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Title:	Enhancing BECCUS (Bio-Energy Carbon Capture Utilization and Storage) Screening Tools
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MICKEY LELAND ENERGY FELLOWSHIP PROGRAM

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Enhancing BECCUS (Bio-Energy Carbon Capture Utilization and Storage) Screening Tools

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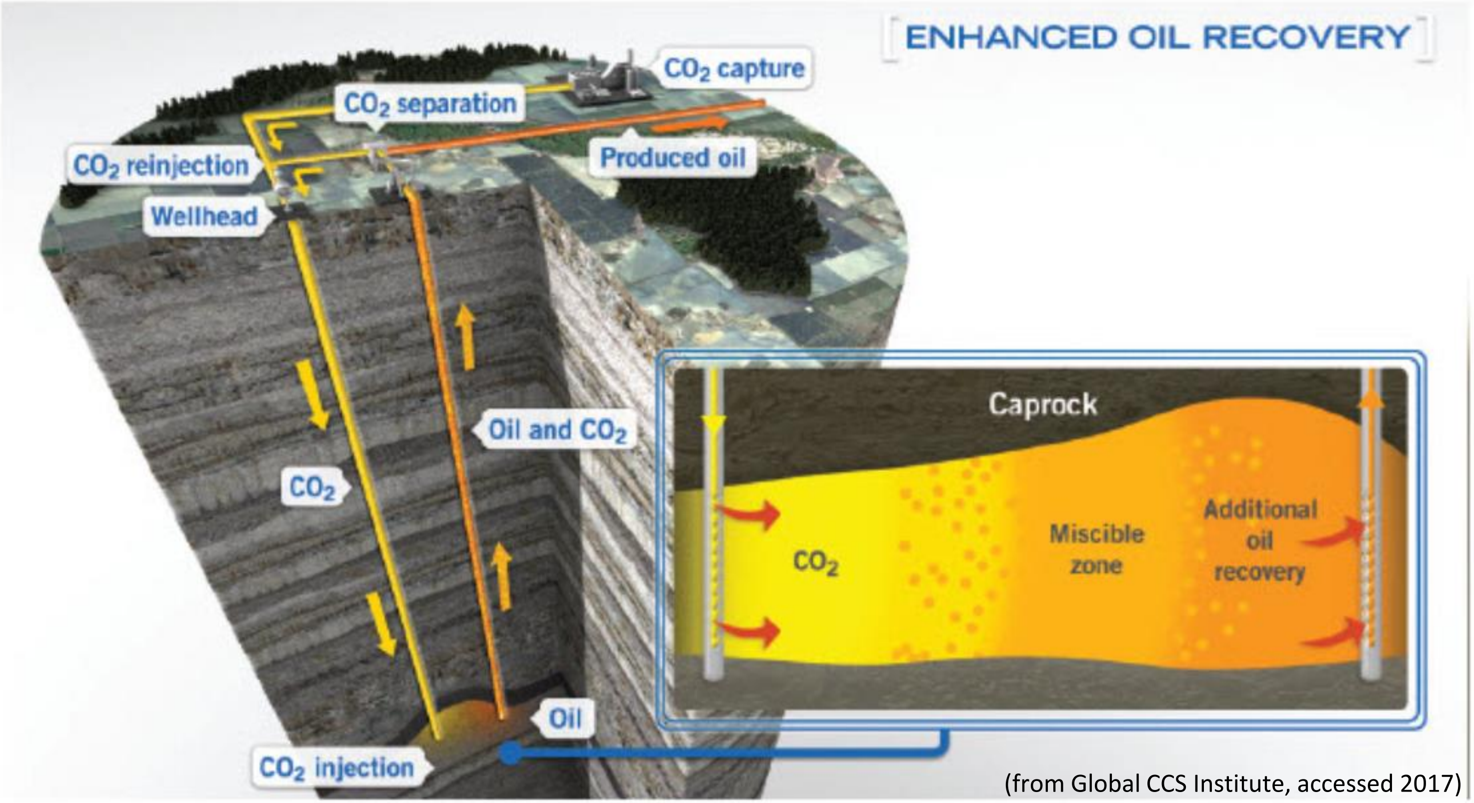
U.S. DEPARTMENT OF ENERGY | Fossil Energy

What is BECCUS?

