Bakken Crude Oil Resource of the Williston Basin

Technology ◄=► Geology

By David J. Bardin

"***This Administration continues to seek out and develop new energy options to support our growing economy.***"

Secretary of Energy Samuel W. Bodman, October 17, 2005
"Energy Department Adds Projects to Boost Domestic Oil and Gas Production – Goal is to Boost Recovery of Unconventional Resources and Minimize Environmental Impacts"

"***We must expand domestic production of oil and natural gas in environmentally responsible ways.***"

Secretary of Energy Samuel W. Bodman, December 12, 2005
"Statement of Secretary of Energy Regarding EIA's Long-Term Energy Outlook"

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Acknowledgements

Julie LeFever and Tom Richmond have patiently answered many, many questions and generously shared their insights, experience and curiosity. Other experts also have my gratitude and respect for their attention, criticisms, inputs and suggestions, including, at the risk of omission, Emil Atannasi, Livia Bardin, Dale Bumpers, Guy Caruso, Ron Charpentier, Jim Connaughton, David Fischer, Chris Freitas, Gerry Groenwald, Howard Gruenspecht, Jim Halvorson, John Harju, Lynn Helms, Bill Hochheiser, Robert Kane, Jim Kendell, Vello Kuuskraa, Bruce Langhus, Bill Lawson, Ted McCallister, David Morehouse, Ron Ness, Rick Pollastro, Mike Reisz, Jennie Ridgeley, Chris Schenk, Max Singer, Linda Stuntz, John Wood, Rafi Zeinalpour. I bear sole responsibility, of course, for contents, conclusions, and recommendations.

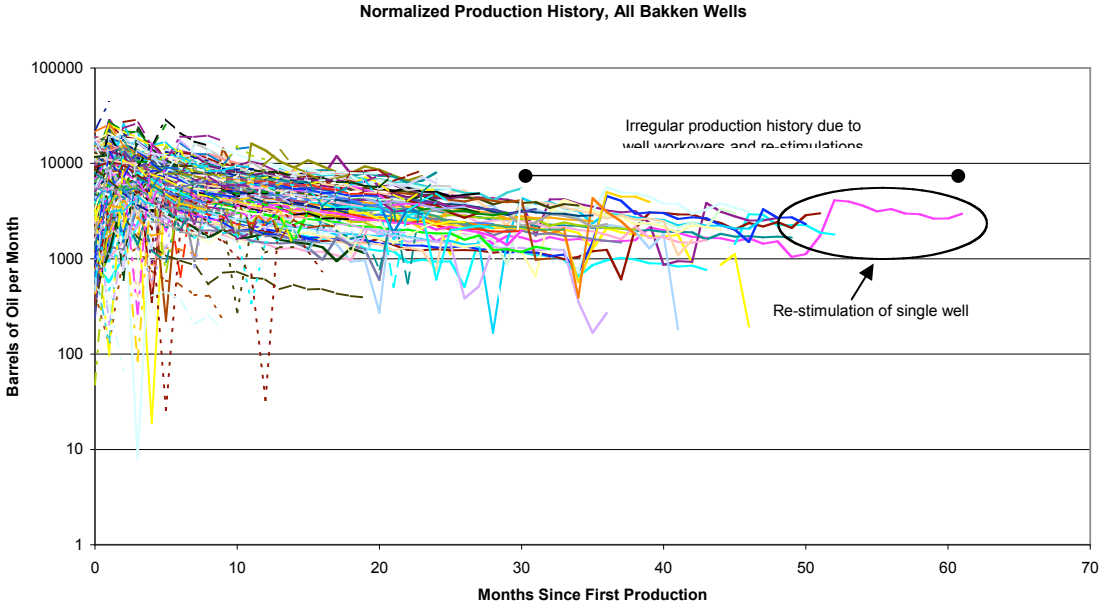
Great teachers, now deceased, piqued my curiosity: Leigh Price, Bruce Netschert, and Julian Simon, Ira Cram and Tommy Gold.

Author Bio

DAVID J. BARDIN is Of Counsel to Arent Fox Kintner Plotkin & Kahn, PLLC (as a retired member) where he specialized in public utilities, energy and environmental law.

Before joining Arent Fox in 1980, Mr. Bardin held Presidential appointments in the Carter Administration as Administrator of the Economic Regulatory Administration in the U.S. Department of Energy (1977-79) and Deputy Administrator of the Federal Energy Administration (1977). He previously held senior federal and state government posts including service in New Jersey Governor Byrne's Cabinet (1974-77) as Commissioner of the Department of Environmental Protection and as a civil servant at the Federal Power Commission (FPC, predecessor to the FERC) under Chairmen Kuykendall, Swidler, White, and Nassikas and General Counsels Gatchell, Spitzer, and Solomon (1958-69), and advised Israel's Attorney General Shamgar and agencies there (1970-77). Since 2001 he has served on the Board of Directors of the D.C. Water and Sewer Authority as an appointee of Mayor Williams. He also serves on the D.C. Building Code Advisory Committee and D.C. Zoning Advisory Committee. Bardin was schooled in New York City, graduating from the Bronx High School of Science (1950), Columbia College (A.B. 1954) and Columbia University Law School (J.D. 1956). He served in the U.S. Army Transportation Research and Engineering Command, Fort Eustis, Virginia (1956-58).

Fig. 1 Monthly Decline Curves for 225 New MT Bakken Wells Showing Re-stimulation of One Well Mid-2000 to 2005 Completions Normalized to Number of Months Since First Production



Source: Jim Halvorson, Montana Board of Oil & Gas Conservation

David J. Bardin
Washington, DC
18 December 2005

Honorable Samuel W. Bodman
Secretary of Energy
Washington, D.C.

Dear Secretary Bodman:

Important Bakken Formation developments in Montana and North Dakota betoken exceptional opportunities for seeking out and developing new energy options to support our growing economy" – goals that you and the Administration have set.
Recent events clarify some crucial issues so that the time seems ripe for actions that could dramatically raise domestic, onshore oil supplies and could lead to commensurate sequestration of CO_2.

Shales in the Bakken Formation were known for decades as sources of hundreds of billions of barrels of crude oil. Geologists once believed that the Bakken oil had migrated to shallower formations (notably the prolific Madison) or leaked to the surface. Scientific analyses show that is not true. Geologists who studied those analyses have concluded that Bakken oil remains in micro-fractures 10,000 feet below ground in the Bakken Formation – some in the shales themselves and much more in immediately adjacent limestones at which current drilling aims in Montana and North Dakota.

Bakken oil is a "continuous-type" of "unconventional" resource: crude oil that's easy to find (true "dry holes" being rare) but often hard to produce. Under past technology profitability of each well was "hit or miss" and depended on hitting "sweet spots" where several fractures crisscross making for substantial production.

- Bakken wells frequently produced for decades, but many of them produced very little.
- Many were economic failures.

Cumulative production of millions of barrels of high-quality oil was less than hoped for when many investments were made.

Production techniques for Bakken crude oil, evolving since 2000, now let independent operators supplement nature and create artificial "sweet spots" at a cost of $3-4 million per well. For a couple of years, Montana wells have been producing millions of barrels of crude oil, previously omitted from federal agency databases. Operators now apply similar techniques in North Dakota.

Scientists who have demonstrated the best understanding of the Bakken resource have proposed a set of additional measures that they believe could significantly increase recovery rates for Bakken oil, using CO_2 injection from the start of production. This class of measures has not yet been tried for getting out more of the Bakken oil.

Federal recognition for Bakken crude oil production -- plus R&D support and encouragement – are in order.

"Continuous-type" resources of *non-associated natural gas* now contribute strategically important production although they were unknown or discounted not long ago. Coal-bed methane now accounts for nine percent of domestic gas production. And the Barnett Shale of north Texas was reassessed two years ago by the U.S. Geological Service (USGS) as 26 trillion cubic feet (TCF) of undiscovered, technically recoverable resource – after cautious assessment at "zero" in 1995 (as "hypothetical" and "questionable").

The enclosed paper asks questions about exploiting vast amounts of Bakken crude oil:

- Do successes of Montana's "technology play" open the door to recovering ten percent of crude oil in place by means of current, state-of-the-art technology in contrast to far-lower (even miniscule) estimates that have predominated?

- Do practices of some operators set a gold standard while others still needlessly strand crude oil by ignoring evolving geologic understanding and petroleum engineering technology for this resource – or by focusing on short-term results?

- How and when may additional technologies -- especially carbon dioxide injection, for pressure maintenance and enhanced oil recovery (CO_2-EOR) – be applied for the first time to this resource? How might the U.S. Department of Energy (DOE) and its Office of Fossil Energy (FE) set up a program, tapping know-how in the Energy Information Administration (EIA) as well as outside DOE, to try out CO_2-EOR and adapt it to and test it for this resource, as soon as practicable?

- How might the administration's Global Climate Change Initiative (GCCI) and attendant advances in power systems (Futuregen) and carbon management (CO_2 sequestration) add technological and economic drivers to realize this potential?

- Have federal agencies understated this crude oil resource?
    - Is the U.S. Geological Survey (USGS) 1995 National Oil & Gas Assessment (NOGA) of "undiscovered" but "technically recoverable" crude oil (not due for updating until 2007) so significantly outdated as to materially understate this recoverable crude oil? Does it misinform DOE and the public?
    - How best to jumpstart reassessment of the Bakken?
    - Since the EIA relies on the USGS NOGA to project domestic crude oil production over the next 20 years, is EIA annually understating domestic production potentials – even in its "rapid technology" case?
    - Can EIA improve its domestic crude oil projections?
    - What are the lessons from EIA's distinction between "conventional" and "unconventional" onshore resources of non-associated natural gas?

  - Do EIA's plans for evaluating and using FE's estimates of technological opportunities to raise crude oil recovery factors for conventional oil fields by means of CO_2-EOR that is already "state-of-the-art" (from 33 percent to almost 47 percent) offer pertinent models for presenting a rapid technology case for the Bakken?

- Can the USA do more to tap "continuous-type" and "unconventional" sources of *crude oil* on scales similar to formations that now account for a large fraction of domestic *non-associated natural gas* production?
  - Those include newcomers like the Barnett Shale of north Texas and coal-bed natural gas in several places, both highlighted in EIA's Proven Reserves 2004 Annual Report. (A giant oldie, the Hugoton-Panhandle Field, has produced since the 1920s.)
  - The Wall Street Journal reports (Nov. 29, 2005, p. A1) that big oil companies are now joining independents who paved a way for a new kind of gas field "unlocking fuel from rock."

  Apart from the Williston Basin Bakken Formation, to what other "continuous-type" *crude oil* resources should DOE, EIA, and USGS give greater attention?

- Could new technology and better understanding applied to "continuous-type" crude oil resources have great national and international significance?
  - Will the USA lead, starting with the well-studied Williston Basin, or will other nations?
  - Are US science and technology up to the job?

- Can inter-disciplinary dialogue be strengthened (*e.g.*, among geologists, geochemists, petroleum engineers, chemical engineers)?

- In addition to the foregoing questions, Executive and Legislative Branch policy makers may ask whether (or to what extent) to encourage greater and earlier use of this domestic, "continuous-type" crude oil resource.

