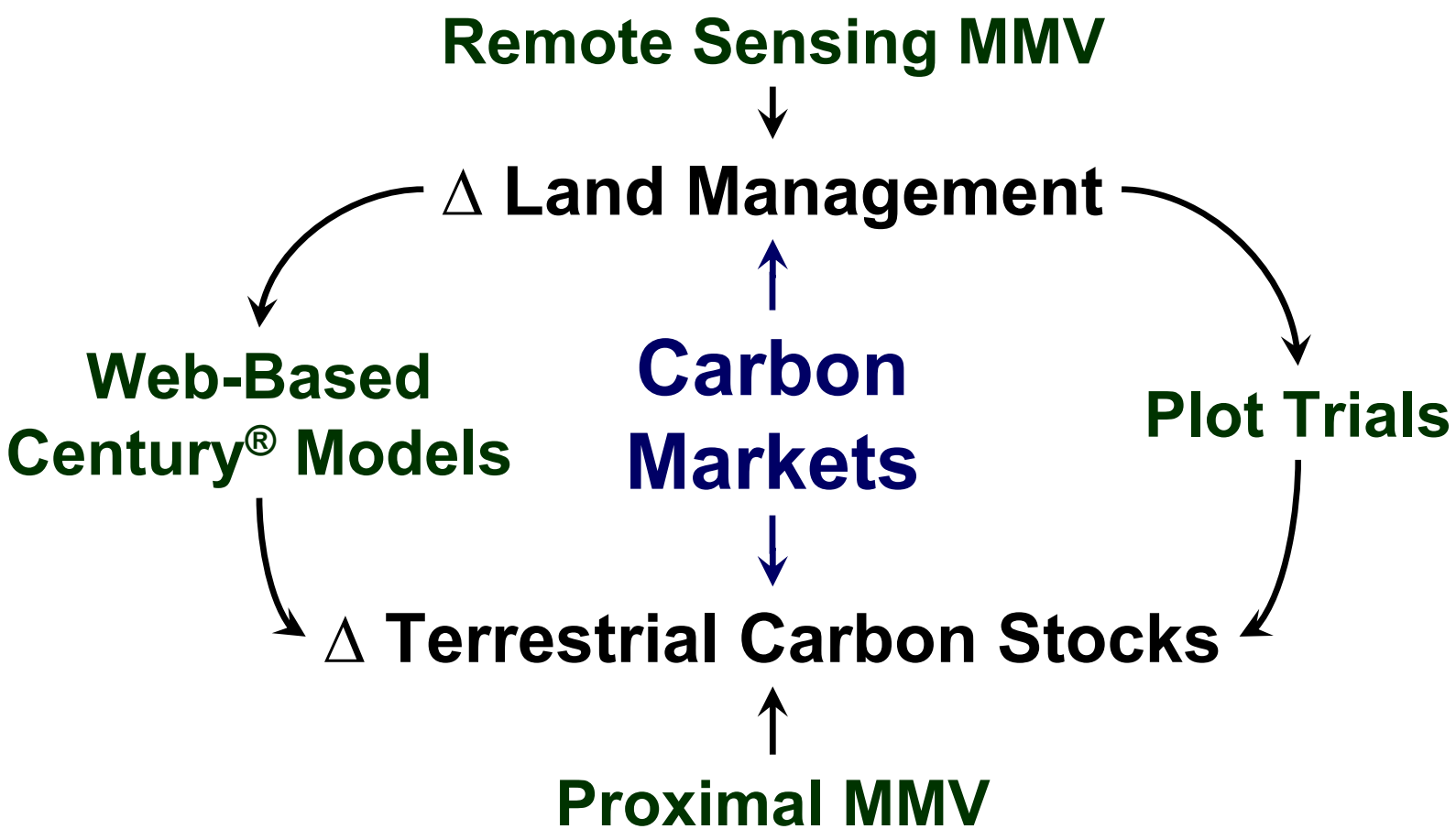
Terrestrial Carbon Sequestration MMV



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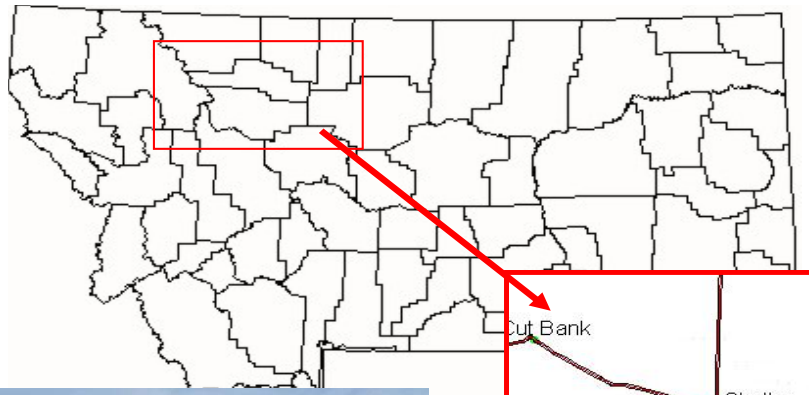
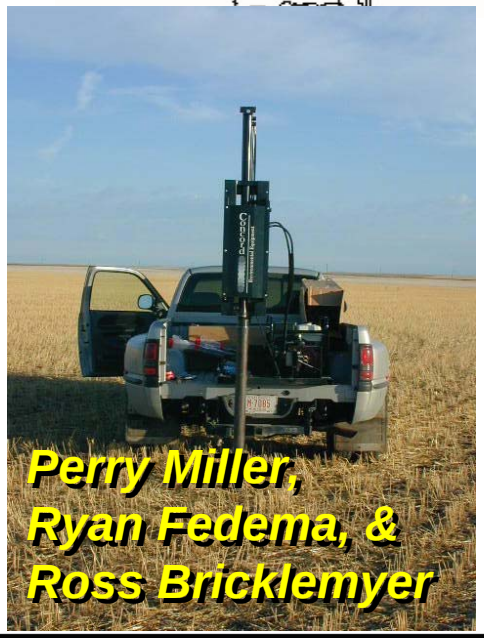
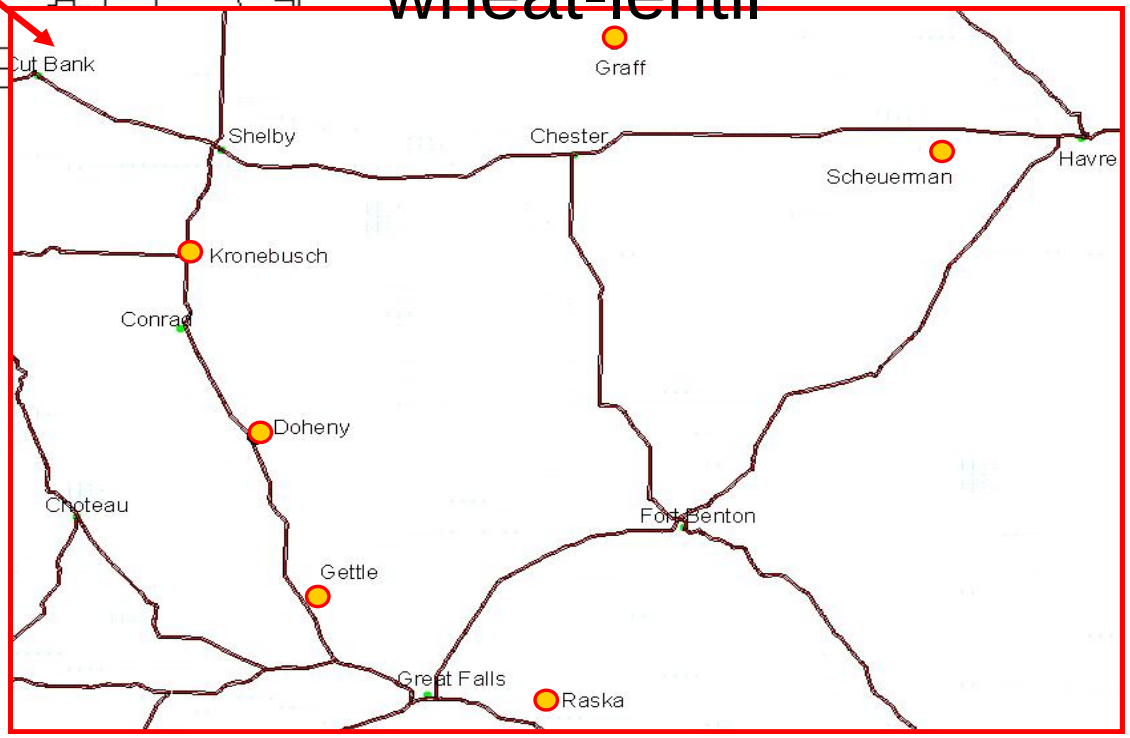
Cropland Controlled Test Sites

Treatments:

- Till vs. no-till
- Wheat-fallow vs. wheat-lentil







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Grazing Treatments

120 day grazing season (mid-June to mid-October) with 250 kg yearling steers.

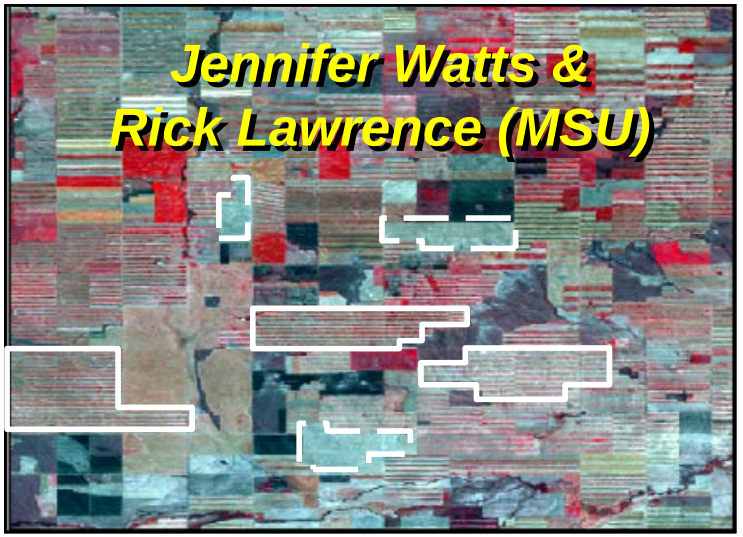
CL: Continuous light (5 steers/41 ha)
CH: Continuous heavy (5 steers/9 ha)
EX: Exclosure, no grazing by livestock

Grazing Intensity Study

- Initiated in 1982
  - Northern mixed-grass prairie
- SOC determined in 1993, 2003 and 2006
  - 50 m permanent transects, 10 m intervals
  - soil samples taken to a 60 cm depth
- Assess the effects of grazing strategies (2007)
  - SOC
  - plant community
  - animal performance

Remote Sensing MMV Objectives

- Map management practices in north central Montana
  - Tillage vs. no-till
  - Crop types & rotations
  - CRP



- Quantify adoption trends
  - Voluntary adoption trends for no-till
  - Current proportion of agriculture in alternative rotations

