EOR/IOR Technology, Incentives and Broadening of the E&P Industry

IOGCC 2016 Midyear Business Meeting

Denver Mariott City Center Hotel

Downtown Denver, Colorado

Session 1:00 - 4:30 pm

Sunday, May 15, 2016

INTERSTATE Oil & Gas COMPACT COMMISSION

Melzer COnsulting

EOR/IOR Technology, Incentives and Broadening of the On-shore E&P Industry

- Trends in the O/G Upstream Sector
- Prudent Development, Conservation Considerations
- Factors Which Affect Development and Capacity (Incl per Bbl Costs, Carbon Intensity, Emission and Disposal Reductions)
- Incentives (“Carrots”) at the State and Federal Level

Oil and Gas Upstream Developments

- Limited (Peak) Oil Ideas Replaced and with a New 'Plentiful Paradigm'
- Industry Has Moved Well Beyond Just Mobile Oil and Gas Zones
  - …to Deep Water
  - …to the Shales
  - …to the Residual Oil Zones
- New Resources Come with New Challenges

PRUDENT DEVELOPMENT

Realizing the Potential of North America's Abundant Natural Gas and Oil Resources

National Petroleum Council • 2011

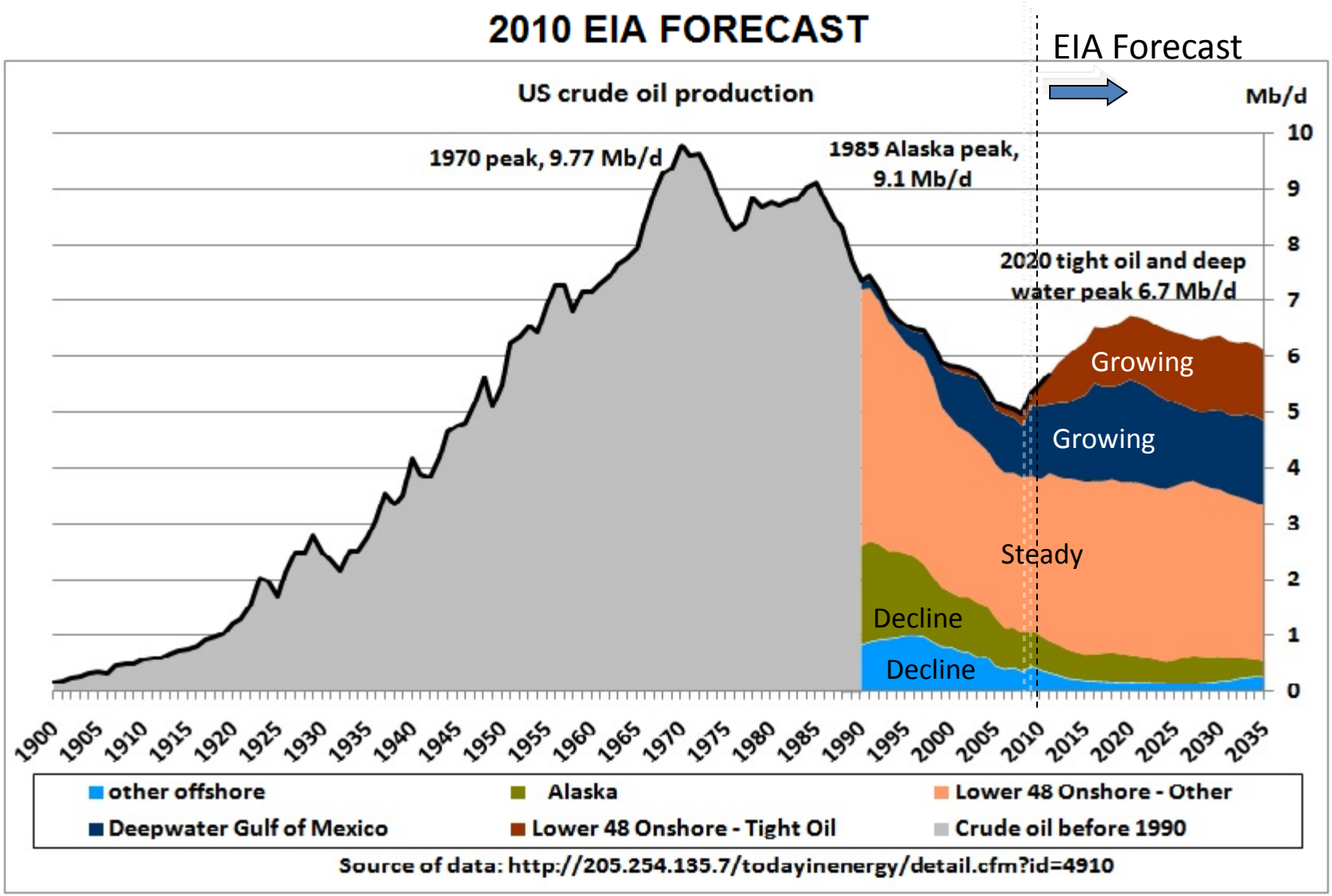
A Baseline for Discussion

NPC Report

INTERSTATE Oil & Gas COMPACT COMMISSION

Where We Were in 2011 at the Time of the NPC Study

"First Signs of the Big Change"



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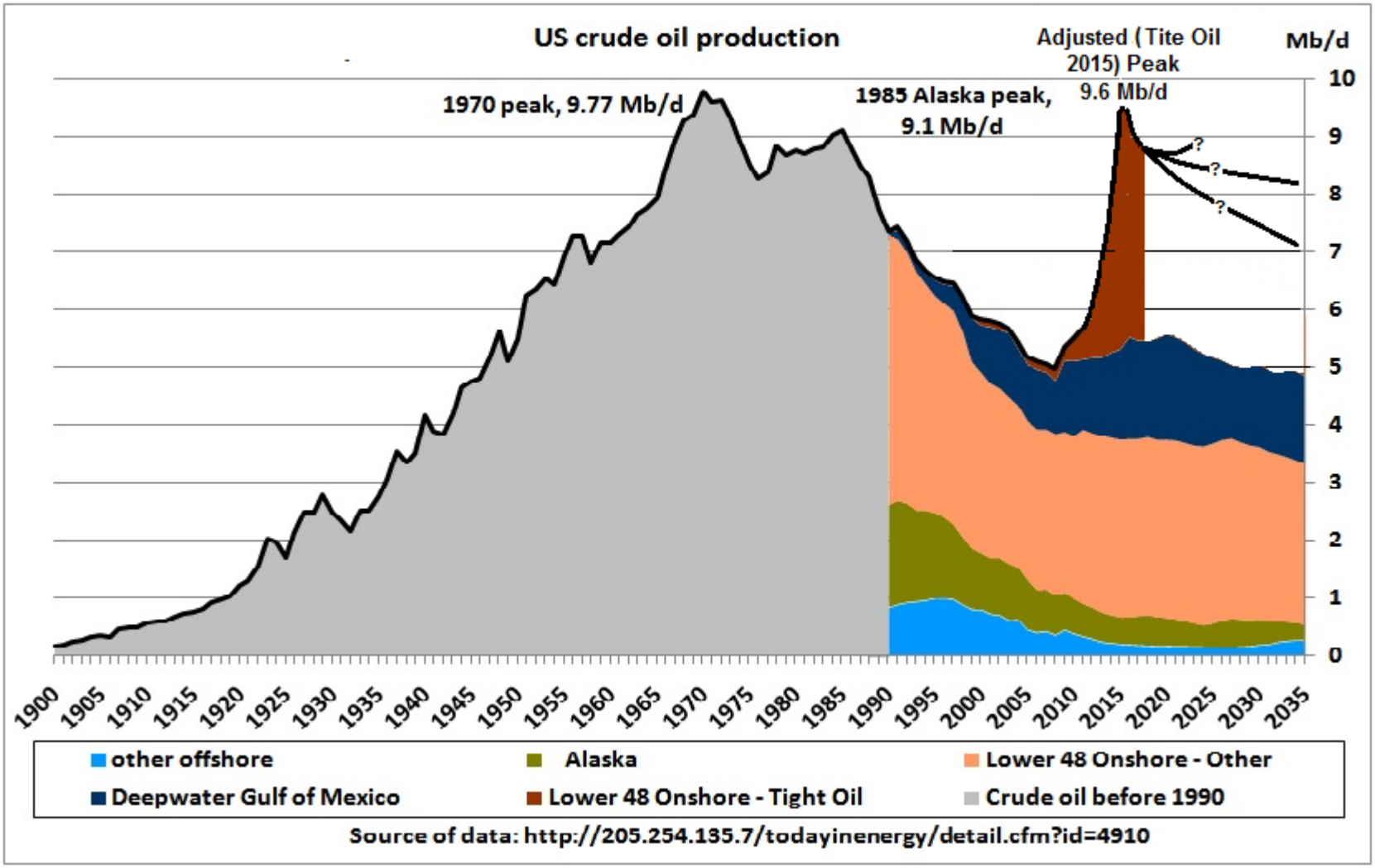
Melzer Consulting