Technological change can make a shambles of conventional macro-estimates of hydrocarbons (and other geological resources), as Bruce Netschert and Julian Simon wisely taught (beginning, respectively, in the 1960s and 1970s). In this century, DOE would serve large national interests by updating its attention to Bakken crude oil technology. Vast resources in place in the Bakken Formation resemble a virtually infinite supply of high-quality crude oil in a giant tank without conventional taps, pumps, or spigots. Oil wells release small amounts, slowly, for many, many years -- as if each well were a pinhole leak. Hitting a natural "sweet spot" in previous plays meant a larger pinhole and the chance for more profitable production. Creating artificial "sweet spots" is key to technology improvements now in use. Exploiting state-of-the-art technology to the hilt and advancing it further offer challenges aplenty to raise production rates further, to keep holes producing, and to make it attractive to drill many more. Of course, an oil tank analogy oversimplifies by implying homogeneity of rock pores, fractures, thicknesses, and accumulation processes. Geologic interpretations (admittedly not immutable) suggest that the greatest concentrations of oil will be in North Dakota, rather than Montana. Be that as it may, the Bakken-play fraction of Richland County, MT, will produce close to 15 million barrels *this year alone*. All of Richland County comprises 2,084 square miles. For the entire 17,800 square miles of Bakken Formation on the US side of the border, the USGS estimated (and your Department still uses) 150 million barrels as the *total*, technically recoverable resource.

It's time for a fresh look: A fresh look at resources in place, recovery factors, state-of-the-art best practices and how to push them forward the next logical step. And it's time to set DOE a one-year target to plan out its appropriate roles for the Bakken Formation and similar resources.

Faithfully, David J. Bardin

Enclosure: Bakken Crude Oil Resource of the Williston Basin

Copies: Undersecretary Garman, EIA Administrator Caruso

* Secretary of Energy Samuel W. Bodman, October 17, 2005, "Energy Department Adds Projects to Boost Domestic Oil and Gas Production – Goal is to Boost Recovery of Unconventional Resources and Minimize Environmental Impacts".

** In 1995, USGS wrote: "This [Barnett Shale] play is classified as both hypothetical and unconventional because it is limited to a single production occurrence [the East Newark Field, near Dallas], and its reservoir permeability of 0.1mD falls in the unconventional-play category. … The reservoir quality is the riskiest aspect of the play and was deemed to be so questionable that the play was not individually assessed." The effect was to *quantify* undiscovered potential as zero, even as the *narrative* acknowledged a "significant" resource potential: "Risk for additional producible discoveries in the play is high but potential for additional discoveries is also significant." By 2003, a new USGS assessment estimated a mean of 26 trillion cubic feet (TCF) of undiscovered, technically recoverable natural gas and over a billion barrels of natural gas liquids (NGL), but did not quantitatively assess undiscovered crude oil. (Underlying estimates of undiscovered reserves in place may exceed 200 TCF.)

In 1995, USGS had refused to consider the prolific East Newark Field as an element in assessing the Barnett Shale. Similarly, in that year, USGS assessment eliminated data from the prolific Antelope Field established in 1953 in the Bakken Formation.

Bakken Crude Oil Resource of the Williston Basin

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Executive Summary and Recommendations

Shales in the Bakken Formation have been known for decades as sources of hundreds of billions of barrels of crude oil. Recent events clarify some crucial issues so that the time seems ripe for action that could dramatically raise domestic, onshore oil supplies.

Geologists once believed that the Bakken oil had migrated to shallower formations (notably the prolific Madison) or leaked to the surface. But scientific analyses show that is not true. Geologists who studied those analyses have concluded that the Bakken oil remains in micro-fractures 10,000 feet below ground in the Bakken Formation – some in the shales themselves, but much more in immediately adjacent limestones at which the current drilling aims in Montana and North Dakota.

This Bakken oil is a "continuous-type" of "unconventional" resource: crude oil that's easy to find (true "dry holes" being rare) but often hard to produce. Under past technology profitability of each well was "hit or miss" and profitability depended on hitting "sweet spots" where several natural fractures crisscross and make for quite prolific production.

Bakken wells frequently produced for decades, but some produced very slowly.

Many wells were economic failures. Cumulative production of million barrels of high-quality oil, was less than hoped for when many investments were made.

Evolving production techniques for Bakken crude oil now let operators supplement nature and create artificial "sweet spots": Montana wells have been producing millions of barrels of crude oil, previously omitted from federal agency data bases, for a couple of years. Operators are now applying similar techniques in North Dakota.

Scientists who have demonstrated the best understanding of the Bakken resource have proposed a set of additional measures that they believe could significantly increase recovery rates for Bakken oil, using CO_2 injection from the start of production. This class of measures have not yet been tried for getting out Bakken oil.

Federal recognition for Bakken crude oil production, plus R&D support and encouragement are in order.

"Continuous-type" resources of *non-associated natural gas* now contribute strategically-important production although they were unknown or discounted not long ago. EIA's latest annual report on proven reserves highlights coal-bed natural gas (which now accounts for nine percent of domestic gas production) the Barnett Shale.[1] The Wall Street Journal reports that big

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[1] Just two years ago, the U.S. Geological Service (USGS) reassessed the Barnett Shale of north Texas as 26 trillion cubic feet (TCF) of undiscovered, technically recoverable resource – after a cautious "zero" assessment in 1995 (as "hypothetical" and "questionable"). In 1995, USGS wrote: "This [Barnett Shale] play is classified as both hypothetical and unconventional because it is limited to a single production occurrence [the East Newark Field, near Dallas], and its reservoir permeability of 0.1mD falls in the unconventional-play category. … The reservoir quality is the riskiest aspect of the play and was deemed to be so questionable that the play was not individually assessed." The effect was to *quantify* undiscovered potential as zero, even as the *narrative* acknowledged a "significant" resource potential: "Risk for additional producible discoveries in the play is high but potential for additional discoveries is also significant." By 2003, a new USGS assessment estimated a mean of 26 trillion cubic feet (TCF) of undiscovered, technically recoverable natural gas and over a billion barrels of natural gas liquids (NGL), but did not quantitatively assess undiscovered crude oil. (Underlying estimates of undiscovered reserves in place may exceed 200 TCF.) In 1995, USGS refused to consider the prolific East Newark Field as an element in assessing the Barnett Shale. Similarly, in that year, USGS assessment eliminated data from the prolific Antelope Field established in 1953 in the Bakken Formation.

oil companies are now joining independents who paved the way for a new kind of gas field – "unlocking fuel from the rock." [WSJ, Nov. 29, 2005, A1.] (The giant oldie "continuous-type" Hugoton-Panhandle Field has produced non-associated natural gas since the 1920s.)

Technological change can make a shambles of conventional macro-estimates of hydro-carbons and other geological resources, as Bruce Netschert and Julian Simon wisely taught beginning, respectively, in the 1960s and 1970s. DOE would serve large national interests in this century by updating its attention to Bakken crude oil technology.

Recommendations for the Office of the Secretary of Energy, EIA, and FE

Recommendation #1:

The Secretary of Energy should take advantage of the forthcoming 14th Annual Williston Basin Conference (May 7-9, 2006, in Minot, North Dakota) to announce and discuss initiatives concerning the Bakken Formation.[2] Recommended initiatives might include:

- Announcement of cooperative programs with the States of North Dakota and Montana, industry, and research organizations to share and spread information about "state-of-the-art" and successful practices to order to progress towards maximum economic production of the Bakken resources.
- Discussion, after consultation with the Secretary of the Interior, of coordinated plans for prompt reassessment of the Williston Basin's unconventional and continuous-type Bakken Formation crude oil resource enlisting the expertise and resources of EIA, DOE/FE and USGS.
- Announcement that DOE/FE is setting up a one-year program, as soon as practicable, to plan for and try out carbon dioxide injection, for pressure maintenance and enhanced oil recovery (CO_2-EOR) in the Bakken Formation, adapting CO_2-EOR to and testing it for this resource (and reaping CO_2-sequestration benefits).
- Discussion of how the Administration's Global Climate Change Initiative (GCCI) and attendant advances in power systems (Futuregen) and carbon management (CO_2 sequestration) add technological and economic drivers to realize the Bakken Formation's potential for the USA economy and the environment (taking account of relevant Administration FY 2007 Budget proposals).
- Announcement of programs to stimulate more inter-disciplinary exchanges (as between engineers, geochemists, and geologists) concerning the Bakken Formation (and, possibly, other "continuous-type" crude oil resources) enlisting the National Academy of Sciences and the National Academy of Engineering.
- Planning for a periodic, prestigious, meaningful recognition for advances in the science, technology, and art of producing continuous-type petroleum resources, especially crude oil resources – to be awarded by the Secretary of Energy or a non-profit organization.

Recommendation #2:

The DOE/FE should

- Promptly plan and set up a program to try out carbon dioxide injection, as soon as practicable, for pressure maintenance and enhanced oil recovery (CO_2-EOR) in the Bakken Formation, adapting CO_2-EOR to and testing it for this resource – so as to reap CO_2-sequestration benefits. Because of limited CO_2 supplies and delivery systems at a promising site, it may make sense to try injection of local high-Btu ("dirty") gas in a first

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[2] Conference hosts are North Dakota Department of Mineral Resources, Saskatchewan Geological Survey, and North Dakota Petroleum Council. The web site will be www.ndoil.org.

stage of a pilot program. FE should tap know-how elsewhere in DOE, including EIA, and coordinate closely with the States of Montana and North Dakota and with academic institutional expertise in energy and environmental issues, including CO_2-sequestration.

- Design and implement additional research and demonstration programs to advance mobilization and recovery of Bakken crude oil, including examining the application of CO_2 (as well, potentially, as compressed air, nitrogen, and methane and other hydrocarbon gas) injection, at or near the start of field development and production. After initiating programs in the well-studied Williston Basin, FE might very possibly reach other continuous-type, domestic petroleum resources.
- Review best ways to include discussion of Bakken Formation potentials within its forthcoming Williston Basin study of how a "next generation" CO_2-EOR technologies would dramatically improve oil recovery efficiency and extend application of the technology to more difficult geologic and reservoir conditions.

Recommendation #3:

(A) As a special study or series of studies aimed at the Williston Basin and its region, EIA should prepare a "rapid technology case," enlisting know-how of its various divisions, to:

(1) (a) Assess pertinent Bakken crude oil resources in place in North Dakota and Montana and recovery factors, at least preliminarily, over a projection horizon; and (b) projected production of Bakken crude oil in North Dakota and Montana using rapid technology gains over current state-of-the-art as a base; and

(2) Projected application of CO_2-EOR in conventional reservoirs of the Williston Basin.

Studies would be performed using both high price and low price trajectories and would discuss refinery, transportation, and resource impacts of assumed growth rates.

(B) An EIA study should discuss whether 89 million bbls of Montana statewide oil reserves "extensions" in the last couple of years represent Bakken Formation crude in Richland County.

Recommendation #4

EIA, FE, and USGS should prepare a prompt and complete reassessment of the Bakken Formation unconventional resource (during 2007, at the latest), making a fundamental effort to estimate and publish oil and gas in place characterized by type of reservoir rock (e.g., shale, dolomite, siltstone) in which the resource resides, in order to provide all stakeholders a target at which to aim efforts for enhanced recovery factors.

Recommendation #5:

EIA should review whether (and how) to project "unconventional" crude oil (and associated natural gas) production in its annual, long-term energy outlook, or at least important categories of "unconventional" either in its base case or in its rapid technology case, or both.

- In addition to continuous-type resources such as the Williston's Bakken, these projections could estimate future oil production from immobile and residual oil in depleted domestic conventional reservoirs using CO_2-EOR.
- These forecasts could utilize several basin-by-basin and national studies of CO_2-EOR by the Office of Fossil Energy (FE) in DOE.

