Enhanced Analytical Simulation Tool (EASiTool) for CO_2 Storage Capacity Estimation and Uncertainty Analysis

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U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

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Presentation Outline

- Benefit to the Program
- Project Overview: Goals and Objectives
- Technical Status
- Accomplishments to Date
- Summary

Benefit to the Program

- <u>Major goal</u>
  - Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
- <u>Project benefit</u>
  - This research project is developing an **Enhanced Analytical Simulation Tool (EASiTool)** for simplified reservoir models to predict storage capacity of brine formations. EASiTool will consider advanced two-phase flow theory, geo-mechanically imposed limitations and active brine management to estimate the storage capacity in open and closed boundary conditions.

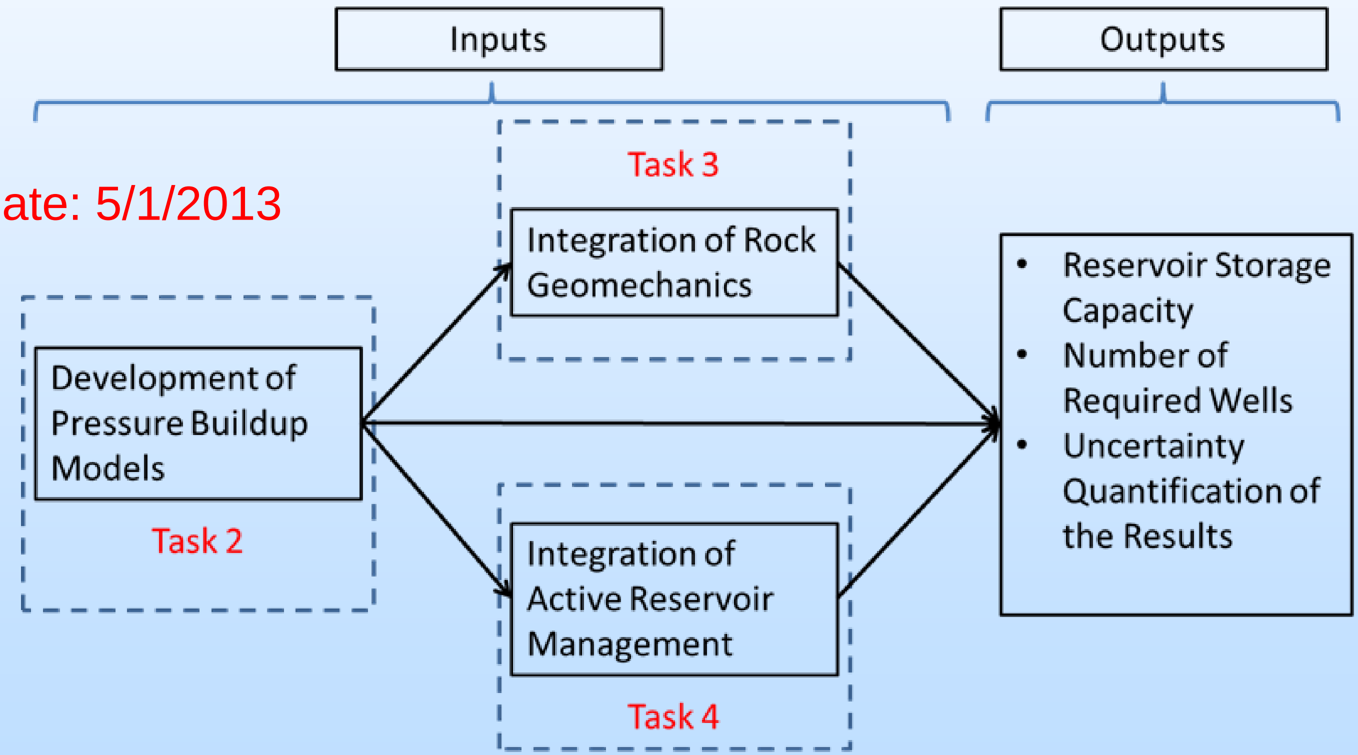
Project Overview: Goals and Objectives

- Project goals and objectives
  - EASiTool is intended to be
    - For technical and nontechnical users.
    - Provide fast, reliable and science-based estimate of storage capacity.
    - Provide uncertainty analysis.

Project Overview: Goals and Objectives

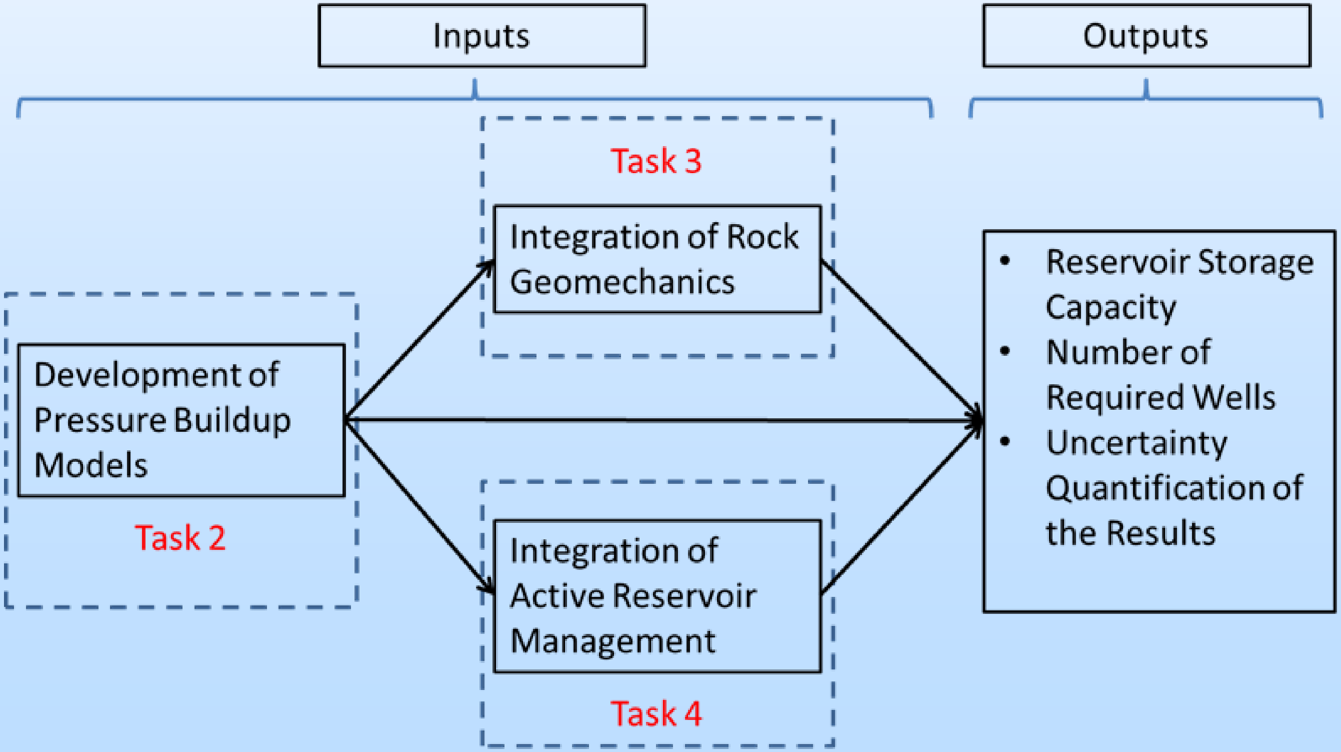
- Task 2 completed.
- Task 3 started.

Project start date: 5/1/2013



Technical Status

- Currently under Task 3 the main focus is on
  - Numerical simulations on seal deformation
  - Theoretical work developing analytical equations for estimating fracture pressure
  - Developing EASiTool interface



Accomplishments to Date-1

- EASiTool V1.0 released on 30/4/2014.

