The Oil Drum
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Stranded Oil Recovery and American Energy Independence

Posted by Dave Cohen on October 13, 2006 - 10:54am
Topic: Supply/Production
Tags: co2 eor, energy independence, heavy oil, residual oil zone, stranded oil, tar sands, thermal eor [list all tags]

In testimony before the House subcommittee on Energy & Resources in June, 2004, Vello A. Kuuskraa, president of Advanced Resources International (ARI), presented a graphic to members of congress showing huge potentially recoverable domestic reserves of stranded oil. This oil would be recovered by use of CO2 EOR (enhanced oil recovery). Here's an updated version of that graphic—from Undeveloped US oil resources: A big target for enhanced oil recovery — published in *World Oil*, August, 2006.

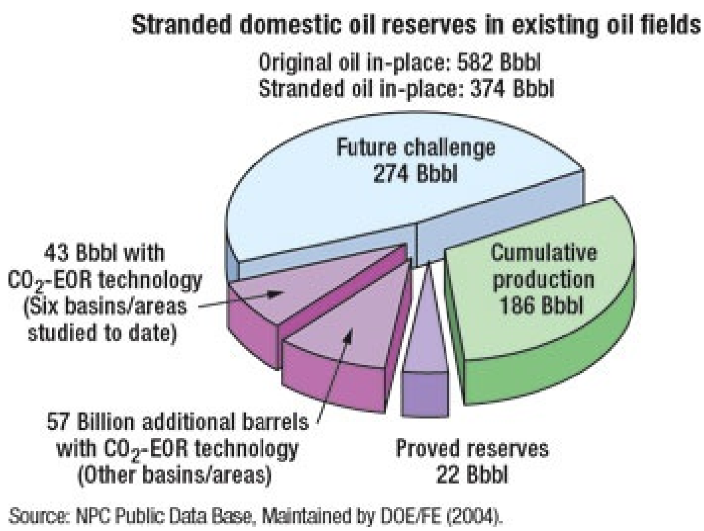

Figure 1

> However, the problem of declining domestic oil production is not due to a lack of resources. We still have nearly 400 billion barrels of oil that is being left behind, "stranded". This is because our primary and secondary recovery methods recover only about one-third of the original oil in-place from our domestic oil fields, [*Figure 1* above].
>
> Numerous approaches are being tried to recover a portion of this "stranded" oil. The one with the highest, but still unrealized, potential is using CO2-enhanced oil recovery (CO2-EOR). Twenty years ago, enthusiasm for this idea was high.

Let's talk about what's going on here, considering the impact it will have on future U.S. domestic oil production and energy independence.

Many efforts are being undertaken to achieve some modicum of energy independence for the United States. These generally include the corn-based ethanol craze promoted by David Morris and Vinod Khosla, among others, and more importantly, attempts to actually produce more crude oil domestically.

An important distinction I've repeatedly tried to make is that huge reserves numbers don't matter much. We are interested in production flows that affect the world's economies. See Stuart Staniford's Do Oil Reserves Tell Us *Anything*? and my answer to a comment by Leo Drollas, Deputy Director and Chief Economist for the Centre for Global Energy Studies, Reserves Growth and Production Flows, for some background. Also, HO has written about stranded oil in How carbon dioxide improves recovery. In what follows, you are going to be seeing some really big resource numbers which, for the uninitiated, might be misconstrued *in toto* as commercially *recoverable reserves*. So, hold on to your hats.

Undeveloped U.S. Oil Resources

From the World Oil article:

> US oil, while in the midst of transformation, provides about 7 million bpd of petroleum production. In 2004, this made the US the world's third largest oil producer, behind Saudi Arabia (10.6 million bpd) and the Russian Federation (9.3 million bpd). While US oil production has declined somewhat in the past five years, with timely implementation of policies and actions noted in this report, this decline can be reversed.
>
> While a mature hydrocarbon province, the US still has large volumes of undeveloped US oil resources in-place, totaling 1,124 Bbbl. Of this, 190 Bbbl is estimated to be technically recoverable with conventional technology, and 210 Bbbl using EOR, Table 1. This resource includes undiscovered oil, stranded light oil amenable to CO2-EOR technologies, unconventional oil (deep heavy oil and oil sands) and new petroleum concepts (residual oil in reservoir transition zones below the traditional oil-water contact).

