West Coast Regional Carbon Sequestration Partnership
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WESTCARB Annual Business Meeting

WESTCARB Phase III: Initial Modeling

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Outline

- **Approach**
  - **The TOUGH codes**
  - **Hysteresis**
- **Kimberlina Pilot**
  - **Model geometry**
  - **Discretization**
  - **Results of preliminary modeling**
- **Discussion Questions**

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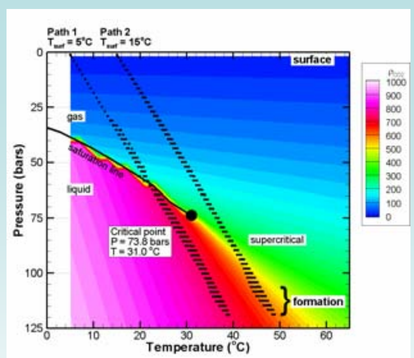
The TOUGH Codes

- Multi-phase, multi-component fluid flow, tracer transport, and heat flow through porous or fractured media
- Integral finite difference method for space discretization
- Implicit time-stepping with Newton-Raphson iteration
- Several Equation of State (EOS) packages relevant for geologic CO_2 storage
- Additional modules for coupled processes
  - TOUGHREACT adds chemical reactions (contact: Tianfu Xu)
  - TOUGH-flac adds rock mechanics (contact: Jonny Rutqvist)
- Additional capabilities
  - TOUGH+ re-engineering of TOUGH codes (contact: George Moridis)
  - iTOUGH2 inverse model (contact: Stefan Finsterle)
  - TOUGH2/ECO2 with hysteretic capillary pressure and relative permeability formulations (contact: Christine Doughty)
  - TOUGH2/EOS7C for natural gas reservoirs (contact: Curt Oldenburg)
  - System-level simulations using TOUGH2 in the GoldSim framework (contact: Yingqi Zhang)

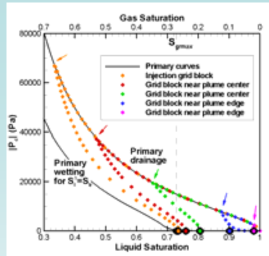
ECO2N

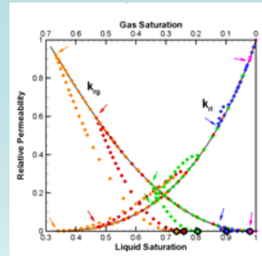


Pruess, K., Soc. Pet. Eng. J., 9(2), 237-248, 2004 (SPE-86098).

- EOS for CO_2 sequestration
- Components:
  - CO_2
  - H_2O
  - NaCl
- Phases
  - Supercritical
    - CO_2 rich, but may contain water vapor
    - ECO2N can gradually transition into gas
      - cannot cross the saturation line
  - Aqueous
    - H_2O rich, but may contain dissolved NaCl and CO_2
    - density dependence on dissolved species included
  - Solid
    - Includes precipitated NaCl
    - Solid formation decreases porosity and permeability

Hysteresis

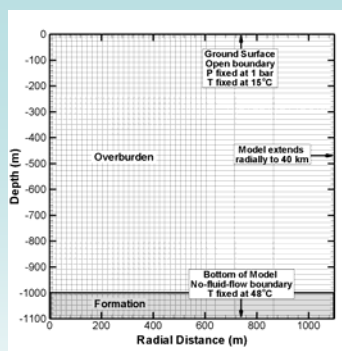




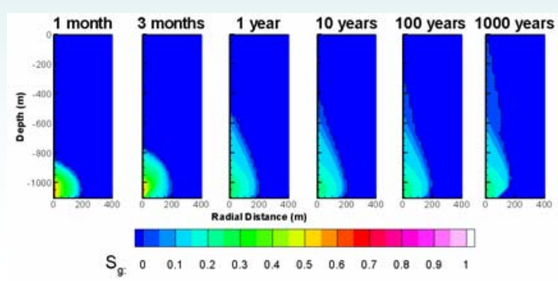
- Capillary pressure and relative permeability are history dependent
- Key feature is S_{gr} residual gas saturation (saturation below which CO_2 is immobile)
  - Drainage (CO_2 replaces brine): S_{gr} is zero
  - Imbibition (brine replaces CO_2): S_{gr} is non-zero and increases with maximum historic saturation
- Important for problems including both CO_2 injection and rest periods
  - Injection: all drainage
  - Rest: drainage at leading edge of plume, imbibition at trailing edge

