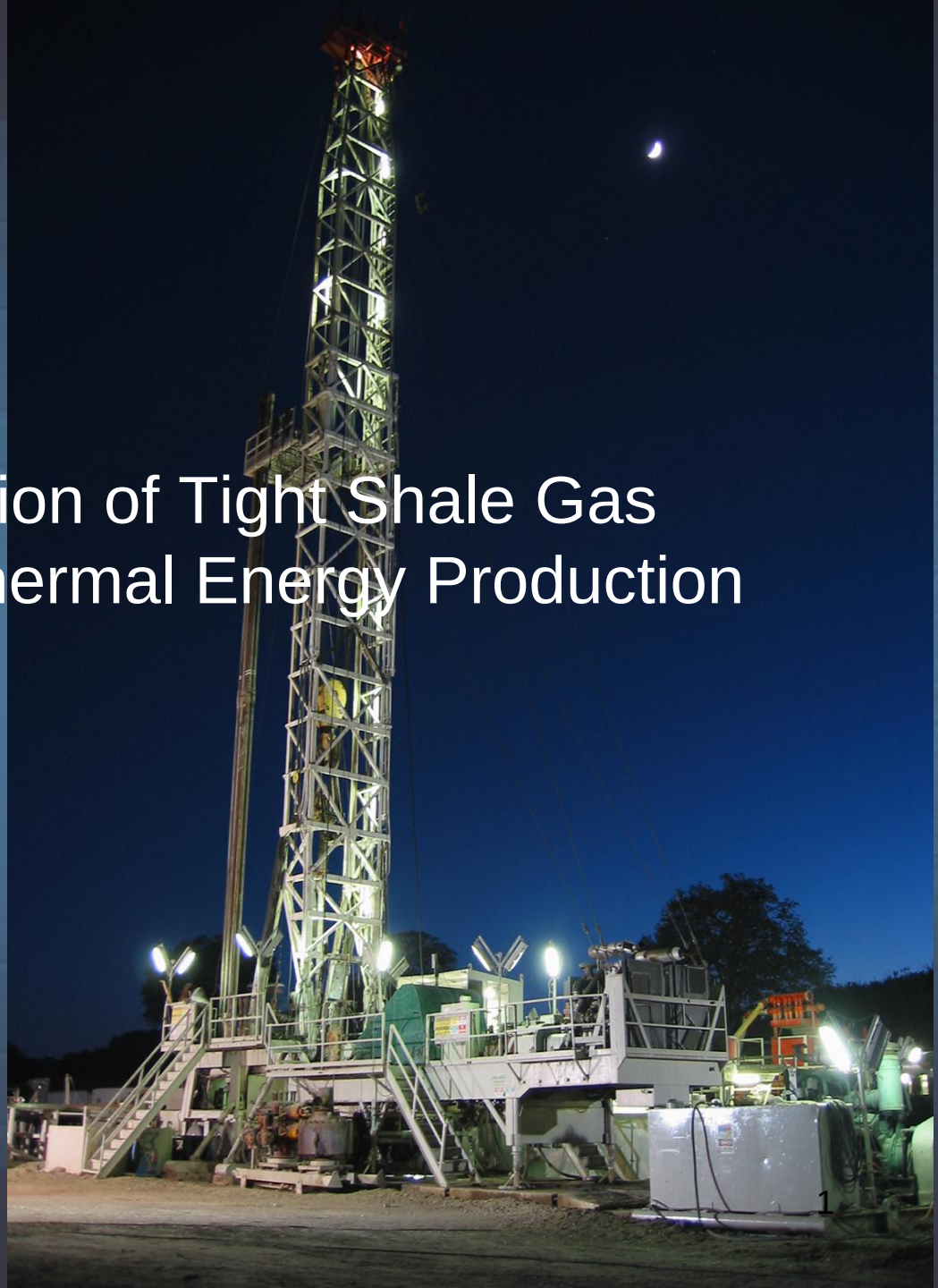
The Transformation of Tight Shale Gas Reservoirs to Geothermal Energy Production



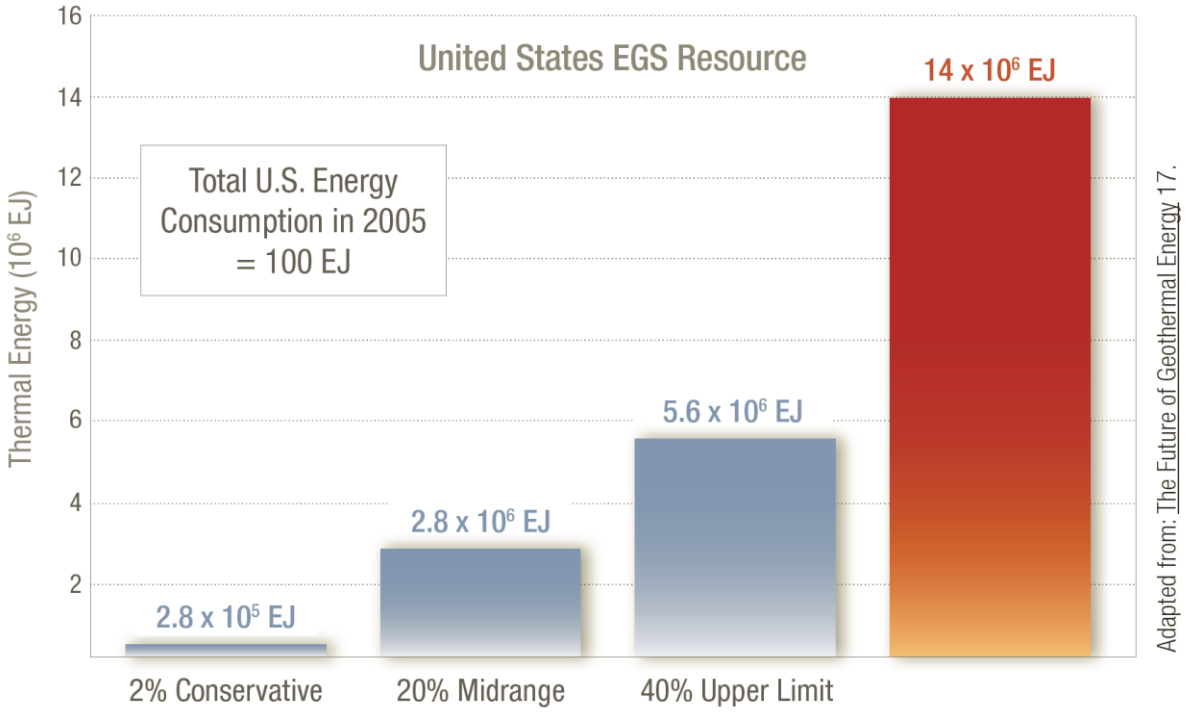
Bruce L. Cutright
Bureau of Economic Geology
University of Texas, Austin Texas
June 14th, 2011

The Transformation of Tight Shale Gas Reservoirs to Geothermal Energy Production

- Geothermal Energy in conjunction with oil and gas development is:
  - Focused on Co-produced fluids or abandon wells
  - Petroleum production (gas, liquids and crude) from tight Shales and other low permeability formations has revolutionized the energy picture of the US, and the world oil market,,,,and largely overshadowed the potential of geothermal energy

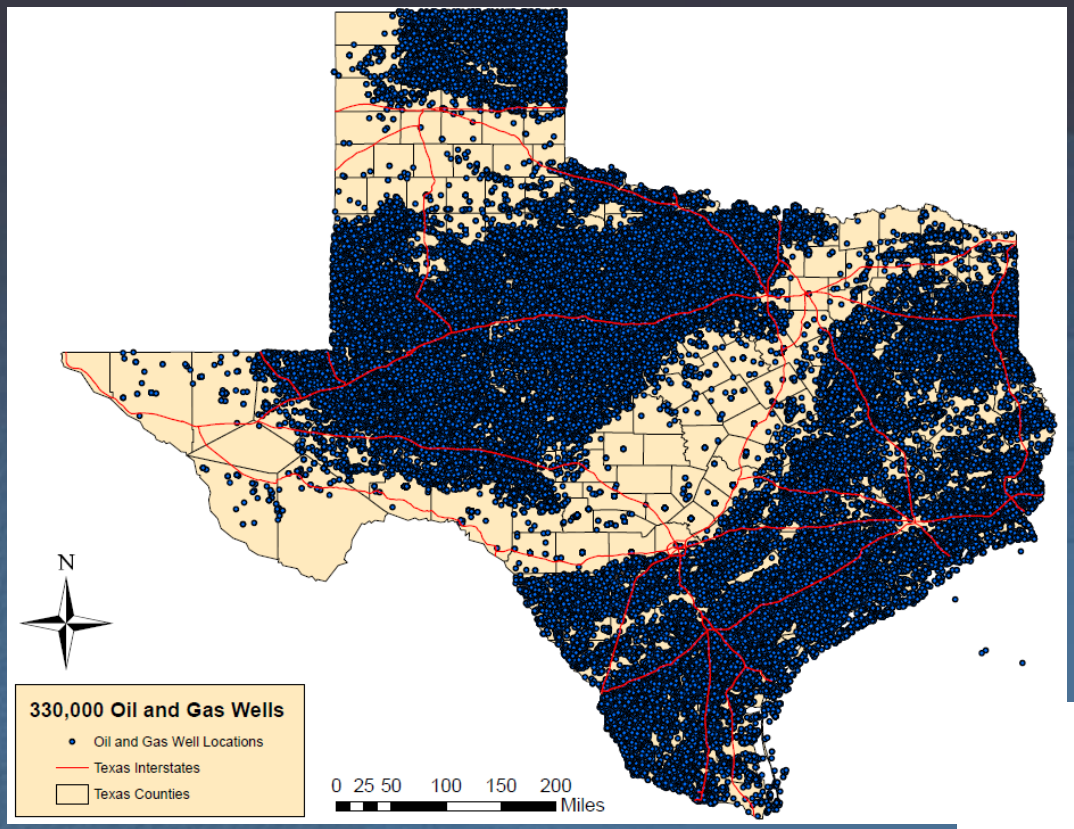
  - *2011 "The Potential Gas Committee (PGC) today released the results of its latest biennial assessment of the nation's natural gas resources, which indicates that the United States possesses a total resource base of* ***1,898 trillion cubic feet*** *(Tcf) as of year-end 2010. This is the highest resource evaluation in the Committee's 46-year history, exceeding the previous record-high assessment by 61 Tcf. Most of the increase arose from reevaluation of shale-gas plays in the Gulf Coast, Mid-Continent and Rocky Mountain areas."*

Figure 1. EGS Development Potential Shown

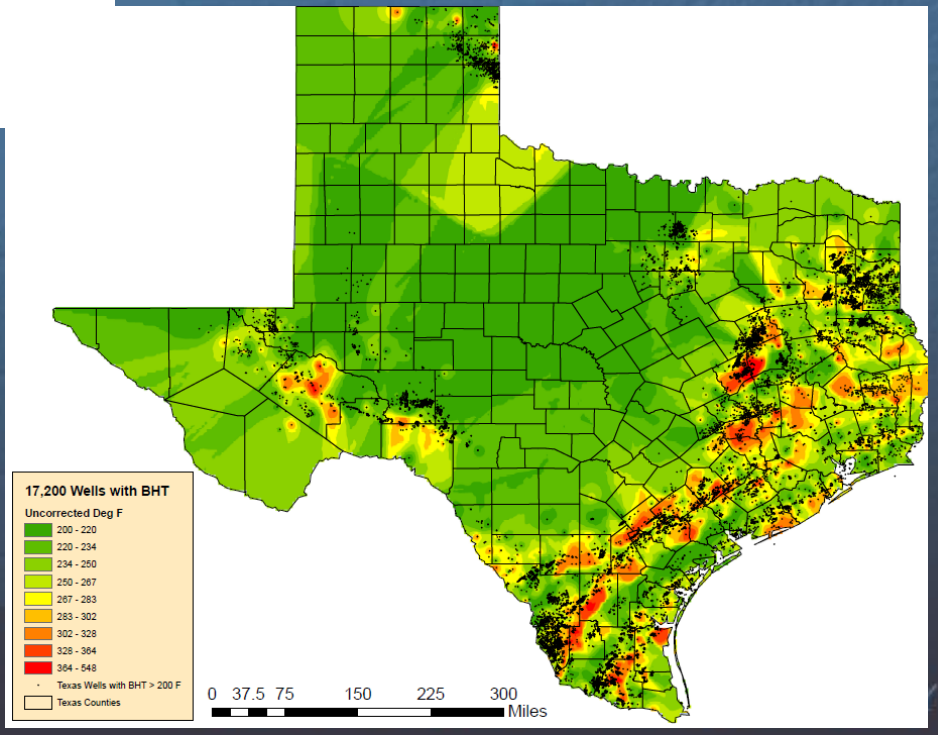


Even when we try to be conservative, estimates of available, marketable geothermal energy in Texas are still significant.