EASiTool

Project Overview

Enhanced Analytical Simulation Tool (EASiTool) for CO2 Storage Capacity Estimation and Uncertainty Quantification

Project PI: Seyyed A. Hosseini

Collaborators: C12 Energy

An analytical-based **Enhanced Analytical Simulation Tool (EASiTool)** will be developed for technical and non-technical users with minimum engineering knowledge. The purpose of EASiTool is to produce a fast, reliable estimate of storage capacity for any geological formation. EASiTool will include closed-form analytical solutions that can be used as a first step for screening of geological formations to determine which formation can best accommodate storage needs over given period of time.

EASiTool will be developed with a highly user-friendly interface, however the analytical models behind the EASiTool will be cutting-edge models that incorporate effects of rock geomechanics, evaporation of brine near the wellbore, as well as deployment of brine extraction in the field to enhance the storage capacity. A net present value (NPV) based analysis will be implemented to devise the best field development strategy to maximize the stakeholder's profit by optimizing the number of injection/extraction wells.

This highly user-friendly tool will provide a unique strategy for CO2 injection combined with brine extraction to optimize any CO2 project by maximizing the project's NPV. Benefits of this project include:

1. application of the advanced closed-form analytical solutions to estimate CO2 injectivity into geological formations,
2. estimation of the number of injection/extraction wells necessary to reach the storage goal, and
3. improving current static storage efficiency coefficients by instead using dynamic closed-form analytical solutions.

C12 Energy (a leading commercial developer of CO2 storage sites in the U.S.A.) will beta-test EASiTool. In addition, uncertainty quantification (UQ) of the results based on Monte Carlo method will be provided to address the uncertainties associated with input model parameters.

The EASiTool developed in this project contributes directly to DOE research needs. At three stages of the development, EASiTool will be released to the possible end users (regulators, private and public companies, coal-fired power plants, etc) at this website.

The project is funded by DOE (DE-FE0009301).

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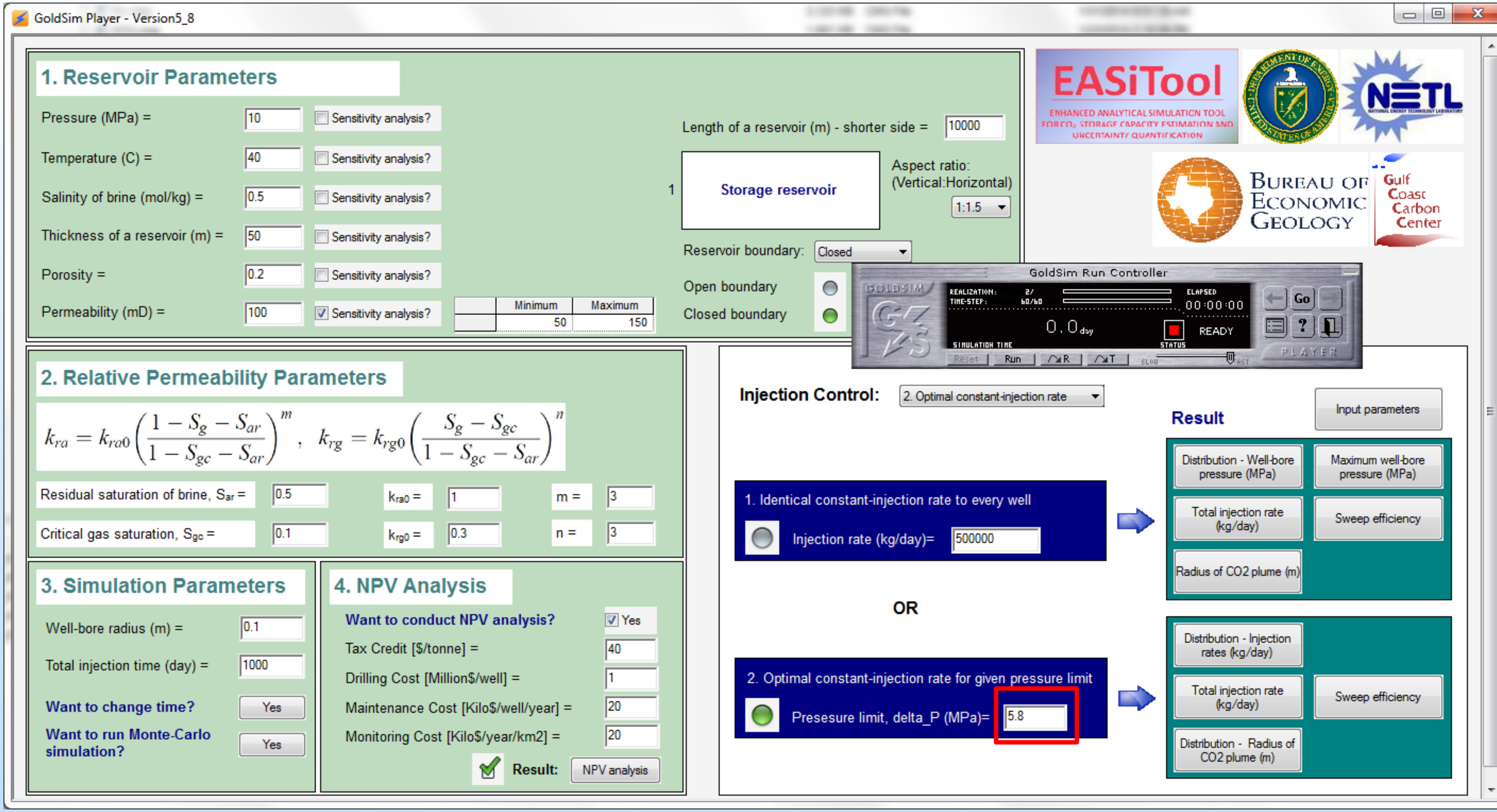
FAQs

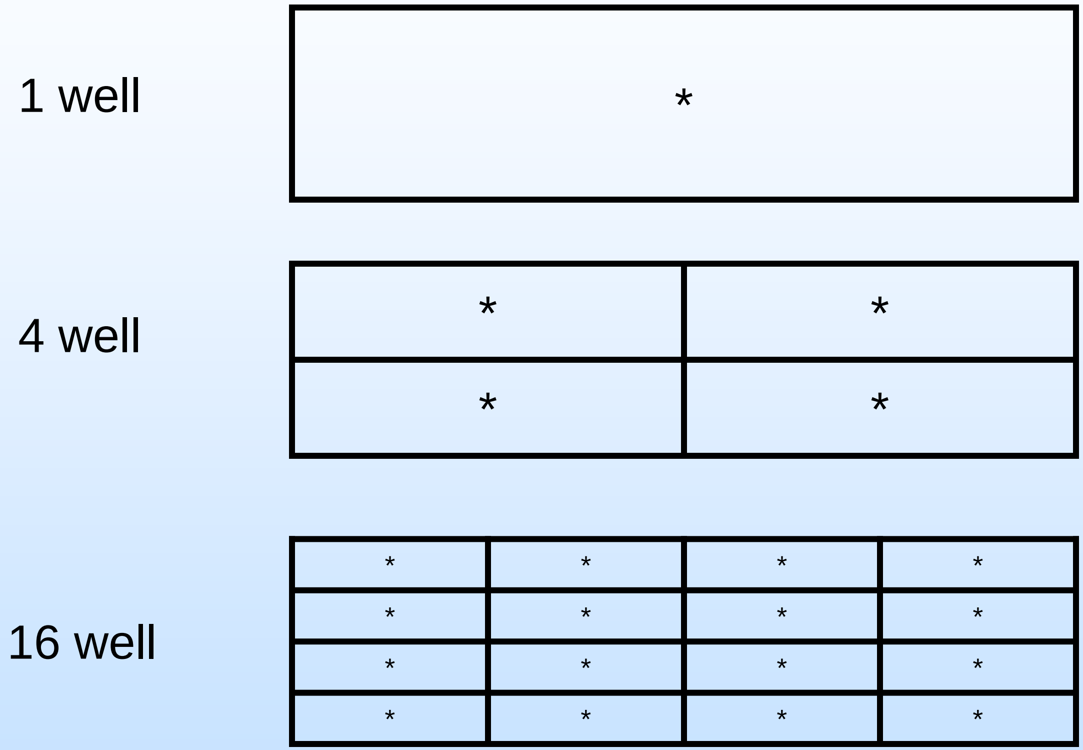
http://www.beg.utexas.edu/gccc/EASiTool/index.php

Accomplishments to Date-2



Supplemented with help and user manual.

