# Underground Coal Gasification: Science and Technology Gaps


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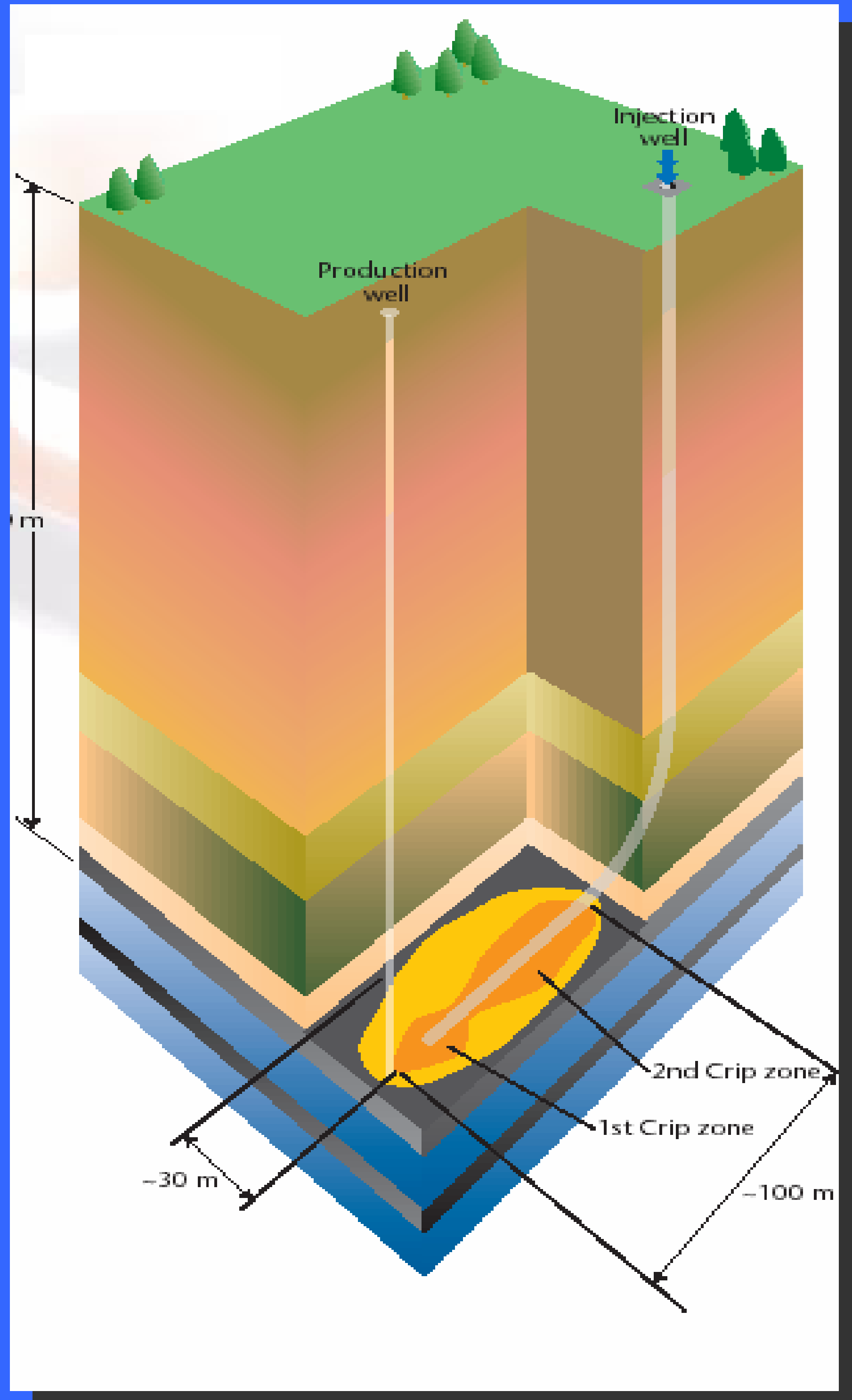

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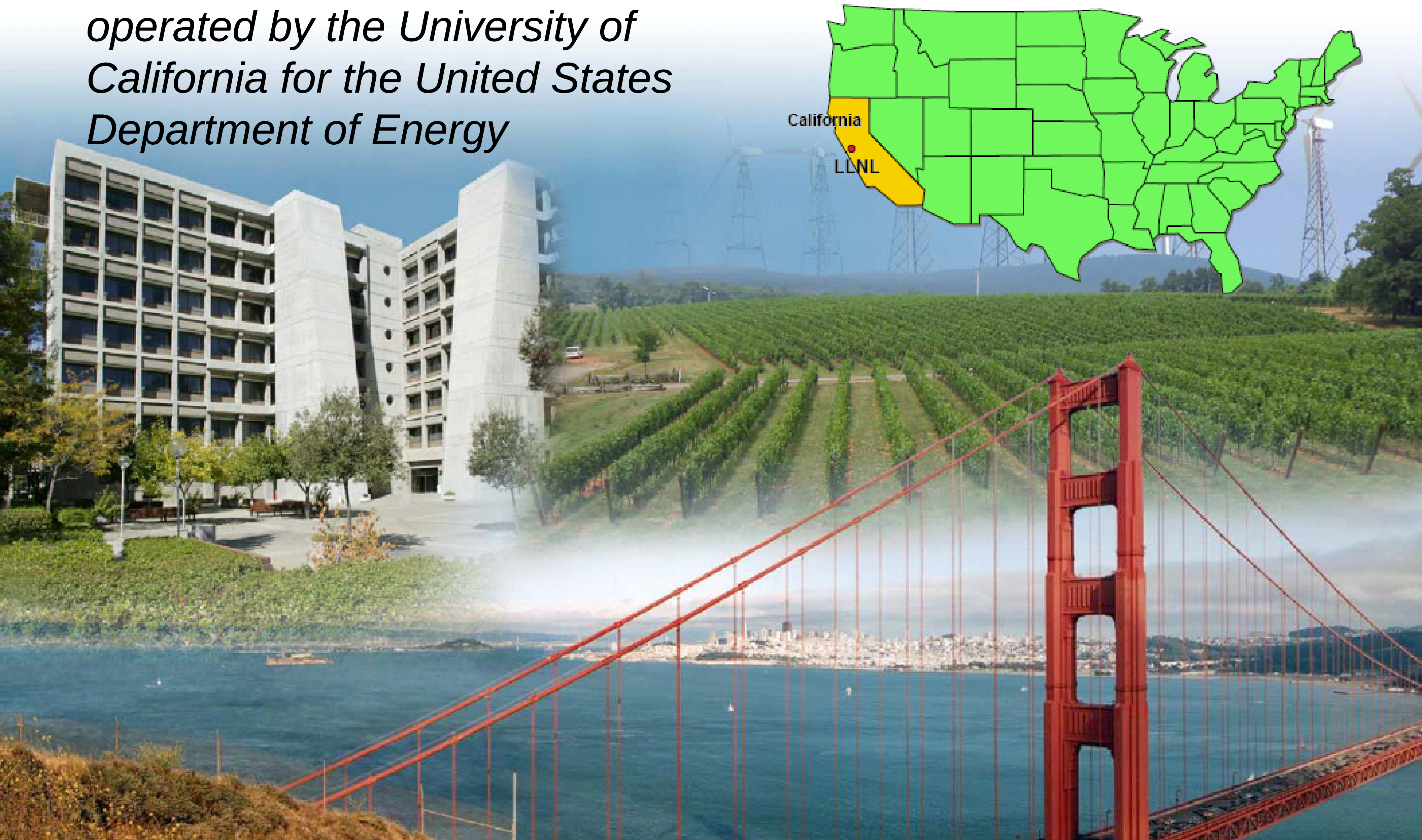