Geothermal Resource Base Estimate for Texas	Exa Joules (1×10^{18} Joules)	Barrels of Oil Equivalent	Megawatt Hours	Value, at $0.07 per Kilowatt Hr.	Value after derating for 10% extraction efficiency, 8% energy conversion efficiency and 90% availability
Co-Produced Fluids	220,000	37.8×10^{12}	6.12E+13	$4,281,200,000,000,000	$30,824,640,000,000
Geo-pressured-Geothermal (low est)	46,000	7.91×10^{12}	1.28E+13	$895,160,000,000,000	$6,445,152,000,000
Geo-Pressured-Geothermal (high est)	110,000	18.9×10^{12}	3.06E+13	$2,140,600,000,000,000	$15,412,320,000,000
Distributed over a 30 year Producing Lifetime			1.02E+12	$71,353,333,333,333	$513,744,000,000
What 1,898 Trillion Cubic of Natural Gas Equates to	2,002	3.45091E+11	5.56E+14	$38,939,038,686,987	$1,297,967,956,233

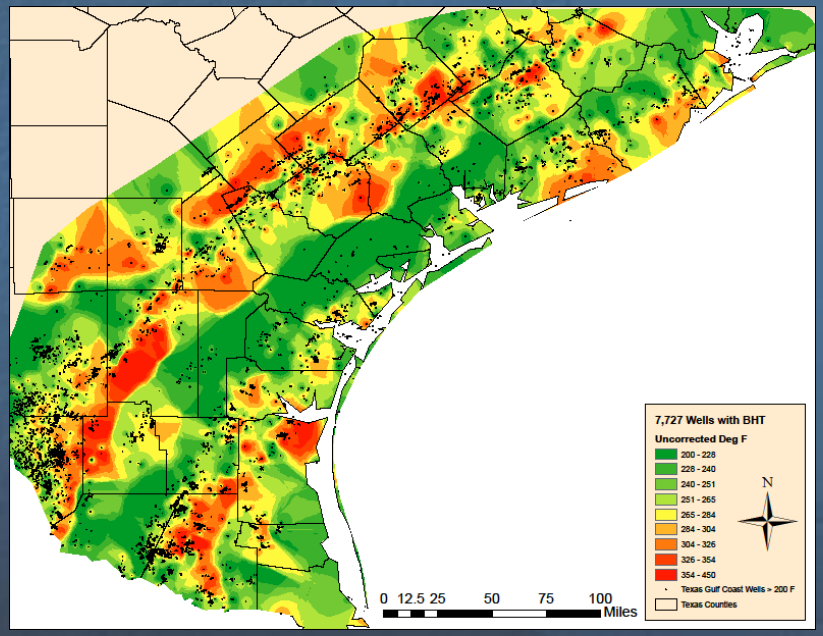


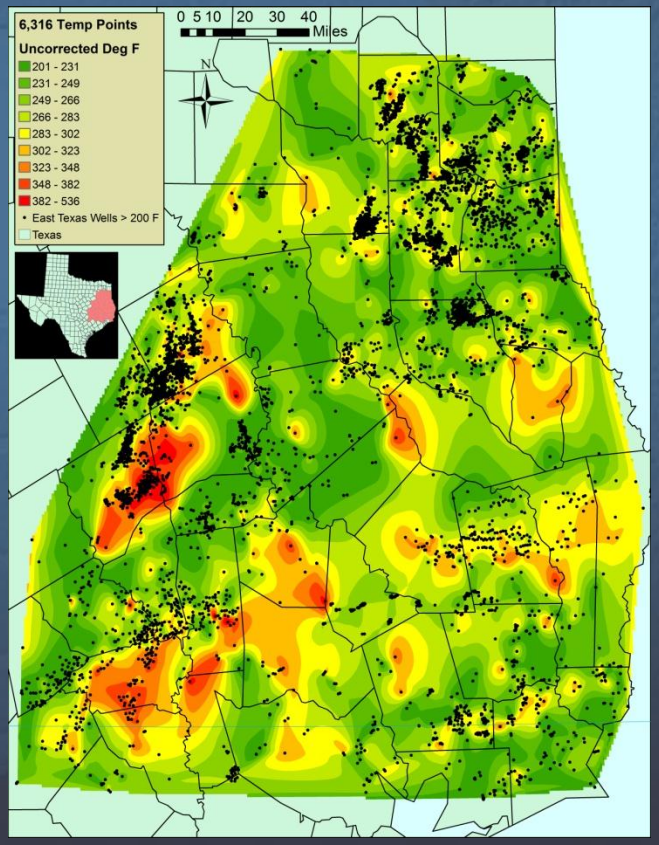
- 1.2 to 1.5 Million well records in the State
- 380,000 records with some electronically accessible information
- 17,200 wells (to date) with Bottom hole temperatures greater than 200 ^{0}F



Geothermal Energy Research Contribution to NGDS

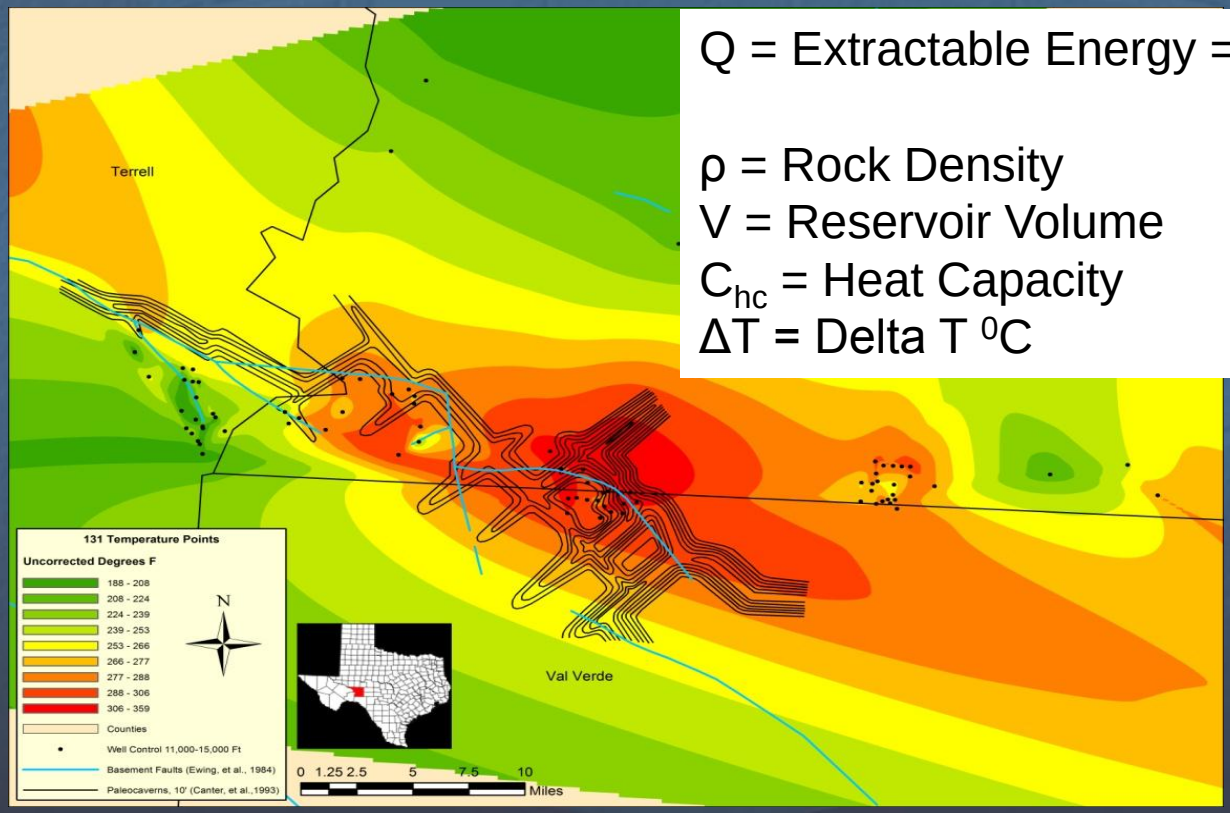
- Identification of areas promising for geothermal energy development





Geothermal Energy Research Contribution to Resource Magnitude Estimate

- West Texas, Example



Q = Extractable Energy = $\rho V C_{hc} \Delta T$

ρ = Rock Density
V = Reservoir Volume
C_{hc} = Heat Capacity
ΔT = Delta T ^0C

Geothermal Energy Research Contribution to Resource Magnitude Estimate

- Stored and Extractable Energy Calculations

Stored Energy in Crockett County Geothermal Area					
150	250	350	150	250	350
BTUs Rock			BTUs Water		
2.25E+15	3.75E+15	5.25E+15	5.29E+15	8.82E+15	1.23E+16
3.77E+14	6.29E+14	8.80E+14	8.86E+14	1.48E+15	2.07E+15
5.02E+14	8.36E+14	1.17E+15	1.18E+15	1.96E+15	2.75E+15
3.36E+14	5.59E+14	7.83E+14	7.89E+14	1.31E+15	1.84E+15
1.46E+14	2.43E+14	3.41E+14	3.43E+14	5.71E+14	8.00E+14
Joules			Joules		
1.32E+19	2.20E+19	3.08E+19	5.58E+18	9.30E+18	1.30E+19
2.33E+18	3.89E+18	5.44E+18	9.87E+17	1.64E+18	2.30E+18
3.07E+18	5.12E+18	7.17E+18	1.30E+18	2.17E+18	3.03E+18
2.02E+18	3.37E+18	4.72E+18	8.56E+17	1.43E+18	2.00E+18
7.39E+17	1.23E+18	1.72E+18	3.13E+17	5.21E+17	7.29E+17

Geothermal Energy Research Contribution to Resource Magnitude Estimate

- Conversion to Kilowatt Hours and Calculated Value at $0.07 Per KWhr.
- Conservatively, this one area may produce $700 million to $1.5 billion per year for 30 years.

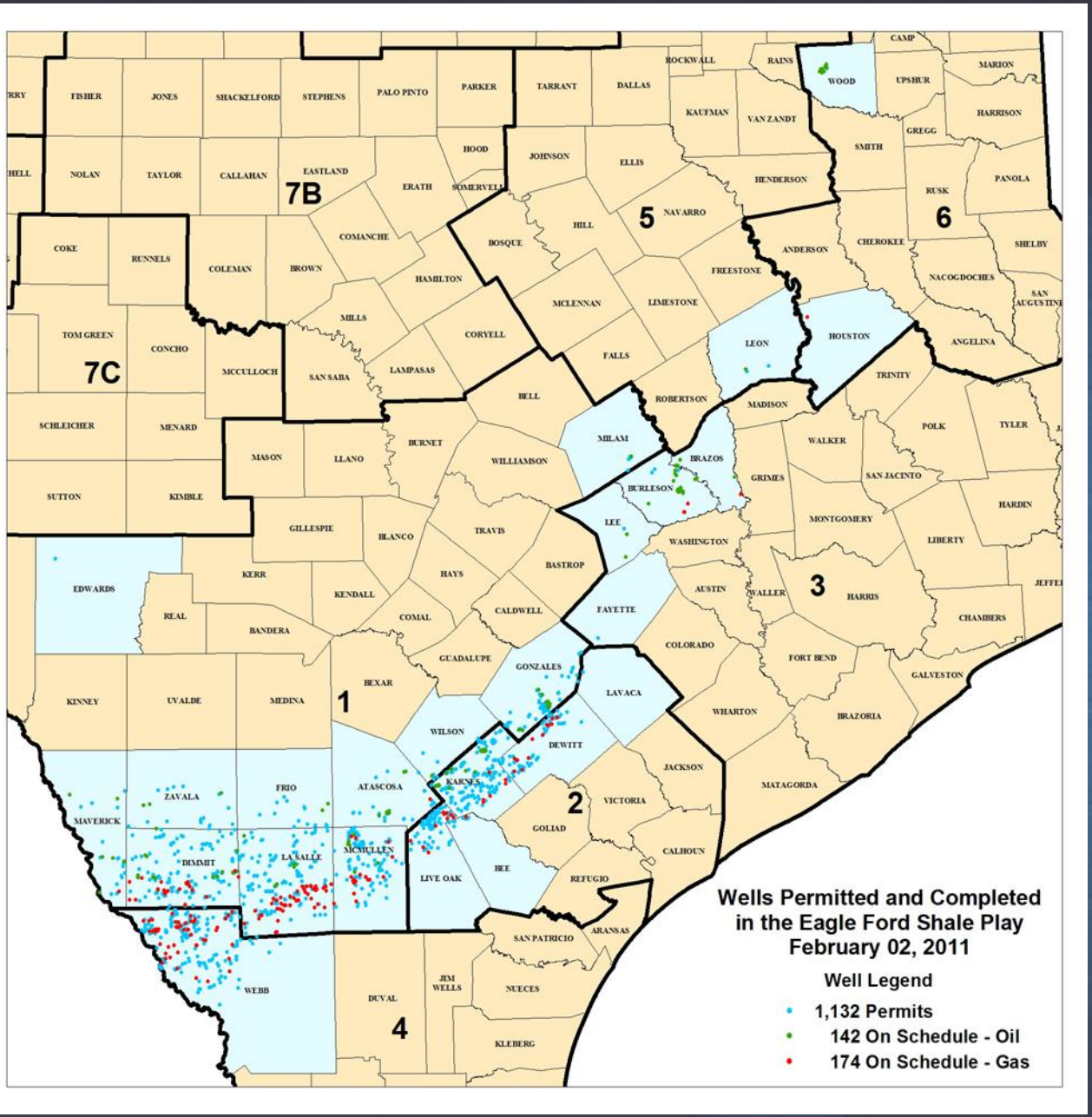
Value at average sale price of			$0.07 per Kilowatt Hour		
Rock Formation Thickness			Contained Heated Water or Brine		
150	250	350	150	250	350
$46,193,123,036	$76,988,538,393	$107,783,953,750	$108,528,712,082	$180,881,186,804	$253,233,661,525
$7,739,914,393	$12,899,857,322	$18,059,800,251	$18,184,588,647	$30,307,647,744	$42,430,706,842
$10,289,090,442	$17,148,484,070	$24,007,877,698	$24,173,765,721	$40,289,609,535	$56,405,453,349
$6,886,197,045	$11,476,995,075	$16,067,793,105	$16,178,817,264	$26,964,695,440	$37,750,573,616
$2,993,998,715	$4,989,997,859	$6,985,997,002	$7,034,268,376	$11,723,780,626	$16,413,292,877
Totals					
$74,102,323,632	$123,503,872,719	$172,905,421,807	$174,100,152,090	$290,166,920,149	$406,233,688,209
Totals Reduced by Conversion Efficiency (.08)					
$5,928,185,891	$9,880,309,818	$13,832,433,745	$13,928,012,167	$23,213,353,612	$32,498,695,057
Totals Reduced by on line Availability (.90)					
$5,631,776,596	$9,386,294,327	$13,140,812,057	$13,231,611,559	$22,052,685,931	$30,873,760,304
Annual Value Distributed over a 30 Year Productive Period and Combining Rock and Fluid Energy Production					
$628,779,605	**$1,047,966,009**	**$1,467,152,412**			

- In our efforts to estimate the magnitude of the resource, we may have neglected a viable area that is now being developed by the petroleum industry and specifically by the hydrofracturing process of developing tight gas formations.