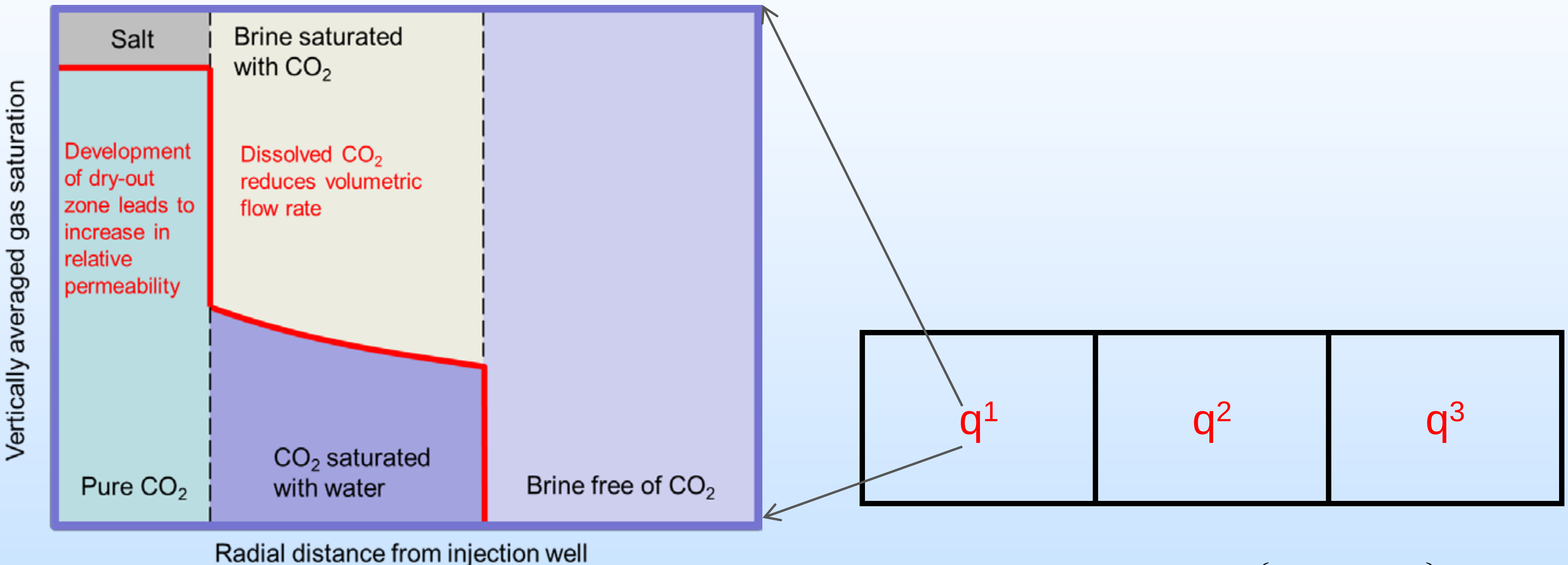
Accomplishments to Date-3



- Simulations done automatically for 1 well up to 99 wells
- Open boundary and closed boundary

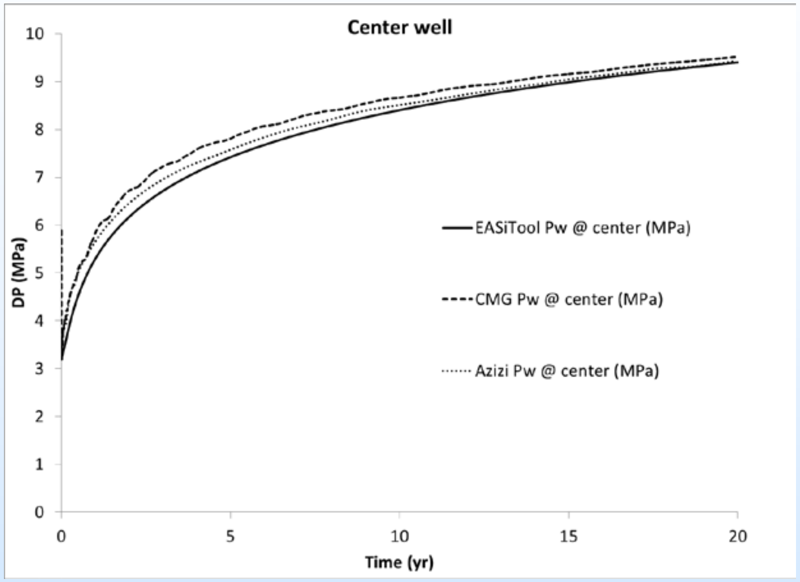
Accomplishments to Date-4

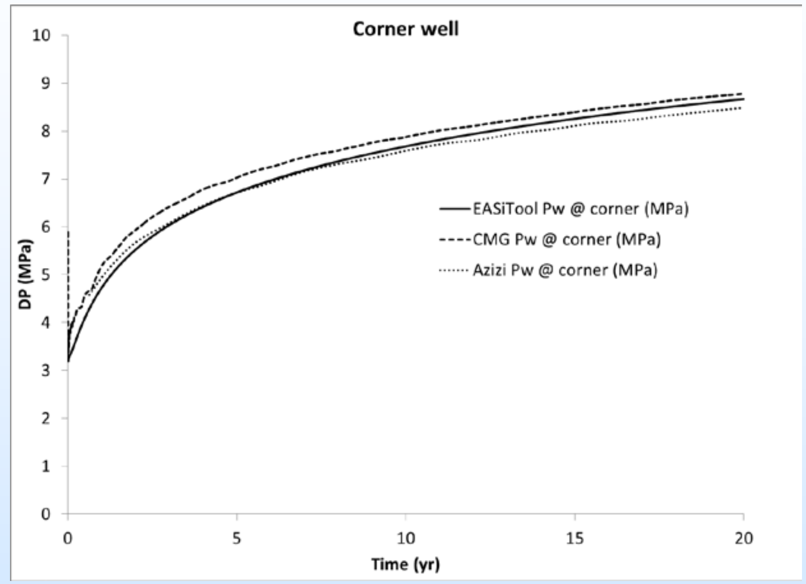
- Finding the optimized rate to maximize storage capacity

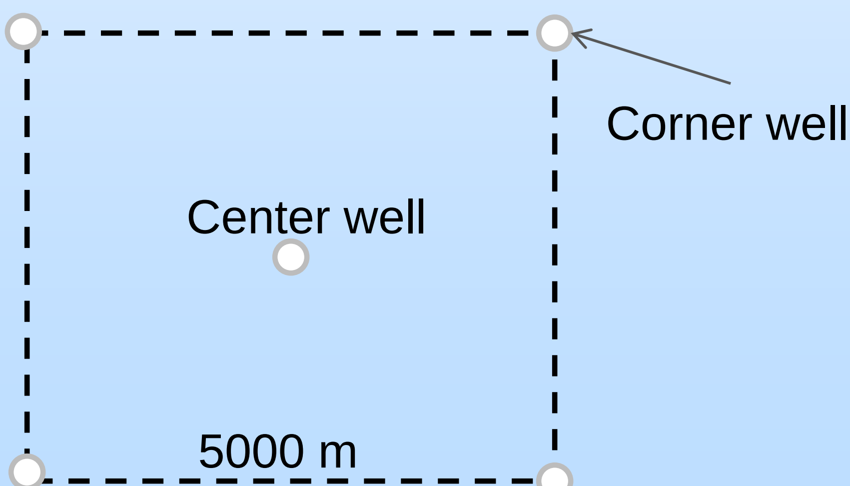


$$\begin{bmatrix} \frac{1}{2}\left(\ln(t_D)+0.80908\right)+S_a & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D1-2}^2}{4\eta_{D3}t_D}\right) & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D1-3}^2}{4\eta_{D3}t_D}\right) \\ -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D2-1}^2}{4\eta_{D3}t_D}\right) & \frac{1}{2}\left(\ln(t_D)+0.80908\right)+S_a & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D2-3}^2}{4\eta_{D3}t_D}\right) \\ -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D3-1}^2}{4\eta_{D3}t_D}\right) & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D3-2}^2}{4\eta_{D3}t_D}\right) & \frac{1}{2}\left(\ln(t_D)+0.80908\right)+S_a \end{bmatrix} \begin{Bmatrix} q^1 \\ q^2 \\ q^3 \end{Bmatrix} = \begin{Bmatrix} \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P \\ \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P \\ \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P \end{Bmatrix}$$