Recommendation #6:

The Secretary and DOE/FE may wish to explore provisions, findings, conclusions, and declarations of policy in several statutes. Bakken Formation resources being left unproduced today exceed by far the national average proportion identified by Section 354(a)(1)(A) of the Energy Policy Act of 2005.

The Current Bakken Play of Montana and North Dakota

Early in 2005, Julie LeFever[3] summarized the current (third) Bakken play:

> The Bakken Formation has once again become the center of attention in the Williston Basin. Unlike the shale play of the early 90s, the focus is directed toward the middle member of the formation. Horizontal drilling of the middle member began in 2001 and until recently has been restricted to Richland County, Montana. As the success rate increased in Montana, leasing increased in North Dakota in an attempt to bring the play across the state line. To date, there is one reportable well drilled in North Dakota with numerous permits for additional wells.
>
> Three years of drilling activity has defined the Bakken play in Montana. The stratigraphy is relatively simple and similar to the area played in the 90s. It consists of each successively higher member of the Bakken Formation onlapping the Devonian Three Forks Formation. As the play area is reached in Richland County, only the middle member and the upper shale remain. These units pinch out further to the south. A bottom seal is formed by the impermeable Three Forks Formation while the Mississippian Lodgepole Formation forms the top seal. A well developed, mappable trend is readily apparent in the middle member on wireline logs over this area.
>
> Technology has finally caught up to the Bakken Formation. The ability to fracture stimulate these horizontal wells is what makes this play work. In the late 80s-early 90s, wells had to rely on encountering natural fractures to supply the oil; wells in the current play create their own fractures. Wells generally consist of two 4000 to 5000 ft laterals drilled on a 1280-acre spacing unit. The middle member is now drilled with saturated brine instead of inverted mud. The zone generally has between 7 to 12% porosity, permeability of 0.01 to 0.02 md, and 70 to 80% oil saturation. Once drilled, the well is then treated with a 650,000 to 1 million pound gelled water-sand frac. The cost per well is approximately $2.2 million with potential production rate of 500 to 700 BOPD initially, leveling off at 250 BOPD with virtually no water.
>
> Statistics from the Montana Board of Oil & Gas demonstrate the success of this play. Production for the Richland County has doubled each year as new wells come on line. There is no evidence that this production trend will slow in the near future.
>
> The same facies that produce in Montana are present and potentially productive in North Dakota. Additional potential within the middle member occurs as the Bakken thickens towards its depositional center in Mountrail County, North Dakota. This is further substantiated by production from another higher lithofacies that is present in the northwestern corner of North Dakota and in the Canadian provinces.

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[3] Synopsis published by Houston Geological Society as "The Bakken Play of Montana and North Dakota" with Speaker Bio: **Julie A. LeFever** has been employed by the North Dakota Geological Survey since 1980 working on petroleum related studies in the Williston Basin. She is currently Director of the NDGS Wilson M. Laird Core and Sample Library. She has presented several papers and core workshops on the Bakken. Julie received her MS from California State University Northridge in 1982. [LeFever @ Houston Geological Society Monthly Dinner, 5 January 2005 - www.hgs.org/en/cev/?314]

Additional pay section may also be present locally in North Dakota. The "Sanish Sand" occurs at the base of the Bakken Formation. Already a significant producer at Antelope Field, this interval is untested and occurs throughout the "Bakken Fairway" (depositional edge of the Bakken). Another potential target is the lower Lodgepole Limestone between the upper Bakken shale and the "False Bakken". Detailed mapping of all of the zones will be required to determine the best location to tap into the oil resources of the Bakken Formation.

See Petroleum Technology Transfer Council, Network "Strong Horizontal Activity in Williston's Middle Bakken" [www.pttc.org/news/3qtr2005/v11n3p1.htm]. Bakken Formation shales were long known as sources of hundreds of billions of barrels of crude oil. But, whereas geologists once believed that Bakken oil had migrated to shallower formations (notably the prolific Madison) or leaked to the surface, scientific analyses show that is not true. Geologists who studied those analyses concluded that Bakken oil remains in micro-fractures 10,000 feet below ground in the Bakken Formation – partly in the shales themselves but even more in immediately adjacent limestones at which the current play aims. Improvements in technology and understanding of the Formation are turning billions of barrels of crude oil once regarded as "hypothetical" by EIA and USGS into proven reserves and as-yet-unproven, but "technically-recoverable" resources.

Richland County, Montana, Specifics[4]

Tom Richmond, Administrator/Petroleum Engineer to Montana's Board of Oil & Gas Conservation, says Richland County's Bakken recent play has increased production by 8 million barrels in 2004 alone – maybe 30% of Montana's production – (and considerably more already in 2005), in contrast to almost zero barrels and zero percent in 2000. See Table 1.

Table 1. 2000-2004 Bakken play in Richland County, MT (adjoining McKenzie County, ND)

	2000	2001	2002	2003	2004
Richland County well drilling results					
Total well completions	6	21	22	44	93
Bakken well completions	1	11	15	38	**89**
Completions in other formations or service well	5	11	6	4	4
Dry holes	0	2	1	2	5
Richland County "Elm Coulee" Field[5]: wells, oil, gas					
Year-end Bakken wells	1	11	26	65	**159**
Bakken Formation production during year:					
Oil - *thousands* of bbls	21	266	776	2,687	**7,523**
Gas – MMcf	11	158	470	1,358	3,414
Oil production - *millions* of bbls – incls. *non*-Bakken					
Richland County per Montana DNRC statistics	2.6	3.0	3.4	5.3	10.2
Statewide per Montana DNRC statistics	15.8	16.3	17.0	19.4	24.7
Statewide per EIA estimates	15	16	18	19	22
Year-end proven reserves, statewide per EIA	235	260	288	315	364

[4] "Tight hole" status of some new North Dakota wells still limits what that State may disclose.

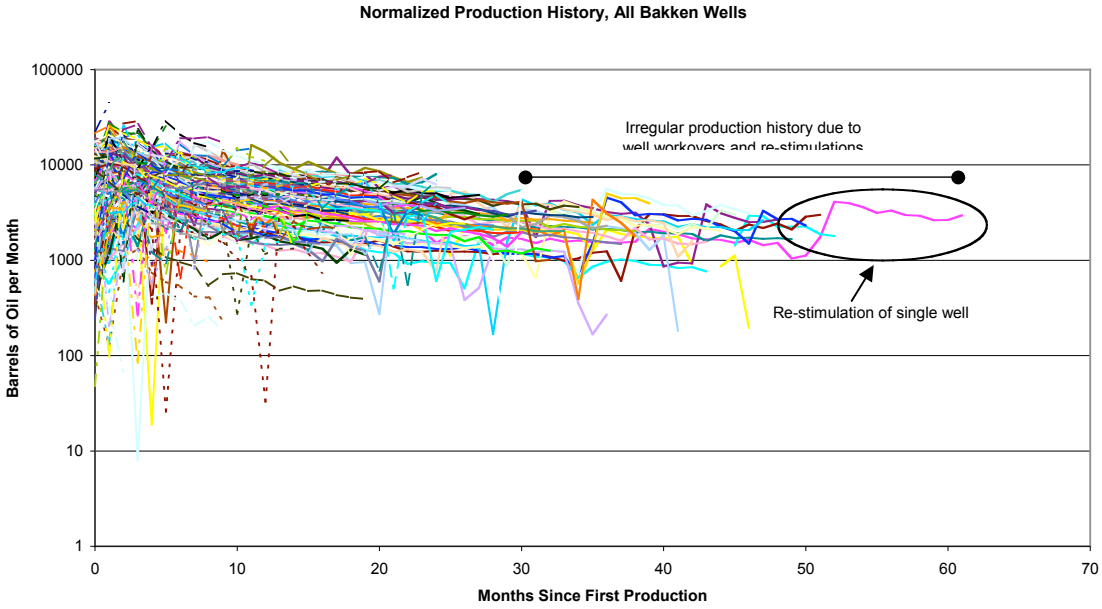
[5] Since 2000, Montana has ascribed all Richland County Bakken completions to the "Elm Coulee" Field. Earlier Bakken completions are ascribed to other fields. I did not examine records of those earlier wells.

Richmond ascribes recent production growth in Richland County to the current Bakken play. In the first nine months of 2005, Elm Coulee Field's 268 Bakken wells produced 11 million barrels of oil and $6^{1}/_{3}$ million Mcf of associated natural gas.[6]

Figure 1 displays *monthly* production decline curves for 225 of those wells (normalized to number of months since first production).[7]

- The oldest well, completed by Lyco Energy Corporation (API#25-083-21881), reported an initial 3,874 barrels of crude oil produced during 22 days of June 2000 (month "zero"). Fig. 1 shows this well as re-stimulated (after month 51 or 52, it appears). The well actually reported 4,090 barrels produced during 30 days of November 2004.
- The highest initial month production plotted in Fig.1 (22,738 barrels in 23 days) is for API#25-083-22255, completed by Continental Resources, Inc. in mid-2005.

Fig. 1 Monthly Decline Curves for 225 New MT Bakken Wells Showing Re-stimulation of One Well Mid-2000 to 2005 Completions Normalized to Number of Months Since First Production Reported Monthly Production (BO/month, no matter how many days in production)



Source: Jim Halvorson, Montana Board of Oil & Gas Conservation

Current practice appears to stimulate the oil-bearing formation at the time of completion or shortly thereafter. Timing patterns for re-stimulation bear study. One wonders whether similar re-stimulation techniques could be used to frac older horizontal wells in North Dakota -- completed in the Bakken Upper Member *shale* during the *previous* play.

Reported initial *daily* production (and the operator) appear in Appendix X-0 for each of the wells in Montana's "Elm Coulee" Bakkan play during 2000 through 2004. There were no big oil

[6] Montana's on-line database (viewed Dec. 18, 2005) showed a well count up to 276. Adding in October production from those wells that had then reported (only 82), the running "YTD" had reached 11.7 million bbls and 57,536 "well days" of production of "Elm Coulee" Field crude oil in 2005 on that database.

[7] The number 225, selected to fit Excel software limitations, omits wells with few months of production.

companies ("majors") in the play. Two independents predominated: Lyco Energy Corporation and Headington Oil LLP.

Wells completed during 2004 reported initial *daily* oil production ranging from 46 to 1066 BO/D (with most above 500). App. X-0, Table 2. Data concerning Bakken completions since 2000 seem consistent with technology improvements over the short period from mid-2000 to now or re-stimulations or both.[8] One hopes forthcoming analyses of average daily well performance of *all* Bakken wells in Richland County, month after month, may prove illuminating.

There were 330 Bakken reported completions in Montana, statewide, and 268 in "Elm Coulee" Field (Richland County) as of early December, 2005.[9]

EIA Estimates of Proven Reserves and Production in Montana and North Dakota

EIA's 2003 annual report on crude oil reserves identified Montana among "other" growth areas. The 2004 annual report identifies both Montana and North Dakota as enjoying major growth in reserves. Neither report identifies the current Bakken play as a factor. The 2004 report identifies a large waterflood project on the Cedar Creek Anticline's east flank (unrelated to the Bakken) as a factor.[10] (One wonders whether EIA's system of reliance on and extrapolation from proven reserves reports of the larger operators will miss a significant part of what has happened.[11])

EIA could usefully review the 89 million bbls of Montana statewide oil reserves "extensions" that EIA reported in the last couple of years (47 million bbls during 2003 and 42 million during 2002) and publish a short narrative discussing whether they represent Bakken Formation crude in Richland County. My hypothesis is, Yes (or mostly, Yes).