WOW!.....A Changed World Today



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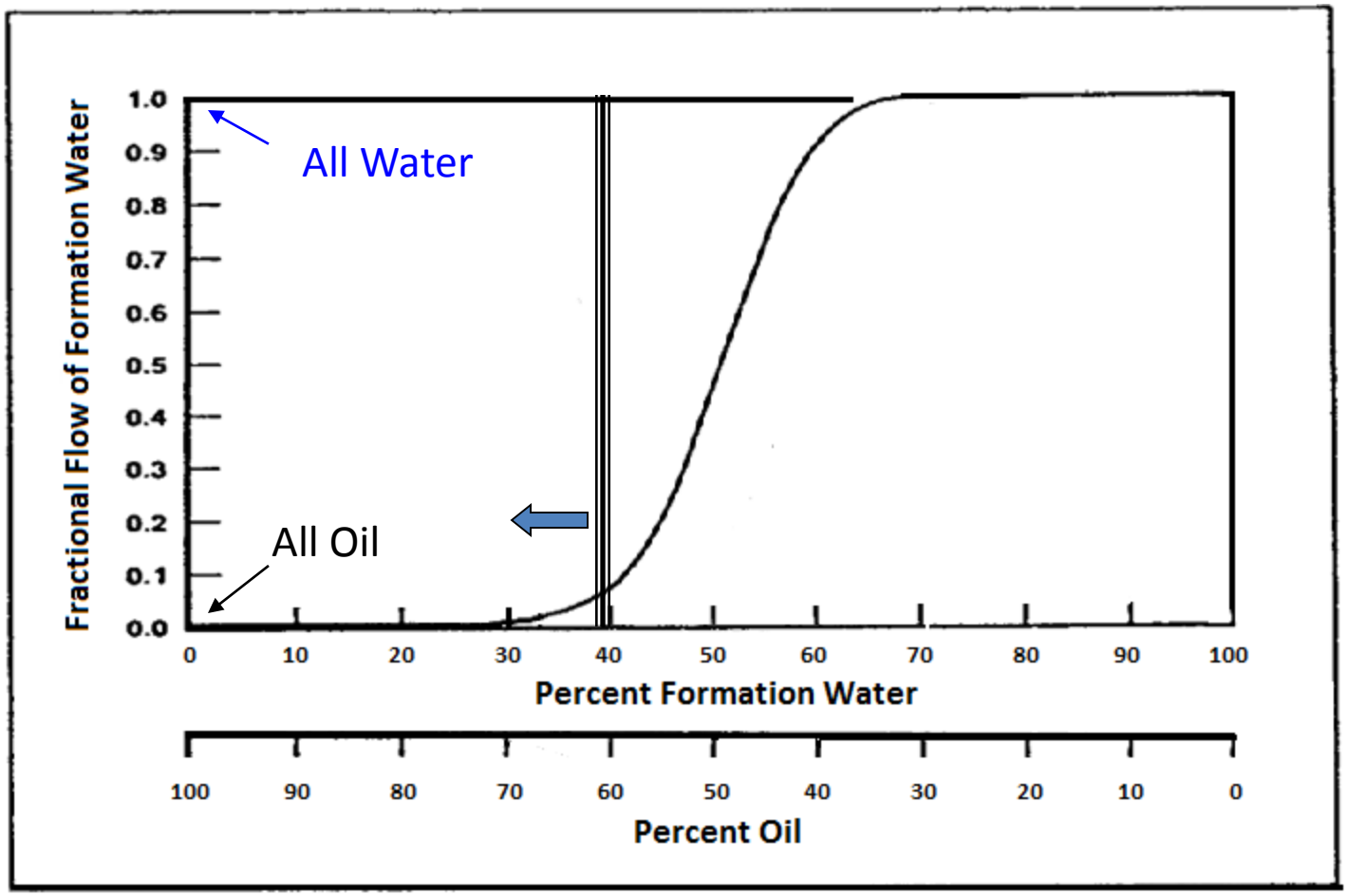
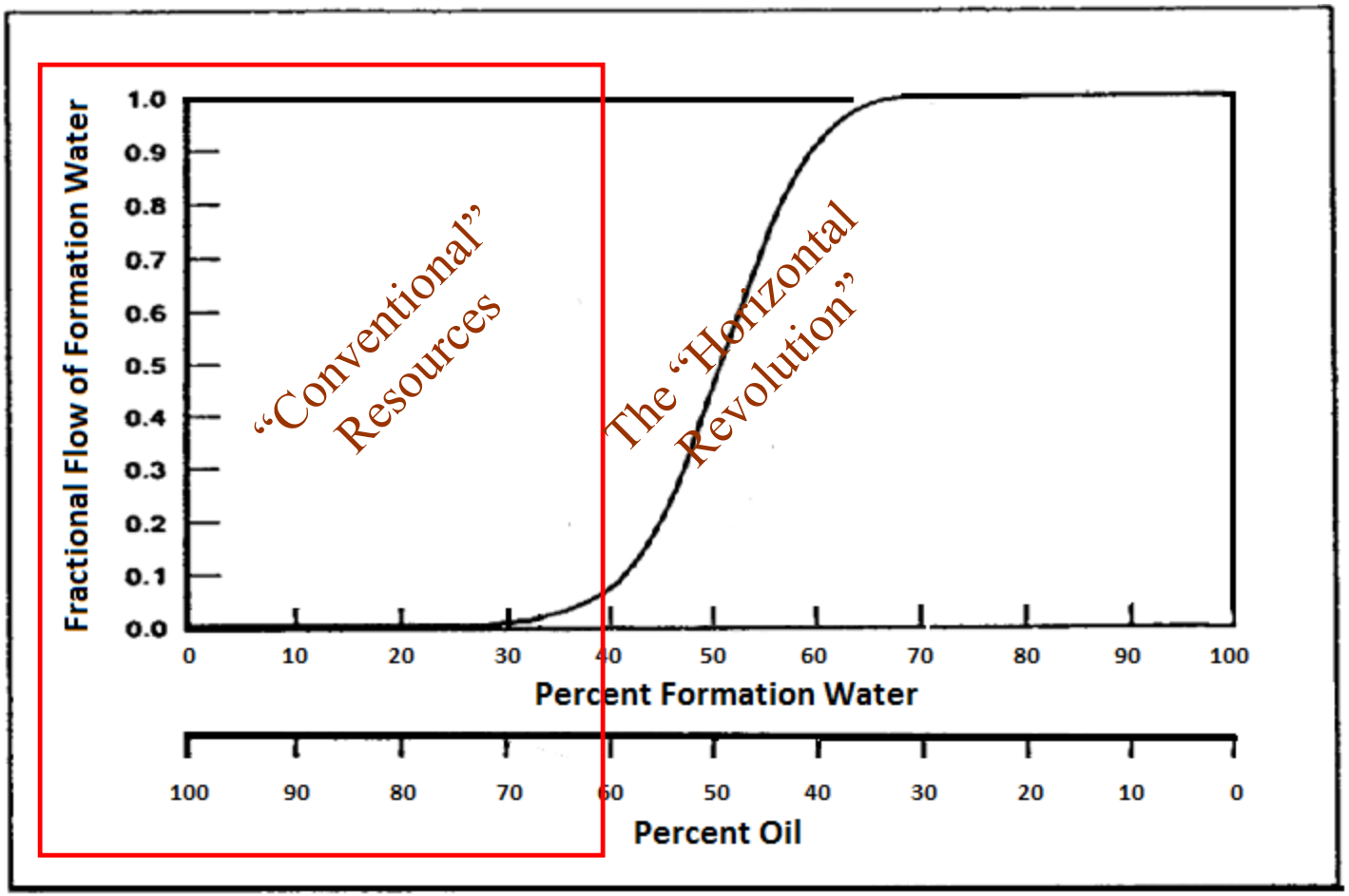
A New, Modern Frame of Reference for the Changed Times

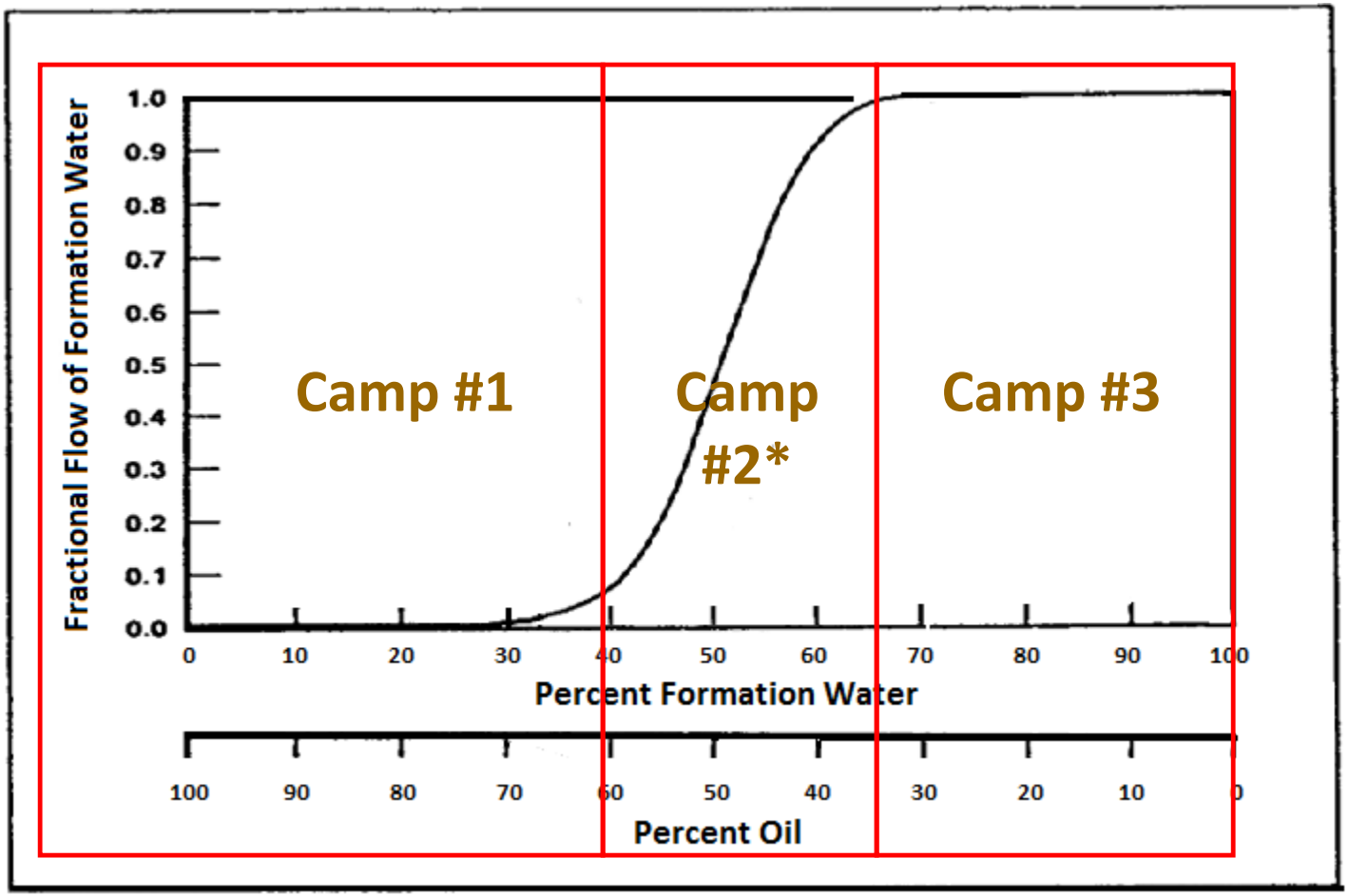
Fractional (Water) Flow as a Function of Oil or Water Saturation



