The CO_2 Capture Project (CCP)

Storage, Monitoring & Verification (SMV): Integration of Technical Results

Presented by Scott W. Imbus
ChevronTexaco ERTC, Houston

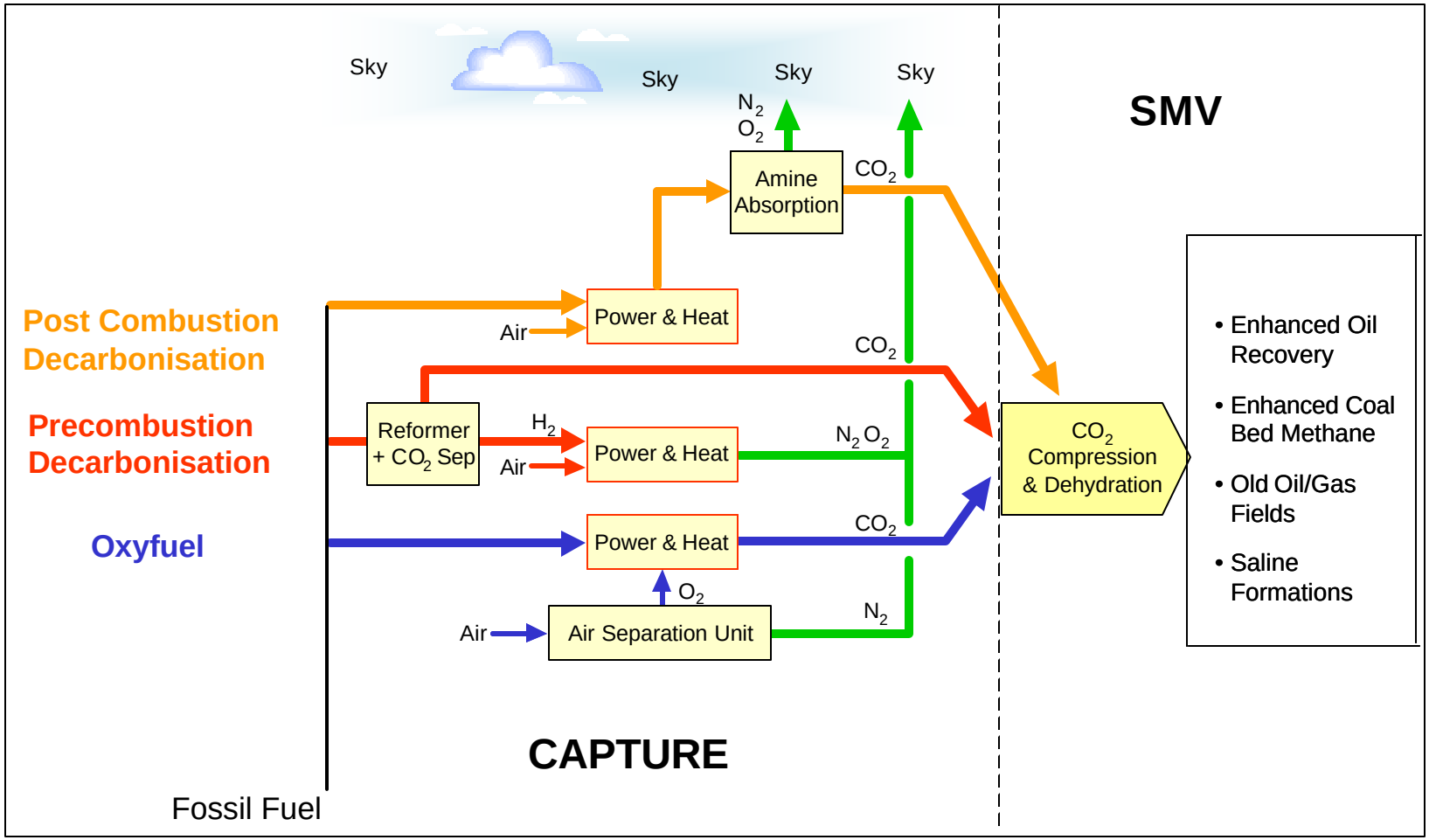
NETL 2nd Annual Conference on Carbon Sequestration
Alexandria, Virginia (May 5-8, 2003)

US Department of Energy

European Union

Klimatek NorCap

Storage, Monitoring & Verification (SMV) in CCP Scheme



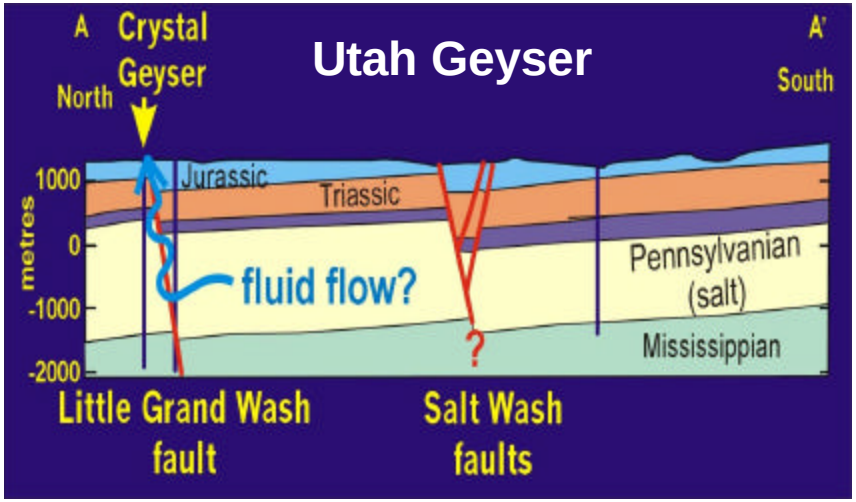
Demonstrate to Stakeholders that CO_2 Storage is Safe, Effective & Verifiable

- **Integrity (IN)**
  - **Characterize Natural CO_2 Reservoirs (Competent vs. Leaky)**
  - **Leverage Experience of the Gas Storage Industry**
  - **Assess Competency of Reservoir / Cap Rocks, Well Cement / Casing**
- **Optimization (OP)**
  - **Evaluate Potential for CO_2 Enhancement (Oil, Gas-Condensate, CBM)**
  - **Acid Gas Disposal and CO_2 Impurities Effects**
- **Monitoring (MO)**
  - **Remote & Surface Detection (Satellite & Aerial)**
  - **Near- and Sub-surface Detection (Geochemical & Geophysical)**
- **Risk Analysis & HSE (RA)**
  - **HSE Issues**
  - **RA Methdologies**
  - **Early Warning and Remediation**

