PHASE I Summary & PHASE II Lead-in

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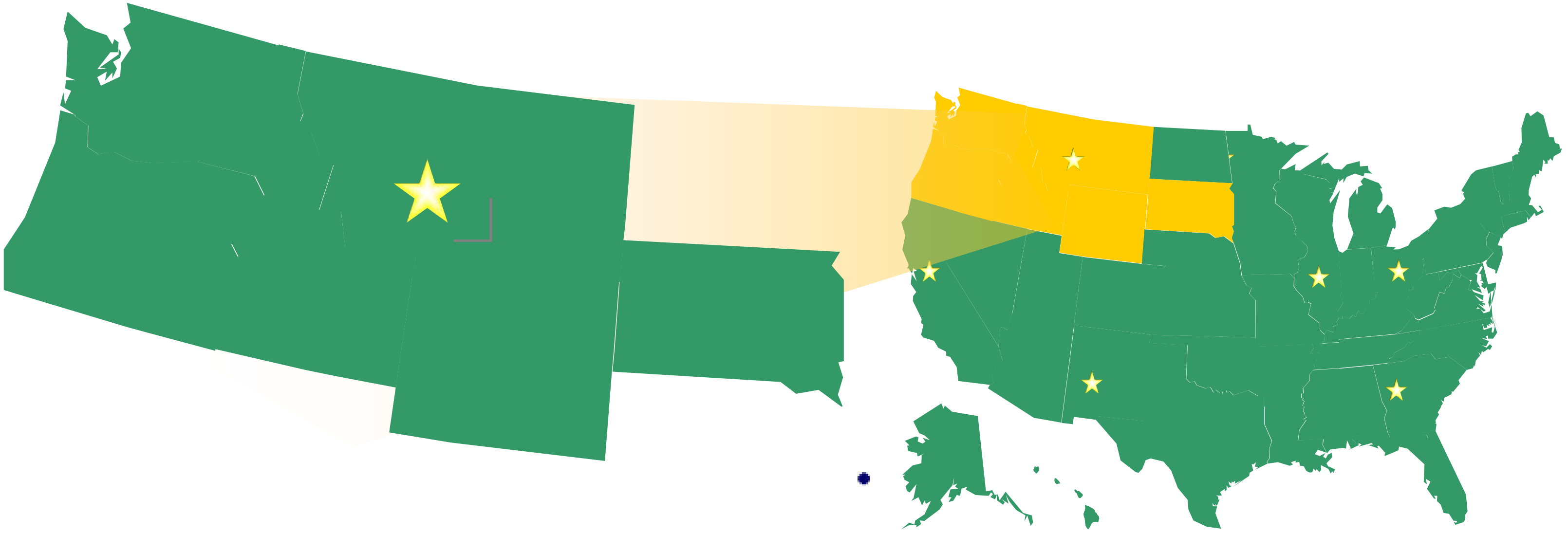
Outline

- Composition/Objectives/Milestones: Phase I
- Collaborators and Major Contributors
- Developing Databases
- Assessing Potential Sinks for Phase II
- Advanced Concepts: designing Phase II efforts

Composition of Partnership

- Research Institutions (universities, labs, others)
- State, federal agencies (includes USDA, USGS, NASA)
- Industry members including major power producers (Energy Northwest, Sempra Generation, Portland General Electric, Puget Sound Energy)
- Carbon trading entities (NCOC)
- Outreach Education partners
- Tribal Nations and Councils
- International Collaborators (includes Canada, Norway, India)

Partnership Area



Context for Phase I

- "Wealth of sinks, wealth for future energy supplies"
- Examining geological and terrestrial sinks
- Energy security, economic growth
- 40% of U.S. coal resources are in Big Sky region
- Marriage of good science-based technologies with good economics

Major Goals for Phase I

- Gauging public awareness of carbon sequestration, clean coal, and energy alternatives
- Developing databases for sources, sinks, energy infrastructure
- Regulatory and permitting issues and constraints
- Assessing potential sinks for Phase II demonstration sites
- Energy future/economic frameworks
- Designing MMV for all sinks that are “doable” & cost effective

Major collaborators for Phase I

- Databases/GIS: LANL, INL, SDSMT, UWYO, MSU
- Terrestrial: MSU, SDSMT, Texas A&M
- Geological Sinks: INL, UI, BSU LANL
- Outreach/Education: Entech Strategies
- Advanced Concepts: LANL, INL, MSU, UI, NCOC

Major Milestones Log Phase I

Project Phase	Milestone	Log
Partnership as a Whole		
• Quantify the region's contribution to meeting Bush administration's target goals of reducing GHG intensity 18% by 2012		End of Year 2
• Develop a risk assessment and decision support framework for optimizing soil C sequestration portfolio to be used in Phase II		End of Year 2
• Identify market-based voluntary approaches to carbon sequestration		End of Year 2

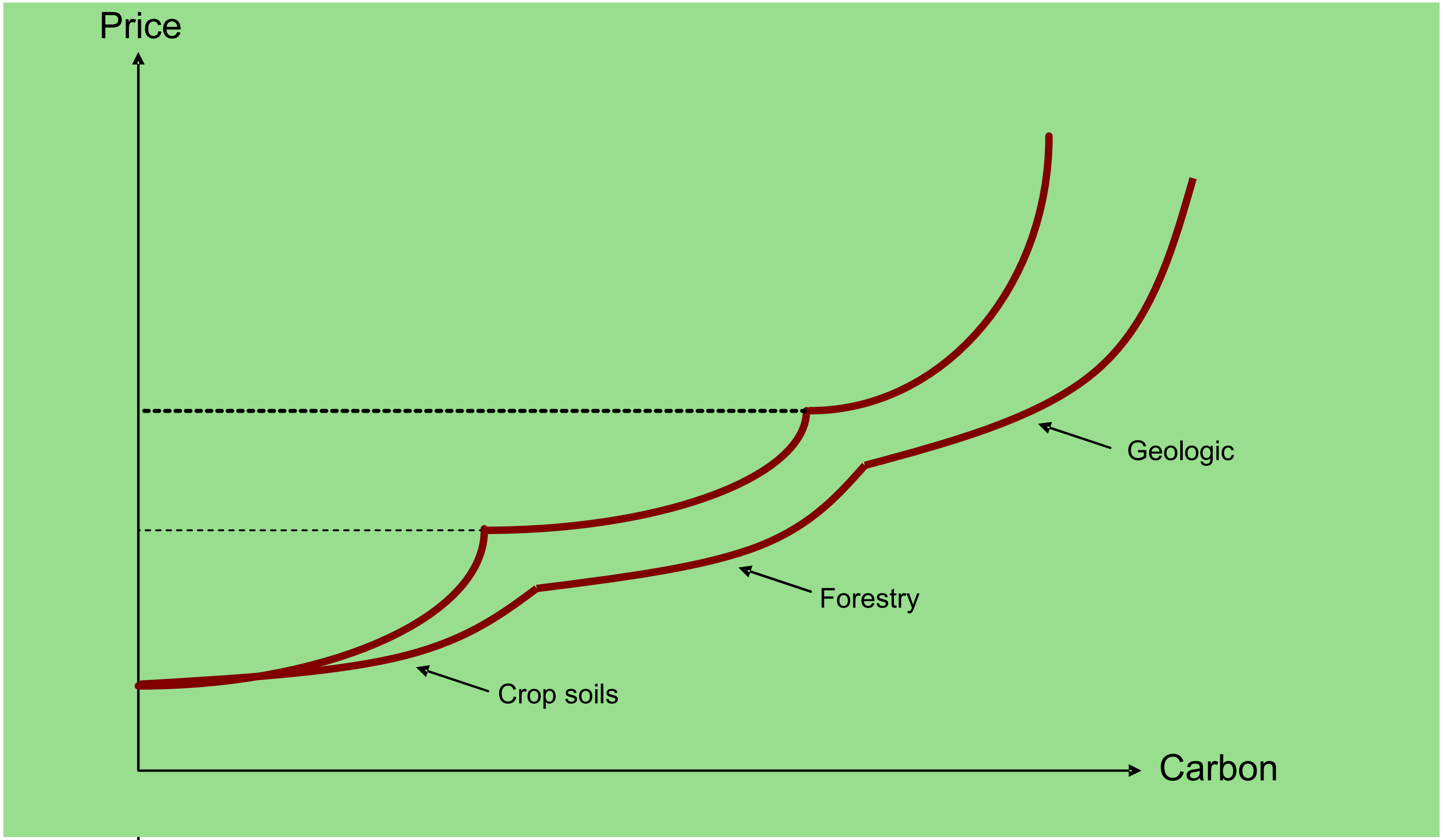
Major Milestones Log Phase I

Project Phase	Milestone	Log
Geological Sequestration Phase		
• Identify sources of CO_2 • Identify and assess promising geological sinks • Identify advanced concept for geological sequestration		End of Year 1 End of Year 1 End of Year 2
Terrestrial Sequestration Phase		
• Identify and assess the potential for soil C sequestration in region • Identify advanced concept for terrestrial sequestration		End of Year 1 End of Year 2
Outreach		
• Web site development • Development of forum for engaging community leaders in the region in carbon sequestration strategies		End of Year 1 End of Year 2

Components of an Economic/Risk Assessment Framework

- Economic input on cost (from private sector)
- Legal and regulatory issues
- Monitoring, Measurement and Verification
- Common units for comparison – spatial, temporal metrics
- End product – regional supply curve(s) for Carbon

Regional Carbon Supply Curve



Phase I Experience

- **Identify, assess and catalogue C sources and promising geological and terrestrial sinks: <u>Carbon Atlas</u>**

  Match up sources and transmission

  Match up sources, sinks, & transmission

Carbon Atlas: Geologic Sequestration

- Develop regional carbon atlas from existing sources
- Assess unique rock types with emphasis on mineralization and other processes that transform CO_2 to carbonate alkalinity and/or solids
- Evaluate the potential of regionally abundant basalt rocks for sequestration

Carbon Atlas: Terrestrial Sequestration

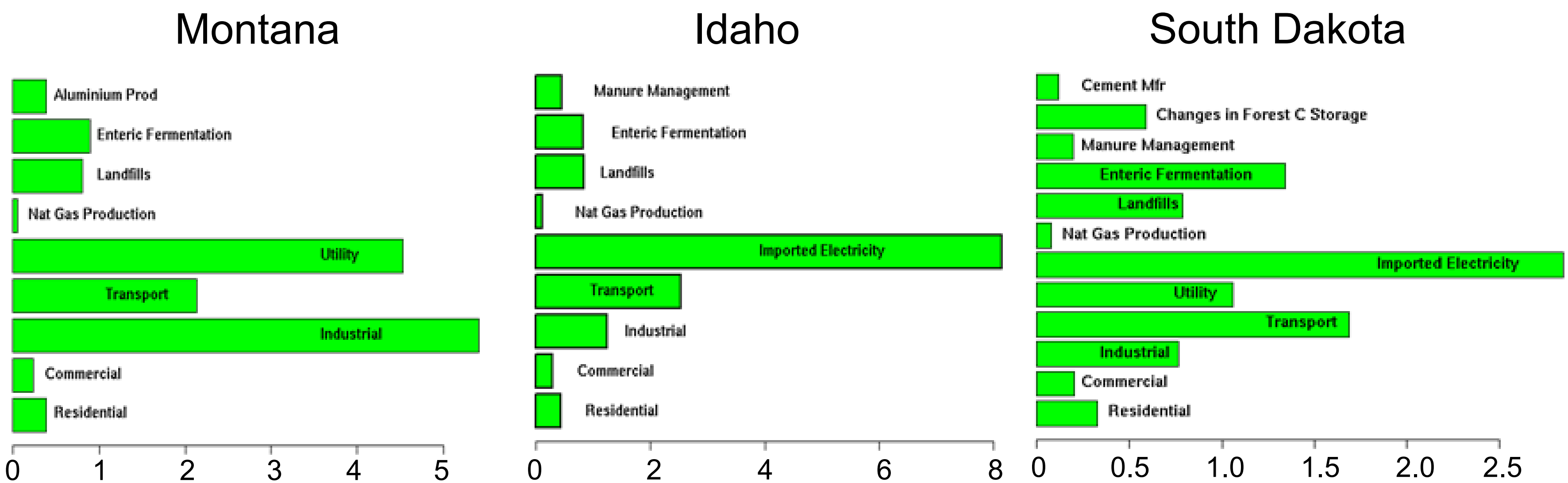
- Bridge to geological sequestration
- Technical potential
- Economic potential
- Pilot studies for carbon trading

