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Geopressured Geothermal Resource and Recoverable Energy Estimate for the Wilcox and Frio Formations, Texas


PIX # 19089

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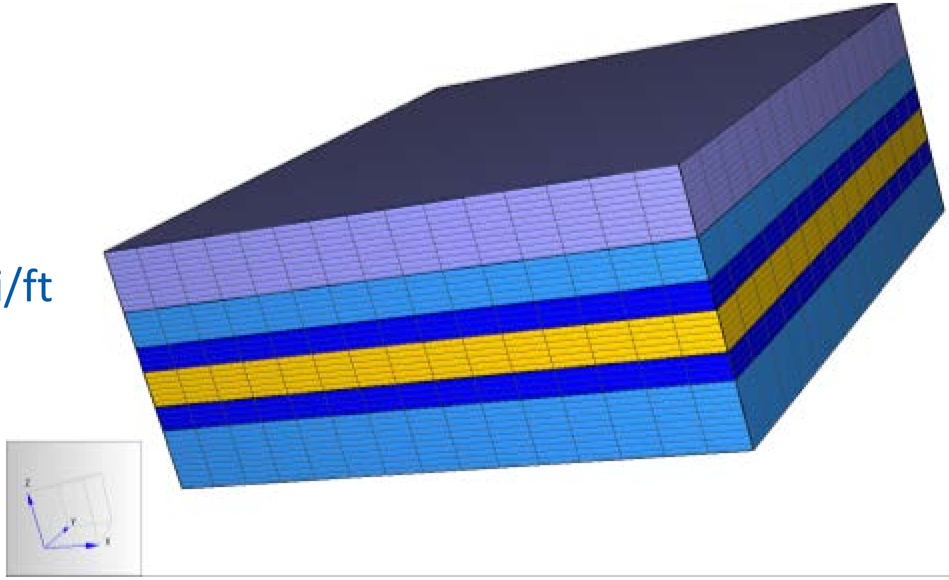
Introduction

Motivation: To apply advances in reservoir modeling techniques to estimate the geopressured geothermal resource in the Gulf Coast last assessed in the late 1970s.

Goals:

1. Estimate recoverable geopressured geothermal resource in the Frio and Wilcox formations in Texas
2. Utilize advanced reservoir modeling software (TOUGH2 – multiphase flow)
3. Include the fluid contribution from bounding shale layers in reservoir analysis
4. Analyze impact of main reservoir parameters on flow rate and reservoir longevity
5. Understand the influence of free methane production on total methane production
6. Determine thermal drawdown rate in geopressured reservoirs

Geopressured Geothermal Resource Definition



Geopressure Definition*

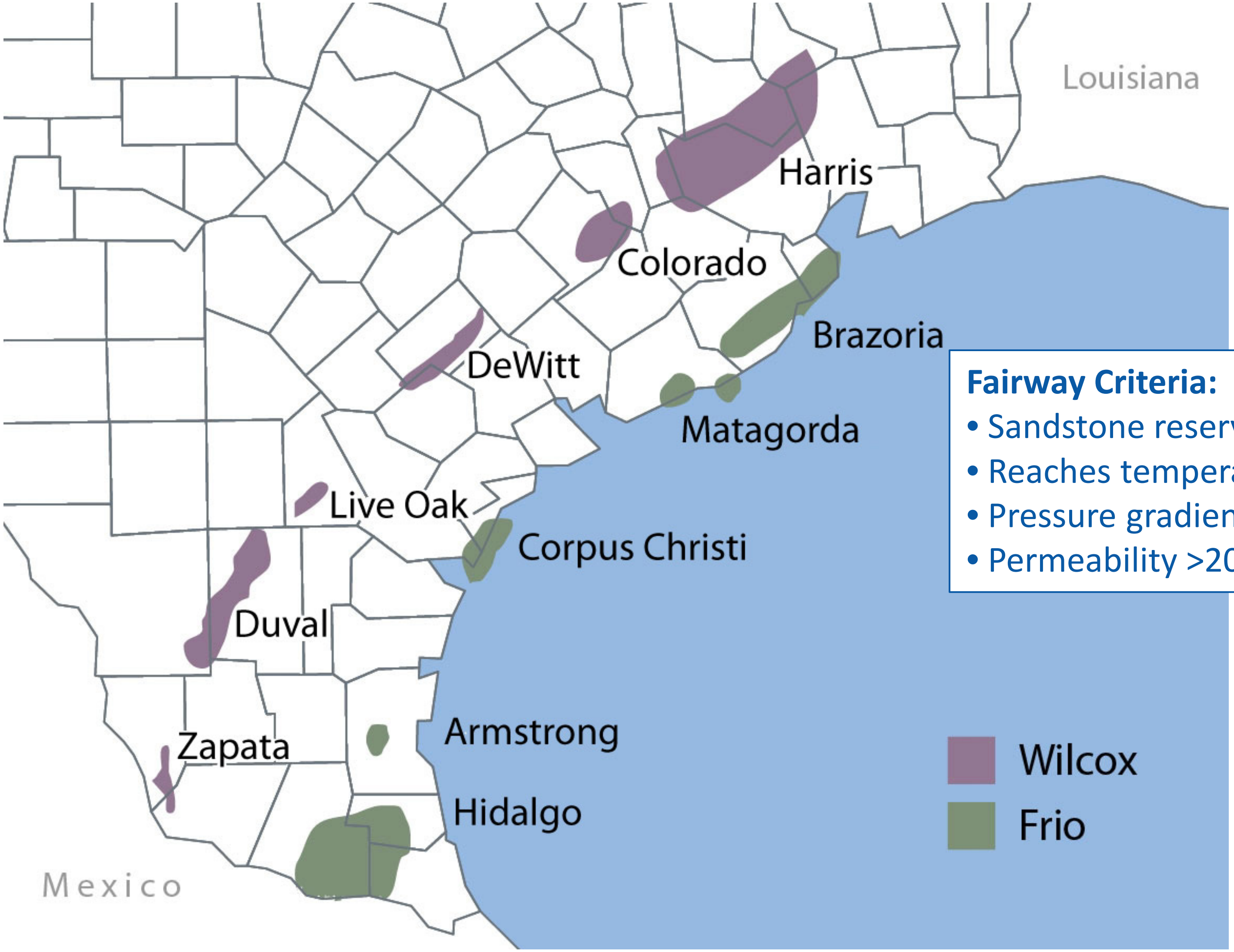
- Greater than hydrostatic
  - Freshwater/Brackish – 0.433 psi/ft
  - Salt Water – 0.465 psi/ft
- Soft Geopressure
  - Hydrostatic to 0.7 psi/ft
- **Hard Geopressure**
  - **0.7 – 1.0 psi/ft (lithostatic pressure gradient)**