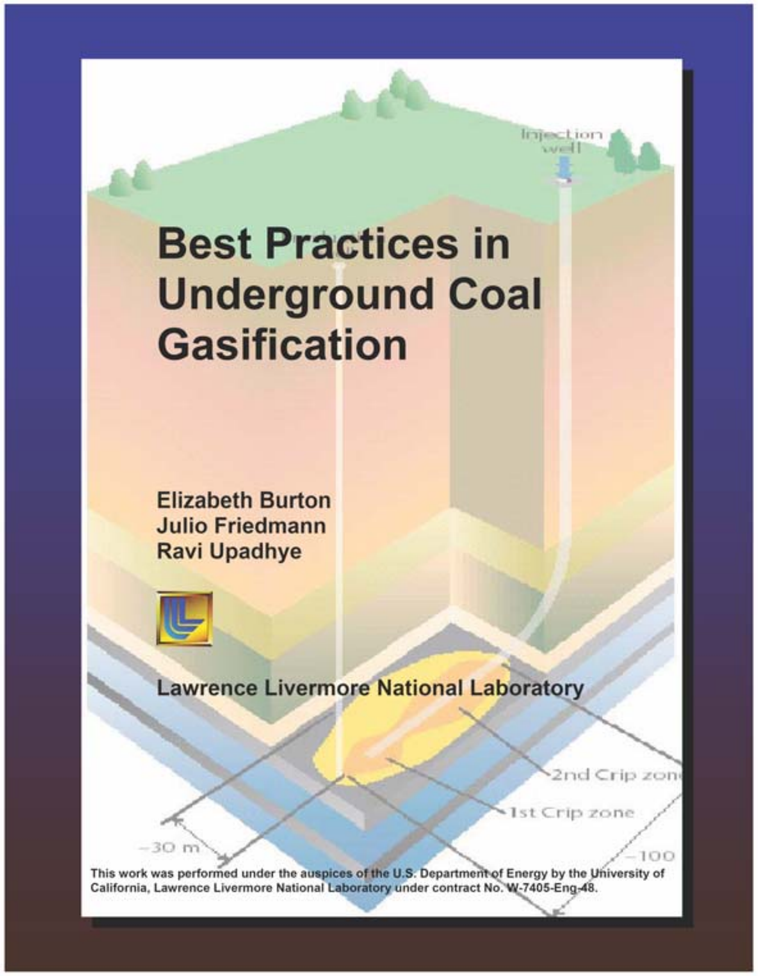
# DOE/LLNL Activity in UCG

- Invented CRIP (controlled retractable injection point) process (1974-1985)
- Conducted numerous field tests (Hoe Creek, Hanna, Centralia)
- Developed and validated cavity growth models
- Developed methodologies for process control monitoring
- Developed a CFD-based gasification model of the UCG process and integrated it with Aspen Plus
- Developing tools for site assessment
- Developing models for environmental risk assessment
- Applying carbon management and $CO_2$ sequestration expertise to evaluate UCG-CCS
- Completed draft report on UCG best practices and lessons learned

# New LLNL-DOE Draft Report

***Contents:***

- **UCG history**
- **Ignition and gasification process**
- **Environmental management issues**
- **Carbon management**
- **Best practices and lessons-learned**
- **Technology and R&D gaps; recommendations for future R&D**




***Copies available soon.***

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# Why Consider Underground Coal Gasification?

- Eliminates conventional coal mining, reducing operating costs, surface damage, eliminating mining safety problems
- Accesses otherwise un-mineable coals (deep or thin seams), increasing exploitable reserves
- Needs no surface gasification facilities, reducing capital costs
- Leaves gasification residuals underground
- Eliminates costs, facilities, and environmental issues associated with transport/storage of mined coal or coal gasification residuals (e.g., ash)
- Reduces overall greenhouse gas emissions and has advantages for geologic carbon storage

# Timeliness of Underground Coal Gasification R&D Investment

- **Economic pressure to find alternative fuel resources given high cost of oil and natural gas**
- **Increased security risk with continued dependence on imported fuel supplies**
- **Access presently un-mineable coal resources**
  - in U.S., UCG increases exploitable coal resources by ≥ 3 times
- **Potential to optimize UCG as a cost-effective clean-coal technology:**
  - Reduced greenhouse gas emissions per unit coal gasified
  - Potential for combined UCG-CCS
  - Reduced overall environmental impact

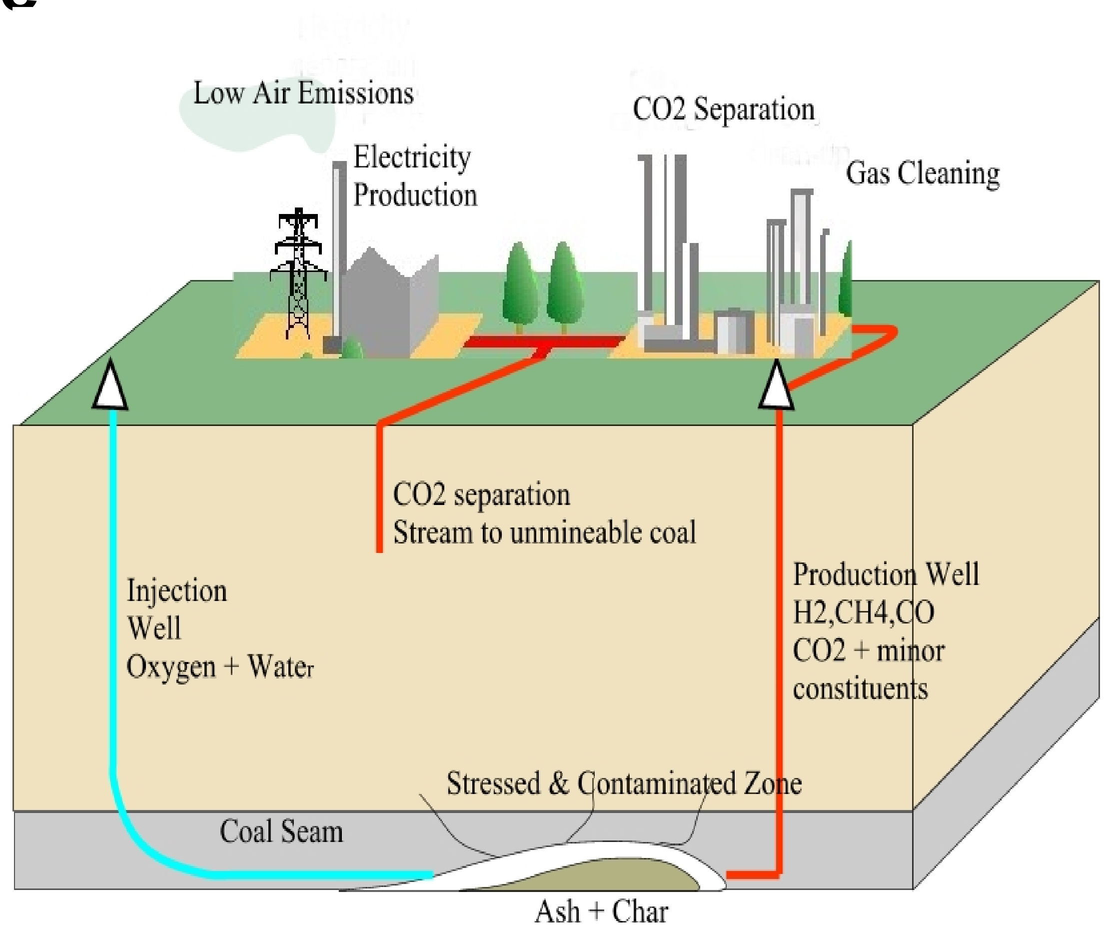
**Increased recent interest in UCG technology globally creates opportunities to leverage R&D and share lessons-learned and best practices**

# Limitations and Concerns for UCG

- UCG has produced significant groundwater contamination and ground subsidence in some previous operations
- The increase in exploitable coal possible with UCG may be less when site selection is constrained by geologic and hydrologic criteria to protect the environment
- UCG is a non-steady state process-- operations cannot be controlled to the same extent as surface gasification
  - Process variables vary as burn progresses and can only be estimated
  - Flow rate and composition (heating value) of product gas will vary over time
- Business case for UCG will remain difficult until there are enough UCG facilities (power, syngas, chemical feedstocks) to provide economic data