GIS Accomplishments

Sources

- Point locations for major utility and industrial emitters

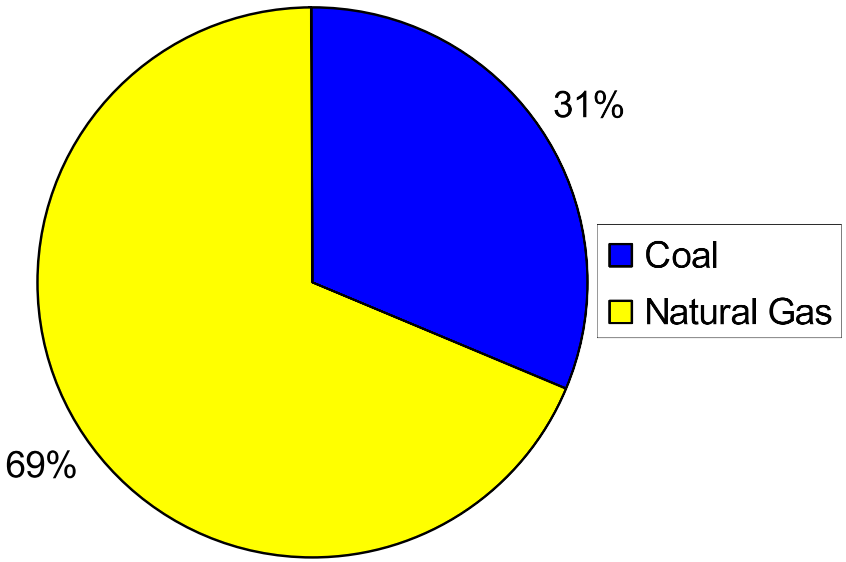
Major Categories (> 0.5 MMTCE)

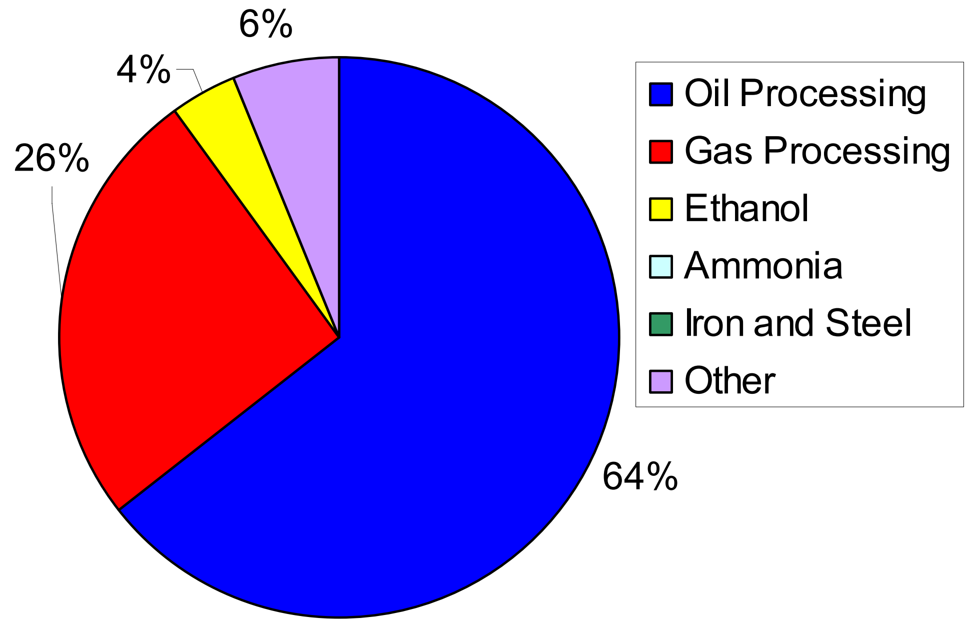


Million Metric Tons Carbon Equivalent

Randy Lee - Idaho National Laboratory
Paul Rich - Las Alamos National Laboratory

Distribution of CO_2 Point Sources in the Big Sky Partnership

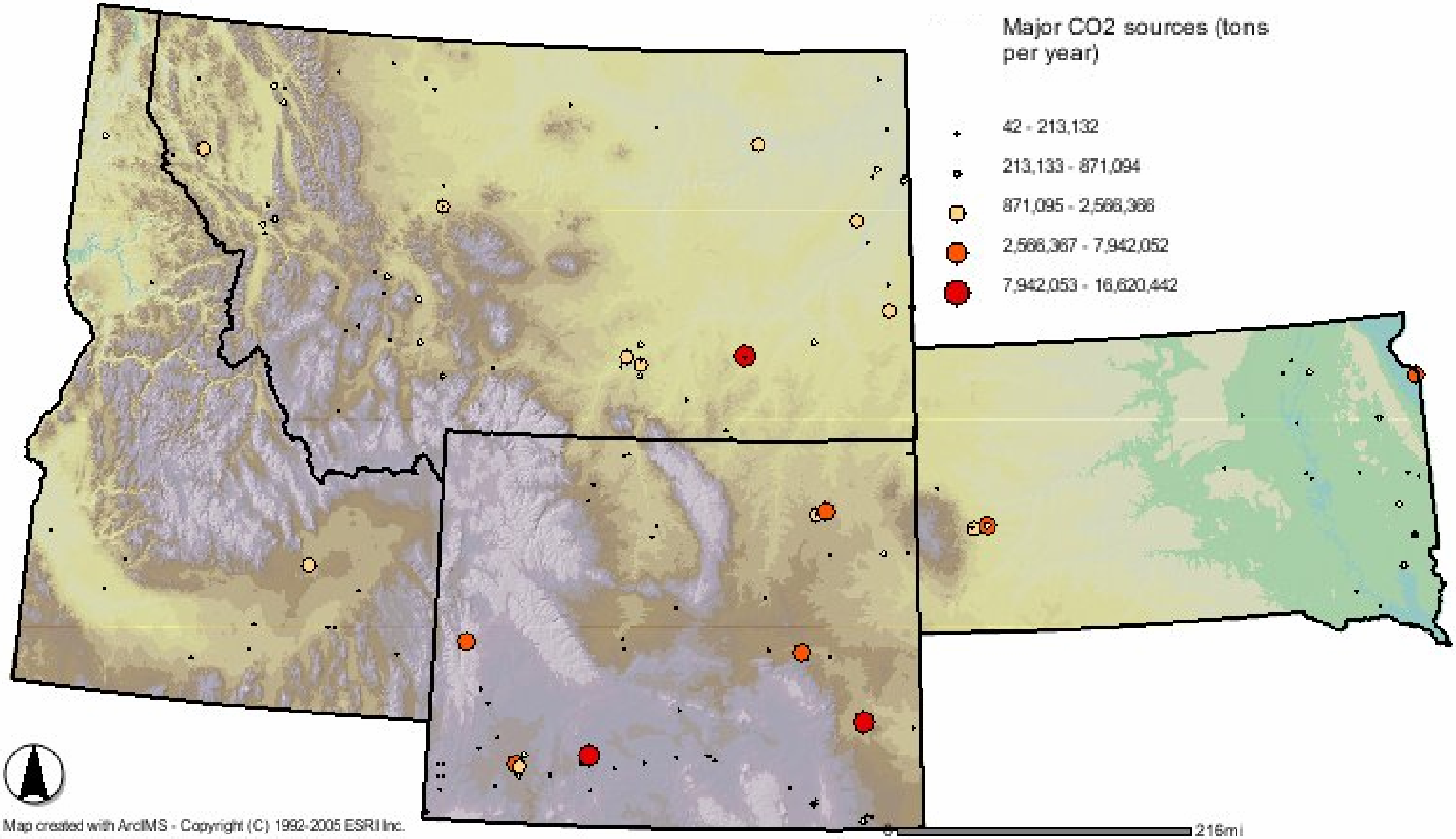




Total Utility: 65mmt CO_2 Eq/yr

Total Non-utility: 41 mmt CO2 Eq/yr

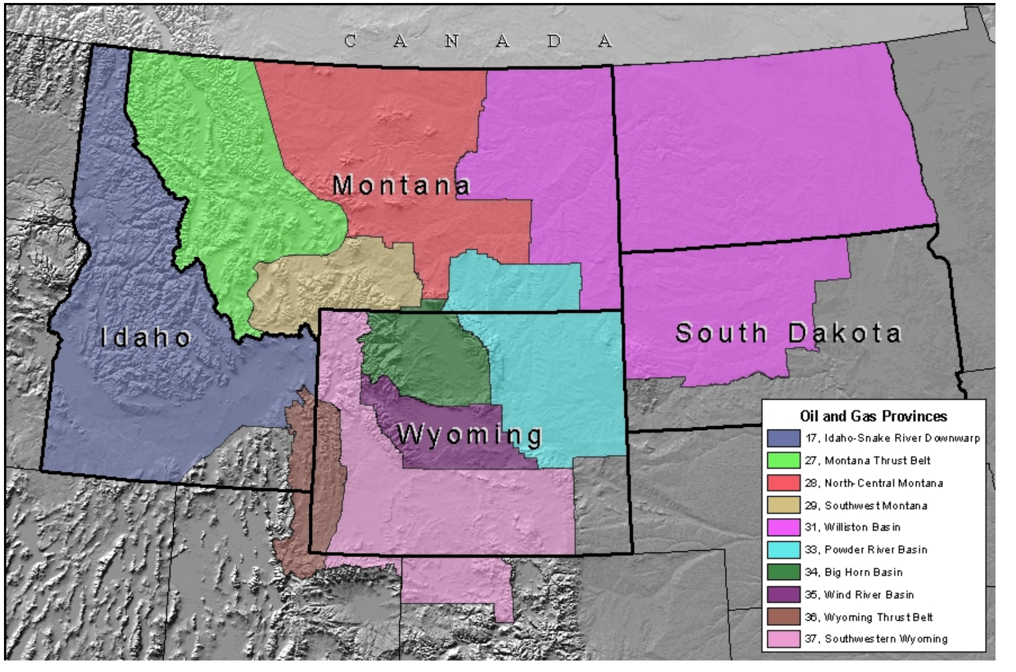
Big Sky Regional CO_2 Sources



RANDY LEE - IDAHO NATIONAL LABORATORY
PAUL RICH - LAS ALAMOS NATIONAL LABORATORY

GIS - Objectives

- Characterize geologic and terrestrial carbon sinks and carbon sources
- Design/build Big Sky Carbon Atlas
- Develop Big Sky Data Warehouse
- Coordinate with Other Partnerships and NatCarb