Doughty, C., Modeling geologic storage of carbon dioxide: Comparison of non-hysteretic and hysteretic characteristic curves, Energy Conversion and Management, 48(6), 1768-1781, 2007.

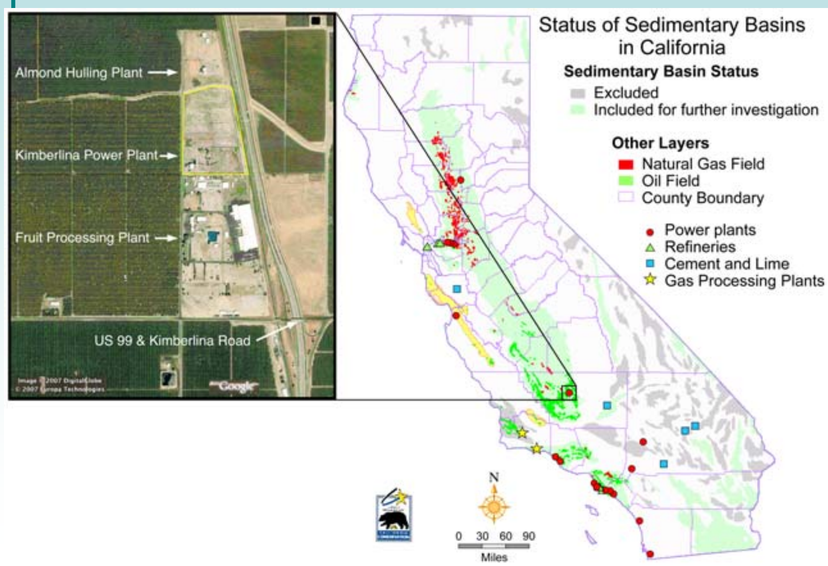
Hysteresis (cont'd)



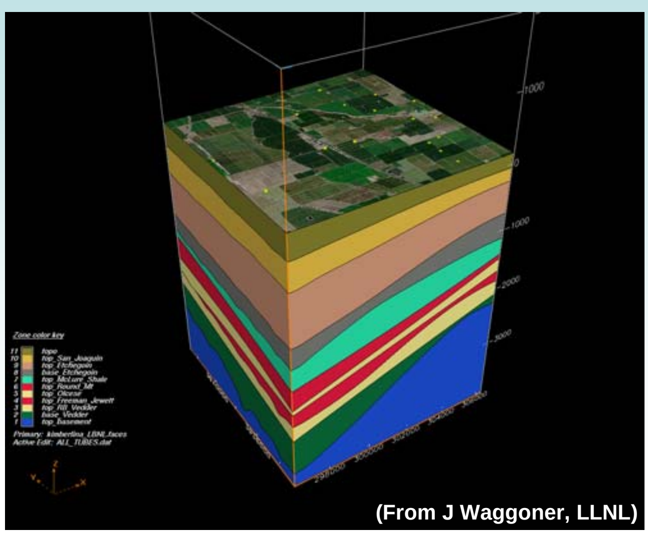
- One month CO_2 injection at 1000-1100 m depth
- Watch plume for 1000 years
- High-permeability overburden (100 md)
- Leading edge of plume continues to move upward, but most of plume remains trapped at depth