- Low carbon to net-negative energy
- Economic incentive to store CO_2

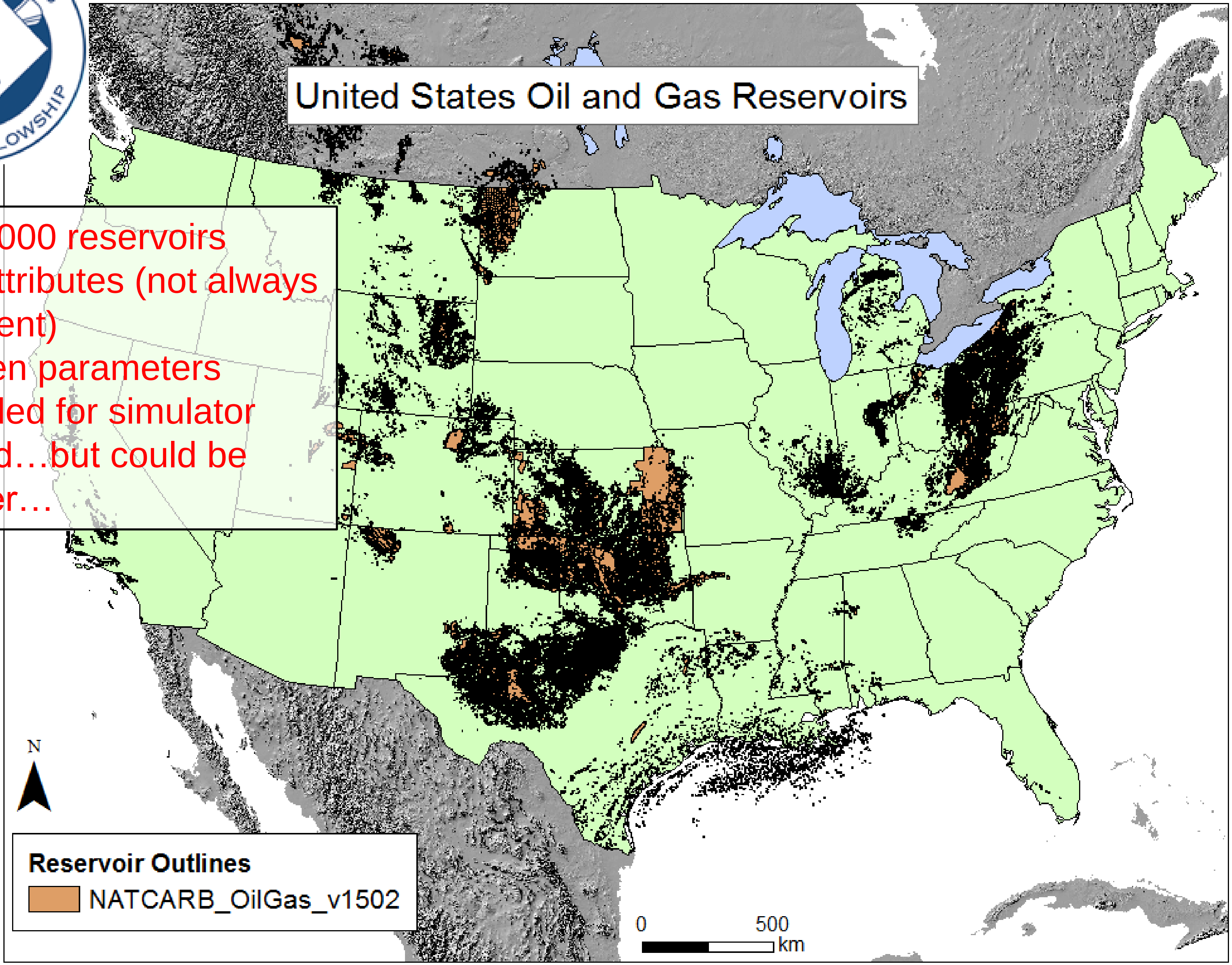


(from Global CCS Institute, accessed 2017)

Project Goals

- Utilize NATCARB database for site screening
- Enhance NATCARB database
- Run CO_2-EOR simulations and economic models using updated reservoir data sets (SCO_2T-EOR)
- Geospatial optimization (SIMCCUS)

- ~69,000 reservoirs
- 20 attributes (not always present)
- Seven parameters needed for simulator
- Good…but could be better…

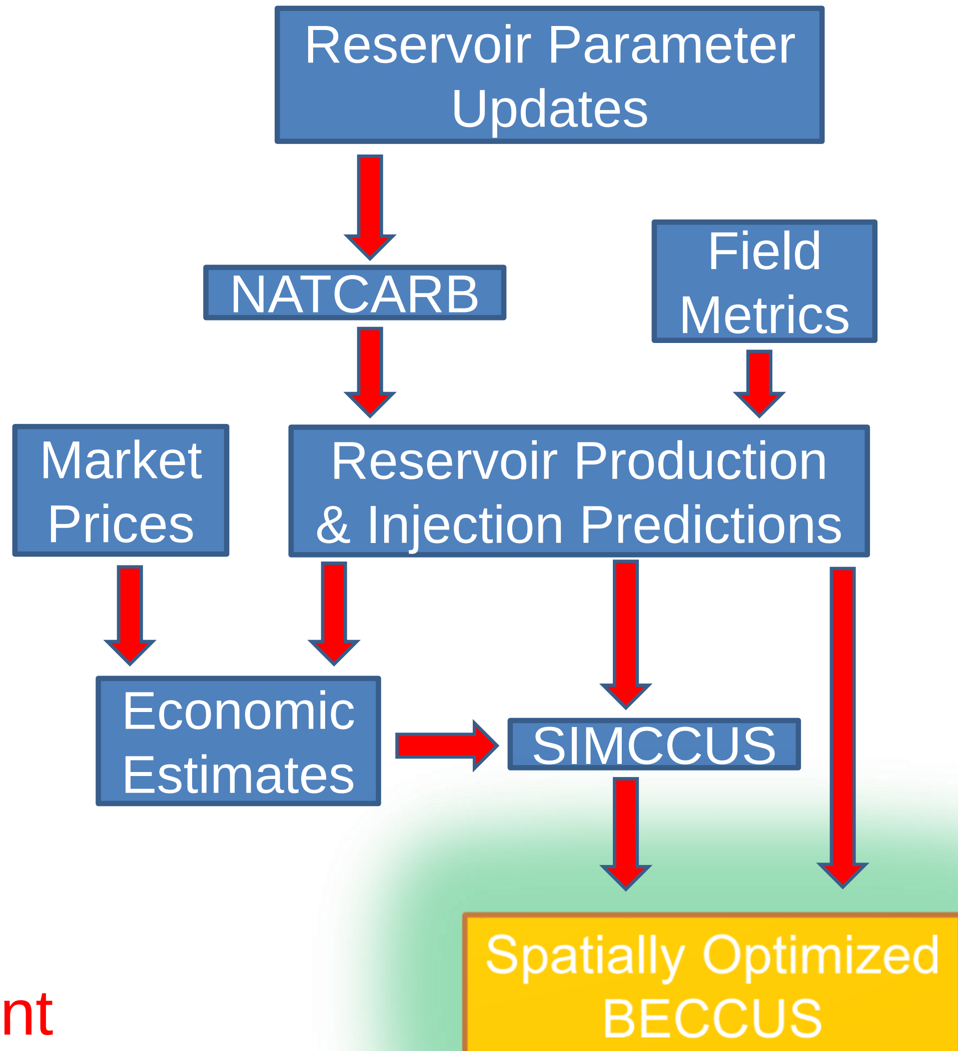


Enhancing NATCARB

- Added ~1300 depths and thicknesses
- ~42,000 new estimated thicknesses
- ~5100 new CO_2 capacity estimates (U.S. DOE, 2008)
- Utilize reservoir depth relationships for:
  - ~3000 new Porosity (Ehrenberg and Nadeau, 2005)
  - Temperature (Blackwell, 2004)
  - 48,000 Pressure (hydrostatic, 0.435ft/psi)
- ~ 18,000 new permeability (Ehrenberg and Nadeau, 2005)