"Continuous-Type" Petroleum Accumulations

USGS characterizes the Bakken Formation as "unconventional" and "continuous-type". Continuous petroleum accumulations have large spatial dimensions, indistinctly defined boundaries (contrast oil or gas "fields"), and exist more or less independently of the water column (contrast oil or gas buoyed up by subsurface water and trapped by impermeable seals). Conventional dry holes, which simply miss a trapped petroleum deposit, hardly happen in

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[8] During 2001 through 2002, initial-month's reported daily production ranged from 150 to 368 BO/D for completions in 2001 and from 146 to 576 BO/D for completions in 2002 (as shown in App. X-0, Table 3). During 2003, reported initial production ranged from 131 to 1280 barrels a day for Bakken completions (App. X-0,Table 4). The first Bakken completion in 2000, had reported an initial-month's flow of 85 BO/D but averaged 129 BO/D that year.

[9] For Elm Coulee Field alone, average production/well/year (BO/yr) rose steadily from 21,164 in 2000 to 47,318 in 2004. Average production/well/day (BO/D) was 129 in 2000 and over 200 in 2005 year-to-date.

[10] I do not understand EIA's accompanying estimates of production: Montana DNRC reports 12 percent *more* statewide in 2004 than the EIA estimate (24.7 versus 22 million barrels) and North Dakota DMR reports four percent *less* in 2004 than the EIA estimate (30.8 versus 32 million barrels – of which only 2% came from the Bakken Formation according to DMR's web site).

[11] "Proven" reserves for a reporting firm are probably those counted as assets backing up financials for the Securities & Exchange Commission. EIA extrapolates statistically to estimate unreported quantities.

continuous-type resources; risks involve how much of the petroleum one can extract efficiently and economically.[12]

"Although virtually all wells drilled into a continuous accumulation encounter a petroleum charged reservoir, it is very possible to drill wells that are economic failures. Therein lies the primary reason that many known continuous accumulations in the United States are developed only locally and have not yet contributed to U.S. oil and gas supplies at levels that might be expected based on their large in-place volumes." Schmoker 2005.

Nature, Location and Extent of Bakken Formation and Historic Production

"The Upper Devonian and Lower Mississippian Bakken Formation in the United States portion of the Williston Basin is both the source and the reservoir for a continuous oil accumulation—in effect a single very large field—underlying approximately 17,800 mi^2 (46,100 km^2) of North Dakota and Montana. Within this area, the Bakken Formation continuous oil accumulation is not significantly influenced by the water column and cannot be analyzed in terms of conventional, discrete fields. Rather, the continuous accumulation can be envisioned as a collection of oil-charged cells, virtually all of which are capable of producing some oil, but which vary significantly in their production characteristics." Schmoker 1996.

This crude oil lies roughly at a depth of 10,000 feet. The Upper and Lower Members of the Bakken Formation are naturally micro-fractured shales rich in organic carbon, including kerogen. Geologists interpret the shales as (a) sources of hydrocarbon (HC), including kerogen and crude oils "cooked" out of kerogen, and (b) a seal. Crude oil "migrated" no further from the shales than the adjacent Middle Member. Kerogen may still be generating crude oil in portions of the Formation today.

The Upper Member is the most extensive. The least extensive is the Lower Member (largely confined to North Dakota). The entire Formation is up to 105 feet thick, with Lower Member (Shale) up to 50 feet, Upper Member (Shale) up to 23 feet, and Middle Member up to 85 feet in North Dakota.[13] In Montana, Middle Member pay zones average only 8 to 12 feet thick (going down to as little as 3 feet). The Middle Member (with multiple lithofacies) includes sandstones and siltstones in North Dakota, dolomite in Montana.

In North Dakota's current Middle Bakken play, wells are drilled vertically for about 10,000 feet, then two laterals are drilled horizontally, each threading some thousands of feet more through the Middle Member.[14] (Earlier plays, beginning in the 1950s, included vertical wells and, later,

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[12] Schmoker 1995; see also Schmoker 2005: "Continuous petroleum accumulations form a geologically diverse group that includes coalbed methane, 'tight' gas, basin-center gas, oil and gas in fractured shale and chalk, gas hydrates, and shallow biogenic gas. Despite their obvious differences, these various petroleum deposits are linked together as continuous accumulations by two key geologic characteristics: (1) they consist of large volumes of rock pervasively charged with oil or gas, and (2) they do not depend upon the buoyancy of oil or gas in water for their existence."

[13] See LeFever, J.A. "Montana – North Dakota? Middle Member Bakken Play" [undated slides; viewed 11/2005 on North Dakota Geological Survey web site].

[14] See exhibits from commission proceedings in Helms, L.D, and LeFever, J.A. "The Bakken Play – Technical Problems & Possible Solutions" Geologic Investigation No. 16 [undated slides; viewed 11/2005 on North Dakota Geological Survey web site].

horizontal wells with only one lateral.) Successes in Montana refocus attention on Bakken crude oil (and associated gas) resources.

Centered in North Dakota, the Williston Basin Bakken oil resource has a track record of several hundred productive wells since 1953 producing light, sweet, high-quality oil:

- Through the end of 2004, North Dakota had produced a cumulative 45 million barrels. But production was down to 600,000 barrels during that year.[15]
- Montana's Richland County produced close to 8 million barrels in 2004 and 11 million more in the first nine months of 2005. Some operators estimate that initial recovery factors there are 10% of the oil in place in the "Middle Member" of the Bakken.
- Hot horizontal drilling plays aimed at Middle Member limestones in Montana and North Dakota now grab attention. They use new stimulation technologies (which operators may also be applying to older horizontals in Upper Member shales).[16]
- Yet those developments barely scratch the surface when one considers estimates of hundreds of billions of barrels of oil in place.

How Much Crude Oil in Place in the Bakken Formation?

Estimates of total Bakken Formation oil in place involve two elements:

(1) How much crude oil was ever generated?
(2) How much of that oil stayed in the Bakken?

As to the former question: "Whatever the volume of Bakken-generated oil, it is very large, in the range of hundreds of billions of barrels." Price and LeFever 1994. "Available evidence indicates that the Bakken Formation of Montana and North Dakota has generated hundreds of billions of barrels of oil." Schmoker 1995 (in Peterson 1995). "Shales within the Bakken Formation have generated more than 100 billion barrels of oil". Schmoker 1996. The "Bakken Formation in … North Dakota generated approximately 200 to 400 billion barrels of oil in place." Pitman, Price, and LeFever 2001 (USGS Professional Paper 1653).[17] "Bakken Formation in North Dakota ….

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[15] North Dakota reports cumulative production of 45 million barrels (32,437,900 from the Bakken and 12,591,225 from the Sanish, which North Dakota segregates) and 2004 production of 587,000 barrels (Bakken 522,235 + Sanish 64,745) and 1,875,000 Mcf of natural gas (Bakken 1,665,334 + Sanish 209,495). [www.oilgas.nd.gov/stats/]

Montana's statistical reports do not cumulate all Bakken production as clearly as North Dakota's seem to do. Montana's 2004 Annual Review reported cumulative Bakken production of 11,275,104 bbls through the end of 2004 from "Elm Coulee" Field (*i.e.*, from wells completed since 2000). There was not much else in the way of Bakken production to report. Wells are being drilled on 640-acre or 1280-acre spacing and are producing 200-1,000 bbls per day from the Middle Member of the Bakken with estimated recovery factors around 10% according to some operators. Some speculative discussions of enhanced recovery seek an additional 10%–15% (out of the Middle Member) by means of CO_2 or compressed air injection. T. Richmond (personal communications, 4, 8, 22 & 28 Nov. 2005).

[16] Petroleum Technology Transfer Council, Network "Strong Horizontal Activity in Williston's Middle Bakken" v. 11 p. 1-2 [http://www.pttc.org/news/3qtr2005/v11n3p1.htm]. See App. A.

[17] USGS Professional Paper 1653 (2001) suggests up to 400 billion barrels, stating that the Bakken Formation in the Williston Basin, North Dakota, is a "closed, low-permeability petroleum system that generated approximately 200 to 400 billion barrels of oil in place. Most of this generated oil was expelled into very fine-grained sandstones and siltstones within the middle member, which is bounded by organic-rich shales that are both sources and shields." Pitman, J.K., Price, L.C., and LeFever, J.A. "Diagenesis and Fracture Development in the Bakken Formation, Williston Basin: Implications for Reservoir Quality in the Middle Member" (first printing Nov. 2001; now posted on the North Dakota Geological Survey's web site).

World Class Source Rock …. HC Generation – 200 to 400 BBbls of Oil" Helms and LeFever 2005, LeFever 2005b. "Volume of Oil Generated – Up to 413 billion barrels (ND&MT)" LeFever 2005b.

As to the latter question: At least 100-150 billion barrels of oil remain in place. Price and LeFever 1992. "Whatever the volume of Bakken-generated oil, it is very large, in the range of hundreds of billions of barrels. Furthermore, the results of Osadetz *et al.* (1992) and our study suggest that very little if any, of the oil generated by the Bakken shales has left the Bakken source system, … We hope that … *stressing the size of the resource base* would result in meaningful research on nonconventional recovery techniques for it." Price and LeFever 1994 [emphasis added][18] (a dogma-smashing study which demonstrated by review of other studies and original geochemical comparisons that almost none of the crude oil generated in the Bakken system leaked, so that almost all is still there). An "enormous volume of oil in-place". Schmoker 1995. "A majority of earlier studies tended to emphasize the source-rock properties of the Bakken Formation … , but both vertical and horizontal drilling have now shown that the Bakken is a significant oil reservoir in its own right." Schmoker 1996.

Vindication of Price and LeFever

Recent Montana successes seem to vindicate interpretations by Price and LeFever who pointed to the Middle Member (rather than the Upper Member) as target for horizontal drilling and who advocated improved technological performance and improved technologies. Apps. X-3 and X-4.

Technology to Recover the Oil: Progress

Technology has progressed substantially since the USGS assessment in 1995:

- "Technology has finally caught up to the Bakken Formation. The ability to fracture stimulate these horizontal wells is what makes this play work." LeFever 2005a.

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[18] "The principal conclusion of, and purpose for, this study is to provide further evidence that huge, in-place oil-resource bases may exist in and adjacent to mature shales not cut by significant faulting nor bounded by laterally transmissive units, not only in the Williston Basin but in all petroleum basins. We hope that underscoring this proposition and stressing the size of the resource base would result in meaningful research on nonconventional recovery techniques for it.

"A second important implication of our study regards models for oil expulsion and accumulation of conventional oil deposits. That the Bakken shale, the richest and most areally extensive source rock in the well-explored Williston Basin, has yielded neither significant conventional commercial deposits of mature oil in any reservoir unit in the basin nor known deposits in the Madison rocks, the most important reservoir in the basin, is startling. …. The currently accepted model of oil expulsion from organic-rich rocks centers on open-system fluid flow in the depocenters of sedimentary basins, highly efficient oil expulsion and trapping of only small percentages of expelled oil, with most expelled oil being lost to surface leakage over geologic time or lost to dispersion along secondary migration paths. …. However, this model of expulsion and accumulation is clearly dysfunctional in the Williston Basin, where the model first originated.