- Productive, low permeability formations are located in areas not generally considered promising for geothermal energy, with the exception of the Mancos, Piceance and Uinta Basins in Utah and Colorado.

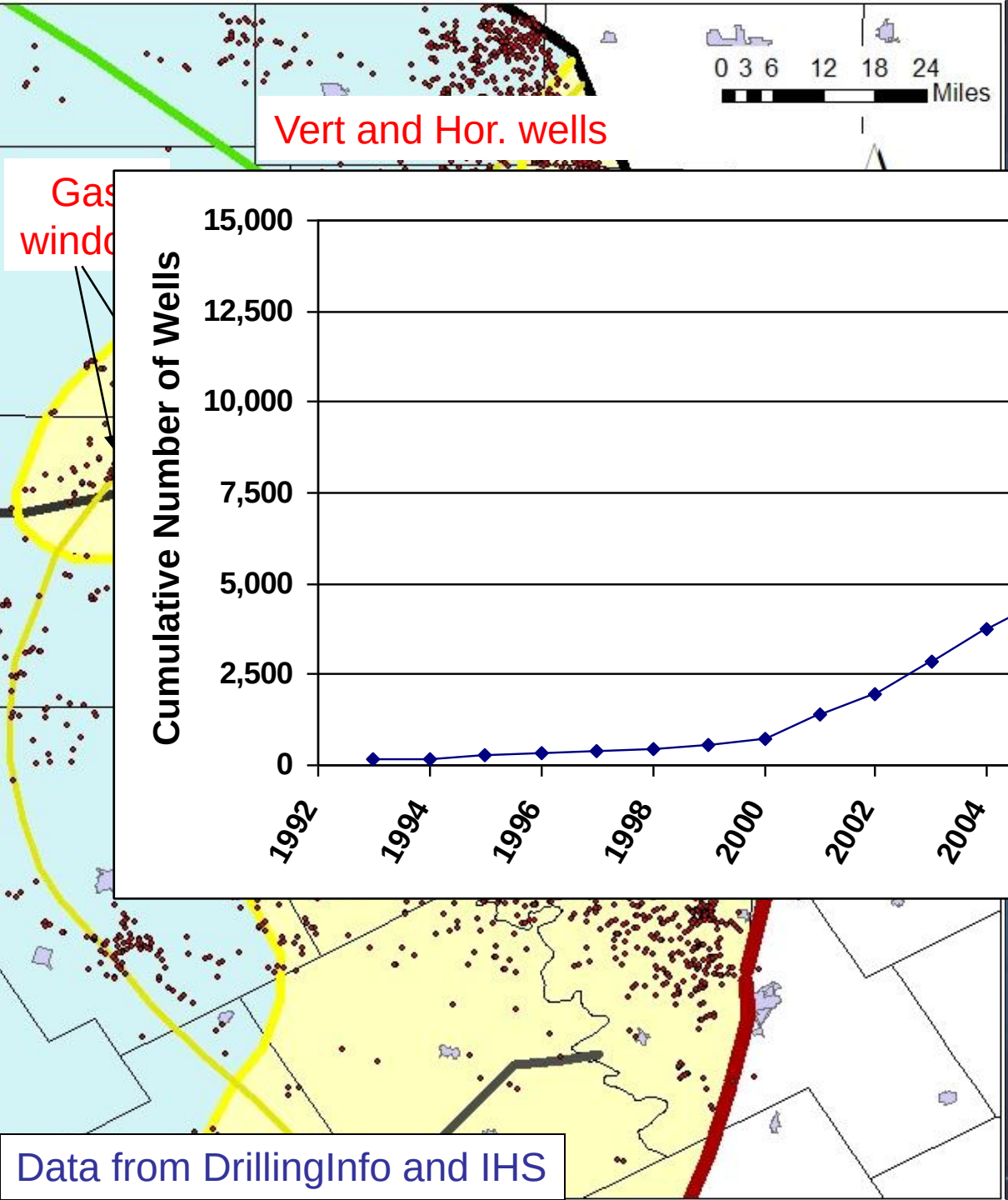
Shale gas plays, lower 48 states

Source: Energy Information Administration based on data from various published studies. Updated March 2010.



In Texas, our focus has been on the Barnett, Haynesville and Eagle Ford Shales

Source: Texas RRC, 2011

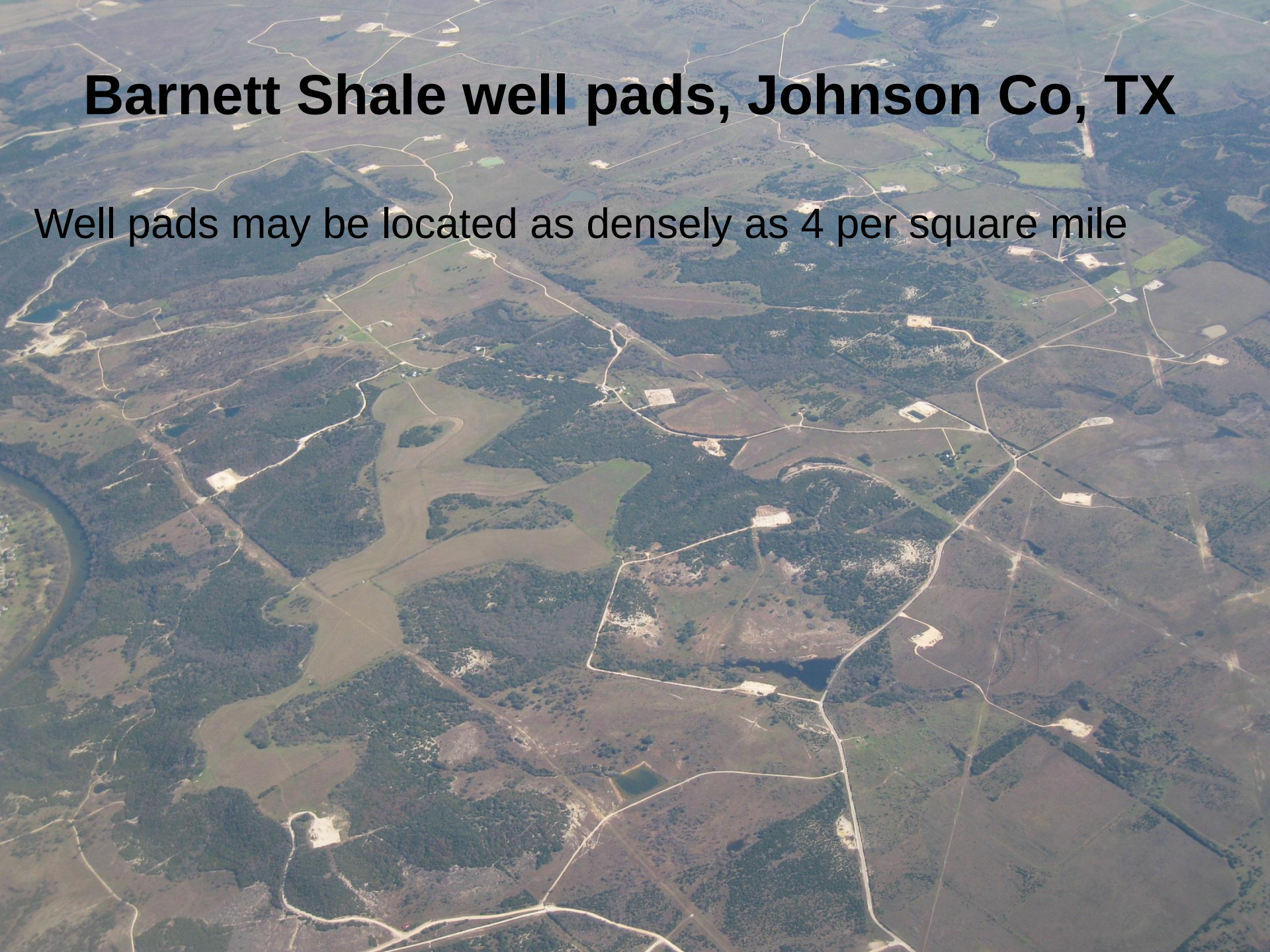


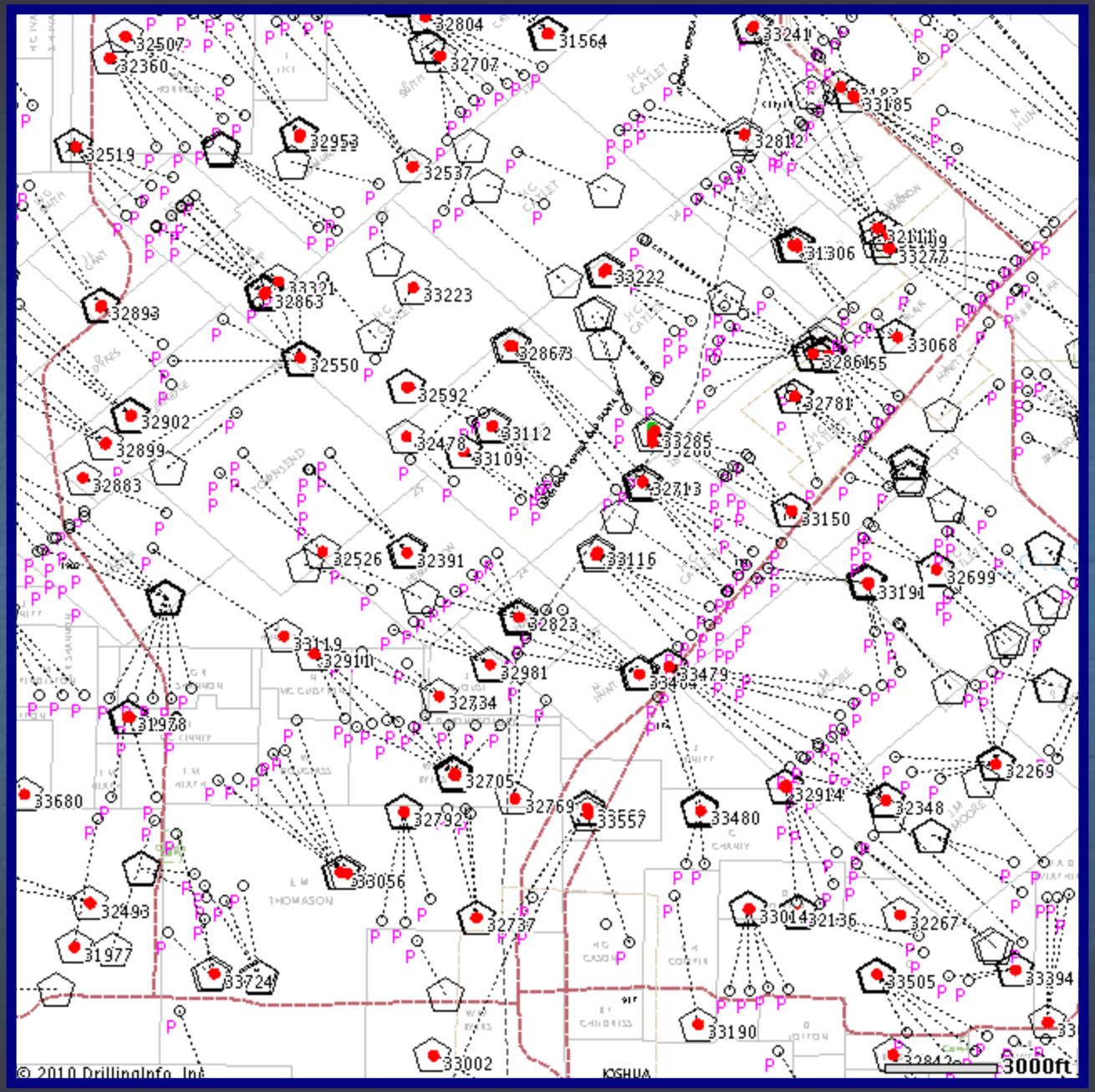
≤ 1997
≤ 1998
9
0
1
02
3
4
5
≤ 2006
≤ 2008
≤ 2010