CO_2 Storage - Natural Analogs

NATURAL CO_2 ACCUMULATIONS			
Characteristic	**McElmo Dome (CO)**	**St. Johns Dome (AZ)**	**Jackson Dome (MS)**
Geologic Province	Colorado Plateau	Permian Basin	Gulf Coast Basin
Reservoir Lithology	Carbonate	Sandstone / Carbonate	Dolomite / Sandstone
Depth (m)	2,300	500	>5,000
CO2 State	Supercritical	Gas	Supercritical, H_2S
Reservoir Thickness (m)	30	500	150-365, Gross
Reservoir Zones	Single	Multiple	Multiple
Reservoir Pressure	Depleted	Hydro	Hydro + 50%
CO2 Origin	Thermal/ Juvenile	Juvenile?	Biological + Thermal
	(K-T Laccolith)	(on PreCambrian Granite)	(K Intrusive)
Operational Stage	Mature	Undeveloped	Partly Developed

S. Stevens (ARI)



J. Evans (Utah State)

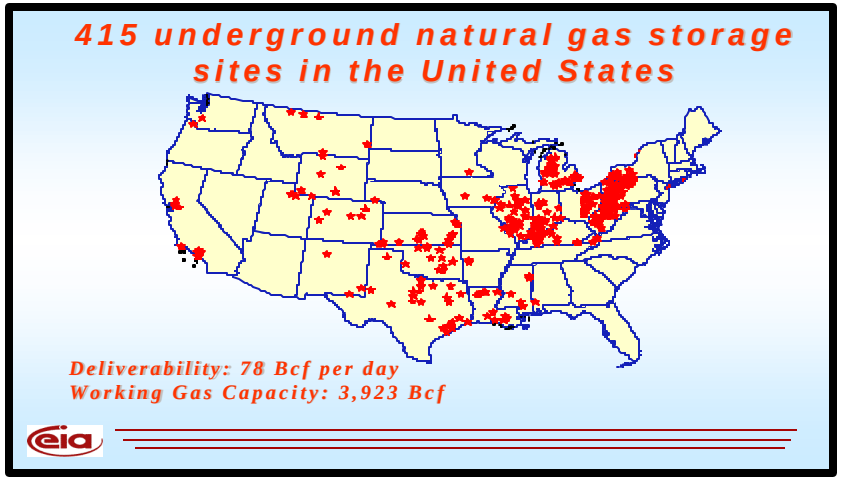
Competent CO_2 Reservoirs

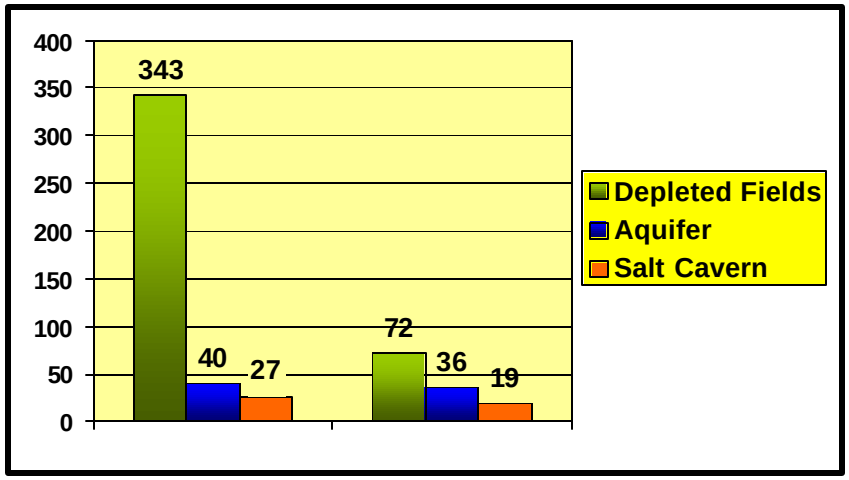
- Diverse Geologic Systems
- Reservoir / Caprock Integrity
- Operations, Safety Record

Incompetent CO_2 Reservoirs

- Fluid Origin and Movement
- Structure / Stratigraphy
- Failure of Barriers

CO_2 - Natural Gas Storage Analogs?





Natural Gas Storage

- Decades of Experience in the US / Europe
- Excellent Safety Record

CO_2 Gas Storage Analog?

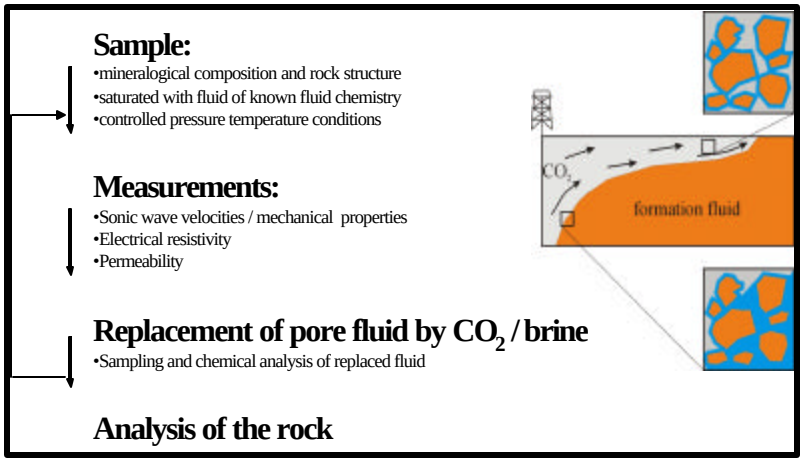
- Non-Flammable Gas
- Toxic / Asphyxiant at High Levels, Heavier than Air
- Reactive to Reservoir / Caprock, Well Equipment
- Easier to Compress; Less mobile?