"Two explanations are possible: 1) the model of deep-basin, open-system fluid flow with efficient oil expulsion and loss of large oil volumes over geologic time is incorrect and generally does not occur in basins worldwide; and 2) the model is correct and does generally occur except in the Williston Basin which is "abnormal". While anything seems possible in the inexact science of geology, we prefer the first explanation for several reasons." Price and LeFever 1994.

- In 1995, USGS assumed that only ten percent of Bakken wells would ever be stimulated and did not anticipate technology to frac horizontal laterals, either in new, Middle Member wells or in older Upper Member horizontals.
- In 1995, USGS regarded production as controlled by natural fractures, "with the result the production rates and ultimate recoveries of wells exhibit a heterogeneous, 'hit or miss' character. Truly dry holes are rare, [but] recovery factors are low …"
- In 1995, USGS concluded that horizontal wells would develop only 1.1 times the reserves of vertical wells in all parts of the Bakken (Fairway, Intermediate, and Outlying). Schmoker 1996. USGS did not discuss the finding of SPE 22389 indicating "that recoverable reserves in the 'Fairway' are 2.5 to 3.0 times a vertical well for 1.5 to 2.0 times the cost." Reisz 1992. App. X-2.
- Today's industry preference for horizontal wells, commonly with twin laterals (and input costs now over $3 million per such well), seems to settle the issue.
- In 1995, USGS divided data base statistics systematically by completion date into three groups, for both the Intermediate area and the Fairway, and compared expected ultimate recoveries (EURs) for each group. Finding no systematic increase (or decrease) over time, USGS concluded "that technical advances were not sufficient to increase recoveries in wells drilled later in the exploration cycle." Schmoker 1996.[19] That has changed.
- In 1995, USGS estimated that the mean well in the Intermediate Area (which includes Richland County, MT and much more) has an estimated ultimate recovery (EUR) of 41,000 BO. Today's average Richland County well produces more in one year.
- In 1995, USGS estimated mean potential additions to technically recoverable resources for the entire Intermediate area (the great bulk of which is in North Dakota) to be 70 million barrels of oil, and the 5th fractile to be 111 million barrels of oil. Schmoker 1996; USGS NOGA. Compare oil production *during 2004 and 2005 alone* in a *fraction of the Montana part* of the Intermediate area – which will exceed 20 million barrels.

I should note that USGS, in 1995, did not estimate reserves in place or overall recovery factors. Instead it projected (extrapolated from) reported EURs.

Appendix X-1 further describes USGS's 1995 methodologies.

Technology to Recover the Oil: Remaining Challenges

Formidable technology challenges still confront more extensive exploitation of this huge store. For example, Price and LeFever 1994 advocated injection of gas (preferably CO_2) *"at the start of production*" [their emphasis] in order to maintain pressures in the shales (*i.e.*, the Upper and

[19] In 1995, USGS cautiously eliminated from its Bakken assessment data from the prolific Antelope Field established in 1953 because no equivalent "sweet spot" had thereafter been found. Similarly, in that year, USGS refused to consider the East Newark Field as an element in assessing the Barnett Shale. "This [Barnett Shale] play is classified as both hypothetical and unconventional because it is limited to a single production occurrence [the East Newark Field, near Dallas], and its reservoir permeability of 0.1mD falls in the unconventional-play category. … The reservoir quality is the riskiest aspect of the play and was deemed to be so questionable that the play was not individually assessed." The effect was to *quantify* undiscovered potential as zero, even as the *narrative* acknowledged a "significant" resource potential: "Risk for additional producible discoveries in the play is high but potential for additional discoveries is also significant." By 2003, a new USGS assessment estimated a mean of 26 trillion cubic feet (TCF) of undiscovered, technically recoverable natural gas and over a billion barrels of natural gas liquids (NGL), but did not quantitatively assess undiscovered crude oil. (Underlying estimates of undiscovered reserves in place may exceed 200 TCF.)

Lower Members of the Bakken Formation) because otherwise "the 'reservoir drive' of these shales would be quickly lost during production, causing the producing cracks around the wellbore to close and severely limit oil recoveries."[20] The authors called for "meaningful research on nonconventional recovery techniques. USGS Professional Paper 1653, Pitman, Price, and LeFever 2001 focused on prediction of Middle Member limestone reservoir quality (not the shale).

In addition to introduction of technologies not heretofore used in exploiting the Bakken Formation, so as to *expand* the state of the art, observers have repeatedly called for *adherence* to current state-of-the-art techniques and expressed concerns that ignorance, inattention, corner cutting and/or reaching for short-term advantage might have precluded maximum economical recovery.

When drilling focused on the Upper Member, a study of reservoir performance in both vertical and horizontal drilling warned, "Formation damage is a major concern in the Bakken." Reisz (1992) [SPE 22389]. App. X-2. (Most of the *current production* is from the Bakken Formation's Middle Member, in Montana, at a distance from the depocenter in North Dakota.)

Price and LeFever (1994) reiterated their 1992 warning that "only a minute fraction of this oil-resource base appears recoverable by conventional drilling, completion, stimulation, maintenance and production techniques. For example, ... the introduction of water into these oil-wet systems greatly damages or destroys their oil productive capabilities." They therefore urged "meaningful research on nonconventional recovery techniques" – the petroleum engineering as well as petroleum-geochemical and geological facets.

"Type of fluid used while drilling may have adverse effects on production." LeFever 2005b

Challenges will face State regulators in Montana and North Dakota as they carry out their missions to encourage and promote the development, production, and utilization of oil and gas in such a manner as will prevent waste, maximize economic recovery, and fully protect the correlative rights of all owners -- to the end that the landowners, the royalty owners, the producers, and the general public realize the greatest possible good from these vital natural resources. For example, unitization may appear important to maximize economic recovery in some instances.

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[20] "Whatever the volume of Bakken-generated oil, it is very large, in the range of hundreds of billions of barrels. Furthermore, the results of Osadetz *et al.* (1992) and our study suggest that very little if any, of the oil generated by the Bakken shales has left the Bakken source system, … Results of Bakken horizontal drilling on the U.S.A. side of the Williston Basin demonstrate that part of this oil is mobile and recoverable. However, as Price and LeFever (1992) stressed, only a minute fraction of this oil-resource base appears recoverable by conventional drilling, completion, stimulation, maintenance and production techniques. For example, ... the introduction of water into these oil-wet systems greatly damages or destroys their oil productive capabilities. Furthermore, aqueous-pyrolysis experiments performed on the Bakken shales ... demonstrate that the organic matter of these rocks has only a limited generation capacity for HC gases compared to type III organic matter. Thus the 'reservoir drive' of these shales would be quickly lost during production, causing the producing cracks around the wellbore to close and severely limit oil recoveries. As Price and LeFever (1992) suggested, recovery of significant amounts of this oil-resource base may only be possible by a gas (preferably CO_2) injection program at the start of production." Price, L.C. and LeFever, J.A. 1994 Dysfunctionalism in the Williston Basin: the Bakken/mid-Madison petroleum system. Bulletin of Canadian Petroleum Geology, v. 42, p. 187-218 (at page 214). The North Dakota Geological Survey's web site posts this paper and others regarding the Bakken Formation.

Why Industry Alone May Not Do It

Total reliance on operators, contractors, or consultants to perform technology research seems out of place:

Major oil companies no longer have research departments. DOE/FE 2004

Mineral ownerships in the Williston Basin tend to be far more fragmented than in foreign countries or the U.S. offshore. Developing and testing out an improved technology for exploiting Bakken resources generally or subsets may have limited value to any single operator. Moreover, private research results may be withheld from other firms.

Private industry participants have to focus on particular opportunities, at times and places and during pricing cycles, which may conflict with long-term maximum economic recovery of the resource (or may seem to decision makers to conflict).

U.S. Government data projections dampen industry interest.

Next Year's EIA Long-Term Projections for 2006 – 2026

EIA's module for projecting domestic long-term production of crude oil relies directly on USGS's National Oil and Gas Assessment (NOGA) of "undiscovered" but "technically-recoverable" resources. (Increasing the USGS resource estimate by 20% increased EIA domestic production by 9% above EIA's reference case in a 2001 sensitivity test.)

- USGS last assessed the Bakken Formation in 1995, concluding that only miniscule portions of crude oil in place could be recovered due to unsolved technological barriers: Crude oil was virtually everywhere under 17,800 mi^2 of the Williston Basin on the USA side of the border with Canada, but natural porosity and permeability were very low and finding natural "sweet spots" was a "hit or miss" matter in a large area very little of which had been tested by drilling. [App. X-1.]
- USGS's assessed only 151 million barrels in 1995 for the entire untested area of the Williston Basin, including 70 million bbls of undiscovered oil, "technically recoverable" oil ascribed to the "hypothetical" 8,185 mi^2 "Intermediate Bakken Play" (of which Richland County – wholly untested then – made up a small fraction).
- The Richland County play so far has tested less than 5% of the "Intermediate" area.[21] It seems reasonable to anticipate that Richland County alone will prove up more than the 70 million bbl in the USGS "Intermediate" area resource assessment.[22]
- USGS NOGA reassessment is not due until 2007. One might expect a much larger Bakken Formation resource estimate, on the order of billions of barrels, in light of current knowledge, technology, and experience in Montana.
    - A new sensitivity test seems in order, as a first step by EIA. What would EIA's model project if one added 30 billion bbls of crude oil resource?
    - Then, EIA and/or DOE could invest in jump-starting USGS's 2007 reassessment.
    - This time, assessment should include estimation of resources in place and recovery factors (instead of skipping directly to recoverable resources), if only to give DOE, DOE's Office of Fossil Energy (FE), researchers, and the industry a base to use in setting recovery technology goals.
- FE's publication this year of basin studies regarding extension of proven reserves in already-discovered fields pose analogous challenges. EIA must now evaluate and decide how much credence to give in its "rapid technology" case to FE's view that use of

[21] At 640-acre spacing, 100 wells represent 100 mi^2. At 1280-acre spacing, 200 wells represent 400 mi^2.

[22] *E.g.*, if 200 wells produced 100 B/D for 10 years, on the average, we would have 73 million barrels.

readily-available, state-of-the-art CO_2-EOR could add tens of billions of barrels of crude oil to domestic supply by raising recovery factors from 33% almost to 47%.

Conclusion: 1993►►►2005

When we brought the vast, "unconventional" Bakken Formation to DOE's attention in 1993 (App. X-5: "Have We A Vast In-Place USA Oil Resource?"), Leigh Price (a brilliant petroleum geochemist in USGS) and Julie LeFever (an indefatigable petroleum geologist in the NDGS) had set out to convince their peers that, contrary to then-conventional wisdom:

- The hundreds of billions of barrels of light, sweet, desirable crude oil once generated in the Bakken Formation *are still there* (and have not migrated upwards);
- most of whatever crude oil is still in the Bakken Formation is now in immediately adjacent limestones (not in the Bakken shale itself, focus of horizontal wells then);
- industry had used unsuitable techniques for drilling and completing wells and stimulating, maintaining, and producing from petroleum-bearing formations; and
- intensive research (both scientific and technological) could yield important dividends for understanding and exploitation of these natural bounties.

Bakken crude oil has come far since 1993. Price, until he died, and LeFever, to this very day, continued to publish and speak, State government and professional forums helped spread their message, people in industry reacted, and results in Montana over the past couple of years already vindicate much of that message. North Dakota "tight hole" results, when soon released, may also do so. But the full measure of their challenge remains unmet.