Data from DrillingInfo and IHS

Barnett Shale well pads, Johnson Co, TX

Well pads may be located as densely as 4 per square mile

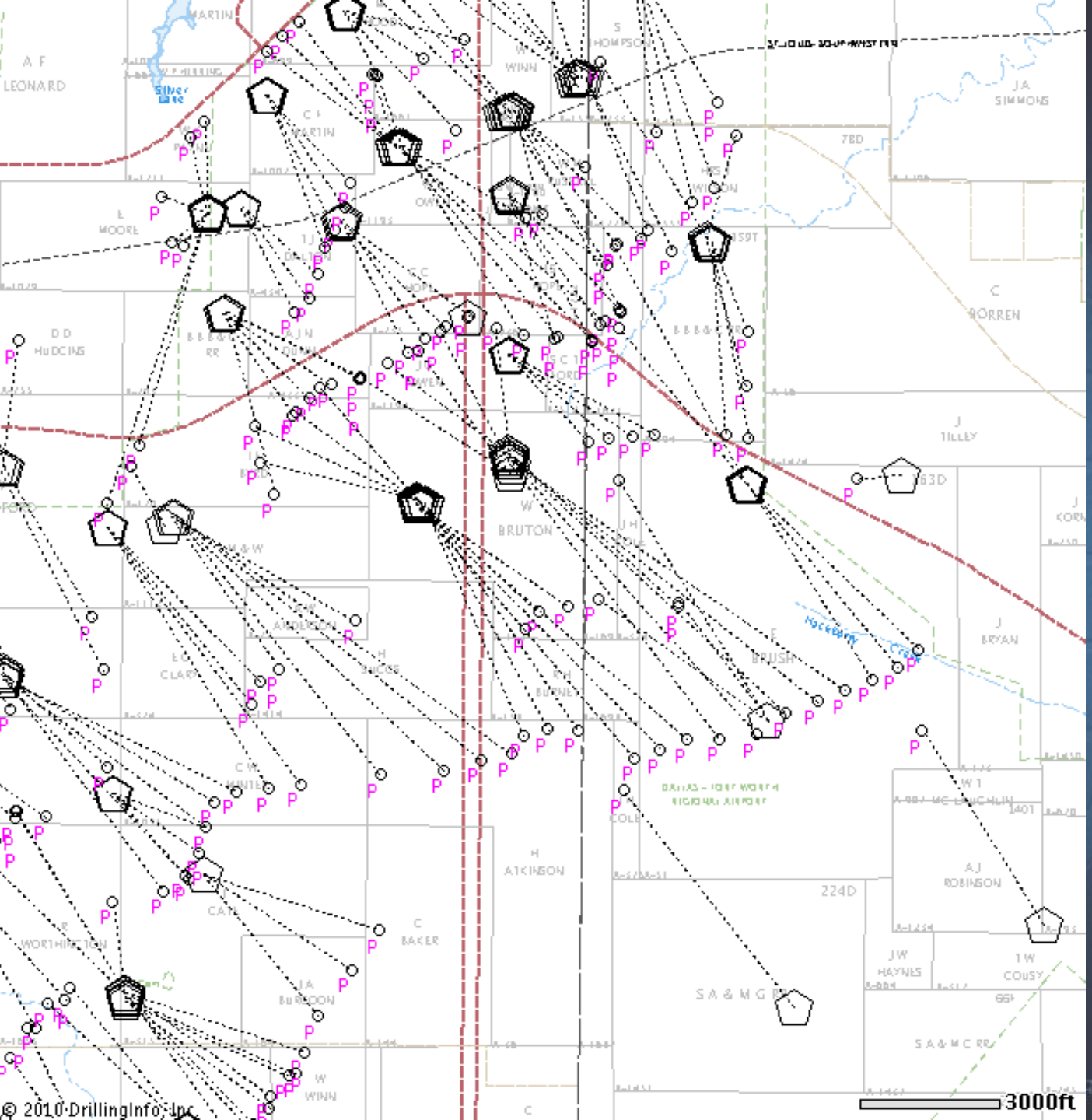




Horizontal wells
in Barnett Shale Play,
Johnson County, TX
April 2010

156 horizontal wells
in this view.

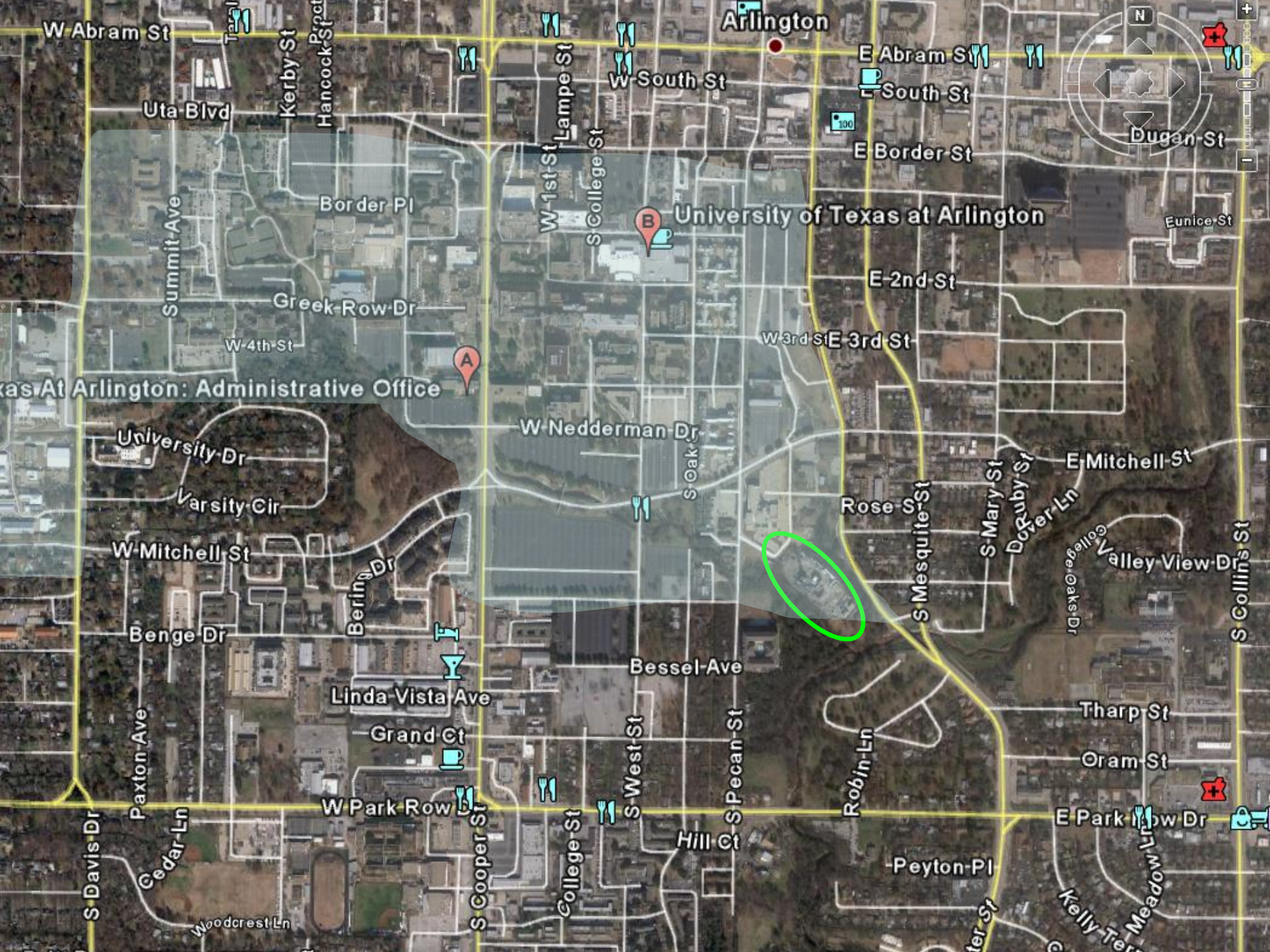
1 mile

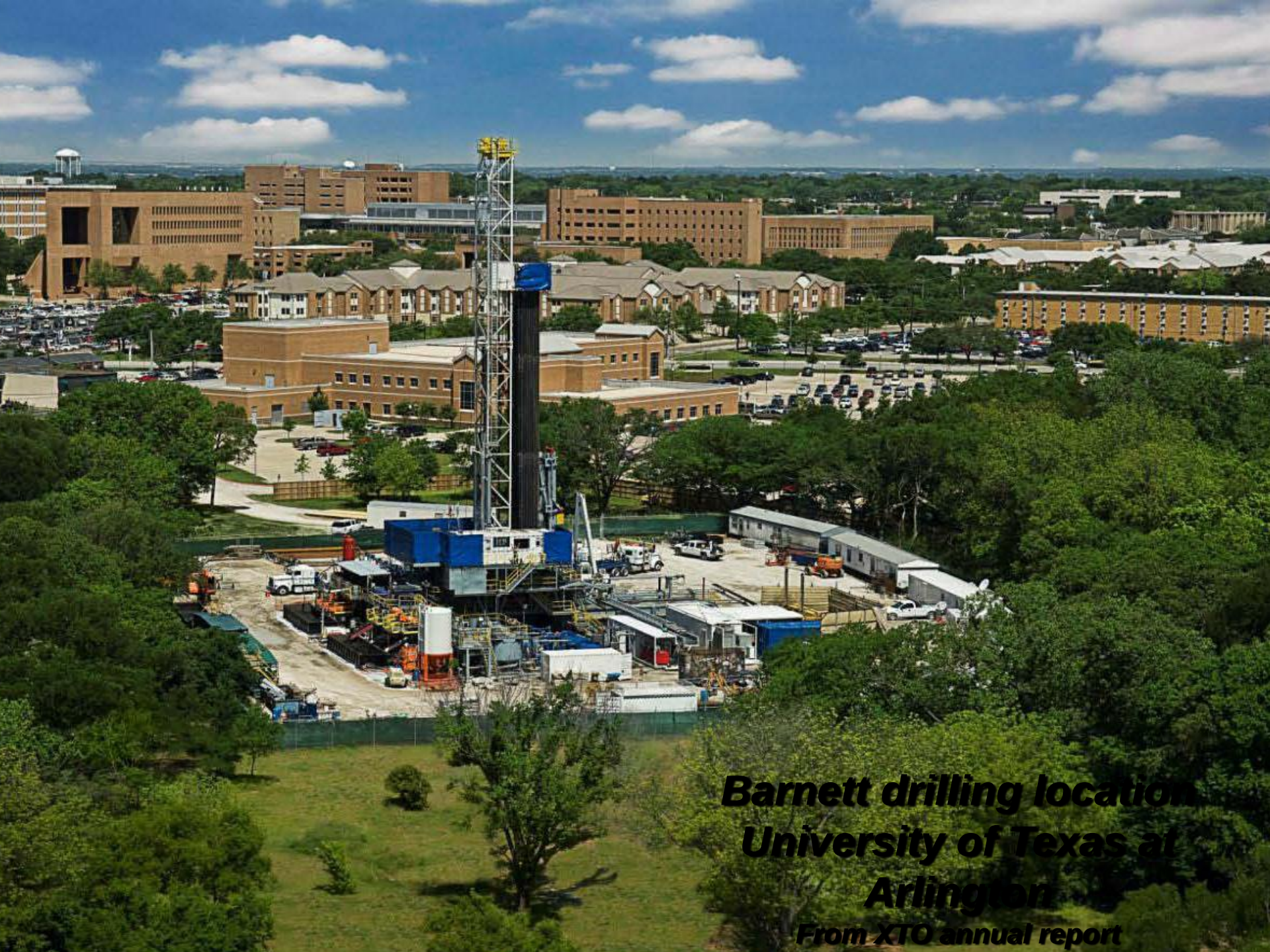


- Source Courtesy of DrillingInfo
- Example of Barnett Shale density of laterals (Dallas-Tarrant county line –DFW airport)

