Geologic Disposal of CO_2 in Deep Saline Formations and Deep Coal Seams in the Ohio River Valley

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Neeraj Gupta

Battelle

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

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Pacific Northwest National Laboratory
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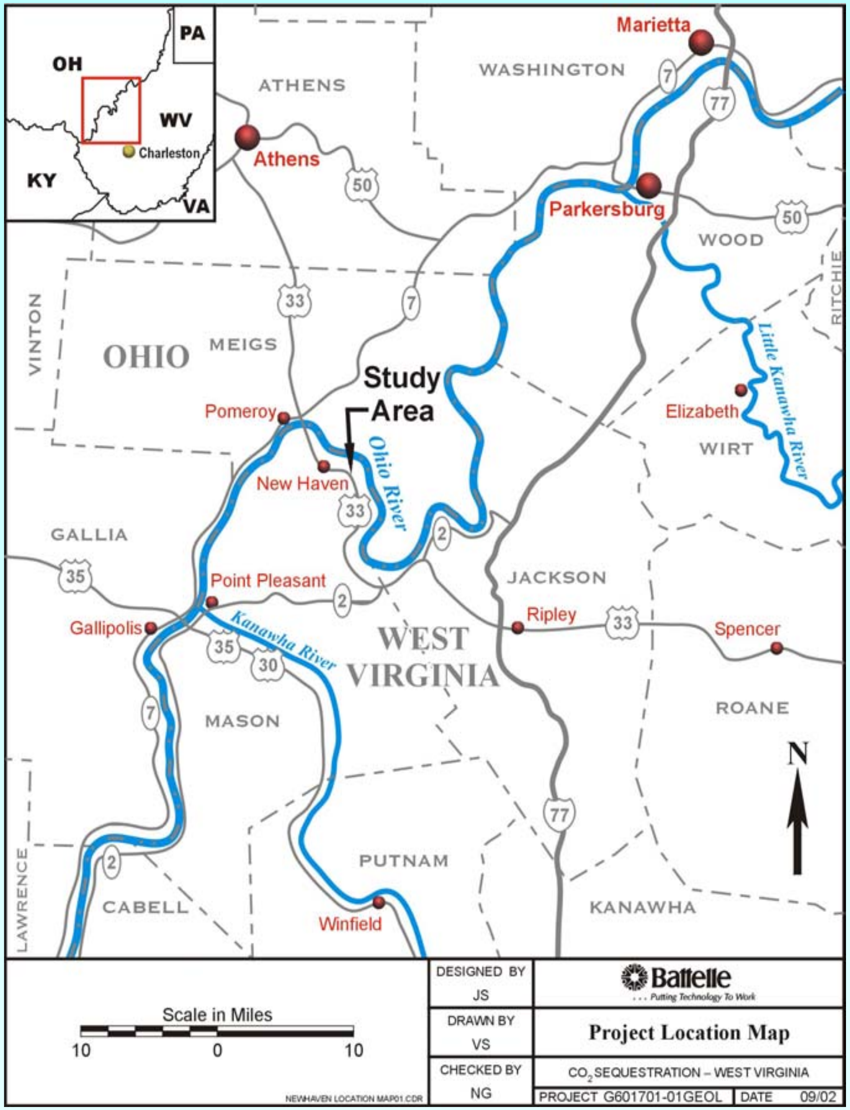
Outline

- What is saline formation storage and what is the Ohio River Valley project?
- What are the key issues?
  - Geologic and scientific aspects
  - Public perception and outreach
  - Economics of CO_2 storage
- Conclusions

Ohio River Valley CO_2 Storage Project

- During summer of 2002 DOE selected a proposal led by Battelle and supported by AEP, BP, OCDO, and Schlumberger to determine the feasibility of a geologic sequestration demonstration
- AEP offered the use of its Mountaineer Power Plant in West Virginia as the host site for this research project
- The project was formally announced by the Secretary of Energy at the National Coal Council Meeting on November 21, 2002
- The primary objective of the project is to characterize the site and its vicinity for CO_2 storage potential in various geologic reservoirs
- The project is designed to be the first phase of a long-term experiment for assessment of scientific aspects and demonstration of deployment of geologic sequestration technologies

Mountaineer Plant Location



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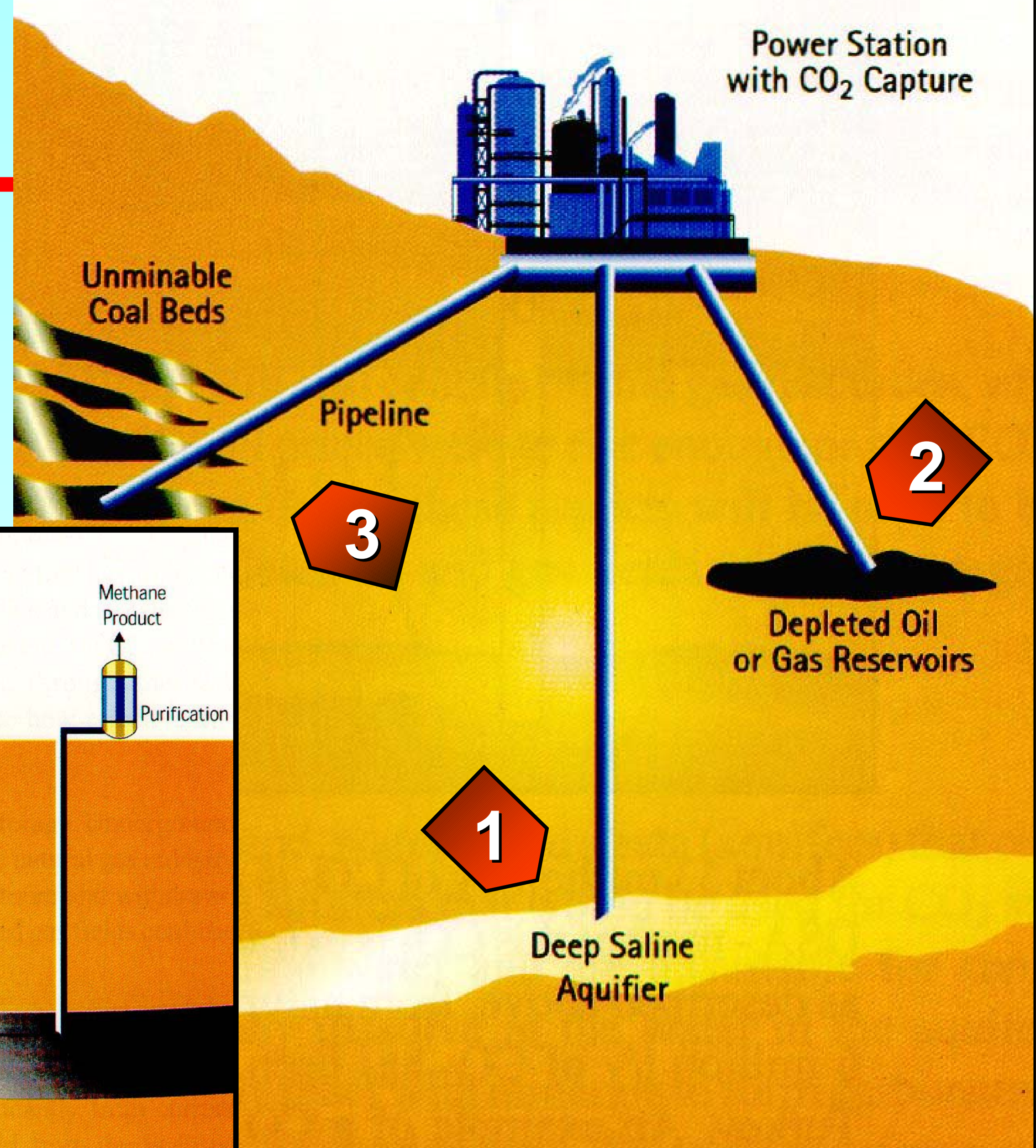
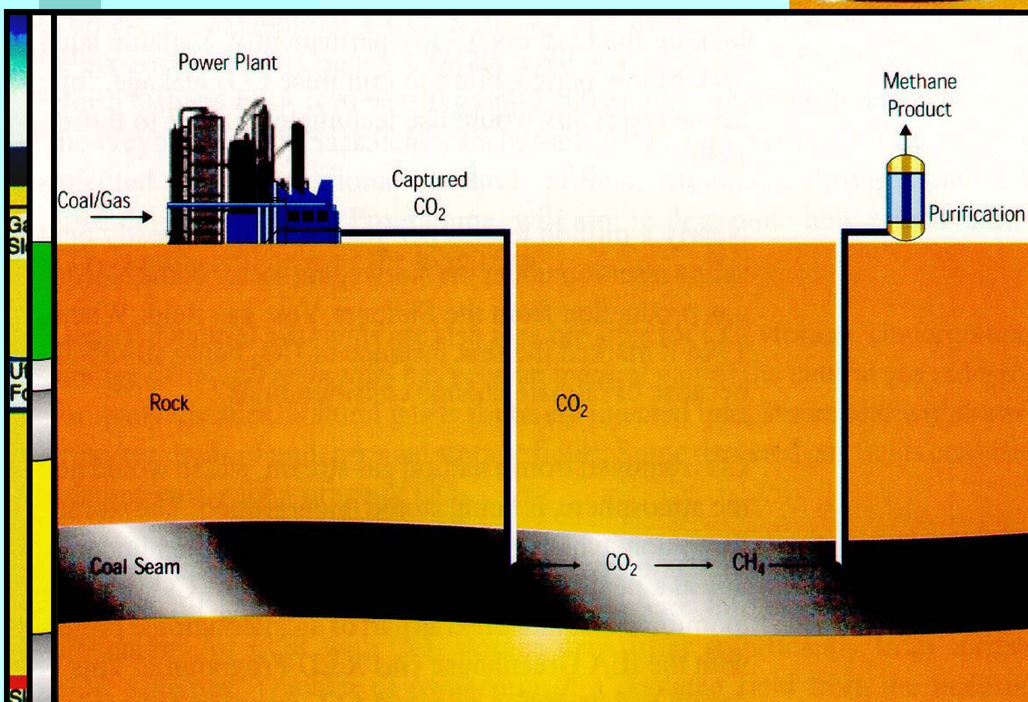
What is Geologic Sequestration?

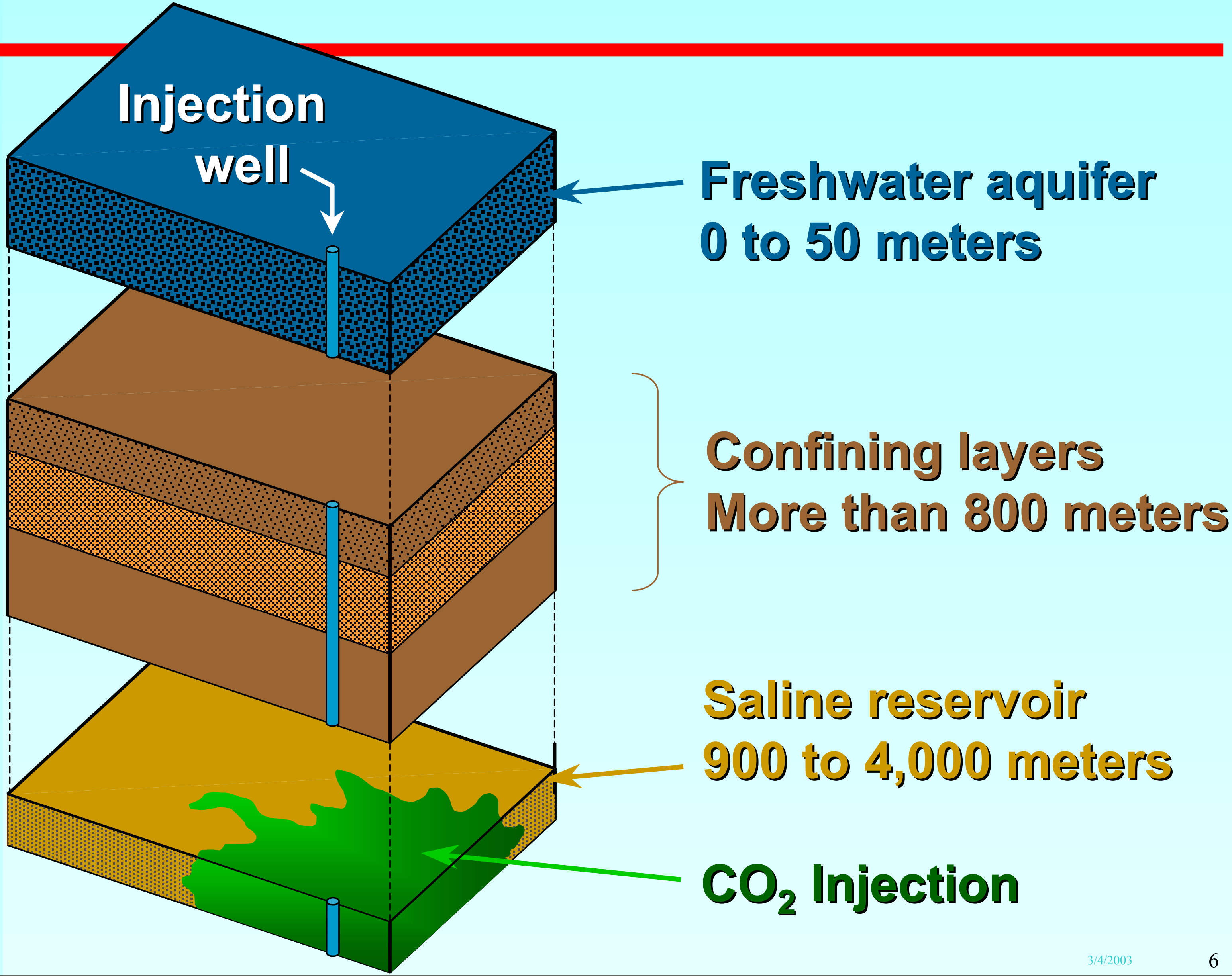
1. Deep saline aquifers
2. Oil & gas reservoirs
3. Unmined coal beds