Geothermal

- Temperature > 212°F (100°C)
- DOE Criteria for Design Wells drilled in 1979
  - Temperature > 275°F (135°C)

* Loucks, R.G., D.L. Richmann, and K.L. Milliken. 1981. "Factors Controlling Reservoir Quality in Tertiary Sandstones and Their Significance to Geopressured Geothermal Production." Report of Investigations No. 111. The University of Texas at Austin, Bureau of Economic Geology.

Texas Fairways



Fairway Criteria:

- Sandstone reservoir volume > 3 mi^3
- Reaches temperature > 300°F
- Pressure gradient > 0.7 psi/ft
- Permeability >20 mD

Source: Bebout et al.(1982, 1983)

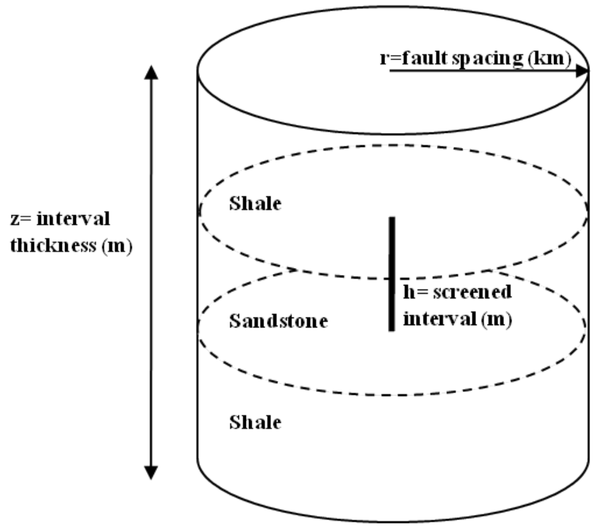
Resource Estimate

TOUGH2 Reservoir Simulator (LBNL & UC Berkeley)

- Multiphase flow in porous media
- Equation of state for water, salt, and gas: H_20, NaCl, CH_4
- Incorporates: capillary pressure, relative permeability, and pore compressibility

Methodology

1. Develop conceptual reservoir model
2. Determine model structure
   - 2D radial axisymmetric grid
3. Add layer properties
   - Wilcox gas saturation = 5%
   - Frio gas saturation = 1%
4. Calibrate natural state of model
   - Run for 100 years without production
5. Simulate reservoir production
   - 20 years of production
   - Constant pressure constraint of 110% of hydrostatic at top of producing interval



2D Radial Axisymmetric Grid

Wilcox Fairway Analysis: Zapata Example

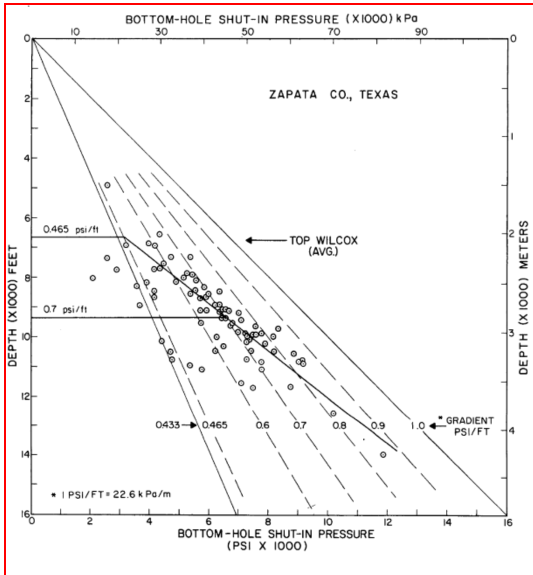


Figure 50. Bottom-hole shut-in pressures plotted as a function of depth for Zapata County.

Bebout et al.(1982)

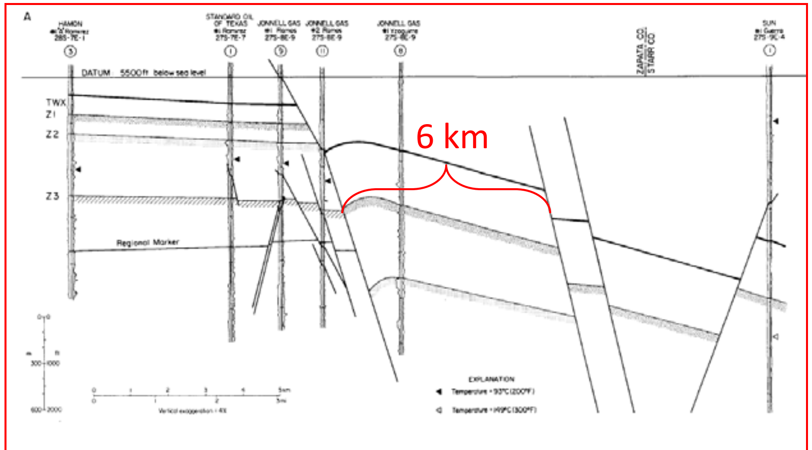


Figure 47. Structural dip section A-A', southern part of the Zapata Fairway.