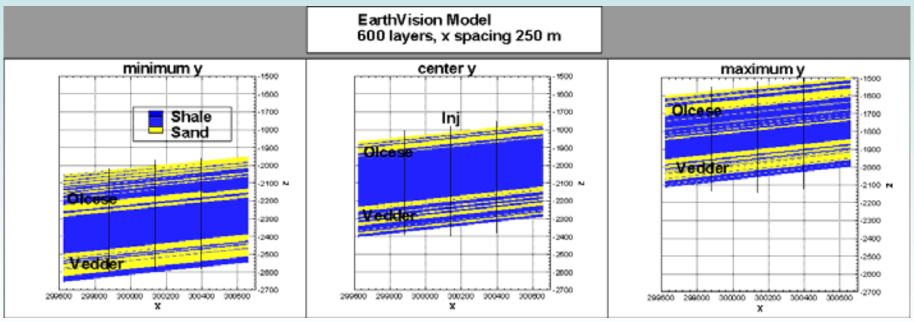
Kimberlina Saline Formation Pilot



Initial Geologic Model Based on Available Well Data



Cross-Sections Through Sand-Shale Model



From J Waggoner, LLNL

- **Geologic model will be revised based on 3D seismic, core well logs**

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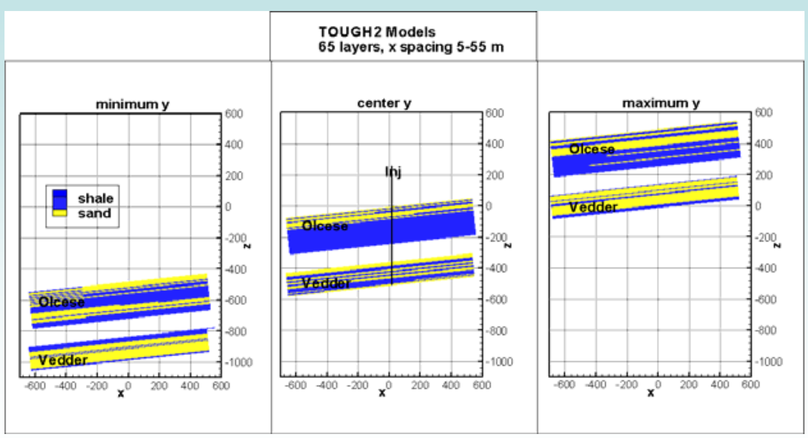
TOUGH2 Model Cross-Sections



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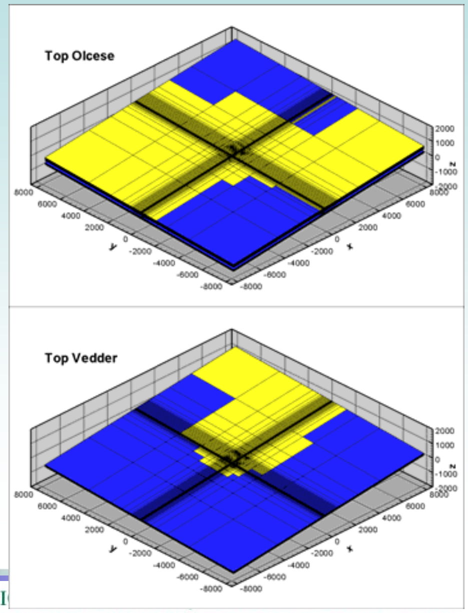
TOUGH2 Models



TOUGH2 Model Development

- EarthVision model of Olcese and Vedder
  - 600 layers
  - 50 x 50 lateral cells
  - x: 250 m wide, y: 200 m wide
- TOUGH2 model
  - Olcese - 35 layers (8 EV layers combined to form each TOUGH2 layer)
  - Vedder - 30 layers (6 EV layers combined to form each TOUGH2 layer)
  - Closed boundaries above and below Olcese and Vedder
  - Constant-pressure boundaries at x extrema, closed at y extrema
  - Lateral grid spacing varies
    - 5 m at injection well
    - 55 m over region where CO_2 plume expected to go
    - Increasing to 2.5 km far from injection well
  - Earthvision facies assigned to TOUGH2 cells
  - Model is a tilted plane – good approximation to the nearly uniform dip observed in the EarthVision model. Dip angle is 7 degrees.