- Geologists have long believed that the Bakken shales generated enormous quantities of crude oil (so enormous that exactly how much seems academic). Some of them now accept that the oil generated did not largely migrate upwards to other productive horizons, such as the Madison, in the Williston Basin.
- In the last couple of years, operators drilling horizontal wells into the limestones adjoining the shale have had excellent results, at least in Montana.
- It is unclear to what extent operators adhere to state-of-the-art techniques. It is clear that the current play is "technology driven" – exploiting for example techniques to frac and stimulate horizontal laterals which have evolved since the previous "economics driven" play of the 1980s/1990s.
- Intensive research has not yet happened.

Technological change can make a shambles of conventional macro-estimates of hydrocarbons (and other geological resources), as Bruce Netschert and Julian Simon wisely taught (beginning, respectively, in the 1960s and 1970s). In this century, DOE would serve large national interests by updating its attention to Bakken crude oil technology.

Vast resources in place in the Bakken Formation resemble (at risk of over-simplification) a virtually infinite supply of high-quality crude oil in a giant tank without conventional taps, pumps, or spigots. Oil wells release small amounts, slowly, for many, many years -- as if each well were a pinhole leak.

- Hitting a natural "sweet spot" in previous plays meant a larger pinhole and chance for more profitable production in the previous plays – the vertical play and the horizontal play into the Upper Member shale.
- Creating artificial "sweet spots" is key to technology improvements now in use.
- Exploiting state-of-the-art technology to the hilt and advancing it further offer challenges aplenty to raise production rates further, to keep holes producing, and to make it attractive to drill many more.

Of course, an oil tank analogy oversimplifies by implying homogeneity of rock pores, fractures, thicknesses, and accumulation processes. Geologic interpretations (admittedly not immutable[23]) suggest that the greatest concentrations of oil will be in North Dakota, rather than Montana.

Be that as it may, the Bakken-play *fraction* of Richland County, MT, will likely produce about 15 million barrels *this year alone*.

- All of Richland County comprises 2,084 square miles.
- For the entire 17,800 square miles of Bakken Formation on the US side of the border, the USGS estimated (and EIA still uses) 151 million barrels as the *total*, technically-recoverable resource.

I find it hard to avoid the conclusions, based on what we know in 2005, that this 1995 USGS estimate is too low, far too low, orders of magnitude too low.

Surely, it's time for a fresh look at the Bakken Formation and all its implications.

[23] Like other sciences, geology should subject both theories and interpretations to testing and attack.

Appendix X-0: Richland County, MT, Bakken Wells, 2000-2004, Reported Initial Daily Production

Tom Richmond, Administrator/Petroleum Engineer to Montana's Board of Oil & Gas Conservation, says that Montana's recent Bakken play (focused entirely on Richland County) has increased production by 8 million barrels in 2004 alone – maybe 30% of Montana's production – (and considerably more already in 2005), in contrast to almost zero barrels and zero percent in 2000. See Table 1. In the first nine months of 2005, Elm Coulee Field's 268 Bakken wells produced 11 million barrels of oil (over 200 BO/D). Richmond ascribes recent production growth in Richland County to the current Bakken play.

Table 1. 2000-2004 Bakken play in Richland County, MT (adjoining McKenzie County, ND)

	2000	2001	2002	2003	2004
Richland County well drilling results					
Total well completions	6	21	22	44	93
Bakken well completions	1	11	15	38	89
Completions in other formations or service well	5	11	6	4	4
Dry holes	0	2	1	2	5
Richland County "Elm Coulee" Field[24]: wells, oil, gas					
Year-end Bakken wells	1	11	26	65	159
Bakken Formation production during year:					
Oil - *thousands* of bbls	21	266	776	2,687	7,523
Gas - MMcf	11	158	470	1,358	3,414
Oil production - *millions* of bbls – incls. *non*-Bakken					
Richland County per Montana DNRC statistics	2.6	3.0	3.4	5.3	10.2
Statewide per Montana DNRC statistics	15.8	16.3	17.0	19.4	24.7
Statewide per EIA estimates	15	16	18	19	22
Year-end proven reserves, statewide per EIA	235	260	288	315	364

Table 2 lists operators in Montana's Bakkan play during 2004, wells they completed, and initial daily oil production they reported -- ranging from 46 to 1066 BO/D (with most above 500).

Table 3 shows the build up of the play during 2001 through 2002, after the first Bakken completion in 2000. Initial production for completions in 2001 ranged from 150 to 368 BO/D and for completions in 2002 from 146 to 576 BO/D as shown in Table 3.

As the play picked up during 2003, reported initial production ranged from 131 to 1280 barrels a day for Bakken completions. Table 4. There were no big oil companies ("majors") in the play. Lyco's year 2000 completion in the Bakken (API#25-083-21881), reporting an initial flow of 85 BO/D, averaged 129 BO/D that year. Monthly production this year ranged from 85 to 117 BO/D. One wonders whether similar stimulation techniques could be used to frac older horizontal wells -- completed in the Bakken Upper Member *shale* during the *previous* play.

One hopes forthcoming analyses of well performance of *all* Bakken wells in Richland County might be illuminating. Data concerning only Bakken completions since 2000 seem consistent with technology improvements over the short period from mid-2000 to now or re-stimulations or both.[25] As of early December, 2005, there were 330 Bakken completions in Montana, statewide, and 268 in "Elm Coulee" Field (Richland County).

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[24] Since 2000, Montana has ascribed all Richland County Bakken completions to the "Elm Coulee" Field. Bakken completions in earlier years are ascribed to other fields. I did not examine or analyze records of those earlier completions.

[25] For Elm Coulee Field alone, average production/well/year (BO/yr) rose steadily from 21,164 in 2000 to 47,318 in 2004. Average production/well/day (BO/D) was 129 in 2000 and 201 in 2005 year-to-date.

Table 2. 2004 Wells, Richland County, Montana: Operators and Initial Bakken Production Rates (BO/D)
[API ## skip prefix "25083"]

	BO/D	API#		BO/D	API#
Lyco Energy Corporation	650	21955	EOG Resources, Inc.	484	21962
	759	22034		701	21984
	450	22038		255	21988
	832	22044		960	22041
	522	22045		86	22043
	172	22056		510	22072
	508	22057		268	22074
	501	22064		445	22092
	461	22085		525	22097
	705	22089		267	22144
	611	22094		439	22156
	639	22117		Dry Hole	22177
	1048	22126		549	22178
	155	22136		140	22210
	654	22137	Nance Petroleum Corporation	Red River	
	Ratcliffe			774	22124
	520	22147		Red River	
	500	22148		428	22142
	611	22149		364	22168
	470	22150		400	22190
	864	22155		13	22193
	352	22181		46	22203
	508	22188		213	22205
	435	22196	Continental Resources Inc	1107	22000
	552	22197		440	22027
Headington Oil LP	1016	21986		694	22062
	306	22068		680	22063
	428	22080		674	22141
	1066	22081		941	22153
	322	22082		1033	22160
	464	22083	Petro-Hunt, LLC	343	22003
	1036	22084		73	22012
	351	22095		420	22024
	229	22111		306	22145
	341	22113		176	22151
	940	22115		Dry Hole	22194
	449	22116		Dry Hole	22223
	734	22123	Burlington Resources O&G	348	22076
	461	22133		535	22087
	146	22157		369	22100
	451	22158		542	22108
	704	22161		305	22159
	834	22167	Slawson ExplorationCompany	1043	22129
	491	22171		87	22176
	772	22172		796	22200
	687	22191		1097	22224
	830	22201	Westport Oil and Gas Co, L.P.	464	22127
				497	22152
				63	22162
			Whiting Oil&Gas Corporation	Dry Hole	22070
			True Oil LLC	Dry Hole	22099

Note: Initial production shown for all Bakken completions, but not for Ratcliffe or Red River wells.

Source: MT Oil & Gas Conservation Div., Annual Review 2004, Sect. 13: Well Completion Summary by County

Table 3. 2000-2002 Wells, Richland County, MT: Operators and Initial Bakken Production Rates (BO/D)

Lyco 2000	85		Headington 2000	Ratcliffe		Luff 2000	Nisku
				Red River		Armstrong 2000	Red River
				Stonewall			
Lyco 2001	368		Headington 2001	126		Armstrong 2001	150
	272			Red River			Red River
	282			Red River			Dry Hole
	276						Red River
	267					Luff 2001	Ratcliffe
	190						Stonewall, Red River
	210					Chesapeake 2001	Dry Hole
	220						Red River
	195					Continental Res. 2001	Red River
						Whiting 2001	Red River
						Choctaw 2001	Ratcliffe
						Flying J 2001	Dakota, Lakota SWD
Lyco 2002	205		Headington 2002	Red River		Petro-Hunt 2002	Red River
	177			445			Red River
	188			436			Red River
	191			356			Red River
	227			342		Chesapeake 2002	Dry Hole
	252			413			
	146						
	339						
	329						
	576						

Note: Initial production shown for Bakken wells, but not for wells completed in other (named) formations

Table 4. 2003 Wells, Richland County, MT: Operators and Initial Bakken Production Rates (BO/D)

Lyco 2003	308	287	440	414	536	709	566	691	1086	460	775
Headington 2003	363	632	748	470	416	401	516	712	557	716	452
	975	865	322	131	216	741	816	692	558		
Petro-Hunt 2003	Dry	Dry	386	Dry	RedRiv						
EOG Res. 2003	269	624	220								
Continental 2003	459	1280	322								
Nance 2003	Stonewall	RedRiv									

Note: Initial production shown for Bakken wells, but not for wells completed in other (named) formations

Appendix X-1: How USGS Assessed Bakken Resources in 1995

USGS used statistical analyses of available data, including analyses searching for technology trends, in estimating 151 million barrels of resource in the entire Bakken Formation (as the mean estimate). Although accompanying narrative said that "potential additions to oil reserves" are "measured" in the "hundreds of millions of barrels" (Schmoker 1995), the 1995 methodology did not disclose any such measurement or use it. The published 1995 reports did not estimate resources in place or recovery factors. USGS statistical analyses skipped any calculation of estimated resources in place.

USGS divided the Bakken Formation into three parts (Schmoker 1996, Fig. 1), and for each part determined a total area, a number of uniformly-sized "cells", and how many cells had been tested by successful drilling, unsuccessful drilling, or not tested, as follows:

- The confirmed "Baken Fairway Play" [#3110] (803 sq. mi. and cell size 480 acres = ¾ of a square mile), which USGS maps entirely in North Dakota, had 1,071 cells of which 246 were productive and 69 were tested nonproductive for a 0.70 success ratio, to be applied to untested cells; and
- the hypothetical "Bakken Intermediate Play" [#3111] (8,185 sq. mi. and cell size one square mile) had 8,185 cells, of which 76 were productive and 303 were tested nonproductive for a 0.20 success ratio, to be applied to untested cells (including Richland County, MT); and
- the hypothetical "Bakken Outlying Play" [#3112] (8,854 sq. mi. and cell size one square mile) in North Dakota and Montana (USGS ignores Canadian portions of the outlying play) had 8,854 cells of which 5 were productive and 206 were tested nonproductive for a 0.10 success ratio, to be applied to untested cells.