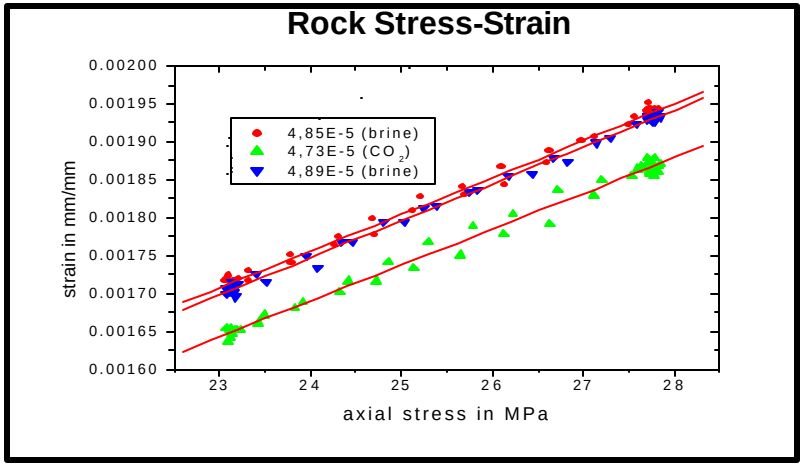
K. Perry (GTI)

CO_2 Effects on Reservoir & Caprocks (Experimental)

Influence of CO2 on Reservoir and Caprock Physical & Chemical Properties at Reservoir T&P

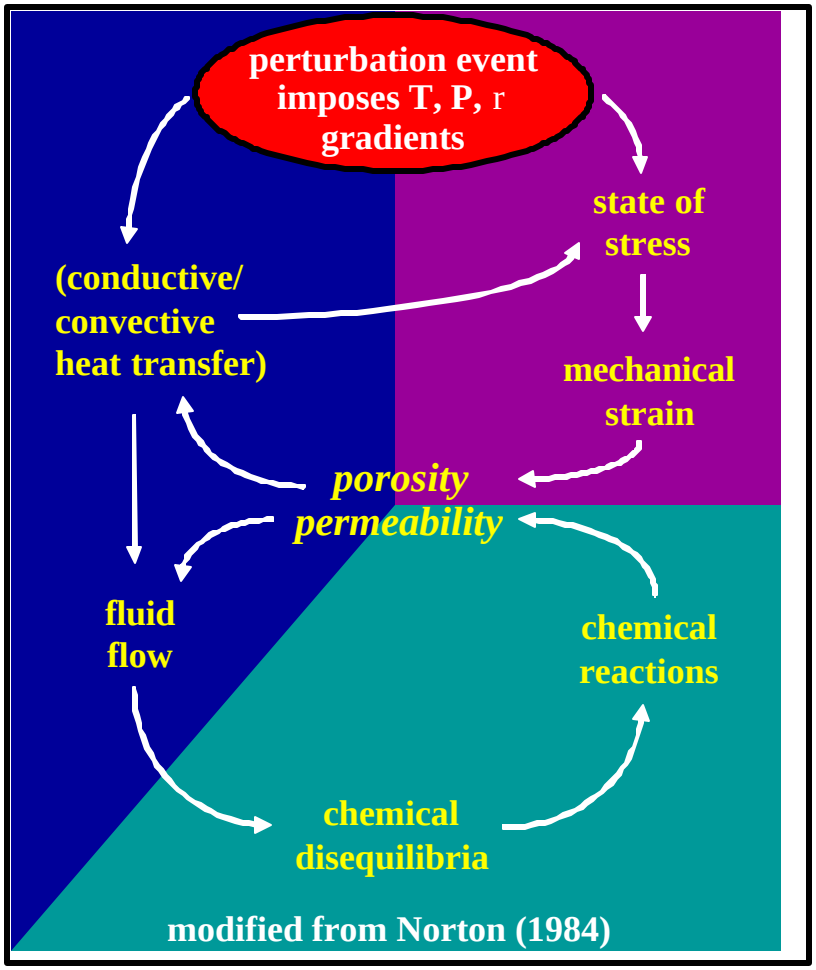
- Water & CO2 Charged Water Flow
- Rock Strength and Chemistry

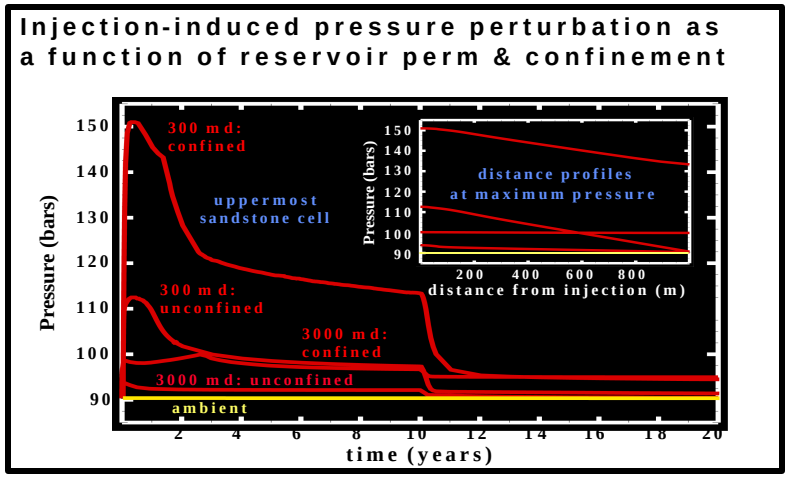


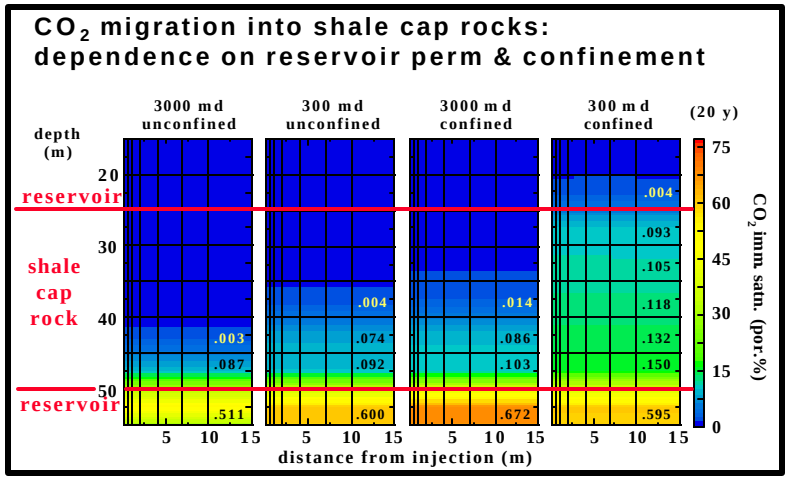


G. Borm (GFZ-Potsdam)

CO_2 Effects on Reservoir & Caprocks (Reactive Transport Modeling)