General Workflow

- SIMCCUS: Next stage



*Uncertainty is large for national scale assessment

SCO$_2$T-EOR (Sequestration CO$_2$Tool)

- Ran simulations on ~18,000 reservoirs
- Major assumptions
  - 40 acre well spacing
  - WAG Ratio 1:1

INPUTS						
1	2	3	4	5	6	7
Input parameters						
Thickness	Depth	Horizontal permeability	Porosity	Injection to production distance	WAG composition	Temperature
m	m	mD	Fraction	m	CO_2 %	°C

SCO2T-EOR (Sequestration CO2 Tool)

- Recovery Factors all between (0.02 - 0.19)
- 20 reservoirs economic
  - emission reductions (16% - 55%)

PREDICTED										Recovery rate
1	2	3	4	5	6	7	8	9	10	
Original fluids in place			Output values							
Water	Oil	Gas	Time	H_2O injected	CO_2 injected	H_2O produced	Oil produced	CO_2 produced	CH_4 produced	
MMSTB	MMSTB	MMCF	Years	m^3	tCO_2	m^3	bbl	tCO_2/d	mmcf	Fraction

Net water (w/o -ve)	Net water (w/ -ve)	Treated water	Net CO^2	Recycled CO^2
m^3	m^3	m^3	tCO^2	tCO^2

SCO2T-EOR Economics

- Fixed costs based on market prices

EOR COST BREAKDOWN	UNIT	VALUE	UNIT	VALUE
Royalties and production tax	$/bbl of oil	18	%	0.21
Capital expense	$/bbl of oil	10	$/bbl of oil	10
Operating expense	$/bbl of oil	20	$/bbl of oil	20
CO_2 expense	$/bbl of oil	15	$/tCO_2$	30
Profit margin	$/bbl of oil	22	-	-
Oil price	$/bbl of oil	85	$/bbl of oil	50
CO_2 recycling	-	-	$/tCO_2$	10
Water purchase	-	-	$/m^3$	1
Water treatment	-	-	$/m^3$	1
Linear well cost (drilling)	-	-	$/m	1000
Linear well cost (re-fitting)	-	-	$/m	100

SCO2T-EOR Economics

- Profits 11.28 – 28.20 $/bbl
- Storage costs ranged 5.47 - 64.57 ($/t$CO_2$)
- What is the net carbon balance?
  - Standards needed
  - Inverse correlation of emissions reduction and profit

Profit		Storage profit	Oil Emissions	Net Emissions	Emissions Reduced
($/bbl)		($/tCO2)	tCO2	tCO2	%