(IEA Greenhouse R&D Programme, 2001)

CO_2 Disposal into Deep Saline Aquifers



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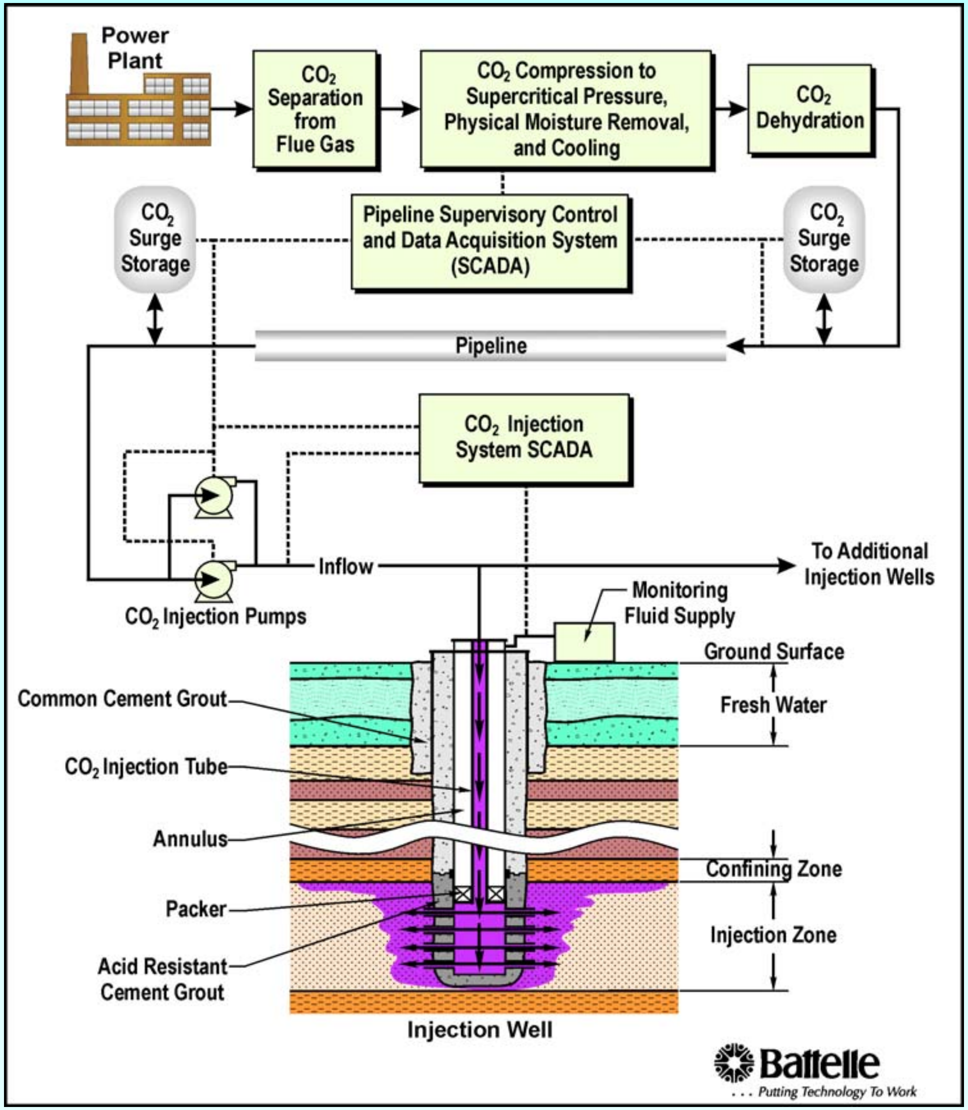
Geologic Sequestration System Components



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Geologic Storage is Already Happening - Sleipner West Platform

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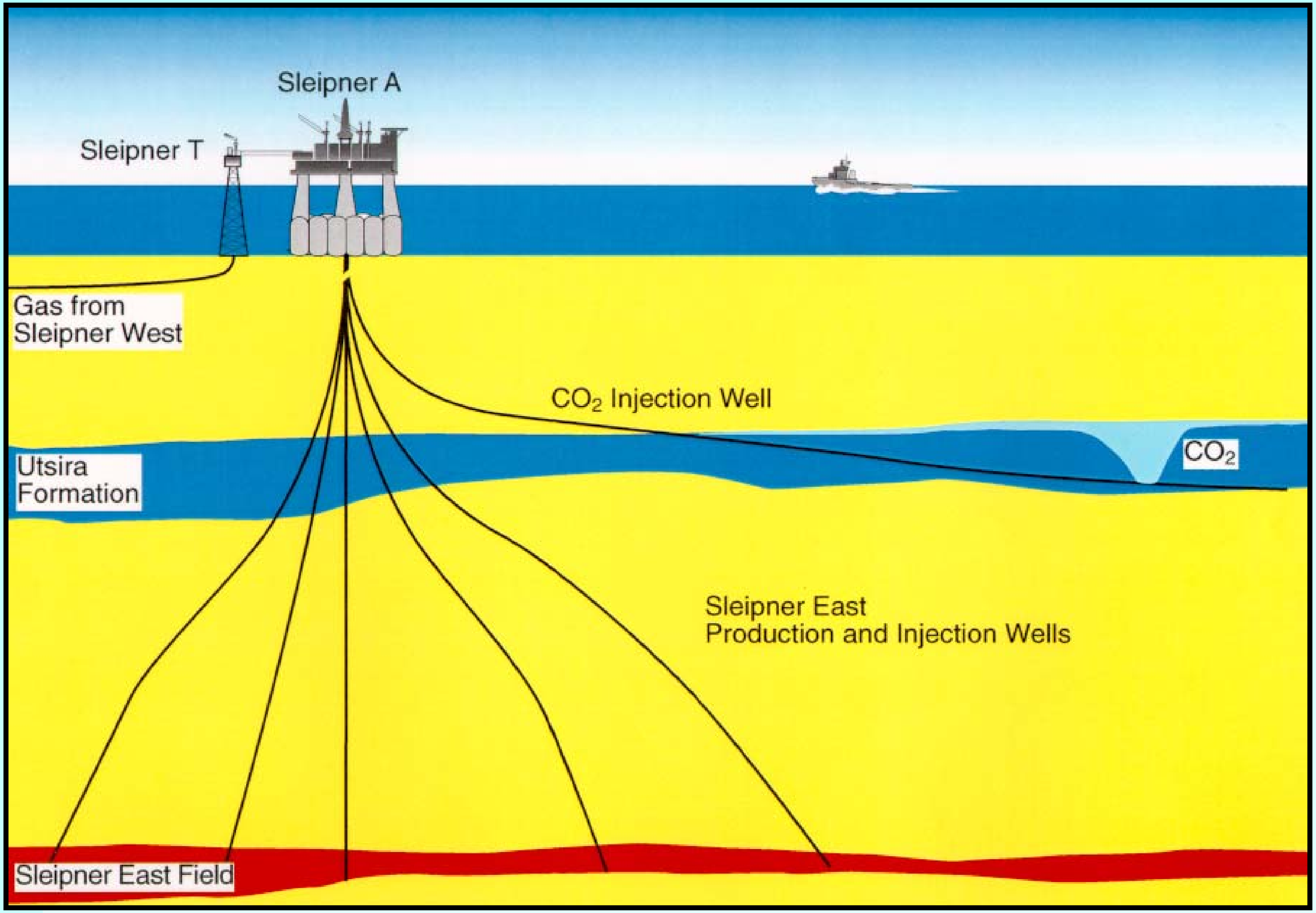
Sleipner West Schematic



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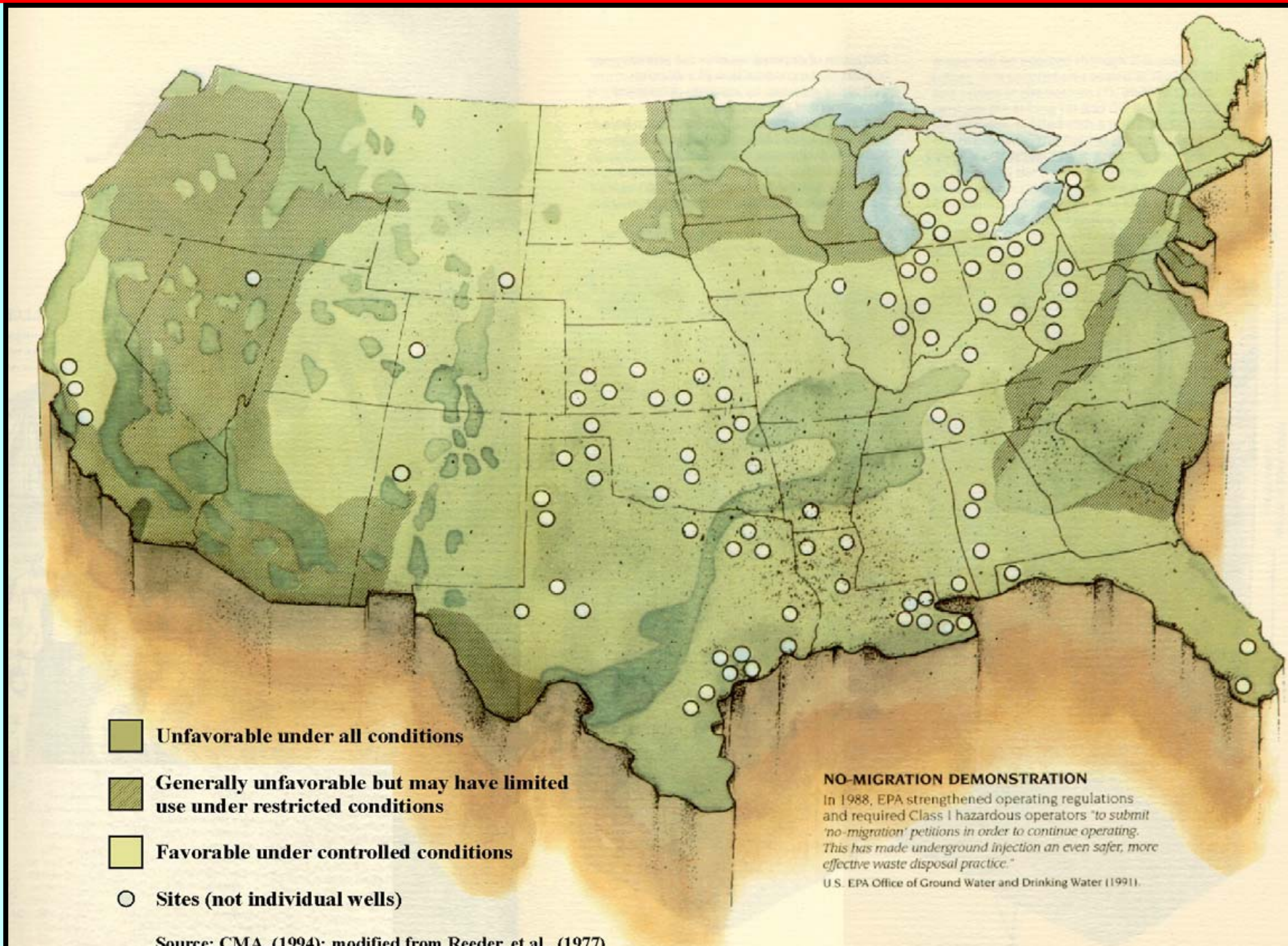
Geologic and Scientific Aspects