150 Years of Looking for These Reservoirs!

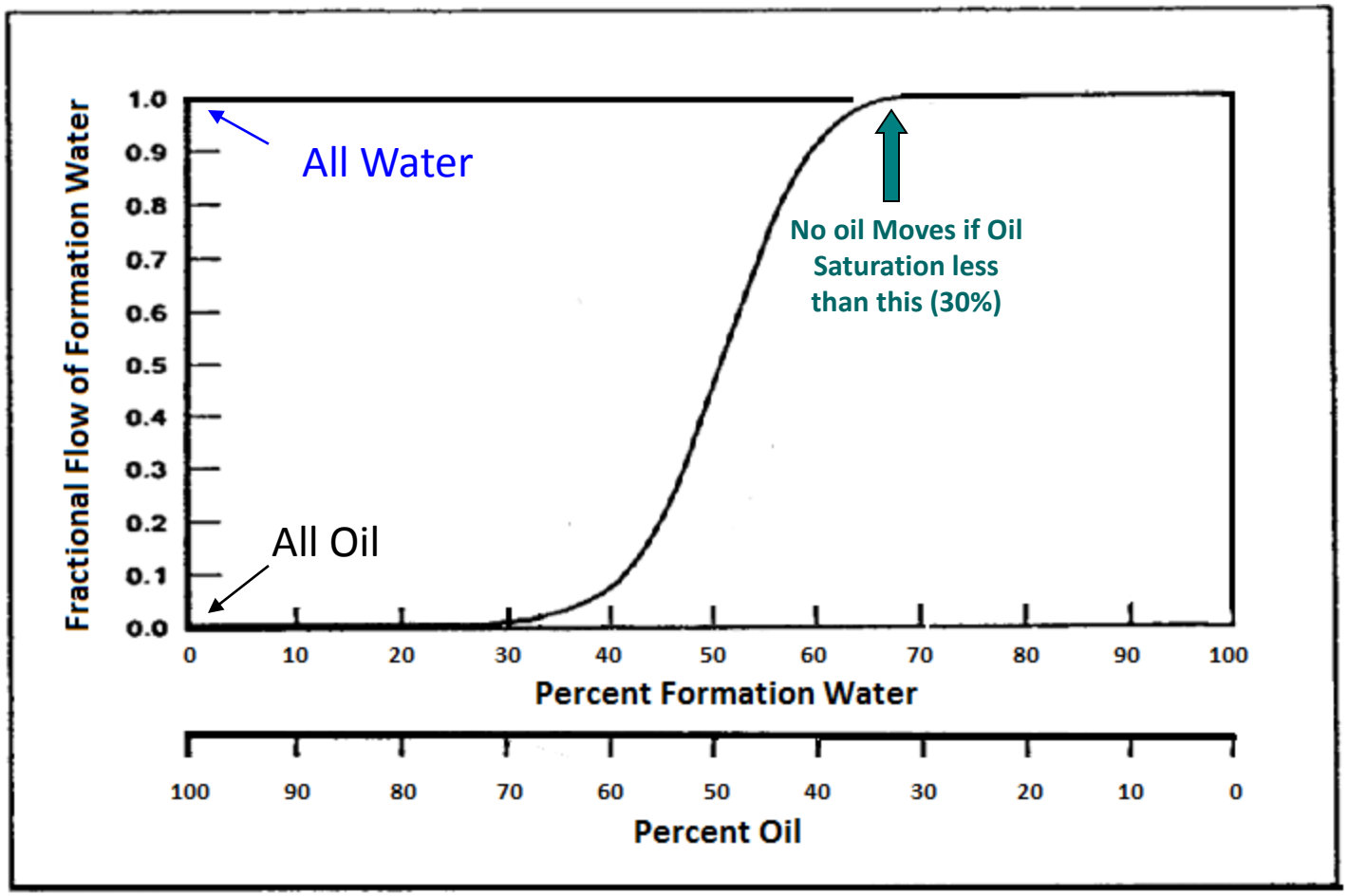


Our Industry Has Moved Beyond the "Conventional" Into Two New Territories

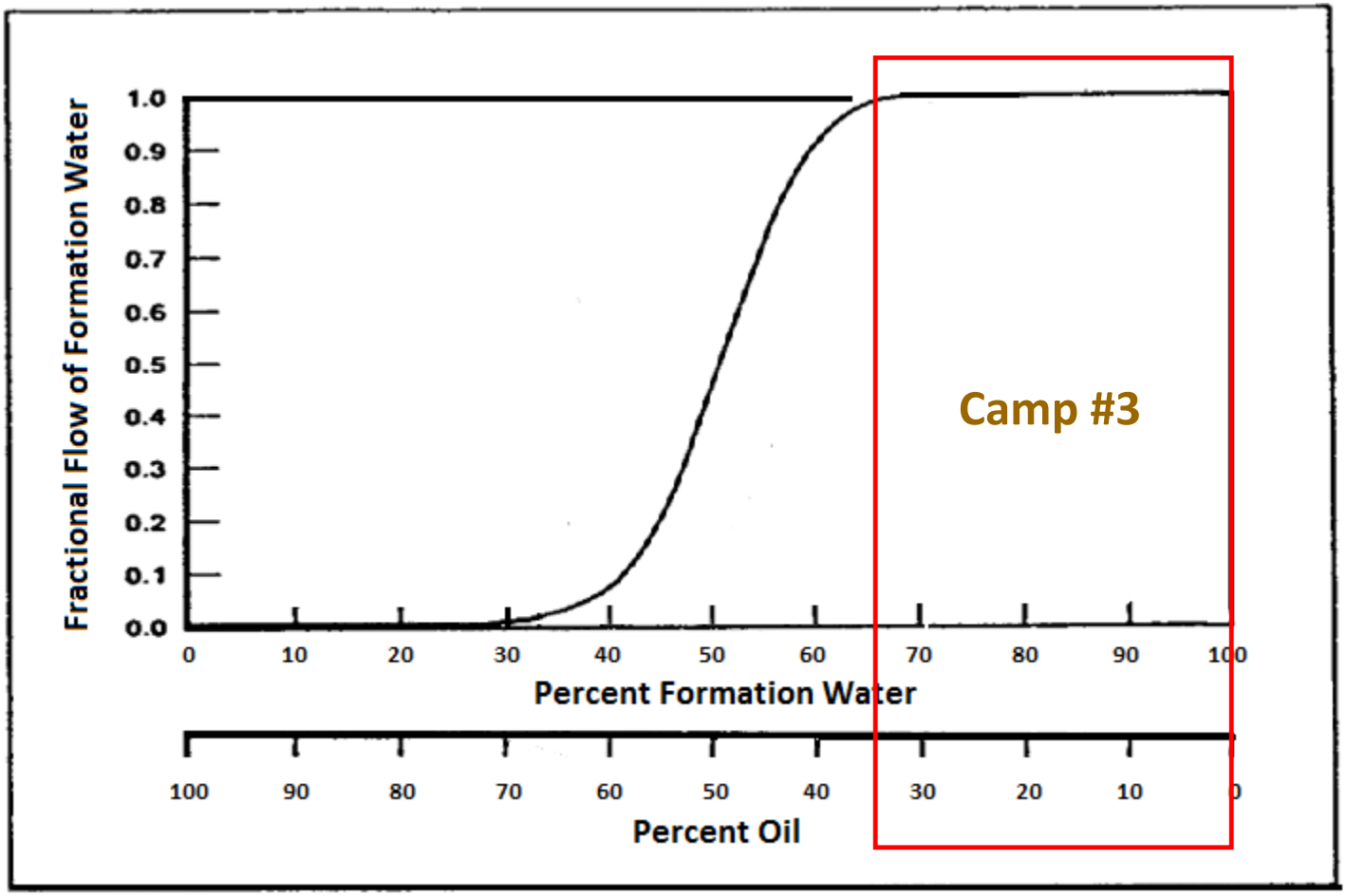


* The Best Example of this are the Shales

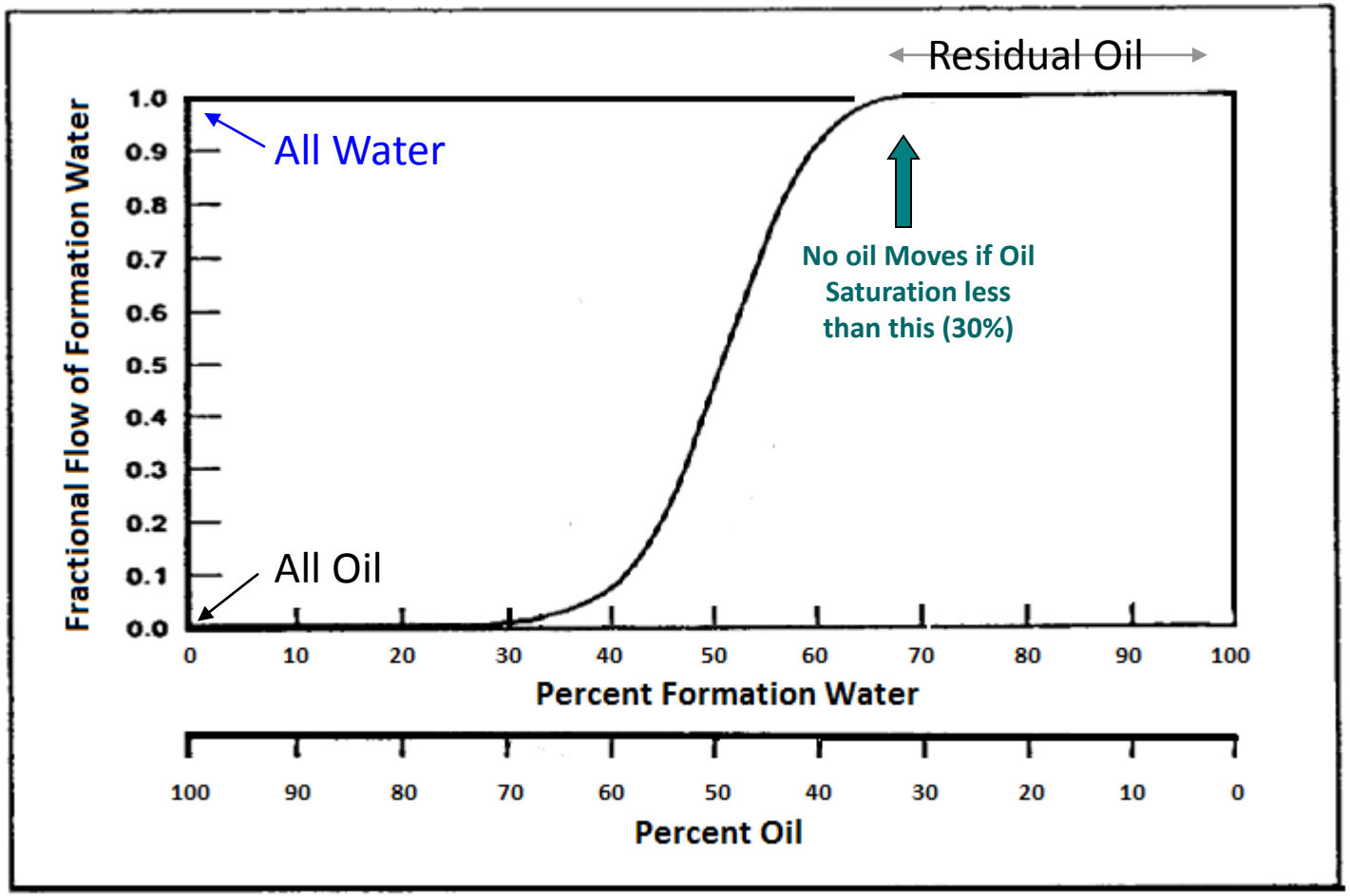
Fractional (Water) Flow as a Function of Oil/Water Saturation



What Ever Would Possess Us to Look to Camp #3?