	Original oil in-place, Bbbl	Developed to date		Remaining oil in-place, Bbbl	Future recovery*		
		Conventional Technology, Bbbl	EOR Technology, Bbbl		Conventional Technology, Bbbl	EOR Technology, Bbbl	Total
I. Crude oil resources							
1. Discovered[1]	582	194	14	374	–	100	100
• Light oil	482	187	3	292	–	80	80
• Heavy oil	100	7	11	82	–	20	20
2. Undiscovered[2,3]	360	–		360	119	60	179
3. Reserve growth	210	–		210	71	40	111
4. Transition zone	100	–		100	–	Unknown	Unknown
II. Oil Sands[7]	80	–	**	80	–	10	10
Total	1,332	194	14	1,124	190	210	400

* Technically recoverable resources
** Less than 0.5 billion barrel

Sources
[1] DOE/FE Basin Rep
[2] USGS National Assessment of Oil and
billion barrels). Oil in-place estimated by assuming 33% recovery efficiency. Future recovery potential assumes 50% recovery efficiency with enhances oil recovery for undiscovered and reserve growth.
[3] Assessment of Undiscovered Technically Recoverable Oil and Gas Resources of the Nation's Outer Continental Shelf, 2003 Update (MMS Fact Sheet, December 2004).
[4] Estimates of Inferred Reserves for the 1995 USGS National Oil and Gas Resource Assessment (USGS OFP 95-75L, January 1997).
[5] Assumptions for the Annual Energy Outlook 2004 (EIA, February 2004).
[6] Preliminary Estimates by Advanced Resources Int'l and Melzer Consulting (2005).
[7] Major Tar Sand

Table 1. Original, developed and undeveloped domestic oil resources (summary)
Figure 2 -- click to enlarge

If you are doing a double take—or checking your math—rest assured that Kuuskraa has just stated that the United States has 1.124 trillion barrels of *oil resources in-place*. Of this, 190 Gb are recoverable with conventional technology and 210 Gb with EOR (enhanced oil recovery) techniques. As usual, the devil lies in the details.

Looking at the table and other parts of the World Oil article, I call your attention to the following items.

- *Undiscovered* oil is based on the MMS estimates for the OCS (Outer Continental Shelf) as described in my [Deep Ocean Energy Resources -- A Critical Analysis]. It is particularly noteworthy that 60 Gb (billion barrels) of this oil—which does not yet exist—will be recovered by CO_2 injection EOR.

- Conventional primary and secondary recovery technology yields 119 Gb from the chimerical 360 Gb of undiscovered resources, while 71 Gb comes from an estimated 210 Gb of reserves growth in existing fields—the tally is 190 billion barrels.

- Kuuskraa notes both in the article and in this Office of Fossil Energy [fact sheet] that U.S. "oil" production is 7.24/mbpd (2004). This represents NGLs (1.809/mbpd) + crude & condensates (5.419/mbpd).

- You may be surprised to see that the U.S. contains large heavy oil resources, amounting to 100 Gb OIP (oil in-place). Of this, 18 Gb have been produced in shallow reservoirs (< 3000 feet), most notably using steam-based EOR in the old [Kern River Basin] fields in California. Kruuskaa's study estimates that 20 Gb might be recoverable by applying thermal EOR —introduction of heat into the reservoir by means of steam injection drives, soaks and perhaps SAGD (Steam Assisted Gravity Drainage) to decrease the oil's viscosity. However, most of this heavy oil (45 Gb) resides in "reservoirs that are too deep for efficient thermal EOR application."

  > Further advances in heavy oil recovery technology will be required to efficiently and economically recover this large volume of deep stranded heavy oil. Development of more advanced technologies involving horizontal wells, low-cost immiscible CO_2, and advanced thermal EOR technology could significantly increase recovery of this otherwise stranded oil. Joint US and Canadian efforts targeted at developing more effective technologies for producing deep heavy oil would be valuable to both countries.
  >
  > Particular emphasis needs to be placed on evaluating technologies that could help recover more of the underdeveloped heavy oil resource in Alaska. Advanced oil recovery technologies, such as miscibility-enhanced CO_2-EOR and CO_2-philic mobility control agents, will be essential for recovering more from the largely undeveloped 25 Bbbl heavy oil resource in Alaska, in the Schrader Bluff, West Sak and other formations, without disturbing the permafrost.