- The site specific characterization for CO_2 injection reservoirs and caprock formations should be based on
  - Regional geologic and capacity assesment
  - Seismic surveys and structural geology
  - Drilling stratigraphic test wells
  - Wireline logging, coring, testing, and brine collection
  - Laboratory analysis and interpretation of rocks and brine
  - Reservoir simulations, risk assessment etc
- Field efforts should be coordinated with the basic science research to address the fate of injected CO_2

Geologic Issues – Sinks and Capacity



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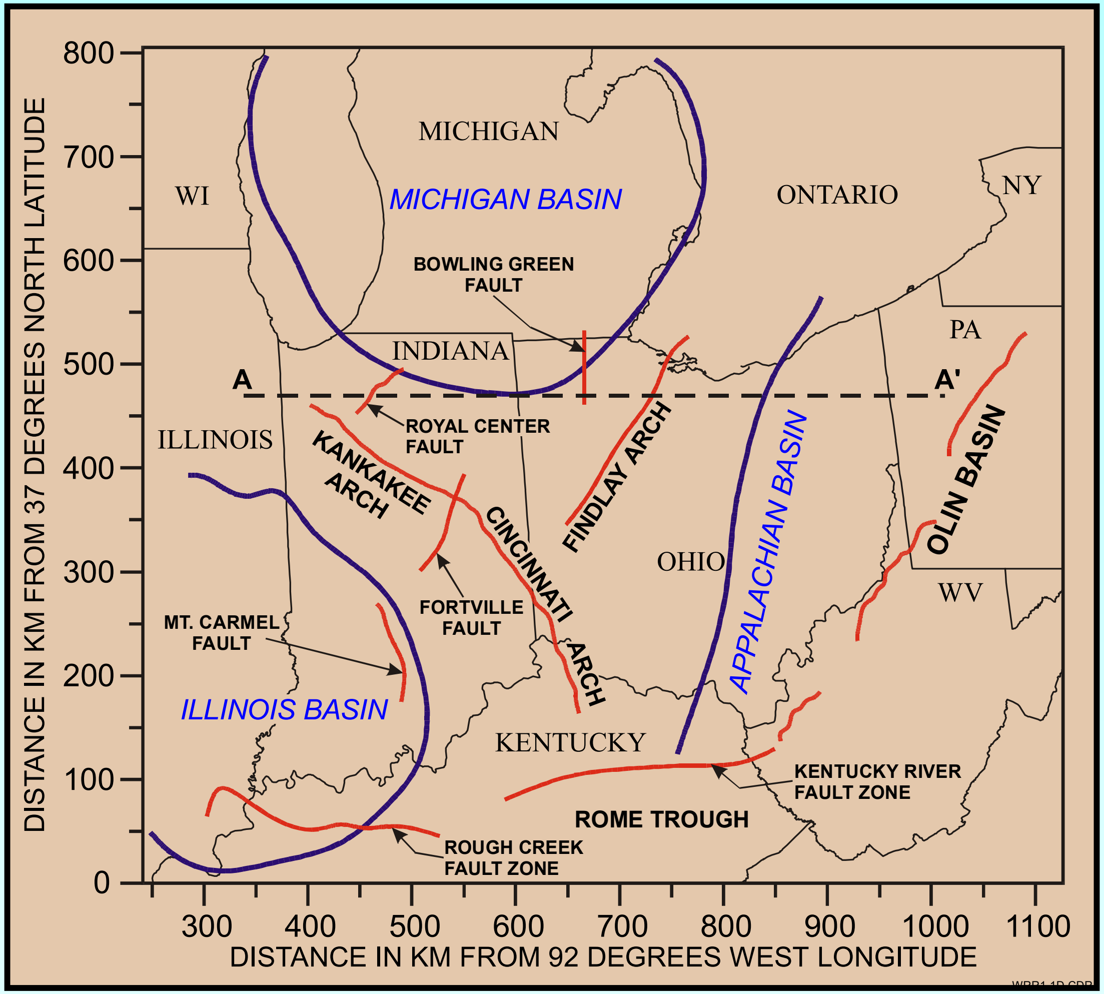
Geographic And Geologic Features in Midwestern USA

Several potential sinks for geologic storage are present in the deep sedimentary basins in the region



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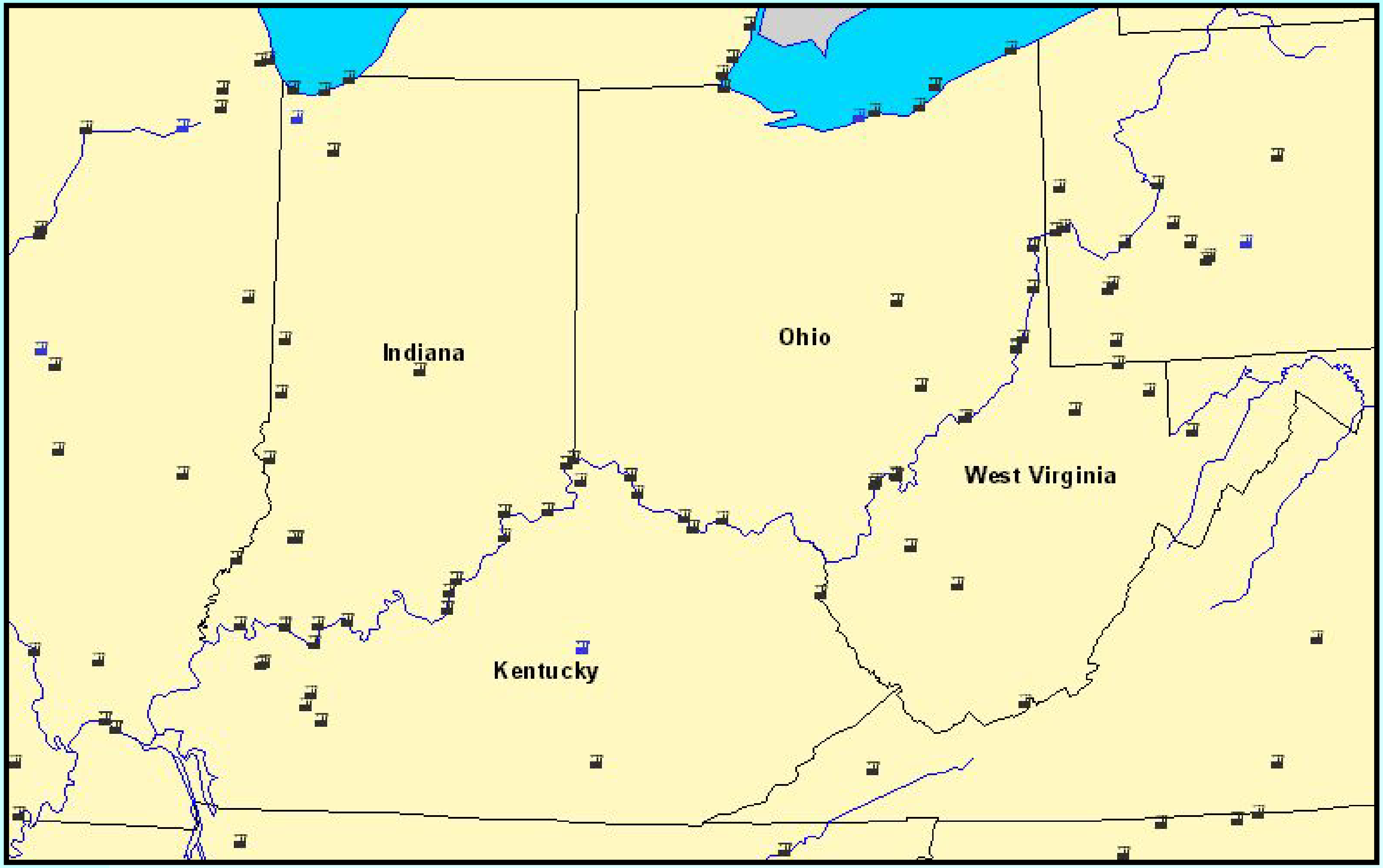
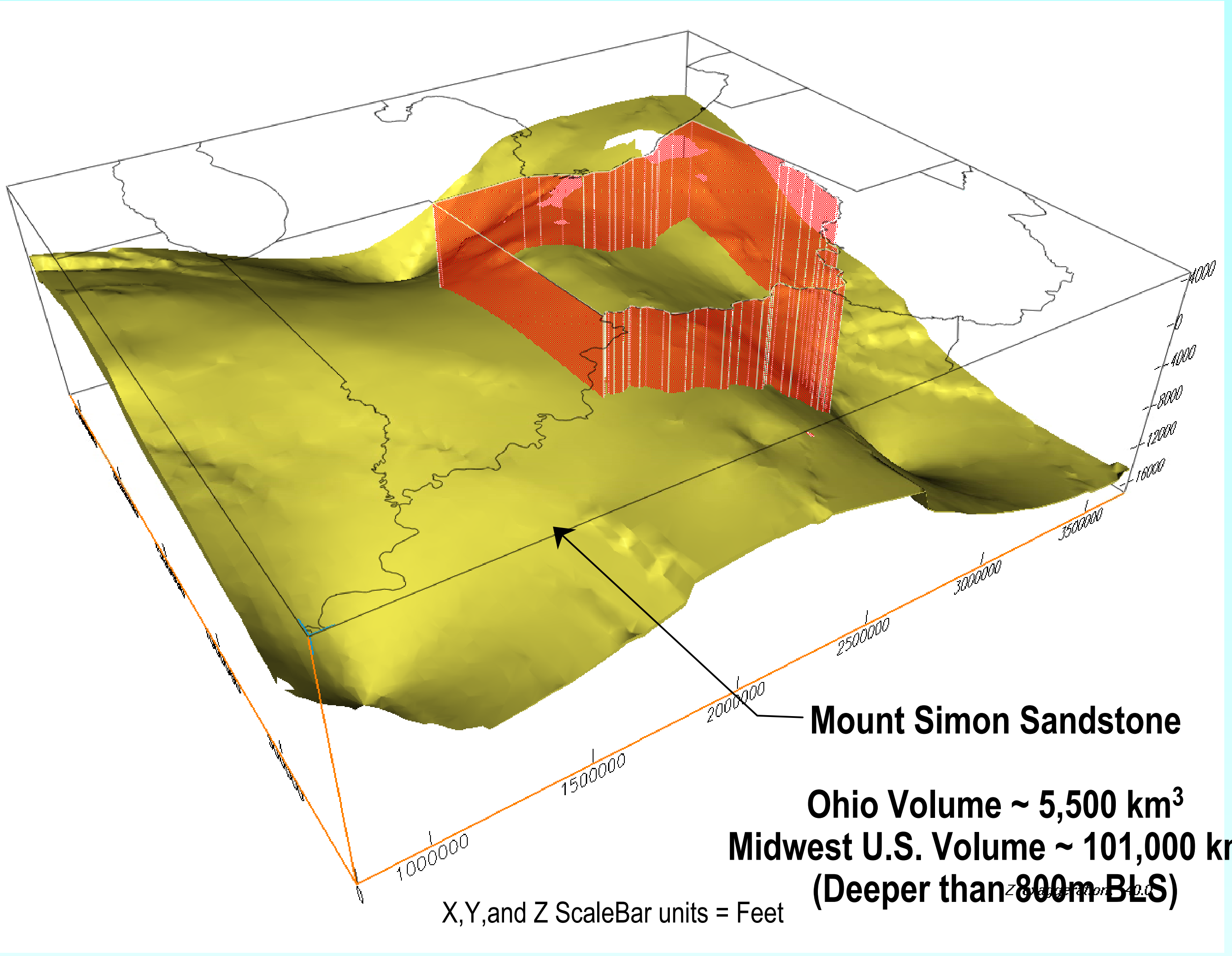
Location of Power Plants in the Midwest USA