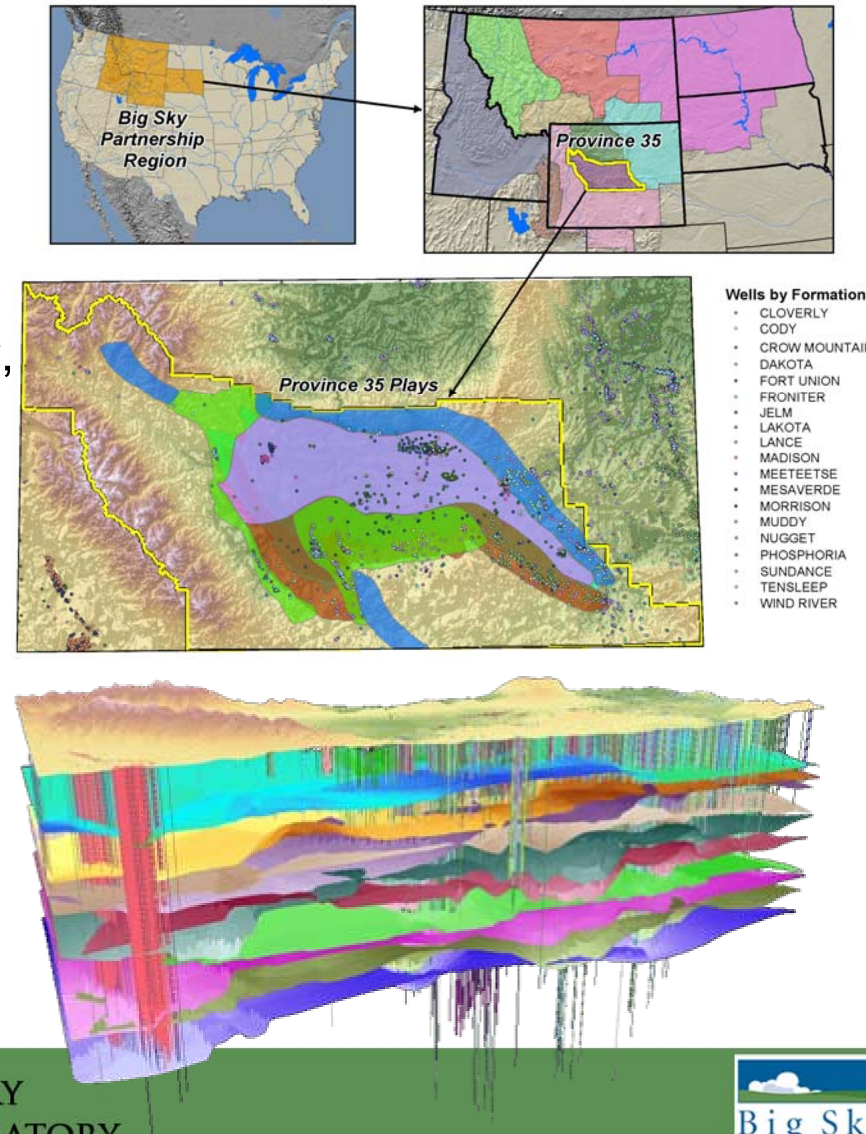


Collaborators

- GIS Coordination
  - Paul Rich (Los Alamos National Laboratory)
- Geologic GIS
  - Randy Lee (Idaho National Laboratory)
  - Jeff Hammerlinck (University of Wyoming)
- Terrestrial GIS
  - Karen Updegraff (South Dakota School of Mines and Technology)
- Big Sky Carbon Atlas / Data Warehouse
  - Todd Kipfer (Montana State University)
  - Aaron Jones (Montana State University)
  - Paul Rich (Los Alamos National Laboratory)

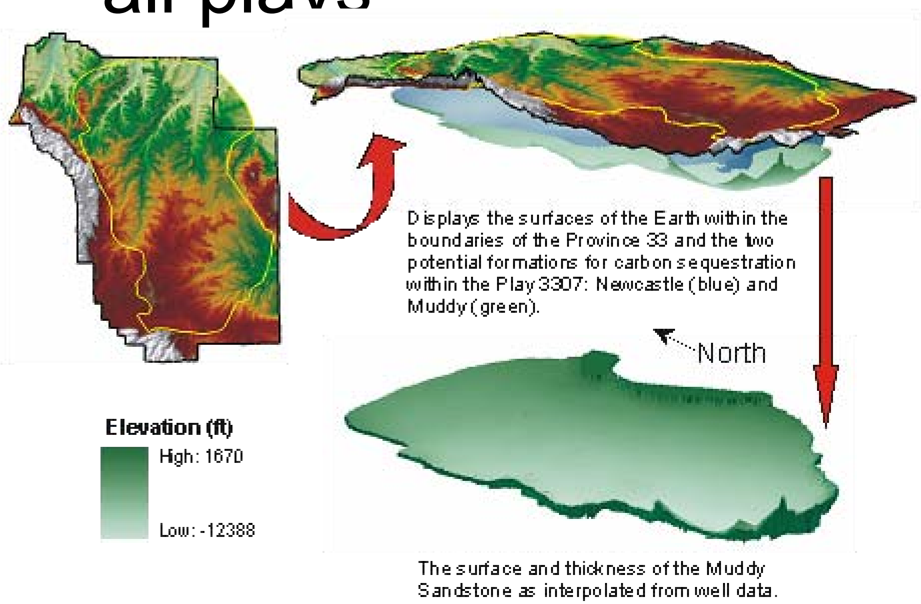
Geologic GIS

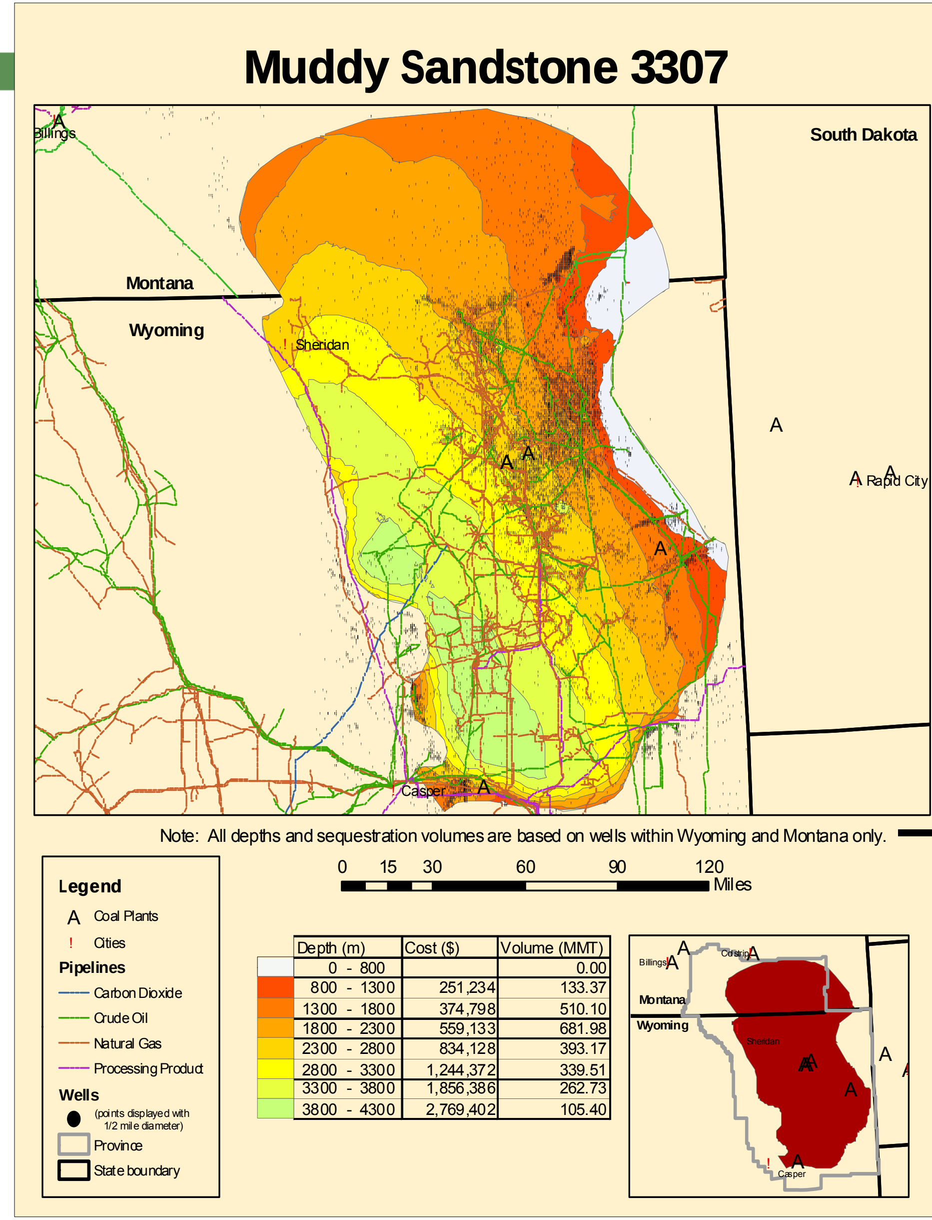
- Compiled data from 117,304 active wells in WY & MT
- Developed GIS model to calculate sequestration volumes (based on depth, temperature, pressure, density, and thickness)
- Characterized sequestration volumes for 283 formations in 57 plays



Randy Lee - Idaho National Laboratory
Paul Rich - Las Alamos National Laboratory

- Developed maps of each formation within all plays

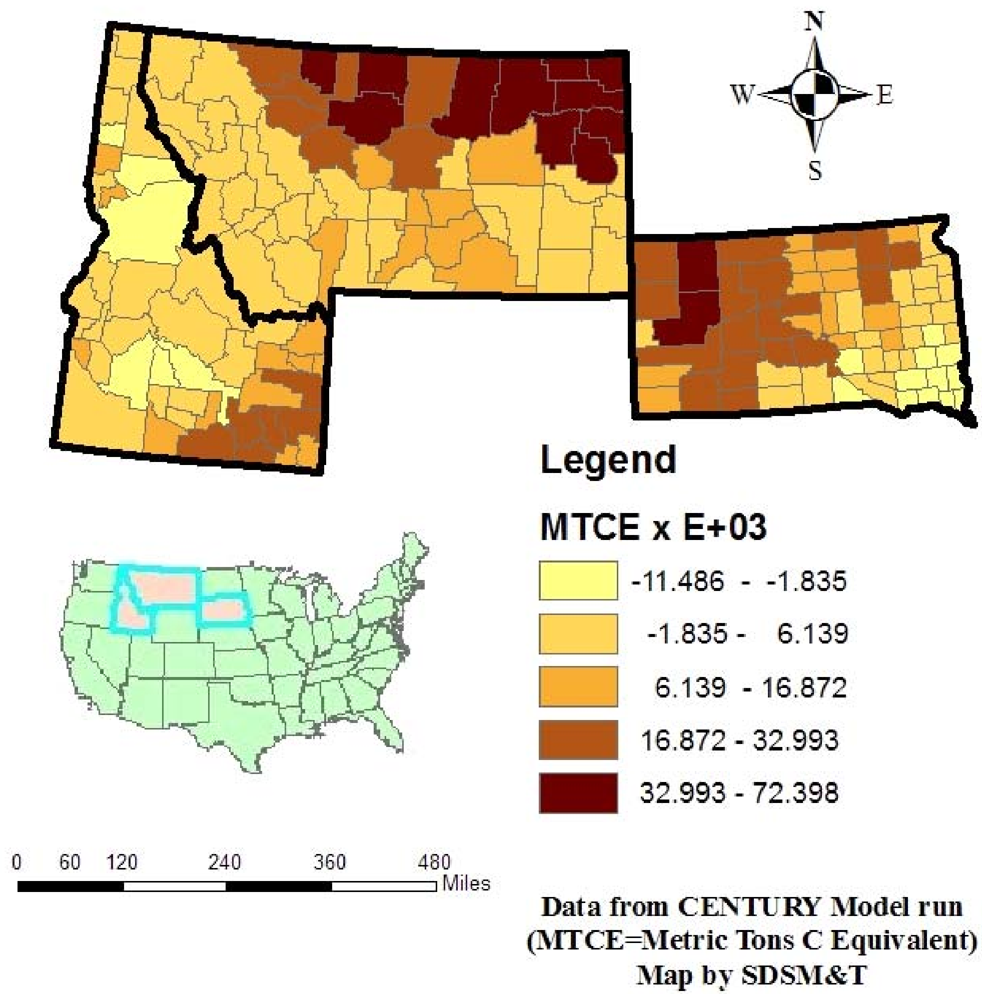




Depth (m)	Cost ($)	Volume (MMT)
0 - 800		0.00
800 - 1300	251,234	133.37
1300 - 1800	374,798	510.10
1800 - 2300	559,133	681.98
2300 - 2800	834,128	393.17
2800 - 3300	1,244,372	339.51
3300 - 3800	1,856,386	262.73
3800 - 4300	2,769,402	105.40