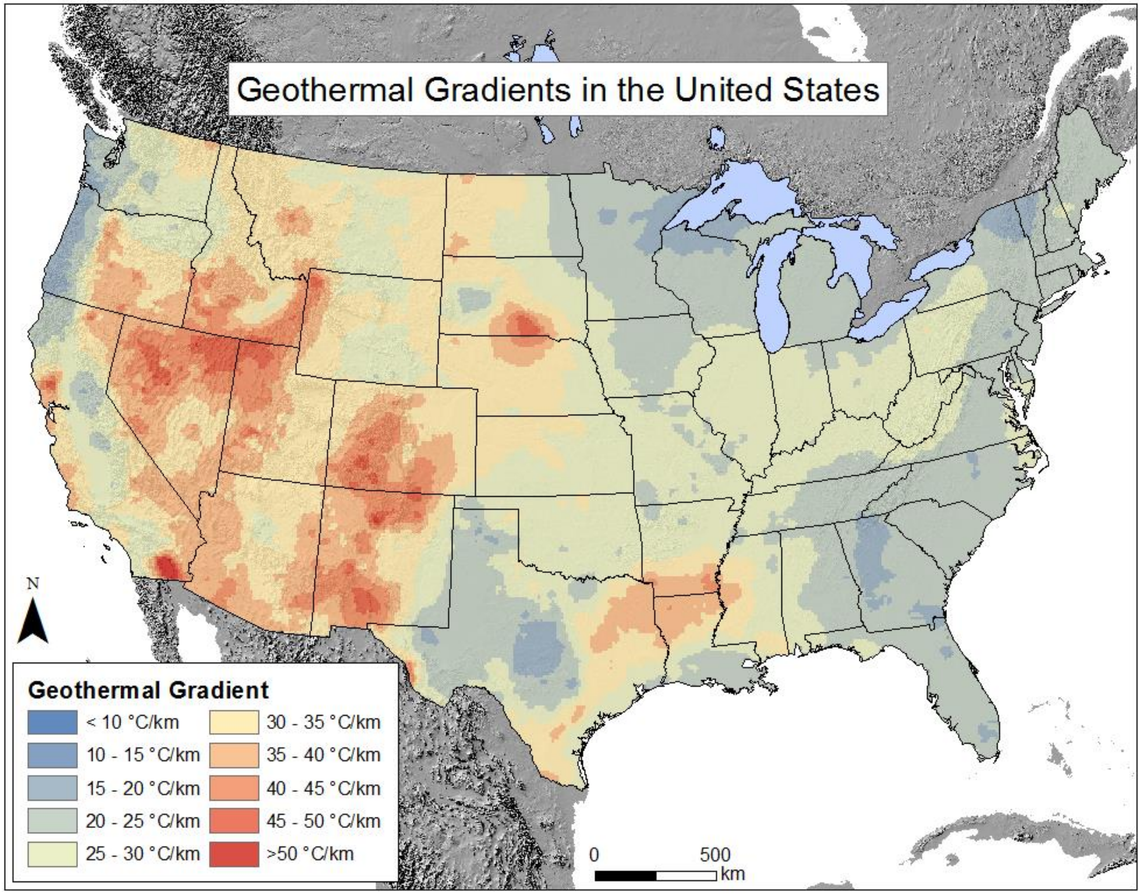
Conclusions and Future Work

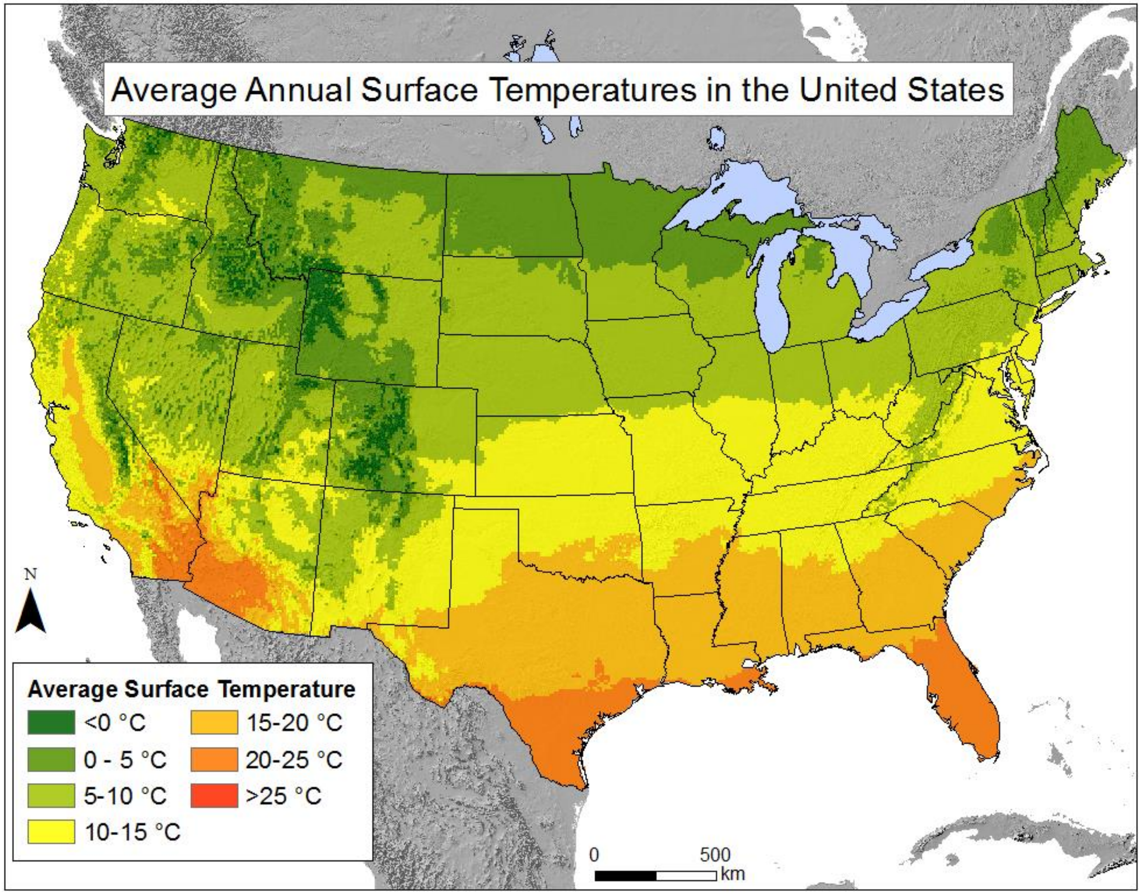
- NATCARB Updates
- Work flow developed for future reservoirs
- First pass simulations/economics
- Field specific data
- Feed into geospatial-infrastructural-economic optimization model (SIMCCUS)
- BECCUS is promising