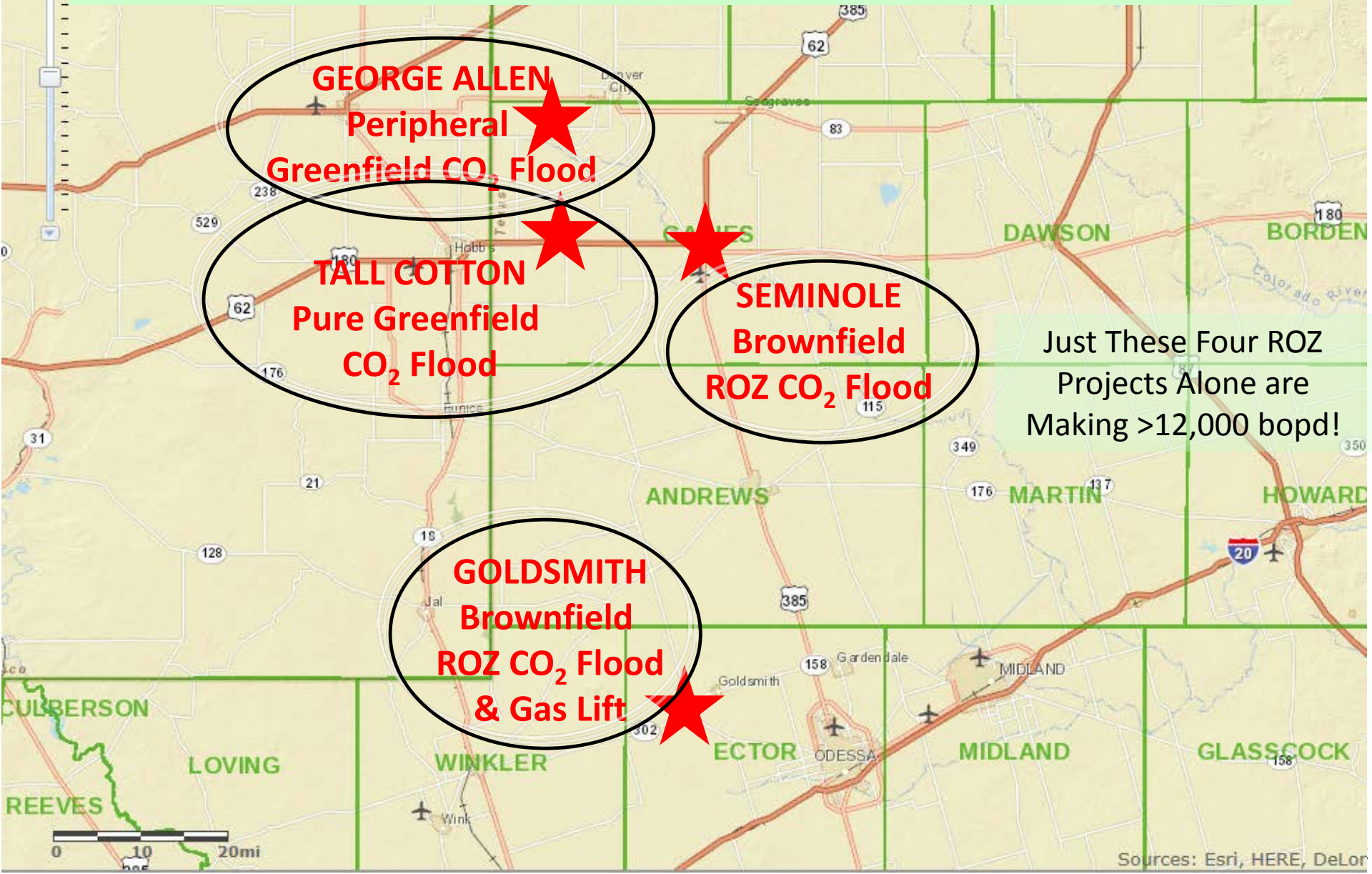
Fractional (Water) Flow as a Function of Oil/Water Saturation



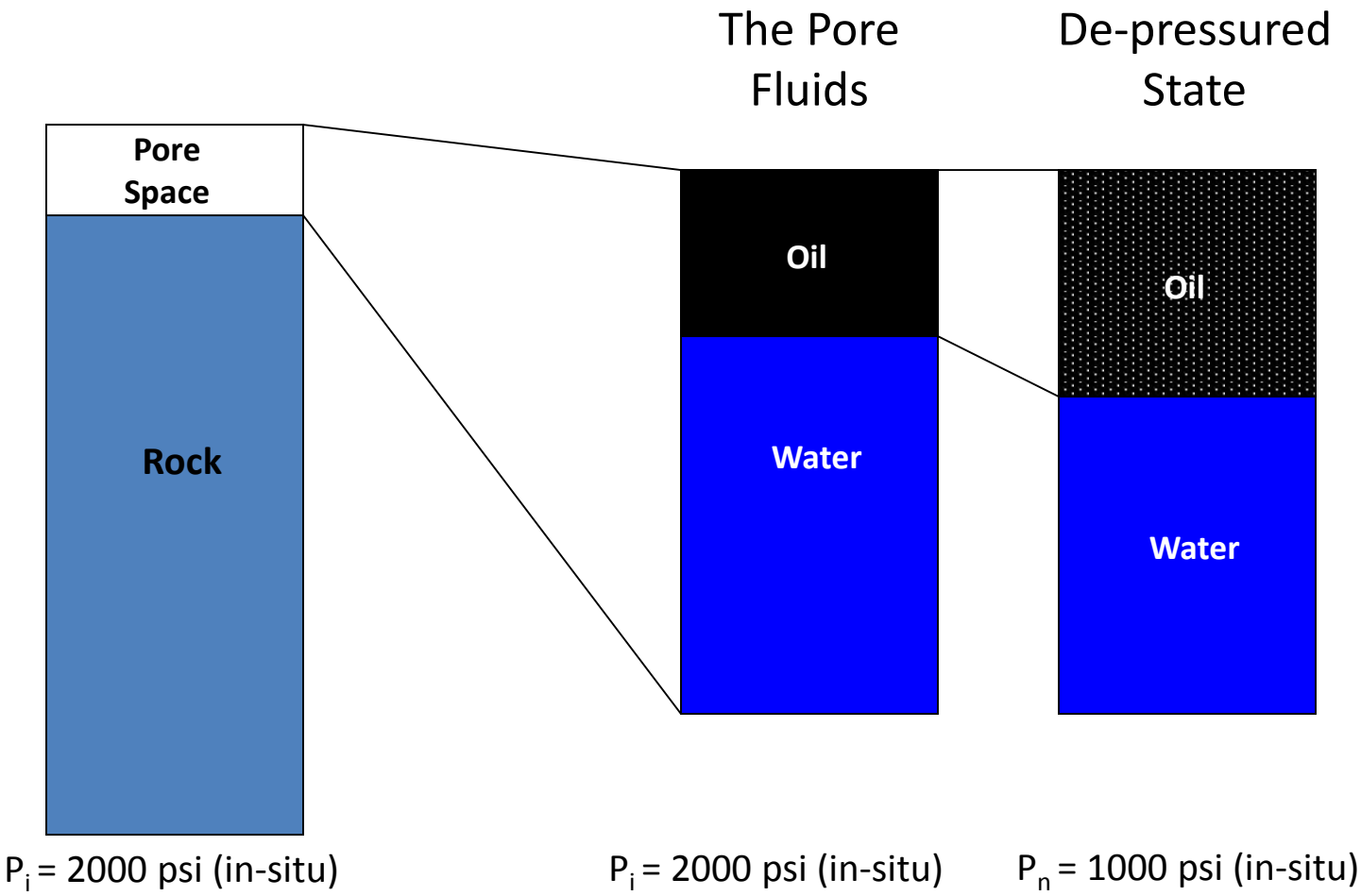
So what could cause the oil to start moving?

Mobilizing Residual Oil Via CO_2 EOR

Four of the 15 Active Residual Oil Zone CO_2 EOR Projects

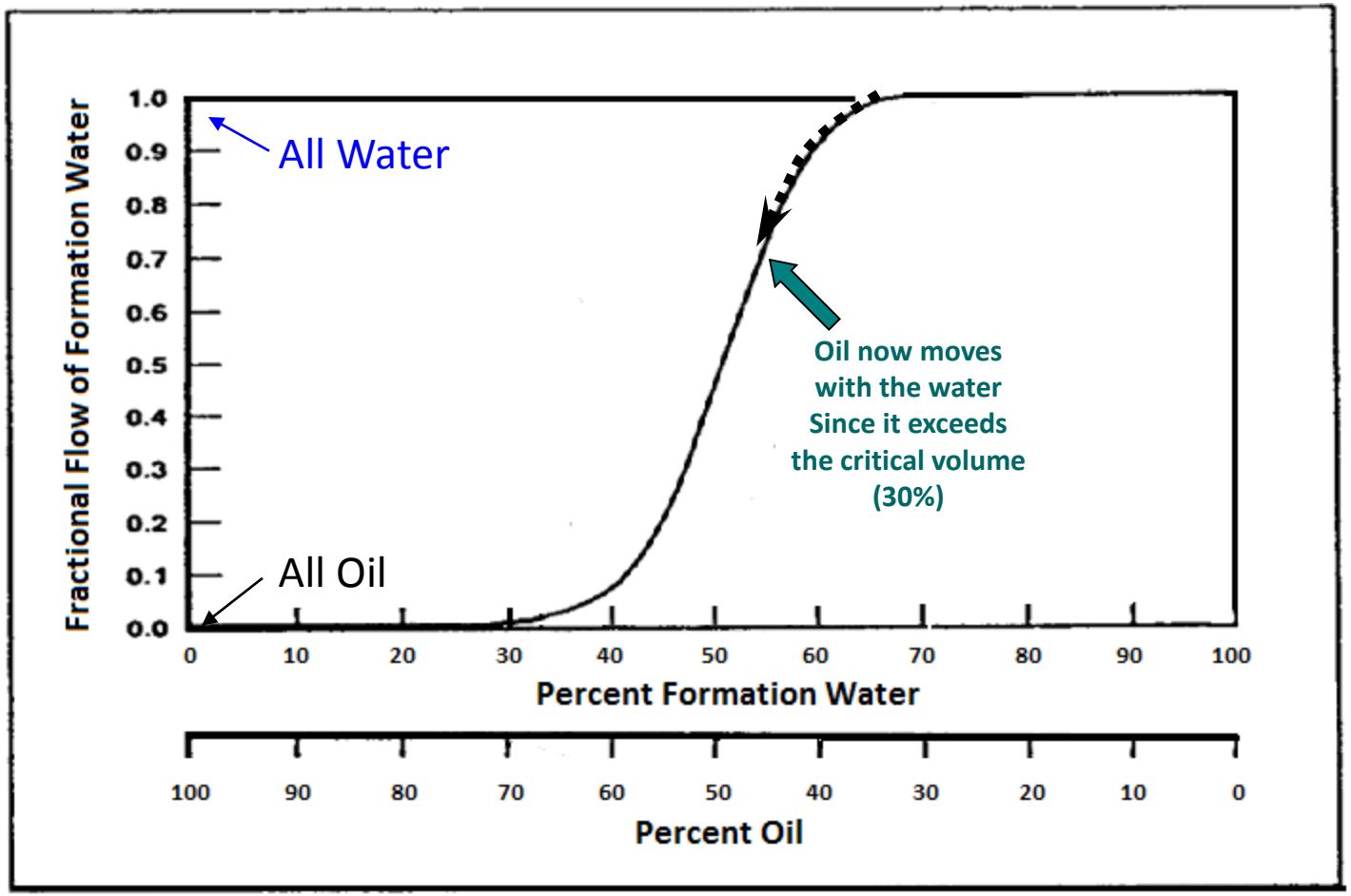


There is a Second Method to Mobilize Residual Oil: Horizontal Wells and Dewatering*