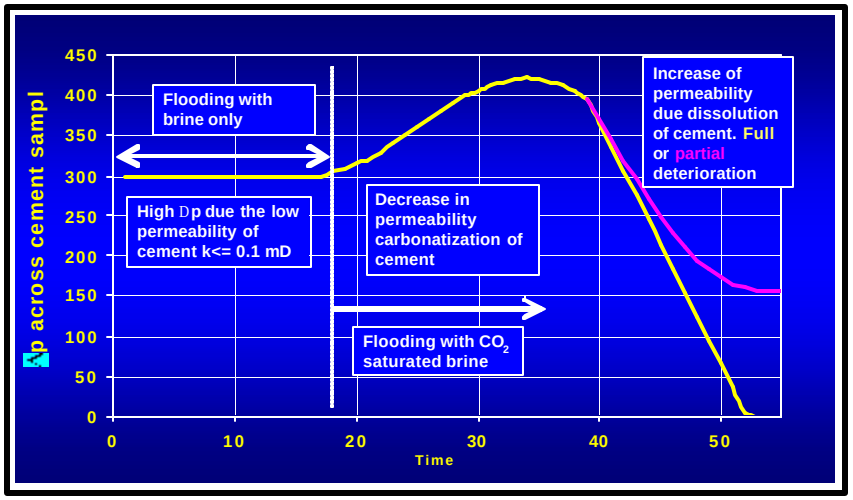
J. Johnson (LLNL)

J. Johnson (LLNL)

CO_2 and Cement / Steel Integrity

Cement Integrity

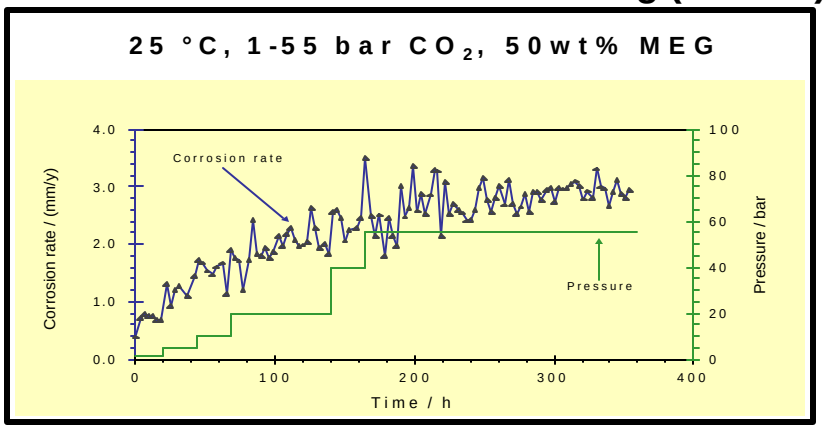
- Artificial Aging of Cement Under Reservoir Relevant T&P; Stagnant and Flowing CO_2
- Permeability Changes due to Dissolution & Carbonatization



E. Lindeberg (SINTEF)

Steel (Carbon) Integrity

- Corrosion Matrix w/ Varying CO_2 P and Inhibitor
- Acceptable Corrosion Rates vs. Need for Alloys

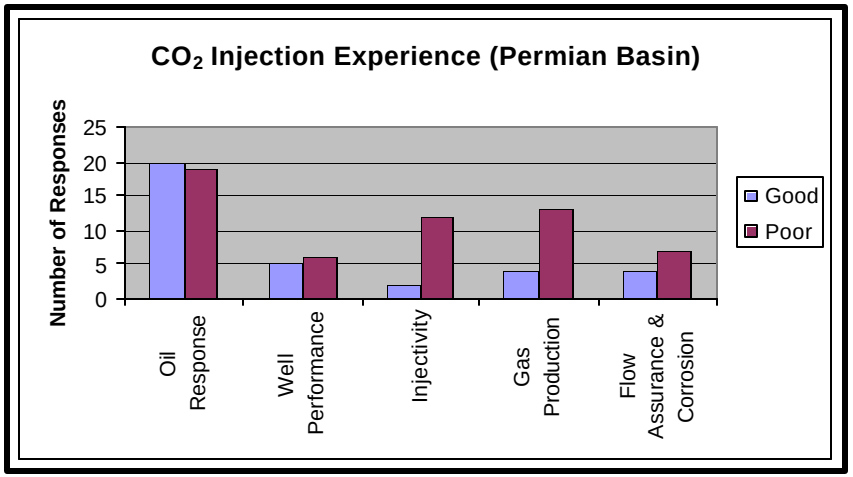


M. Seiersten (IFE)

CO_2 Storage With EOR & EGCR

CO_2 EOR Experience

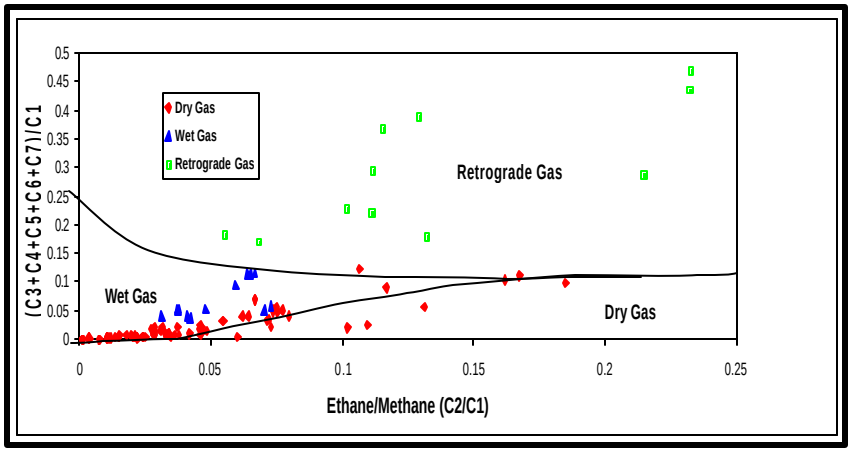
- Survey of 135 Active, Terminated or Future Projects in US
- CO_2 Effective at Oil Recovery
- By Problems Attributed to Incomplete Reservoir / Fluid Characterization