The USGS methods derived the following data for each of the three Bakken Plays:

Table 5. USGS 1995 NOGA Bakken Assessment Summaries

	Fairway	Intermediate	Outlying	Total
Gas-Oil Ratio (CFG/bbl)	900	800	800	NA
API gravity	41	41	41	41
Depth (ft) median	10,500	10,500	8,800	NA
Fraction of untested cells to be tested by wells primarily targeted for play itself [or a deeper horizon]	0.95 [0.05]	0.80 [0.20]	0.50 [0.50]	NA [NA]
Fraction of wells likely to be stimulated	0.10	0.10	0.10	0.10
Potential reserve additions – oil (MMBO) – mean	72.72	70.30	8.16	151.18
Potential reserve additions – gas (BCFG) – mean	65.45	56.24	6.53	128.12

Schmoker 1996 summarizes the USGS NOGA Team assessment process and 1995 results:

- The Bakken "accumulation as a whole is far from depleted."
- In 1995 the Team "estimated the mean potential additions to technically recoverable resources for the Bakken Formation in North Dakota and Montana at 151 MMBO."
- "This estimate of remaining potential is based on existing technology and development practices, and is a small fraction of the oil in place (Price and LeFever 1992). As of July 1993, cumulative production from horizontal and vertical Bakken Formation wells in North Dakota and Montana (including Sanish Pool wells) totaled about 34 MMBO."
- Performance of wells "considered individually is varied and unpredictable" but the "concept of a continuous accumulation sampled by many boreholes leads to statistical predictability for groups of wells."

The USGS NOGA Team excluded from the sample of boreholes the very prolific wells of the Antelope Field, which first established Bakken production in 1953.

- "Vertical Bakken Formation (Sanish Pool) wells in Antelope Field have produced about 12 MMBO. Typical recoveries of Sanish Pool vertical wells compare very favorably to those of vertical (and horizontal) wells drilled in other parts of the Bakken Formation …"
- "… 80% of productive, early Sanish Pool wells have produced more than 43,000 BO, 50% have produced more than 165,000 BO, and 20% have produced more than 450,000 BO. The mean well

… has produced 237,000 BO. Cumulative production from these wells is approaching ultimate production."

- The "evidence suggests but does not prove that the Sanish Pool is unique, and that the potential for additional Bakken production from analog geologic settings is low."

None of the foregoing data entered into any of the USGS Team's assessments.

- Outlying area (8,854 mi^2): "Meaningful Bakken Formation production has not been established in the Outlying area despite several hundred penetrations since 1980 by wells targeted for deeper horizons. As of July 1993, total reported Bakken Formation production from wells within the Outlying area amounted to only 5,755 BO."
- The USGS Team "estimated additions of 8 MMBO (mean), with a 30% chance that technically recoverable reserves are less than 1 MMBO."

There is no indication whether the "several hundred penetrations" stopped and tested in the Bakken Formation or, if so, which members of the Formation were tested, or what mud weights drillers used when penetrating the overpressured Bakken.

- Intermediate area (8,185 mi^2): "Horizontal-drilling activity in the Intermediate area has been very low. However, … data from vertical wells can be useful in depicting the fundamental performance characteristics of a fractured reservoir such as the Bakken Formation, even though development by horizontal drilling might be contemplated for the future."
- "Excluding the Sanish Pool of Antelope Field, Bakken Formation production from vertical wells in both North Dakota and Montana portions of the Intermediate area has been established since 1976."
- "… 80% of productive vertical Bakken Formation wells in the Intermediate area (excluding the Sanish Pool) will ultimately produce more than 2,000 BO, 50% will ultimately produce more than 18,000 BO, and 20% will ultimately produce more than 64,000 BO."
- "In a general sense, these values are an order of magnitude lower than the cumulative production figures for the Bakken Formation of Antelope Field … The mean well … has an estimated ultimate recovery (EUR) of 41,000 BO."
- "EUR probability distributions for vertical wells of the Intermediate area completed between 1/76 and 8/82 (1st third), 9/82 and 4/86 (2nd third), and 5/86 and 12/91 (3rd third) are similar …"
    - "EUR expectations do not decrease significantly from one time period to the next, showing that the more productive cells of the Intermediate area were not methodically identified early in the exploration cycle."
    - "Conversely, EUR expectations do not increase significantly from one time period to the next, showing that technical advances were not sufficient to increase recoveries in wells drilled later in the exploration cycle."
- The USGS Team "estimated mean potential additions to technically recoverable resources for the Intermediate area at 70 MMBO."

All of Richland County, Montana, is within the Intermediate area. The 268 Bakken wells completed there since 2000 now produce over 200 BO/D on the average and will produce close to 15 MMBO during 2005.

- Fairway area (803 mi^2): "Bakken Formation production from vertical wells … has been established since 1977. Over 200 horizontal wells have been drilled in the area since 1988, which, as of July 1993, had a cumulative production of 12.2 MMBO."
- "The 75 vertical Bakken Formation wells [of the Fairway area] had cumulative production, as of August 1992, of 8.0 MMBO; their ultimate production is estimated to be 9.4 MMBO."
- "… 80% of productive vertical Bakken Formation wells in the Fairway area will ultimately produce more than 18,000 BO, 50% will ultimately produce more than 89,000 BO, and 20% will ultimately produce more than 210,000 BO. These values are significantly higher than those for the Intermediate area … Comparison of the Fairway and Intermediate areas … is based on vertical wells drilled during the same period of time and therefore presumably incorporates similar engineering practices."
- The USGS Team "estimated mean potential additions to technically recoverable resources for the Intermediate area at 73 MMBO."
- "Some wells of the 3rd time period drilled near or within an existing cluster of vertical or horizontal wells encountered reduced reservoir pressures and, in consequence, have somewhat reduced ultimate recoveries …"

Appendix X-2: Excerpts from SPE 22389

Reisz, M.R. 1992 Reservoir Evaluation of Horizontal Bakken Well Performance on the Southwestern Flank of the Williston Basin

The Mississippian Devonian age Bakken shale is a naturally fractured formation that is both source and reservoir rock. The Bakken consists of three members. …. The overpressured Bakken, found at approximately 10,000' [3048 m] with a virgin reservoir pressure corresponding to a 0.6 to 0.7 psi/ft gradient [13.6 – 15.8 kPa/m], has generated over 100 billion barrels [15.9 E+09 m^3] of oil based on industry estimates.

….

In the "Fairway" only the upper Bakken is considered net pay, and [I] will refer to the upper Bakken as Bakken.

Since late 1987 the Bakken play has been dominated by horizontal drilling. There are approximately 140 horizontal wells that have produced oil from the Bakken formation, and an equal number of vertical wells.

….

Several key points are supported by performance data: an average initial decline of 40-45%, a final decline of 25-35%, a breakeven point of approximately 150 MBO [23.8 E+03 m^3] at NPV(15) = 0, recoverable reserves 2.5-3.0 times a vertical well, and 20-25% of recoverable reserves produced in the first year.

….

A total of 21 wells from 7 fields were studied in detail.

….

An examination of storage capacity in fractures indicates that less than 10% of the total oil in place may be stored in the fractures of the upper Bakken member.

PRODUCTIVITY PROBLEMS

[F]our major reasons for less than ideal results:

1. Formation damage

The inability to effectively remove formation damage will become worse as reservoir pressure decreases.

2. Overdrilling

Current well spacing in the "Fairway" appears too dense in some areas for horizontal drainholes.

3. Orientation

Ideally the drainhole is parallel to the low permeability direction of the reservoir.

4. Porpoising

Problems at the wellsite can prevent zonal penetration in the desired horizontal segment of the drainhole.

….

Formation damage is a major concern in the Bakken. The invaded zone around the wellbore may reduce well productivity. Thus, a key benefit in the drilling of horizontal drainholes may be lost or reduced. This condition will be more prevalent when excessive mud weights are used to control problems of hole stability, or when a portion of the reservoir is partially depleted. Undoubtedly, fracture collapse and near wellbore formation damage have occurred and prevented some of the Bakken horizontal drainholes from achieving their productive potential.

RECOVERY FACTORS

Documented numbers are not available for recovery factors in horizontal Bakken wells. Joshi indicates a 16% recovery factor is a good approximation and is consistent with the 15 to 20% range listed in Table 5. These numbers were obtained from commission hearing exhibits. Joshi has indicated that increased recovery factors from drainholes may be 2 – 5% higher than for vertical wells.

CONCLUSIONS

6) Bakken drainholes usually recover 20-25% of their reserves in the first year.
7) Formation damage can have significant impact on productivity
8) Effective H (thickness) of the reservoir is larger than the actual thickness (h) of the upper Bakken shale.

Appendix X-3: Excerpts from Price and LeFever, 1994

Dysfunctionalism in the Williston Basin: the Bakken/mid-Madison petroleum system.
Bulletin of Canadian Petroleum Geology, v. 42, p. 187-218.

[p 188] In a pioneering petroleum-geochemical study, Williams (1974) concluded that the shales of the Upper Devonian and Lower Mississippian Bakken Formation were the source of the oils produced from the limestones in the middle of the Lower and Upper Mississippian Group in the Williston Basin. Based on Williams' (1974) conclusions, Dow (1974) … postulated oil expulsion from the Bakken shales, vertical migration via fractures and accumulation in the mid-Madison reservoirs. This early work is the foundation for current models of oil expulsion and accumulation. …. Indeed, Dow's (1974) early synthesis was a foundation for the present-day "petroleum-system" (Magoon and Dow, 1991).

Osadetz *et al.* (1992) … extensively studied many rocks and oils from the Canadian portion of the Williston Basin and concluded that the mid-Madison oils there had not been sourced by the Bakken shales … . (Canadian oil deposits make up 75-80% of the discovered recoverable oil in the Williston Basin.)

….

In this study, we interrelate with the work of Osadetz and co-workers …

[p 207] Our data and conclusions disagree with those of Williams (1974) and, therefore, with the subsequent models developed by Dow (1974). ….

[p 211] The conclusion that the Bakken shales have sourced the Williston Basin Madison oils is firmly embedded in both petroleum-geochemical literature and thought. However, after careful examination of the evidence for it we find that there is no foundation for this conclusion.

Osadetz *et al*. (1992) … found that Madison oils did not correlate to either Bitumen from the Bakken shales or to their three Bakken-sourced oils. ….

….

None of our Madison oils, nor those of Osadetz *et al*. (1992), are in the Bakken oil family. …

[p 213] We conclude that the Bakken oils and the Madison oils are two distinct oil families with fundamental differences inherited from different source rocks.

[p 214] IMPLICATIONS

We suggest that the absence of Bakken-generated oil in the Williston Basin Madison reservoirs has important implications for both models of oil expulsion and accumulation and for the existence of very large in-place oil resource bases in self-sourced fractured shales. … [B]y conventional wisdom oil expulsion from organic-rich rocks is efficient. … However, … using the Bakken shale as an example, Price and LeFever (1992) proposed the existence of very large in-place oil-resource bases in self-sourced, organic-rich, fractured mature shales. ….

….

The principal conclusion of, and reason for, this study is to provide further evidence that huge, in-place oil-resource bases may exist in and adjacent to mature shales not cut by significant faulting nor bounded by laterally-transmissive units, not only in the Williston Basin but in all petroleum [p 215] basins. We hope that underscoring this proposition and stressing the size of the resource base would result in meaningful research on nonconventional recovery techniques for it.

[p215] The Williston Basin is the, or among the, structurally simplest basins in the world with significant oil reserves … [and] had an atypically simple geologic history. … {U]ntil the petroleum geochemistry of the relatively simple Williston Basin is understood, it will be very difficult to achieve an acceptable understanding of the petroleum geochemistry of much more complex basins such as Los Angeles, North Sea, Persian Gulf, Alberta or U.S. Gulf Coast. This is especially true considering the excellent [Williston Basin] sample base available for study … and … amount of published and unpublished research carried out there.