Bebout et al.(1982)

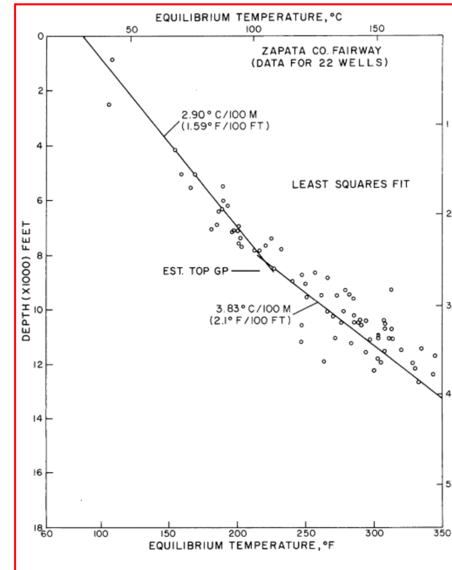


Figure 52. Temperatures and geothermal gradients for Zapata Fairway.

Bebout et al.(1982)

Fault Spacing

Pressure

Reservoir Model

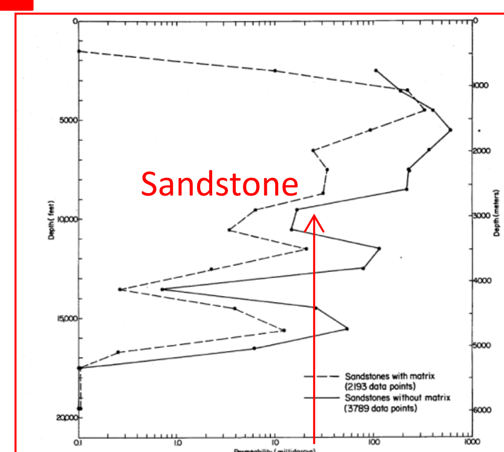
Temperature

Rock Properties

Table 2. Sidewall-core data from two wells in Zapata County.

	DEPTH (ft)	PERMEABILITY (md)	POROSITY (%)
Shale	9,153 to 9,558	0 to 2.9 (avg. 0.5)	17 to 21 (avg. 18.0)
Shale	10,027 to 10,634	0 to 6.6 (avg. 2.0)	18 to 22 (avg. 20.0)
	10,498 to 10,499	8 to 19	18 to 20

Bebout et al.(1982)



Loucks et al.(1979)

Geopressured Geothermal Resource Estimate: Frio and Wilcox Formations

Wilcox Fairways	Zapata	Duval	Live Oak	De Witt	Colorado	Harris
Depth to Top of GP-GT Resource(m)[1]	2,438	3,078	2,438	2,743	3,048	3,505
Depth to Bottom (m)[1]	3,657	4,023	3,810	3,658	4,267	4,704
Rounded Interval Thickness (m)	1,200	940	1,360	920	1,230	1,200
Sandstone Thickness (m)[1]	180	180	180	160	495	300
Shale Thickness (m)[1]	1,020	760	1,180	760	735	900
Depth to Top of Sandstone Reservoir I (m)[1]	2,926	3,353	2,804	3,197	3,341	3,810
Depth to Top of Sandstone Reservoir II (m)[1]	3,200	3,658	3,353	3,249	3,475	4,115
Porosity (%)[1]	19	14	15	18	14	15
Permeability Sandstone (mD)[1,2]	27	44	35	40	150	19
Pressure at Top (Pa)[1]	3.45E+07	4.89E+07	3.45E+07	2.69E+07	4.37E+07	5.38E+07
Pressure at Bottom (Pa)[1]	5.79E+07	8.96E+07	6.34E+07	6.76E+07	6.12E+07	9.10E+07
Temperature Range (°C)[1]	111–157	138–192	106–177	111–154	97–157	130–181
Fault Spacing Reservoir I (km)[1]	3	2.5	3.5	3	3.5	10
Fault Spacing Reservoir II (km)[1]	7	5	4.5	5	7.5	8
Area Represented Model I (km^2) [1]	144	428	82	380	410	2,243
Area Represented Model II (km^2) [1]	96	998	124	253	410	2,243

Frio Fairway Analysis

Data Available for the Frio Formation :

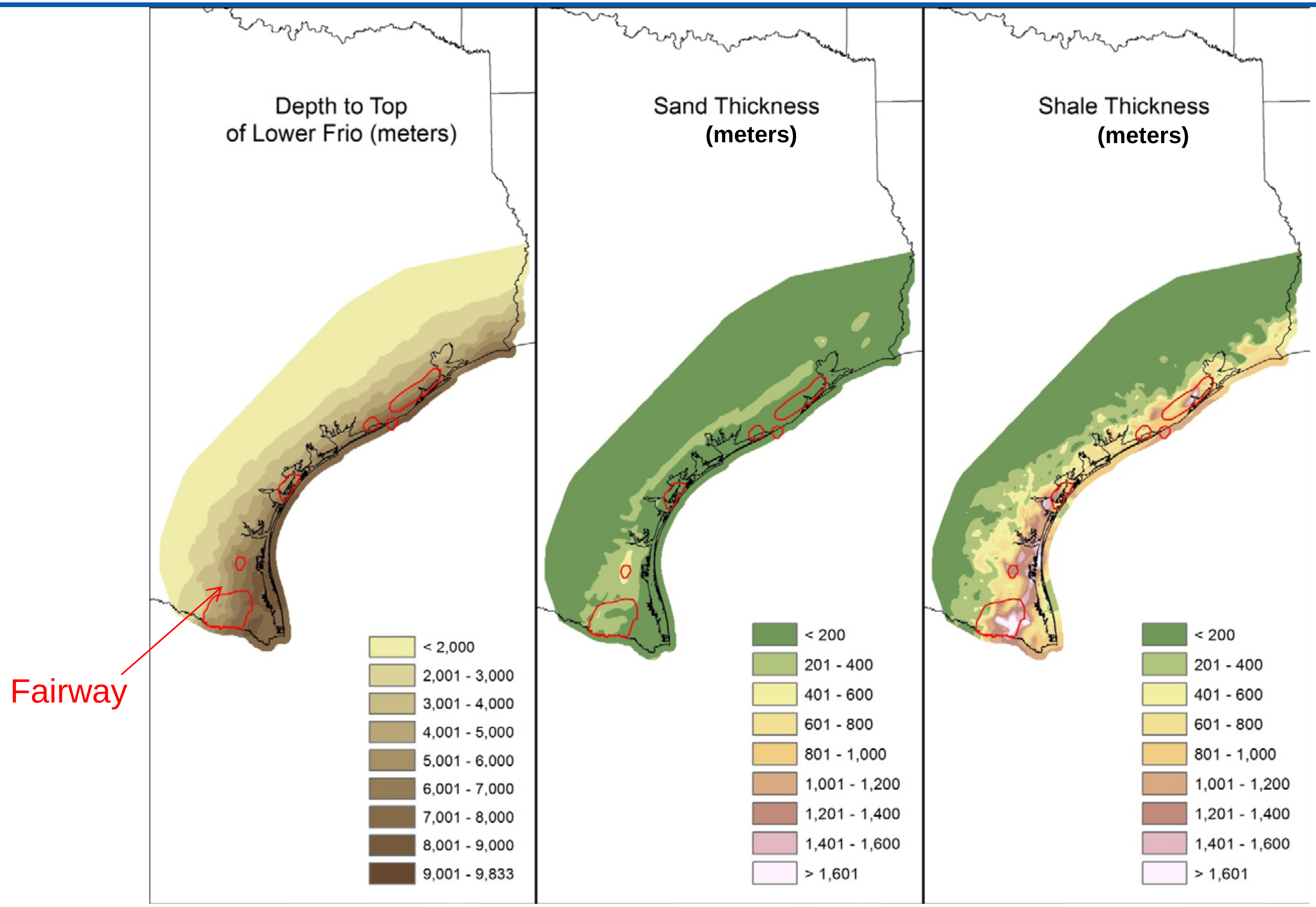
- Depth to geopressure [3]
- Depth to top of Frio [4]
- Thickness of Frio [4]
- Net sandstone thickness (lower, middle, upper) [4]
- Percent sandstone (lower, middle, upper) [4]
- Major faults [5]