  Therefore, *only* 20 Gb of this resource is adjudged as being potentially recoverable—this depends on thermal EOR technology that is in the early stages of development. Looking further on the bright side, there's little need to worry about *disturbing the permafrost* anymore.

- You may also be surprised to learn that America also has tar sands—now called "oil" sands, of course. Take that, you Canucks!

> The domestic oil sand resource is substantial, on the order of 60 to 80 Bbbl of OOIP. While it is distributed widely, the bulk is concentrated in five states - Utah (19 - 32 Bbbl), Alaska (19 Bbbl), Alabama (6 Bbbl), California (5 Bbbl) and Texas (5 Bbbl). Uncertainty exists about the quality of the oil sand in Utah, reflected in the wide range of estimates.

Given the *great uncertainty* in Utah—I myself have also always regarded Utah with some ambivalence— Kuuskraa throws in a mere 10 Gb of potential oil from sands into his estimate, noting that recovery will be aided by more R&D and lessons learned from Canadian applications of SAGD and VAPEX (Combination of solvent and heat).

As both *Figure 1* and *Figure 2* indicate, the largest share of recoverable stranded conventional original oil in-place comes from application of CO_2 injection EOR in the various basins. The lavender-shaded part of *Figure 1* indicates that 100 Gb of oil will be recovered—a nice, round number. Let's focus on this part of Kuuskraa's study.

CO_2 Injection for Enhanced Oil Recovery

CO_2 EOR is viewed as an increasingly important technology for recovering stranded oil and sequestering carbon dioxide. See my story on the Weyburn pilot project for some background. Here are Kuuskraa's remarks on the technology.

> ... widespread application of CO_2 and other EOR technologies could raise the average national oil recovery efficiency to nearly 50%. More advanced CO_2-EOR and other EOR technologies, such as gravity stable CO_2 injection and horizontal wells, could improve the recovery efficiency of stranded oil from domestic reservoirs. Miscibility enhancers, conformance control agents and advanced immiscible CO_2-EOR technology could extend the application of CO_2-EOR to reservoir and basin settings now excluded from further development. Extending these technologies to recovery of Residual Oil in the transition Zone (ROZ) would add additional volumes of recoverable oil. Successful pursuit of advanced EOR technology will be central to achieving the 60%+ national oil recovery efficiency goal established by DOE/FE for its oil technology R&D program.

Whether CO_2 EOR (flooding) is miscible (blended) or immiscible depends on the reservoir temperature and pressure. *Figure 3*, from Enhanced Recovery Through CO_2 Flooding illustrates miscible CO_2 flooding as envisioned for the Natural Gas Systems, Inc. (NGSY)/Denbury Resources, Inc. acquisition of the Delhi Holt-Bryant Unit (Delhi) in northern Louisiana.

> Delhi is a potential carbon dioxide ("CO_2") tertiary flood candidate. The Company initially has estimated that this field has an estimated net reserve potential from CO_2 tertiary floods of up to 30 to 40 million barrels of oil equivalent ("MMBOE"), net of the projected reversionary interest based on a $60 oil price.

Miscible CO_2 Flood
Figure 3

As you can see, the idea is to drive the blended CO_2 and oil from the injector well on the left toward the production well on the right. The project will be economical subject to the pilot start-up costs, the price of commercially available CO2 and a $60/barrel oil price. This text and graphic from [Oil Field Screening Study for CO2 Sequestration and Enhanced Oil Recovery in the Illinois Basin] explains miscibile versus immiscible flooding.

> **Conditions for CO2 EOR: Miscible vs. Immiscible**
> Defining plays of oil reservoirs as miscible or immiscible is important in determining the potential for EOR during CO2 sequestration. The use of miscible describes CO2 and crude oil that become a single mixture under certain temperature and pressure conditions via the mass transfer of intermediate hydrocarbons (C5 - C12) from the crude oil to the CO2 phase. Immiscible describes CO2 and crude oil under conditions where there is a distinct and identifiable separation of the two fluids. Mass transfer exists in immiscible CO2 flooding of the oil reservoir, however, there is a CO2 rich phase and a crude oil rich phase.
>
> The critical pressure (1073 psia) and temperature (87.8 deg. F.) of CO2 are important to determining miscible and immiscible potential of oil reservoirs. For miscibility to occur CO2 must exist as a critical fluid (i.e. dense phase, liquid-like, supercritical CO2); this is only possible for reservoir temperature exceeding the critical temperature of CO2 and reservoir minimum miscibility pressure (MMP; which increases with temperature and is at least equal to the critical pressure of CO2).
>
> Immiscible conditions exist at reservoir temperature and pressure generally less than the critical temperature of CO2 and temperatures above the critical temperature when reservoir pressure is less than the MMP pressure. Under immiscible conditions, liquid or gas-like phases of CO2 are possible. The charts to the left and above illustrate these criteria for assessing im/ miscibility conditions of a reservoir, with a +/- 2 deg. F. and approx. 1000 psia "window" where either condition of CO2 EOR may be possible.