Accomplishments to Date-5

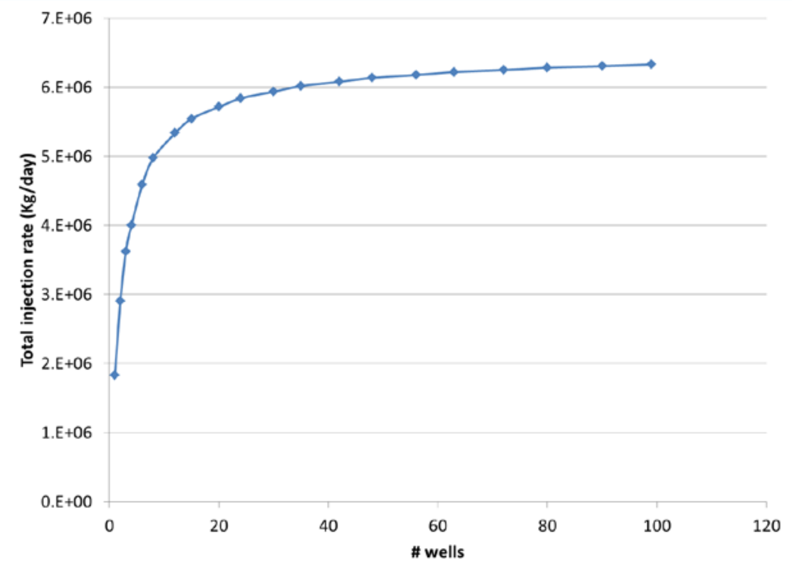






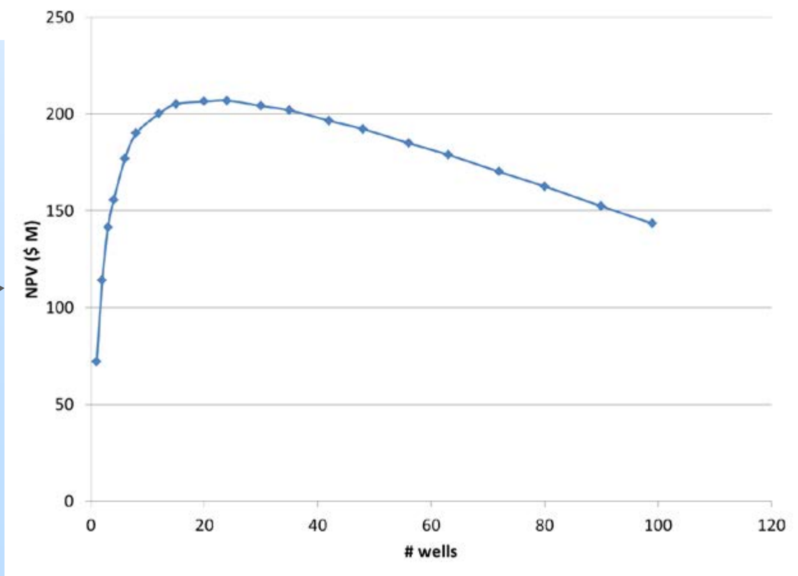
C12Energy independently beta tested and verified the outputs of EASiTool.

Accomplishments to Date-6

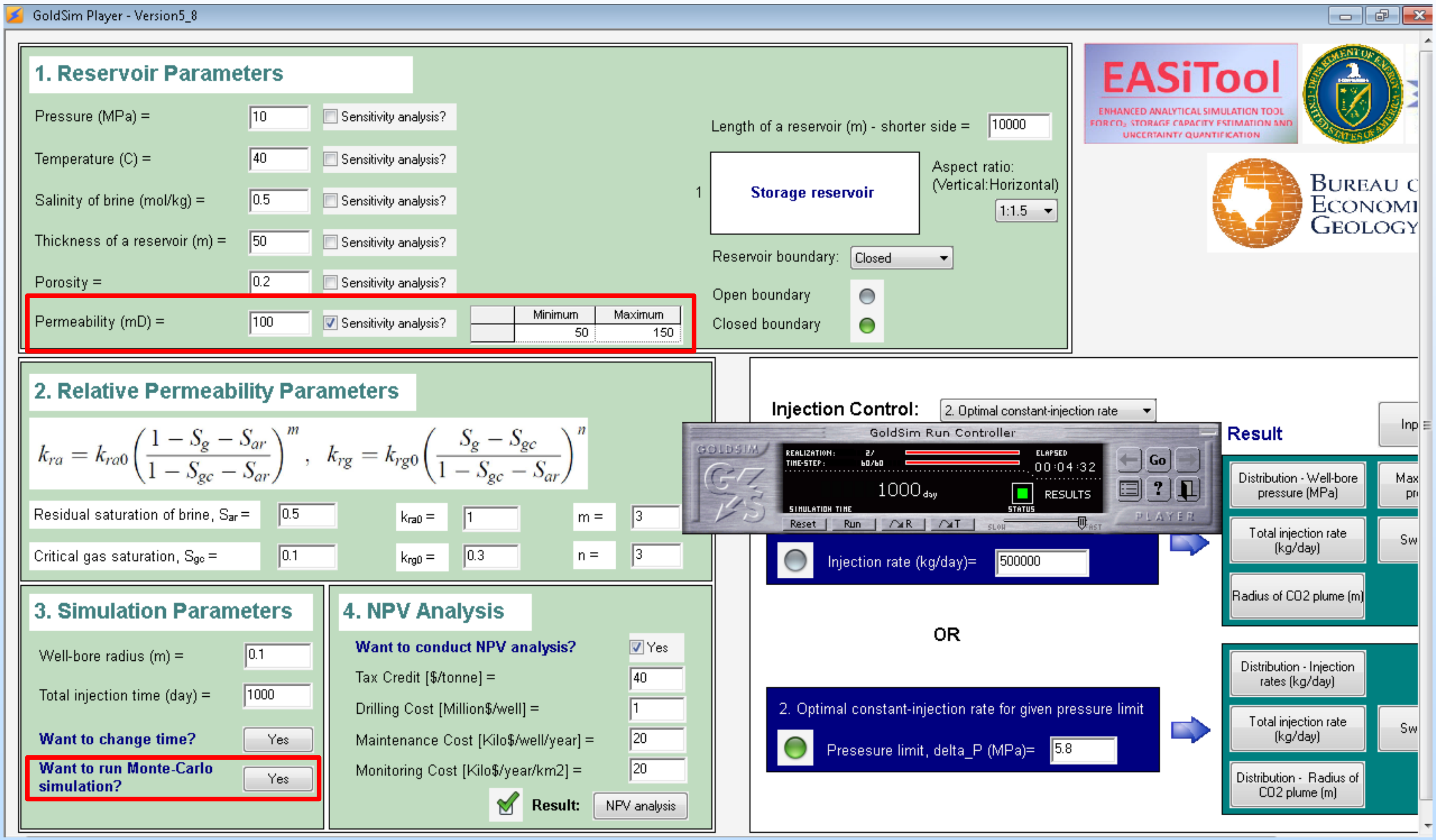


Storage capacity vs. number of injection well

NPV vs. number of injection well



Accomplishments to Date-7



Accomplishments to Date-8

Array View: NPV_Estimate (1)