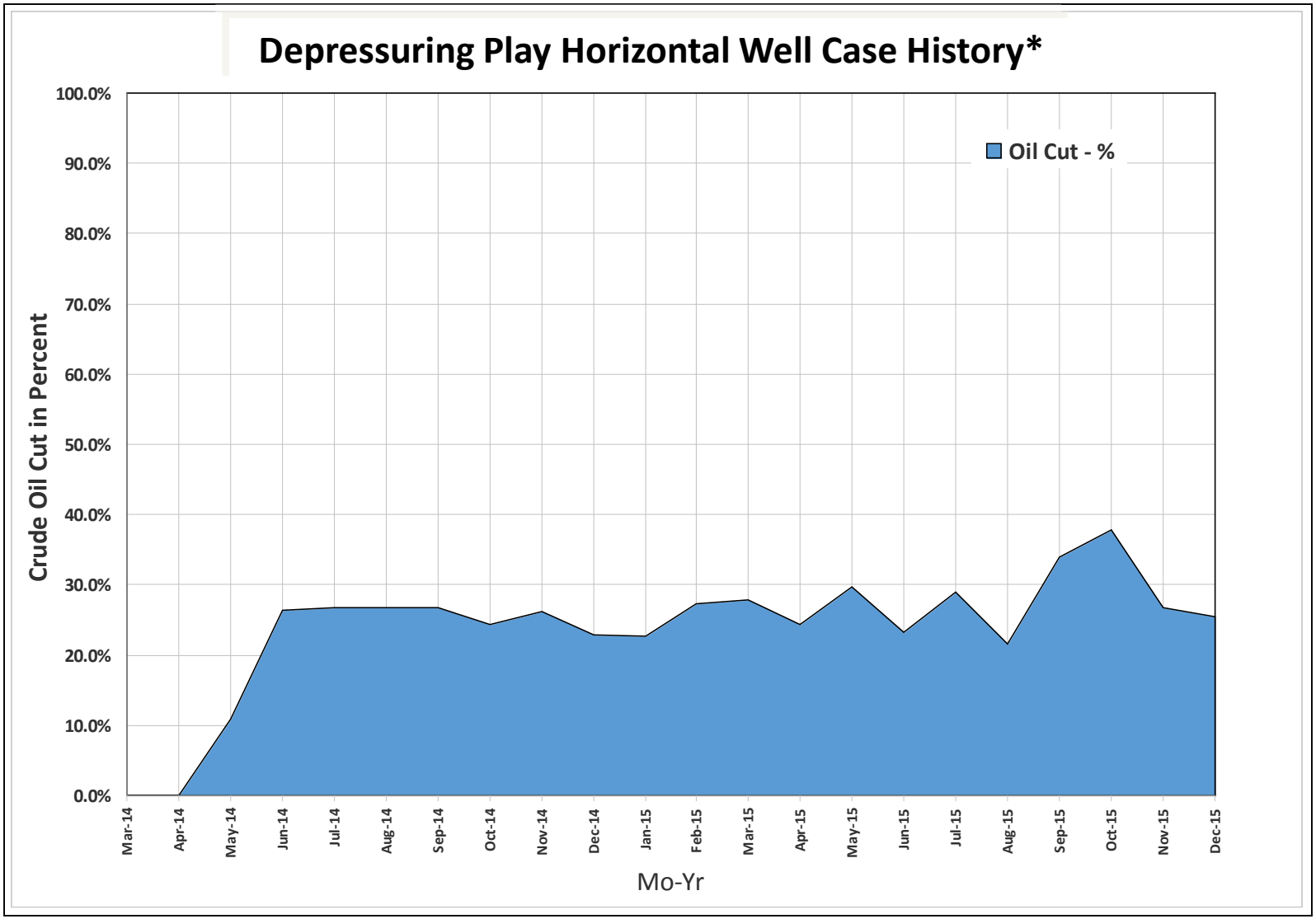
** We prefer the Term "Depressuring"*

Fractional (Water) Flow as a Function of Oil/Water Saturation



Oil Begins to move as the Oil Volume Grows

But, as with Light Tight Oil, Depressuring Plays Come with a Lot of Produced Water



* *North Shelf PB HZ San Andres Discovery Well (Lea Co.)*

Reservoir Depressuring

- Requires Processing and/or Disposal of Produced Water
- Leaves 90-95% of the Residual Oil Behind (Which, BTW, Remains a Target for EOR)
- Builds Infrastructure of Aggregated Leases, Wellbore and Surface Facilities (at a Profit)
- Cuts Upfront Cost of Any Follow-on EOR
- Facilitates Huge Pore Space for CO_2 Storage

The Horizontal Depressuring Play in the PB San Andres Formation (Started in 2013) is Now Making 12,000 bopd!

PRUDENT DEVELOPMENT

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National Petroleum Council • 2011

Let's Return to the NPC Report Published in 2012

INTERSTATE Oil & Gas COMPACT COMMISSION

Would like to call your attention to the

NPC Study on Prudent Development of North American Oil and Gas Resources

Resources and Supply Task Group (RTSG)

Sub-Groups

Arctic oil and gas (onshore and offshore)

Offshore (non-Arctic) oil and gas

Onshore gas

Unconventional oil

Oil infrastructure

Natural gas infrastructure

Onshore Oil/EOR Sub Group:

S. Melzer (consultant)	**T. Menges (ret.)**	**L. Schoeling (Kinder Morgan)**
P. Budzik (EIA-retired)	**J. Mosher (AERA)**	**Paul Tauscher (Marathon)**

NPC Study on Prudent Development of North American Oil and Gas Resources

Resources and Supply Task Group - Framing Questions

Oil & Gas Resources: Let's Look at Several Sources of Oil by Production Cost

What is the scope of technically recoverable conventional and unconventional oil and gas resources available in the U.S. and Canada, according to most recent estimates?

Productive Capacity:

How much of these oil and gas resources can be translated into productive capacity by 2050 under reasonable technical and economic assumptions?

What are the main drivers or assumptions behind existing NA oil and gas supply projections?

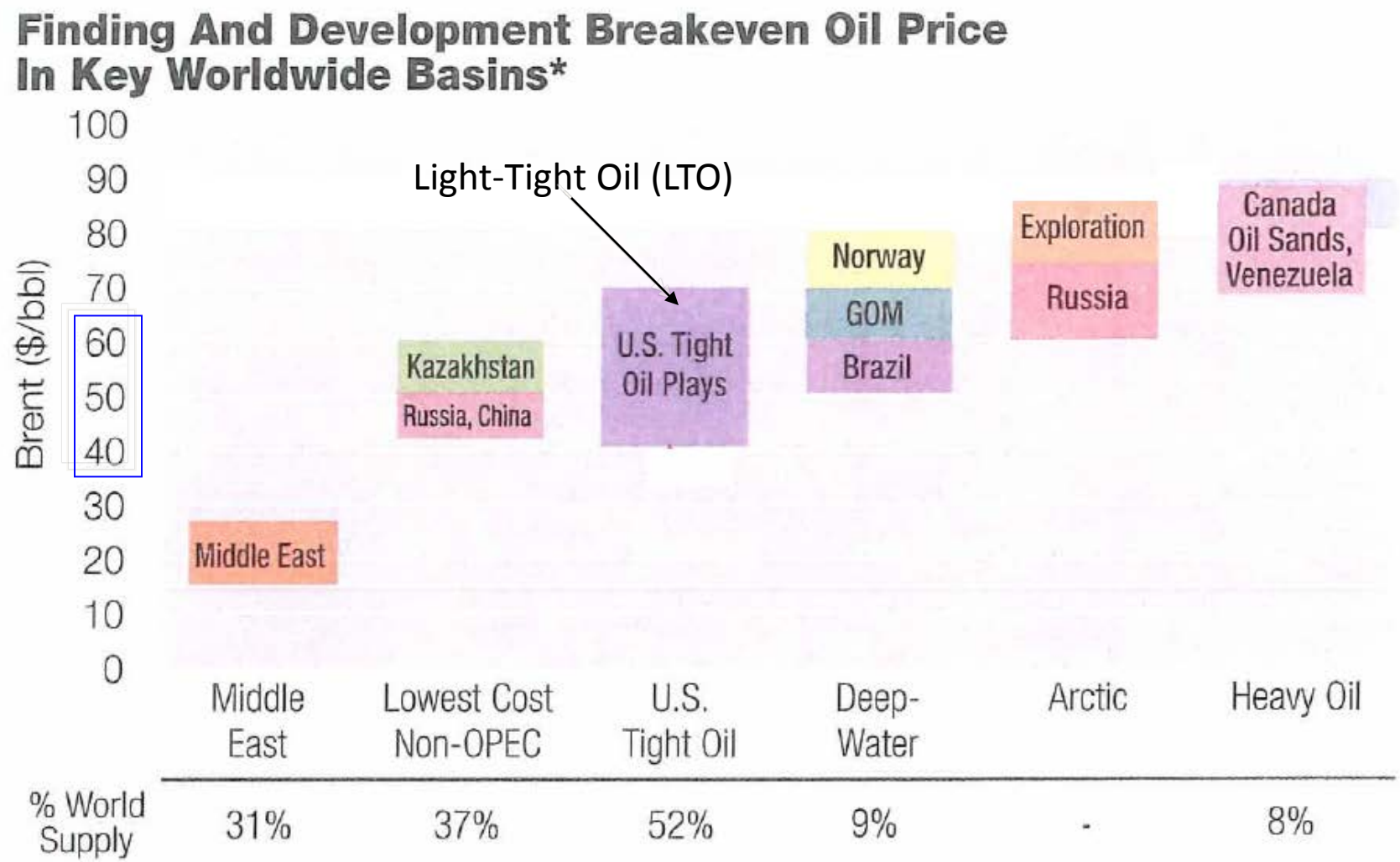
What factors could significantly increase or decrease the productive potential of these resources (e.g., geology, geography, access, technology, non-environmental regulation, etc.)?

What could be the particular contribution of each of the major types of oil and gas resource considered in this study and what specific development challenges may they face?

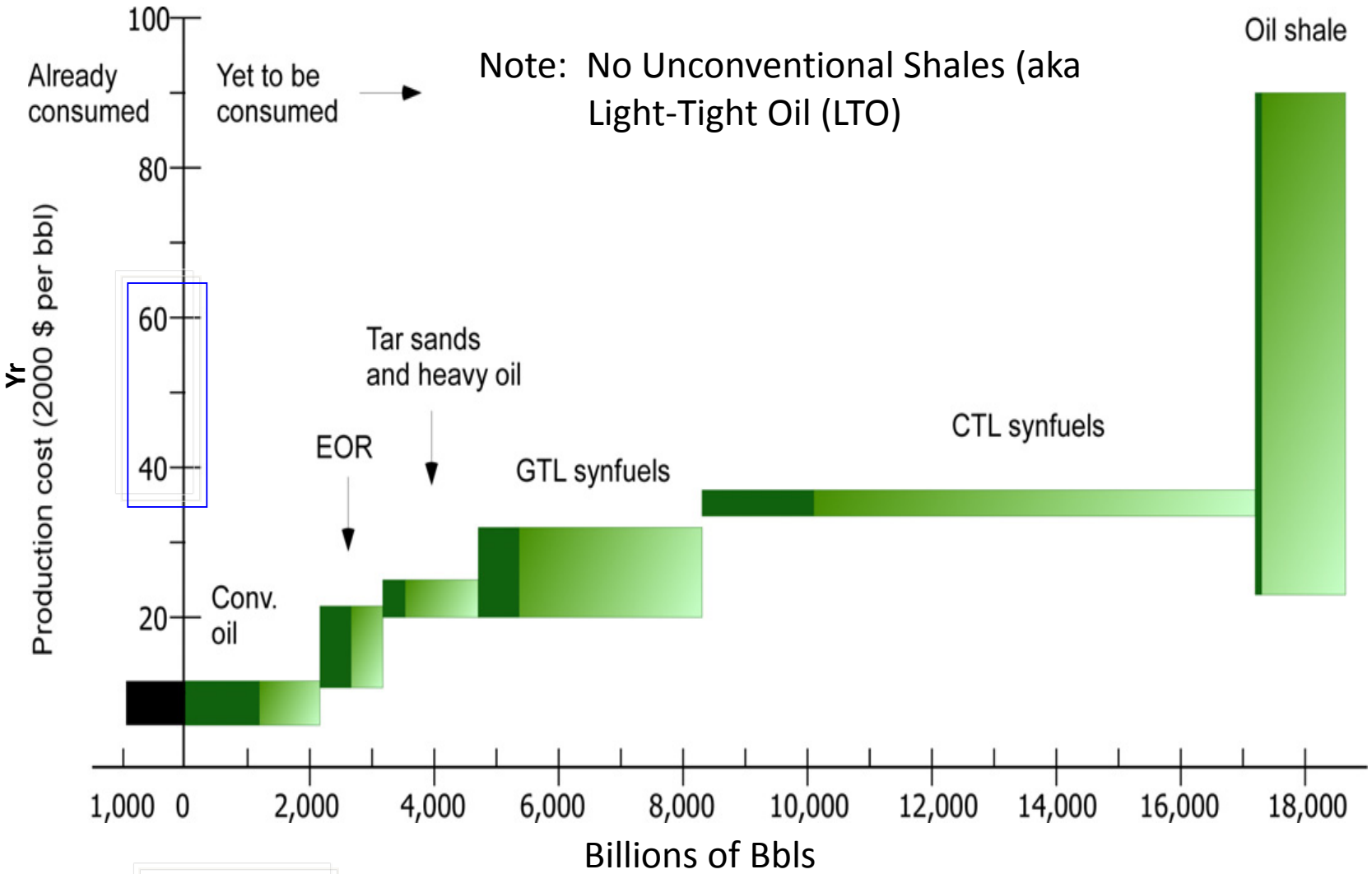
Infrastructure to Market:

How will sufficient infrastructure (gathering systems, gas processing plants, crude oil, gas pipelines, and gas storage) be developed to link these resources to the market?