Criteria	Condition	Comments
T_{res} < 86° F	Immiscible	
86° F < T_{res} < 90° F	Miscible/Immiscible	Either Possible T_{CO2} = 87.8° F
Tres > 90° F	Miscible Possible	

Criteria	Condition	Comments
P_{res} < 1000 psia	Immiscible	
1000 psia < P_{res} < 1200 psia	Miscible/Immiscible	Either Possible P_{cCO2} = 1073 psia
Pres > 1200 psia	Miscible Possible	

Critical temperature and pressure of CO2 and identified miscibility conditions.

Figure 4 -- Click to enlarge

Miscible CO2 flooding is the standard technology used in current production. An ARI presentation by Michael Godec, [Opportunities for Producing the "Stranded" Hydrocarbon Resources of Louisiana] (powerpoint) indicates that immiscible CO2 EOR using large volumes of CO2 is a "state of the art" technology (slide #20) which would "enable nearly 3 billion barrels [in Louisiana] to become economic (at oil price of $25 per barrel and CO_2 cost of 5% of oil price)"—as opposed to only 430 million economic barrels that could be produced using miscible flooding only. It is hard the reconcile the $25/barrel oil price cited by Godec and the $60/barrel price used by Denbury.

Even more "advanced" CO_2 EOR includes gravity-stable CO_2 injection and horizontal wells as cited by both Kuuskraa and Godec. All I know about it is that the DOE awarded ARI and Kinder Morgan a 3-year $5,119,103 contract to investigate it in December, 2004.

> Advanced Resources International Inc. (Houston, Texas) will investigate gravity-stable CO_2 injection at the giant Permian Basin location in West Texas. The goal is to increase oil recovery in the Scurry Canyon Reef field, which has the potential of an incremental oil recovery on the order of 53 million barrels of oil. Detailed reservoir characterization will be performed, and actual CO_2 migration will be assessed by time-lapse crosswell seismic surveys to compare to predictions based on reservoir simulation.

Finally, there is Stranded Oil in the Residual Oil Zone (ROZ). The elementary geology is shown in *Figure 5*. The study (a large pdf) is by L. Stephen Melzer of Melzer Consulting, subcontracting to ARI and DOE. The text below the figure is from the Executive Summary.