Image from connect.innovateuk.org, accessed 2017

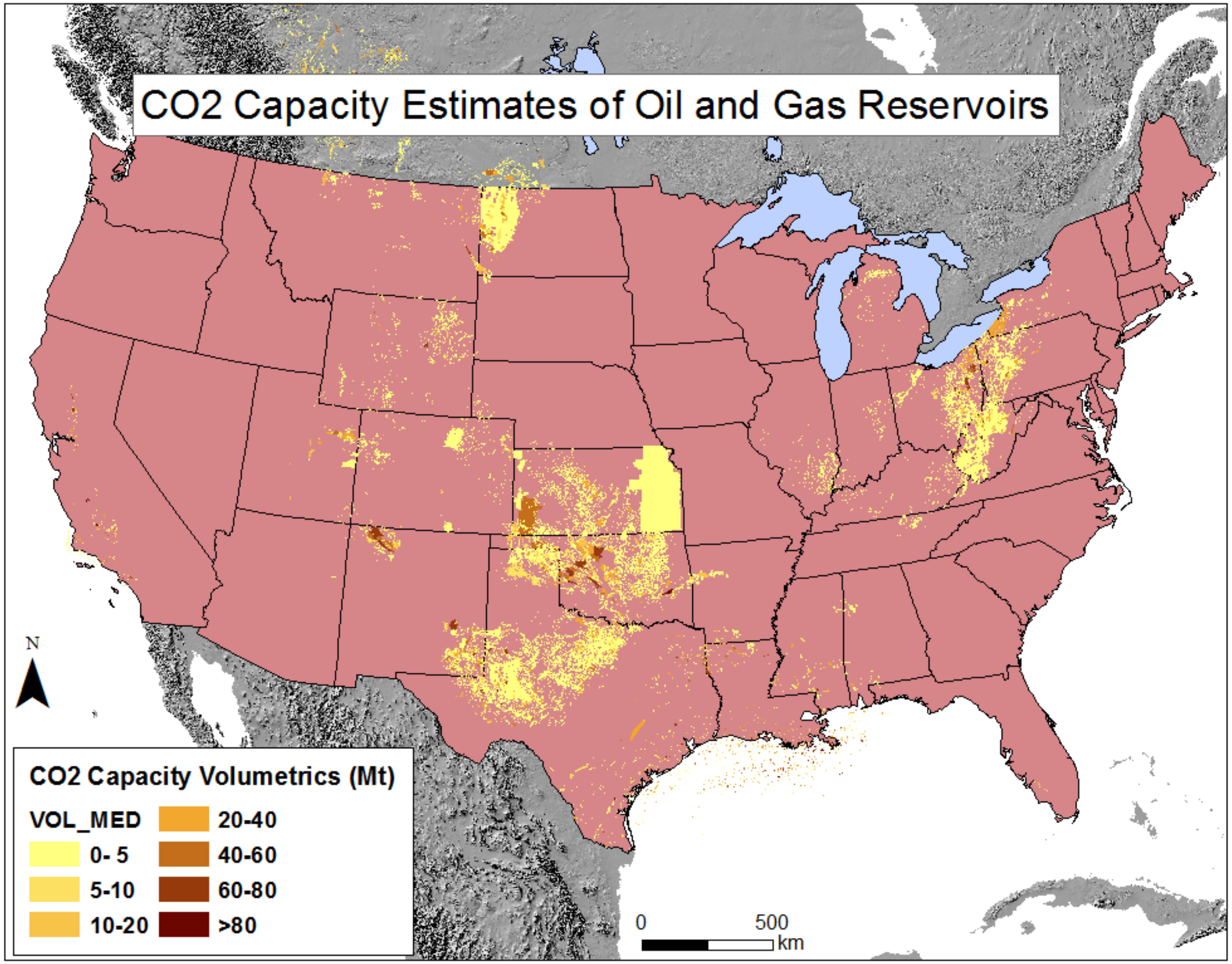
Enhancing BECCUS (Bio-Energy Carbon Capture Utilization and Storage) Screening Tools

Questions?

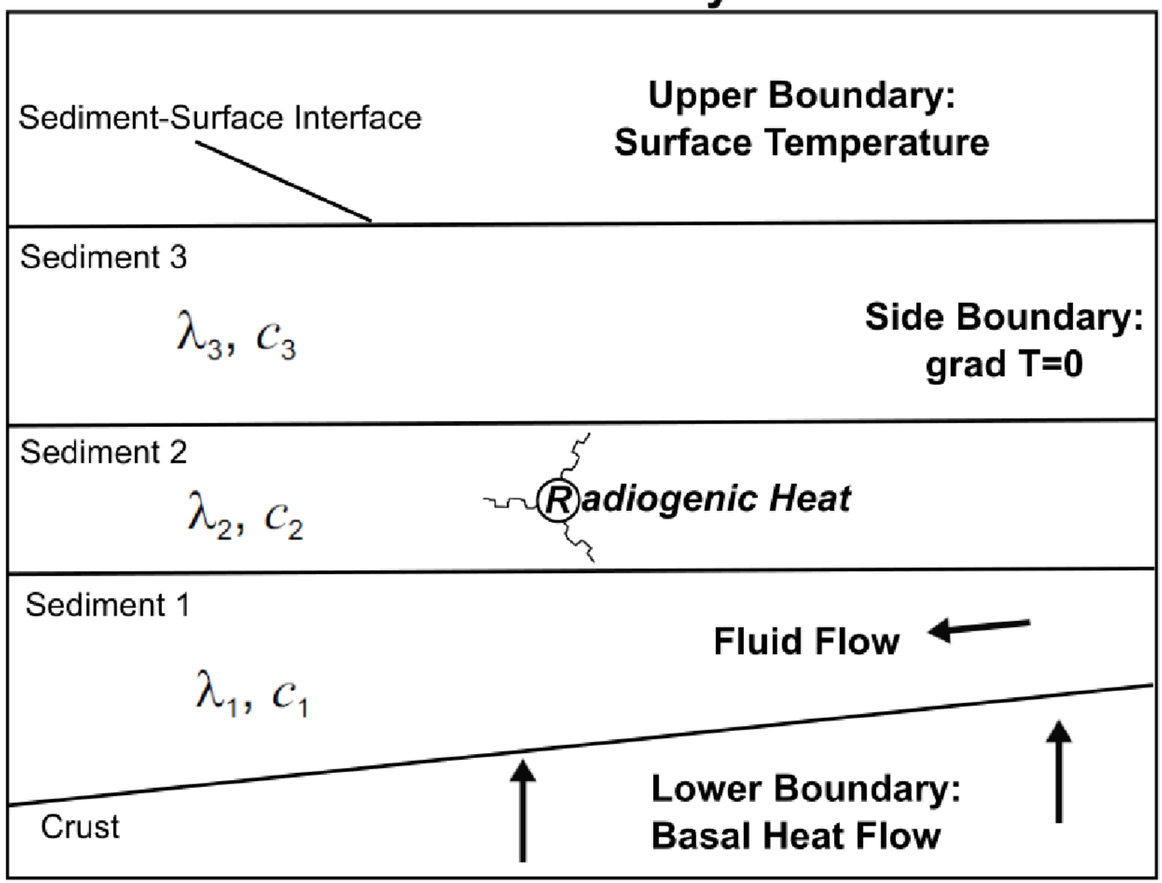

Geothermal Gradients in the United States
Geothermal Gradient
< 10 °C/km
10 - 15 °C/km
15 - 20 °C/km
20 - 25 °C/km
25 - 30 °C/km
30 - 35 °C/km
35 - 40 °C/km
40 - 45 °C/km
45 - 50 °C/km
>50 °C/km
N
0
500
km