Model Parameters

Facies	Porosity	Horizontal Permeability	Vertical Permeability	Residual Liquid Saturation	Maximum Residual Gas Saturation
Sand	28%	200 md	20 md	0.2	0.277
Shale	15%	0.1 md	0.01 md	0.4	0.28

- Residual gas saturation
  - zero during drainage
  - non-zero during imbibition, depends on saturation history

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Simulated Cases

- CO_2 Injection over full thickness of Vedder (158 m)
- CO_2 Injection over full thickness of Olcese (245 m)
- CO_2 Injection in uppermost Vedder sand body (25 m)

- Notes on Vedder and Olcese communication
  - Continuous shale
  - Thickness >100 m
  - Assume no communication
  - Can use separate models for each formation

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CO_2 Injection in Vedder

- Inject 250,000 t per year for 4 years
- Pick a central location in model for injection well
- Inject over entire thickness of Vedder (158 m thick)
- At injection location, about 50/50 sand/shale, so net sand thickness is about 79 m
- P = 220 bar, T = 81°C, density of CO_2 = 632 kg/m^3

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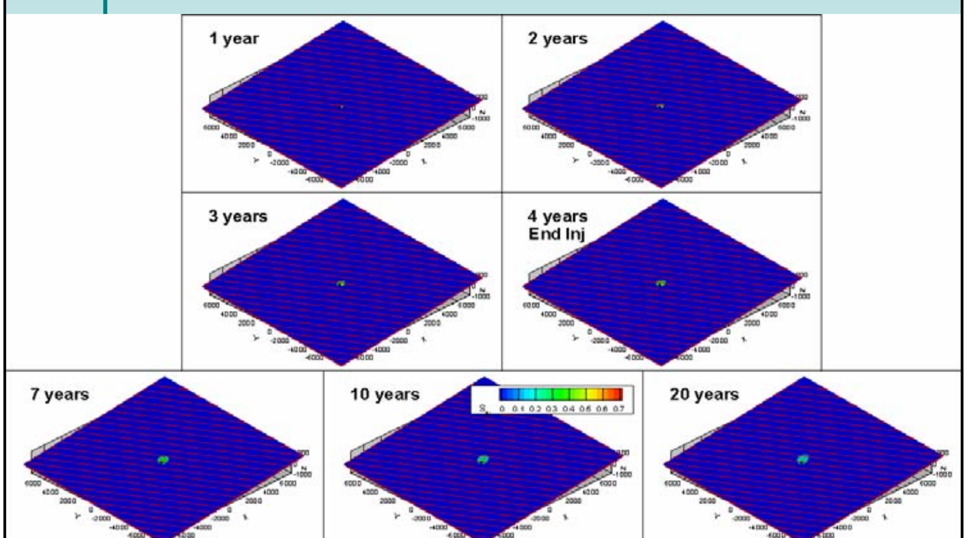
Vedder Injection