Terrestrial GIS

- Used Century Model to examine terrestrial carbon flux (based on climate, soil, land use)
- Evaluated management scenarios for continuous grassland and conventionally-tilled cropland
- Estimated current annual soil carbon fluxes in Big Sky states

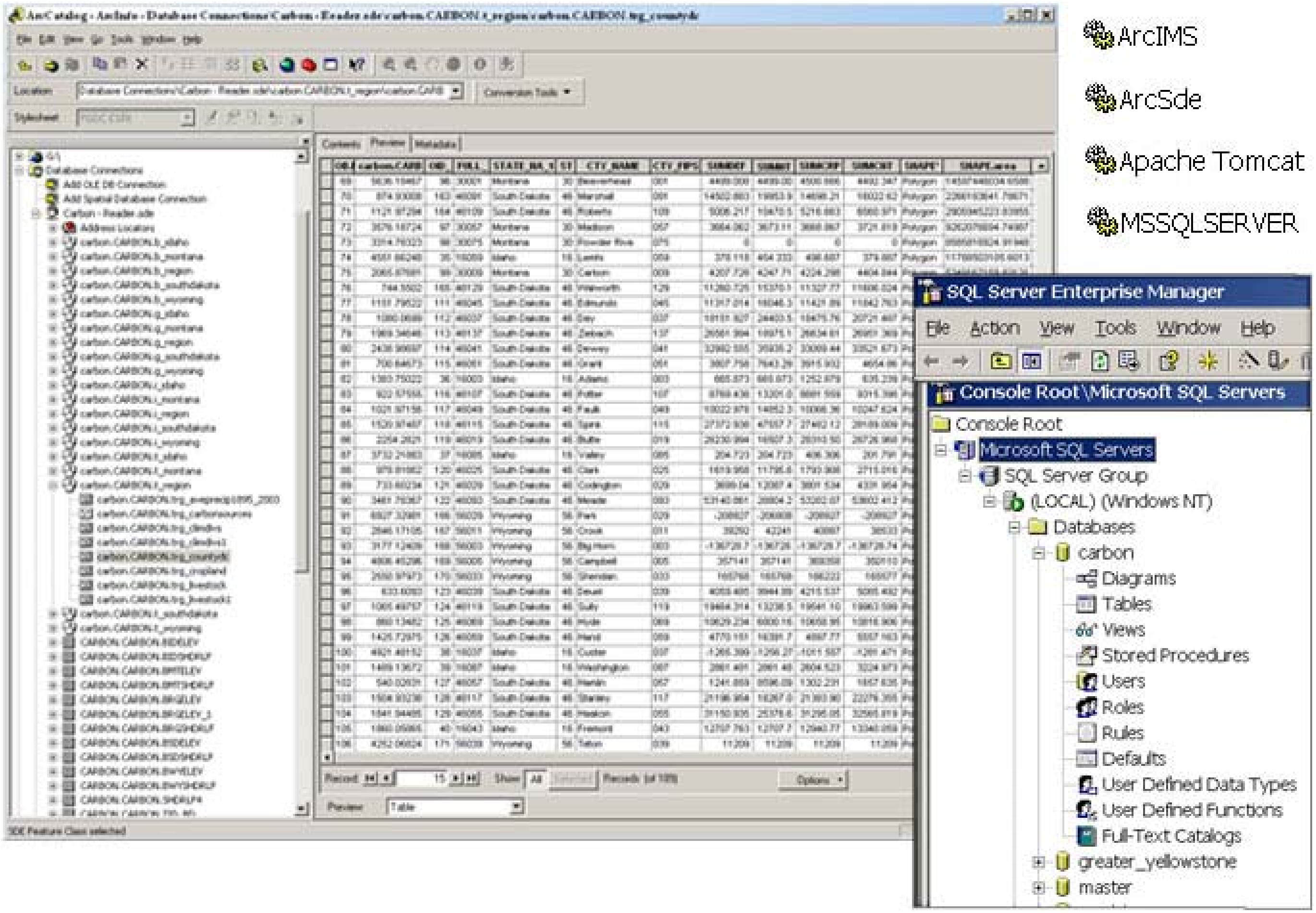


Big Sky Carbon Atlas

Data Type	Description	Served by Big Sky
GHG Sources	Emission point locations	Yes
GHG Inventory	State-level source & sink emission summaries	Yes
GHG Livestock	County-level livestock emission summaries	Yes
Terrestrial Sinks	Actual/potential soil sink estimates (CENTURY)	Yes
Soil	SSURGO/STATSGO & Soil Texture Grids	Yes
Climate	Monthly precipitation/temperature 1900–present	Yes
Climate Divisions	NCDC climate division boundaries	Yes
Ag Management	Cropland areas (various tillage/rangeland)	Yes
Political	State/County Boundaries	Yes
Infrastructure	Transportation/Pipelines/Powerlines	Partial
Geologic Sinks	Oil/Gas Provinces & Plays	Yes
Wells	Oil & Gas wells	Yes

Infrastructure data layers such as gas pipelines are not served due to homeland security issues.

Big Sky Data Warehouse



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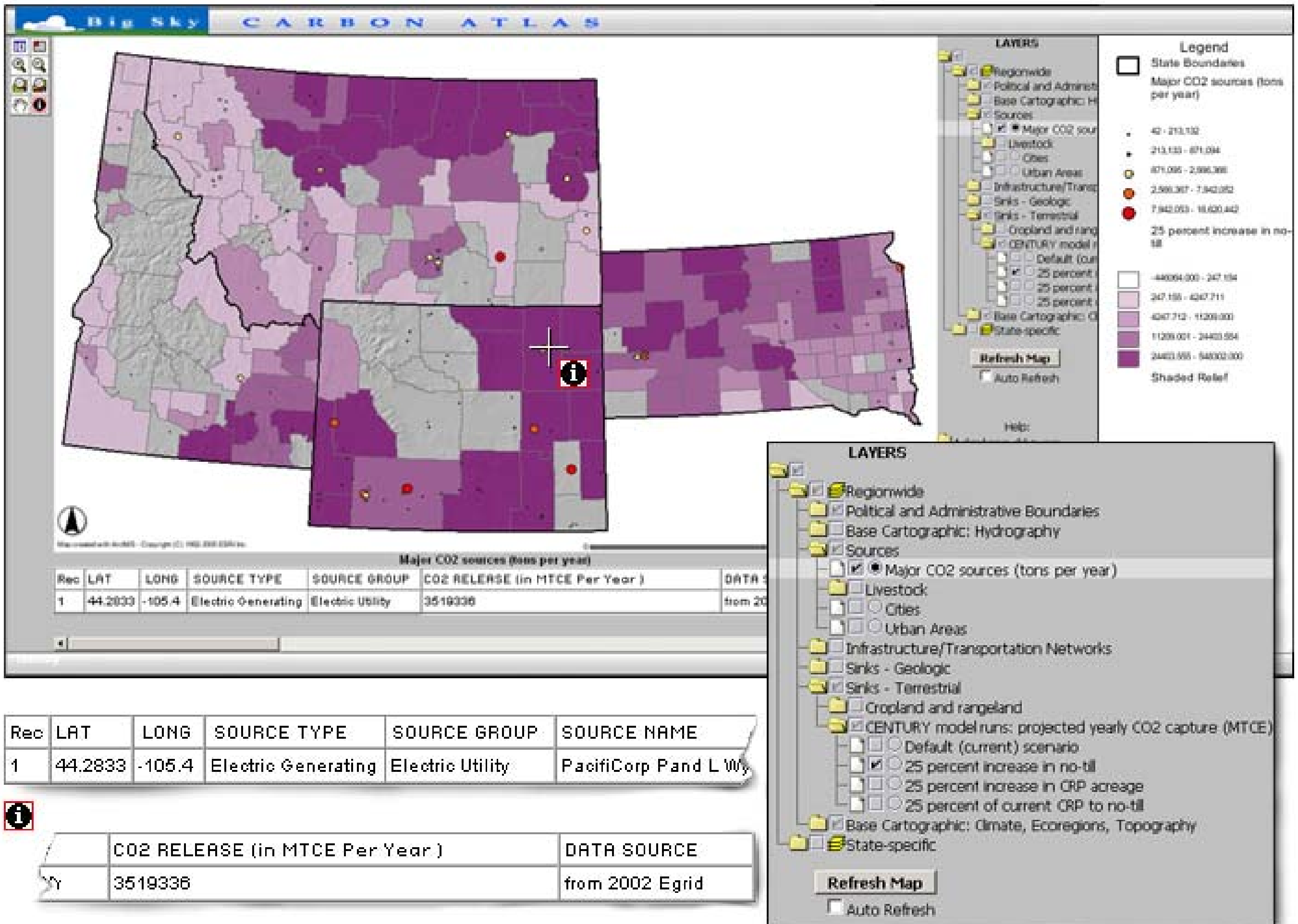
Paul Rich - Las Alamos National Laboratory

Data Warehouse



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Paul Rich - Las Alamos National Laboratory

Phase I Geologic Sequestration

Basalts and Mineral Trapping

Robert Smith (UI)
Travis McLing (INL)

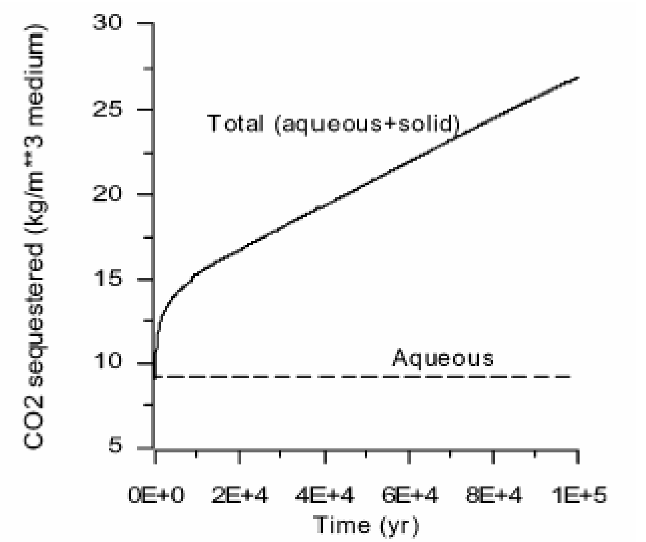
Partnership Geologic Sequestration Objectives

- Evaluate the geologic sequestration potential regional sedimentary and volcanic basins
  - Favorable and worthy of further consideration
  - Unfavorable
  - Insufficient information to classify
- Identify potential pilot-scale sequestration site(s)
  - Focus on ***Mineral Trapping – Conversion of CO_2 to permanent solid phase***

Mineral Trapping

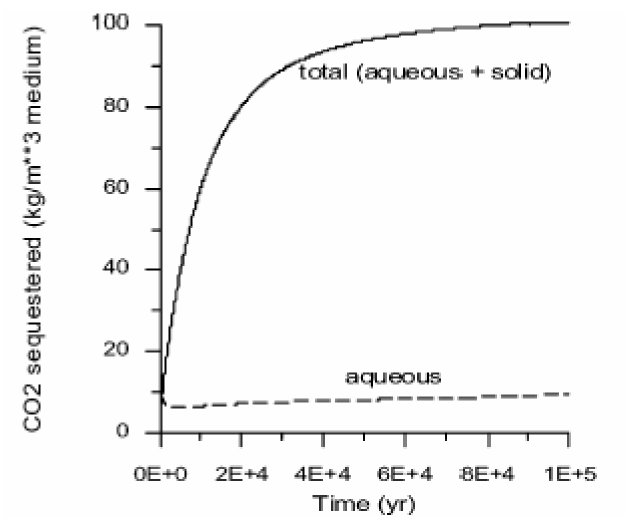
Xu *et al*. (2004)