Average Annual Surface Temperatures in the United States
N
Average Surface Temperature
<0 °C
0 - 5 °C
5-10 °C
10-15 °C
15-20 °C
20-25 °C
>25 °C
0
500
km

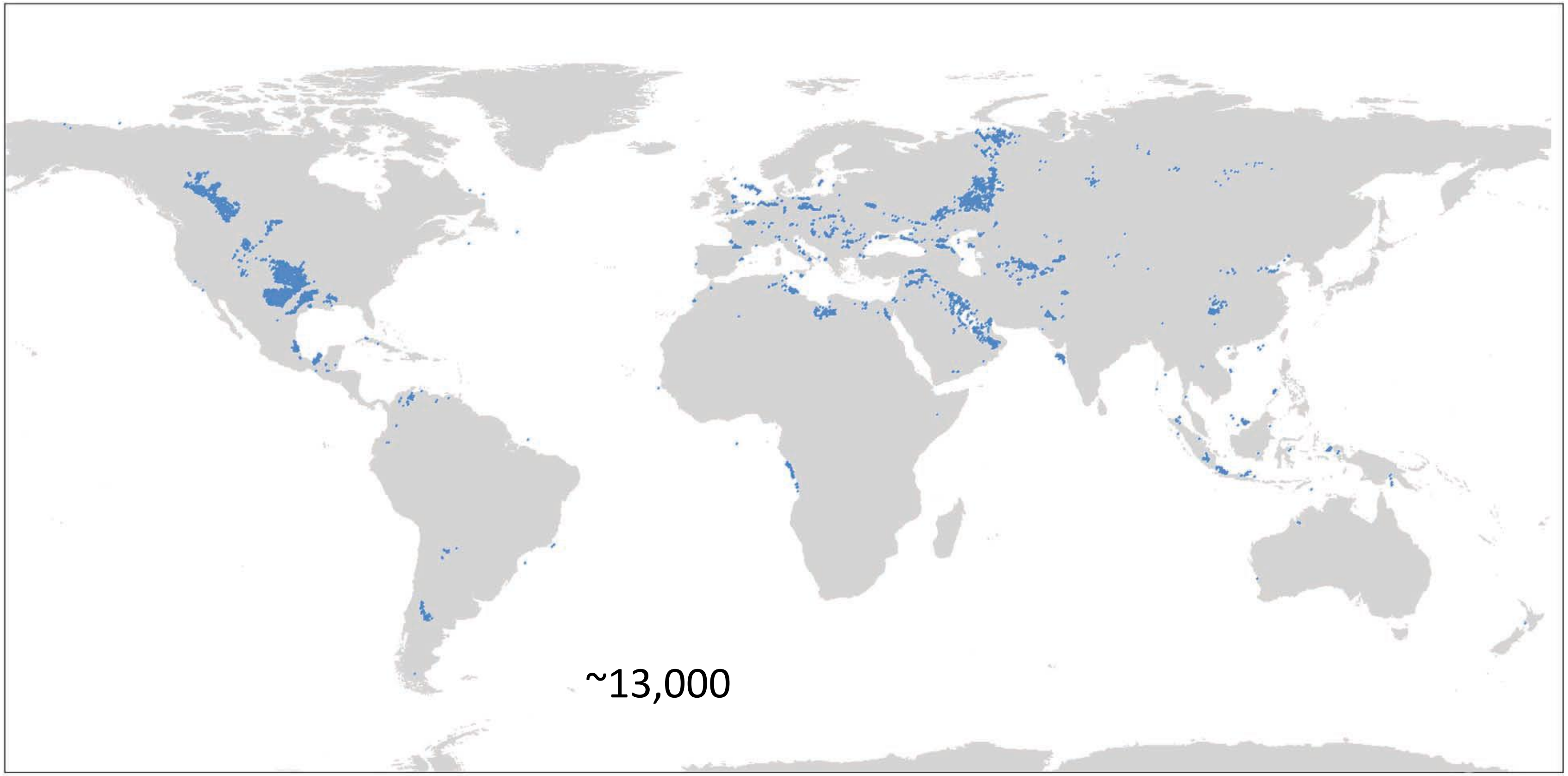

CO2 Capacity Estimates of Oil and Gas Reservoirs
CO2 Capacity Volumetrics (Mt)
VOL_MED
0- 5
5-10
10-20
20-40
40-60
60-80
>80
N
0
500
km