By WW Basins



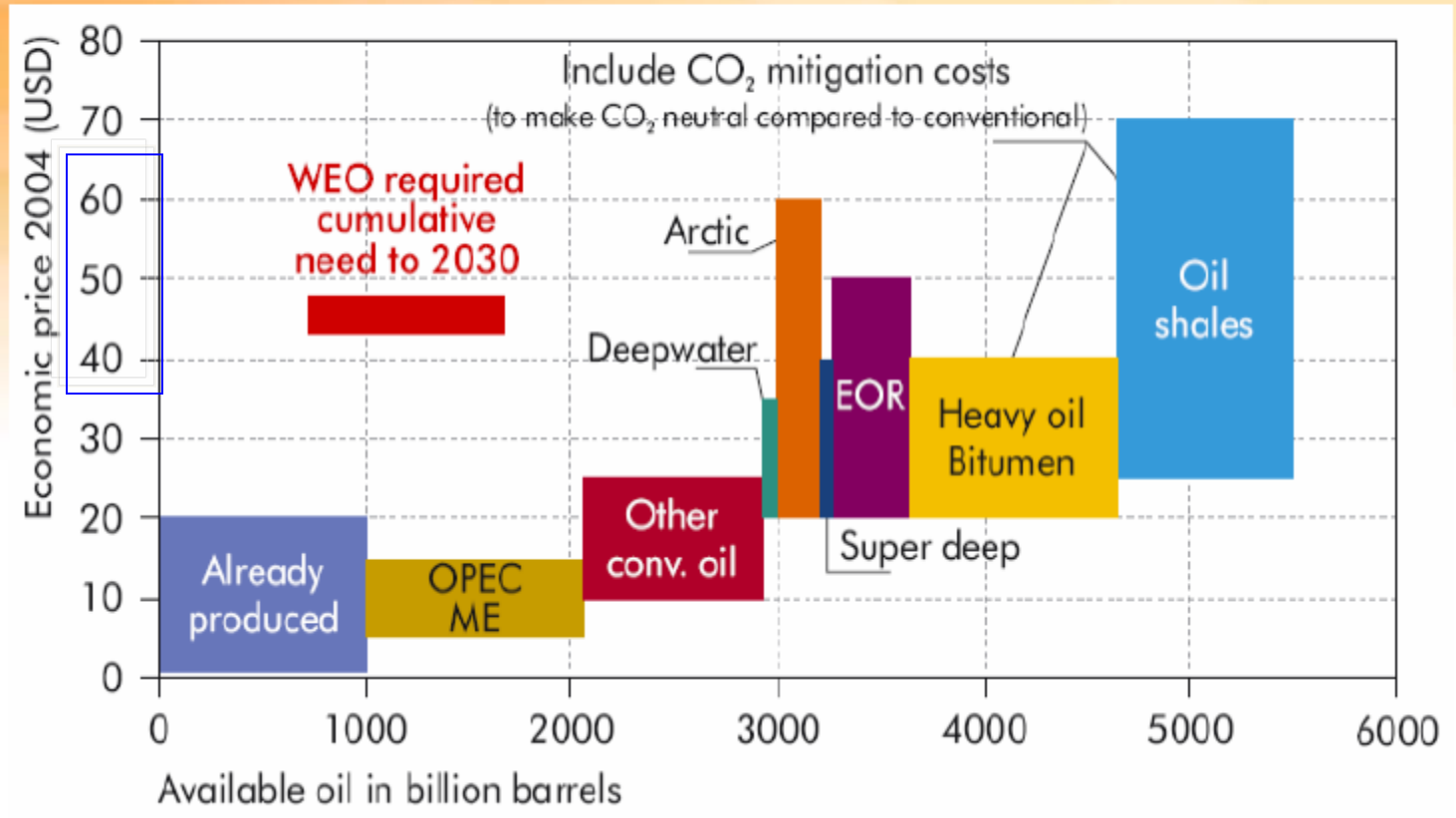
Source: PIRA Energy Group – Circa 2010



2000 data per Farrell & Brandt, 2006 (original source?)

……And Yet Another Look (EIA 2004)

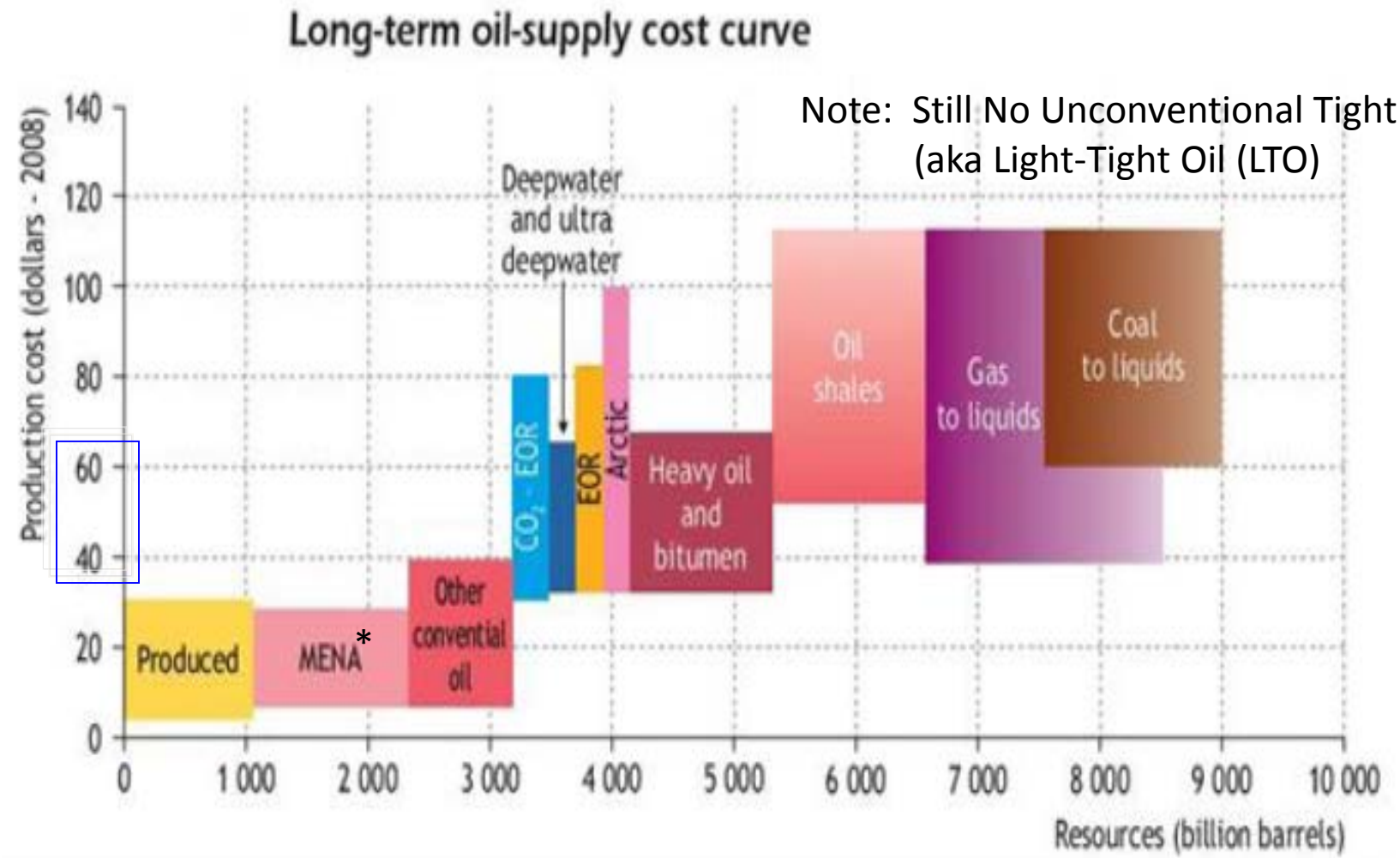
Oil cost curve, including technological progress: availability of oil resources as a function of economic price (Source: IEA)



2004 IEA Data

Note: No Unconventional Tight Oil (aka Light-Tight Oil (LTO)

EIA's Updated Look (2008)