There are numerous other sources of CO_2 emissions in the region

3D Block Diagram of Mount Simon Sandstone – A Potential Storage Reservoir



Regional CO_2 Storage Capacity Calculation for Mt. Simon and Rose Run Sandstones

Storage Capacity = Vp x Storage Efficiency x density of CO_2

(Based on Joule II Report)

- Vp = Bulk aquifer volume x Net:Gross x Porosity
- Bulk aquifer volume from regional geologic data
- Net:Gross = 50 to 95%
- Porosity = 5 to 15%
- Storage efficiency = 6%
- Density of CO_2 = 700 kg/m^3

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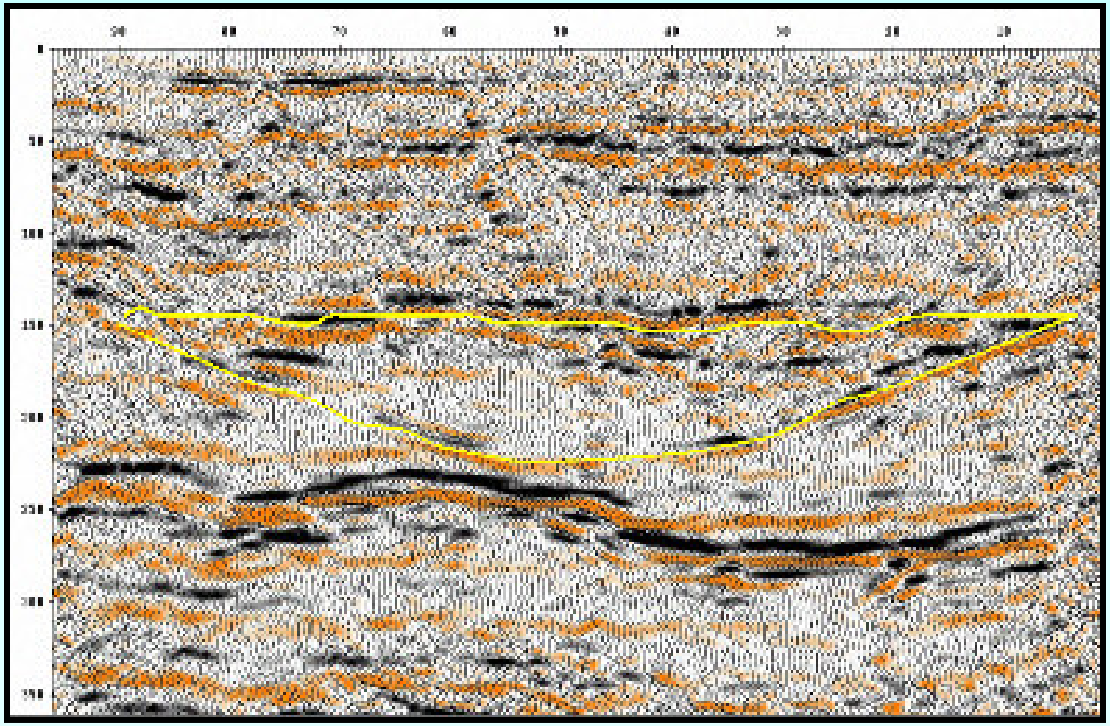
Estimated Regional CO_2 Storage Capacity in two Midwestern U.S. Formations

- Based on Joule II equation for continuous reservoirs:
  - Mt. Simon Sst. (Ohio) 6 – 34 Gt
  - Mt. Simon Sst. (Midwest) 115 – 655 Gt
  - Rose Run (Ohio) 1.5 – 8.6
  - Rose Run (Midwest) 8.5 - 48
- Power Plant Emissions (Ohio) ~150 Mt/Yr
- Conclusion: There is enormous potential capacity on a regional scale. ***However, local-scale injectivity needs to be verified due to geologic heterogeneity.***
- Note: Rose Run is a source of oil/gas

Geologic Assessment - Seismic Survey and Data Interpretation

Example of Seismic Survey Truck

Example of Seismic Survey



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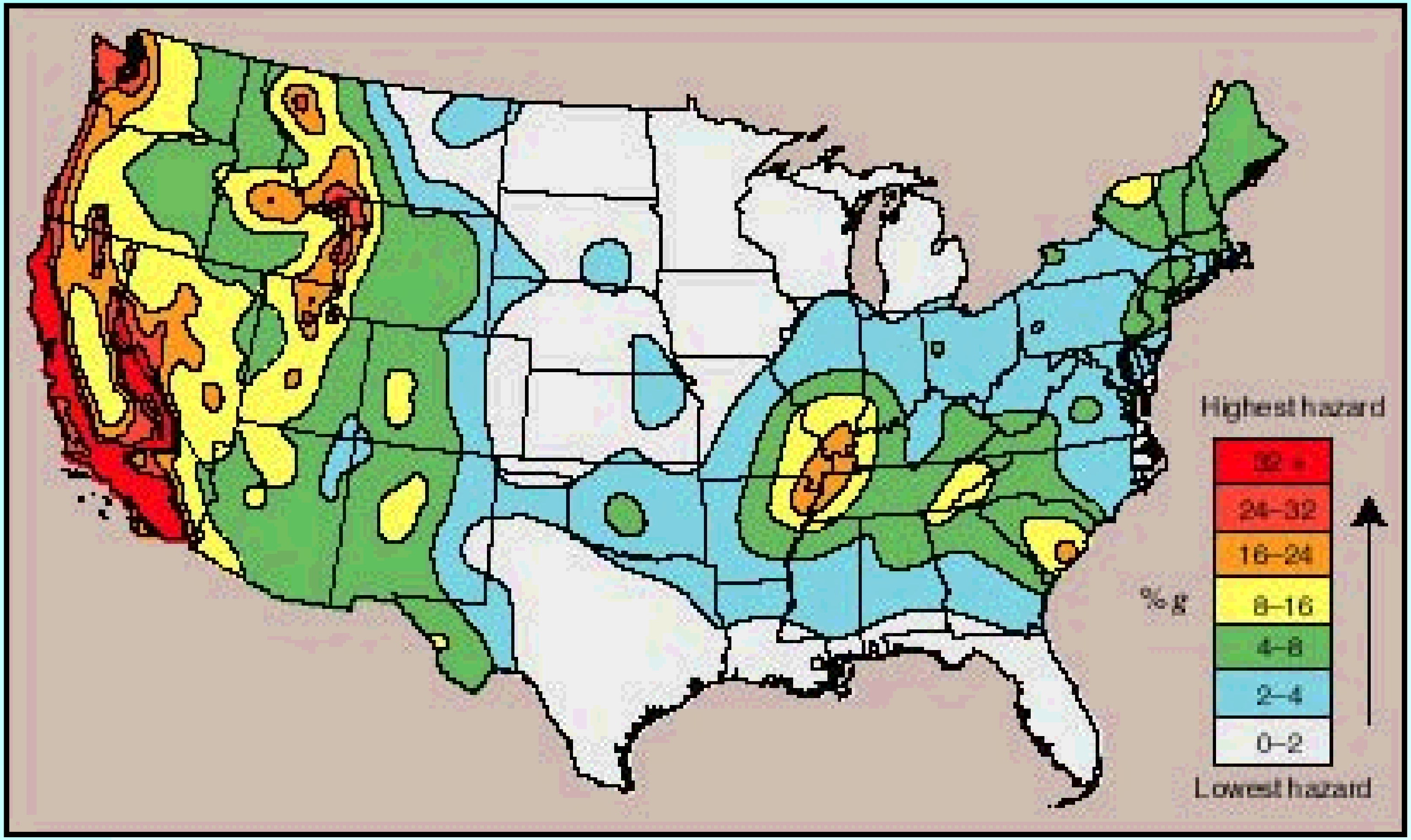
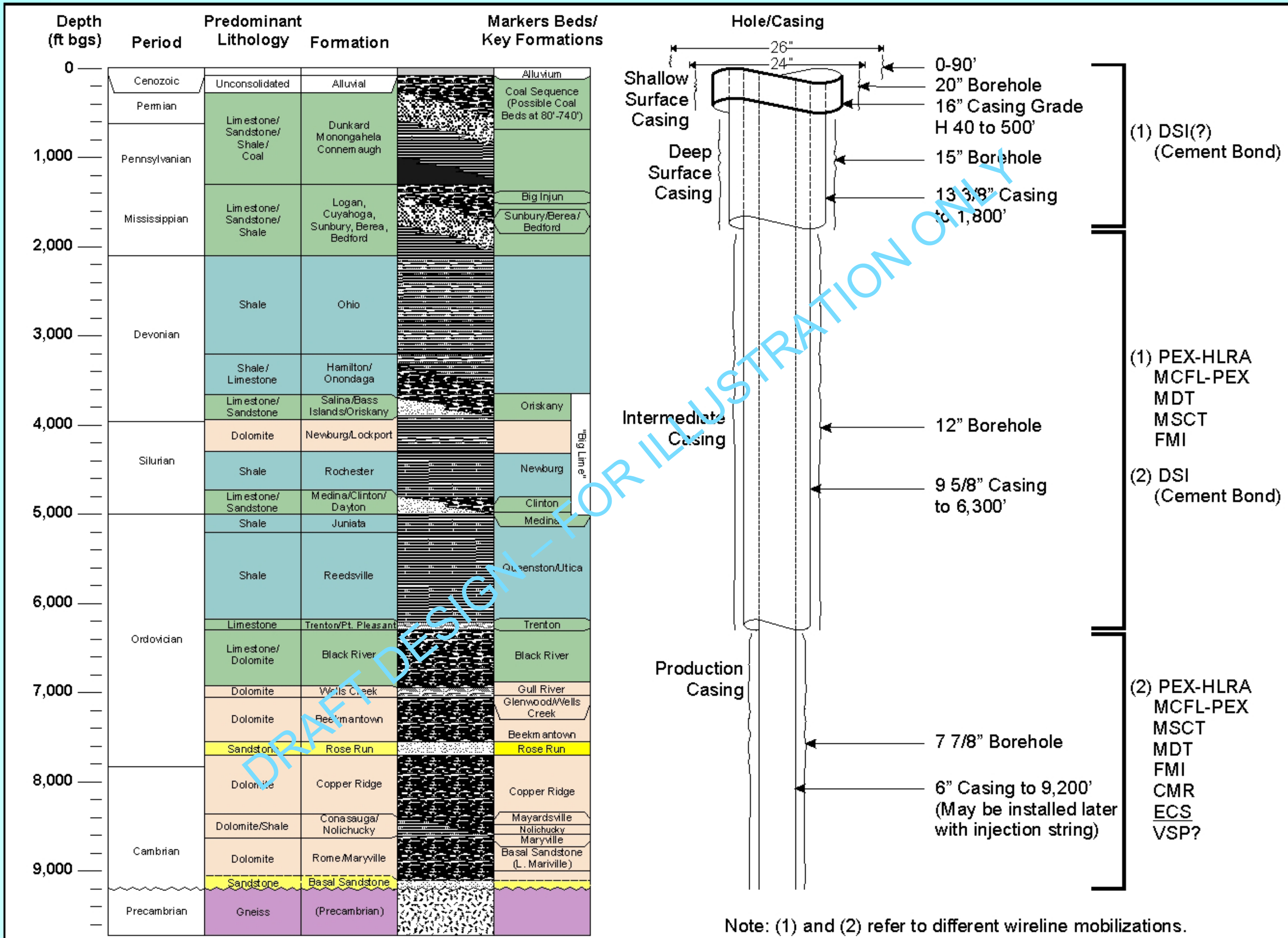
Seismic Hazard Map for the United States (USGS National Seismic Hazard Mapping Project)