Multiple wells from a single surface pad

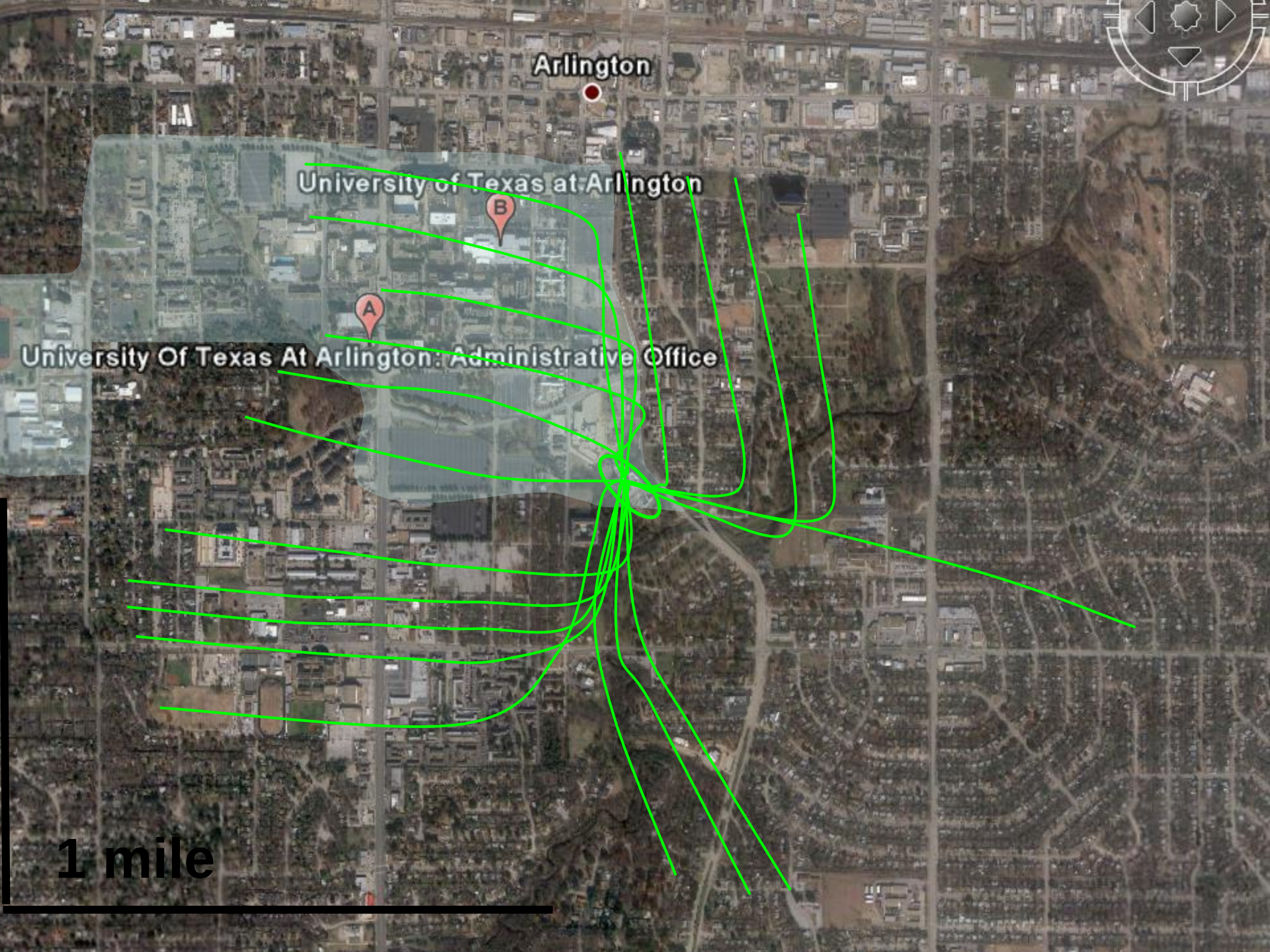
Wellheads for 2 previously drilled wells, not frac'd yet

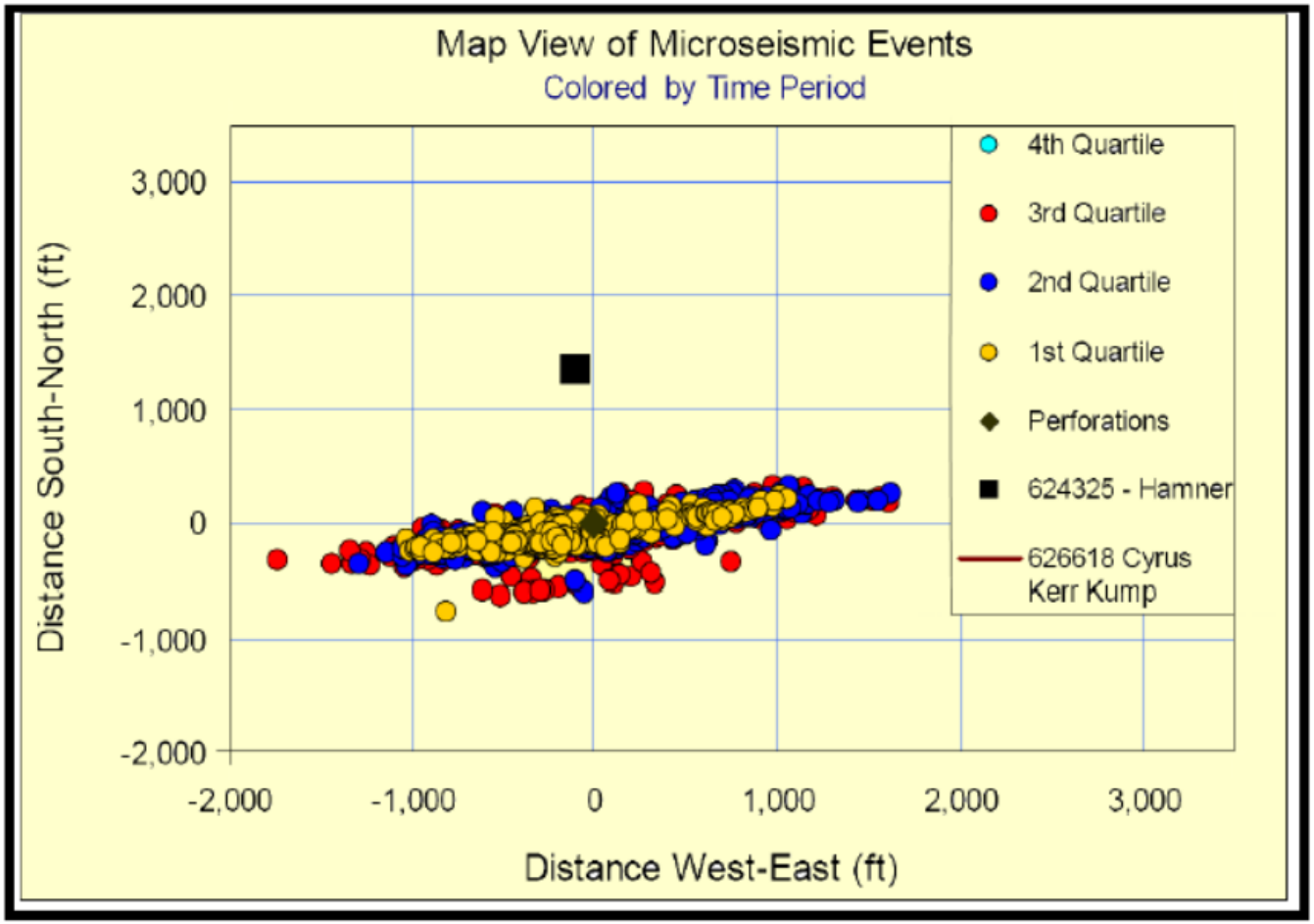

W Abram St
Arlington
E Abram St
W South St
E South St
Uta Blvd
Kerby St
Hancock St
Lampe St
S College St
W 1st St
E Border St
Dugan St
Border Pl
Summit Ave
University of Texas at Arlington
Eunice St
E 2nd St
Greek Row Dr
W 4th St
W 3rd St
E 3rd St
A
B
Arlington: Administrative Office
W Nedderman Dr
University Dr
Varsity Cir
S Oak St
E Mitchell St
Rose St
S Mesquite St
S Mary St
Dover Ln
College Oaks Dr
Valley View Dr
S Collins St
W Mitchell St
Bering Dr
Benge Dr
Bessel Ave
Linda Vista Ave
Grand Ct
Tharp St
Oram St
Paxton Ave
S West St
S Pecan St
Robin Ln
W Park Row Dr
E Park Row Dr
S Davis Dr
Cedar Ln
S Cooper St
College St
Hill Ct
Peyton Pl
Woodcrest Ln
Kelly Ter
Meadow Ln



Barnett drilling location University of Texas at Arlington

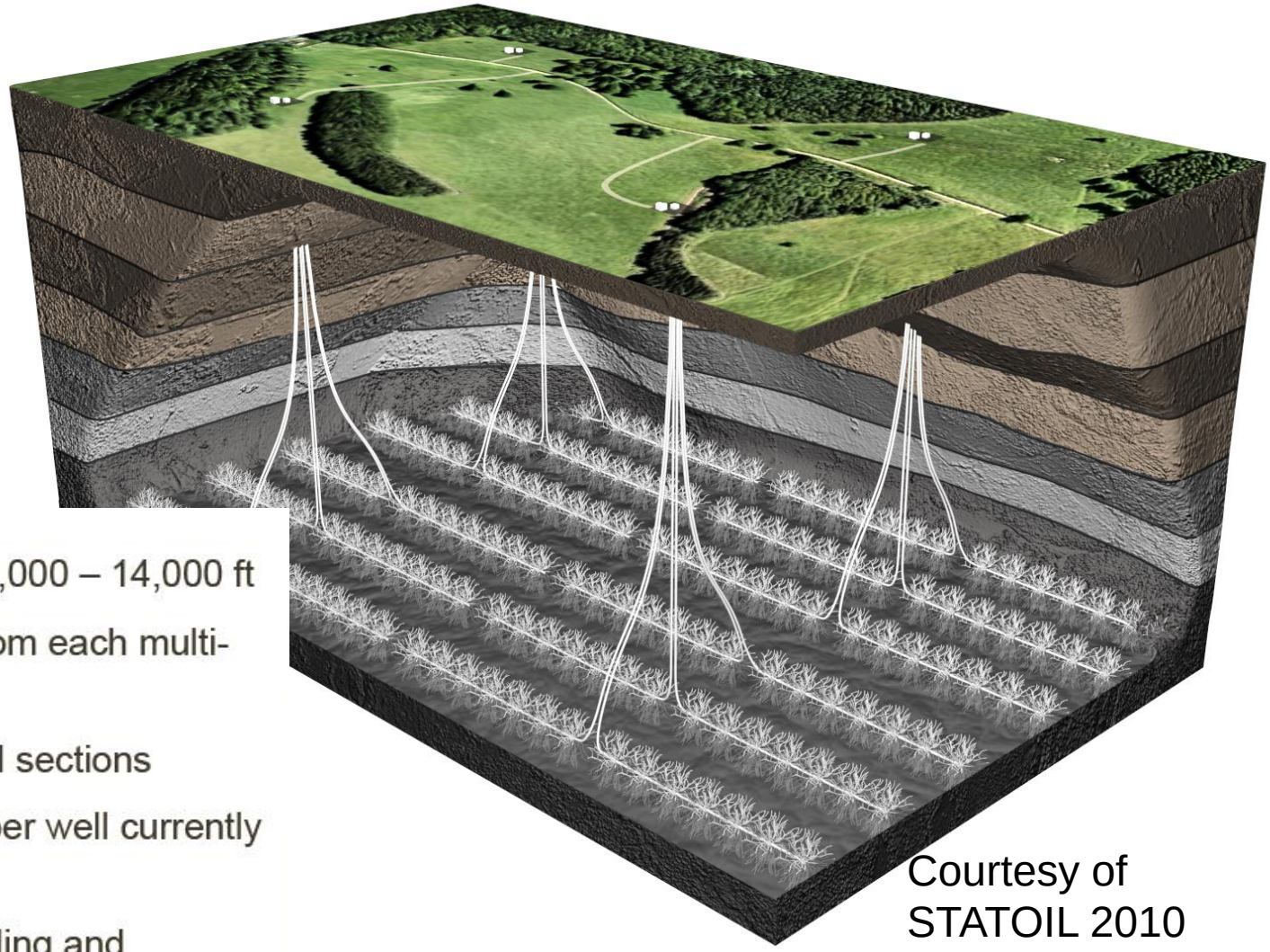
From XTO annual report


Arlington
University of Texas at Arlington
B
A
University Of Texas At Arlington: Administrative Office
1 mile



Source: Oilfield Service Company, 2008

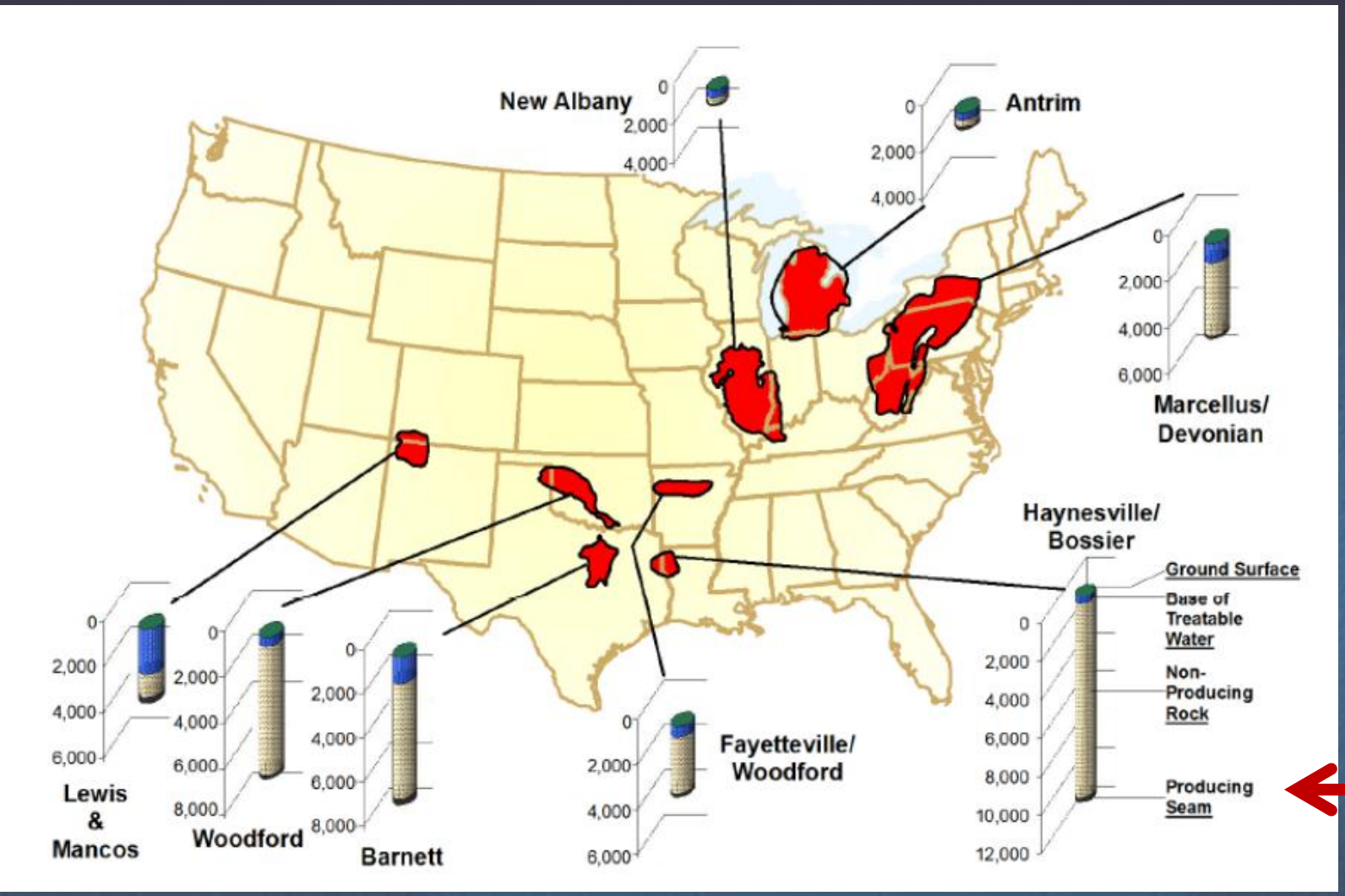
Fracture orientation is controlled by in-situ stress field and formation fractures, joints and layering.