Fixed CO_2 pressure of 260 bars



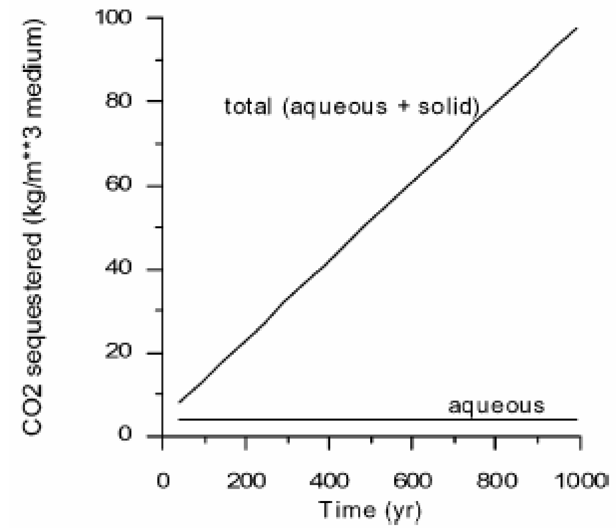
Glauconitic sandstone

~0.2 g yr^{-1} m^{-3}



Gulf Coast sediments

~3 g yr^{-1} m^{-3}



Dunite

~100 g yr^{-1} m^{-3}

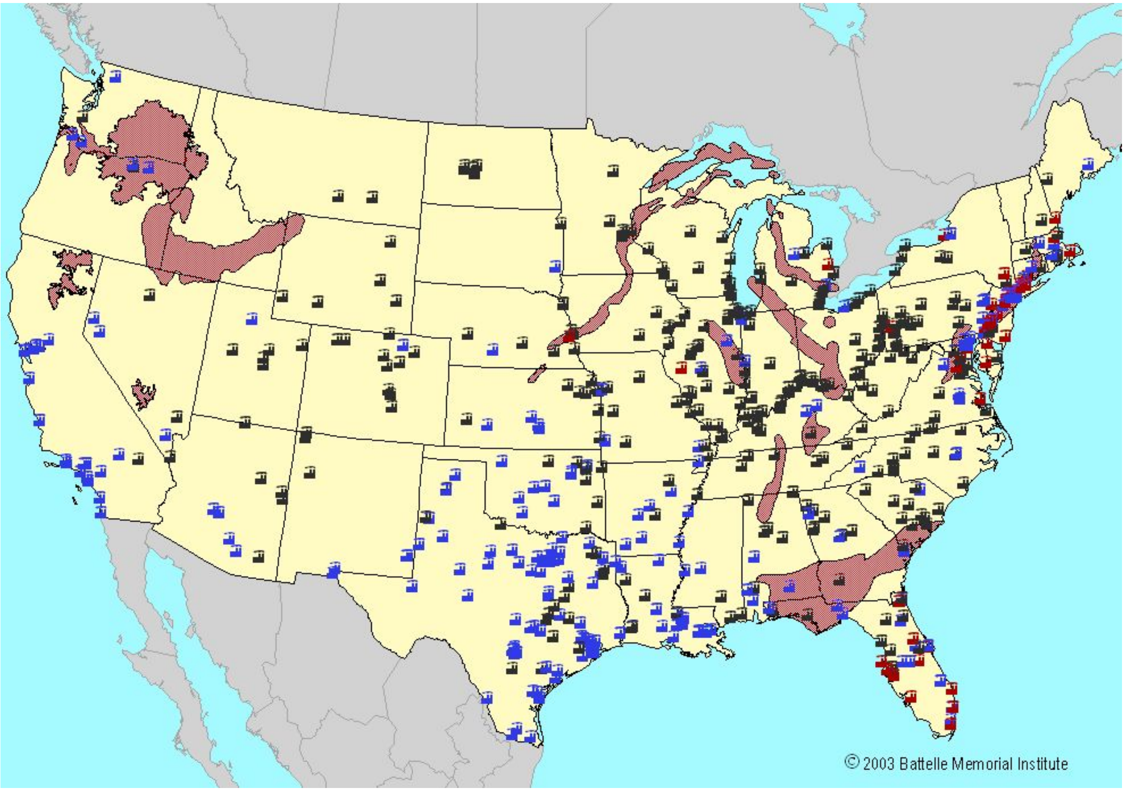
Basalts and Sequestration

- Significant basalt formations in the region
  - 164,000 km^2 – Columbia River Basalt Group
  - 64,000 km^2 – Snake River Plain
- Chemical makeup favorable for mineralization reactions

$$\text{Plagioclase}[CaAl_2Si_2O_8] + 2H_2O + CO_2 \rightarrow$$
$$\text{Calcite}[CaCO_3] + \text{Clay}[Al_2Si_2O_5(OH)_4]$$

- Theoretical capacity ~150 kg C m^{-3}
- Deeper aquifers contain non-potable water

Large Basalt Provinces and Power Plants in the US



ROBERT SMITH (UI)
TRAVIS MCLING (INL)

Flood Basalts at Twin Falls, Idaho

Normalized Mineralogy

Snake River Plain Basalt

Oxides	Wt %
SiO_2	46.10
TiO_2	2.60
Al_2O_3	14.51
Fe_2O_3	2.62
FeO	10.57
MnO	0.20
MgO	8.49
CaO	10.34
Na_2O	2.47
K_2O	0.93
P_2O_5	0.70
Total	99.53

Normalized Mineralogy	Wt %
Orthoclase (Or)	5.51
Albite (Ab)	20.89
Anorthite (An)	25.77
Diopside (Di)	17.09
Hypersthene (Hy)	3.31
Olivine (Ol)	16.64
Magnetite (Mt)	3.80
Ilmenite (Il)	4.93
Apatite (Ap)	1.63
Total	99.55

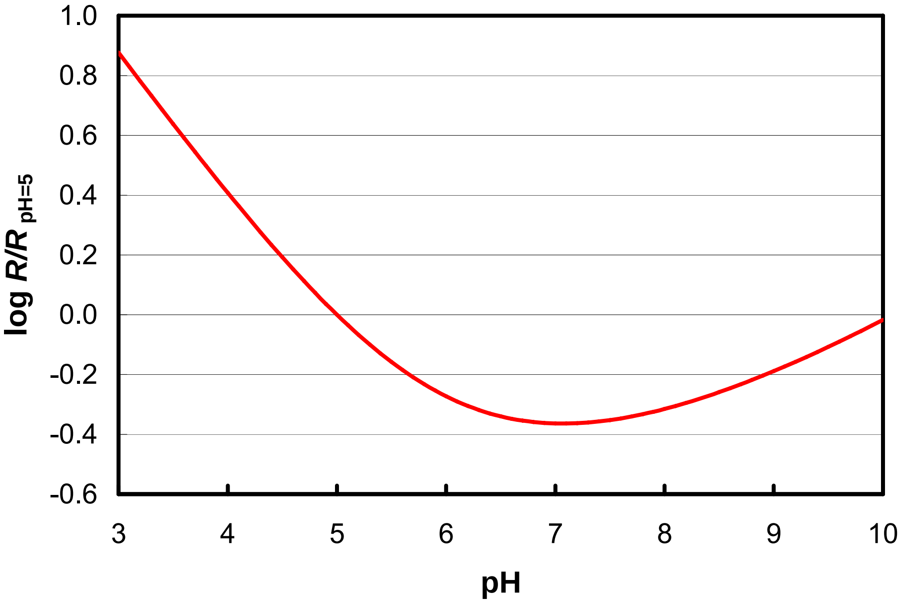
Ti, P Free	Wt %	Surface Area $cm^2\ g^{-1}$
K-Feldspar $KAlSi_3O_8$	5.51	123
Plagioclase $NaCaAl_3Si_5O_{16}$	46.66	115
Clionpyroxene $Ca_3Mg_2FeSi_6O_{18}$	17.07	87
Orthopyroxene $Mg_2FeSi_3O_9$	3.31	87
Olivine $Mg_4Fe_2Si_3O_{12}$	16.64	84
Magnetite Fe_3O_4	3.80	115
Total	92.98	

Robert Smith (UI)
Travis McLing (INL)

Reaction Rate Model

$$R = k_{+} \cdot A \cdot \left(a_{H^{+}}^{0.5} + 10^{-3} + 10^{-5} \cdot a_{H^{+}}^{-0.25} \right) \left[1 - \frac{Q}{K} \right]$$

k_{+}	Forward Rate Constant
A	Surface Area
a_{H+}	Hydrogen ion activity (pH)
Q	Ion Activity Quotient
K	Equilibrium Constant



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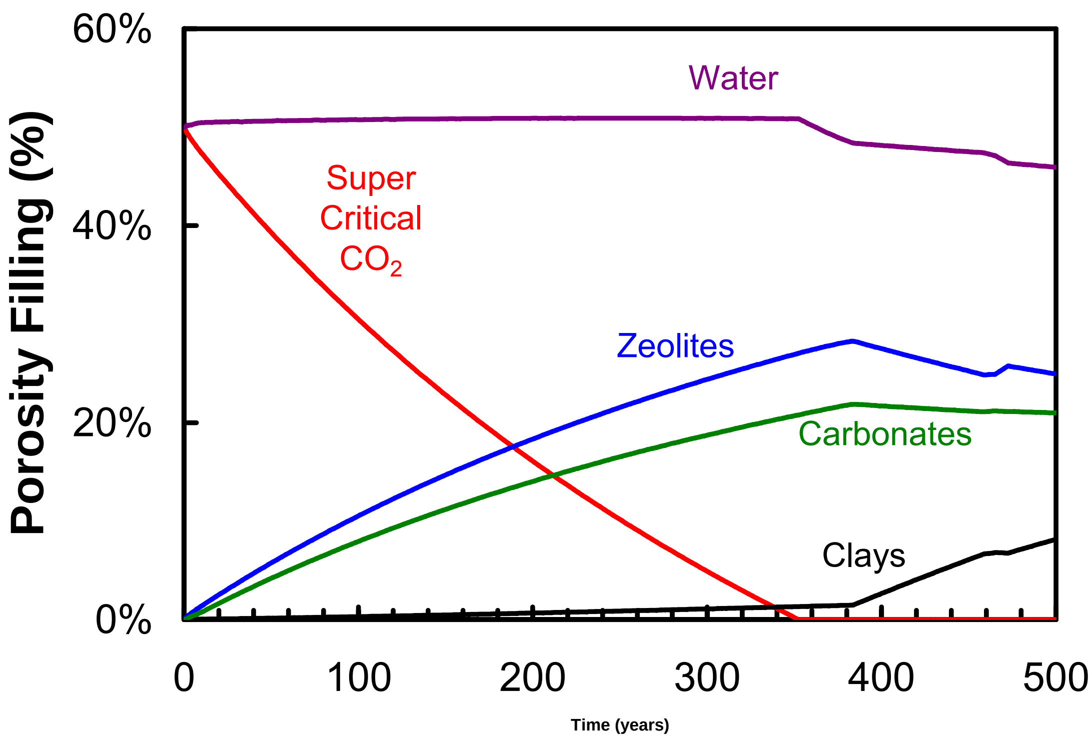
Model Conditions

- Porosity → 12.5 %
  - 6.25% supercritical CO_2
  - 6.25% groundwater
- Pressure → 200 bars (2 km hydrostatic load)
- Temperature → 40 ^{o}C
- Super critical CO_2 density → 821 kg m^{-3}
- Relative reactions rates from “literature” rate law
- Calibrated to estimated basalt reaction rate of 150 mg L^{-1} yr^{-1} (Roback *et al*. 2001)