Most parts of midwestern USA are in seismically stable zones

Typical Design for the Deep Test Well and Wireline Logging



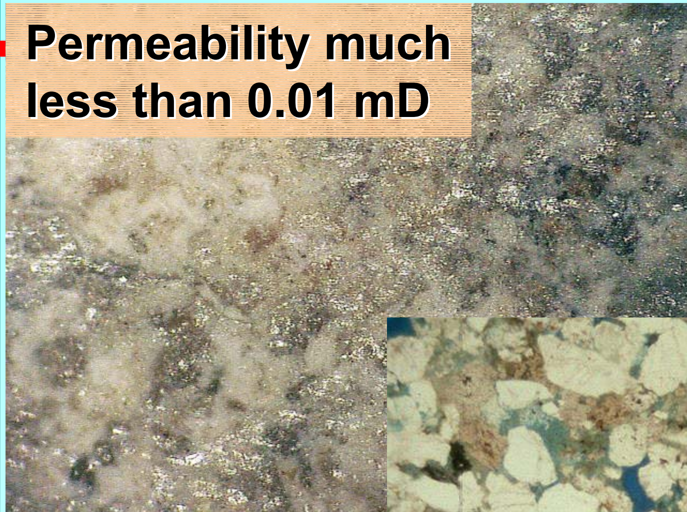
Drilling the Deep Test Well

Example of Drill Rig

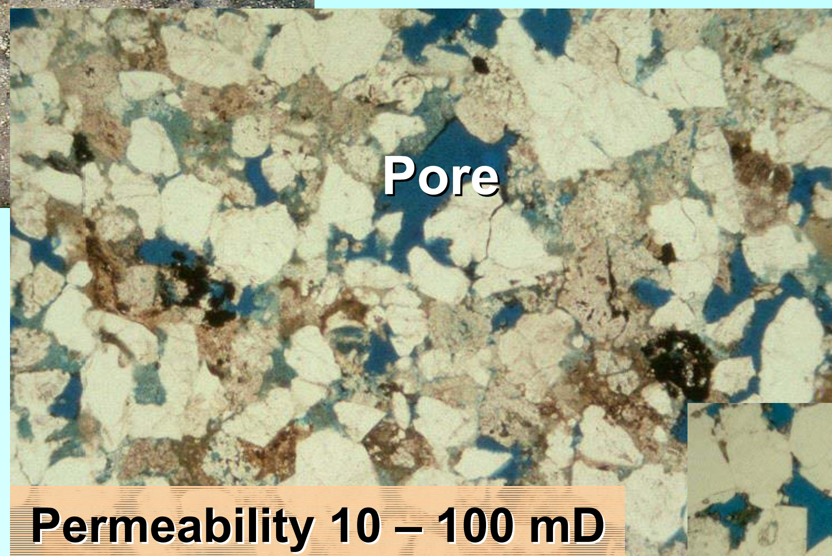
Drilling a Test Well - Regulatory Issues

- The overlap of oil and gas regulations for drilling within the framework of power industry regulations can provide interesting challenges including:
  - Management of drilling related wastes
  - NPDES permits compliance
  - Stormwater management
  - Wellhead protection
  - Bulk fuel storage
  - Chemical storage

Microscopic View of Sedimentary Rocks

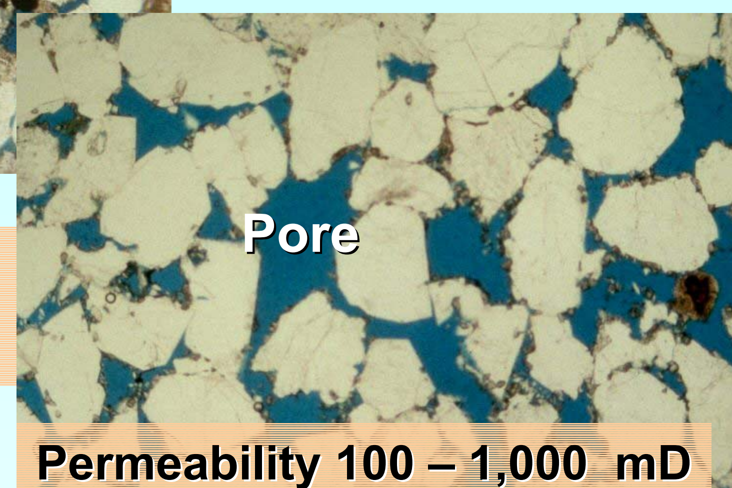


Shale with Extremely Low Permeability Forms Good Caprock



Sandstone with Medium Permeability Forms Good Host Reservoir

Sandstone with High Permeability Forms Excellent Host Reservoir



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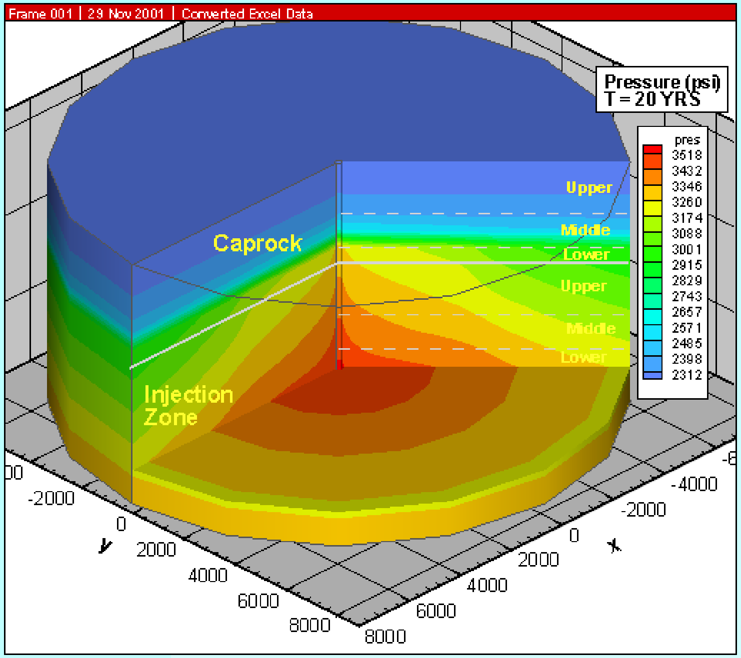
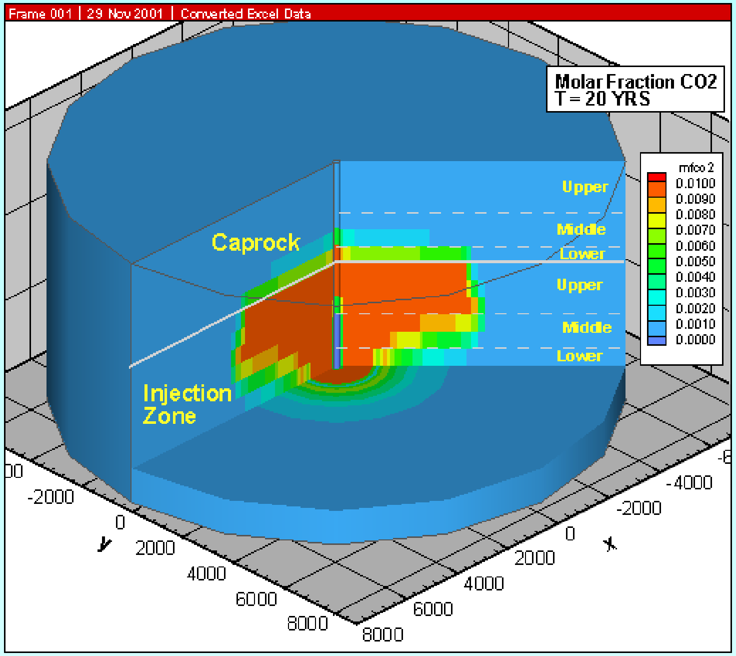
Understanding the Fate of CO_2 and Determining Facility Design and Operational Parameters?





- Simulated pressures are used to determine safe and optimum injection rates and determine number of injection wells
- Simulated CO_2 distribution is also used to predict CO_2 movement in the subsurface and design an appropriate monitoring plan

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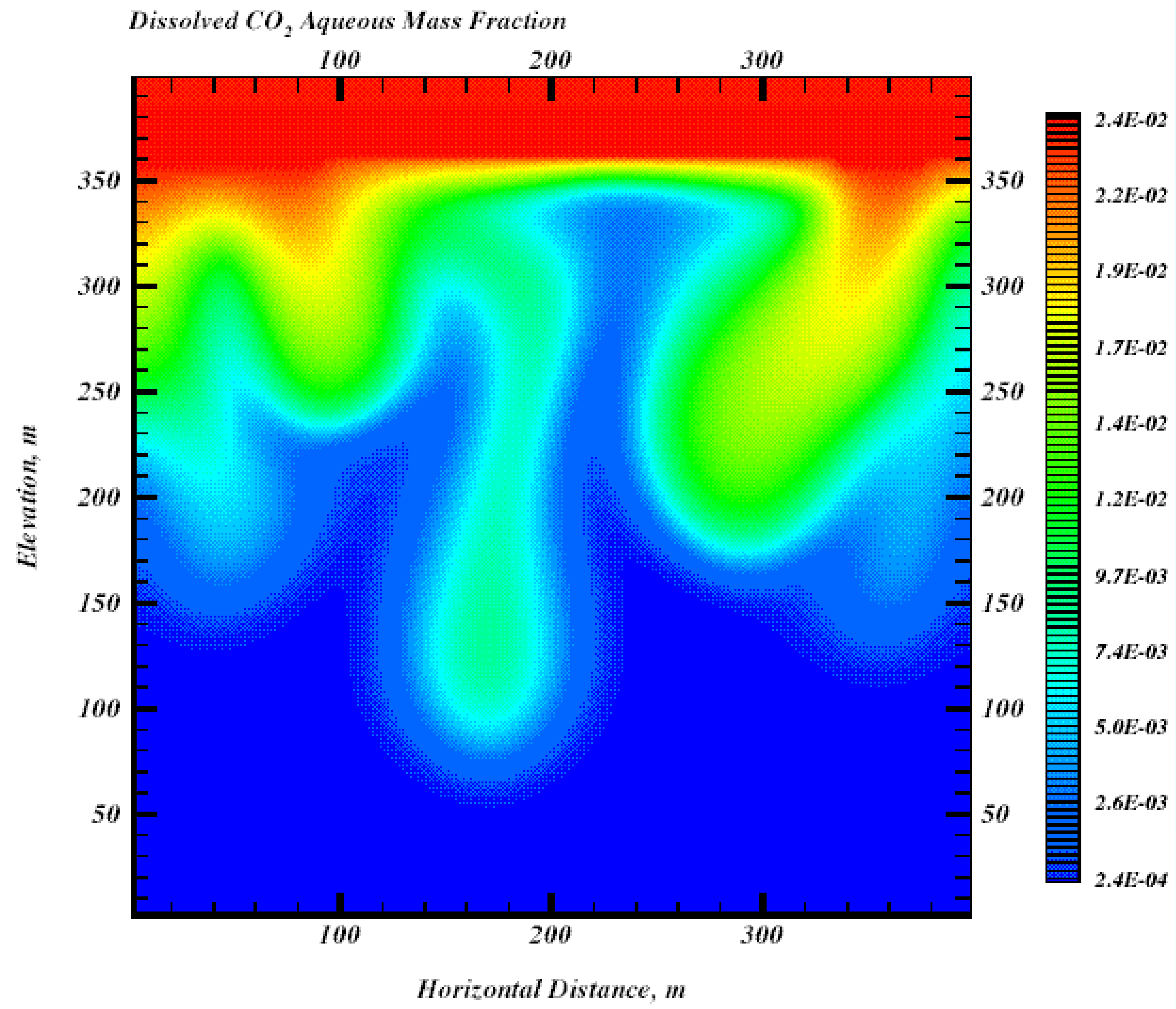
Understanding CO_2 behavior in the Reservoir – Advanced Reservoir Simulations

- Example - Dissolution of CO_2 may be further enhanced by the formation of Rayleigh convection cells at field-scale due to density differences