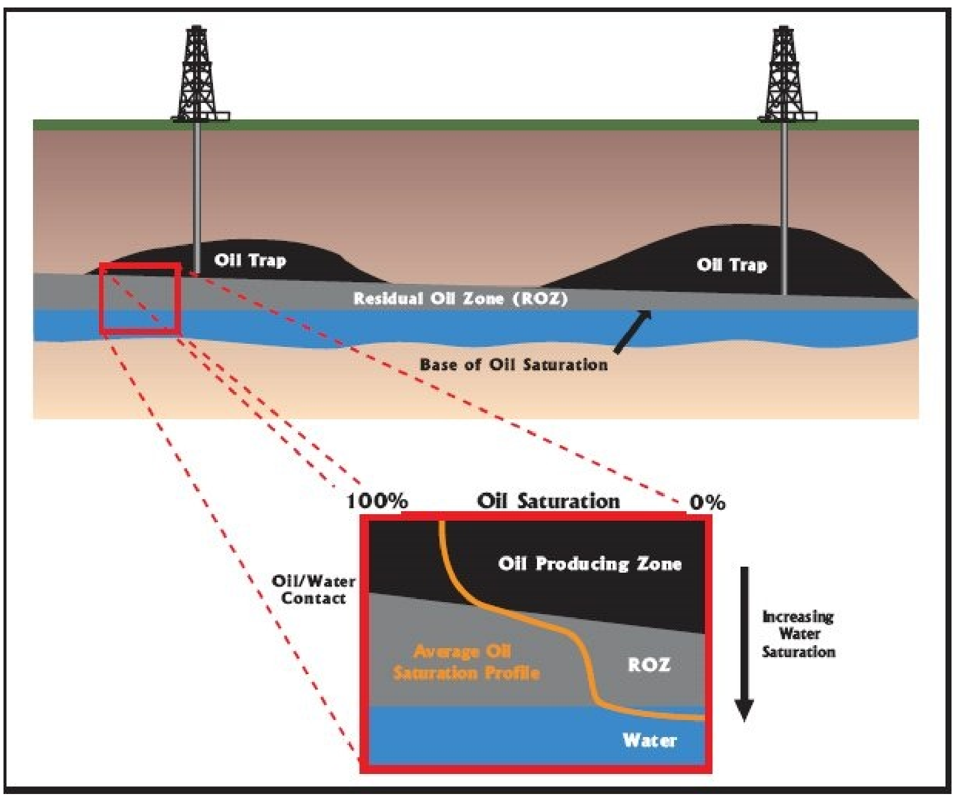

Figure 5 -- Click to enlarge

> The presence of an oil bearing transition zone (TZ) beneath the traditionally defined base oil-water contact (OWC) of an oil reservoir is well established. What is now clear, and as established by this study, is that, in certain geologic and hydrodynamic conditions, an additional residual oil zone (ROZ) may exist below this TZ. This zone may be extensive, thick, and filled with a residual oil that may be recoverable using CO_2 enhanced oil recovery (EOR). These thick residual oil zones exist where nature has waterflooded the lower portion of an oil reservoir.

> Past investigations of the origins and presence of these naturally-formed ROZ's have been hampered by two limitations: a general lack of interest in these intervals, as they would add little or no additional oil during primary and secondary production; and, clear preference for avoiding drilling into these residual oil transition zones to avoid or reduce the production of water.

Melzer's extensive study covers the geology and some commercial demonstrations of the technology in the Permian Basin of West Texas and New Mexico. See the document for details. Another Melzer Consulting document—CO_2 Flooding—describes the history of CO_2 EOR in the U.S., including the original project at Wasson (West Texas) and subsequent developments both in the Permian and elsewhere. Concerning the costs & benefits of standard miscible CO_2 injection, the author W.H. Leach states:

> CO_2 flooding is not for everyone. Start-up costs, coupled with waiting time for flood response, discourage any number of operators. Furthermore, the condition of the infrastructure of many older fields makes enhanced recovery impractical due to re-equipping costs, and this can be particularly true in the case of corrosive CO_2-water mixtures.
>
> But, for the patient firms with the requisite engineering skill and a deep pocketbook, CO_2 flooding can offer lucrative rewards.

As if to highlight these remarks, Norway had considered CO_2 injection for tertiary recovery in the North Sea. However, the Norwegian Petroleum Directorate (NPD) conducted a feasibility study which concluded that CO_2 injection [is] too expensive and too risky.

> There are several challenges that must be surmounted before CO_2 injection for improved oil recovery can be implemented. CO_2 injection is technically feasible, and the potential for increased recovery is substantial. However, the threshold costs for establishing a delivery chain for injection of CO_2 are so high that other methods of improving recovery emerge as being more attractive for the licensees at this time. CO_2 for improved oil recovery is capital-intensive, at the same time as production will take place over a long period of time.

The Norwegian findings should weigh heavily on those evaluating Kruuskaa's much more ambitious plans for recovering stranded oil using CO_2 EOR in the United States.

Future Production from Undeveloped Resources

Kuuskraa told the house members (June, 2004) that

> An aggressive, successful initiative [using CO_2 EOR] could add one million barrels per day of domestic oil production by 2015 and twice this by 2025, helping maintain a viable domestic oil production and service industry and improving energy security. Several efforts are underway in the geologically most favorable reservoirs. For example, Anadarko Petroleum has started CO_2-EOR in three Wyoming oil fields that are

projected to add 50,000 barrels of oil per day by 2010. Kinder-Morgan is conducting a CO_2-EOR project at SACROC in West Texas that is expected to have similar results.