	1	2
1	1	72.994
2	2	115.16
3	3	142.5
4	4	156.44
5	6	177.53
6	8	190.59
7	12	200.4
8	15	205.28
9	20	206.45
10	24	206.91
11	30	204.02
12	35	201.69
13	42	196.3
14	48	191.9
15	56	184.66
16	63	178.55
17	72	169.76
18	80	162.16
19	90	151.96

Array View: NPV_Estimate (2)

	1	2
1	1	54.511
2	2	92.48
3	3	120.11
4	4	136.31
5	6	161.65
6	8	178.52
7	12	193.65
8	15	201.53
9	20	205.9
10	24	208.43
11	30	207.53
12	35	206.63
13	42	202.57
14	48	199.21
15	56	192.9
16	63	187.57
17	72	179.46
18	80	172.46
19	90	162.79

Uncertainty Analysis

Bureau of Economic Geology

Gulf Coast Carbon Center

Accomplishments to Date-9

Training workshop for a delegation from Botswana

2014 IEAGHG Summer School in Austin

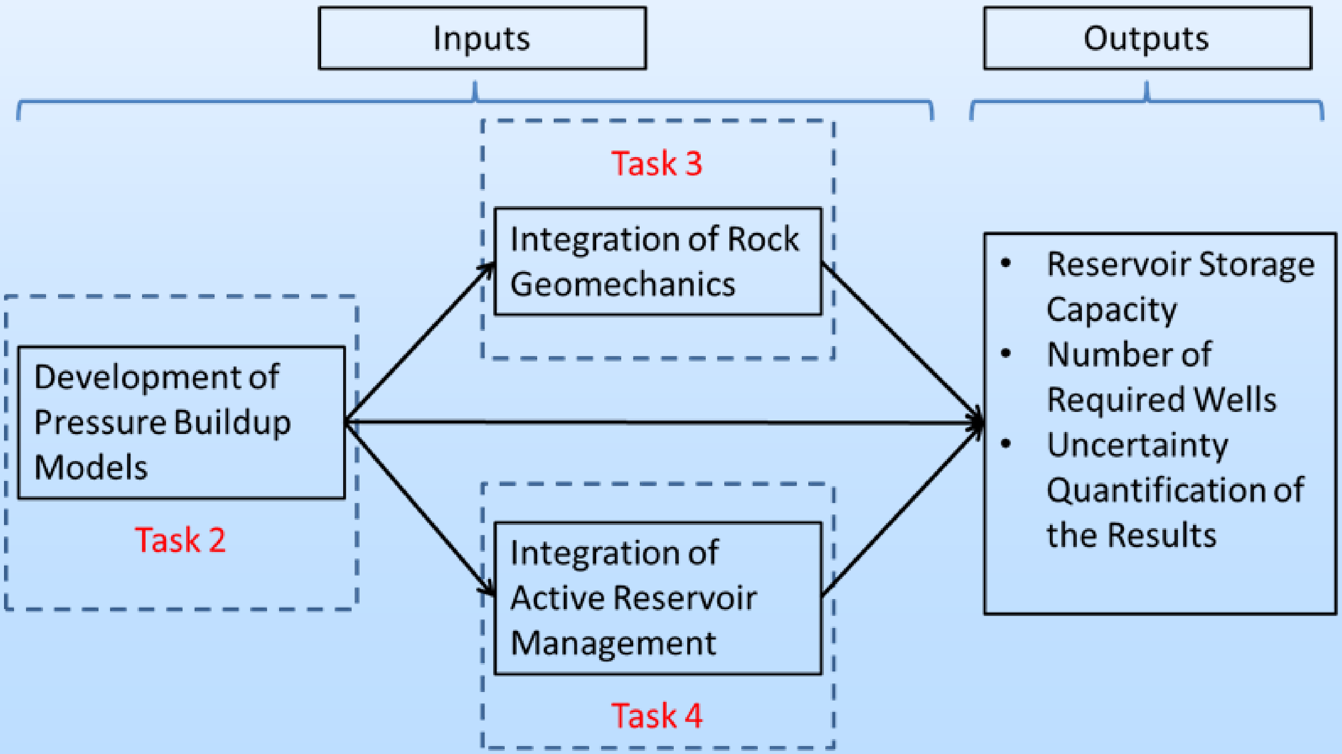
EASiTool website stats:
58 downloads over passed 3 months

Summary

- First version of software released on 4/30/2014.
- EASiTool is using analytical models which consider (CO_2 dissolution, brine evaporation, relative permeability, multi-well injection, …)
- EASiTool calculates the storage capacity fast and reliable (minutes to run tens of simulations).
- EASiTool runs for open and closed boundary conditions.
- EASiTool carries out uncertainty analysis.

Future Plans

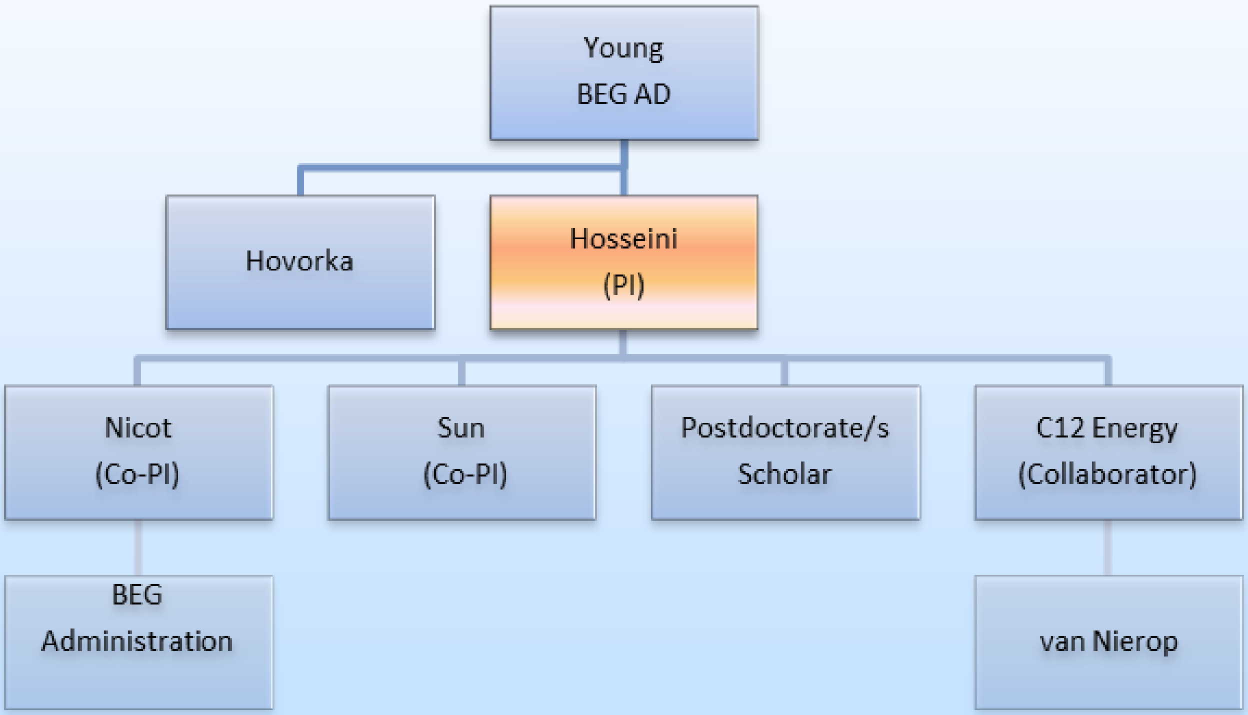
- Currently under Task 3 the main focus is to define fracture pressure.
  - ❑ Consider stress-pore pressure coupling
  - ❑ Consider thermal stress effects
- Verification (Numerical simulations, independent users)
- Further develop user interface