} Spatial Analysis of Lower Frio

Methodology

1. Determine shale thickness of lower Frio
2. Calculate pressure in lower Frio (assume $\Delta p = 0.7$ psi/ft)
3. Calculate temperature gradient from AAPG BHT dataset
4. Use conservative rock properties and average porosity
   - Sandstone permeability: 20 mD
   - Shale permeability range: 0.001 -1 mD

Spatial Analysis for Lower Frio Formation



Adapted from Galloway et al.(1982)

Geopressured Geothermal Resource Estimate: Frio and Wilcox Formations

Frio Fairways - Reservoir I	Hidalgo	Armstrong	Corpus Christi	Matagorda	Brazoria
	Largest Fault Spacing	Thickest Sandstone	Smallest Fault Spacing		
Depth to Top of GP-GT Resource (m)[3]	2,743	3,150	3,569	4,291	3,388
Depth to Bottom (m)[4]	3,854	4,913	4,468	4,808	4,692
Rounded Interval Thickness (m)	1,100	1,770	900	510	1,300
Sandstone Thickness (m)[4]	275	660	40	30	175
Shale Thickness (m)[4]	825	1,110	860	480	1,125
Depth to Top of Sandstone (m)[4]	3,368	4,050	4,229	4,571	4,313
Porosity (%)[3]	15	23	18	20	15
Pressure at Top (Pa)[3]	4.53E+07	4.99E+07	6.05E+07	6.79E+07	5.36E+07
Pressure at Bottom (Pa)[3]	5.71E+07	7.78E+07	7.07E+07	7.25E+07	7.43E+07
Temperature Range (°C)[6]	108–146	139–178	134–165	149–168	120–163
Fault Spacing (km)[5]	15.5	8.0	3.2	8.0	11.2
Area Represented (km^2)[5]	1,187	194	332	362	990

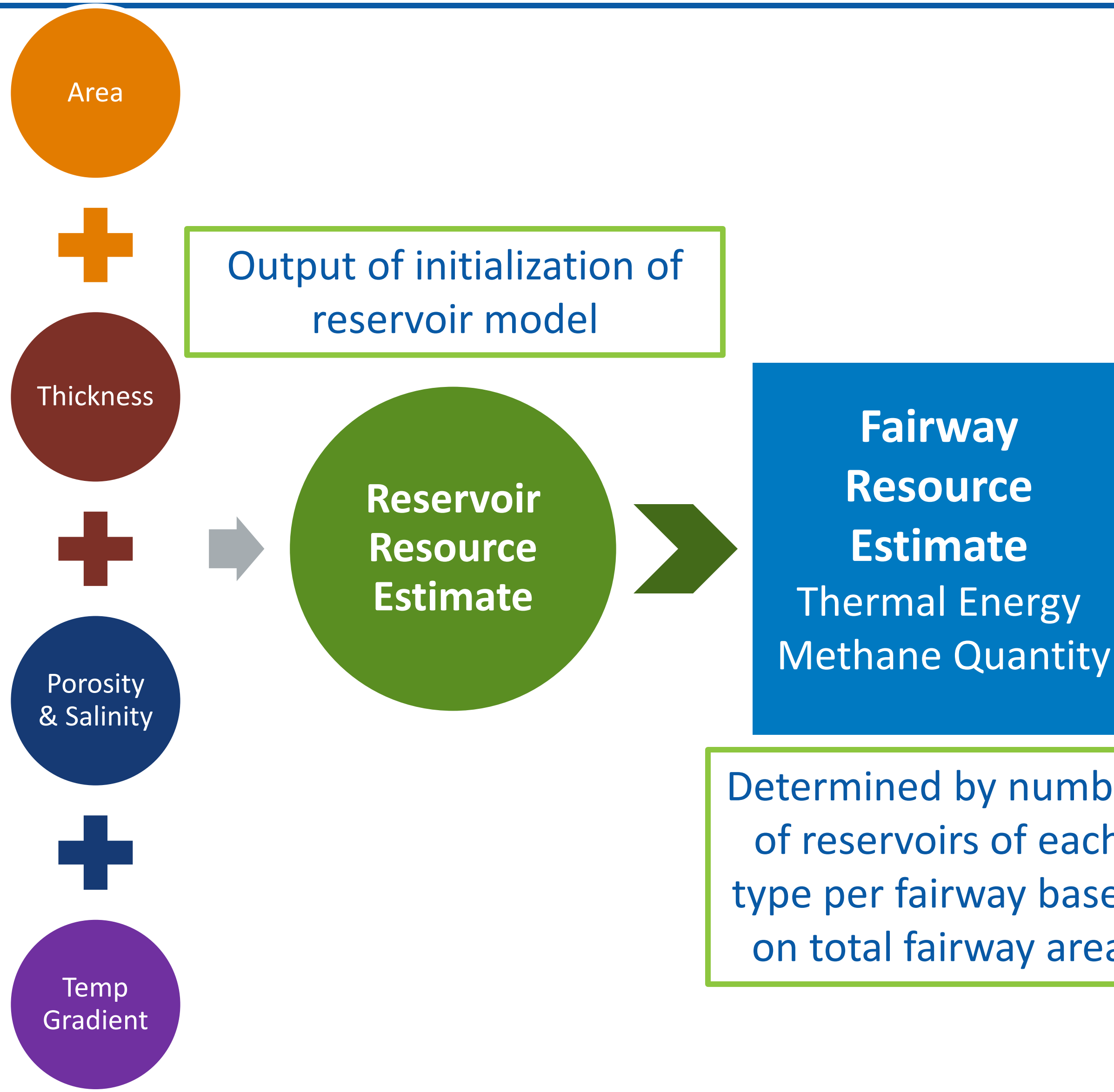
Geopressured Geothermal Resource Estimate: Frio and Wilcox Formations