Pedometrics – soil variability

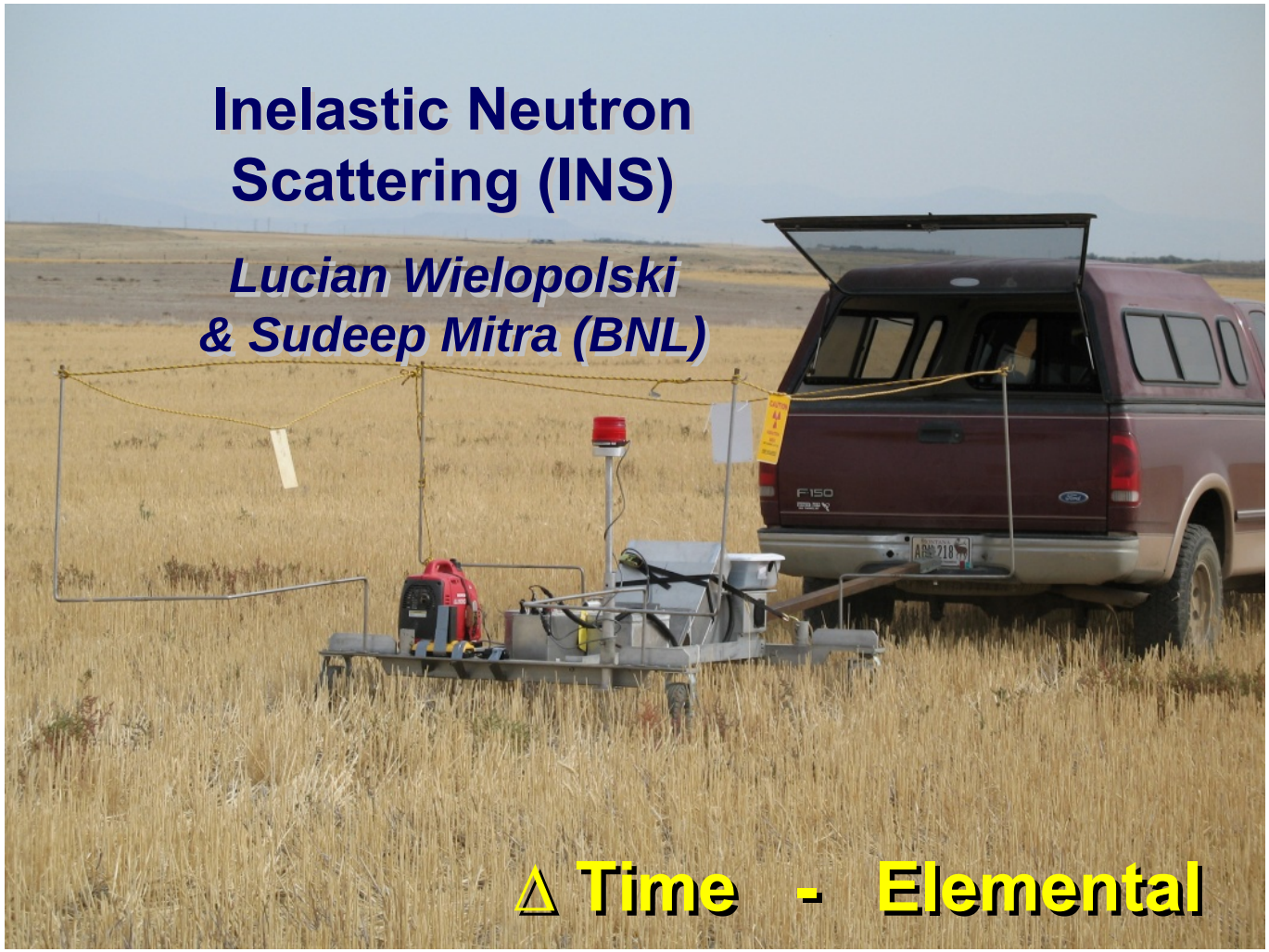
“On the Fly”
VisNIR spectroscopy

Colin Christy
Veris Technologies

Mapping soil variability
for
efficient core acquisition

- 9 fields scanned
- SOC/SIC completed (surface)

VisNIR + INS, *complementary*



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Monitoring and verification of carbon in croplands, rangelands and forests

Conclusions

- Preliminary data suggest detectable differences of rates of carbon sequestration for different management practices

- Manifestation of sequestration rates occurs several years after adoption of new management practices

- Carbon sequestration rates on grazing lands are heavily influenced by changes in plant community composition

- In-situ MMV and remote sensing MMV offer cost-effective alternatives to monitoring land management practices and standard soil sampling techniques to determine soil organic carbon

Economic Feasibility Modeling and Analysis

Objectives

•Establish economic model framework for geologic sequestration that incorporates the relationship between source and sink and sequestration practices (e.g. EOR, ECBM, etc)

•Conduct an economic analysis of geologic sequestration potential for different geologic systems including basalts, saline formations, and unmineable coal beds.

•Establish economic model framework and analysis for terrestrial sequestration of cropping, tilling and grazing practices.

•Prepare a report that assesses the total costs of large scale deployment of CCS.