Appendix

- Organization Chart
- Gantt Chart
- Bibliography
- Extra Slides

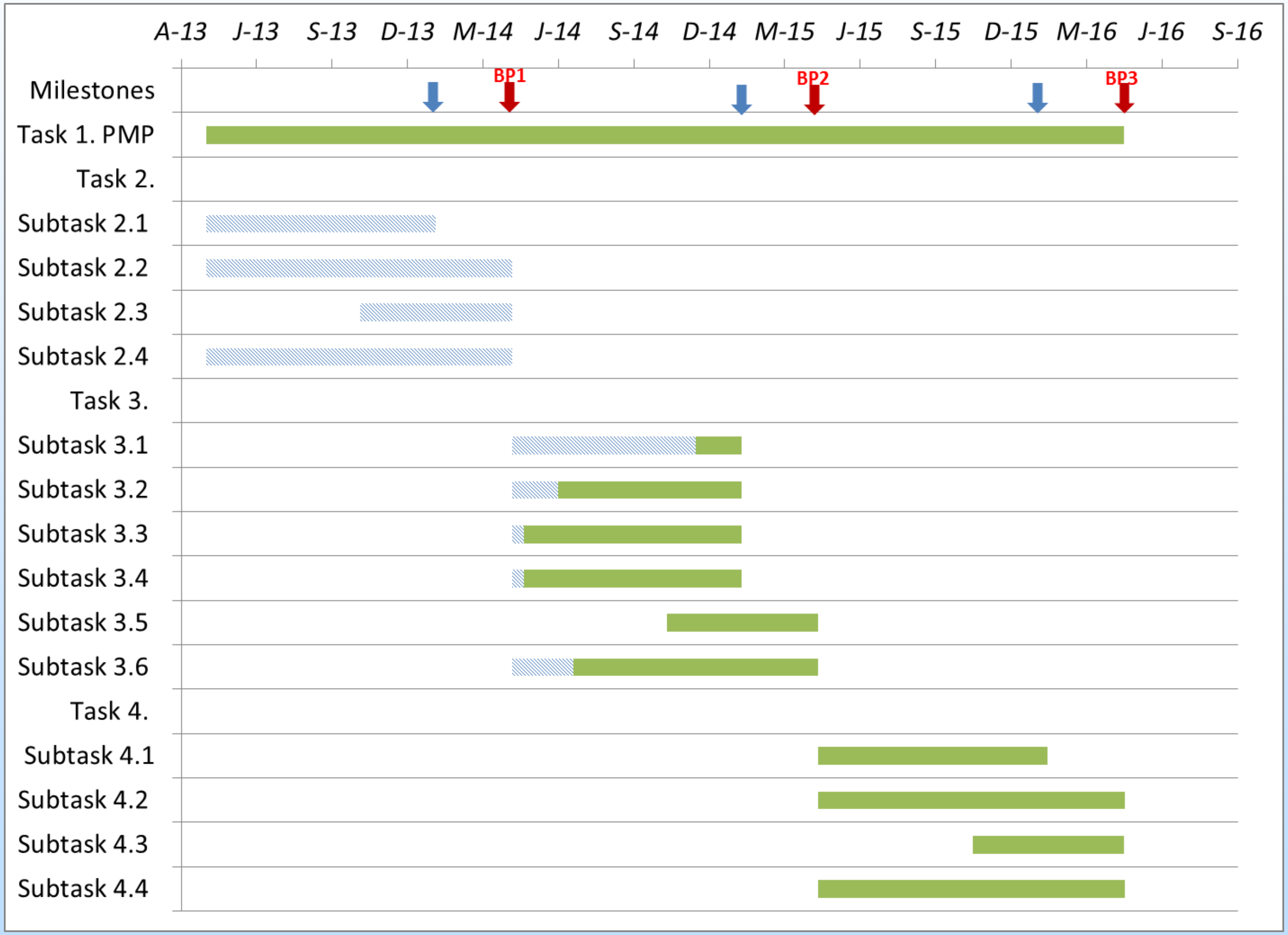
Organization Chart



Organization Chart

Project PI: Seyyed A. Hosseini			
Task 1 Project Management and Planning	**Task 2** Development of Analytical Solutions for Pressure Buildup	**Task 3** Rock Geomechanics Impact on Pressure Buildup and Capacity Estimation	**Task 4** Brine-Management Impact on CO_2 Injectivity and Storage Capacity
Task Leader/Backup Nicot/Hosseini	Task Leader/Backup Hosseini/Sun	Task Leader/Backup Hosseini/Sun	Task Leader/Backup Hosseini/Sun
Task 1 Team Nicot/Hosseini/ Young/Hovorka	Task 2 Team Subtask 2.1 Hosseini/Sun/ Postdoc/s Subtask 2.2 Hosseini/Sun/C12 Energy Subtask 2.3 Sun/Hosseini Subtask 2.4 Sun/Hosseini	Task 3 Team Subtask 3.1 Hosseini/Sun/ Postdoc/s Subtask 3.2 Hosseini/Sun/ Postdoc/s Subtask 3.3 Sun/Hosseini Subtask 3.4 Hosseini/Sun Subtask 3.5 Sun/Hosseini Subtask 3.6 Sun/Hosseini	Task 4 Team Subtask 4.1 Hosseini/Sun/ Postdoc/s Subtask 4.2 Sun/Hosseini/ Postdoc/s Subtask 4.3 Sun/Hosseini Subtask 4.4 Sun/Hosseini

Gantt Chart



A-13
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D-13
M-14
J-14
S-14
D-14
M-15
J-15
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M-16
J-16
S-16
Milestones
BP1
BP2
BP3
Task 1. PMP
Task 2.
Subtask 2.1
Subtask 2.2
Subtask 2.3
Subtask 2.4
Task 3.
Subtask 3.1
Subtask 3.2
Subtask 3.3
Subtask 3.4
Subtask 3.5
Subtask 3.6
Task 4.
Subtask 4.1
Subtask 4.2
Subtask 4.3
Subtask 4.4

Bibliography

– Journals

- Kim, S., Hosseini, S.A, 2013, Above-zone pressure monitoring and geomechanical analyses for a field-scale CO_2 injection project in Cranfield, MS, Greenhouse Gases: Science and Technology, 4 (1), 81-98, DOI: 10.1002/ghg.1388

– Conferences

- Kim, Seunghee, Hosseini, S. A., and Hovorka, S. D., 2013, Numerical Simulation: Field Scale Fluid Injection to a Porous Layer in relevance to CO_2 Geological Storage: Proceedings of the 2013 COMSOL Conference, Boston, Massachusetts.
- Kim, Seunghee, Hosseini, S. A., 2014, Optimization of Injection Rates for Geological CO_2 Storage in Brine Formations, 13th Annual Conference on Carbon Capture Utilization & Storage.
- Kim, Seunghee, Hosseini, S. A., 2014, Effect of Pore Pressure/Stress Coupling on Geological CO_2 Storage, 13th Annual Conference on Carbon Capture Utilization & Storage.