After R. Grigg (NMT)

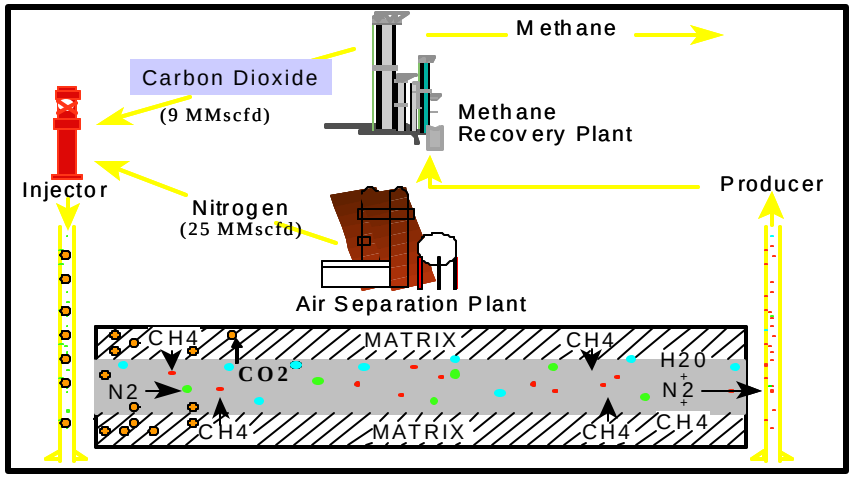
CO_2 EGCR Experience

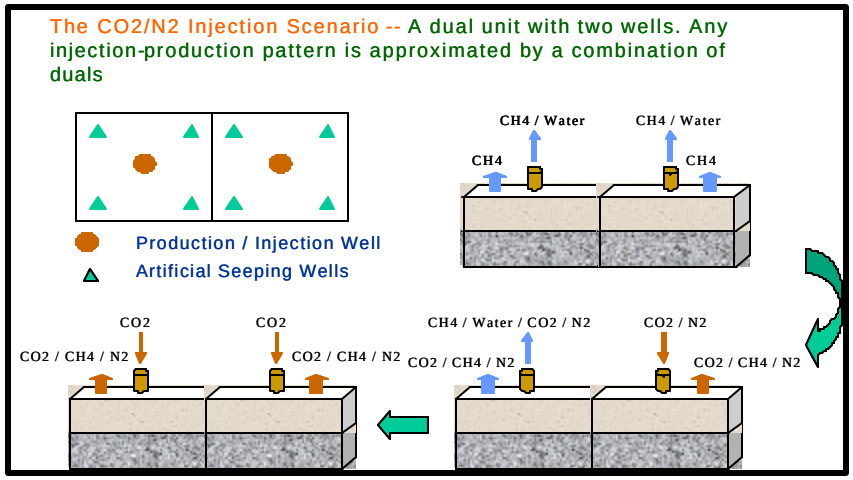
- New Area of Study
- Complex Phase Behavior
- Concern With Reserve Contamination
- Use as "Cushion" for Storage?



S. Frailey (Texas Tech)

ECBM & CO_2 Storage





CBM With CO_2 Storage

- > 2 mol CO_2 / mol CH_4

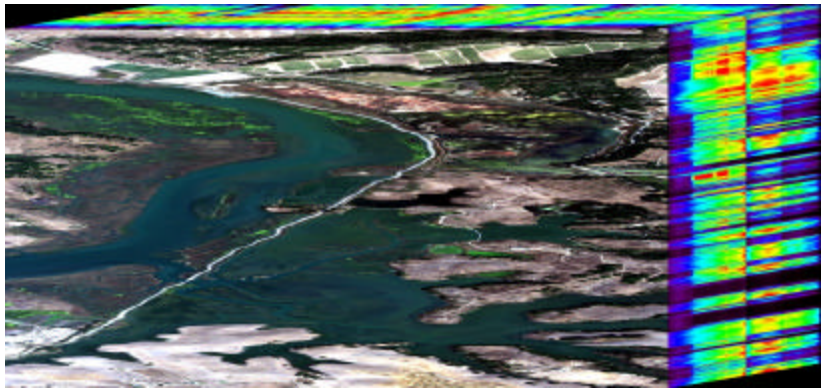
Tiffany Field (San Jaun B.)

- Primary, Then N_2 Flood
- Geologic Characterization & Production History
- Detailed Monitoring Plan
- Doubles as RA Study

J-T Liang (INEL)

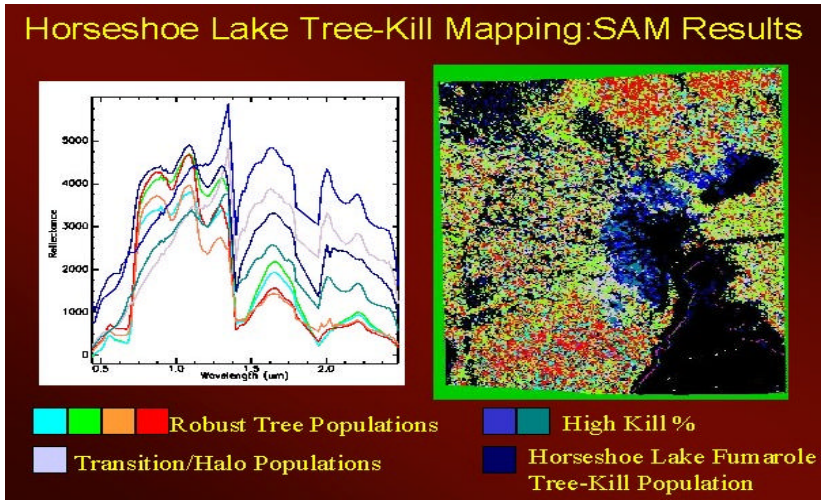
OP2

Atmospheric Monitoring Systems



SMV Survey by Shuler & Tang

- Satellite
- Airborne
- Near Surface



B. Pickles (LLNL)

Hyperspectral Monitoring

- Indirect Detection of Biotic Stress
- Mammoth Lake (CA) Tree Kills Detected & Ground-Truthed
- Aerial Survey Data Over Rangely Field Processing in Progress With Ground-Truthing From Soil CO_2

