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Correspondence with EIA Administrator, The Honorable Guy F. Caruso

David J. Bardin

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Honorable Guy F. Caruso, Administrator
Energy Information Administration
U.S. Department of Energy
By e-mail

Subject: How Will EIA Capture and Report Information as to Bakken Crude Oil?

Dear Administrator Caruso:

How can EIA best adjust long-term projections of domestic crude oil production (as well as annual estimation of proven reserves in Montana and North Dakota) in response to results and implications of the hot, new Bakken crude oil play in the Williston Basin?

- Petroleum Technology Transfer Council, Network "Strong Horizontal Activity in Williston's Middle Bakken" [www.pttc.org/news/3qtr2005/v11n3p1.htm]; and
- "The Bakken Play of Montana and North Dakota" by Julie A. LeFever of the North Dakota Geological Survey – synopsis of a presentation to the Houston Geological Society in January 2005 [copied as Attachment A1 to this letter] describe that play.

Bakken Formation shales have been known for decades as sources of hundreds of billions of barrels of crude oil. But, whereas 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 the Bakken oil remains in micro-fractures 10,000 feet below ground in the Bakken Formation – either in the shales themselves or, even more so, in immediately adjacent limestones. [See Attachment A3.]

Improvements in technology and understanding of the Bakken Formation are turning billions of barrels of crude oil that EIA and the USGS once regarded as "hypothetical" into proven reserves and as-yet-unproven, but "technically-recoverable" resources. If the Bakken becomes a major petroleum province, will EIA be the first or last to know?

Table 1. Bakken play in Richland County, MT (which adjoins McKenzie County, ND)

	2000	2001	2002	2003	2004
Richland County well completions					
Total completions	6	21	22	44	98
Bakken 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
Oil production – millions of barrels					
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	??
Year-end proven reserves statewide --millions of barrels	235	260	288	315	????

Tom Richmond, Administrator/Petroleum Engineer to Montana's Board of Oil & Gas Conservation, says Richland County's Bakken 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 2004 wells in Attachment A2.]

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. But will EIA's forthcoming estimates for year-end 2004 fully capture reserves that Montana's new wells prove up? Major oil companies have not had a big hand in the current play. So 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. Will Montana operators listed in Attachment A2 receive EIA's reserves-reporting form?[1]

Julie LeFever (Attachment A1) points out two features distinguishing this Bakken Formation play from the previous (economically disappointing) horizontal play of the 1980s/1990s:

(1) Technology has evolved to allow frac stimulation of horizontal laterals. (Operators previously had to seek "sweet spots" where micro-fractures naturally converge, a "hit or miss" process in the judgment of the U.S. Geological Service, now operators can also create artificial sweet spots.)[2]

(2) Operators are aiming this time at "middle member" limestones, immediately adjacent to "upper member" shale. (She has co-authored papers explaining that the middle member holds most of the crude oil now in place.)

"Tight hole" status of some new North Dakota wells still precludes officials of that State from sharing what they may now know. EIA estimated a new high in North Dakota's proven reserves in its most recent report, reaching 353 million barrels at year-end 2003, but EIA's estimates of North Dakota production were down to 30 million barrels in 2003 (of which only 2% came from the Bakken Formation according to that State's web site).

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. [Attachment A3]
- 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).

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[1] Tom Richmond says 150-160 new Bakken Formation wells were producing in Richland County earlier this year; he expects a like number more to be drilled. Initial production generally ranges from 200 to 1,000 barrels a day per well, generally spaced on 640 or 1280 acres (1 or 2 mi^2). At a depth of about 10,000 feet deep, drillers often run two horizontal laterals (each some thousands of feet long) through Bakken Formation limestone, adjacent to Bakken shale. Such wells may cost over $3 million (costs, of course, rising when oil prices go up). Several operators anticipate 10% recovery of crude oil in place.

[2] The earliest play, beginning in 1953, involved vertical wells which could be completed in both shale and limestone members of the Bakken Formation. Some were. Some are still producing today.

- The Richland County play so far has tested less than 5% of the "Intermediate" area.[3] 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.[4]
- Chris Schenk, USGS project manager for the NOGA, informs me that reassessment is not due until 2007. As Attachment A3 suggests, 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 could invest in jump-starting USGS's 2007 reassessment.
    - This time, I urge that assessment include estimatation 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 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%.

Technology Transfer Information Issues

EIA probably has a role to perform also, together with the States, Petroleum Technology Transfer Council (PTTC), DOE/FE, and academic leaders, regarding information and education to share present "state-of-the-art" widely and intensively, in order to minimize waste or stranding of a vast Williston Basin resource.

I would welcome an opportunity to discuss all these issues at your convenience. (This letter does not address other important DOE issues, such as R&D, because it focuses on EIA.)