Economic Framework for Geologic Sequestration

- Five major options
  - Enhanced oil recovery (EOR)
  - Enhanced coalbed methane recovery (ECBM)
  - Depleted oil and gas reservoir storage
  - Deep saline aquifer storage
  - Mineralization in mafic rock

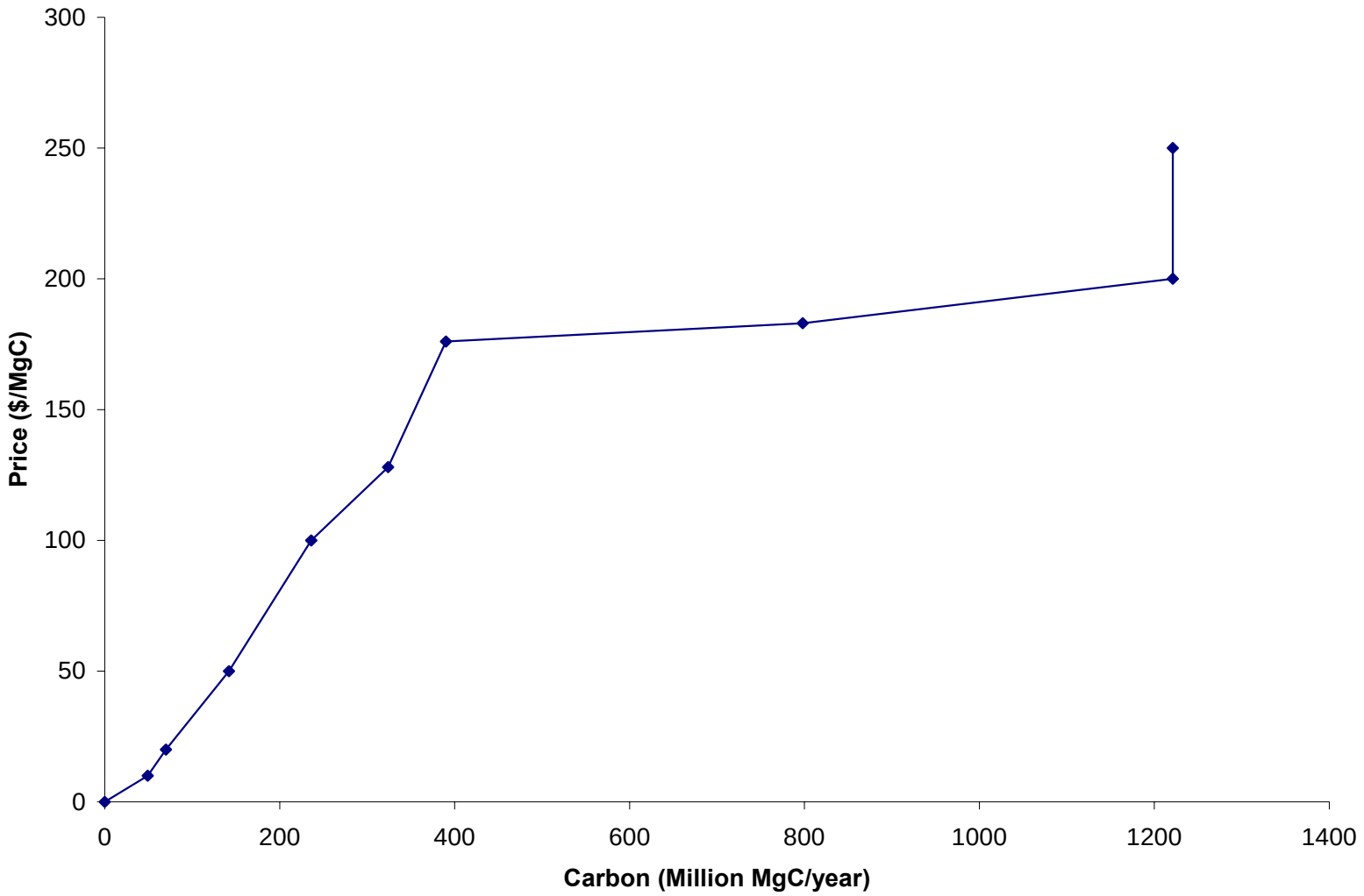
Geologic Economic Modeling Strategy

- Identify main regional sources and sinks
- Quantify quantities and costs
  - Capture for electric power plants
  - Transport from source to sink
  - Injection
- Integrate to obtain feasible C sequestration

Terrestrial Economic Modeling Strategy

- Crop Soils: Regional estimates available from prior work
- Forestry: OSU team has adapted national model to BSCSP region, will provide regional estimates of potential sequestration
- Rangelands: review of literature completed, preliminary estimates made based on “minimum-data” procedures