Frio Fairways - Reservoir II	Hidalgo	Armstrong	Corpus Christi	Matagorda	Brazoria
	Thickest Total Interval		Lowest Temperature	Deepest Reservoir	
Depth to Top of GP-GT Resource (m)[3]	4,030		2,743	4,771	4,359
Depth to Bottom (m)[4]	5,761		3,879	5,831	5,220
Rounded Interval Thickness (m)	1,725		1,140	1,056	860
Sandstone Thickness (m)[4]	150		200	33	30
Shale Thickness (m)[4]	1,575		940	1,023	830
Depth to Top of Sandstone (m)[4]	5,405		3,483	5,594	4,989
Porosity (%)[3]	15		18	20	15
Pressure at Top (Pa)[3]	6.38E+07		4.34E+07	7.55E+07	6.90E+07
Pressure at Bottom (Pa)[3]	8.86E+07		6.14E+07	8.90E+07	7.85E+07
Temperature Range (°C)[6]	152–211		105–145	166–203	152–180
Fault Spacing (km)[5]	4.8		12.0	5.0	8.0
Area Represented (km^2)[5]	1,781		332	155	660

Total Geopressured Geothermal Resource Estimate

Calculating total resource is the important first step to determine recoverability factors of thermal and methane energy from geopressured geothermal reservoirs

Output of initialization of reservoir model



Determined by number of reservoirs of each type per fairway based on total fairway area

Results: Total Resource Estimate - Frio and Wilcox Formations

Wilcox Fairway	Area (km²)	Total Heat (J)	Total Methane (MMSCF)	Frio Fairway	Area (km²)	Total Heat (J)	Total Methane (MMSCF)
Zapata	239	1.04E+20	4.72E+07	**Hidalgo**	2,968	1.93E+21	4.85E+08
Duval	1,425	5.86E+20	2.52E+08	**Corpus Christi**	663	2.49E+20	6.10E+07
Live Oak	206	1.02E+20	3.61E+07	**Matagorda**	517	1.62E+20	5.19E+07
De Witt	633	2.09E+20	9.65E+07	**Brazoria**	1,650	7.37E+20	1.72E+08
Colorado	819	3.16E+20	1.21E+08	**Armstrong**	194	1.51E+20	5.19E+07
Harris	4,486	2.22E+21	1.10E+09				
Total	7,808	3.54E+21	1.65E+09	**Total**	5,992	3.23E+21	8.22E+08

Results: Wilcox Fairway Recoverable Energy

Wilcox Fairway	Reservoir Type	Average Water Flow Rate (kg/s)	Average Methane Flow Rate (MMSCFD)	Produced Gas Water Ratio (scf/bbl)
Zapata	Reservoir I	50.5	1.1	38.6
	Reservoir II	63.7	2.6	74.8
Duval	Reservoir I	39.9	3.4	156.9
	Reservoir II	74.3	34.4	849.6
Live Oak	Reservoir I	43.1	0.8	33.1
	Reservoir II	55.9	13.8	454.2
DeWitt	Reservoir I	18.3	0.8	79.3
	Reservoir II	32.5	1.1	59.1
Colorado	Reservoir I	51.6	1.8	63
	Reservoir II	291.9	24.5	154
Harris	Reservoir I	120.2	4.3	65
	Reservoir II	158.8	12.6	144.9