# Science and Technology Gaps

- **Environmental and site assessment**
- **Process and environmental monitoring**
- **(Computational Fluid Dynamics) CFD gasification model**
- **Issues with Carbon Capture and Storage (CCS) with UCG**



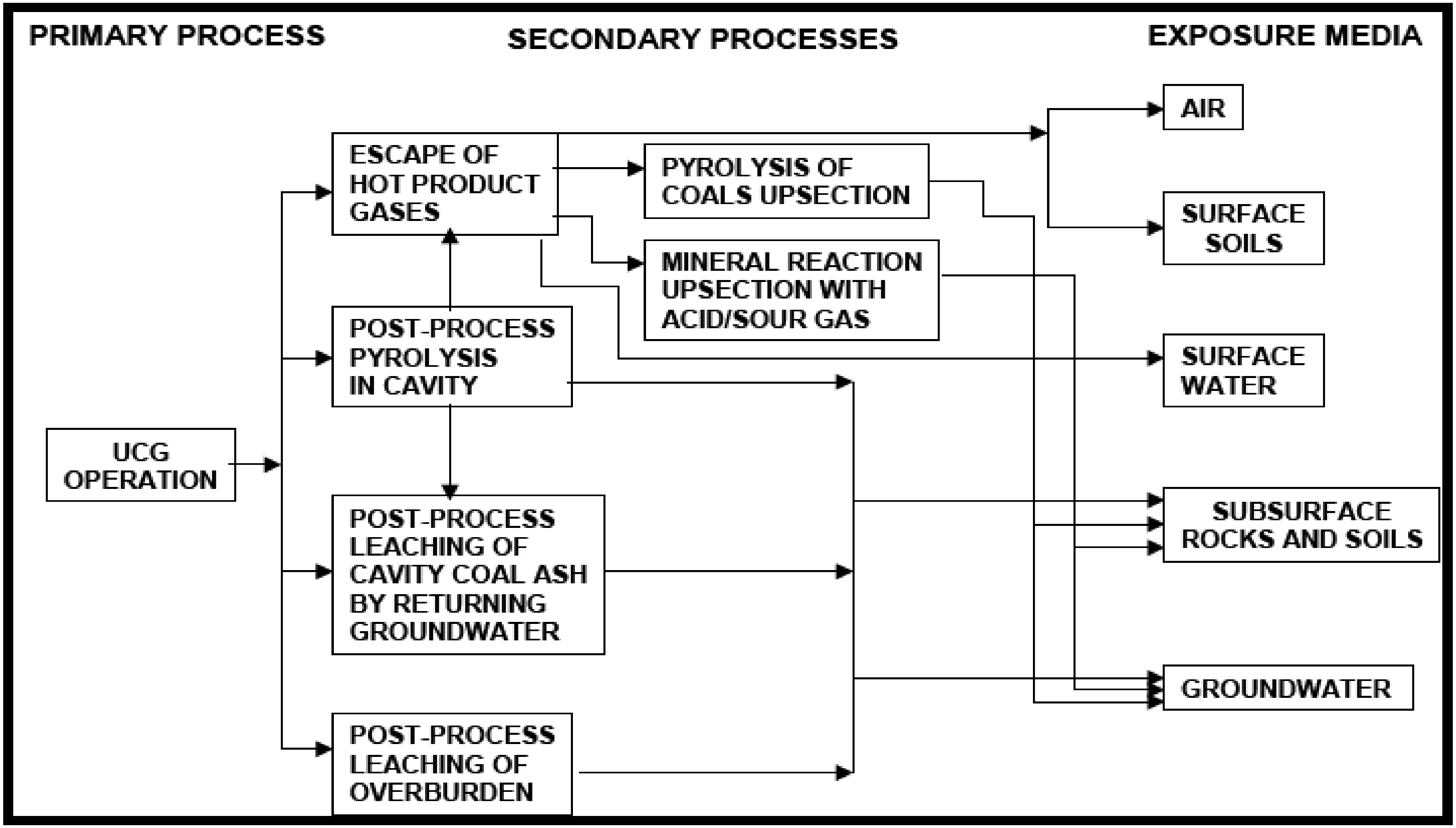
# Environmental and Site Assessment Objectives

- **Reduce risk of UCG to acceptable levels through assessment tools for:**
  - Site selection and screening
  - Operations and facilities planning based on site-specific risk-indexing
  - Setting operations guidelines based on site parameters
- **Identify UCG operating ranges that limit production of contaminant compounds, and prevent contaminant migration out of the cavity during- and post-UCG**
- **Include evaluation of mitigation and remediation options and economics appropriate to UCG sites, including bioattenuation rates**
- **Include capability to assess combined UCG-CCS**

# Environmental and Site Assessment Tools

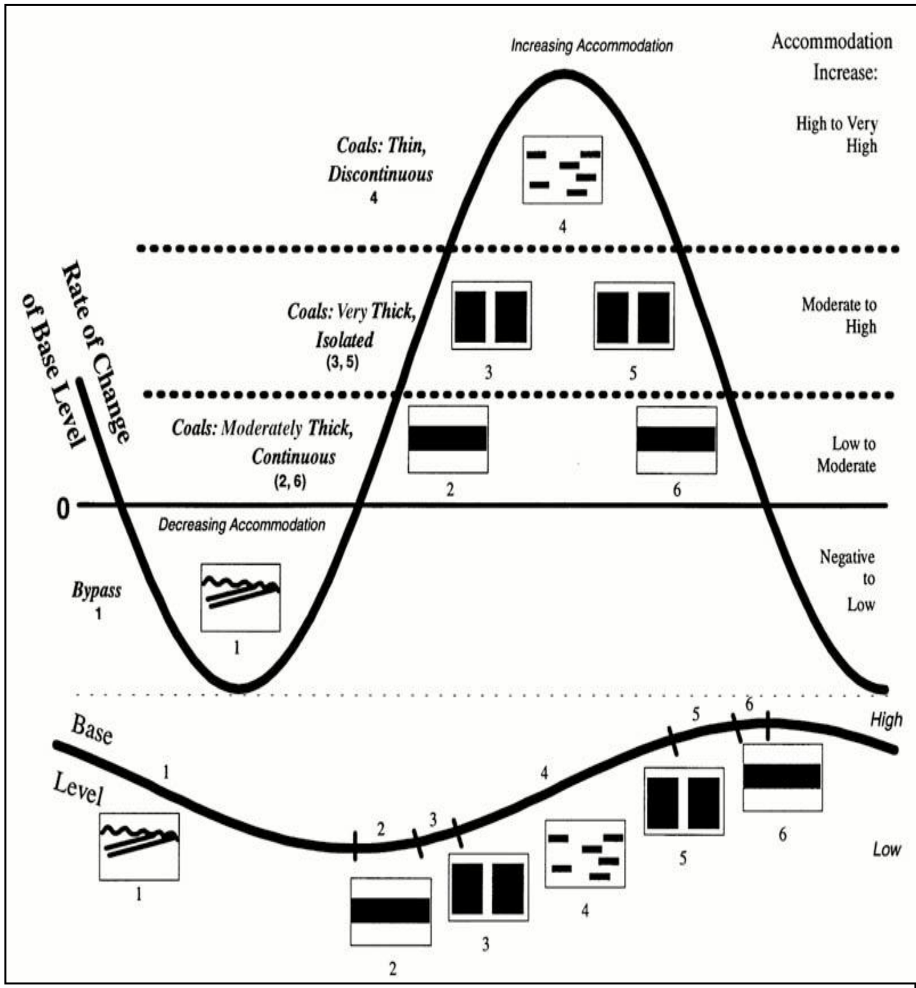
- **Risk-based Decision-making Framework for UCG and UCG-CCS**
- **Site characterizations incorporating geologic and hydrologic systems**
- **Accurate, integrated geomechanical-hydro-chemical simulations of UCG impacts that include:**
  - Effects of thermal changes on density and viscosity, hydrologic gradients, and on contaminant migration
  - Effects of linkage and burn processes, cavity growth, cavity collapse, fracture/fissure propagation, and coal swelling on hydraulic connectivity and gradients
  - Integration and inversion techniques, including stochastic inversion using Monte-Carlo Markov-chain approaches