U.S. oil production (crude + condensate) has declined 20.8% in the last 10 years (since 1996) and stood at 5.121/mbpd in 2005. If the next ten years show the same overall decline percentage, production will stand at 4.056/mbpd in 2015. Adding in the expected 1 million barrels per day from CO_2 EOR, given an aggressive initiative, 2015 production would still be less than it was in 2005. A realistic assessment of future U.S. production that includes reasonable projections about existing field declines (for example, the shallow-water Gulf, Prudhoe Bay), new fields (like Thunderhorse and Tahiti in the Gulf) and potential future production from new basins (such as Jack and the Lower Tertiary of the Gulf) is still missing. However, there are other amazing initiatives in the works to increase America's oil production and "energy independence."

If you want to see the really big picture for future North American production, look at North American Energy Freedom from the U.S. House Committee On Resources.

Description	2010	2015	2020	2025	2030
Alaska Onshore	.35	.95	1.80	2.40	2.60
Alaska Offshore	.15	.30	.80	1.20	1.50
Heavy Oil/Tar Sands	.00	.20	.60	1.00	1.00
Oil Shale	.00	.40	2.00	3.00	4.00
CO_2 EOR	.30	.80	1.20	1.70	2.00
Canada	1.20	2.50	3.95	5.10	6.10
Grand Totals	**2.00**	**5.15**	**10.36**	**14.40**	**17.20**

Efforts to Increase Domestic Supply Could Yield an Additional 17.20 Million Barrels a Day by 2030

[editor's note, by Dave Cohen] Conveniently, the data above includes production numbers for the Great White North, which, as far as I know, has already achieved "energy independence". However, given NAFTA, the House committee apparently has a keen interest in these territories. Most of this so-called "Canadian" production comes from the province of Alberta, which might as well be considered the 51st state as far as U.S. policy goes. The rest comes from those "Canadian" outer continental shelves. The document is silent about Mexico, which, the last time I checked, was in North America. Imagine that.

What are we to make of this remarkable tabulation? The numbers of immediate interest—those mentioned by Kruuskaa—are sourced from his studies. CO_2 EOR shows a 0.3/mbpd increase over the current production of 0.2/mbpd. The 2015 production shows an additional increase of 0.8/mbpd—mostly in accord with Kuuskraa's testimony in 2004. If you thrown in the heavy oil & tar sands, the tally stands at +1.3/mbpd 10 years out. As for the other numbers, these can be the subject of future posts. For example, the ever-warming Arctic—making the region more amenable to oil E&P—contributes heavily to the Alaska projections, as does a dubious addition of 0.3/mbpd by 2015 from ANWR. Others here at TOD, including HO and Robert Rapier, have written extensively on the oil shales. See the "energy freedom" document itself for the sources of these numbers and a more detailed breakdown.

As is usually the case, the further one goes out in time, the rosier the picture becomes. A comprehensive analysis of these production numbers is beyond the scope of this post—suffice it to say that, looking 10 years out, I am skeptical about the stated production increase of 5.15/mbpd from the U.S. and Canada. The 0.4/mbpd from oil shale and the inclusion of ANWR production would seem to be dead giveaways. Not even Shell has ever set such an expectation about production from oil shale. Extraordinary claims require extraordinary evidence. Finally, in the 2010 timeframe, there is little or no help outside the Canadian tar sands increase of 1.20/mbpd. This number, too, appears suspiciously high.

The bottom line is this: regarding oil production, these idealized projections do not serve as a realistic pathway toward "energy independence" for the United States. Indeed, the view here is that weaning America off oil imports is now, and on any timescale we care about, a fiction. The inclusion of Canadian production by the *American* congressional committee under the guise of "North American" energy freedom is shameful. Concerning the long range estimates out to 2030 —if you choose to believe them, then you can just toss those Hubbert Linearizations right out the window. And to think that the purchase of Alaska from Russia in 1867 for $7,200,000 was called *Seward's Folly*!

As the Nobel Prize winning physicist Niels Bohr said, "predictions are hard to make, especially about the future." 17.2/mbpd —11.1/mbpd from the U.S. alone— by 2030? There's only 24 years to go. And although it is generally a mistake to automatically project past trends into the future, if we go backward in time whilst trying to remember what was happening 24 years ago—

8.649/mbpd (crude + condensate)
American Production in 1982
And A Big Hello! from The Gipper

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