Low	
High	

Conversion: 20,000 bpd = 36.8 kg/s

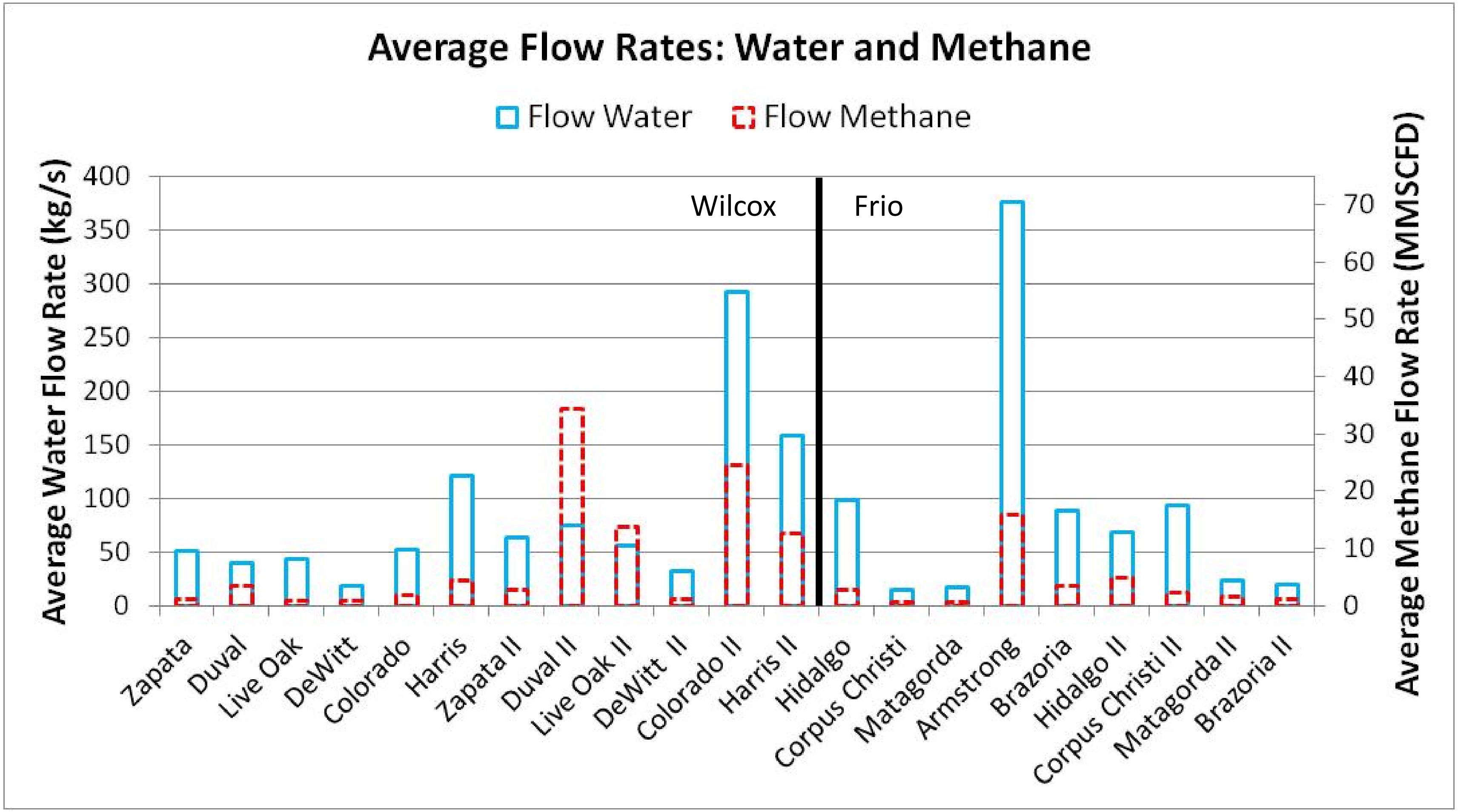
Results: Frio Fairway Recoverable Energy

Frio Fairway	Reservoir Type	Average Water Flow Rate (kg/s)	Average Methane Flow Rate (MMSCFD)	Produced Gas Water Ratio (scf/bbl)
Hidalgo	Reservoir I	98.2	2.6	48.2
	Reservoir II	68.3	4.8	127.8
Corpus Christi	Reservoir I	14.8	0.5	62.7
	Reservoir II	93.7	2.3	45.5
Matagorda	Reservoir I	17.3	0.7	69.8
	Reservoir II	23.1	1.5	116.9
Armstrong	Reservoir I	376.2	15.9	77.3
	Reservoir II			
Brazoria	Reservoir I	88.2	3.3	67.8
	Reservoir II	19.4	1	93