Preliminary Results: US C Supply Curve



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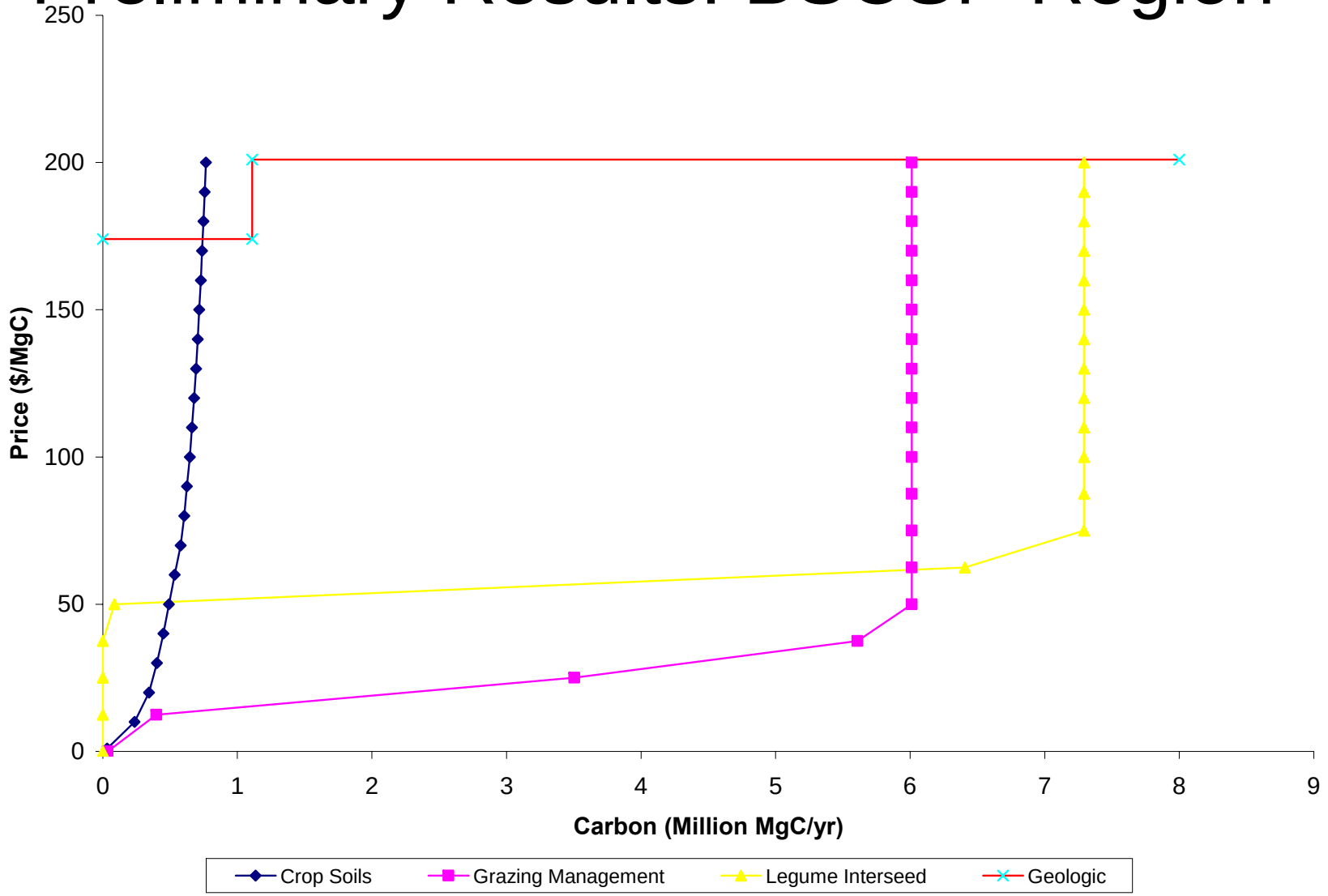
Preliminary Results: BSCSP Region



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Regulatory Compliance Overview

BSCSP will prepare and file all regulatory permits required for its field validation tests. **Accomplishments include:**

- A report of sequestration regulatory issues was created by the Big Sky regulatory team and placed on the Partnership website (www.bigskyco2.org).
- The Partnership has developed a Regulatory and Public Involvement Action Plan that outlines the various regulatory permitting requirements required for field validation tests and full-scale implementation projects.
- BSCSP is conducting a gap analysis on existing state and regulatory frameworks that identifies “gaps” within these frameworks that may limit available options for geologic sequestration.
- BSCSP is developing regulatory guidelines for future sequestration efforts

Public Outreach Objectives

- Inform and educate the public and stakeholders on carbon sequestration and the role of the Partnership
- Engage stakeholders to promote awareness and acceptance of the Partnership's goals and pilot projects
- Gain information and feedback from our partners and stakeholders to respond to environmental, safety and health concerns as they emerge
- Provide training and capacity building for students, educators, industry representatives and policy makers,
- Foster communication and representation among the general public, stakeholders, state and federal agencies and non-profit groups

Public Outreach Activities

- Annual Big Sky Energy Forum
- State Legislative Carbon Sequestration Symposia
- General Outreach – material and events
- Web Site and multi-media
- Surveys
- RECS program
- Press releases
- Newsletters

Big Sky Carbon Atlas - Accomplishments

- 11 new regional, 5 localized maps and 295 capacity maps added to **Map Gallery**
- Development of customized **Interactive Map**
- Data sources for current maps reviewed and referenced
- 7 pages of regional maps/technical graphics provided to NETL for the *Carbon Sequestration Atlas of the U.S. and Canada*
- Spatial data feed contributing to Natcarb's *National Carbon Explorer*
- Online account of GIS efforts reviewed, updated, and transferred

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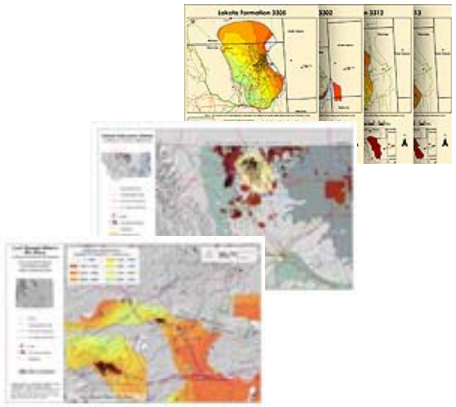
Big Sky Carbon Atlas