Heatflow Analysis



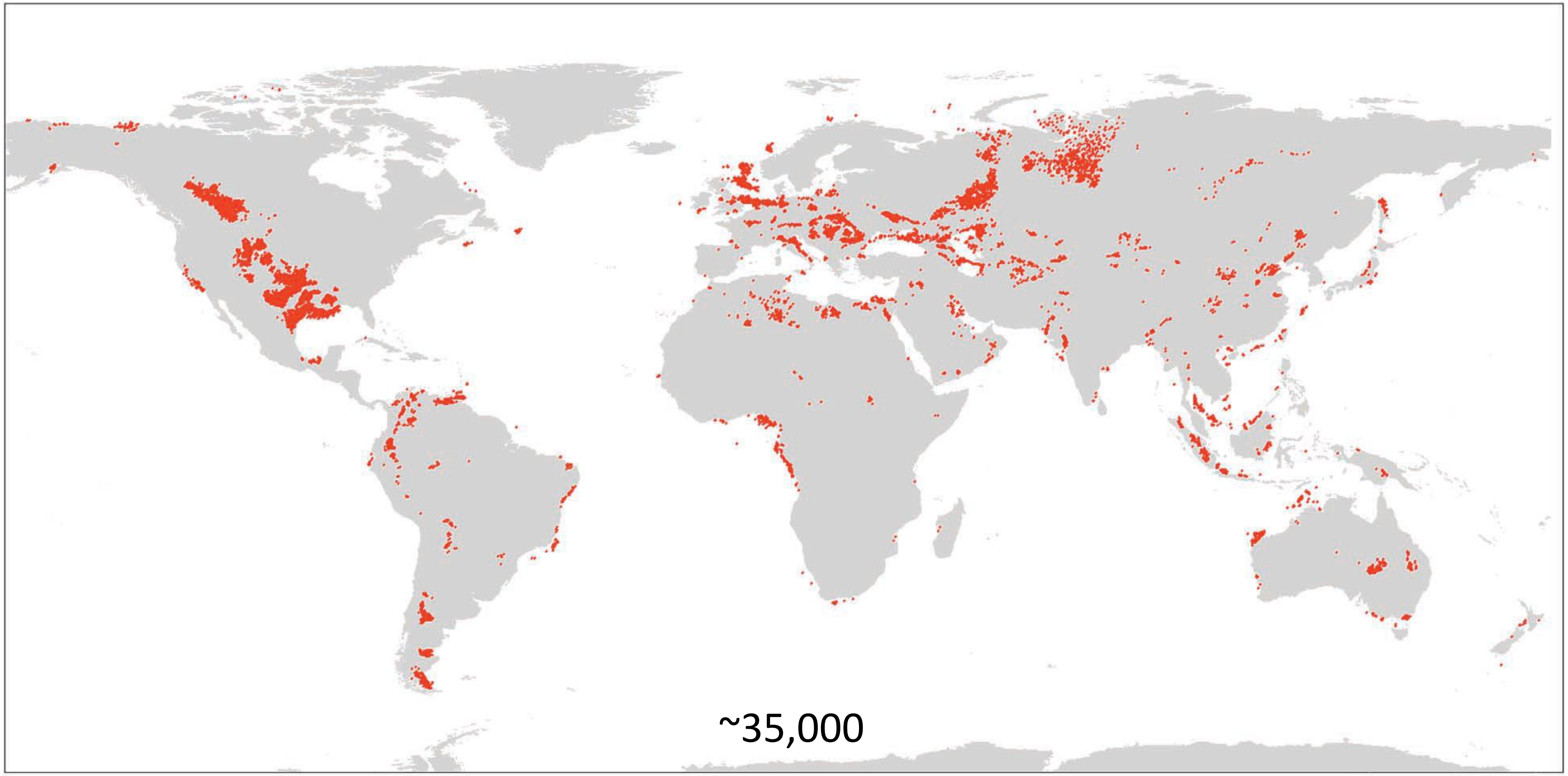
From Gragg, 2016

Carb Por/Perm samples



From Ehrenberg and Nadeau, 2005

SS Por/Perm samples



From Ehrenberg and Nadeau, 2005

POR/PERM Relationships

Average Reservoir Porosity (%) vs. Depth (Figure 2)

	P90		P50		P10	
Depth (km)	SI	CB	SI	CB	SI	CB
0–0.25	13.0	6.0	24.0	18.0	31.0	28.0
0.25–0.75	14.0	6.0	22.0	16.0	30.5	28.0
0.75–1.25	14.0	10.0	20.0	12.2	30.0	20.0
1.25–1.75	12.6	8.0	20.0	12.0	28.0	19.0
1.75–2.25	12.0	5.1	20.0	10.1	27.0	19.5
2.25–2.75	11.0	4.5	18.0	10.0	27.0	19.0
2.75–3.25	10.5	4.9	16.0	8.7	23.9	16.0
3.25–3.75	10.0	4.9	15.0	7.8	24.5	14.2
3.75–4.25	8.5	3.0	13.9	8.0	24.0	14.0
4.25–4.75	8.3	2.6	12.9	8.0	22.0	15.0
4.75–5.25	6.8	1.2	11.0	7.3	18.0	12.5
5.25–5.75	6.8	0.9	10.3	6.2	20.0	10.8

Arithmetic-Average Reservoir Permeability (md) vs. Average Porosity (Figure 4)

	P90		P50		P10	
Porosity (%)	SI	CB	SI	CB	SI	CB
2.5–7.5	0.30	1.1	10	17	92	100
7.5–12.5	2.0	4.6	29	42	190	177
12.5–17.5	5.0	6.0	40	46	200	250
17.5–22.5	18	7.0	95	58	468	525
22.5–27.5	48	10	243	100	1000	700
27.5–32.5	73	19	570	260	1660	2201
32.5–37.5	120	–	1000	–	2972	–