# Risk-based Decision-making for UCG

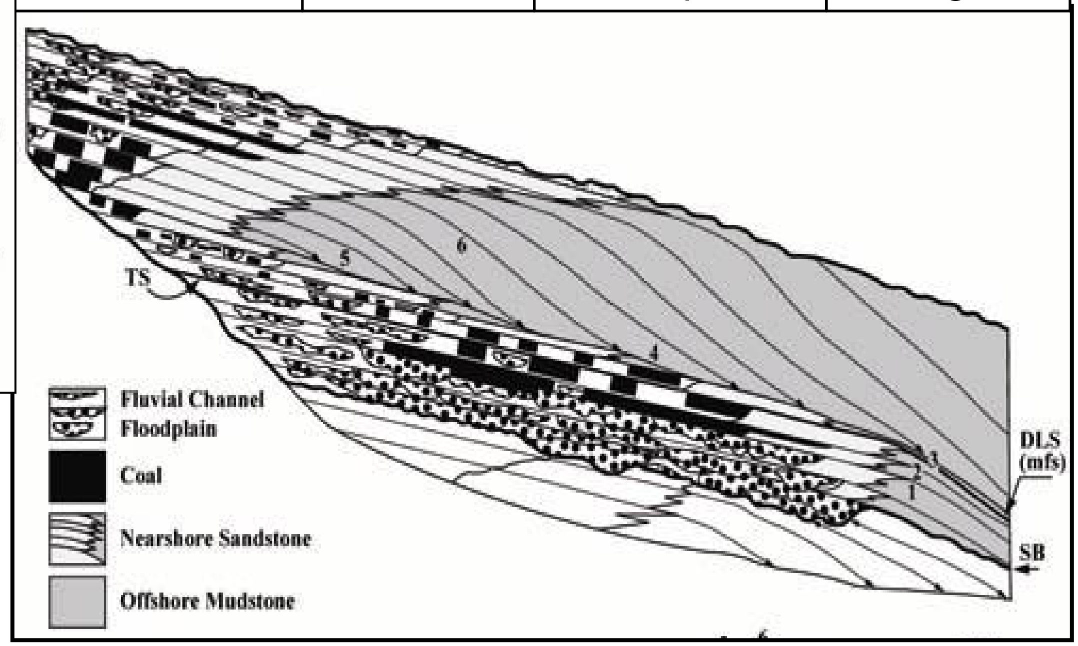



*Additional secondary processes apply with CCS*

# Geologic Characterization for Site Assessment: Stratigraphic Screening




| Stratigraphic category | Lateral Isolation | Overlying Unit Character | Relative Risk |
|---|---|---|---|
| 1 | Low | Sand-prone | High |
| 2 | Low | Shale-prone | Moderate |
| 3 | High | Shale-prone | Low |
| 4 | Moderate | Shale-prone | Moderate |
| 5 | Moderate | Sand-prone | High |
| 6 | Low | Sand-prone | High |

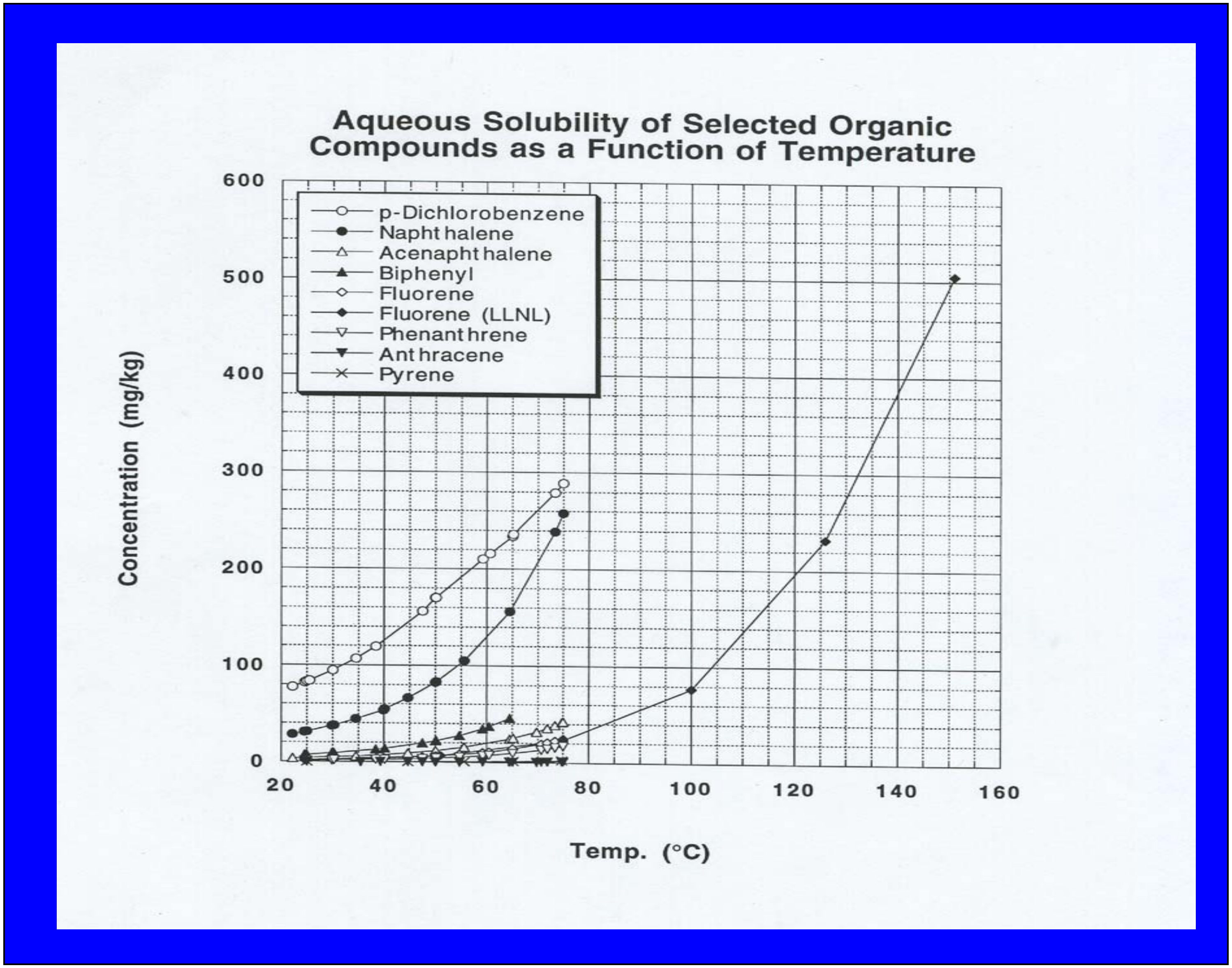



**Stratigraphic sequences give first-cut screen for likelihood of good sealing caprock**

# Simulations of UCG Impacts on Geologic-Hydrologic Systems

- **UCG environmental assessment cannot be done with a standard toolbox of environmental tools**
- **UCG requires use of coupled process, hydrological, geochemical and geomechanical models to capture:**
  - Balancing gasifier operational pressure against hydrologic pressure and other gradients in the field to prevent outward contaminant migration
  - Impact of gasifier operating conditions on creation and behavior of contaminants within the burn chamber
  - Enhanced vertical hydraulic conductivity of the rock matrix above the burn chamber as a result of collapse and fracturing
  - Buoyancy-driven upward flow of groundwater in the vicinity of the burn chamber toward potable water resources at shallower depths