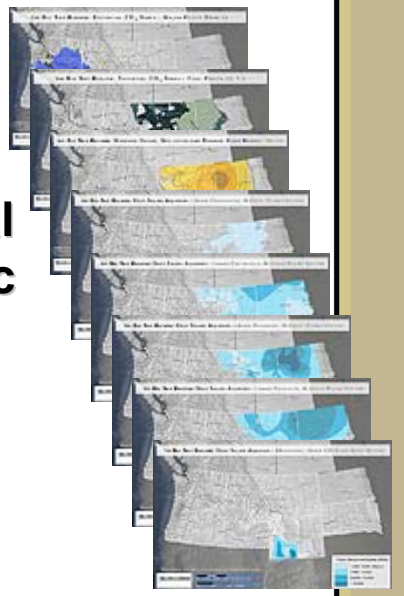
Map Gallery

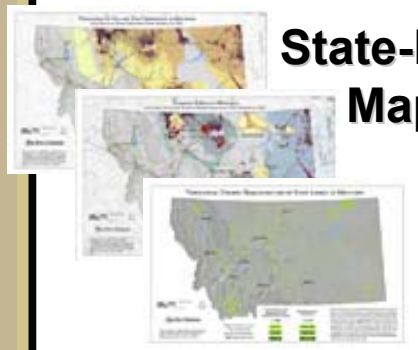
General Reference

Project-Level Maps



Potential Geologic Sinks



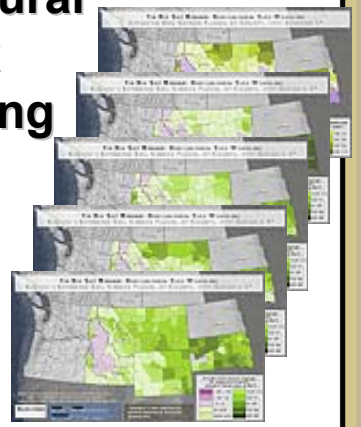


State-Level Maps

Civic and Energy Infrastructure

CO_2 Emissions and Energy Demand

Agricultural Sink Modeling



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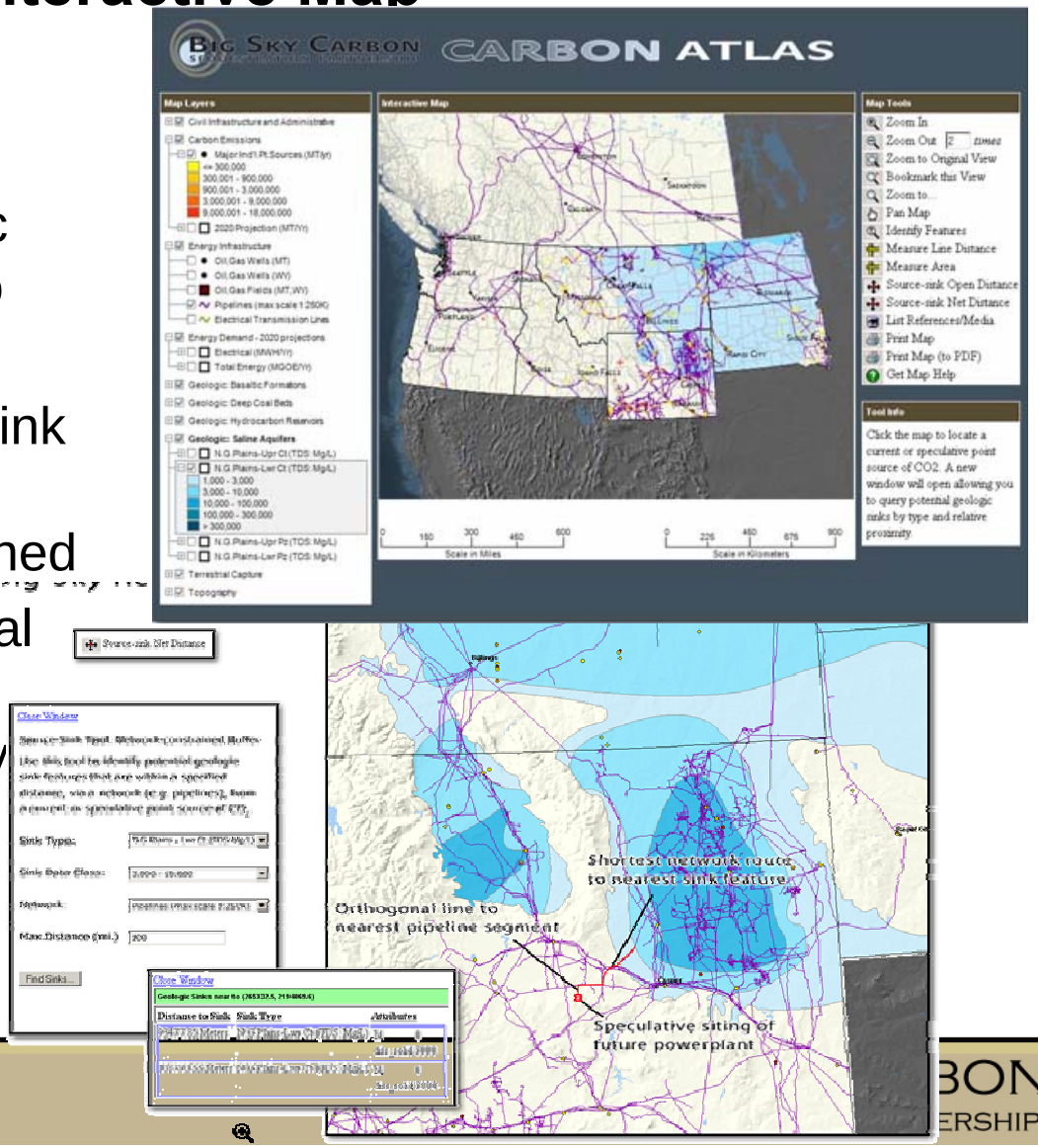
Big Sky Carbon Atlas