Geophysical Monitoring : Seismic

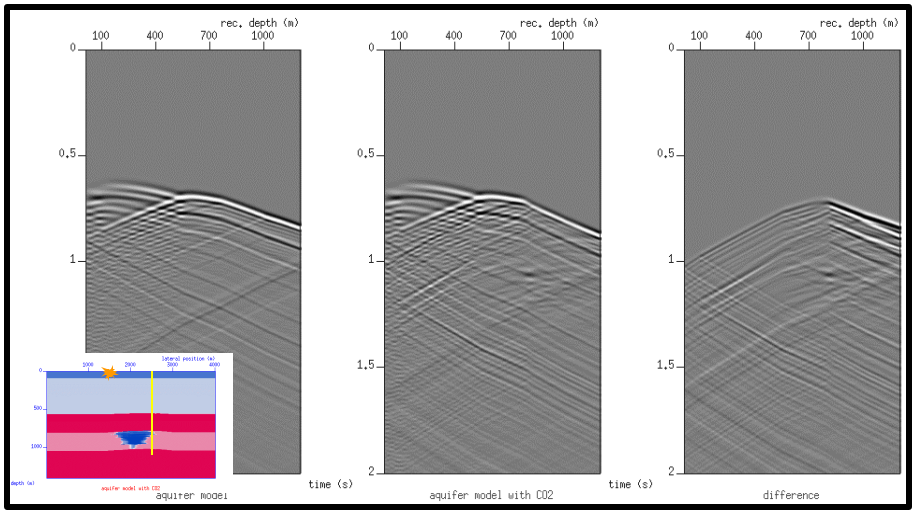
Seismic vs. Other Geophysical Methods

- Microseismic
- Vertical Seismic Profiling (VSP)
- Cross-Well Seismics
- Repeated 3D Seismic

Seismic Modeling (Sleipner-Like)

- Shot gather with VSP acquisition
- Before CO_2 Injection, After CO_2 Injection and Difference

	Time lapse seismic	sub-bottom profiling	Sonar	Gravity	EM	Geodetic	InSAR	Tiltmeters
Cap rock* integrity (leakage)	good	in case of leakage to the sea	in case of leakage to the sea	low resolution	low resolution	x	x	x
Ground movements	x	x	x	x	x	good	good	good
Lateral spreading	good	x	x	low resolution	low resolution	x	x	x
Verification or mass balance	fair	x	x	too low resolution	too low resolution	x	x	x

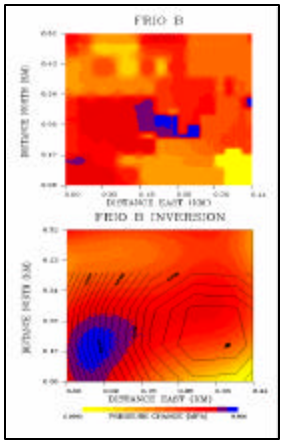


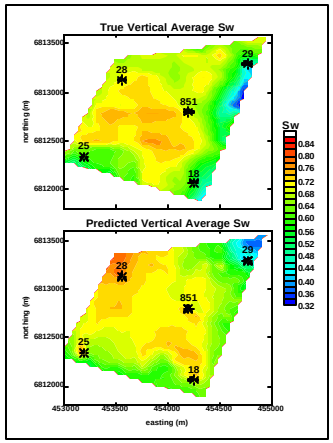
R. Arts (TNO)

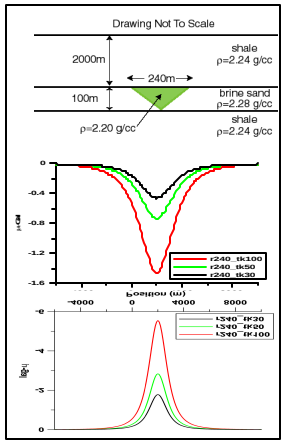
Geophysical Monitoring : Non-Seismic

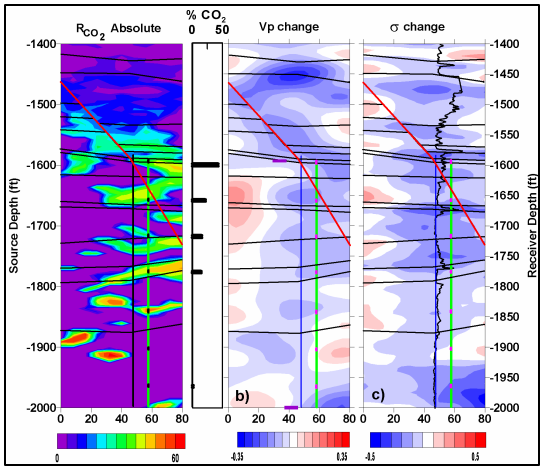
Survey & Models of Non-Seismic Geophysical Approaches (Clockwise from Upper Left)

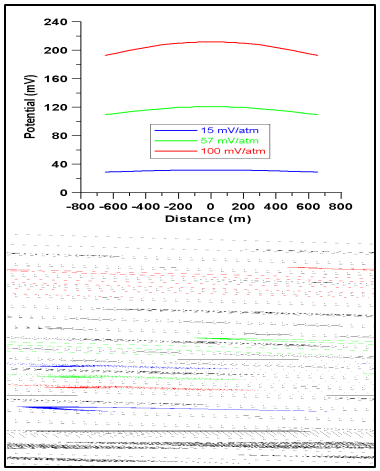
- Tilt & Gravity Model
- 3D EM Inversion Model
- Gravity Response Model
- R_{CO2} Image Model
- SP Sleipner vs. Liberty Field