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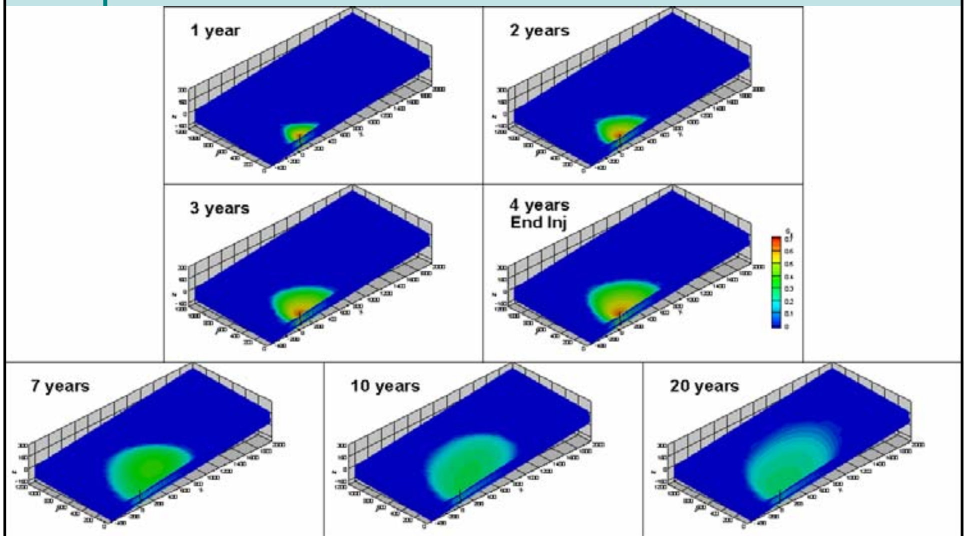
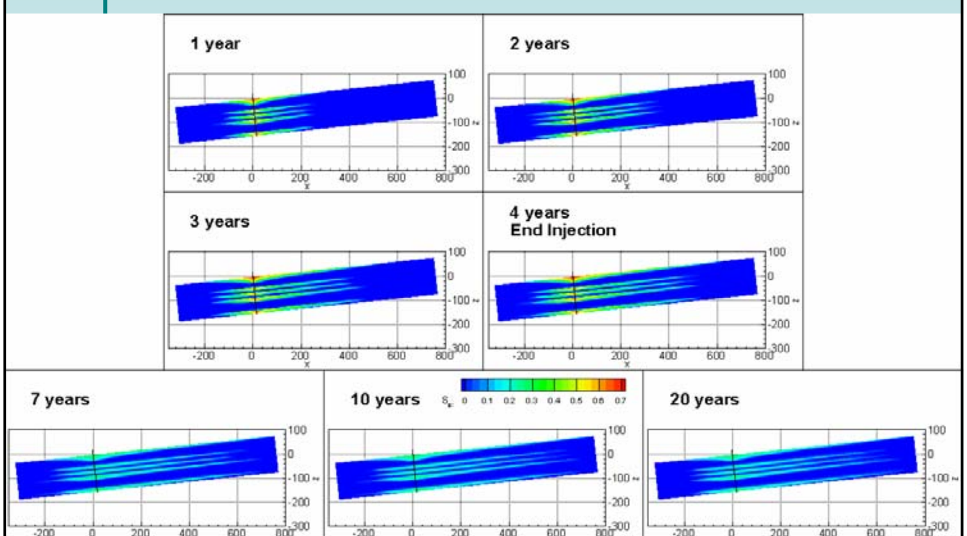
Vedder Injection (cont'd)



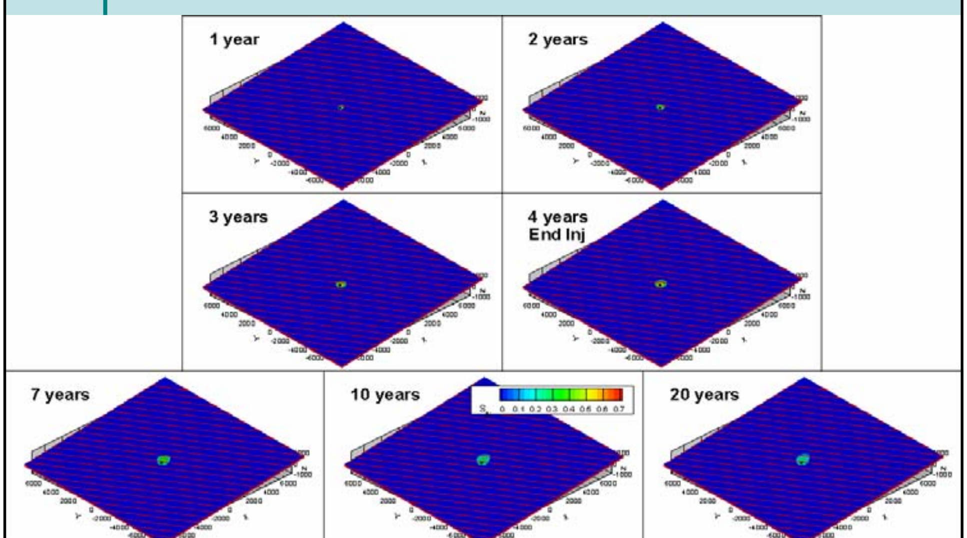
Vedder Injection (cont'd)