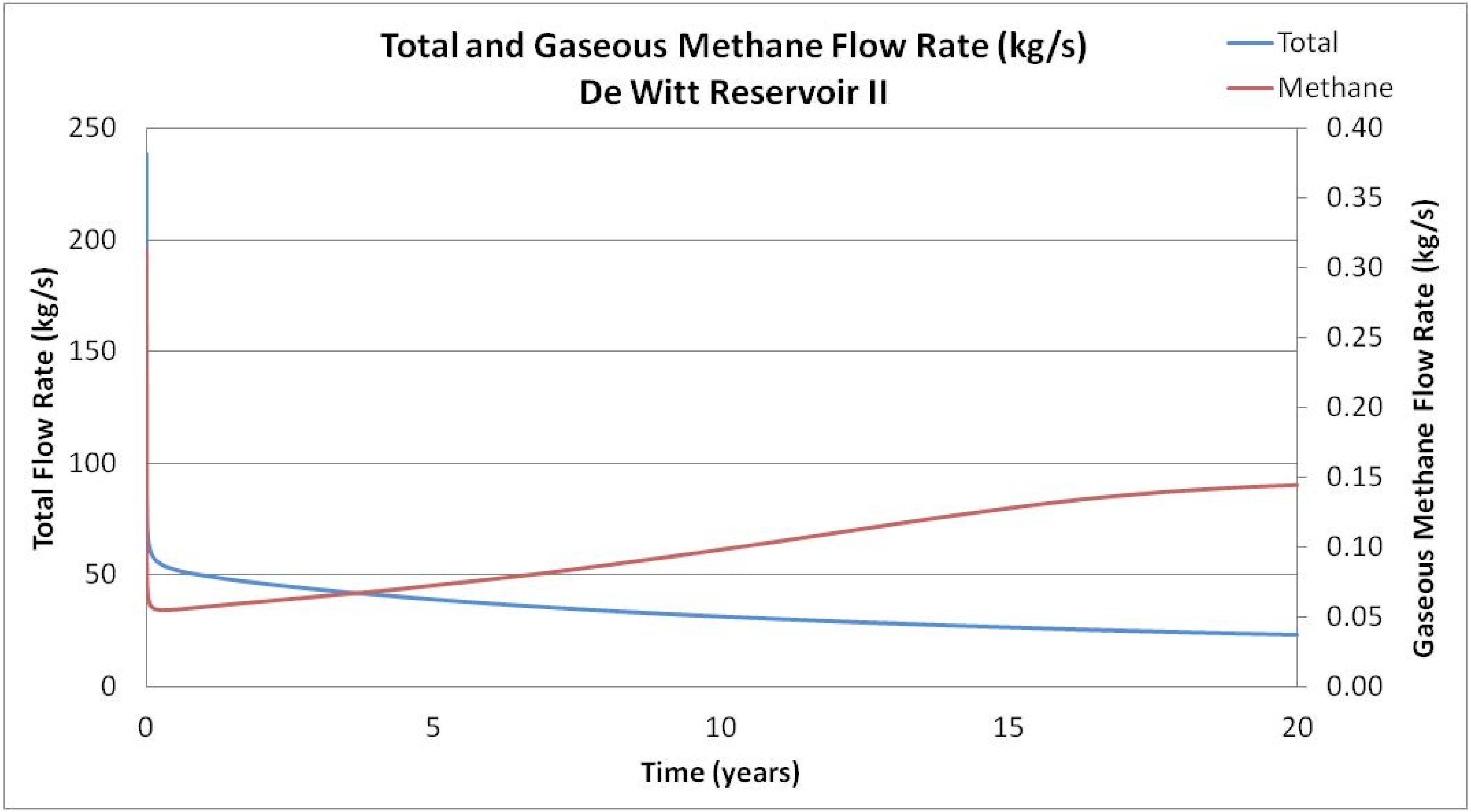
Low	
High	

Conversion: 20,000 bpd = 36.8 kg/s

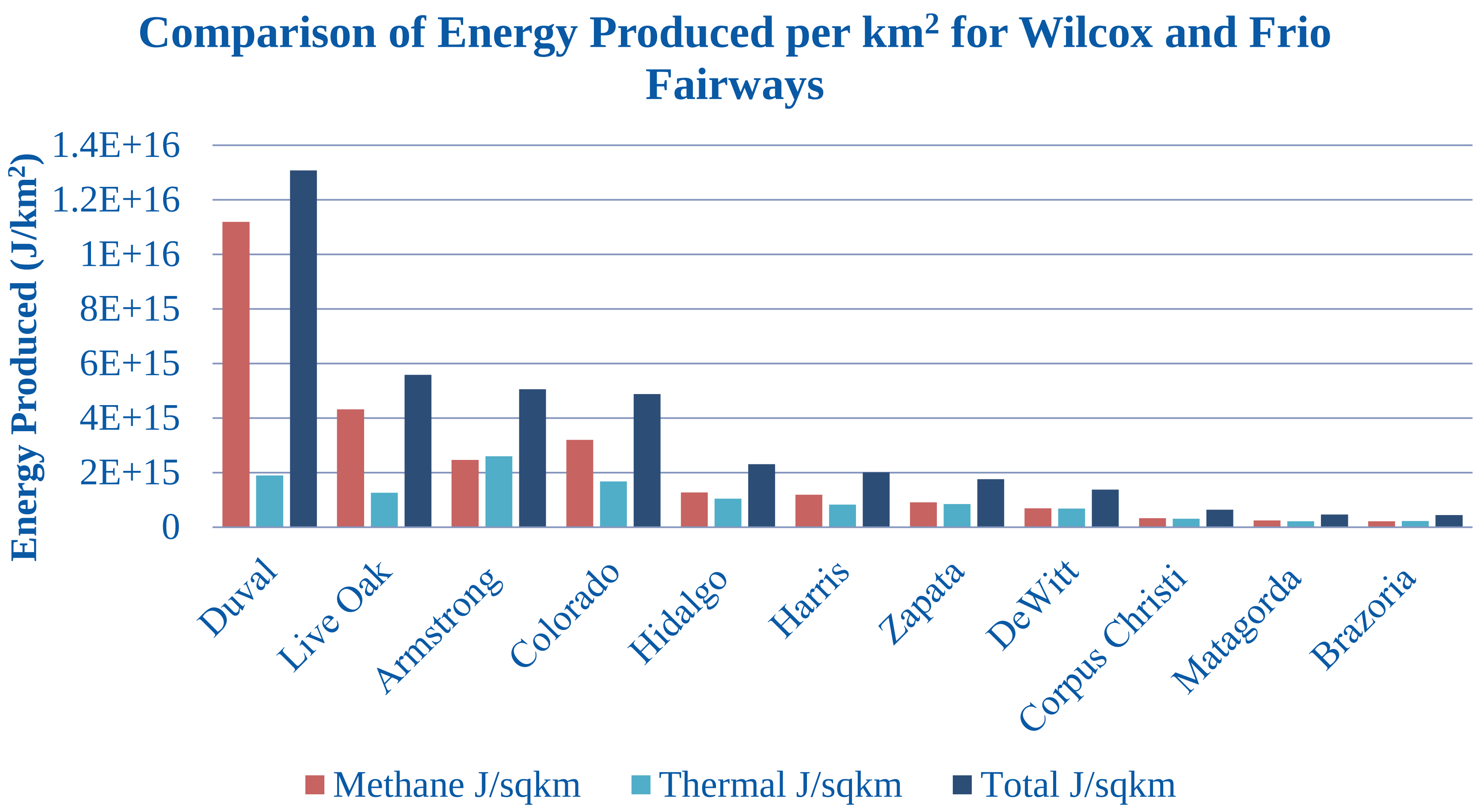
Results: Frio and Wilcox Reservoirs - Average Flow Rates