Interactive Map

- Custom query tools for locating potential geologic sink features proximate to CO_2 point source(s)
- Calculation of source-to-sink distances – “as the crow flies”, or network-constrained
- Tool for retrieving technical references for areas of interest (e.g., sedimentary basins)
- Data download tool



Connecting Sources, Sinks and Siting

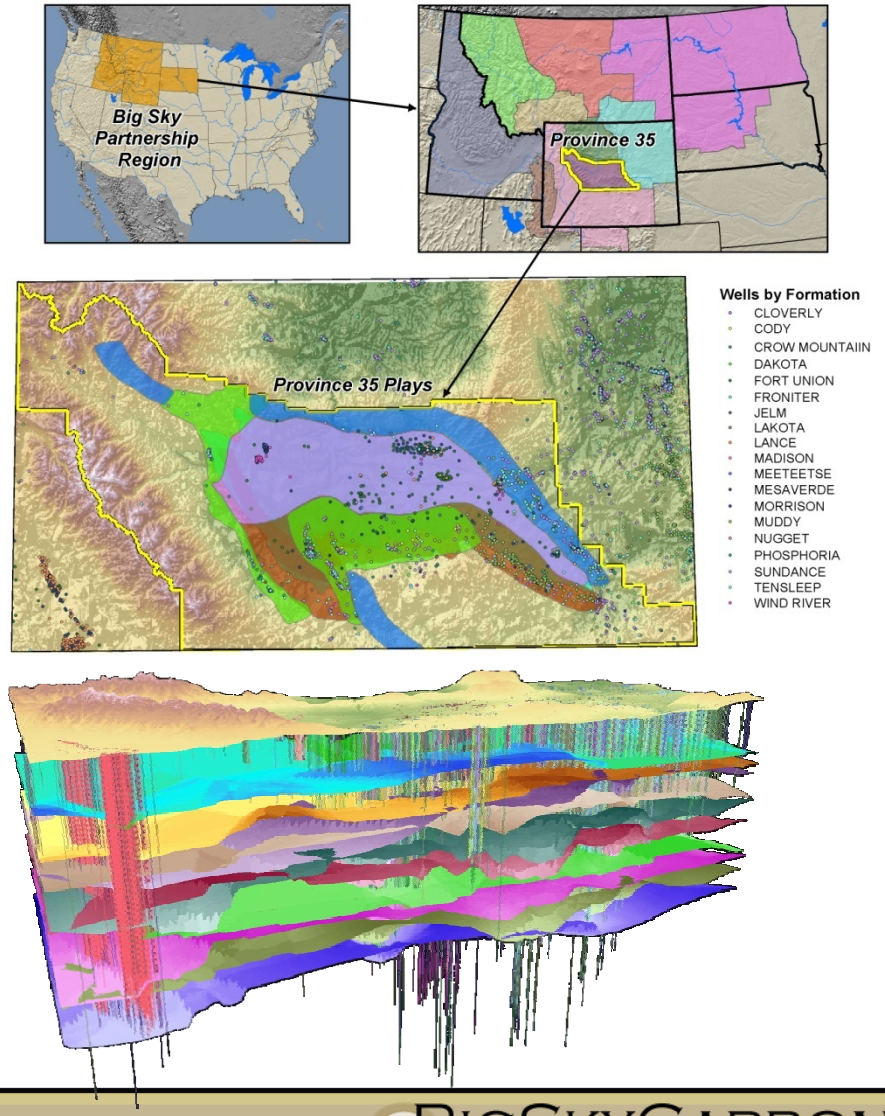
- **The relationship between energy sources and energy demand**
- **Fossil energy sources may not be proximal to potential sinks or transportation and transmission infrastructure**
- **Existing CO2 transportation infrastructure is limited to EOR pipelines and nominal rail and truck capacity**

Sources and Sinks

- Building the Carbon Atlas
  - Sources and Sinks Identification and Characterization
  - National Mafic Rock Atlas
  - Site Specific Characterizations
  - Base Data/Infrastructure
  - Terrestrial and Economic Data Layers

Building the Geological Carbon Atlas

- Compiled data from 117,304 active wells in WY and MT
- Developed GIS model to calculate sequestration volumes (based on depth, temperature, pressure, density, and thickness)
- Characterized sequestration volumes for 283 formations in 57 plays