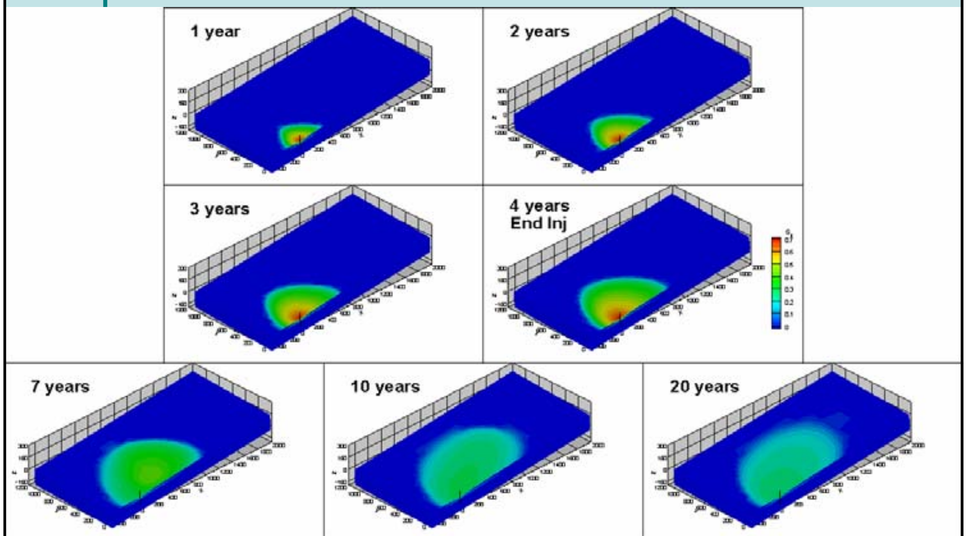
CO_2 Injection in Olcese

- Inject 250 kt per year for 4 years
- Pick a central location in model for injection well
- Nominally, inject over entire thickness of Olcese (245 m thick)
- At injection location, sand is all in upper third of formation, net sand thickness is about 50 m
- P = 180 bar, T = 69°C, density of CO_2 = 621 kg/m^3

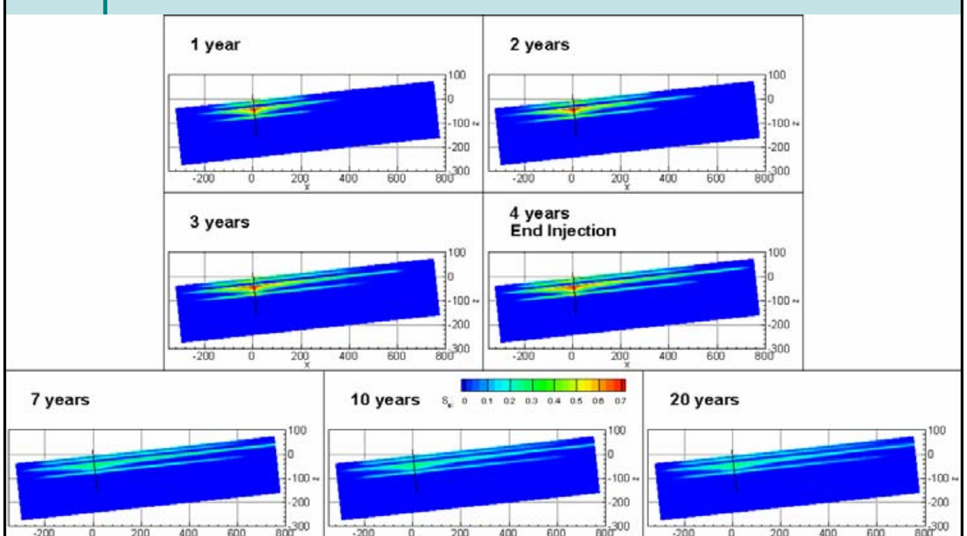
Olcese Injection



Olcese Injection (cont'd)