From Ehrenberg and Nadeau, 2005

CO2 Storage Estimation

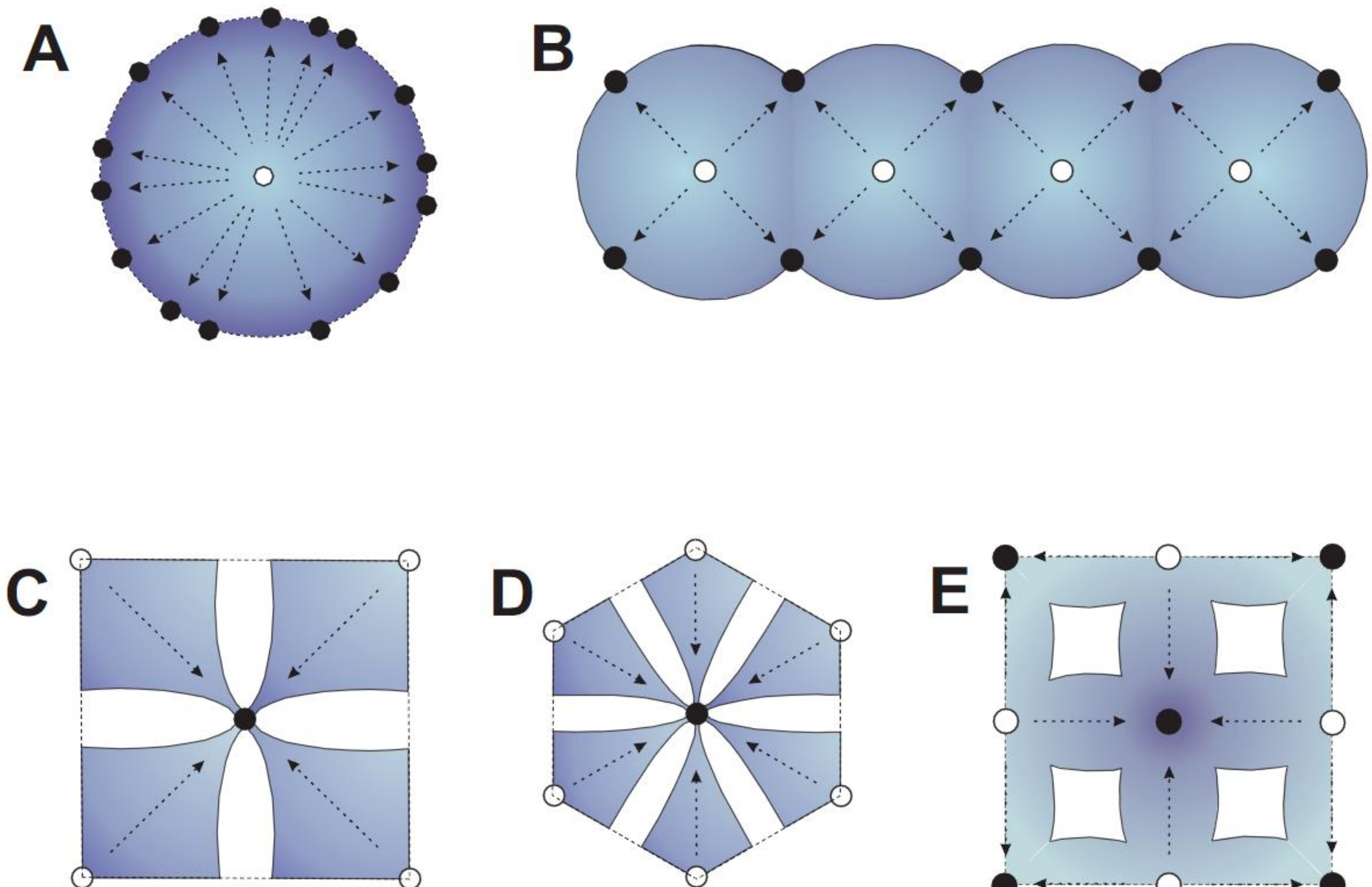
$$Q_{CO_2} = \rho_{CO_2} * \Theta * A * H (1 - S_w) / 2200 \qquad (1)$$

where:

Q_{CO_2} = CO_2 sequestration capacity (metric tons).
ρ_{CO_2} = Density of CO_2 under reservoir conditions (lbs/ft^3).
Θ = Porosity (%).
A = Area (acres).
H = Thickness of the geologic sequestration unit (ft).
S_w = Water Saturation (%).
2200 = Conversion from lbs to metric tons.

From Riley et al., 2010

WAG Designs



From Riley et al., 2010

Buckles Law

$$Porosity \times Irreducible\ Water\ Saturation = Constant$$

Ranges of the constant are:

Sandstones 0.02 to 0.10
Intergranular Carbonates 0.01 to 0.06
Vuggy Carbonates 0.005 to 0.06

The relationship can be linearized to:

$$LogS_{wi} = log\ C - log\ Phi$$

Where:

S_{wi} = Irriducible water saturation
C = Constant
Phi = Porosity

Buckles, 1965; Holmes et al., 2009

Hydrocarbon Volumetrics

$$N = 7758 A h \phi (1 - S_{\mathrm{w}}) / B_{\mathrm{oi}}$$

where

- N = OOIP (STB)
- 7758 = conversion factor from acre-ft to bbl
- A = area of reservoir (acres) from map data
- h = height or thickness of pay zone (ft) from log and/or core data
- ø = porosity (decimal) from log and/or core data
- S_w = connate water saturation (decimal) from log and/or core data
- B_{oi} = formation volume factor for oil at initial conditions (reservoir bbl/STB)

From http://wiki.aapg.org/Reserves_estimation, accessed 2017

Attributes and data added to NATCARB

PARTNERSHIP	THICKNESS_
FIELD_NAME	SALINITY_T
FIELD_AREA	PRESSURE_P
FIELD_TYPE	TEMPERATUR
RESERVOIR_	POROSITY_P
STATE_SRC	PERMEABILITY
VOL_LOW	CYCLE_OF_L
VOL_MED	Shape_Length
VOL_HIGH	Shape_Area
DEPTH_FT	POR_LS_50
Recovery Factor Low	POR_LS_10
Recovery Factor High	PERM_SS_90_90
Swircarb	PERM_SS_50_90
Swirss	PERM_SS_10_90
Buckles Constant Carb	PERM_SS_90_50
Buckles Constant SS	PERM_SS_50_50
OOIPcarb	PERM_SS_10_50
OOIPss	PERM_SS_90_10
Boi	PERM_SS_50_10
NGR	PERM_SS_10_10
Incremental Oil Low SS	PERM_LS_90_90
Incremental Oil High SS	PERM_LS_50_90
Incremental Oil Low LS	PERM_LS_10_90
Incremental Oil High LS	PERM_LS_90_50
X	PERM_LS_50_50
Y	PERM_LS_10_50
POR_SS_90	PERM_LS_90_10
POR_SS_50	PERM_LS_50_10
POR_SS_10	PERM_LS_10_10
POR_LS_90	

Reservoir Parameter	Total Data Added
Porosity	289,000
Permeability	866,000
Temperature	48,138
CO2 Capacity	5,140
Pressure	48,138
Depth	1,300
Thickness	43,300