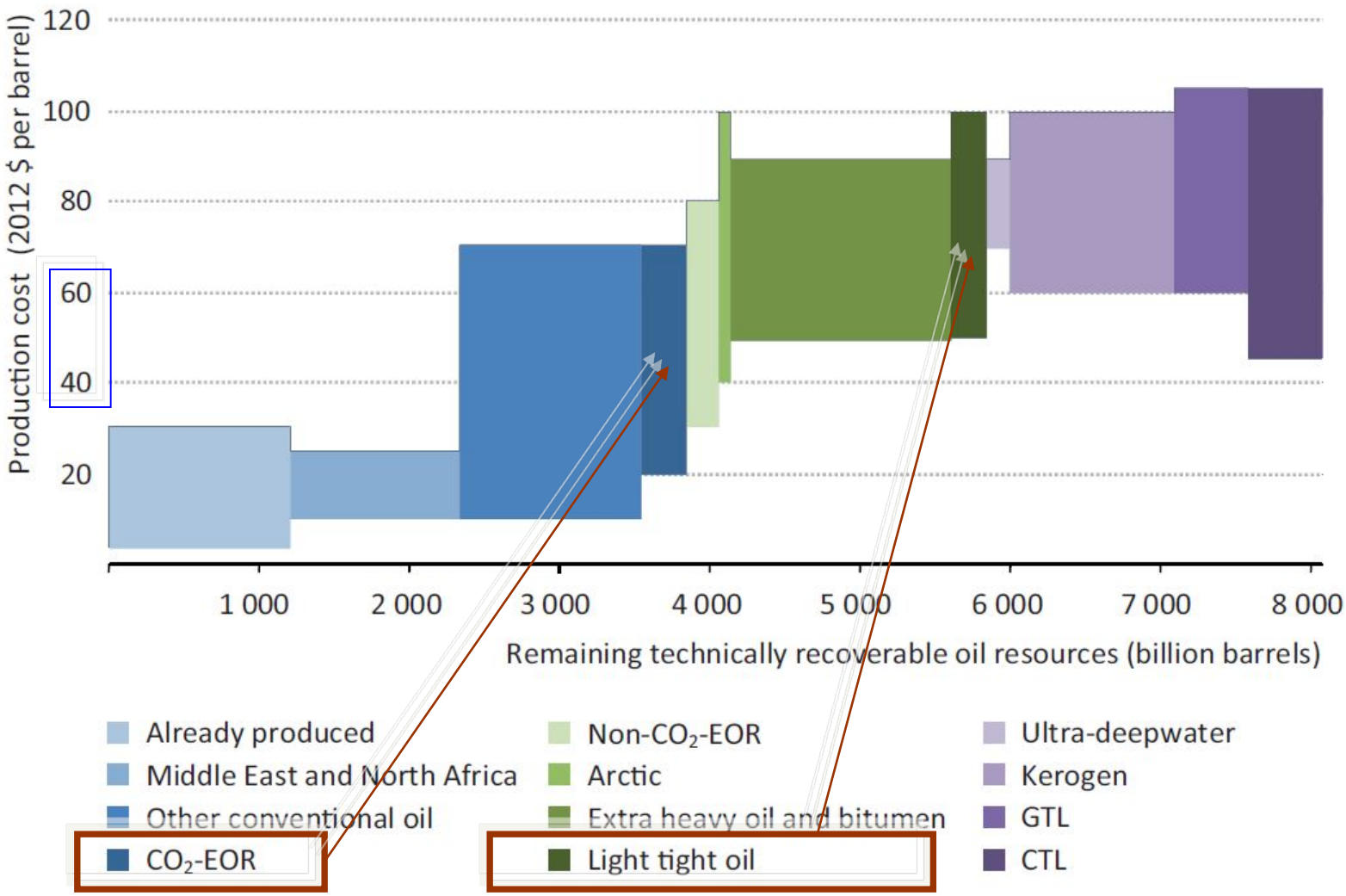
Note: Still No Unconventional Tight Oil (aka Light-Tight Oil (LTO)

Source: 2008 World Energy Outlook, IEA

* MENA = Middle East and North Africa

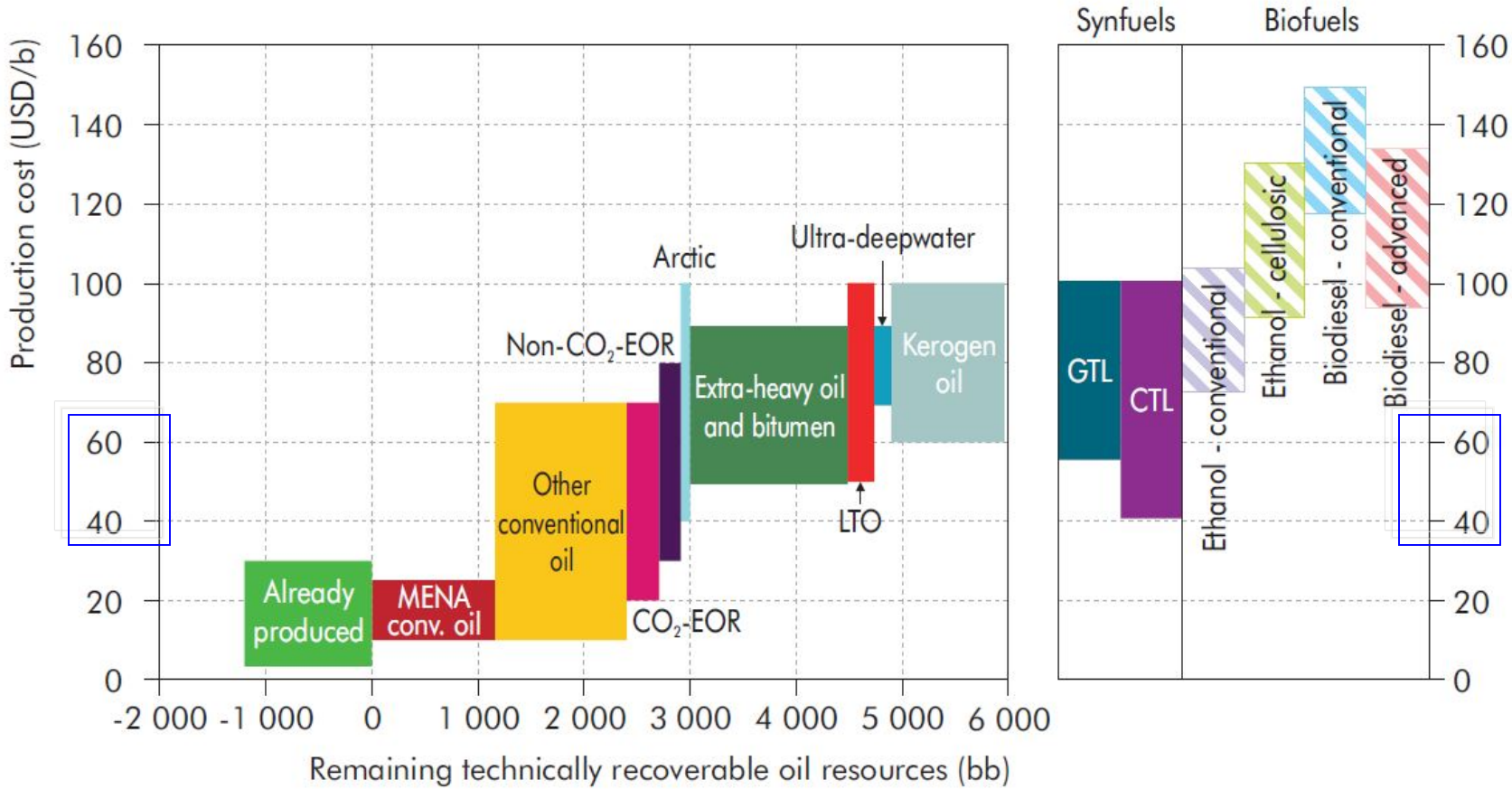
EIA's Updated Look (2013)

Figure 13.17 ▷ Supply costs of liquid fuels



Source: *Resources to Reserves* (IEA, 2013).

***Figure 8.3** • Oil production costs for various resource categories**



Notes: unless otherwise indicated, all material in figures and tables derives from IEA data and analysis. CO_2 = carbon dioxide; MENA = Middle East and North Africa. "Other conventional oil" includes deepwater. No carbon pricing included. Synfuel resources are difficult to assess due to competition with other natural gas and coal uses. Biofuels are renewable and, in theory, not resource constrained. Biofuels production costs have been credited with a "refiner's margin", using the ratio of gasoline and diesel spot prices in the United States compared to the West Texas Intermediate crude oil price. The ratio was, on average, 1.3 for gasoline and 1.35 for diesel between 2007 and 2012.

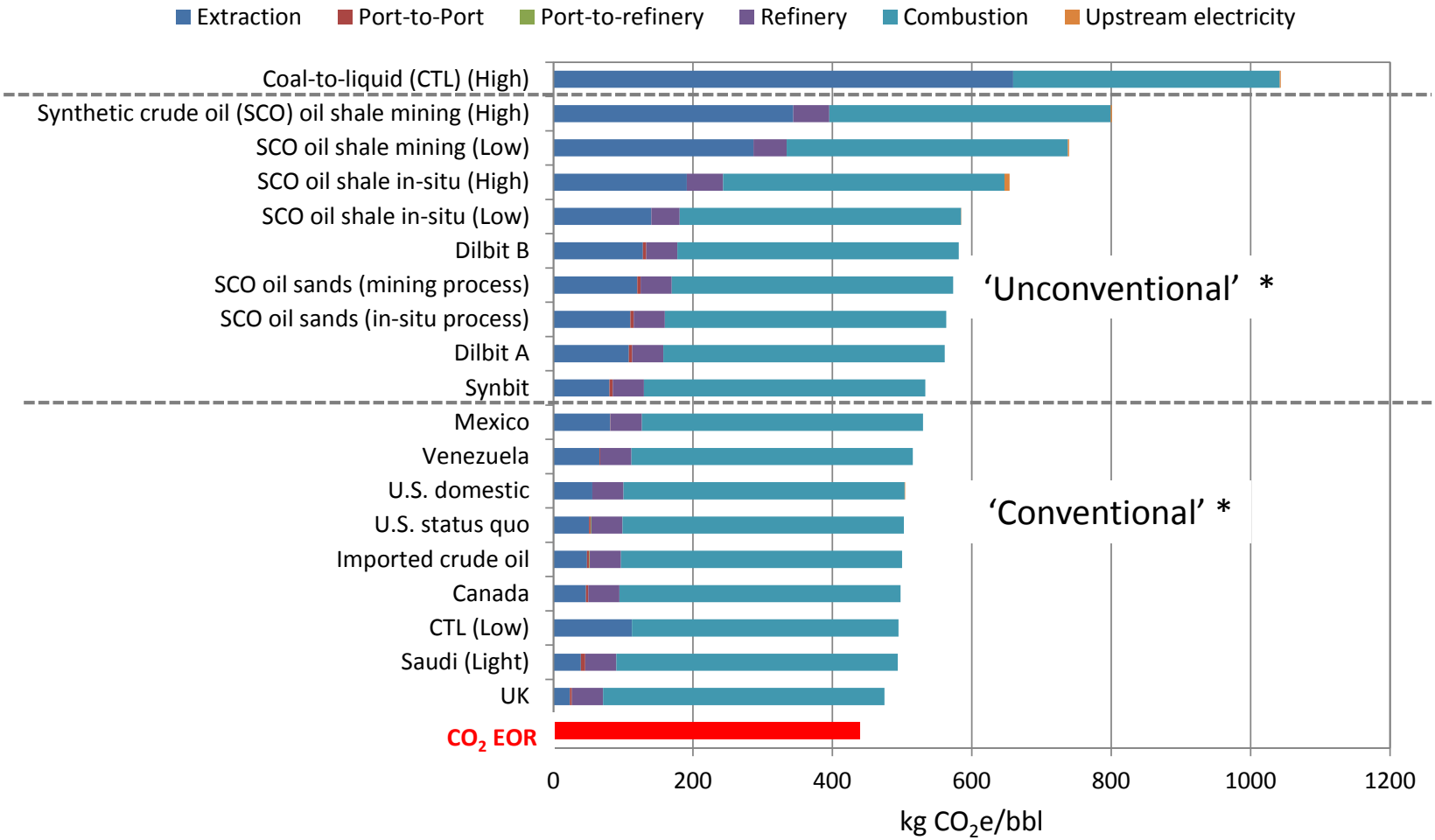
** Source: Energy Information Administration 'Resources to Reserves' (2013)*

For the Future, Maybe it is Not Just Per Bbl Costs

Does Oil's Carbon Footprint Play Into Our Future?

Comparing CO_2 EOR to "Regular" Oil GhG Emissions

Life Cycle Analysis (LCA)



Mangmeechai, A. (2009) *Life Cycle Greenhouse Gas Emissions, Consumptive Water Use and Levelized Costs of Unconventional Oil in N. America*. Dissertation, Carnegie Mellon University: Pittsburgh, PA.