# Contaminant Behavior: Increases in Solubility with Temperature



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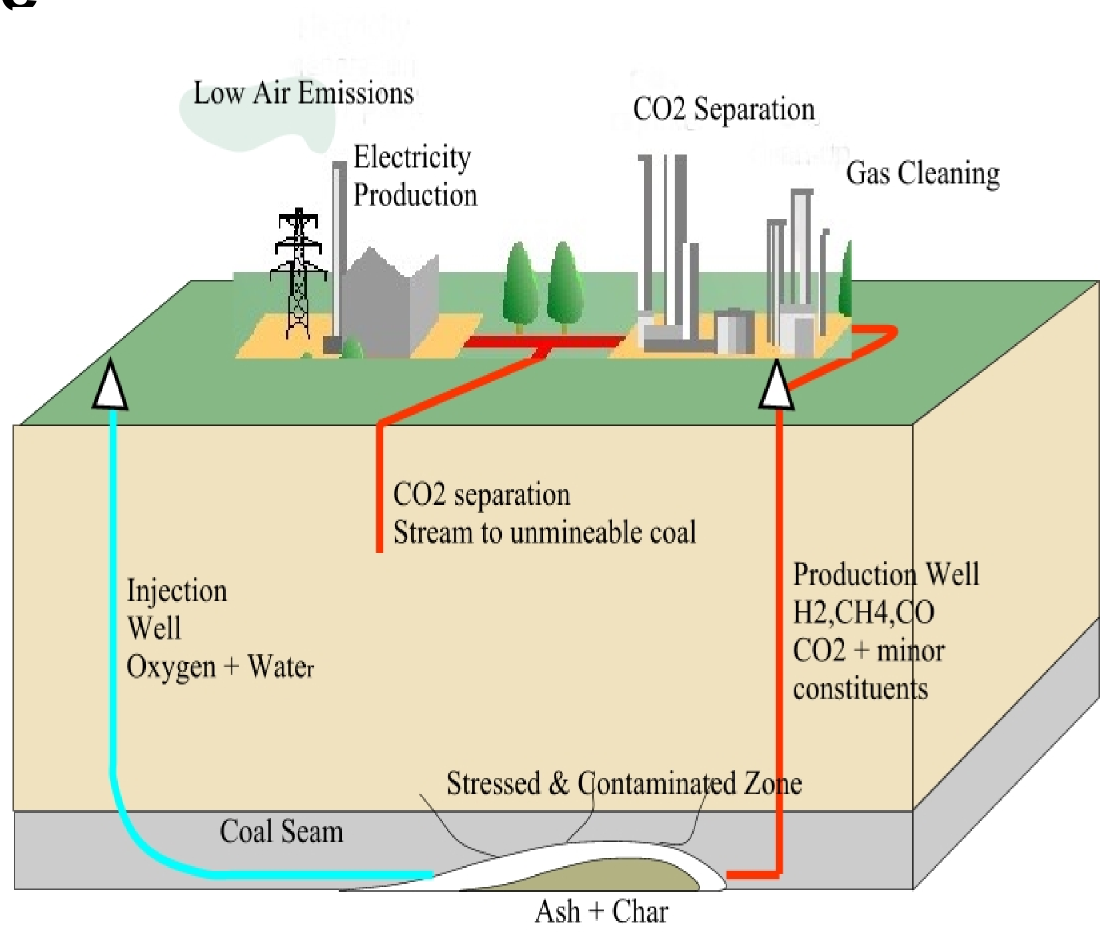


# Monitoring Objectives

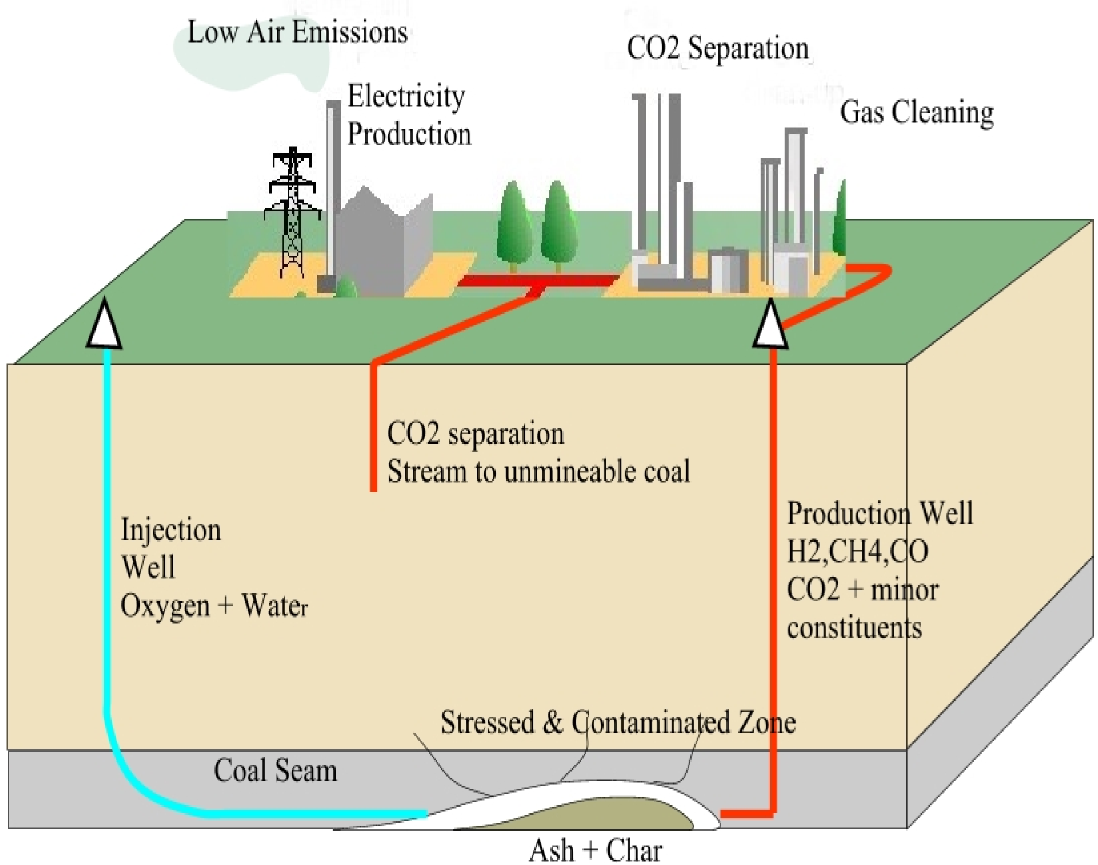
- Real-time insight into potential hazards (subsidence, groundwater contamination) as the UCG burn progresses through the coal seam
- Validate models and improve understanding of the UCG process
- Improve understanding of the geomechanical, geochemical, and hydrogeological changes induced by UCG
- Allow for the possibility of real-time process control of the UCG “reactor”