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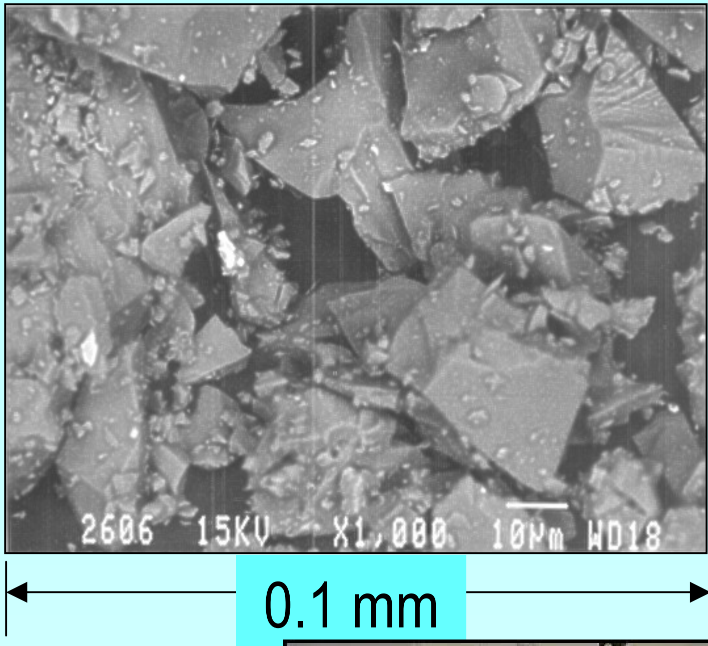
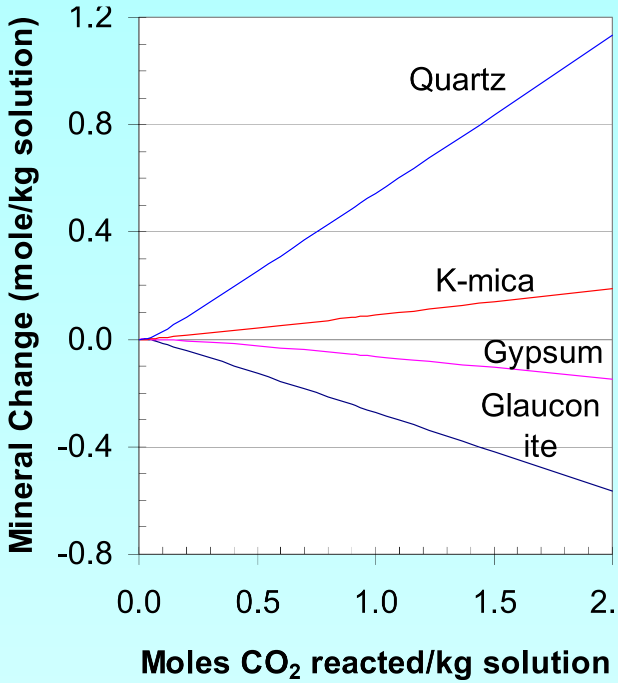
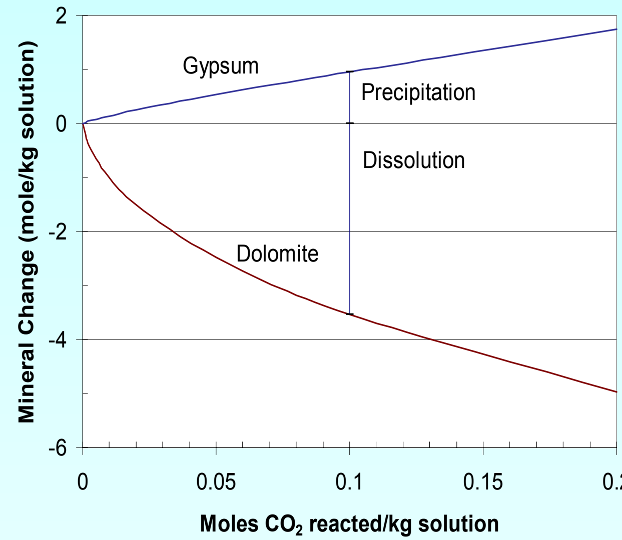
(Courtesy – Pacific Northwest National Laboratory)

Geochemical Behavior of CO_2 – Experiments and Modeling







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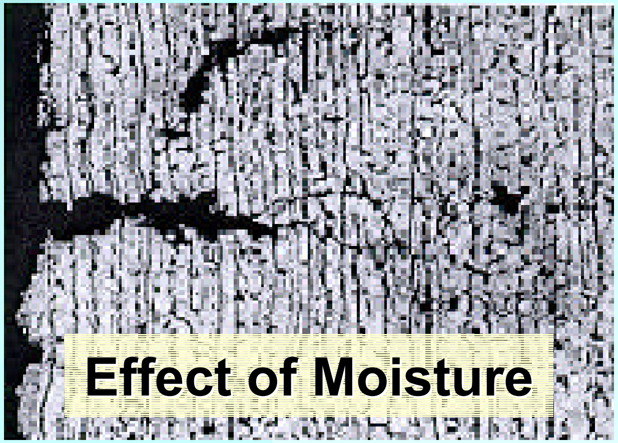
Pipeline Transport Aspects

- Operating Pressure 1,500 to 2,000 psi
- Carbon Steel, buried most of the length with block valves and booster stations
- ASME Standard B31.4 Design
- High non-condensable gas reduces transport efficiency (see table below)
- Dehydration is essential to prevent corrosion in carbon steel

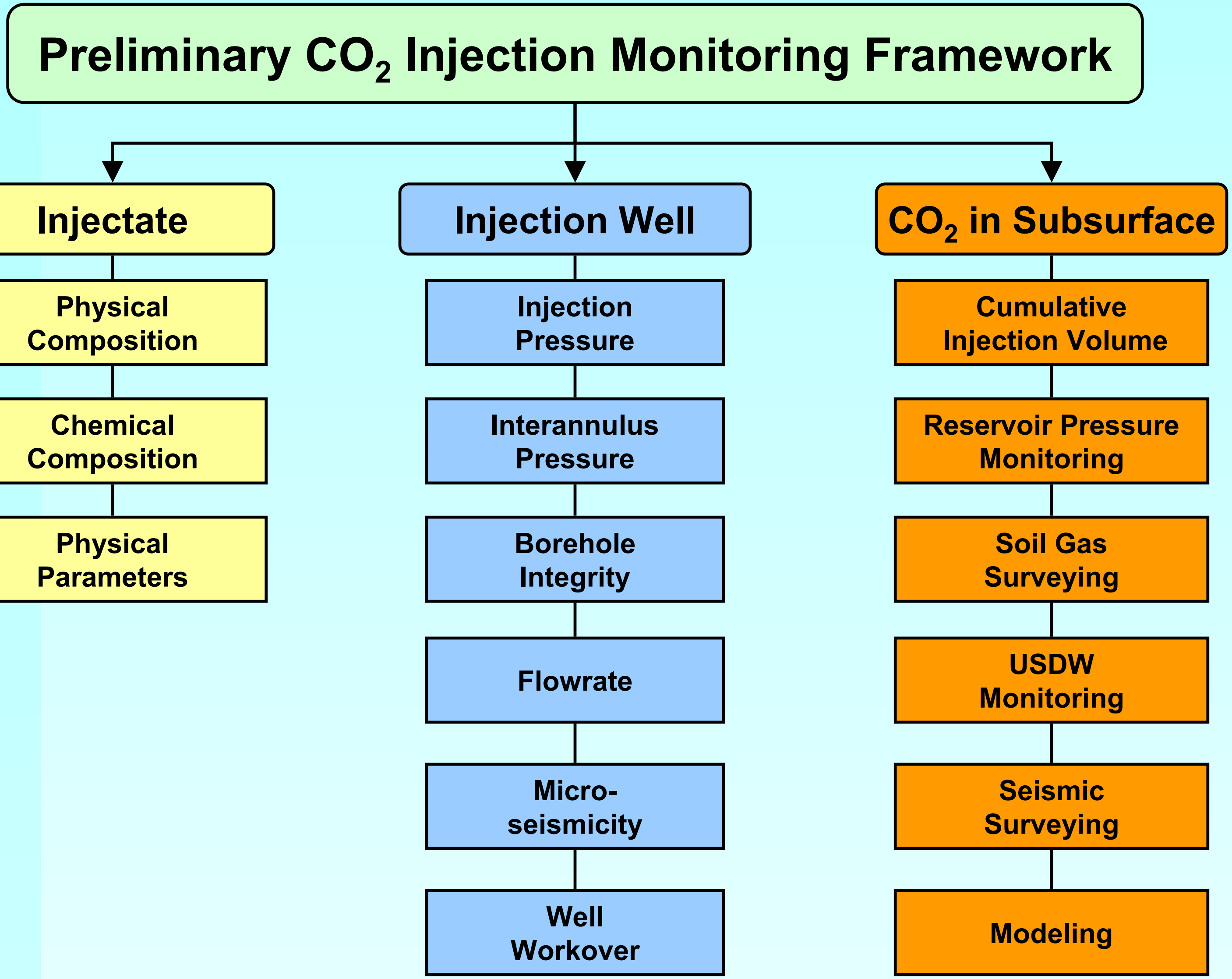


Composition of Flowing Fluid	Flow Velocity at Design Pressure Drop (m^3/s)	Relative Flow Loss
CO_2	98.3	1.00
CH_4	90.8	0.92
N_2	63.9	0.65
CO_2 + 10% CH_4	82.3	0.84
CO_2 + 10% N_2	77.0	0.78

Monitoring Strategies and Tools

- A detailed plan is needed to monitor the fate of injected CO_2 and provide a protocol for future demonstrations
- The monitoring plan should take into account the:
  - Monitoring required under UIC permits – Regulatory Monitoring
  - Monitoring needed to address scientific and carbon management aspects of CO_2 sequestration – Performance Assessment Monitoring
- Both surface monitoring and in-situ monitoring in deep wells should be considered
- The experimental monitoring technologies need to be tested

An Example of Systematic Monitoring Framework



Framework for – Risk Assessment and Mitigation

- Potential risk to human health and the environment associated with the capture of CO_2 and its geologic disposal might result from:
  - capture, cleaning, and effluent handling system
  - CO_2 leakage from the geologic structure
- Current project is focused on the scientific exploration of the acceptability of the geologic structure for CO_2 disposal, therefore, the risk assessment will focus on potential risks associated with CO_2 leakage

Risk Assessment – Proposed Approach for Ohio River Valley Project

- Follow EPA/NAS 4-Part Risk Assessment Paradigm (see Figure)
- PNNLCARB model to evaluate hazards associated with leaking CO_2 concentrations and fluxes (combines probability data and consequence data)
  - Risk = $P_H C_H$
  - P_H is the probability (frequency) of occurrence C_H is the consequence score assigned to the predicted hazard (i.e., emission flux or concentration in an environmental medium)
- STOMP model will be used to assess potential leakage fluxes for those pathways addressed by the STOMP model.
- Stand-alone atmospheric model may be used if more in-depth atmospheric dispersion analysis is required

HAZARD ASSESSMENT

Identify/document (from scientific literature) potential health hazards associated with exposure to CO_2 and chemical co-constituents

DOSE RESPONSE ASSESSMENT

Identify/document (from scientific literature) health-based benchmarks (NIOSH/OSHA/ACGIH Exposure Limits in Air, Reference Doses, Cancer Slope Factors) that describe the relationship between exposure and health effect for CO_2 and chemical co-constituents

EXPOSURE ASSESSMENT

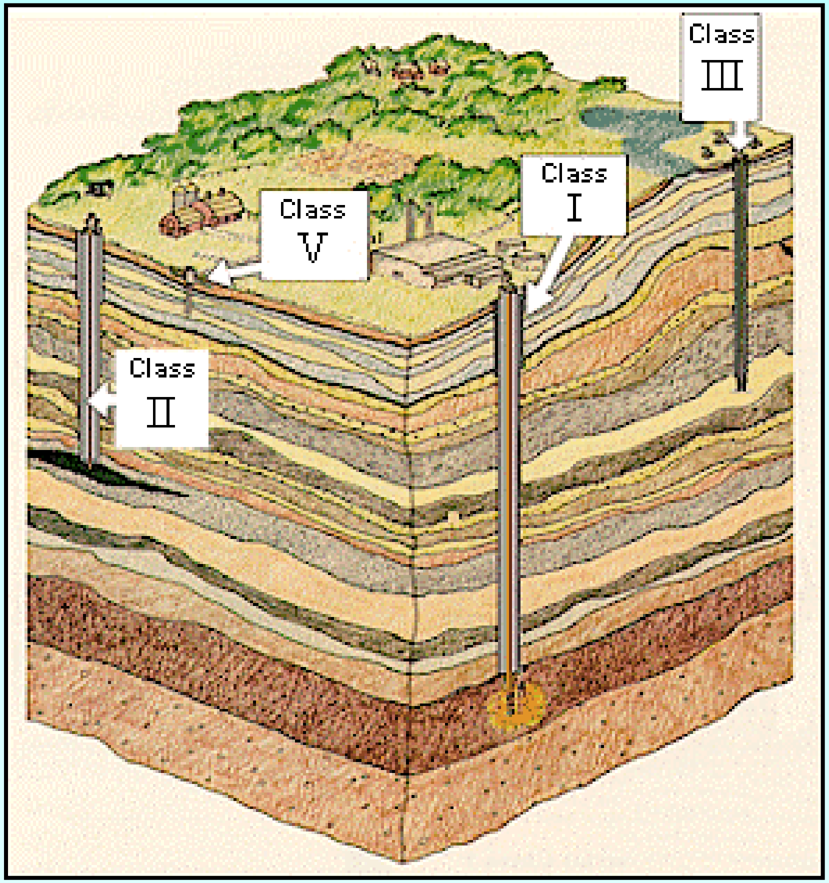
Use models to ***predict*** possible concentrations and extent of (CO_2 and co-chemicals) in the environment (air, water, soil) resulting from CO_2 leakage