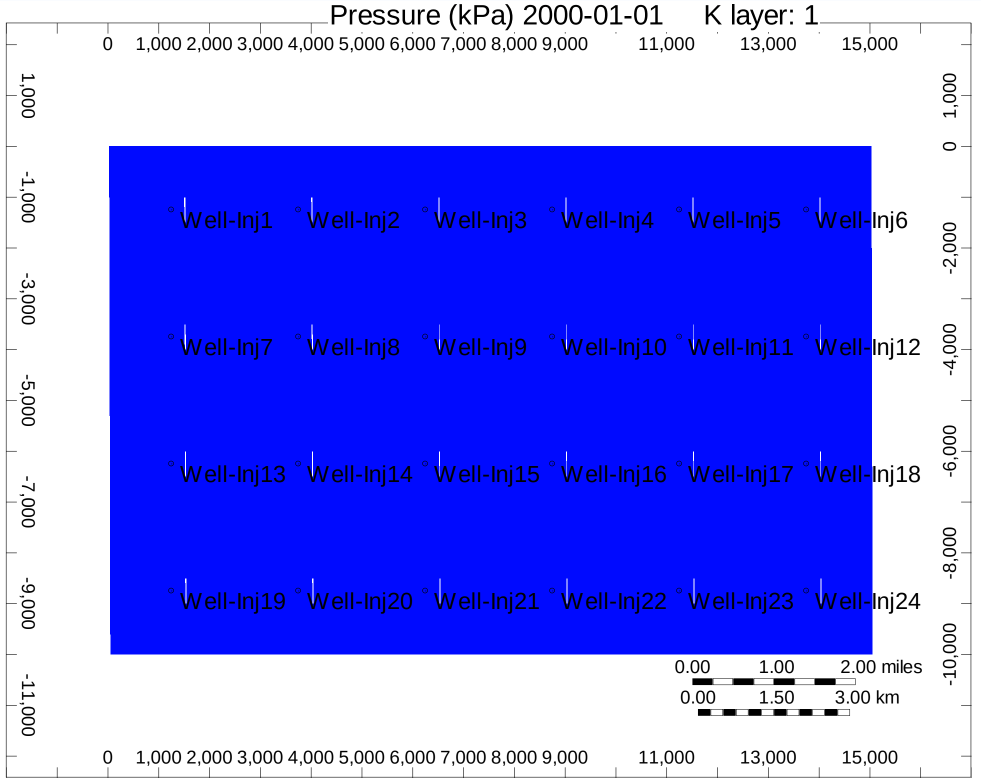
- Two papers to be presented at GHGT12 in Austin.

Capacity Estimation Methods

Tool/Approach Name	DOE/NETL	EERC	CSLF	USGS	EASiTool	Numerical Simulators
Reservoir scale	Yes	Yes	Yes	Yes	Yes	Yes
Accuracy	Low	Medium	Low	Low	Medium/High	High
Boundary conditions	No	No	No	No	Yes	Yes
Rock geomechanics	No	No	No	No	Yes	Yes
Brine management	No	No	No	No	Yes	Yes
Required expertise	Low	Low	Low	Low	Low	High
Cost of use	Low	Low	Low	Low	Low	High
Speed	High	High	High	High	High	Low
Dynamic	No	No	No	No	Yes	Yes
Uncertainty quantification	No	No	No	Simple	Yes	Yes

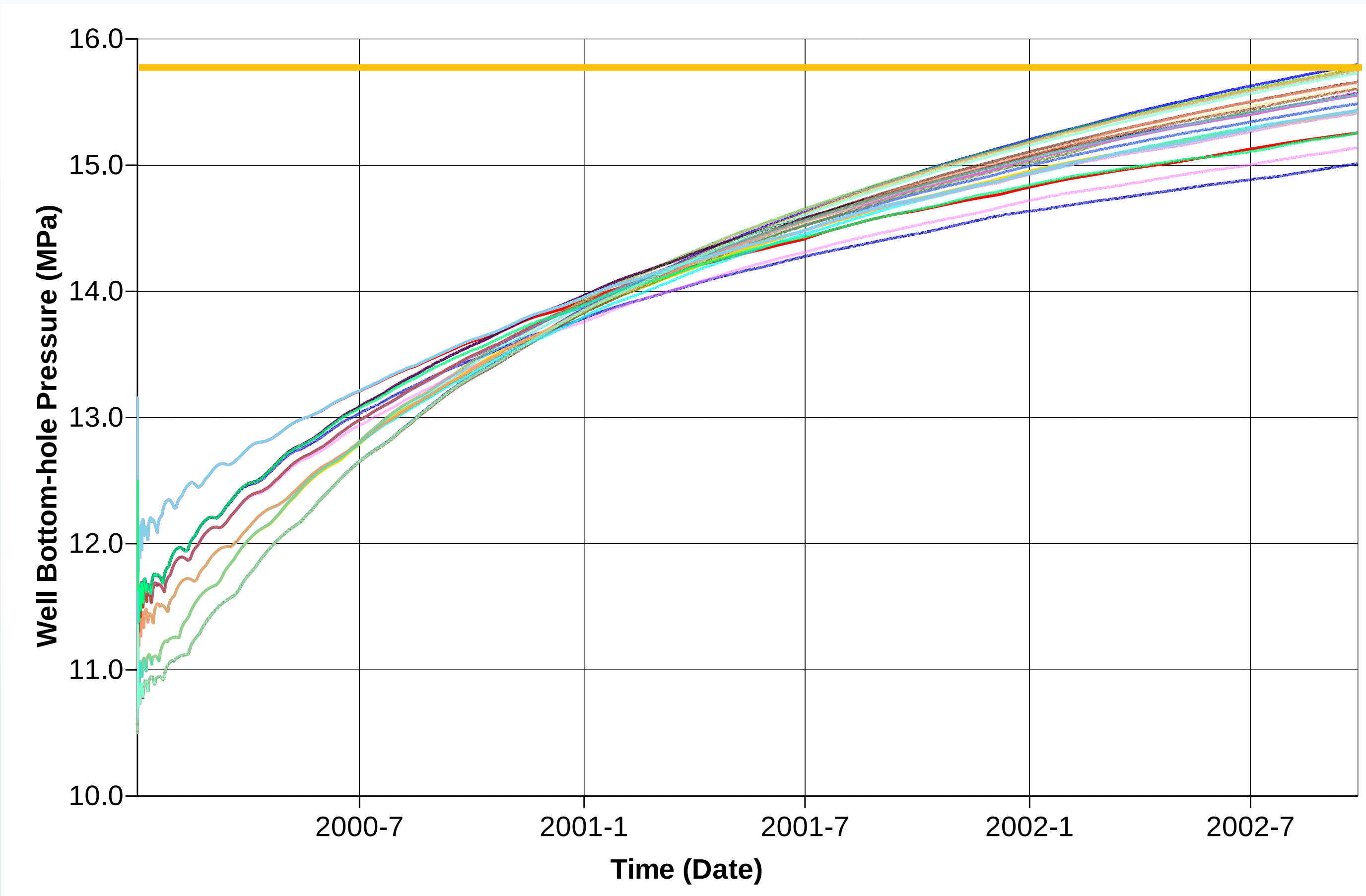
Verification - 24 wells - optimized injection rate

Pressure (Mpa)	10
Temperature (C)	40
Salinity	0
Reservoir	Rectangle
Shorter side (m)	10000
Longer side (m)	15000
Boundary condition	Infinite, closed
Thickness of a reservoir (m)	50
Porosity	0.2
Total time (day)	1000
Residual saturation of brine	0.5
Critical gas saturation	0.1
End-point relative permeability of brine	1
End-point relative permeability of CO_2	0.3
Power-law exponent (brine)	3
Power-law exponent (CO_2)	3
Pressure increase limit, ΔP (Mpa)	5.8
Mole fraction of CO_2 (in water)	0.0217568
Mole fraction of H_2O (in CO_2)	0.0040998
Density of CO_2 (kg/m^3)	607.6
Compressibility of rock (1/Pa)	5*10^-10
Compressibility of gas (1/Pa)	1.87*10^-8
Compressibility of brine (1/Pa)	4.27*10^-10
Permeability (mD)	100
Well bore radius (m)	0.1