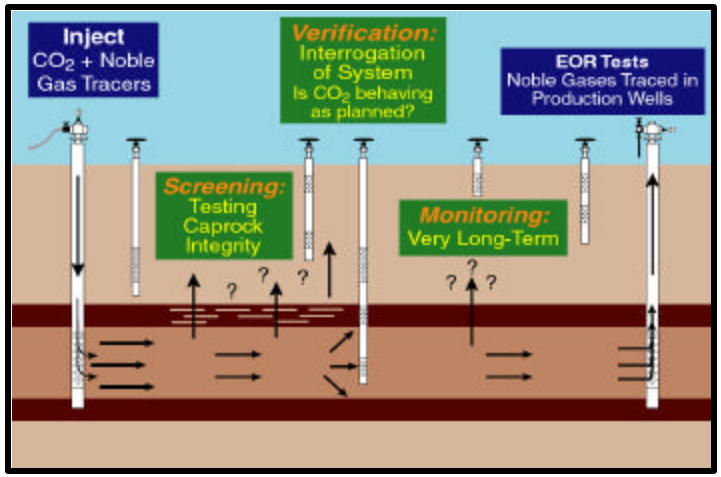


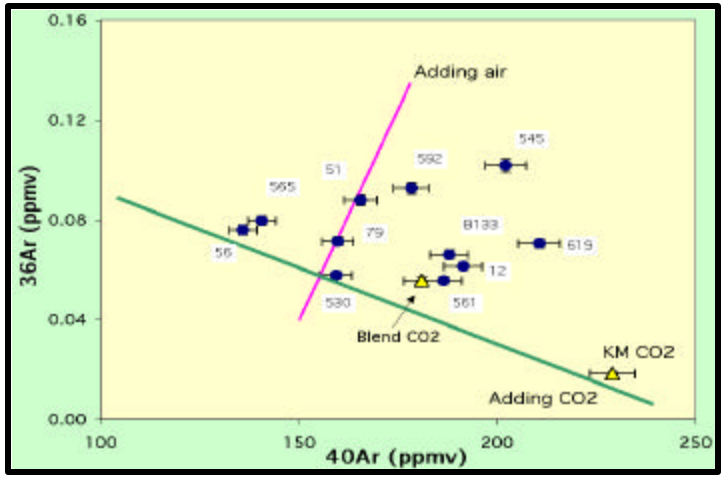


MO3

M. Hoversten (LBNL)

Geochemical Monitoring





Noble Gas Monitoring of CO2 Flooding (Mabee Field)

- Inert, Non-Toxic, Easily Detected
- Analysis of Gases (Reservoir, CO_2 Injectant, Soil)
- Tracer Tests

Mabee Field System Dominated by Atmospheric Noble Gases (WAG Operation)

Interesting Migration Rate Systematics

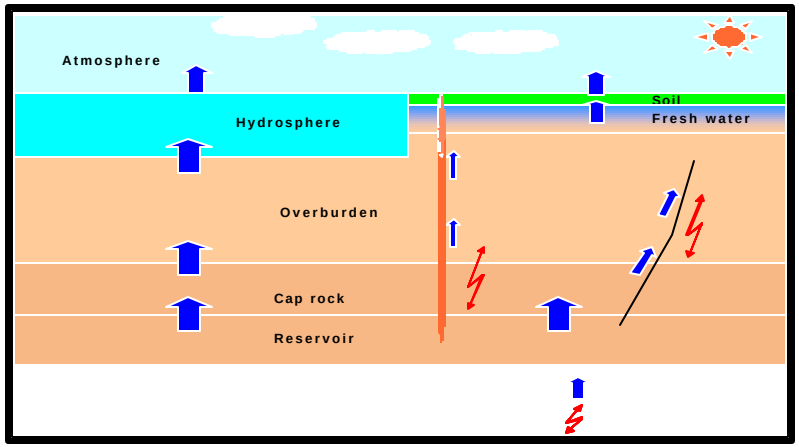
Risk Analysis - Scenarios

Approach

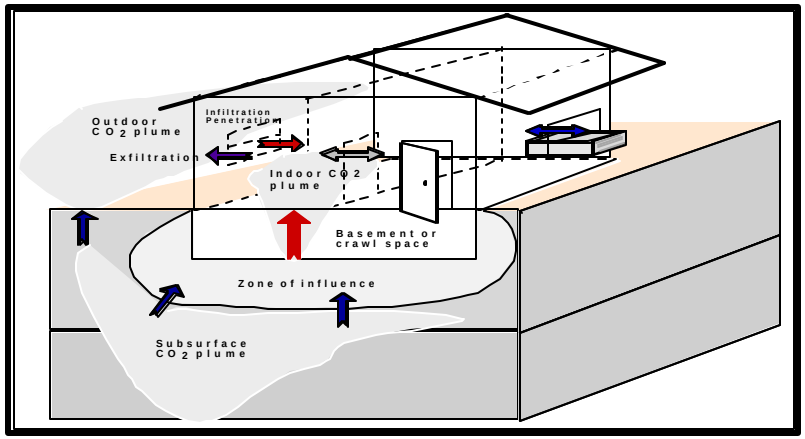
- Scenario Analysis
- Model Development
- Consequence Analysis

Basic Scenarios for Risk Assessment

- Offshore Depleted Gas Field
- Onshore Aquifer
- Onshore Coal Seam
- Onshore Near Surface