RISK CHARACTERIZATION

Develop quantitative estimates of the magnitude and probability of adverse health effects resulting form leakage by comparing predicted concentrations or doses to health-based benchmarks

Dominant Regulatory Issues

- Injection wells are regulated under the U.S. EPA's Underground Injection Control Program, administered in WV by Office of Water Resources, Division of Environmental Protection.
- Many other regulations apply to drilling, construction, monitoring etc.
- New regulations may be needed for CO_2 injection for CO_2 trading purposes



Types of Injection Wells

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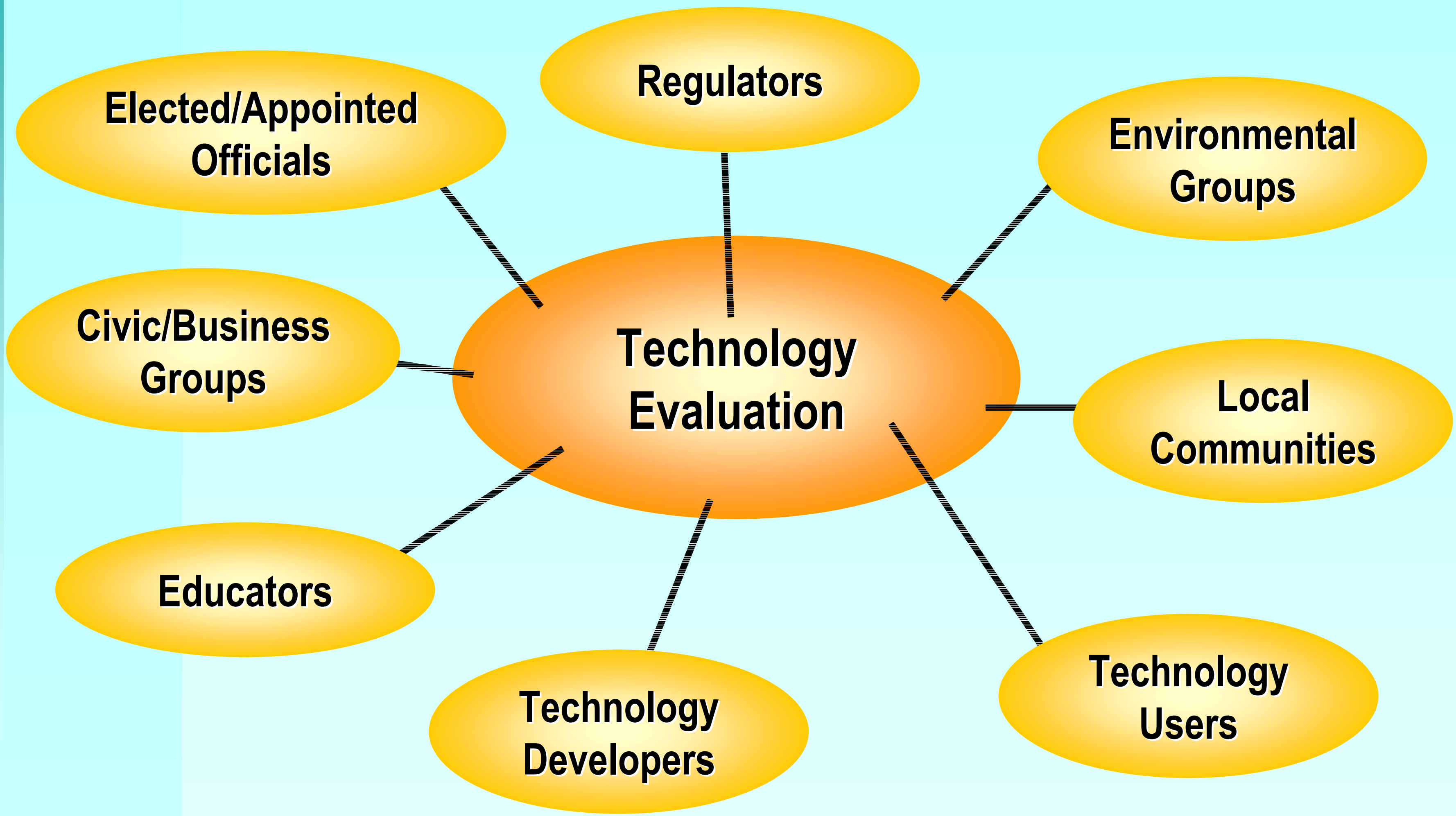
Stakeholder Outreach

- Technical progress on this subject must be accompanied by a strong outreach and stakeholder component at national, regional, and local levels
- Providing information to stakeholders in a timely manner is crucial for ultimate success of the project
- Listening to stakeholder and taking actions to address any issues of concern are important

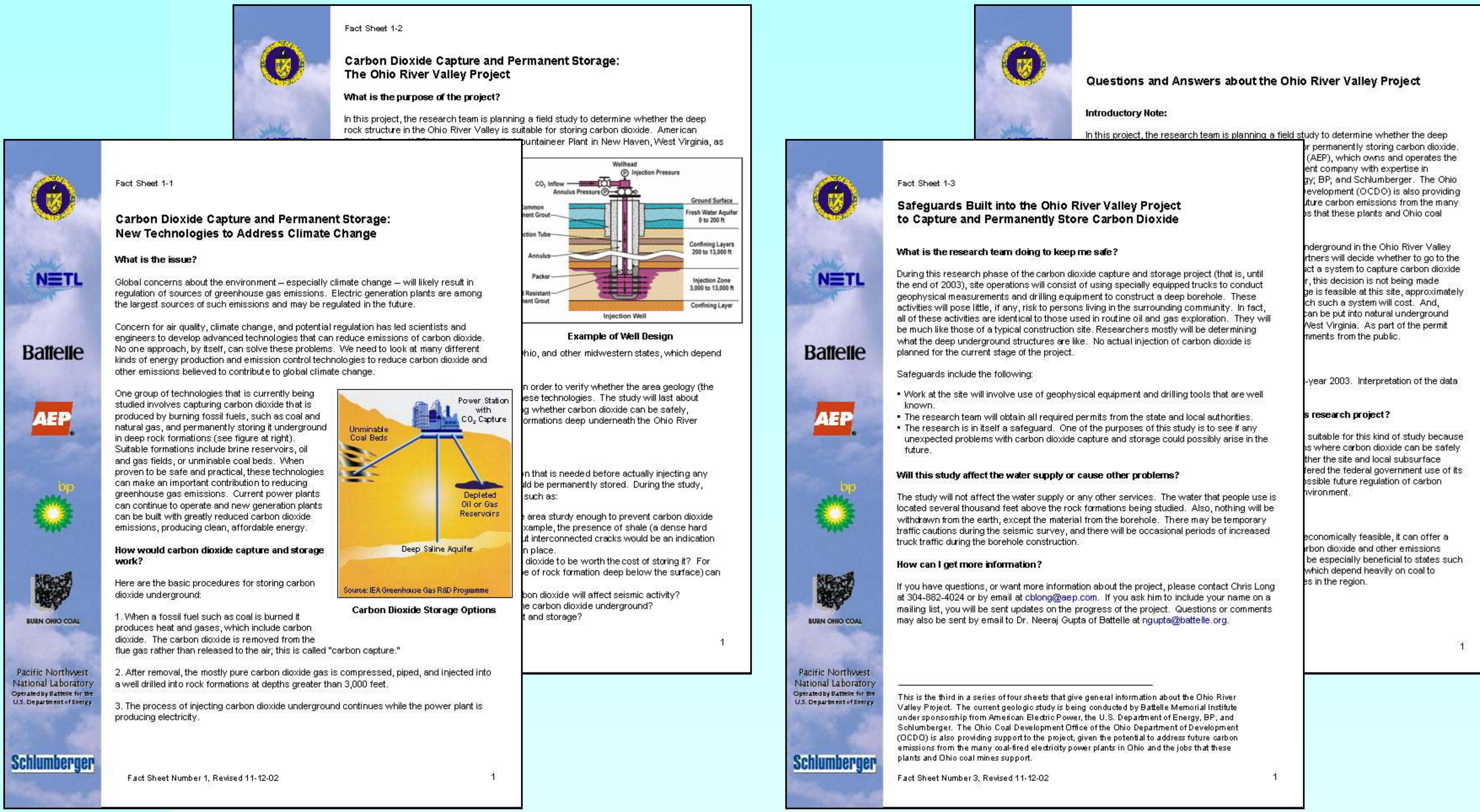
Potential Stakeholder Interactions



Stakeholder Outreach – Early Steps in Ohio River Valley Project

- Developed schedule and talking points for local and regional outreach
- Developed project fact sheets for distribution to public with collaboration and approval of all the project sponsors
- Numerous meetings by Battelle and AEP personnel to inform key stakeholders about the project
  - Plant managers and employees at and near the power plant
  - Regional and national NGOs
  - Local and state officials – mayors, county commissioners
  - Elected Officials - State legislators, federal senators and congressmen
  - State PSC, Development Office, Energy Task Force
  - State DEP or EPA officials
  - Scientific meetings and workshops

Stakeholder Outreach – Fact Sheets



Fact Sheet 1-2

Carbon Dioxide Capture and Permanent Storage: The Ohio River Valley Project

What is the purpose of the project?

In this project, the research team is planning a field study to determine whether the deep rock structure in the Ohio River Valley is suitable for storing carbon dioxide. American …ountaineer Plant in New Haven, West Virginia, as

Example of Well Design

Questions and Answers about the Ohio River Valley Project

Introductory Note:

In this project, the research team is planning a field study to determine whether the deep

Fact Sheet 1-1

Carbon Dioxide Capture and Permanent Storage: New Technologies to Address Climate Change

What is the issue?

Global concerns about the environment – especially climate change – will likely result in regulation of sources of greenhouse gas emissions. Electric generation plants are among the largest sources of such emissions and may be regulated in the future.

Concern for air quality, climate change, and potential regulation has led scientists and engineers to develop advanced technologies that can reduce emissions of carbon dioxide. No one approach, by itself, can solve these problems. We need to look at many different kinds of energy production and emission control technologies to reduce carbon dioxide and other emissions believed to contribute to global climate change.

One group of technologies that is currently being studied involves capturing carbon dioxide that is produced by burning fossil fuels, such as coal and natural gas, and permanently storing it underground in deep rock formations (see figure at right). Suitable formations include brine reservoirs, oil and gas fields, or unminable coal beds. When proven to be safe and practical, these technologies can make an important contribution to reducing greenhouse gas emissions. Current power plants can continue to operate and new generation plants can be built with greatly reduced carbon dioxide emissions, producing clean, affordable energy.

How would carbon dioxide capture and storage work?

Here are the basic procedures for storing carbon dioxide underground:

1. When a fossil fuel such as coal is burned it produces heat and gases, which include carbon dioxide. The carbon dioxide is removed from the flue gas rather than released to the air; this is called "carbon capture."

2. After removal, the mostly pure carbon dioxide gas is compressed, piped, and injected into a well drilled into rock formations at depths greater than 3,000 feet.

3. The process of injecting carbon dioxide underground continues while the power plant is producing electricity.

Carbon Dioxide Storage Options

Fact Sheet Number 1, Revised 11-12-02 1

Fact Sheet 1-3

Safeguards Built into the Ohio River Valley Project to Capture and Permanently Store Carbon Dioxide

What is the research team doing to keep me safe?