Verification – 24 wells – open bounda

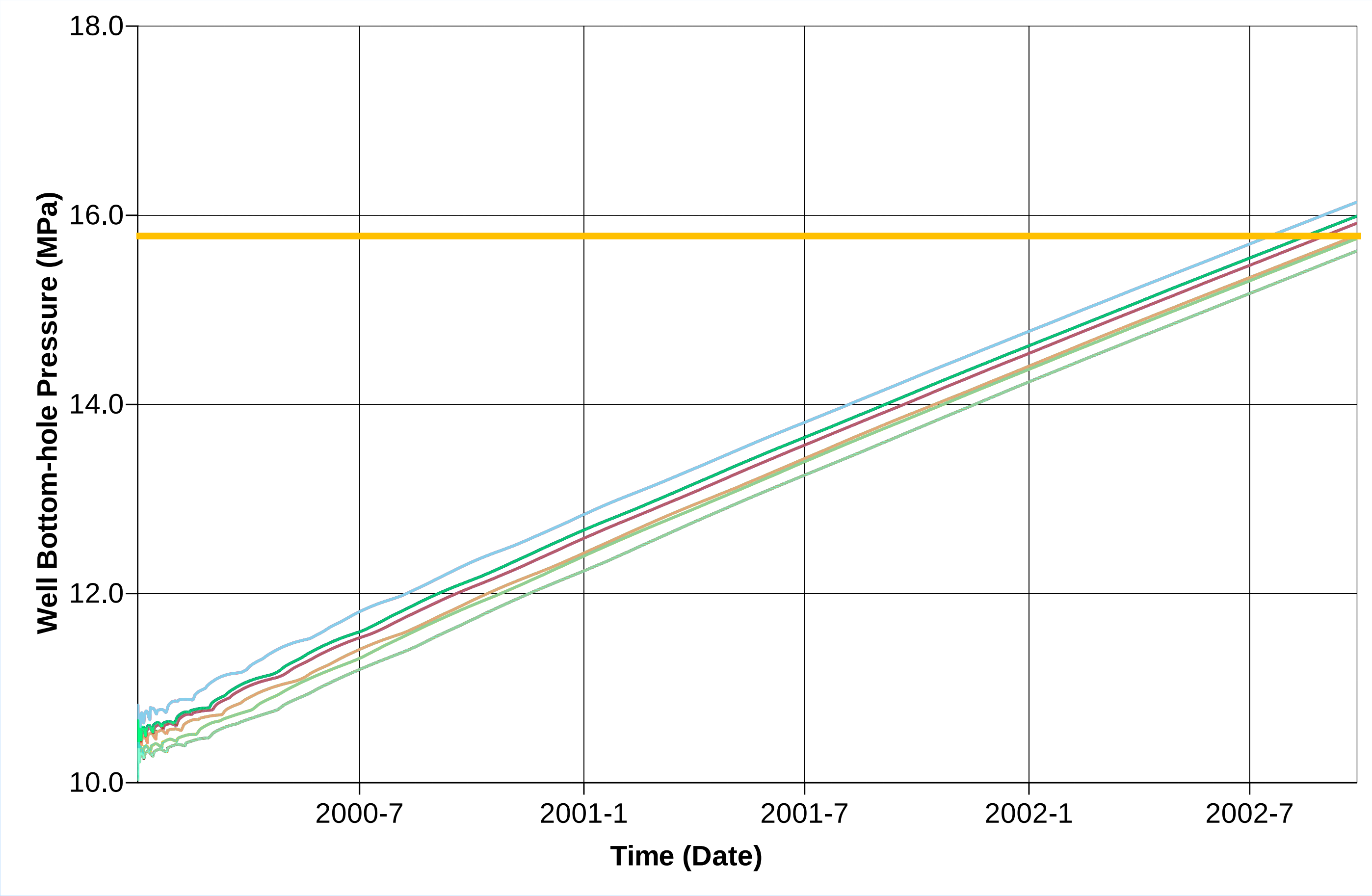
Flow rates of 24 wells (ton/day)					
1152.2	831	734.16	734.16	831	1152.2
874.04	528.18	431.65	431.65	528.18	874.04
874.04	528.18	431.65	431.65	528.18	874.04
1152.2	831	734.16	734.16	831	1152.2



Total injection in 1000 days: 18.20 million tone

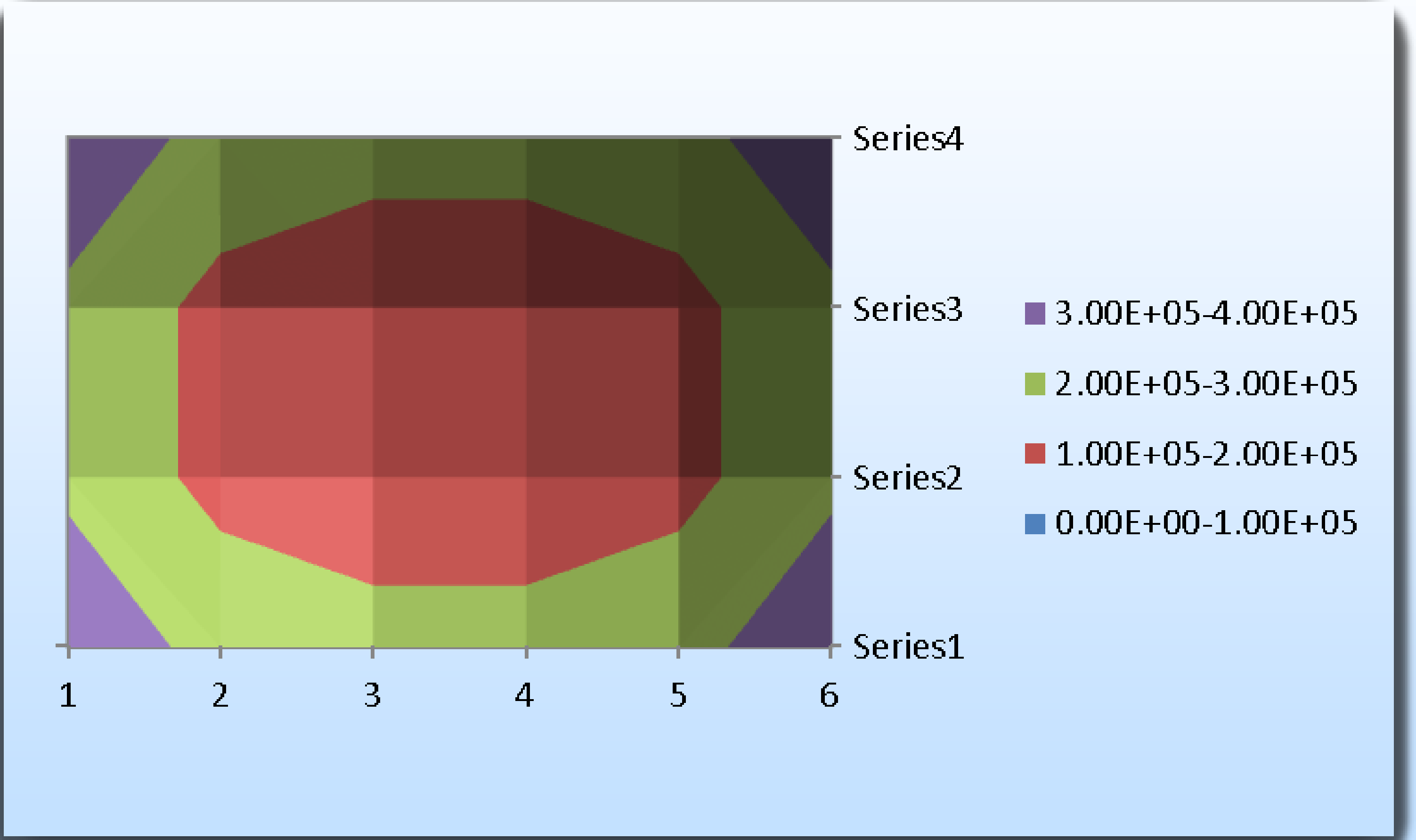
Verification – 24 wells – closed boundary a

Flow rates of 24 wells (ton/day)					
394.65	288	255.07	255.07	288	394.65
302.79	187.24	154.05	154.05	187.24	302.79
302.79	187.24	154.05	154.05	187.24	302.79
394.65	288	255.07	255.07	288	394.65



Total injection in 1000 days:
6.33 million tone

Optimal constant-injection rate



24 wells rate distribution

Analytical model