# Monitoring Tools

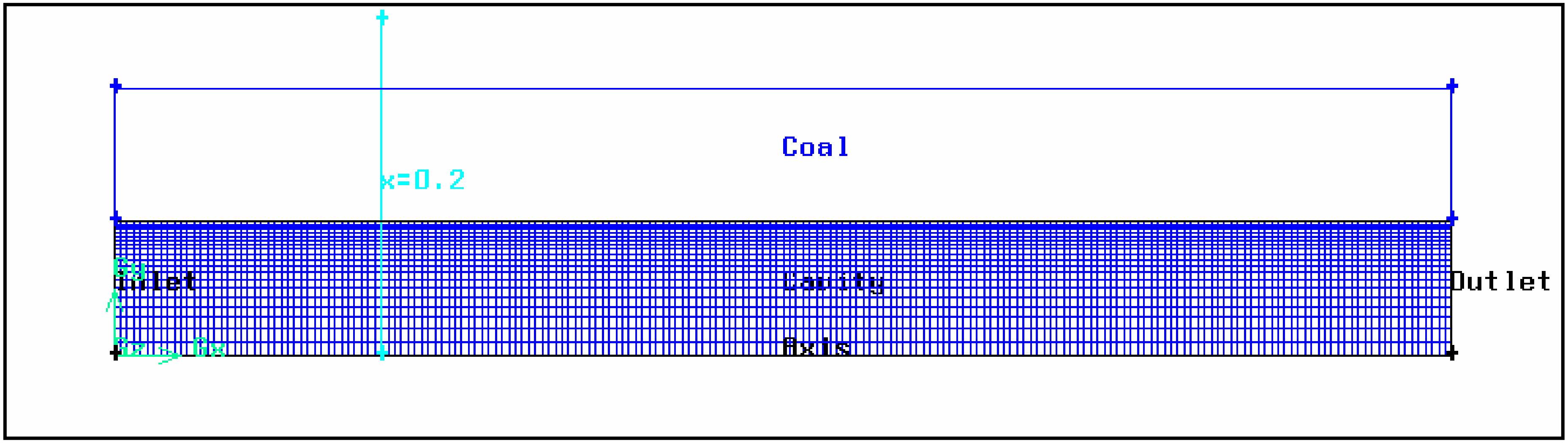
- **Geophysical tools to detect burn front progression, fracturing, cavity collapse, subsidence**
  - Electrical resistance tomography (ERT) and EM induction tomography (EMIT)
  - Seismic monitoring (e.g., 3-d, microseismic)
  - Tilt meters
- **Remote sensing tools to detect surface changes due to UCG**
  - hyperspectral imaging of plant and soil changes from gas leakage, or incipient subsidence
- **Down-hole tools (“smart” borehole casings) for real-time continuous monitoring of temperature, pressure and chemistry**

# Science and Technology Gaps

- Environmental and site assessment
- Process and environmental monitoring
- (Computational Fluid Dynamics) CFD gasification model
- Issues with Carbon Capture and Storage (CCS) with UCG



# LLNL's CFD Model: Approach



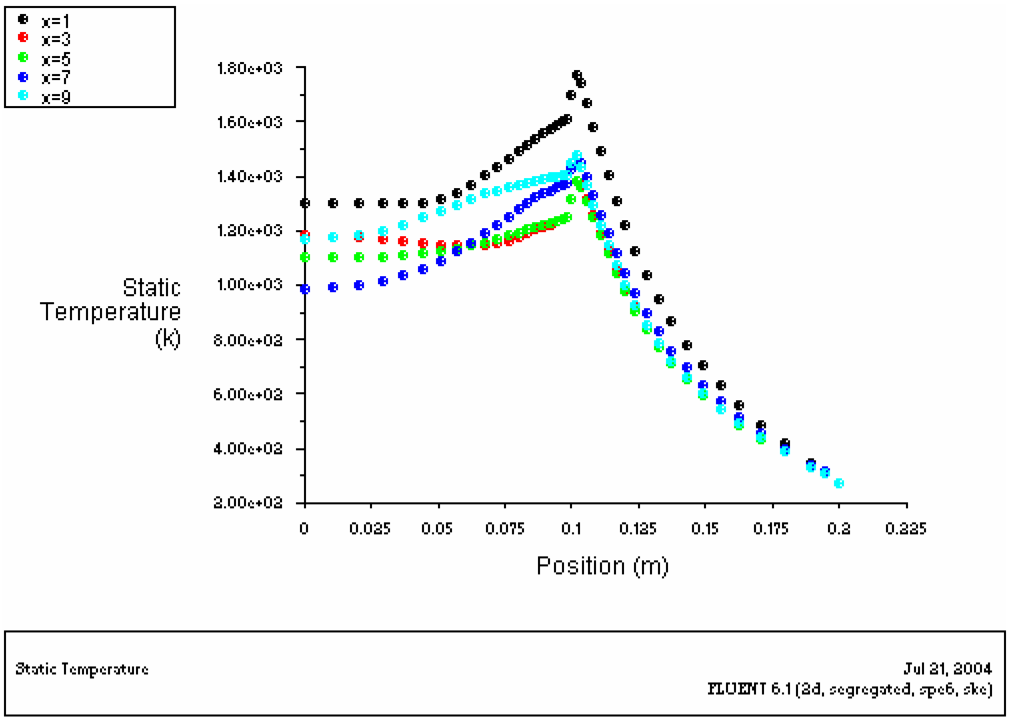

- Cylindrically symmetric cavity
- Considers influx of water and coal pyrolysis
- 1-cm thermal wave ahead of surface reactions
- Coal = $CH_{0.08}$
- WG shift reaction and coal gasification reactions are considered to be volumetric, but known kinetics are used
- Radiation effects are ignored

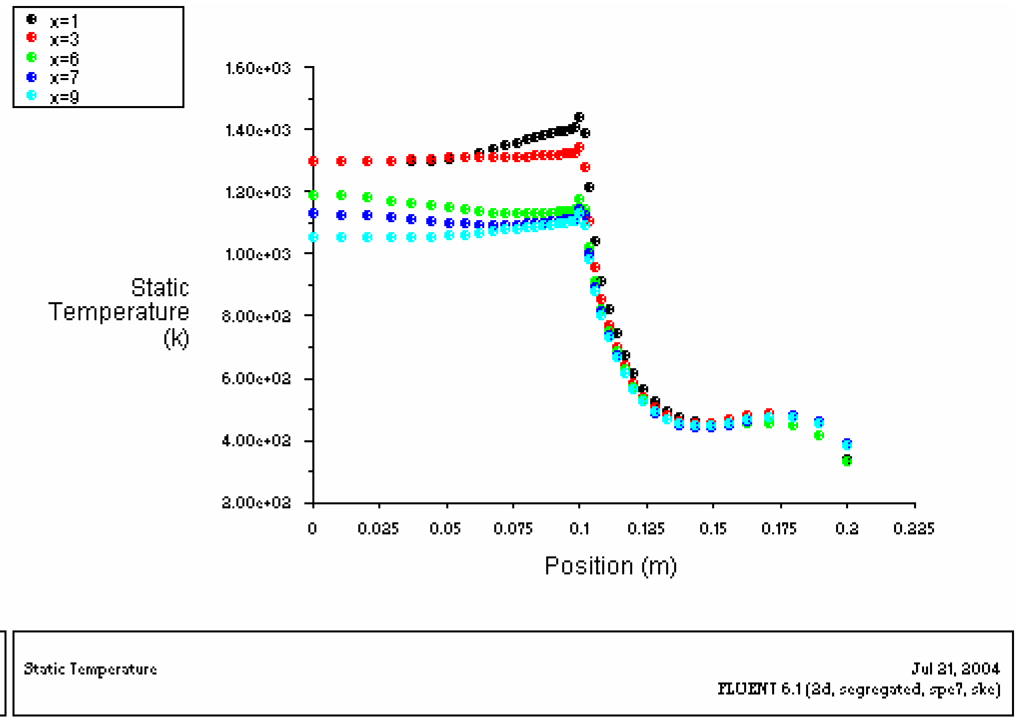
# LLNL's CFD Model: Predicted gas Compositions

Typical UCG gas compositions adjusted to 33 mol% water content.

| Component | UCG Model | Field Measurement[1] |
|---|---|---|
| $H_2$ | 27.2 | 27.3 |
| CO | 13.0 | 6.4 |
| $CO_2$ | 19.4 | 27.2 |
| $CH_4$ | 7.4 | 6.4 |
| $H_2O$ | 33.0 | 33.0 |

# Temperature Profiles from the CFD Model




**Temp vs radial position, without and with water influx (0.3 kg/kg coal)**

# Improvements Planned for CFD Model

- Steady-state to dynamic
- 2D-3D model, no assumption of axial symmetry
- Include radiative heat transfer
- Include coal-methane kinetics
- Accommodate surface reactions
- Include separate kinetics for combustion and reforming
- Improvements in treatment of the porous zone
- Calculation of local recession rate for coal
- Integration with environmental/hydrogeologic models