Reaction Products



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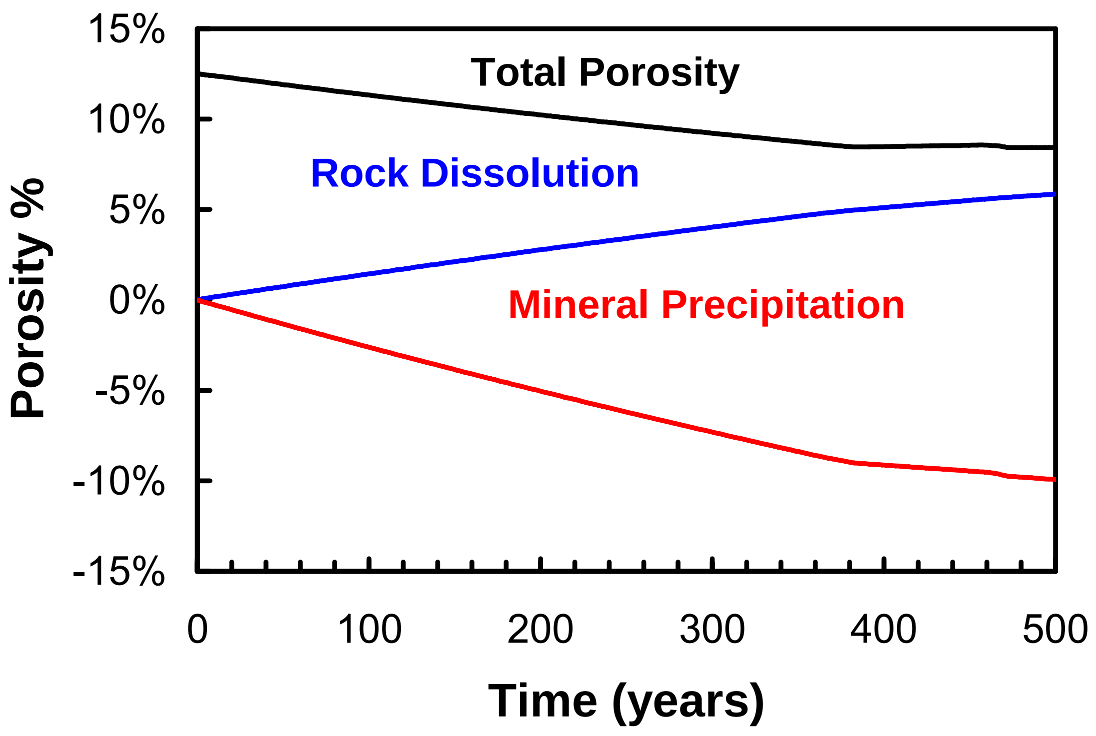
Porosity Changes



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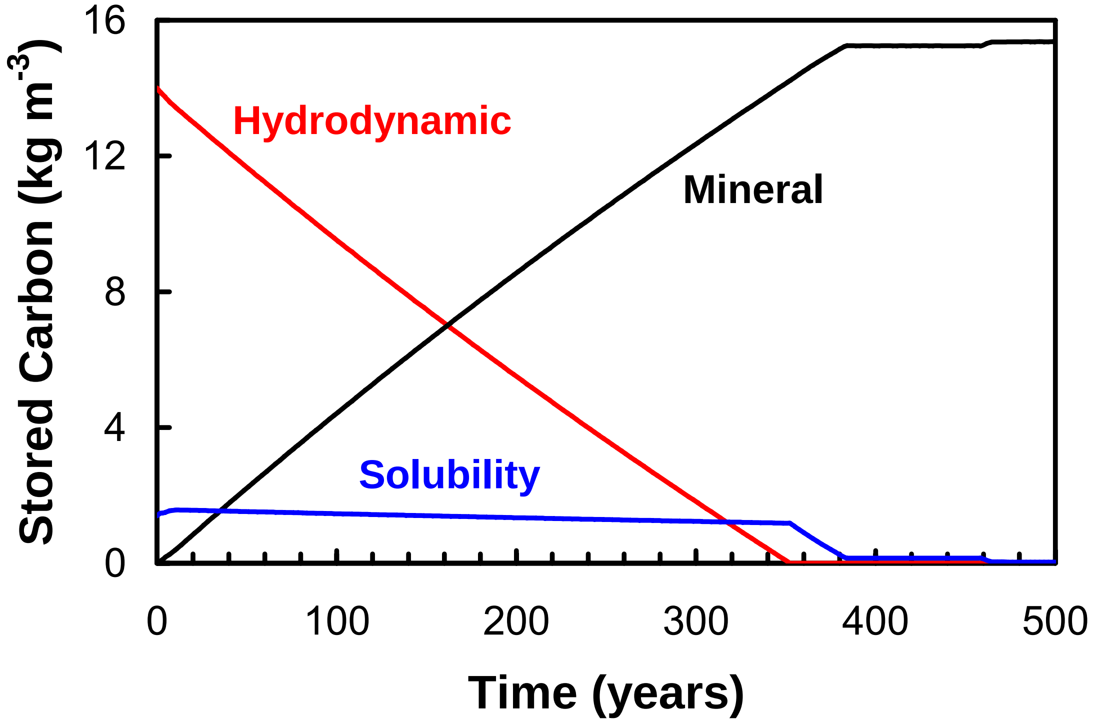
Trapping Processes



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Summary

- Hydrodynamic, solubility and mineral trapping contribute to long-term storage of CO_2
- Relative importance of mineral trapping is a function of rock type
- For mafic rocks, mineral trapping is dominate mechanism after ~150 years
- Mineral trapping eliminates risk of leakage

Phase I Terrestrial Sequestration

Forestry, rangelands, croplands

Robert Smith (UI)
Travis McLing (INL)

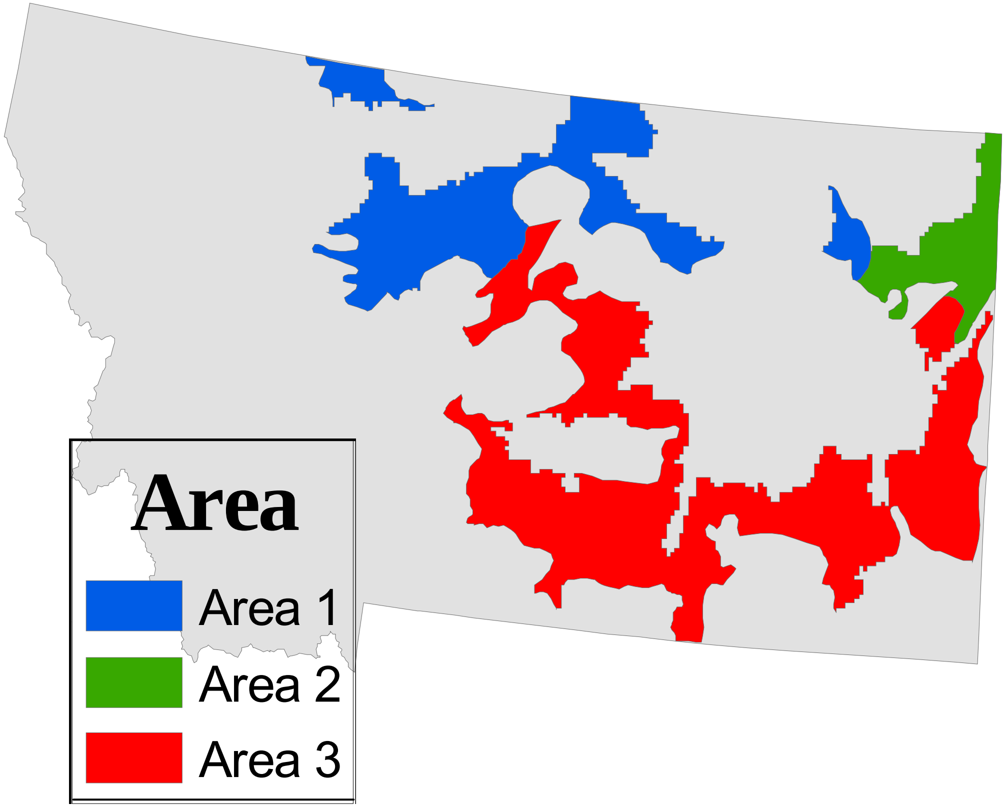
Forestry Sequestration Potential

Practice	Available Area (1000 Ac.)	Potential Area (1000 Ac.)	Potential Mitigation ($TgCO_2e/yr$)
Afforestation	34,000	3,400	4 – 6
Forest Management	10,900	6,200	1.5 – 2
Field Windbreaks	594	300	1.0 – 1.5
Riparian Forests	1,500	750	2 – 2.5
Biomass for Energy	10,500	330	0.25 – 3
Total			9 – 15

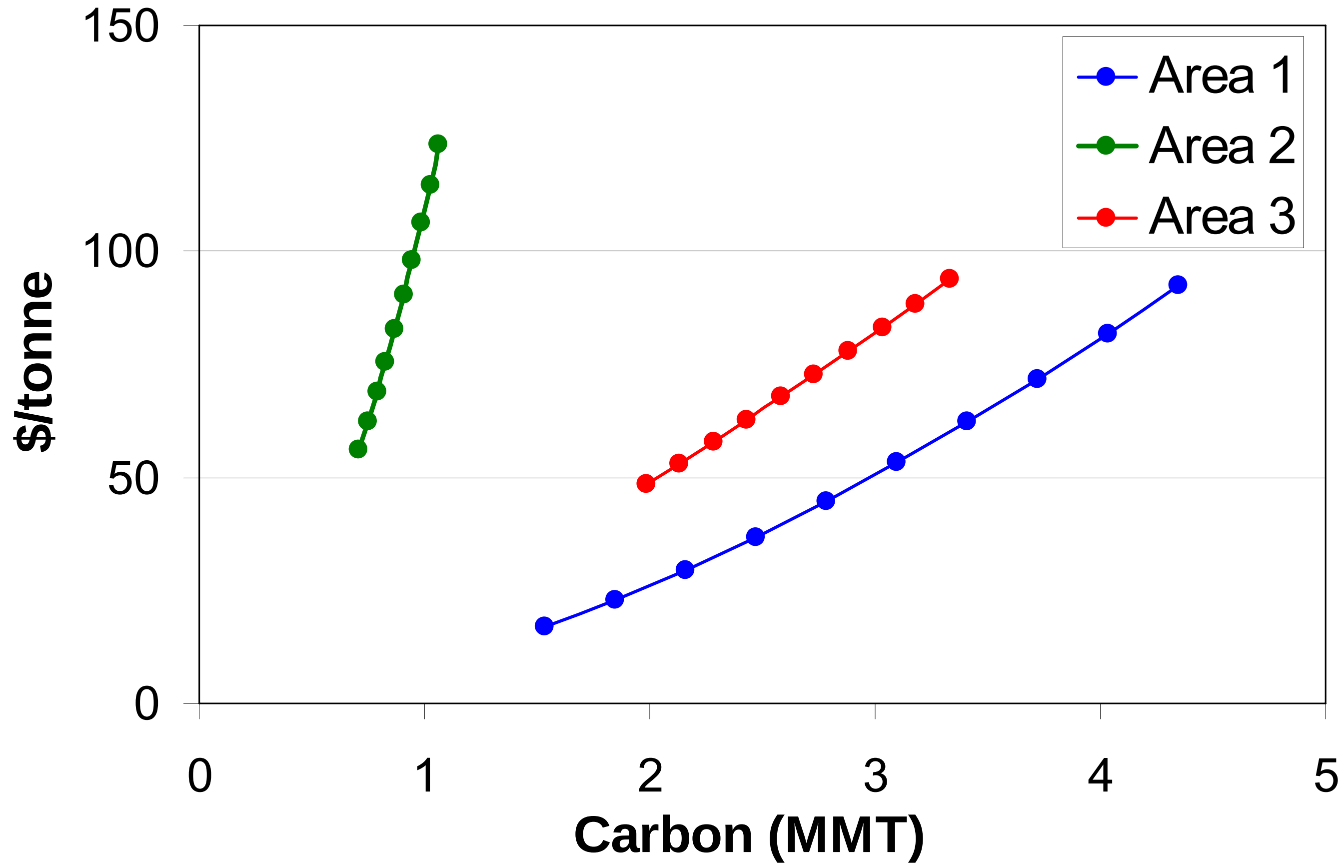
Big Sky agricultural land areas (1000 km^2)