Courtesy of STATOIL 2010

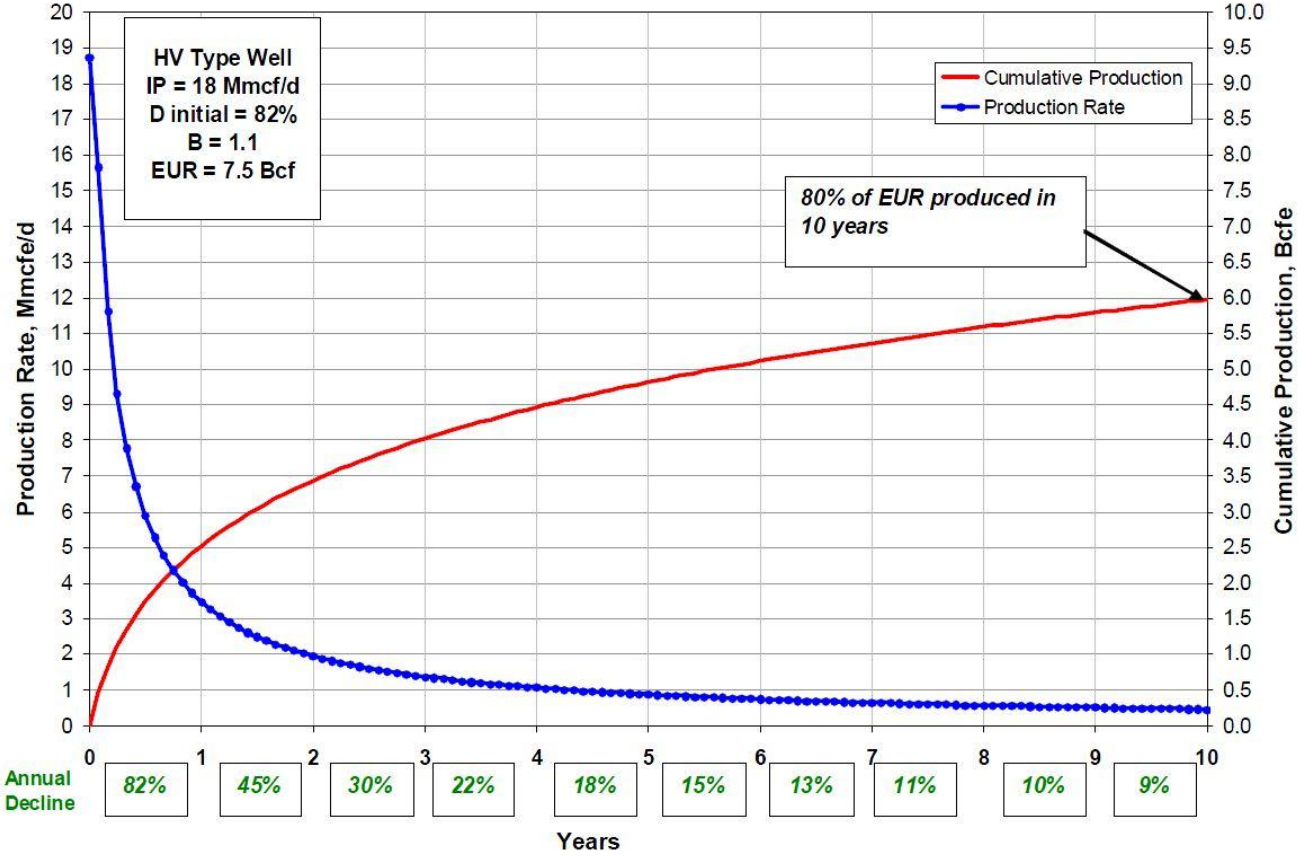
- Reservoir located at 9,000 – 14,000 ft
- 4-8 horizontal wells from each multi-well pad
- 3,000 – 5,500 ft lateral sections
- Average drilling time per well currently 40 days
- Utilising horizontal drilling and hydraulic fracturing technology
- Decline from initial production rate but long tail production
- 55,000 acres of Enduring land already held by production (100%)

Producing from the Eagle Ford



Gas production from the Haynesville/Bossier is from depths where formation temperatures are well above 250 ^{0}F

Current Haynesville Shale Type Curve

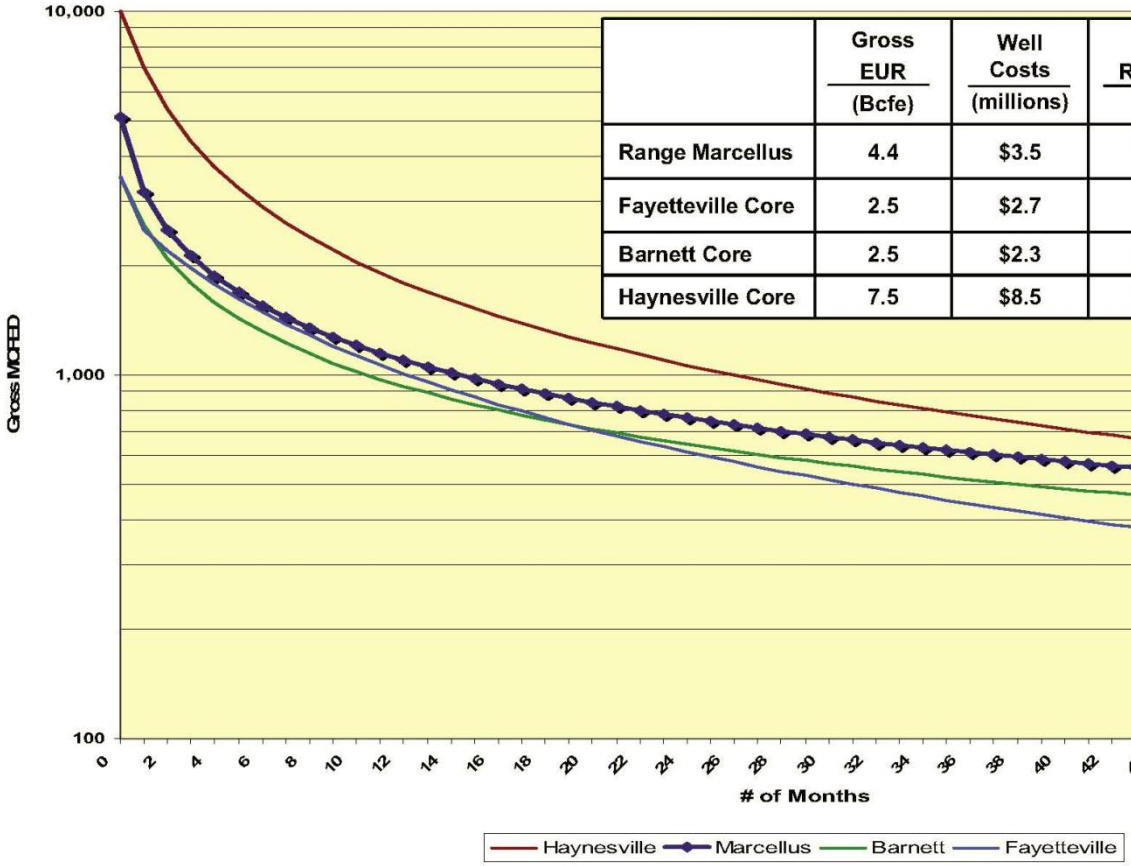


*Petrohawk's estimated type curve for wells produced typically on a 24/64" choke

13

There is a serious problem, however, with production from the fractured shale reservoirs.

Shale Play Comparison

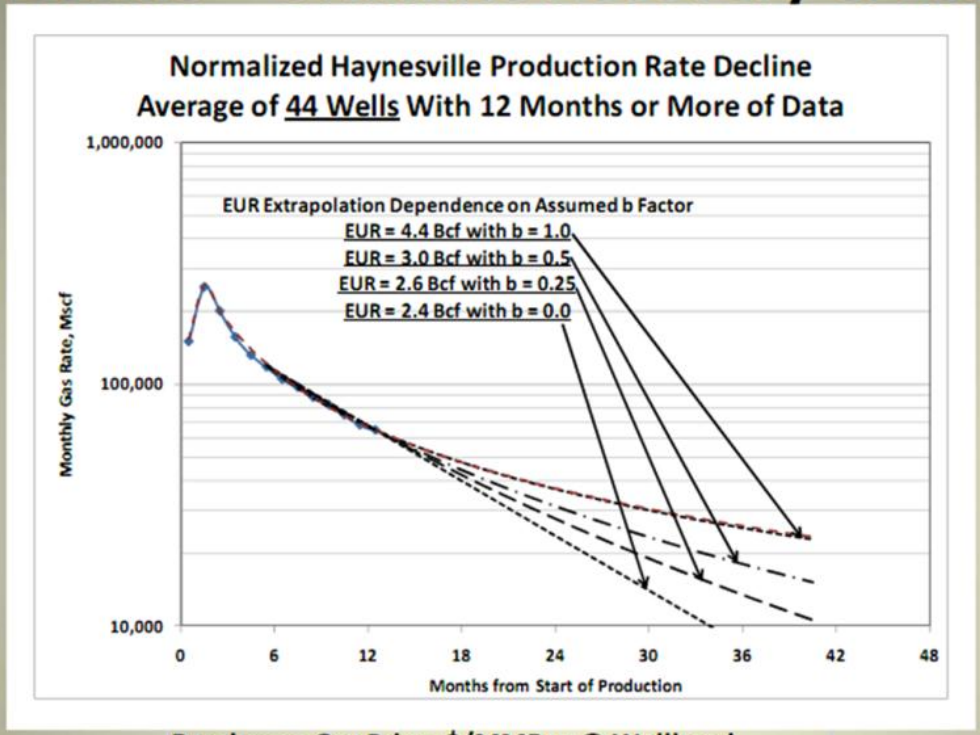


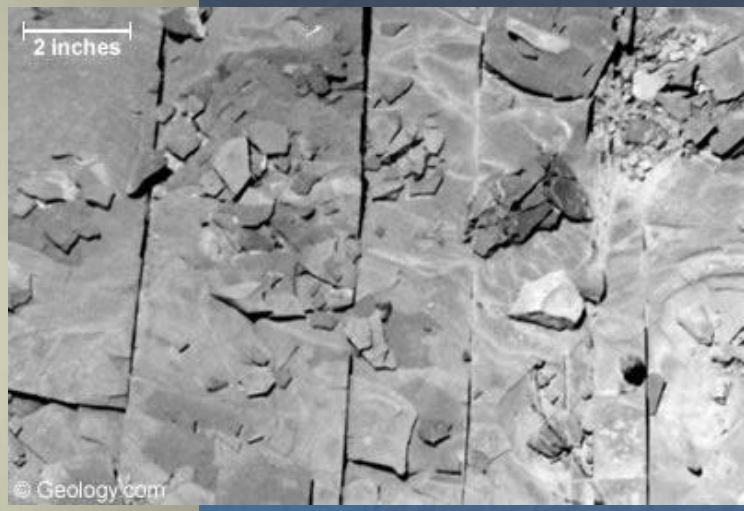
	Gross EUR (Bcfe)	Well Costs (millions)	Royalty	F&D Cost (per mcfe)	ROR ($6 NYMEX)
Range Marcellus	4.4	$3.5	15%	$0.95	64%
Fayetteville Core	2.5	$2.7	16%	$1.29	52%
Barnett Core	2.5	$2.3	25%	$1.22	39%
Haynesville Core	7.5	$8.5	25%	$1.51	36%

- **Type curves for Barnett, Fayetteville and Haynesville based on public production information**
- **Zero time curve for Marcellus based on production results from 24 Range wells only**