T. Wildenborg (TNO)

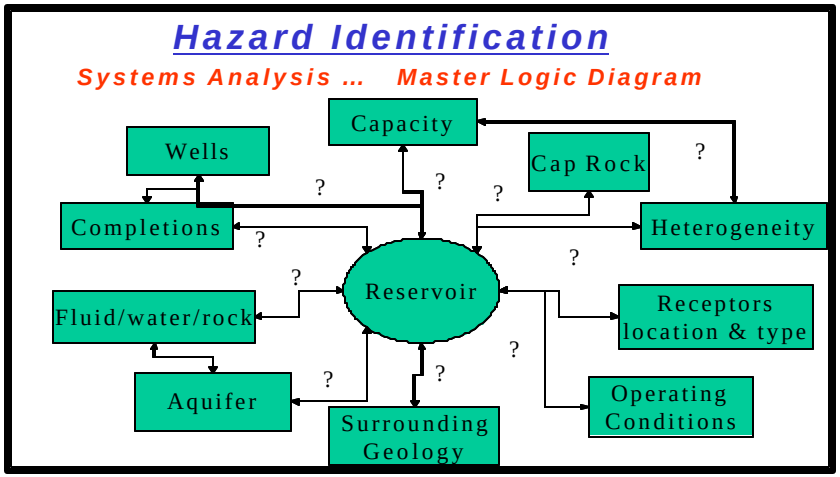


C. Oldenburg (LBNL)

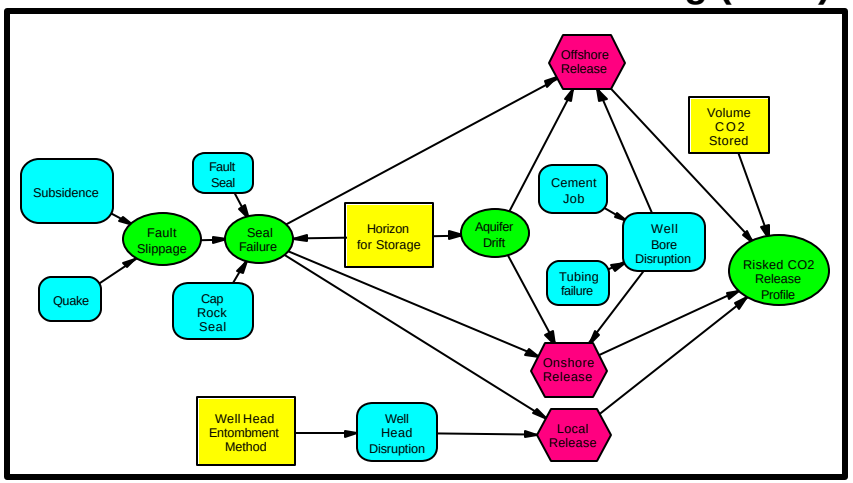
Risk Analysis – Hazard Identification

Identification of Risks Associated with CO2 Storage

- Site Specific Hazards
- FEPs (Features, Events, Processes)
- Influence Diagram



J-T Liang (INEL)

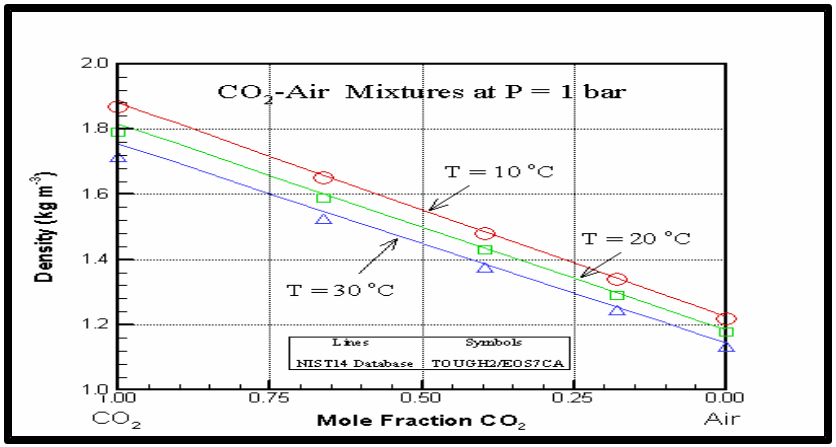


T. Wildenborg (TNO)

Risk Analysis – Physical Modeling

Compartment	Mechanical processes	Hydraulic processes	Physico-chemical processes	Marine hydraulic processes	Atmospheric physical processes
Storage reservoir	DIANA	SIMED DIANA	TAFFETAS/ MARTHE		
Seal					
Overburden					
Shallow aquifer/soil			STOMP		
Hydrosphere (sea)				DELFT3D	
Atmosphere					PLUME+/ LOTOS/UAM

T. Wildenborg (TNO)



C. Oldenburg (LBNL) RA3

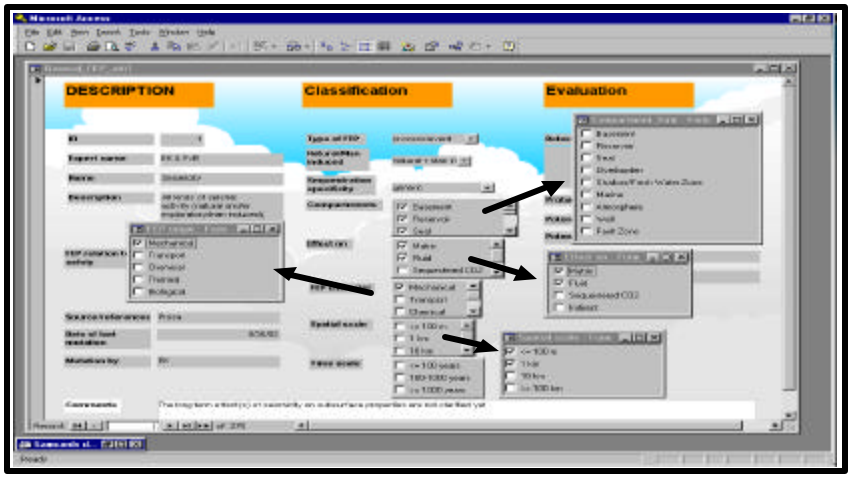
Numerical Modeling Used to Characterize and Quantify Risks

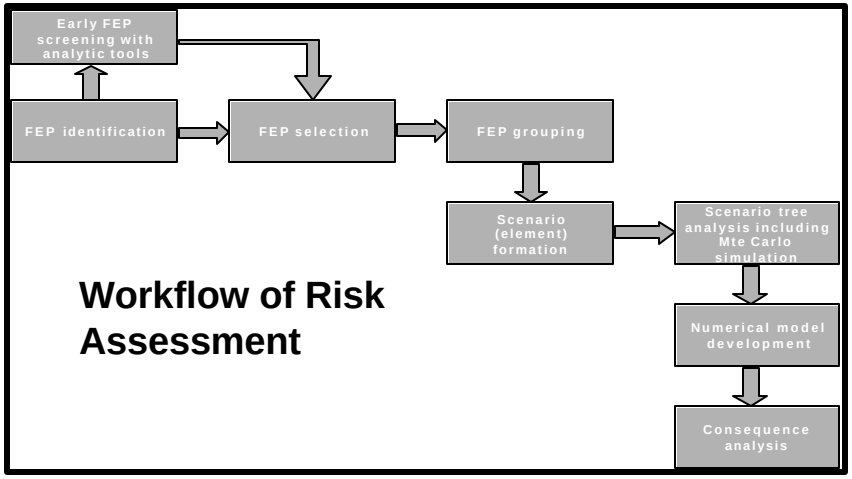
- Reservoir / Caprock System
- Overburden
- Shallow Hydrology
- Surface or Seafloor

Risk Analysis – Quantification

Quantification of Risk for Specific Scenario…

- Relevant Hazards & FEPs
- Historical & Modeled Frequency and Impact
- Probability Distributions
- Consequence Analysis





T. Wildenborg (TNO)