	------ Cropland -------				
State	**Conv. Till**	**No till**	**Grazing**	**CRP**	**Total**
Idaho	19	1	23	3	47
Wyoming	9	0	127	1	138
South Dakota	52	15	105	6	178
Montana	40	4	142	11	197

Major Cropland MLRA's in Montana



Montana Carbon Sequestration Potential



PERRY MILLER (MSU)
DAVID BROWN (MSU)

Terrestrial Sinks in MT

SubMLRA	MMT of Carbon Sequestered	Marginal Cost ($/tonne)	Acres	Hectares
52_high	1.53	$16.91	1,665,140	674,146
52_low	1.84	$23.11	1,968,963	797,151
53a_high	0.71	$56.05	554,894	224,653
53a_low	0.81	$31.54	1,068,704	432,674
58a_high	1.98	$48.43	1,019,513	412,758
58a_low	1.22	$56.17	906,600	367,045

Rangeland potential
(Texas A&M)

- GIS based analysis
- Climate Conditions
  - **No Potential - Less than 130 mm (~5 inches) of annual precipitation**
  - **Low potential – 130 to 230 mm (~5 to 9 inches) of annual precipitation**
  - **Moderate potential – 230 to 460 mm (~9 to 18 inches) of annual precipitation**
  - **High potential – Greater than 460 mm (18 inches) of annual precipitation**
- Land use Types
  - **Shrublands**
  - **Grasslands/Herbaceous**
  - **Pasture/Hay**

Rangeland Potentials by State
Idaho

- 11 million hectares could be classified as rangeland cover types --
  - 7.5 million hectares were shrublands,
  - 2.8 million hectares were grassland/herbaceous,
  - 0.8 million were pasture/hay cover
- Land tenure
  - 7.1 million hectares fell under federal jurisdiction,
  - 0.32 million were Indian Reservations, and
  - 3.7 million hectares were private or other non-federal lands.
- Climatic potential rangeland
  - high 39%
  - moderate 57%
  - low 4%
- Average carbon that can be sequestered: 0.1-0.05 tons/yr/ha

Rangeland Potentials by State
Montana

- 21 million hectares could be classified as rangeland cover types --
  - 3.3 million hectares were shrublands,
  - 17.0 million hectares were grassland/herbaceous,
  - 0.8 million were pasture/hay cover
- Land tenure
  - 4.8 million hectares fell under federal jurisdiction,
  - 2.0 million were Indian Reservations, and
  - 14.5 million hectares were private or other non-federal lands.
- Climatic potential rangeland
  - high 17%
  - moderate 83%
  - low 0.1%
- Average carbon that can be sequestered: 0.05 tons/yr/ha

Rangeland Potentials by State
South Dakota

- 12 million hectares could be classified as rangeland cover types --
  - 0.3 million hectares were shrublands,
  - 8.7 million hectares were grassland/herbaceous,
  - 3.0 million were pasture/hay cover
- Land tenure
  - 1.0million hectares fell under federal jurisdiction,
  - 2.7 million were Indian Reservations, and
  - 8.4 million hectares were private or other non-federal lands.
- Climatic potential rangeland
  - high 55%
  - moderate 45%
  - low 0.0%
- Average carbon that can be sequestered: 0.075 tons/yr/ha

Rangeland Potentials -- Summary excluding WY

- 31.5 million hectares could be classified as rangeland cover types – non-federal
- Average carbon that can be sequestered: less than 0.060 tons/yr/ha

Phase I
Advanced Concepts for Implementation Readiness

- Carbon Markets
- Economic Analysis
- Regional Energy Analysis
- MMV activities

Objective of Carbon market Component

- Provides an opportunity for landowners, corporations, tribal and local governments to participate in a market-based conservation program
- Offers industry a cost-effective way to achieve their carbon dioxide emission reduction goals
- Transfer of carbon credit rights is a new marketable commodity that provides landowners and communities a new source of revenue

NCOC's Documents for Phase I

NCOC has completed

- The project planning handbook;
- project planning forms;
- listing agreements;
- contracts;
- vintage credit portfolio design;
- assessment of forestry & agroforestry potential in the region;
- and volume tables for key agroforestry species (contained in the handbook.

External Coordinating Efforts

- established a **regional technical assistance and outreach network** for private and state lands and a **national network** for tribal lands.

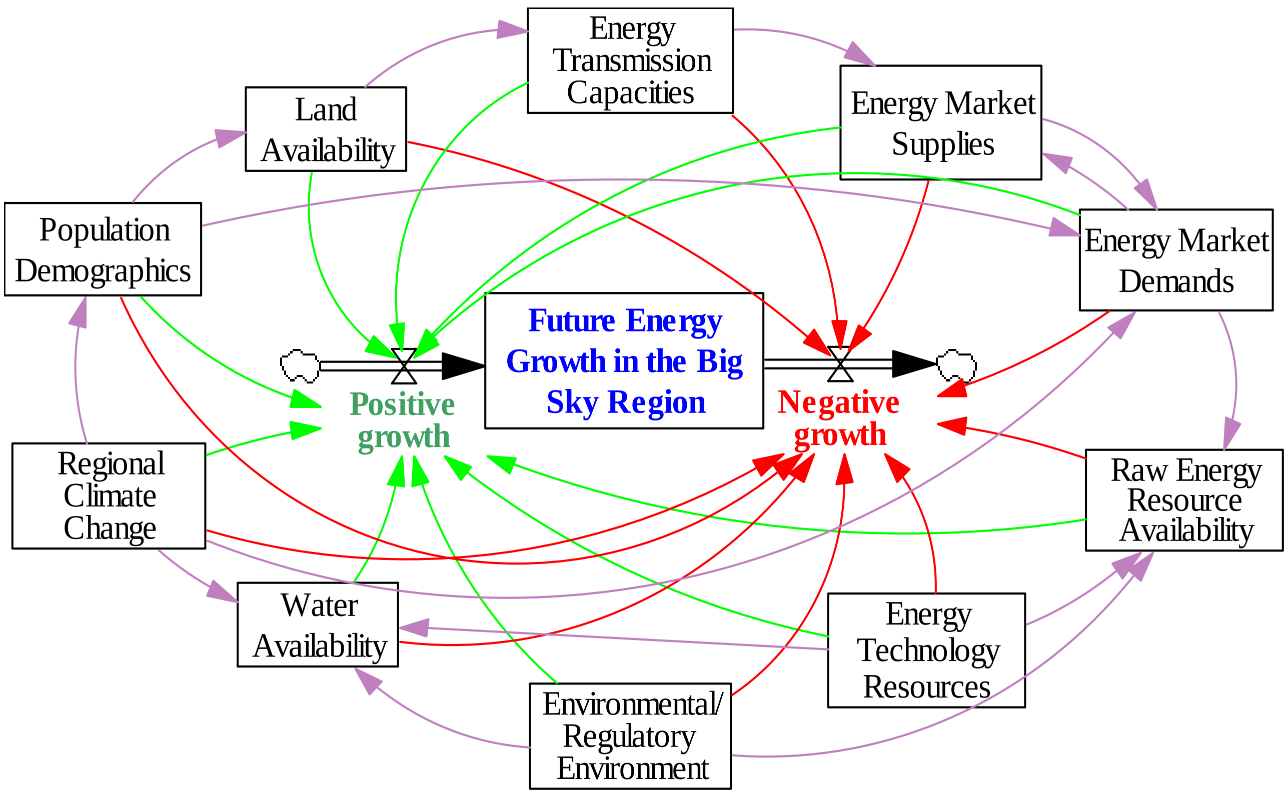
  The network will be used to obtain pilot projects with landowners' field test all aspects of the proposed trading system in phase II.

- established a **technical standards committee**.

  The committee representing private and public natural resource technical professionals, state and tribal staff, university researchers and financial advisors will recommend the final portfolio protocols (project categories and definitions) to be followed in phase II.

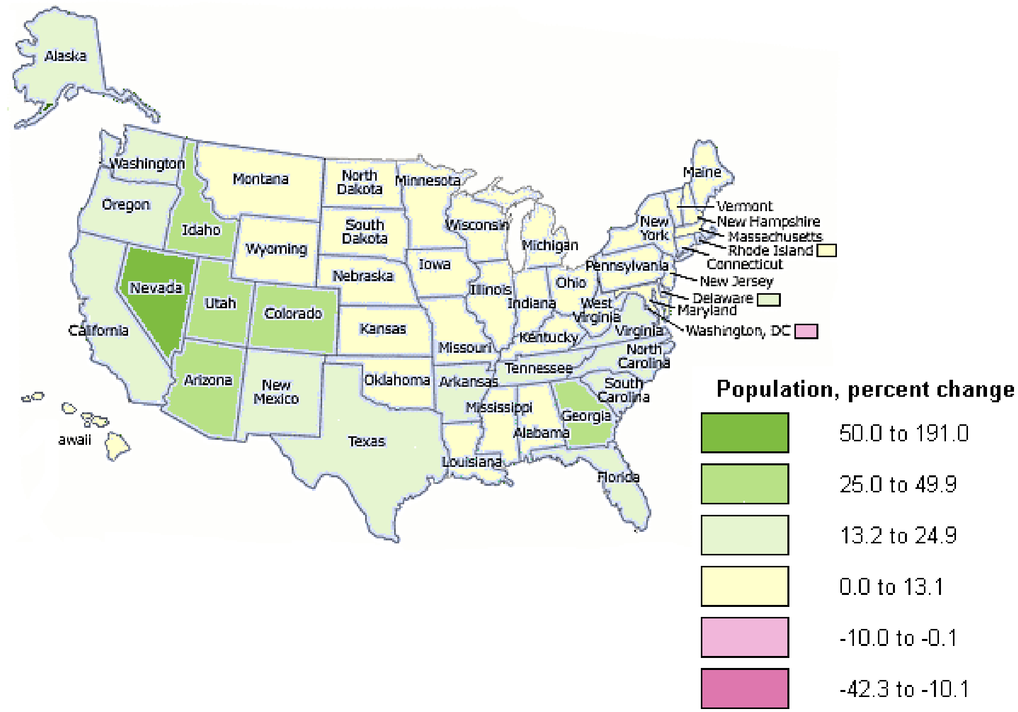
Regional Energy Growth Assessment

- Complex dynamic process with many factors and policy drivers



Big Sky Regional Population Growth

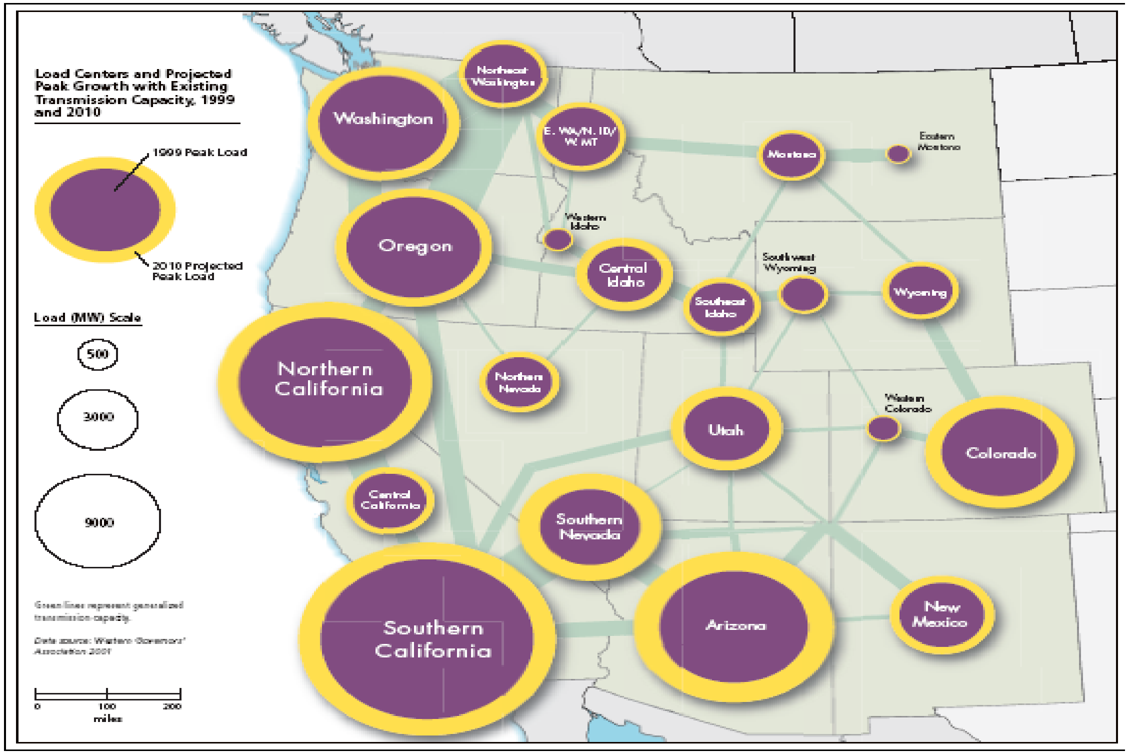
- Western states are the fastest growing region in the U.S.