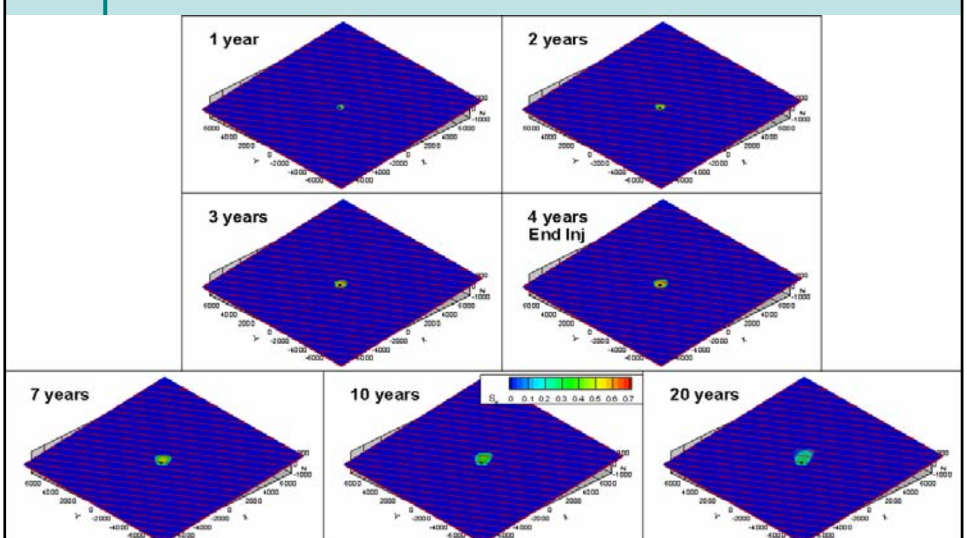
Olcese Injection (cont'd)



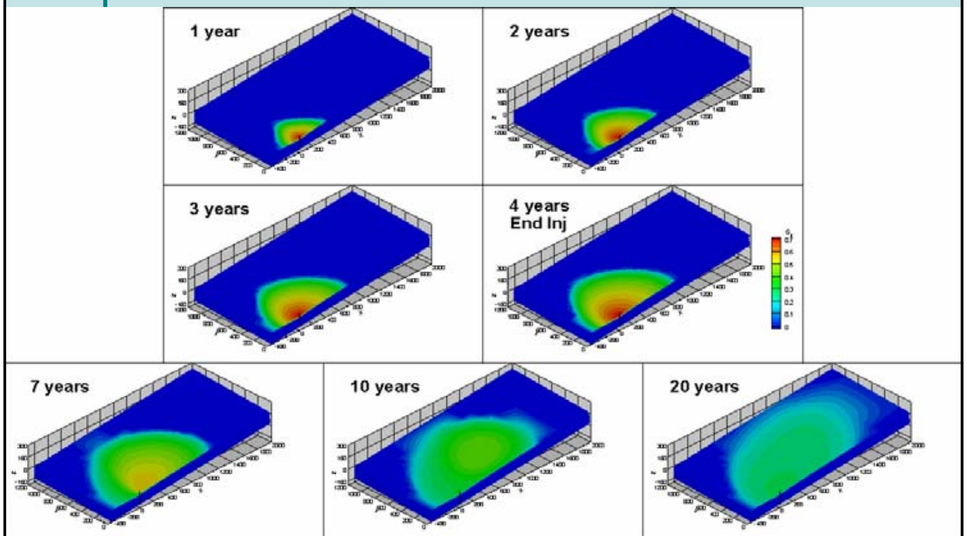
CO_2 Injection in Upper Vedder

- Inject 250 kt per year for 4 years
- Pick a central location in model for injection well
- Inject over uppermost sand body within Vedder (25 m thick)
- P = 220 bar, T = 81°C, density of CO_2= 632 kg/m^3

Upper Vedder Injection



Upper Vedder Injection (cont'd)