Results: Most Common Total and Gas Production Trend

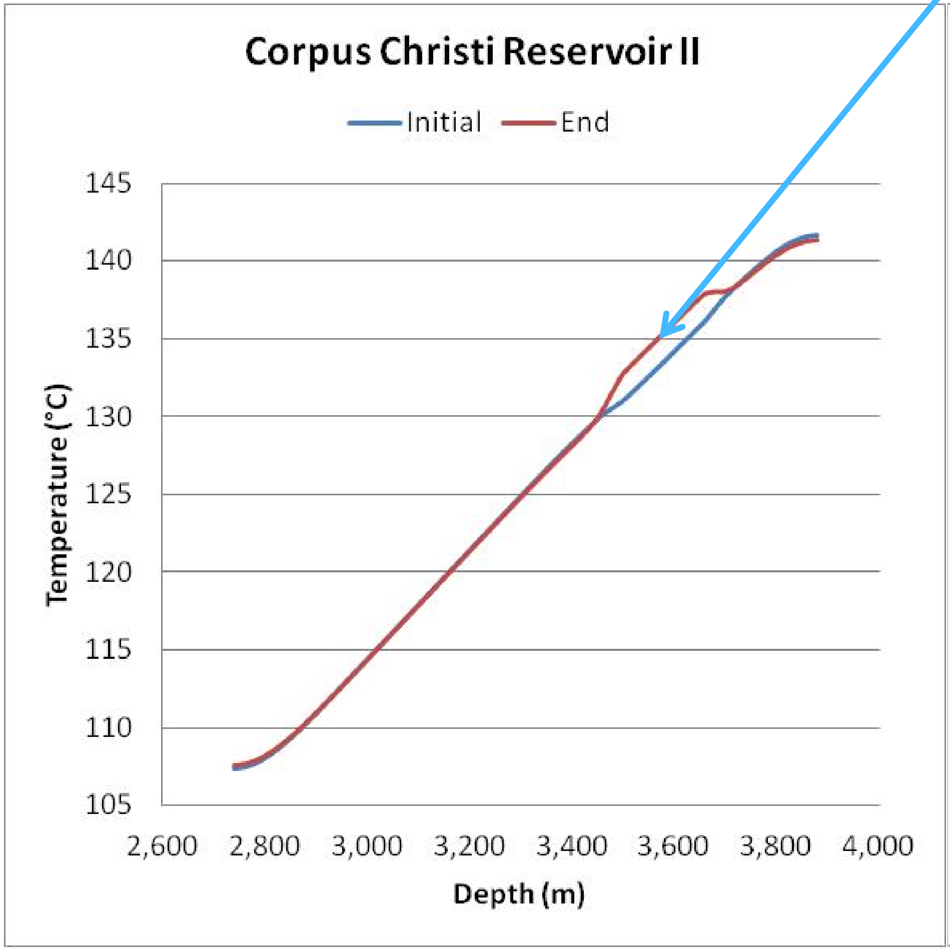


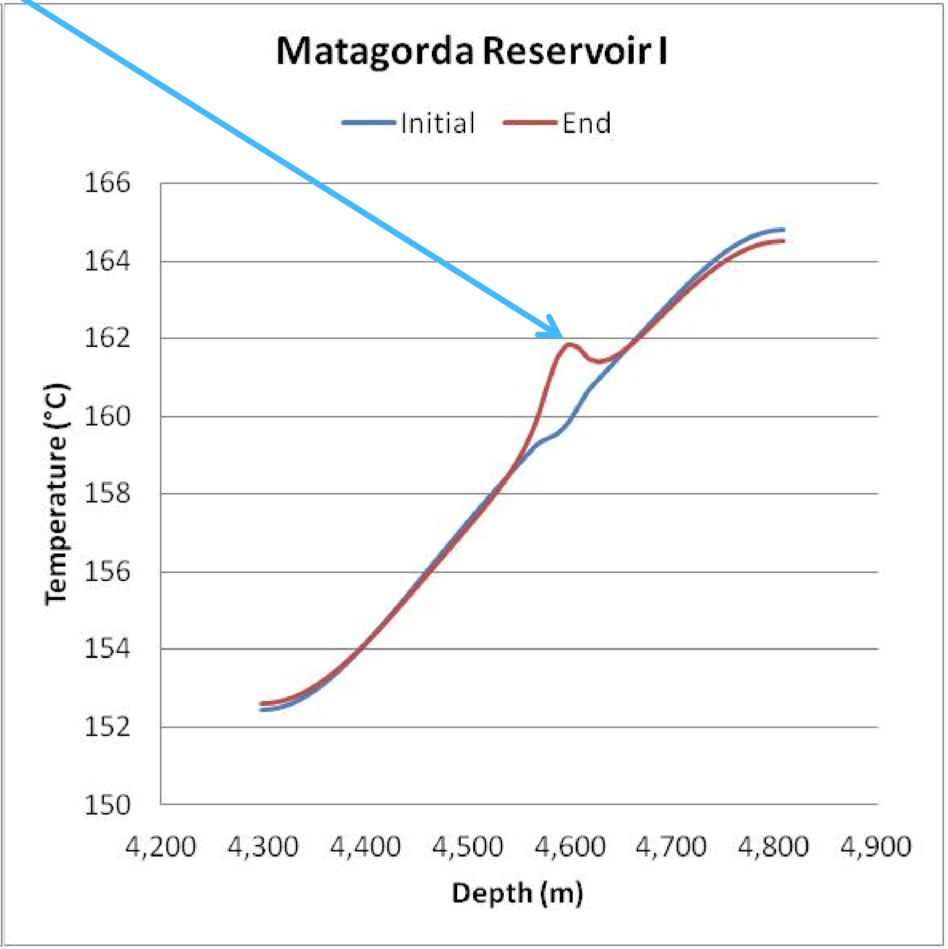
Results: Energy Density Analysis



Results: Temperature at End of 20-year Production Period

Temperature in producing interval increases after production due to upward flux of fluid from lower shale layer





Conclusions

- **Reservoir simulation technique that included multiphase flow and contribution from shale layers led to unique results**
  - Bounding shale layers help maintain reservoir pressure
  - Modeling of multiphase flow led to predictions of higher methane production than in previous analyses that assumed only saturated fluid flow
  - Temperature increases slightly in sandstone layer due to upward flux of fluid from lower shale layer
- **Multiple factors interact to influence flow**
  - Sandstone thickness
  - Fault spacing/reservoir boundary
  - Rock properties: porosity and permeability
  - Initial reservoir pressure
- **Large range in flow rates of geothermal fluid and methane**
  - Water flow rate: most 40 kg/s – 90 kg/s
  - Methane flow rate: most 0.5 MMSCFD – 4.8 MMSCFD
- **Total recoverable energy (thermal and methane) per unit area varied significantly among fairways: 4.38 x 10^{14} J/km^2 to 1.31 x 10^{16} J/km^2**

Additional reservoir data such as potential gas pockets or permeability heterogeneity will improve development of reservoir model and provide more insight to main factors influencing recovery

THANK YOU!

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Sources:

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