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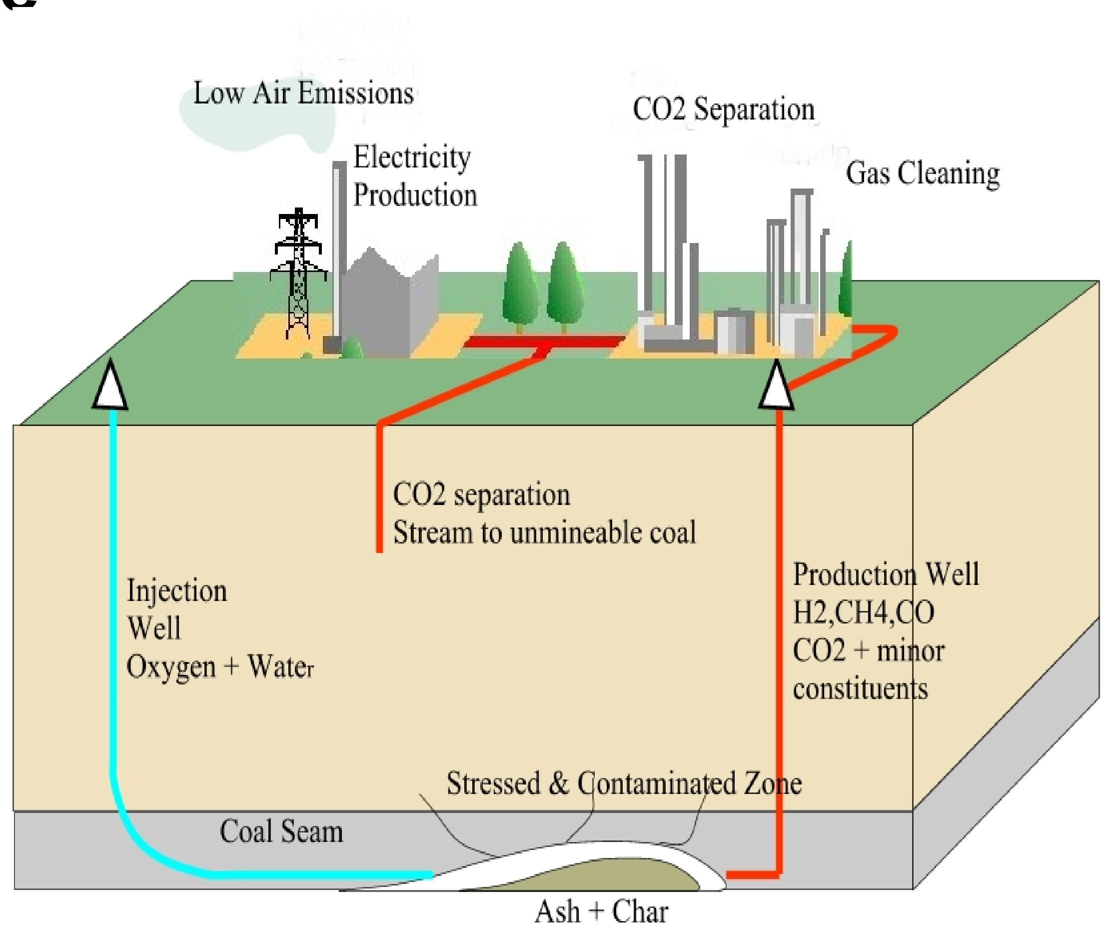
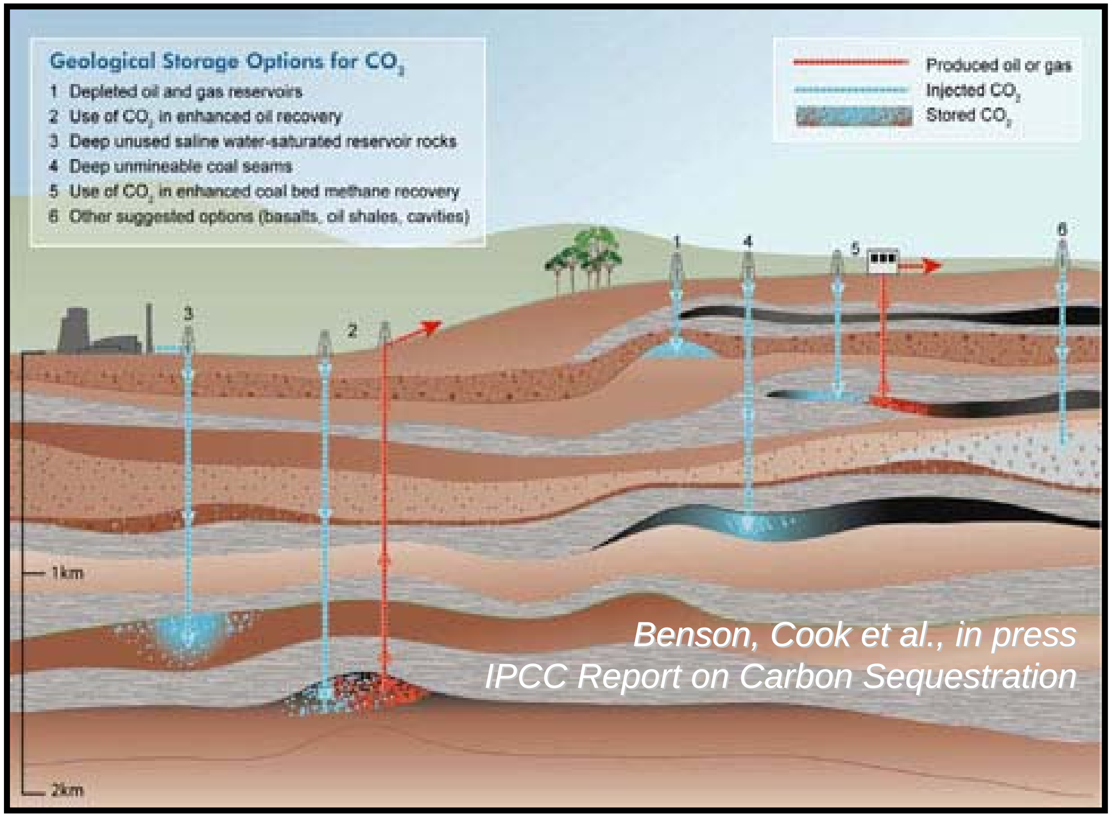


# UCG with Carbon Capture and Storage (UCG-CCS)

***Carbon capture and storage (CCS) aims to reduce net greenhouse gas emissions, chiefly $CO_2$, through storage of gas underground .***