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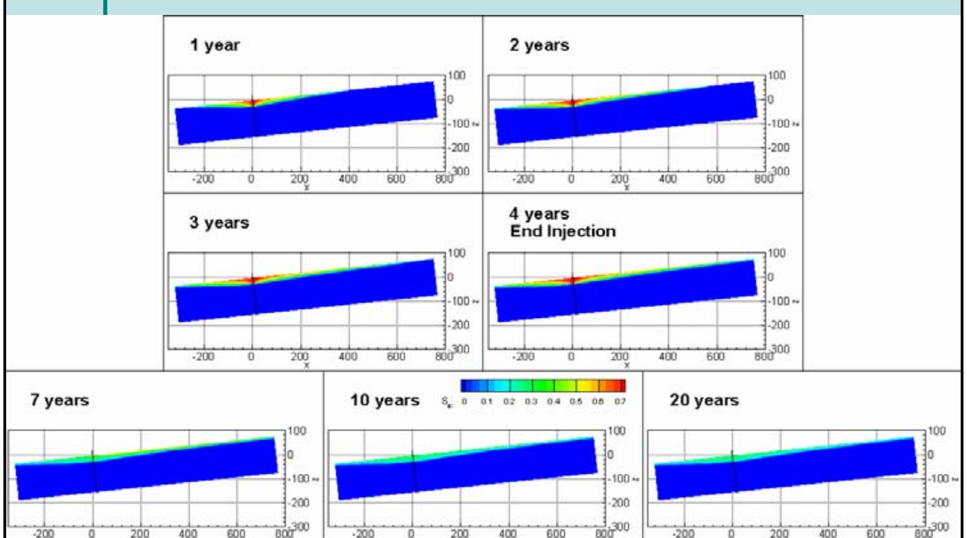
Upper Vedder Injection (cont'd)



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Summary

- Modeling is needed to predict plume migration and design CO_2 storage systems
- The TOUGH codes are available for a wide variety of CO_2-related modeling needs
- Application of TOUGH2/ECO2N with a preliminary version of the Kimberlina geologic model suggests plume size is small relative to the geologic model, but large relative to the property lines of the site

Discussion

- How do we use these results for Phase III?
- How will predictive results be used in general?
  - Needs of project proponent
  - Needs of regulators and public
- What can we do in Phase III to inform future projects?
- As more detailed information becomes available, how do we incorporate or update models and the uses to which results have been put?

Acknowledgments

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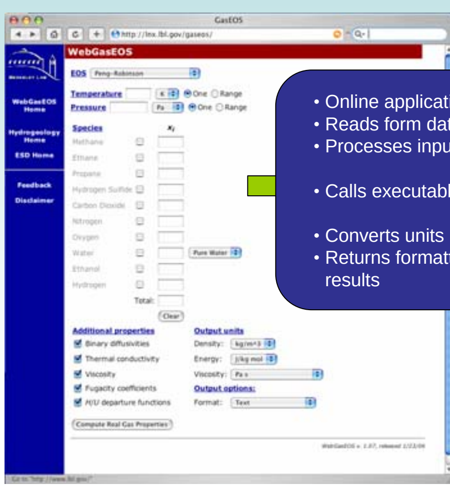
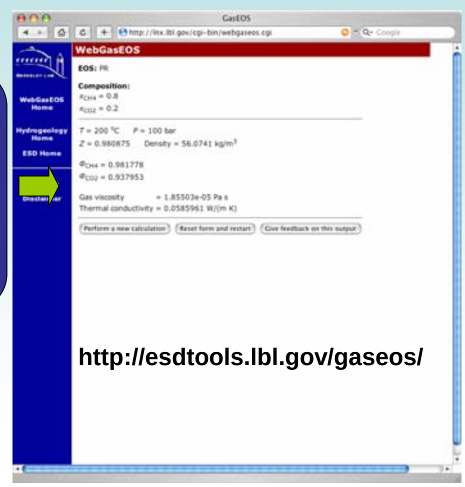
WebGasEOS

LBNL interactive online application



- Online application
- Reads form data
- Processes inputs
- Calls executable
- Converts units
- Returns formatted results



http://esdtools.lbl.gov/gaseos/