During this research phase of the carbon dioxide capture and storage project (that is, until the end of 2003), site operations will consist of using specially equipped trucks to conduct geophysical measurements and drilling equipment to construct a deep borehole. These activities will pose little, if any, risk to persons living in the surrounding community. In fact, all of these activities are identical to those used in routine oil and gas exploration. They will be much like those of a typical construction site. Researchers mostly will be determining what the deep underground structures are like. No actual injection of carbon dioxide is planned for the current stage of the project.

Safeguards include the following:

- Work at the site will involve use of geophysical equipment and drilling tools that are well known.
- The research team will obtain all required permits from the state and local authorities.
- The research is in itself a safeguard. One of the purposes of this study is to see if any unexpected problems with carbon dioxide capture and storage could possibly arise in the future.

Will this study affect the water supply or cause other problems?

The study will not affect the water supply or any other services. The water that people use is located several thousand feet above the rock formations being studied. Also, nothing will be withdrawn from the earth, except the material from the borehole. There may be temporary traffic cautions during the seismic survey, and there will be occasional periods of increased truck traffic during the borehole construction.

How can I get more information?

If you have questions, or want more information about the project, please contact Chris Long at 304-882-4024 or by email at cblong@aep.com. If you ask him to include your name on a mailing list, you will be sent updates on the progress of the project. Questions or comments may also be sent by email to Dr. Neeraj Gupta of Battelle at ngupta@battelle.org.

This is the third in a series of four sheets that give general information about the Ohio River Valley Project. The current geologic study is being conducted by Battelle Memorial Institute under sponsorship from American Electric Power, the U.S. Department of Energy, BP, and Schlumberger. The Ohio Coal Development Office of the Ohio Department of Development (OCDO) is also providing support to the project, given the potential to address future carbon emissions from the many coal-fired electricity power plants in Ohio and the jobs that these plants and Ohio coal mines support.

Fact Sheet Number 3, Revised 11-12-02 1

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Economic Aspects - Power Plant Data for Cost Estimate

	Pulverized Coal	Integrated Coal Gasification Combined Cycle (IGCC)
System Power Output		
Power without CO_2 capture	500	500
Power with CO_2 capture	362	428
System Cost		
Electricity price without capture (bus bar) (c/kWh)	4.9	5.3
Electricity price with capture (bus bar) (c/kWh)	7.4	6.3
CO_2 Capture Output		
CO_2 released without capture (kgs/kWh)	0.828	0.756
CO_2 released with capture (kgs/kWh)	0.083	0.136
CO_2 supply pressure	170 kPa (25 psig)	170 kPa (25 psig)

Capture/Transmission/Sequestration Costs

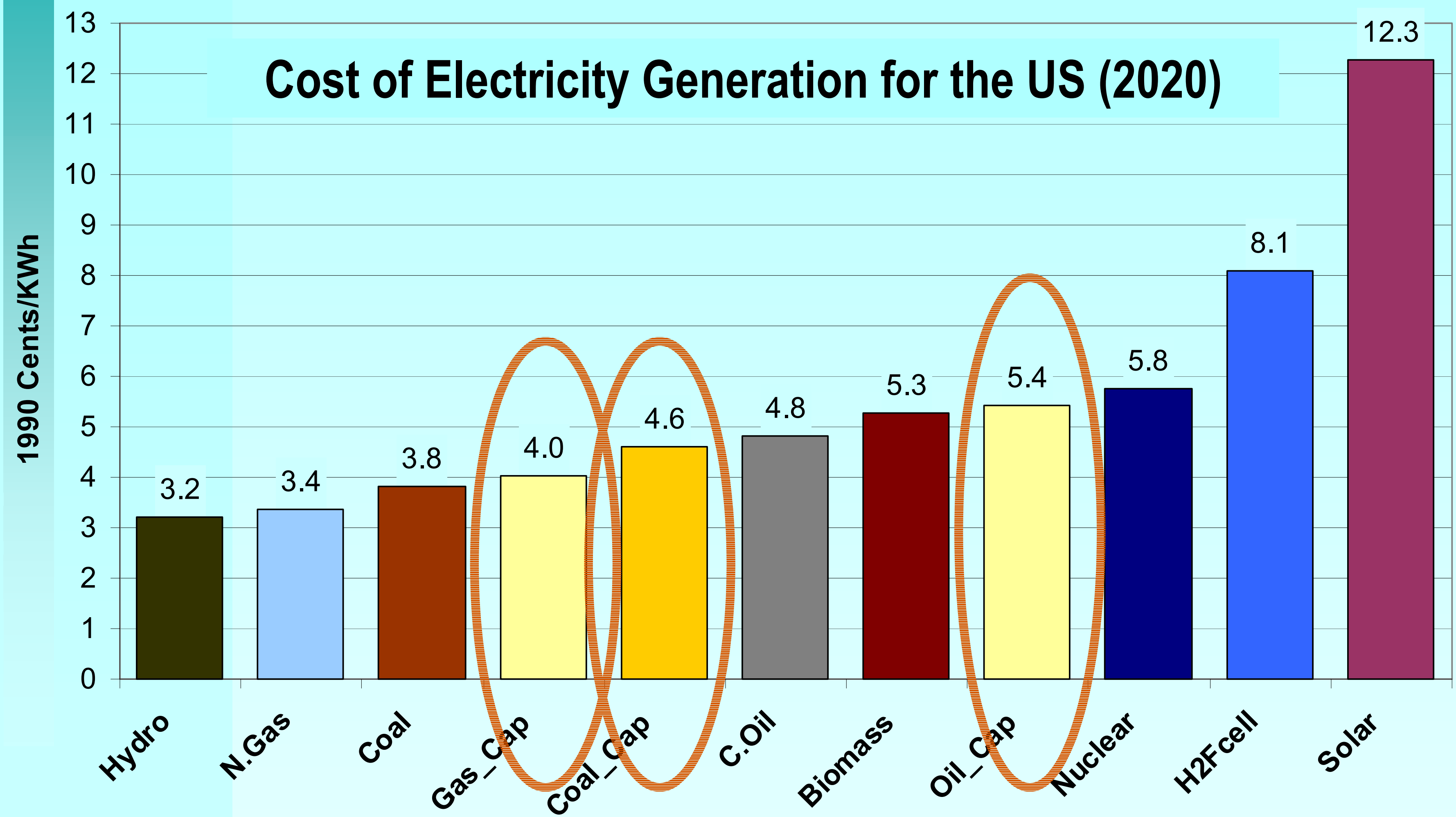
Well Depth (m)	Cost of CO_2 Avoided for Various Scenarios ($/metric ton)				
	15 km and Normal Terrain	100 km and Normal Terrain	400 km and Normal Terrain	15 km and Rocky/Hilly Terrain	15 km and Urban Terrain
PC/FGD Plants					
1,000	62.48				
2,000	63.26	66.05	76.49	63.56	63.45
3,000	65.40				
IGCC Plants					
2,000	39.77				

Annualized Cost Components ($mil/yr)

	PC with FGD	IGCC
Capture	20	4
Compression	33	28
Pipeline (15 km)	2	2
Injection (2,000 m)	4	4
Total	59	38

- Increasing pipeline length to 400 km increases cost by 27 $mil/yr
- Injection depth has very little impact on total cost
- IGCC Plants produce less CO_2 at higher pressure and allow capture by cheaper physical absorption method. This results in significant reduction in total cost

Carbon Capture Systems Can Be Significantly Cheaper Than Many Other Competing Energy Technologies



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Courtesy – Edmonds et. al

Summary

- On a regional basis there is enormous potential sequestration capacity due to favorable formation thickness, hydrogeology, seismicity, and proximity to sources of CO_2.
- The site-specific sequestration potential varies due to local thickness, permeability, porosity, structural features, and depth.
- Therefore, local-scale reservoir characterization is critical to building CO_2 disposal facilities that can win stakeholder acceptance.

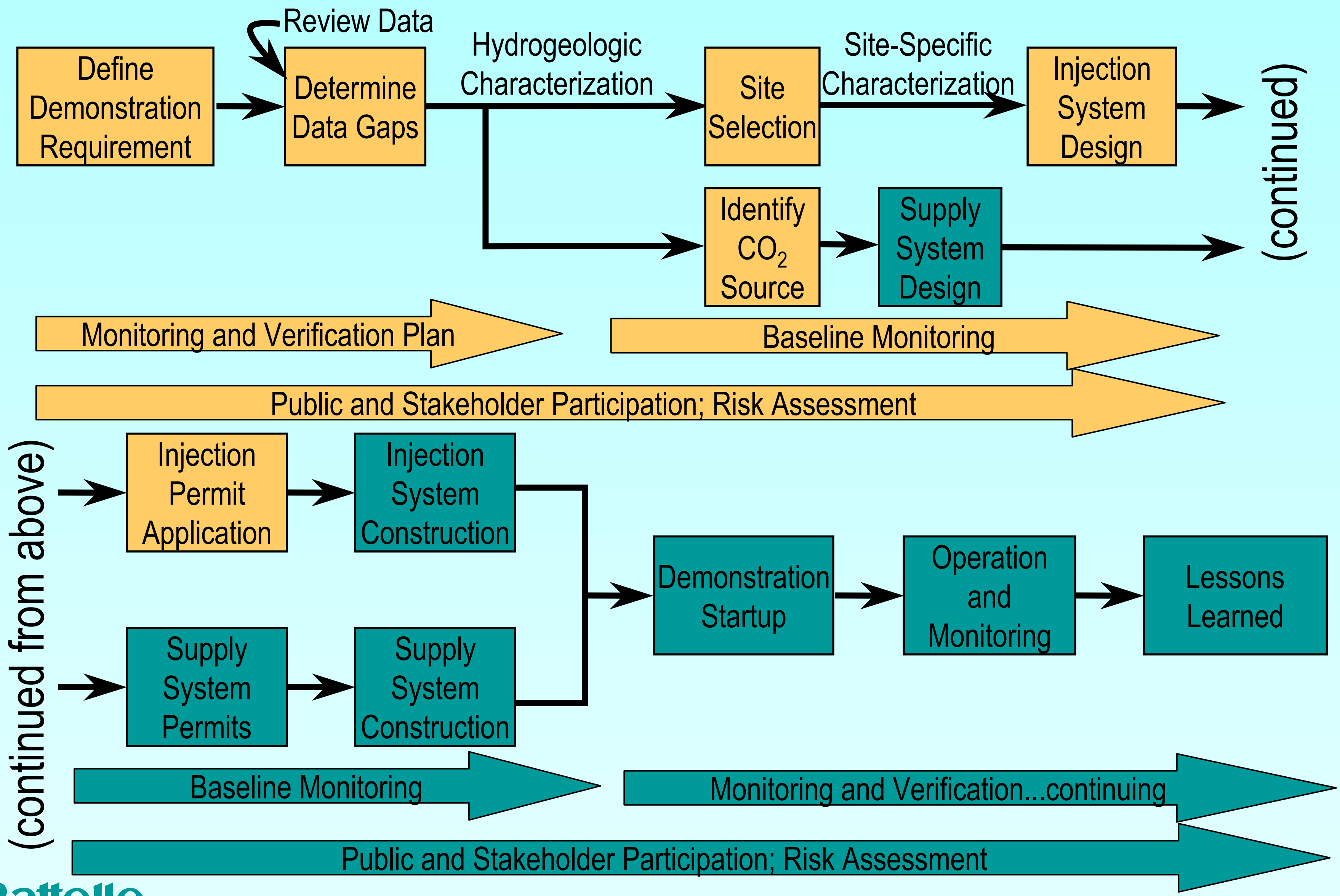
Summary - Requirements for Geologic Disposal

- Acceptance of geologic disposal technologies hinges on their ability to retain CO_2 in the reservoir for the time period required to address climate change concerns.
- Acceptance of these technologies also requires that any stakeholder (public, industry, and government) concerns about safety, cost, engineering feasibility, and regulations be addressed properly.
- Site-selection for geologic disposal projects must demonstrate that above conditions are being addressed.

Requirements for Geologic Disposal (contd.)

- These issues may be addressed through:
  - Comprehensive regional and local geologic assessment
  - Demonstrated understanding of CO_2 fate and transport
  - Comprehensive design and engineering
  - Transparent monitoring and verification program
  - Regulatory compliance
  - Realistic cost assessment
- In addition to short-term experiments, long-term and industry relevant scale demonstrations are needed to win stakeholder confidence.

Key Steps in Developing a CO_2 Capture and Disposal Demonstration



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  - BP – Charles Christopher and Tony Espie
  - Schlumberger – T.S. Ramakrishnan and Austin Boyd
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