*Benson, Cook et al., in press*
*IPCC Report on Carbon Sequestration*

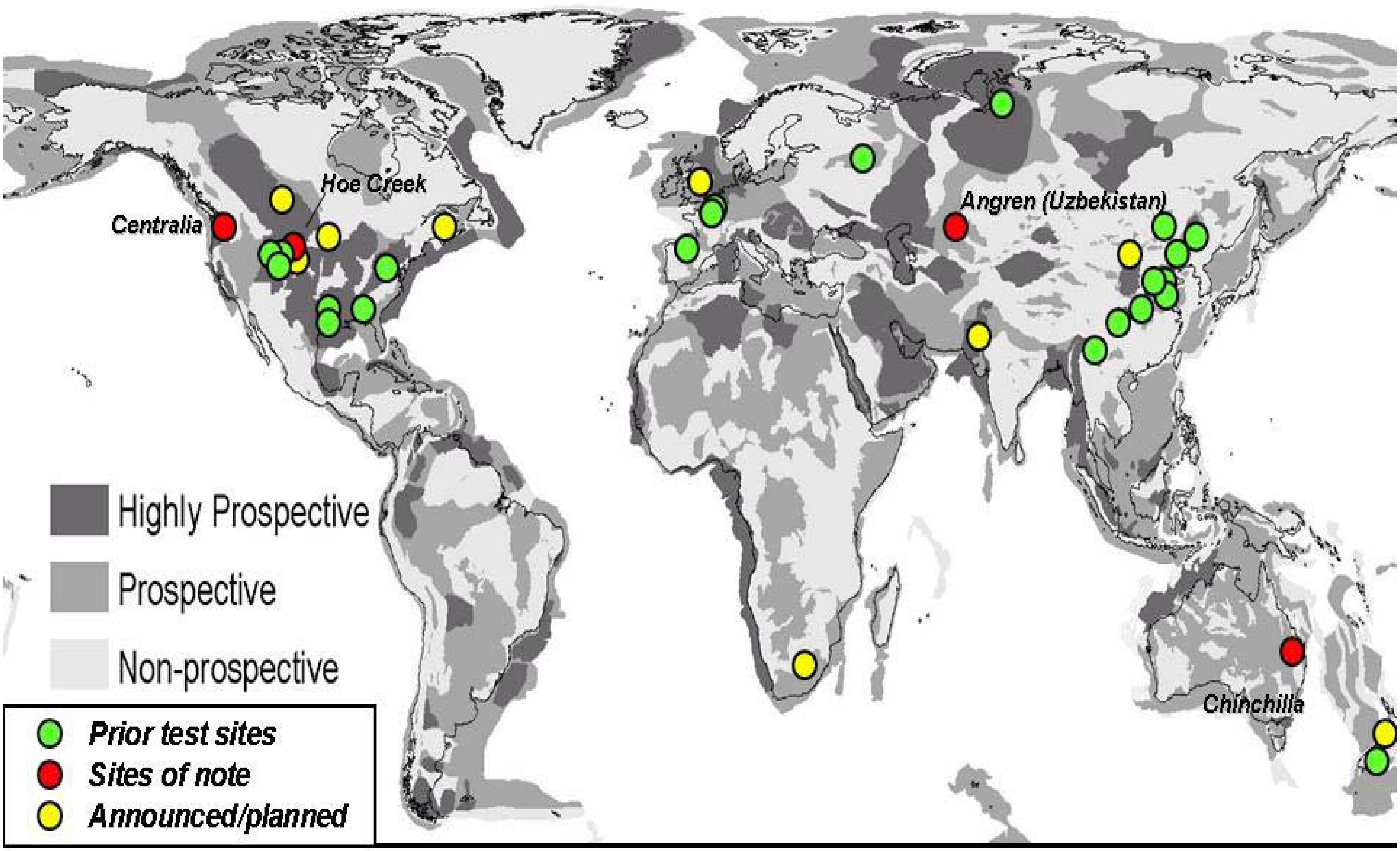
## Storage Targets

- Saline Aquifers
- Depleted Oil & Gas fields (w/ or w/o EOR and EGR)
- Unmineable Coal Seams (w/ or w/o ECBM)

# CCS with UCG: Advantages

- **Good coincidence between CCS and UCG sites**
- **Substantial increase in capacity:**
  - The UCG burn enhances permeability and creates cavity to hold $CO_2$
  - Rubbleized coal, ash and char residuals have significantly enhanced surface area for $CO_2$ sorption.
- **Facilities in place:**
  - Gas processing plant and wells already in place
  - Eliminates substantial cost for CCS project (e.g., well drilling)
- **Response of coal likely to enhance sequestration capacity and lower leakage risk:**
  - Sorption of $CO_2$ onto organic matrix will immobilize and attenuate potential $CO_2$ migration and leakage
  - Coals swell and plasticize in the presence of $CO_2$, which could close fractures and porosity

# Global Prospects for Carbon Storage and UCG Sites




From Bradshaw and Dance, 2005

# $CO_2$ storage within UCG zones: Caveats

**UCG processes cause thermal, geomechanical, and geochemical changes to the reservoir:**

- Heating/quenching effects on fractures and rock properties
- Enhanced permeability from acid leaching of ash, tars, char, coal, rock minerals
- Changes in fluid density from temperature and TDS
- Increased solubility of organic contaminants in $CO_2$
- Increased solubility of metals in acid groundwaters

**Objective: Evaluate benefits against drawbacks to quantify risk of UCG/CCS operations**

# Integrated UCG-CCS Tools

- **Expansion of environmental and site assessment capabilities to include aspects pertinent to CCS**
  - Include CCS aspects in RBDM framework
  - Enhanced solubility of organic compounds in $CO_2$
  - Leakage risk for $CO_2$
- **Expansion of monitoring capabilities to include detection of $CO_2$ migration underground and to detect leakage to surface**
- **Consider engineering and economic aspects of CCS during UCG planning**

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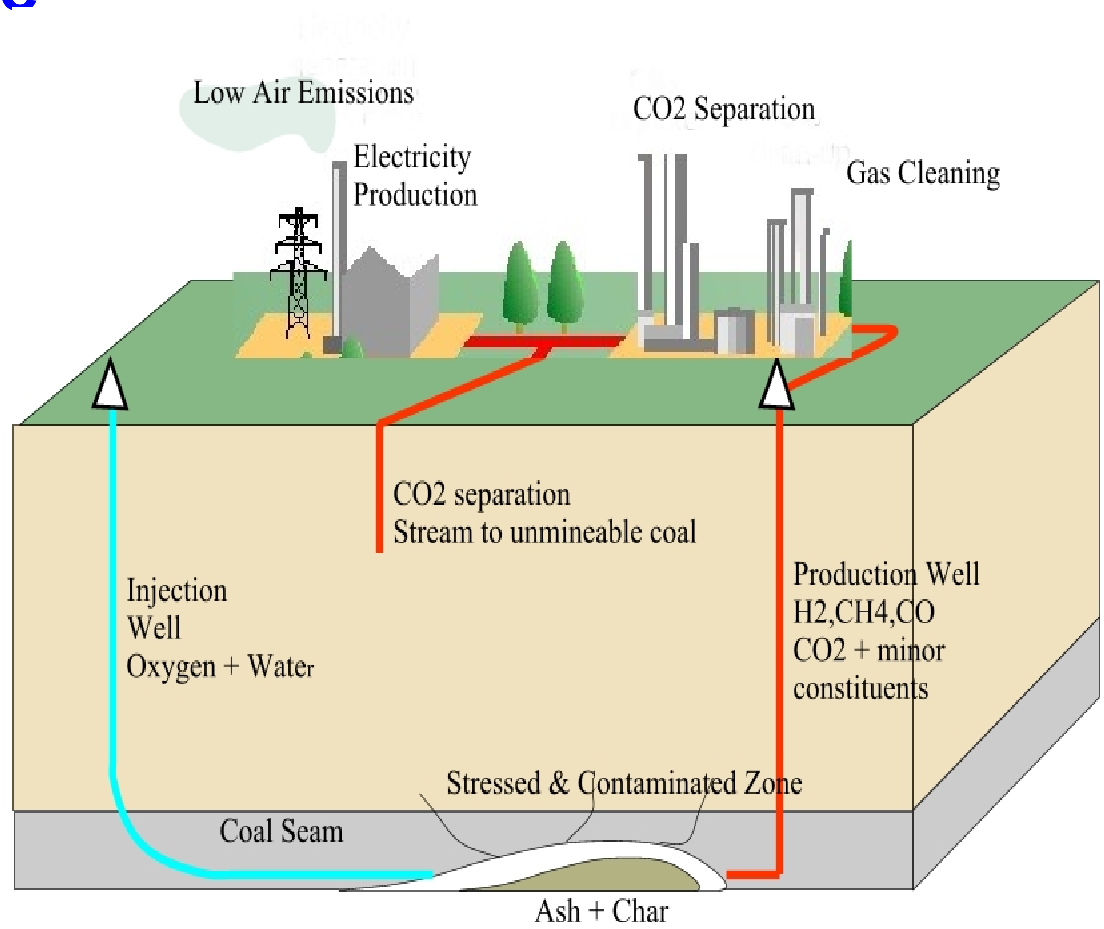

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