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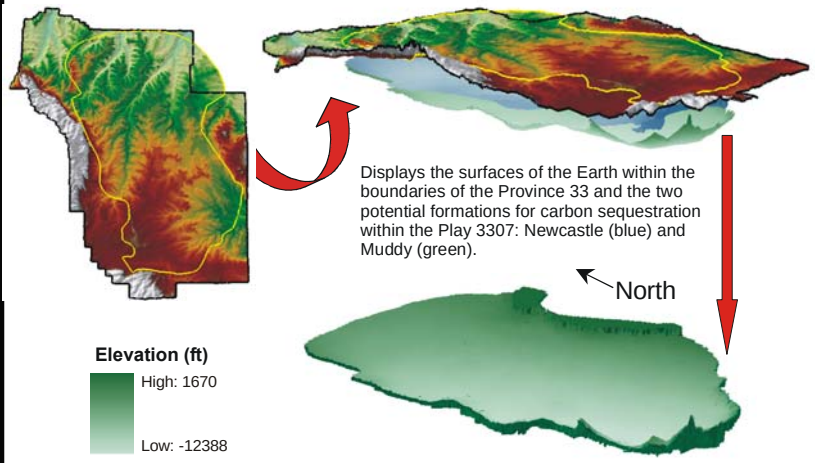
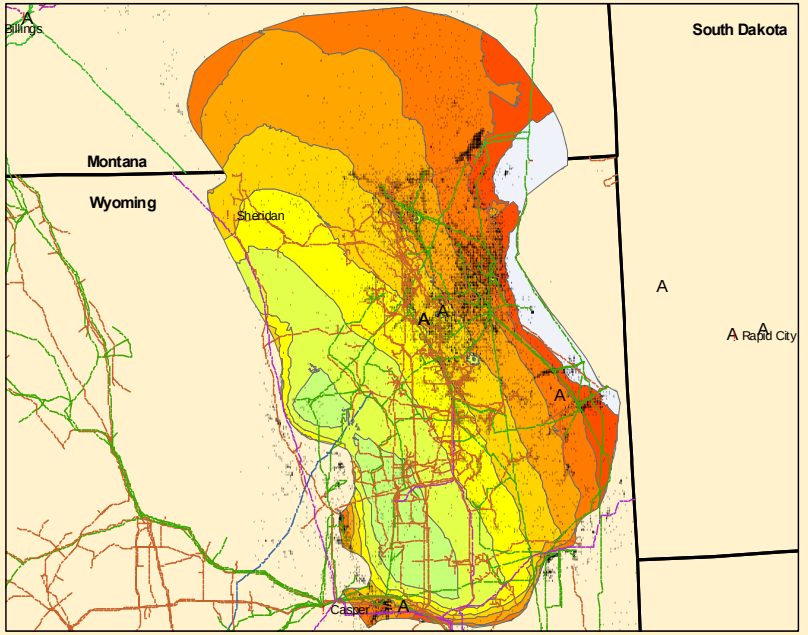
Developed maps of each formation within all plays



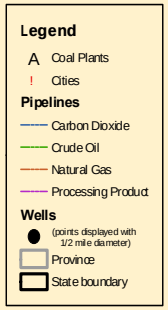
Displays the surfaces of the Earth within the boundaries of the Province 33 and the two potential formations for carbon sequestration within the Play 3307: Newcastle (blue) and Muddy (green).

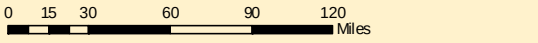
The surface and thickness of the Muddy Sandstone as interpolated from well data.

Muddy Sandstone 3307

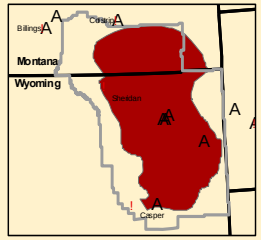


Note: All depths and sequestration volumes are based on wells within Wyoming and Montana only.





Depth (m)	Cost ($)	Volume (MMT)
0 - 800		0.00
800 - 1300	251,234	133.37
1300 - 1800	374,798	510.10
1800 - 2300	559,133	681.98
2300 - 2800	834,128	393.17
2800 - 3300	1,244,372	339.51
3300 - 3800	1,856,386	262.73
3800 - 4300	2,769,402	105.40



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SEQUESTRATION PARTNERSHIP

Connecting Sources, Sinks and Sites

- Legal Issues
- Regulatory Issues
- Policy Issues
- Environmental Issues
- Economic Issues
- Risk Issues
- Uncertainty

Legal Issues

- Eminent domain – ROW for non commodity pipelines, injection fields, transmission lines, etc
- Who owns the pore space?
- Ownership of CO2 for non-EOR sequestration
- Economic discrimination or principles of prior appropriation
- Institutional setting – international, national, state and local (11th amendment)

Regulatory Issues

- Primacy – international or national; federal or state
- Administrative discretion in the absence of legislative action (UIC, *Chevron v. US)*
- Administrative oversight – is it a pollutant, or a commodity; is it an environmental problem, an energy problem, or an engineering problem?
- Regulatory streamlining for energy producers that incorporate CCS
- Regulatory certainty

Policy Issues

- Market oriented instruments vs coercive instruments (emission trading vs. carbon taxes
- Economic competitiveness (carbon tariffs or clean development mechanisms)
- Human risk policies
- Environmental risk policies
- Energy independence

Environmental Issues

- Long term persistence of sequestration (leakage, contamination of aquifers, catastrophic failures)
- Increased reliance on fossil fuels and subsequent environmental degradation
- Environmental impacts of transportation and sequestration infrastructure
- Long term impacts on saline aquifers, seismic events
- Lack of environmental analogs aside from nuclear and toxic wastes (Hanford, Rocky Flats)

Economic Issues

- Increased cost of CCS
- Comparable costs and reduced emissions resulting from renewable energy, improved efficiency, conservation policies,terrestrial sequestration, etc.
- Economic risk associated with deployment of new technologies and systems
- Who will bear the cost of CCS and who will benefit? Can the costs and benefits be equitably distributed?

Economic Issues

Power plant system	Natural Gas Combined Cycle (US$/kWh)	Pulverized Coal (US$/kWh)	Integrated Gasification Combined Cycle (US$/kWh)
Without capture (reference plant)	0.03 - 0.05	0.04 - 0.05	0.04 - 0.06
With capture and geological storage	0.04 - 0.08	0.06 - 0.10	0.05 - 0.09
With capture and EOR*	0.04 - 0.07	0.05 - 0.08	0.04 - 0.07

Risk

- Economic risks associated with investment in untried commercial scale technologies
- Long term storage
- Unintended consequences (aquifers, seismic events, catastrophic releases)
- “Silver bullet” syndrome
- The “garbage can” model – solutions in search of a problem to attach themselves to

Uncertainty

- International and national policies
- Climate change or climate periodicity
- Technological
- Liability
- Carbon markets
- Monitoring
- Scale

Questions?

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