Source: Range Resources in "G. MacFarland, Oil & Gas Evaluation Report. March 17, 2010

Haynesville – Ultimate Recovery & Economics





Breakeven Gas Price, $/MMBtu @ Wellhead

(at 10% Discount Rate)

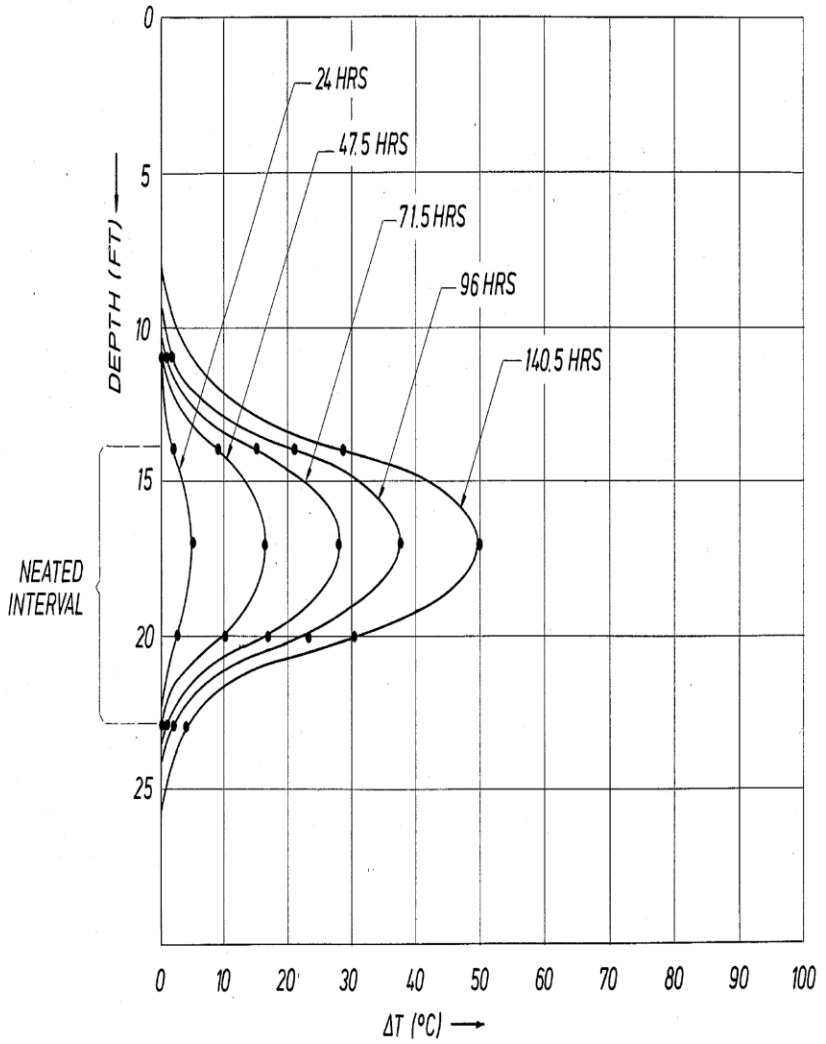
EUR Scenario	EUR/Well, Bcf	Full Cycle
Group Avg, Projected w/ b = 0	2.3	$9.00
Group Avg, Projected w/ b = 0.5	3.0	$7.80
Group Avg, Projected w/ b = 1.0	4.4	$6.70
Operator View, 14 MMsfd IP, b=1.07	6.5	$4.70

$8MM/well, $5,000/acre, 120 acre/well, ½ of land leased is fully developed

The Transformation of Tight Shale Gas Reservoirs to Geothermal Energy Production

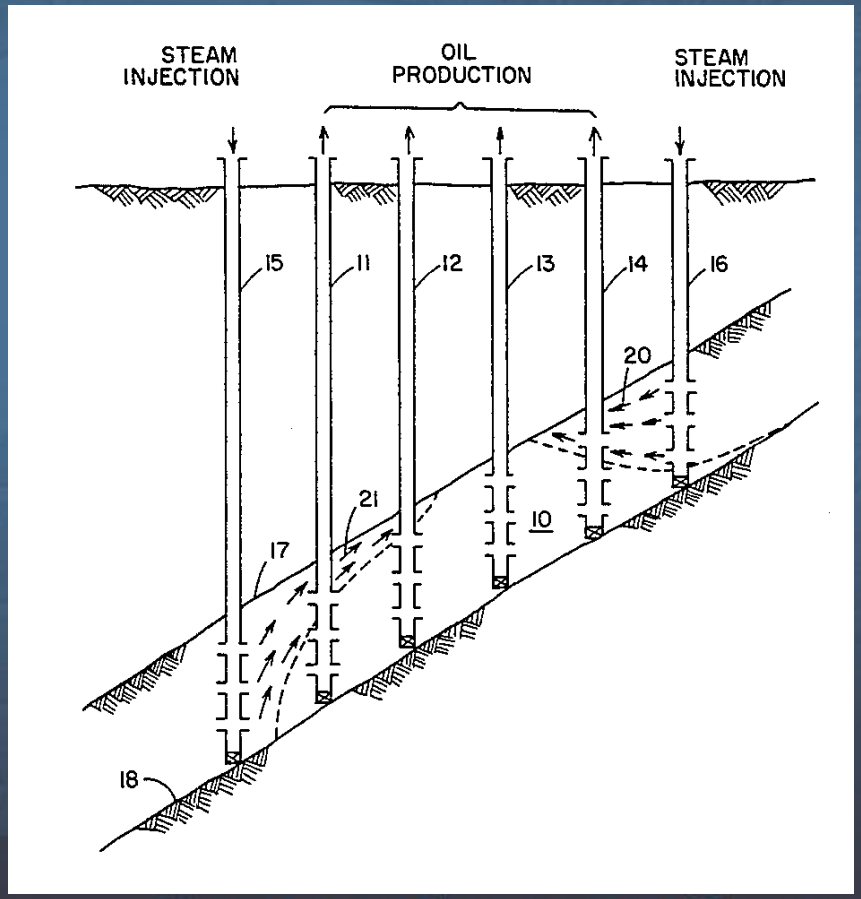
- So, how do we assess the significance of this potential geothermal resource?
  - Early work in extracting oil from oil shales in the 1970s and 1980s provided good information on heat-rock interactions.
  - Reverse this process, and heat extraction can be calculated.

FIG. 3

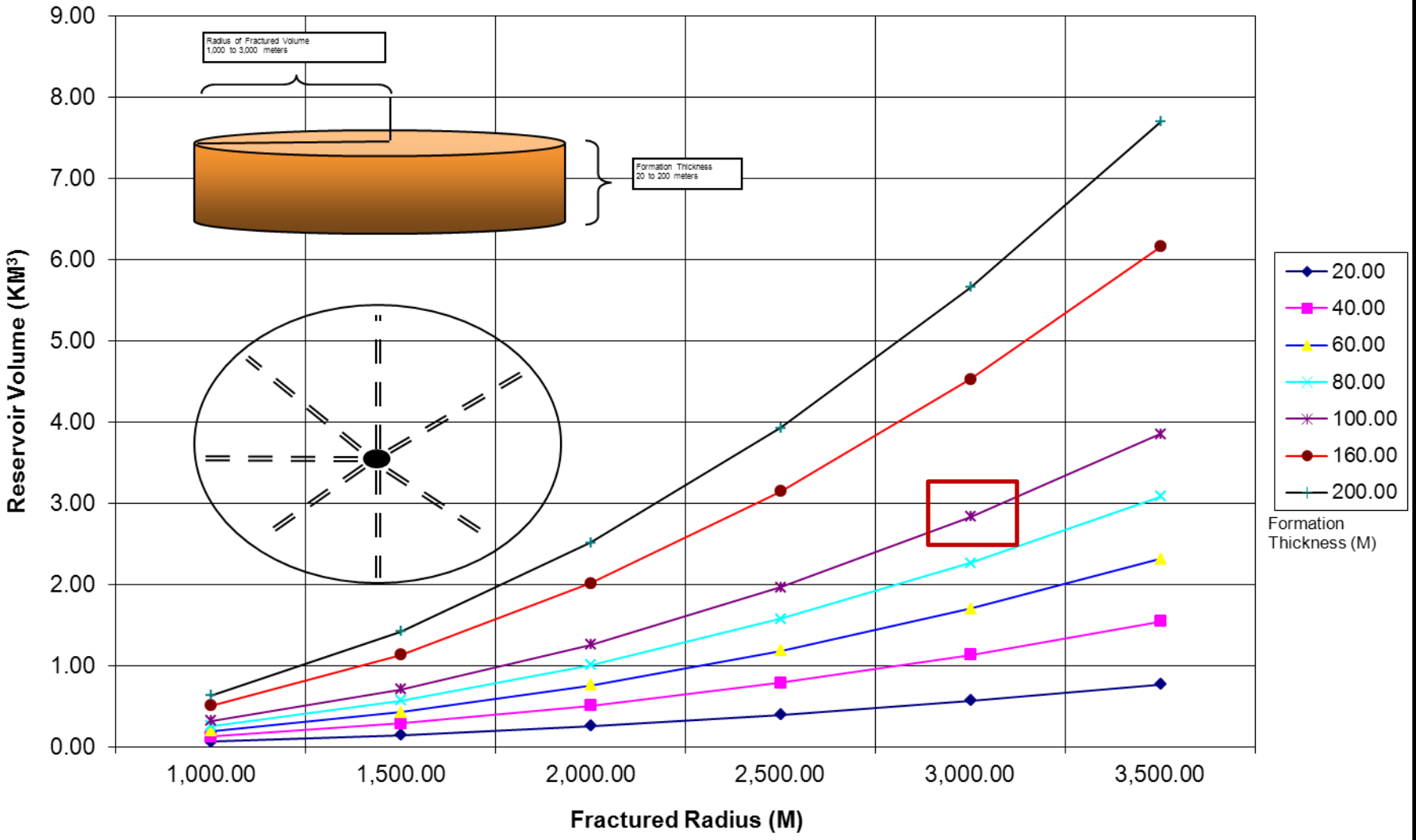


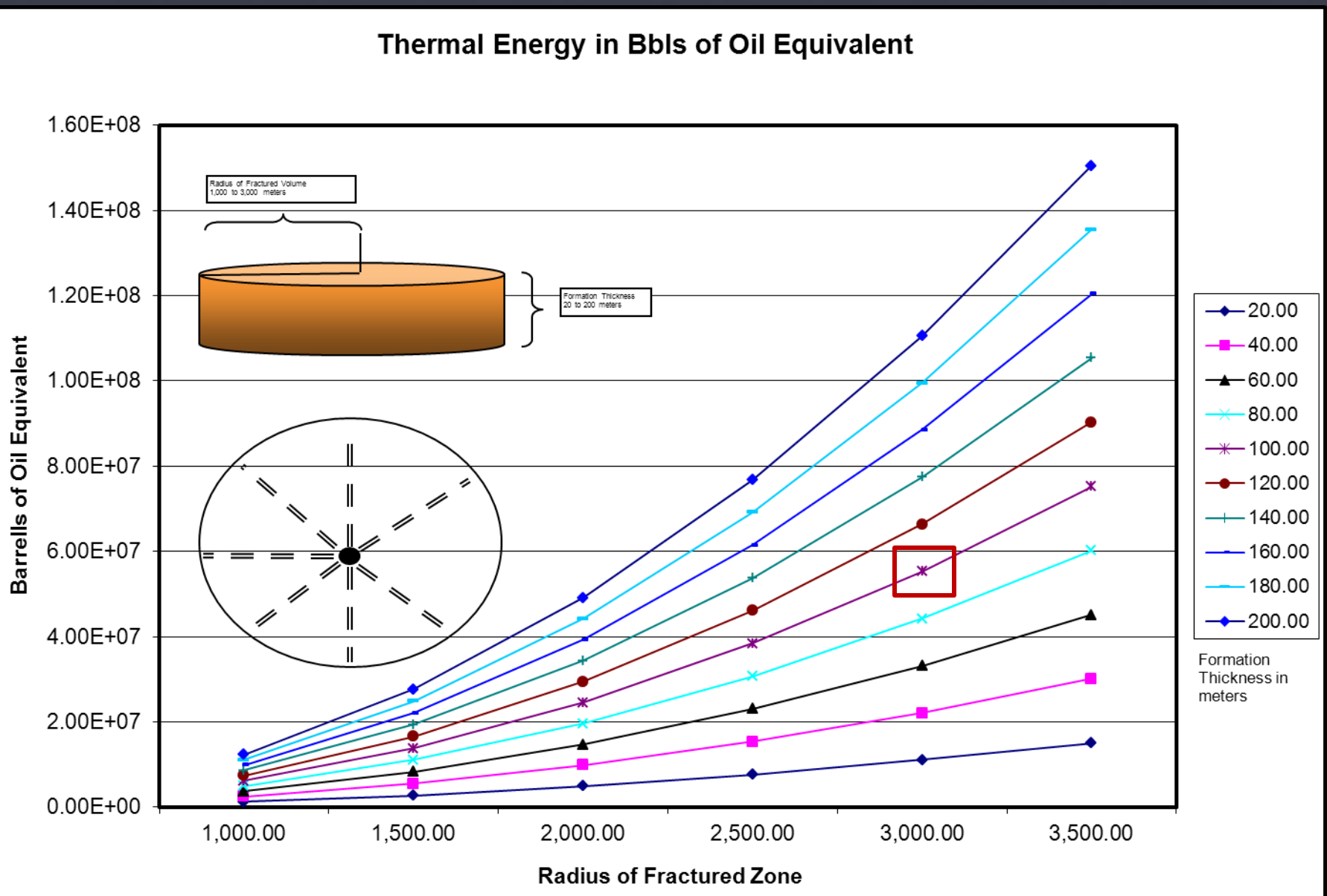
U.S. Patent Dec. 12, 1989 Sheet 3 of 8 4,886,118

Patent Filed Feb 17th 1988, held by Shell Oil Company.