Best personal wishes. Faithfully, David J. Bardin

Attachments:

A1 LeFever 2005a, "The Bakken Play of Montana and North Dakota"
A2 2004 Wells in Richland County, MT: Operators and Initial Production Rates
A3 USGS 1995 Assessment of Bakken "Continuous-Type" Petroleum Is Outdated and Now Understates the Recoverable Resources
A4 References

c:

EIA:	John Wood, Jim Kendell, Howard Gruenspecht
Montana:	Tom Richmond
North Dakota:	Lynn Helms, Julie LeFever
U/ND EERC:	Gerry Groenwald, John Harju
USGS:	Chris Schenk, Emil Attanasi

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

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

Attachment A1: The Bakken Play of Montana and North Dakota
LeFever @ Houston Geological Society Monthly Dinner, 5 January 2005
[www.hgs.org/en/cev/?314]

Details

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.

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.

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.

Attachment A2: 2004 Wells in Richland County, Montana:
Operators and Initial Bakken Production Rates (BO/D)

Lyco Energy Corporation	650		EOG Resources, Inc.	484	
	759			701	
	450			255	
	832			960	
	522			86	
	172			510	
	508			268	
	694			445	
	501			525	
	461			267	
	611			439	
	705			Dry Hole	
	611			549	
	639			140	
	1048		Nance Petroleum Corporation	Red River	
	155			774	
	654			Red River	
	Ratcliffe			364	
	520			400	
	500			46	
	611			213	
	470		Continental Resources Inc	1107	
	864			440	
	352			694	
	508			680	
	435			674	
	552			941	
Headington Oil LP	1016			1033	
	306		Petro-Hunt, LLC	343	
	428			73	
	1066			420	
	322			306	
	464			176	
	1036			Dry Hole	
	351			Dry Hole	
	229		Burlington Resources O&GCo	348	
	341			535	
	940			359	
	449			542	
	734			305	
	461		Slawson ExplorationCompany	1043	
	146			87	
	451			796	
	704			1097	
	834		Westport Oil and Gas Co, L.P.	464	
	491			497	
	772			63	
	687		Whiting Oil&Gas Corporation	Dry Hole	
	830		True Oil LLC	Dry Hole	

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

Attachment A3: USGS 1995 Assessment of Bakken "Continuous-Type" Petroleum Is Outdated and Understates the Recoverable Resources

Contents:

"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 continuous-type resources; risks involve how much of the petroleum one can extract efficiently and economically.[5]

"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 and the Lower Member (largely confined to North Dakota) is the least. The entire Formation is up to 105 feet thick, with Lower Member (Shale) up to 50 feet, Upper

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[5] 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."

Member (Shale) up to 23 feet, and Middle Member up to 85 feet in North Dakota.[6] 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.[7] (Earlier plays, beginning in the 1950s, included vertical wells and, later, 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.[8]
- Montana's Richland County produced close to 8 million barrels in 2004 and more than that in the first eight 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 in Montana and North Dakota now grab attention.[9]
- 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

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

[7] 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].

[8] 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 Bakken production as clearly as North Dakota's. But Montana cumulative Bakken production through the end of 2004 was probably no more than 10 million barrels. Production in 2005 through August was about 9.5 million (in contrast to barely 100,000 in 2000). Some 150-160 Bakken wells are in production there and an equal number more may be anticipated. Wells are 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, Montana Oil & Gas Board (personal communications, 4, 8, 22 & 28 Nov. 2005).

[9] 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.

to 400 barrels of oil in place." Pitman, Price, and LeFever 2001 (USGS Professional Paper 1653).[10] "Bakken Formation in North Dakota …. 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][11] (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. See Attachment A1.

Technology to Recover the Oil: Progress and Remaining Challenges

Technology has progressed substantially since the USGS assessment in 1995:

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[10] 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).

[11] "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.

- "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 (copied as Attchmt. A).
- In 1995, USGS assumed that only ten percent of Bakken wells would ever be stimulated and did not anticipate technology to frac horizontal laterals.
- 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 for the Intermediate area and for the Fairway systematically by completion date into three groups, 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.[12] That appears to have changed. See Attachment A1.
- 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 NO&GA. Compare close to 20 million barrels of oil *produced during 2004 and the first months of 2005 alone* by new wells in a *small fraction of the Montana portion* of the Intermediate area. See note 8.

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 1995 methodologies.

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 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."[13]

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[12] 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. (Natural gas estimates ranged from 22 TCF at the 95% fractile to 32 TCF at the 5% fractile. Underlying estimates of undiscovered reserves in place may exceed 200 TCF.) By the end of 2003 cumulative production was 0.8 TCF.

[13] "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

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.

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 conflict with long-term maximum economic recovery of the resource.

U.S. Government data projections dampen industry interest.

Appendices
X-1 (How USGS Assessed Bakken Resources in 1995)
X-2 (Excerpts from SPE 22390 -- 1992**)**
X-3 (Excerpts from Price and LeFever, 1994)
X-4 (Excerpts from USGS Professional Paper 1653 -- 2001)

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.

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 2. 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 in the Intermediate area.

- 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 22390

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. ….

[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.

Attachment A4: References

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