Expanding populations + Growing economies = Increased energy demand

Energy Transmission Infrastructure

- The Big Sky region is central to many load centers, but is currently constrained by transmission capacity



Phase II: regional energy analysis will be coupled to the capacity for sequestration

- Evaluate key factors affecting energy growth
- Understand relationship between variables
- Build dynamic economic/policy analysis model
- Benchmark model to energy demand models
- Couple model to GIS database interface
- Collaborate with regional policy centers
- Support state and regional energy planning

MMV activities

- Storage capacity needs to be matched with storage integrity
- coordinate MMV outputs with the following actions:
  - Regulatory Operations and Compliance,
  - Community Outreach and Communications,
  - GIS Systems and Predictive Applications and
  - Economic and Risk Assessment Modeling—making better decisions.

Seismic MMV Methods

- ## Active Doublet Method

Objective: Measure very small (< 1%) velocity changes occurring over time due to CO_2 movement.

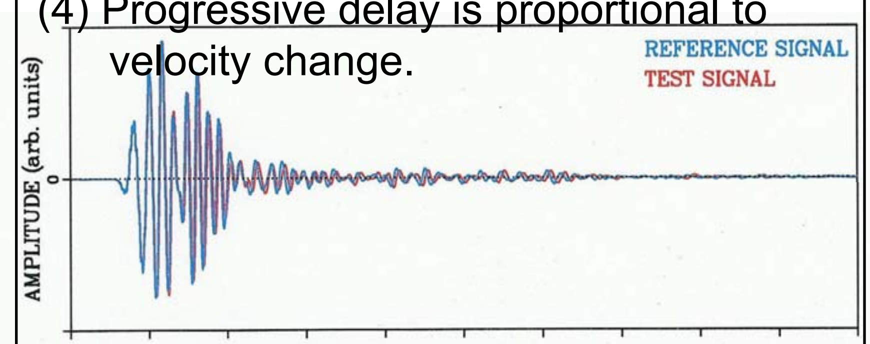
Procedure:

(1) Record signals from permanent source-receiver pairs.

(2) Repeated recordings at different times are "doublets".

(3) Analyze relative progressive signal delay of doublets.

(4) Progressive delay is proportional to velocity change.



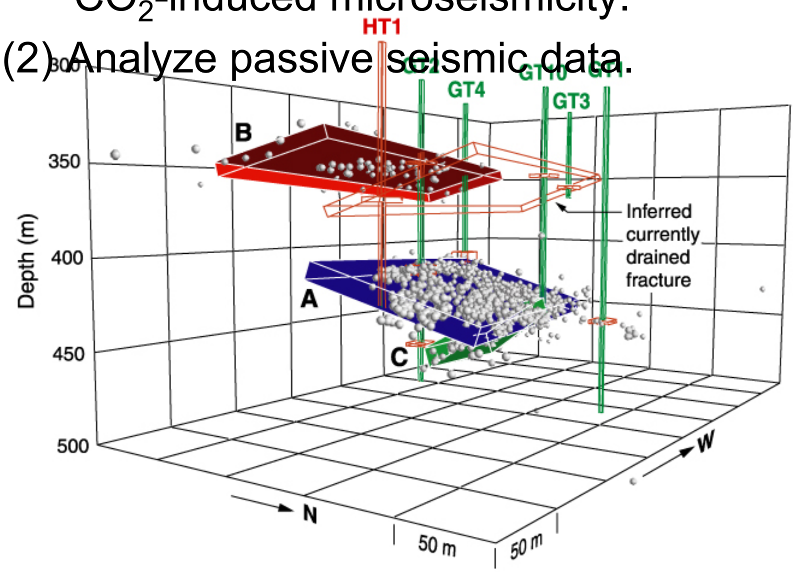
- ## Passive Seismic Method

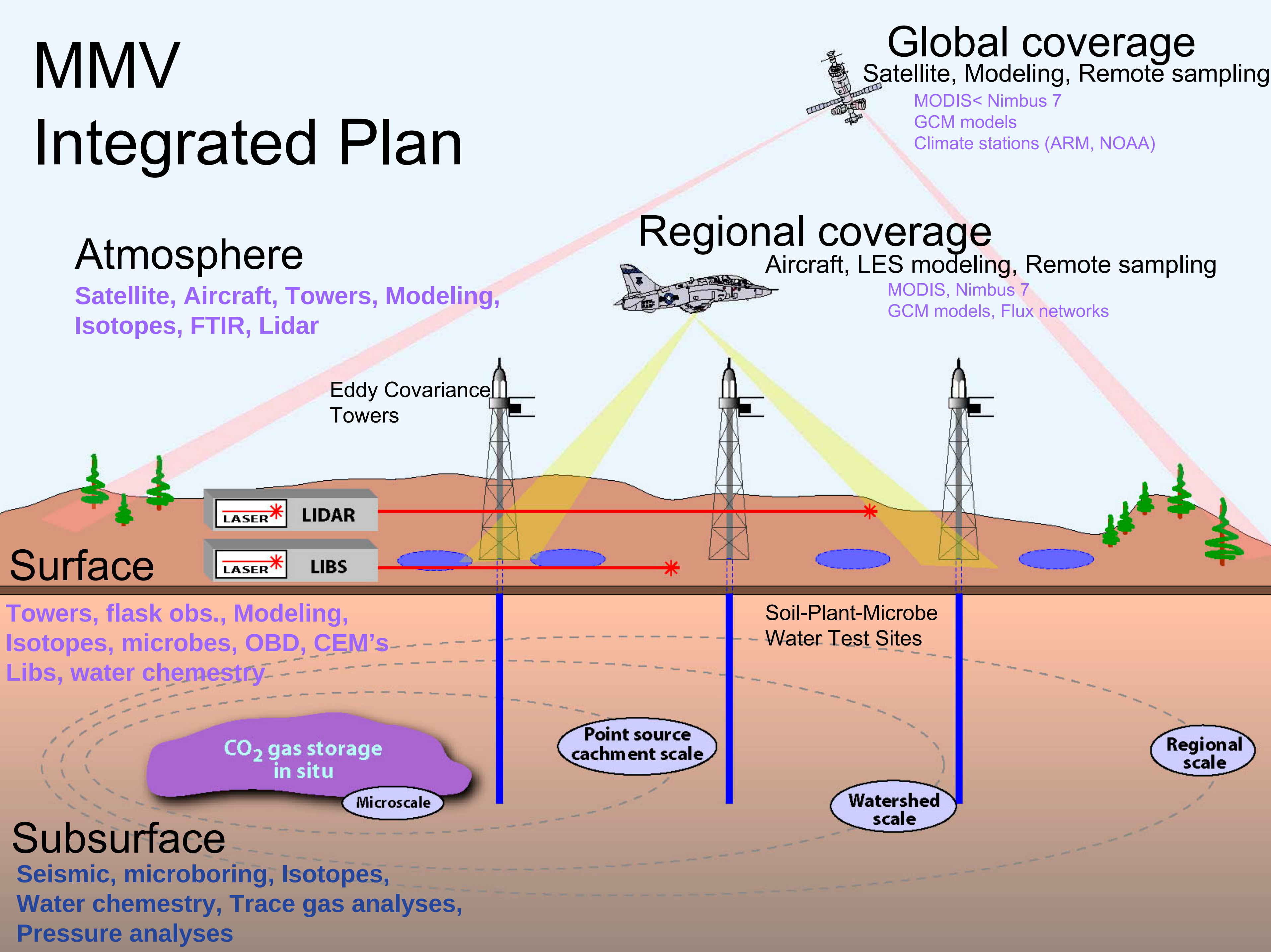
Objectives: Map fluid flow paths, monitor reservoir deformation and cap rock integrity.

Procedure:

(1) Place borehole seismometers at reservoir depth for months to record CO_2-induced microseismicity.

(2) Analyze passive seismic data.




MMV
Integrated Plan
Global coverage
Satellite, Modeling, Remote sampling
MODIS< Nimbus 7
GCM models
Climate stations (ARM, NOAA)
Regional coverage
Aircraft, LES modeling, Remote sampling
MODIS, Nimbus 7
GCM models, Flux networks
Atmosphere
Satellite, Aircraft, Towers, Modeling,
Isotopes, FTIR, Lidar
Eddy Covariance
Towers
LASER
LIDAR
LASER
LIBS
Surface
Towers, flask obs., Modeling,
Isotopes, microbes, OBD, CEM's
Libs, water chemestry
Soil-Plant-Microbe
Water Test Sites
CO2 gas storage
in situ
Microscale
Point source
cachment scale
Watershed
scale
Regional
scale
Subsurface
Seismic, microboring, Isotopes,
Water chemestry, Trace gas analyses,
Pressure analyses

Phase I
Public education and Outreach

Approach

- Materials Development (Action Plan, Web Site, Poster, Fact Sheets, etc.)
- Discussions/Roundtables with Key Decision Makers:
  - State Govt and Sequestration Advisory Committees
  - Environmental NGOs
  - Tribal Council Leaders
  - Economic Development Groups
  - -- Departments of Environmental Quality and EPA

Approach

- Establish Web Networks to Disseminate Information
  - Access to about 800 people
- Establish CO2 Networks
- Workshops/Symposia
- News Coverage

Web page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A new energy future for Montana, Idaho, South Dakota, Wyoming, the Pacific Northwest and the nation
Partner Log-In
Big Sky Carbon Sequestration Partnership
The Big Sky Carbon Sequestration Partnership is building a new energy future for Montana, Idaho, South Dakota, Wyoming, the Pacific Northwest and the nation. Led by Montana State University, the Big Sky Partnership is one of the U.S. Department of Energy's (DOE) seven regional partnerships. The Partnership is developing a framework to address carbon dioxide (CO2) emissions that contribute to climate change and working with stakeholders to create the vision for a new, sustainable energy future that cleanly meets the region's energy needs. Because energy is not an optional commodity, carbon sequestration will play an important role.
The phase I work of the Partnership clearly identified the geological similarities among Montana, Idaho, Wyoming, Washington, and Oregon. There are similar land use patterns and cropland practices among these states and the Canadian provinces. Thus as we proceed into Phase II, we have expanded the Partnership to include the states/provinces with similar and contiguous geological and terrestrial sinks. This expansion is also justified by the common economic interests of these States, including many regional energy companies operating across States and Provincial lines.
For more information on the Big Sky Partnership's efforts, visit the links below:
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Internet
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Score card

- Presentations: 48
- Poster Sessions: 10
- Workshops/Symposia: 8
- Stakeholder Meetings: 21
- External News Articles: 9
- Internal News Articles: 5

Lessons

- Climate change is 800 lb gorilla
- Sequestration associated with terrestrial and opportunities for farmers and foresters
- General interest in geologic - some skepticism, little overt hostility
- Questions about permanence/safety
- Economic development matters a lot

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