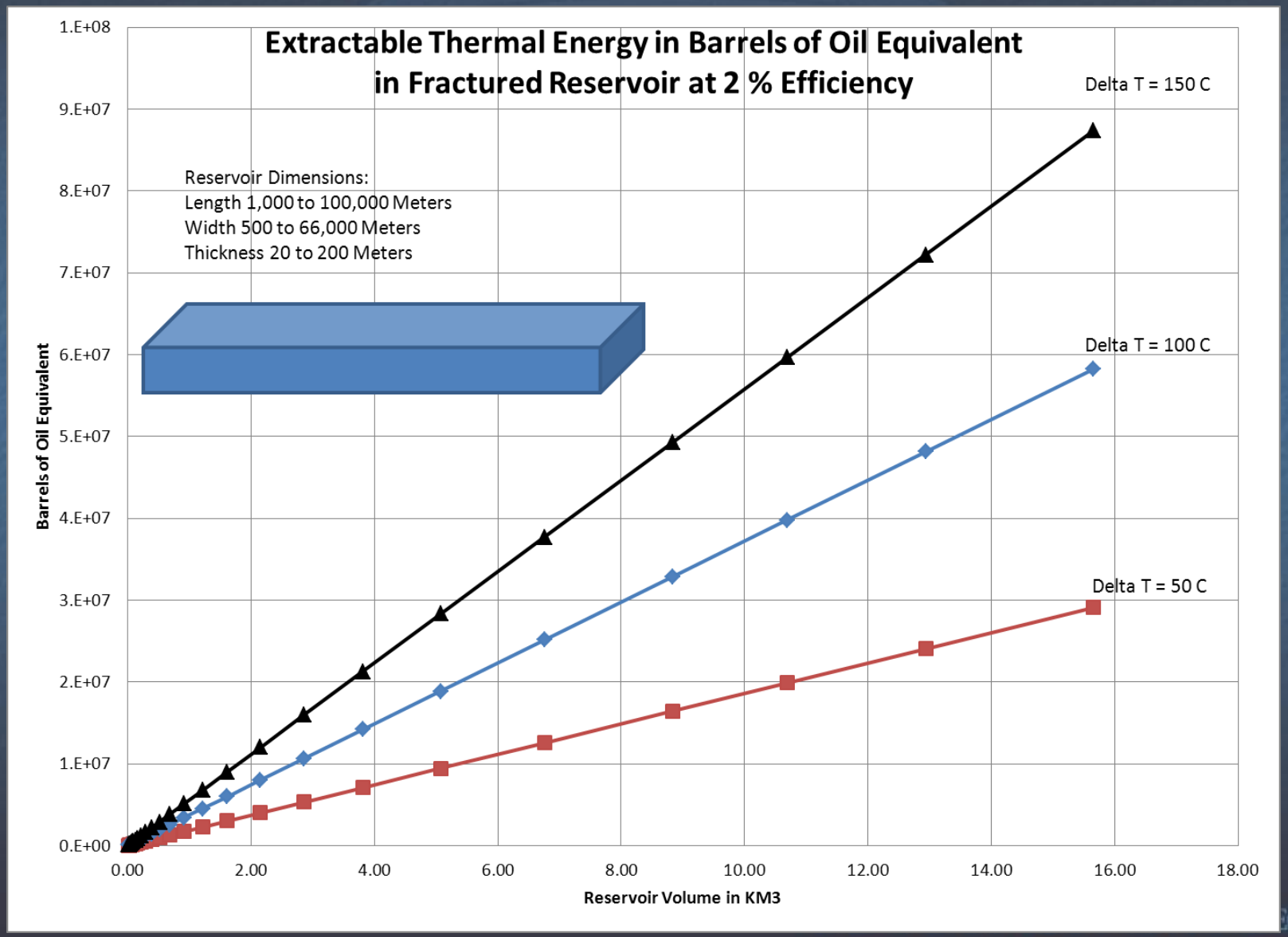


Fractured Reservoir Volume Created by Hydrofracturing Tight Shales



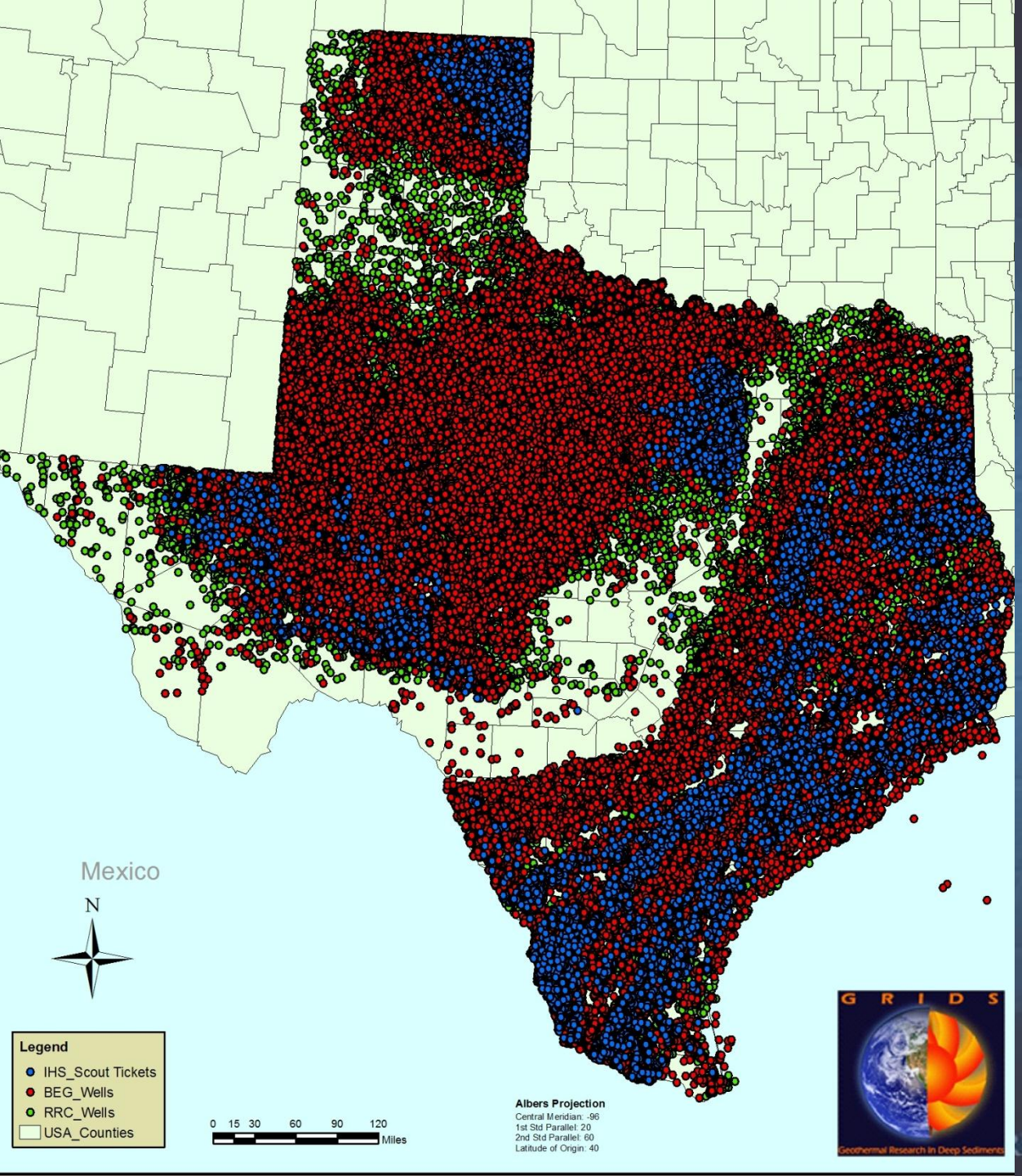

Thermal Energy in Bbls of Oil Equivalent
Barrells of Oil Equivalent
1.60E+08
1.40E+08
1.20E+08
1.00E+08
8.00E+07
6.00E+07
4.00E+07
2.00E+07
0.00E+00
1,000.00
1,500.00
2,000.00
2,500.00
3,000.00
3,500.00
Radius of Fractured Zone
Radius of Fractured Volume
1,000 to 3,000 meters
Formation Thickness
20 to 200 meters
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
Formation Thickness in meters

The Transformation of Tight Shale Gas Reservoirs to Geothermal Energy Production



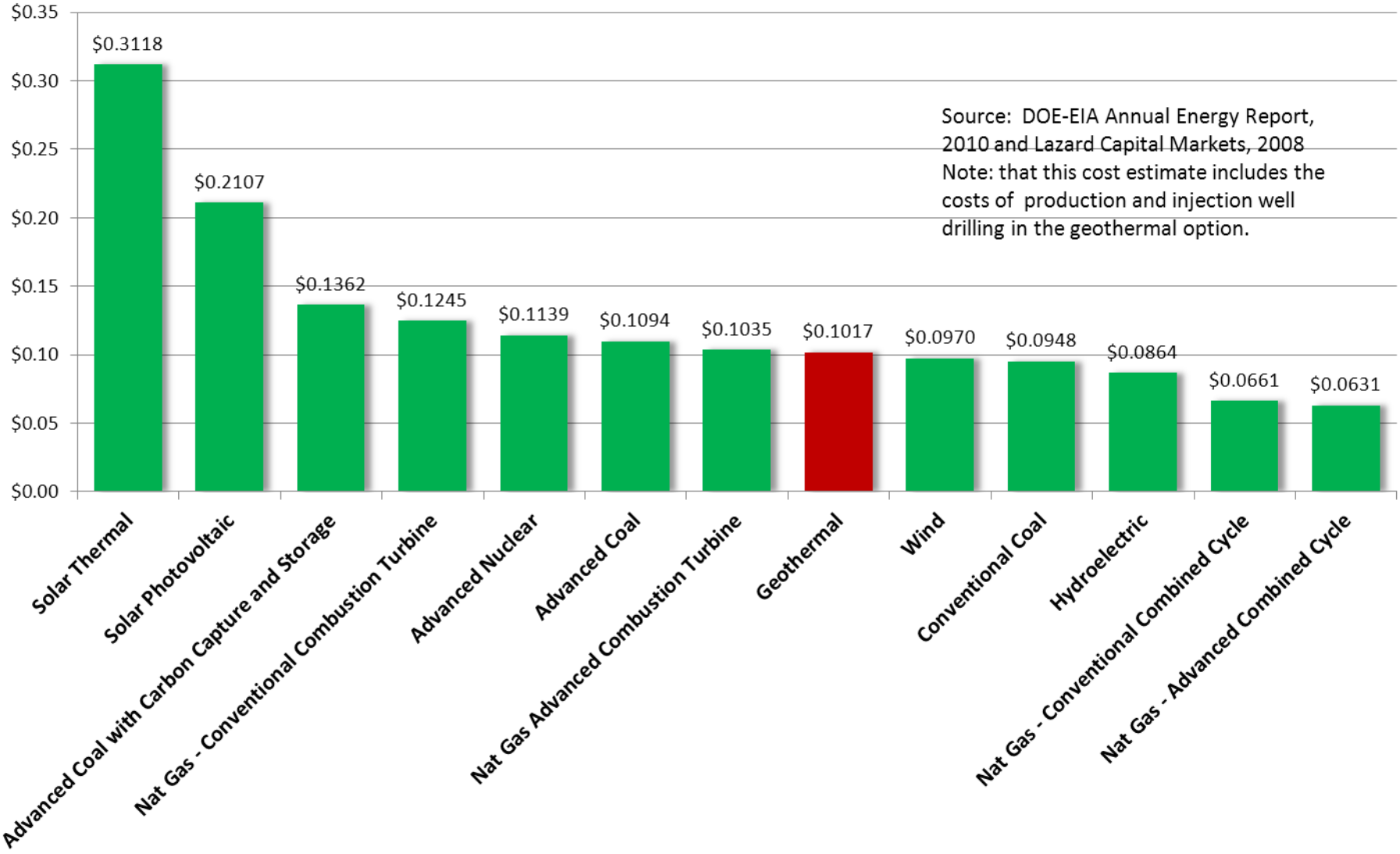
The Transformation of Tight Shale Gas Reservoirs to Geothermal Energy Production

- The Haynesville has a basin area of 9,000 square miles
- Average depth is between 10,500 and 13,500
- Average thickness is 250 feet, feet
- With bottom hole temperatures above 250 ^{0}F
- The potentially extractable thermal energy in this formation alone is 0.33 quadrillion BTUs, or approximately 1/3 of the annual world energy consumption.



With forethought and planning, existing gas production wells can transition to geothermal energy production wells, saving an initial investment of $5 million to $9 million dollars, and providing a sustainable energy resource for at least 30 years into the future.

Comparison of Total System Levelized Cost for Various Methods of Electricity Generation ($/KWhr)



Thank you
Bruce L. Cutright