[p 216] We envision the existence of very large in-place oil-resource bases in or adjacent to mature, self-sourced, organic-rich, fractured, fine-grained rocks in the unstructured areas of deep petroleum basins, world-wide.

Appendix X-4: Excerpts from USGS Professional Paper 1653

Pitman, J.K, Price, L.C., and LeFever, J.A. 2001

Diagenesis and Fracture Development in the Bakken Formation, Williston Basin:
Implications for Reservoir Quality in the Middle Member

[p 1] Most oil in the Bakken Formation resides in open, horizontal fractures in the middle member. Core analysis reveals that sandstones and siltstones associated with thick mature shales typically have a greater density of fractures than sandstones and siltstones associated with thin mature shales. Fractures were cause by super lithostatic pressures that formed in response to increased fluid volumes in the source rocks during hydrocarbon generation.

[p 4] In North Dakota, the Bakken occurs solely in the subsurface and has been informally subdivided into lower, middle, and upper members. The lower member consists of … competent and massive to fissile, slightly to highly organic rich shale that is locally calcarious at its base. In the deeper portion of the basin, the shale is a kerogen-rich, mature source rock with the organic material evenly distributed throughout. ….

The lithology of the middle member is highly variable … ….

The upper member … is lithologically similar to the lower member and consists of … organic-rich shale … It … has a higher organic matter content [than the lower member].

[p 8] Multiple fractures types occur on a macroscopic and microscopic scale in the Bakken Formation and are most abundant in the lower and middle members. In sandstones and siltstones in the middle member, the vast majority of these fractures are open (nonmineralized), discontinuous features oriented subparallel (horizontal) to bedding with aperture widths commonly exceeding 30 μm … … . An important characteristic of these fractures is that they typically form a dense network that is highly visible on wetted, slabbed rock surfaces if the host sandstones and siltstones have high residual oil saturations … Such fractures are generally absent in rocks that have little or no residual oil.

[p 14] Measured core porosities in the middle member range from 1 to 16 percent but generally are low, averaging about 5 percent … ….

[p 15] Measured permeability ranges from 0.1to 20 millidarcies in the middle member and typically is very low, averaging 0.04 millidarcies … ….

Core studies reveal that reservoir rocks with permeability values greater than 0.01 millidarcies in the middle member commonly contain open, natural hydraulic fractures … …. The highest permeabilities in the middle member correspond to sandstones and siltstones with high residual oil concentrations and well-developed open fractures. At depths greater than 2,500 to 3,000 m, permeable fractures focus hydrocarbon fluids and locally serve as oil reservoirs.

[p 16] [C]oncentration, density, and vertical distribution of fractures in the reservoir interval all dramatically increase as source rocks are progressively buried and proceed through the hydrocarbon-generation window. …. The best developed and most extensive fracture network occurs in oil-saturated reservoir rocks adjacent to mature to over-mature source rocks that are actively generating hydrocarbons. The fractures in these rocks are highly visible when the rock is wet …, indicating they are highly permeable …

Horizontal fracturing in the middle member is hypothesized to have resulted from expulsion of bitumen from upper and lower shales into interbedded, low-permeability sandstones and siltstones by means of early-generated CO_2 … [formed in the] organic-rich shales by H_2O chemically reacting with kerogen ... in which the products of the reaction (oil and gas) increase in volume by about 150 percent relative to the reactant kerogen …. The cross-cutting relations of fractures indicate that oil expulsion from the upper and lower shales did not occur during one event; rather, it took place episodically initiated by pressure buildups in the source-rock interval … [indicating] that the limestone units bounding the Bakken source system acted as pressure seals to the impermeable shales and sandstones.

[p 17] Most oil in the Bakken petroleum system resides in open, horizontal (bedding-parallel) fractures and in secondary micro-porosity adjacent to fractures, with only small amounts dispersed in matrix pores.

Appendix X-5: Have We A Vast In-Place U.S.A. Oil Resource?
[Submitted February 1993 to U.S. Department of Energy]

Summary

- New studies and a peer-reviewed article by Leigh Price, USGS, and Julie LeFever, N.D. Geol. Survey, indicate that enormous crude oil resources wait to be tapped in North Dakota:
  - at least 100-150 billion barrels in place -- perhaps 250.
  - this resource is omitted from all current resource base estimates -- just as coal-bed methane used to be omitted as a gas resource until a couple of years ago.

- North Dakota alone may double the U.S.A. oil reserves.
  - Applying similar analyses across the U.S.A. may add several times the reserves of Saudi Arabia to potential crude oil resources for the lower-48 contiguous states.

- DoE needs to examine whether technology currently exists or can be readily developed to enable commercial production.
  - There is enormous job-generating potential at generally low environmental costs and risks.
  - There are extraordinary international strategic stakes.

- This is a very desirable, marketable crude oil, at accessible and environmentally-acceptable locations.
  - This is a 40-45E API gravity crude.
  - It is mobile and found at depths up to 10-11,000 feet.
  - It is not waxy and thus easily producible.

- Some has been produced already from non-optimum areas (but not in great quantities) despite use of production techniques inappropriate for the resource base.

- Much of the in-place oil could be produced -- in all probability -- but the well drilling and completion and production techniques, including pressure maintenance, have to be tailored to this resource, or operators will miss most of their opportunity, making many prospects uneconomical.
  - Like coal-bed methane, the correct techniques may be quite simple, yet seem radically innovative at first.
  - Each North Dakota well will cost hundreds of thousands of dollars. Recoverable reserves may be 1-5 million barrels per well or even more. However much remains to be tested and demonstrated.

- DoE could spark private and public sector attention and debate, and sponsor testing and demonstration projects.

1. Price & LeFever studies identify possible vast in-place oil resource bases

US Geological Survey senior geologist/geochemist Leigh Price and North Dakota Geological Survey geologist Julie LeFever have just published a peer-reviewed article suggesting enormous crude oil resources waiting to be tapped. "Does Bakken Horizontal Drilling Imply a Huge Oil-Resource Base in Fractured Shales?" in GEOLOGICAL STUDIES RELEVANT TO HORIZONTAL DRILLING: EXAMPLES FROM WESTERN NORTH AMERICA (Rocky Mtn. Assoc. of Geols., Denver: 1992) 199-214.

- Price is a senior research geologist at the USGS, Denver. He is a well-known, independent, controversial and daring thinker who has no fear of challenging accepted wisdom. Two previous challenges to accepted wisdom, which are now accepted paradigms, are:
  - ability of oil to migrate from source rocks to reservoir rocks in gas-phase solution;

  - non-local generation of oil, in the deeper parts of petroleum basins ("oil kitchens"), with extensive vertical and horizontal migration, to shallower reservoir rocks.
- Price's professional recognition includes several awards by the AAPG and regional geological associations and editorship of the Journal of Petroleum Geology in 1992.
- LeFever is a more conservative thinker in her state's government who is responsible for stimulating resource utilization.
- Price and LeFever have studied this resource for years.

2. Estimated size of North Dakota's Bakken shale resource

Focusing solely on North Dakota Williston Basin's Bakken shales, Price & LeFever estimate at least 100-150 billion barrels in place -- perhaps as much as 250 billion barrels.

- This in-place resource is omitted from all current resource base estimates -- just as coal-bed methane used to be omitted as a gas resource until a couple of years ago.
- If this North Dakota oil resource could be proven with a 20% recovery factor, we would add 20-30 billion barrels or more to -- and so double -- DoE/EIA's current estimate of 25 billion barrels of proven, remaining, recoverable crude oil for all of the United States combined (including Alaska)!
- DOE/EIA estimated that North Dakota's year-end 1991 proven, remaining recoverable crude oil was 232 million barrels -- perhaps 0.1% of the Price-LeFever in-place resource base.

3. Nature of North Dakota's Bakken shale crude oil resource

This in-place resource is a desirable commodity, readily marketable as soon as it can be commercially produced. It will displace oil imports, and thus could favorably and significantly impact the U.S.A. balance of payments.

- This 40-45° API gravity crude oil is an extremely desirable refinery feedstock.
- It will flow up the well bore. (This is not a synthetic fuel to be made by heating the shales. Past geologic heat flows have already made the oil.)
- It is found at depths up to 10-11,000 feet.
- Because it is not waxy, it is easily producible. It is mobile, and some has been produced already (but not in great quantities, only about 5 million barrels) despite the operators' use of technologies that reflect serious misunderstanding of and are inapproriate for the resource.
- The resource base exists in regionally interconnected fractured networks which should be highly amenable to sustained recovery using appropriate secondary oil recovery techniques -- which the DoE is already examining in a program seeking to exploit a part of some 76 billion barrels of the in-place conventional oil resource base.
- A significant portion of Bakken oil possibly could be produced -- but well drilling, completion, stimulation and production techniques, including pressure maintenance, have to be tailored to the non-conventional characteristics of the resource.
- Industry has spent roughly half a billion dollars on a horizontal drilling program in the Bakken shales without finding an effective, economical approach. These efforts concentrated on non-optimum portions of the Williston Basin and used drilling, completion, stimulation and production techniques quite inapplicable to the characteristics of this resource base.

4. What DoE should do

The issue which DoE needs to resolve is whether technology is already available -- or can be readily developed -- to enable commercial recovery of such in-place oil resources.

- Like coal-bed methane, the correct techniques may turn out to be quite simple, yet seem radically innovative at first.
- These North Dakota wells will only cost hundreds of thousands of dollars each. Recoverable reserves may be 1-5 million barrels per well or more. However much remains to be tested and demonstrated.
- There is an enormous job-generating potential associated with this resource base at generally low environmental costs or risks.

- There are extraordinary strategic stakes.
- Profound and responsible curiosity should impel DoE now.
- Affirmative findings might reverse the U.S.A.'s decline as a crude oil producer within a very few years.
- Even before significant production is achieved, just proving up a significant new petroleum province will be strategically important (as was North Sea, for example).

5. Implications beyond North Dakota

The potentials go well beyond North Dakota. Turning to what is known of the organic-rich source rocks and petroleum geochemistry of other basins, Price & LeFever speculate that in-place oil resources on the order of tens to hundreds of trillions of barrels may exist in the lower 48 contiguous states.

- If you assume ultimately proving up 10 trillion barrels in place with a 10% recovery factor, you would be considering one trillion barrels of recoverable oil.
- Current crude oil reserve estimates are 260 billion barrels for Saudi Arabia and close to one trillion barrels for the world as a whole.

6. Why this resource has been overlooked

The Bakken shale of North Dakota is, conveniently, one of the best-known and most studied organic-rich source rocks in the world. Price and LeFever's extraordinary estimates reflect the following principal factors:

- Contrary to industry beliefs through the 1980s (formerly shared by Price), almost none of the oil in place in the North Dakota Bakken shales ever migrated from the shale ("primary migration") and none of the shallower conventional production in North Dakota has come from the Bakken shales.
- The Bakken shales contain much more oil than previously estimated. Past analyses of Bakken rock samples were misleading because most of the oil escaped into the drilling fluids as rock chips moved up the well bore and pressures dropped.

Petroleum geology deals in issues of great uncertainty and is still a developing field. Petroleum geochemistry is an even less exact science at this time. It often takes a long time for new ideas to get real attention and to take hold.

7. Conclusion

DoE can go far to accelerate evaluation and development of this resource by judicious, timely, efficient and persistent interest and a relatively modest level of effort.

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