* Author's Definition of Conventional and Unconventional

NPC Study on Prudent Development of North American Oil and Gas Resources

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How will sufficient infrastructure (gathering systems, gas processing plants, crude oil, gas pipelines, and gas storage) be developed to link these resources to the market?

RSTG Onshore Oil and EOR (1)

[Finding 1]: Onshore conventional oil (including EOR) production can respond quickly to price signals and increased regulatory certainty

[Evidence]: The crude oil prices in the 2008-2015 time frame led to 4.5 million b/d of additional US onshore production (90% increase), first flattening then dramatically increasing the resource-wide decline curve *(numbers here updated from NPR report)*

[Implications]: A favorable development environment can lead to rapid payoff in new production

Consequences of doing nothing: Overall production decline could continue and steepen

- **Support organisations which develop or disseminate technologies**
- **Support efforts which lead to regulatory certainty**
- **Avoid new fiscal burdens; consider incentives where appropriate (i.e., tax credits for low volume wells)**

RSTG Onshore Oil and EOR (2)

[Finding 2]: CO_2 EOR oil production is critical to onshore oil production growth. It is the only component of onshore <u>conventional</u> oil which is increasing, with future growth dependent on the availability of affordable CO_2 supplies. *New Reservoir Targets Abound*

[Evidence]: CO_2 EOR production has been increasing since 1986 and now accounts for 0.3 million b/d in US and Canada, primarily using naturally occurring pure CO_2. Forecasted growth (up to 1+ million b/d by 2030) will require economic supply from a variety of new sources with high CO_2 content by-products such as natural gas processing and other industrial processes.

[Implications]: Actions which add costs, increase regulatory burdens or reduce development opportunities should be avoided. Actions which help enable new sources of CO_2 supply to become viable can be pursued; this will improve oil supply from the sector.

Consequence(s) of doing nothing: no growth in production potential from CO_2 EOR

- **Ensure new carbon regs do not impact existing EOR** ✓
- **Avoid rules which incent premature abandonment of old fields** ✓
- **Maintain flexible transport options for new supply** ✓
- **Codify liability rules** ✓

IOGCC **Very** Active Here!!! USDOE Also

RSTG Onshore Oil and EOR (3)

[Finding 3]: To extend CO_2 EOR oil production above levels indicated by recent growth rates will require increased CO_2 supplies from more dilute anthropogenic sources.

[Evidence]: Recent growth reflects an environment where the supply of CO_2 has been limited to pure or relatively pure sources. There is a large in-place oil volume (several hundred billion barrels) which could be targeted for recovery if CO_2 supply from dilute sources (i.e. combustion by-product) could be developed. Incremental rates of over 1 million b/d of lower carbon footprint oil have been forecasted.

[Implications]: Given the increased cost and complexity to produce a purity CO_2 product from dilute by-product streams, this increased production will require significant activity in the technological and regulatory arenas. It is very likely to be linked to carbon storage.

Consequence(s) of doing nothing: CO_2 EOR limited by the supply of naturally occurring CO_2 and that from relatively pure sources. CO_2 Emissons Not Reduced

- **Ensure clear rules for new transportation infrastructure**
- **Codify liability rules for CO_2 storage in the reservoir**
- **Support efforts to demonstrate CO_2 capture technology**

USDOE Very Active Here

RSTG Onshore Oil and EOR (4)

[Finding 4]: Residual oil zones (ROZs) in existing oil fields could have 10s of billions of barrels of recoverable resources, greenfield even more, making huge targets for CO_2 and other technologies

[Evidence]: Besides in-place oil remaining after current production processes (including depressuring), there are known "oil-water transition zones" beneath existing fields. Commercial production tests are advancing but still in an early stage of development.

[Implications]: CO_2 flooding is (was at the time) the only currently demonstrated recovery technology for ROZs. Besides additional experience, existing infrastructure and CO_2 supply sources likely to be needed for viable development

Consequence(s) of doing nothing: 80-300 billion barrels of in-place oil not targeted

- **Support efforts to better identify and delineate the target**
- **ROZ technology R&D support** (DOE is working this under a CCUS Flag)
- **ROZ tax credits for R&D or pilot work**

Sadly, RPSEA was Very Active Here and Deserves a Lot of the Credit

RSTG Onshore Oil and EOR (5)

[Finding 5]: Technology Development and deployment can enhance reserves growth

[Evidence]: Horizontal wells now account for 50% of wells-drilled in US (2010)*. Efficient fracturing technology has opened up new development opportunities where multiple formations are accessed for production.

[Implications]: It will be critical to future reserves growth to continue advances in well drilling and stimulation to access in-place oil. Understanding of well performance and fluid flows in reservoirs with new technologies will be important as well.

Consequence(s) of doing nothing: Sub-optimal development, lower recovery factors and fewer opportunities.

- **Avoid limits on hydraulic fracturing** IOGCC Very Active Here
- **Support appropriate efforts to comingle multiple formations**

- *Updated %age Estimate in 2015 is 60%*
  (just a guess but I bet it is 80-90% of Total Footage

Closing Summary and Further Discussion (1)

General Philosophy

- Where the O/G Industry is Actively Moving – Leave those Market Forces Alone*
- Re-examine any New or Longstanding Regulatory Disincentives that May Not be Providing the Expected Benefits
- Incentivize Key Holes in the Market Activity

* Intercede only where necessary and get the States in front of EPA

Summary – Further Discussion (2)

<u>Where Industry is Actively Moving Ahead – Leave the Market Forces Alone</u>

- Increasing Use of Natural Gas and Lower Carbon Intense Energy (Electricity)
- Keep Up the Well Stimulation Fight (Frac Focus, etc)[1)]
- Assist with Technology Transfer, Reporting of Accurate Data, and Posting of Data (Some States are Doing Great at This – Canada is Better)

1) - Is IOGCC "Tainted"

Summary – Further Discussion (3)

Incentivizing Key Holes in the Market Activity

- With the New Paradigm of Prolific O/G Resources, Industry is Effectively Abandoning Conservation of Resources (e.g., Become only a Drilling Industry)
- To Compensate, Do We Need Incentives to Renew Advanced Recovery Projects?
- Shales and ROZs Produce Unprecedented Volumes of Water, Can We Incentivize Water Reuse vs. Pure Disposal
- CO_2 EOR Can Provide Lowest Carbon Footprint Oil
- Mineral vs. Storage Rights Issue May Be Coming – Get Ahead of that?
- Potential Incentives (Next Slide)

Summary – Further Discussion (4)

Potential Incentives

- National
  - Nat'l Enh Oil Rec Initiative (Underway - $30/tonne Capture + CO_2 EOR / Storage)
  - Federal Loan Guarantees (Capture)
  - Clarify CO_2 Storage During EOR (Capturers Need it Concurrent with Injection)
  - Others?
- State
  - Continue Severance Tax Abatement for IOR (on-going in many States) – Supplemented Tax Abatement using Anthro CO_2 (Tx Model)
  - Get out in Front of the Water Re-Use Dilemma* to Incentivize & Facilitate Alternatives to Pure Disposal (Beyond Ok Curtailment Strategies?)

** Some Impediments are Legal (e.g., Moving Water off Lease), Some are Induced Seismicity, but the perceived big one is economics of reprocessing*

Summary – Further Discussion (5)

More Incentives Discussion (General)

- Carrots and Sticks
- Texas SACROC Improved Oil Recovery Model
- Turn the Induced Seismicity Issue into an Opportunity?
  - Current Approach: Disposal Injection Permits as a Lever? ('Stick')
  - Find a Broad Incentive ('Carrot') to Encourage Water Processing (is the use of Nat Gas and NGL streams going to help here and also Contribute to Reduced Flaring?)

Producing excessive volumes of water are a big part of our Energy Future. How Best to Proceed?

Seismic Shifts in Oklahoma Lead to Stricter Regulations

Trent Jacobs, *JPT* Senior Technology Writer

Industry regulators in Oklahoma have rolled out broad new restrictions on more than 600 disposal wells as part of the largest action of its kind taken in response to earthquakes.

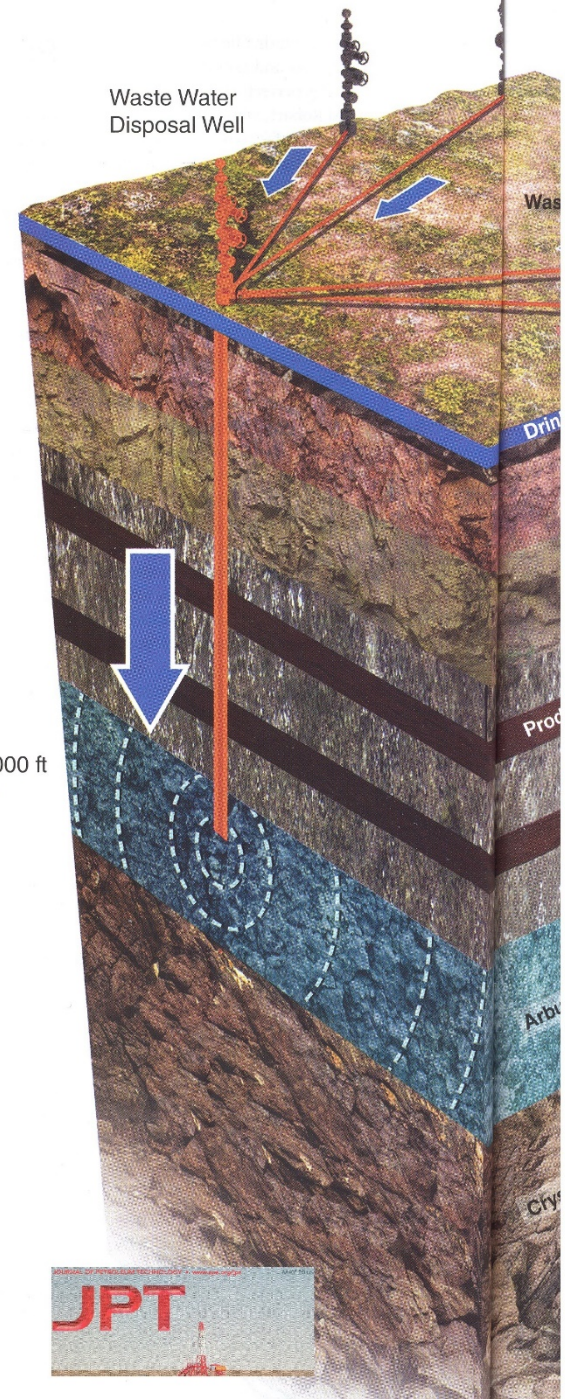
An additional 118 wells have been included in an "area of interest" and face increased reporting and monitoring requirements. Altogether, the plan affects approximately 20% of the state's disposal wells and marks a major change for the fourth-largest oil- and gas-producing state in the US.

The Oklahoma Corporation Commission, the state's industry regulator, spent a year issuing volume reductions and shut-ins at a number of specific disposal sites, efforts that failed to slow the rising rate of earthquakes. Then on 13 February, the third-strongest earthquake in Oklahoma history shook homes across the state and was felt hundreds of miles away by residents of three neighboring states. No serious damage or injuries were reported. But just days after the 5.1 magnitude trembler, regulators abandoned their pinpoint approach and announced a "regional earthquake response plan" that covers approximately 10,000 sq miles—an area twice the size of Qatar.

For the foreseeable future, no new disposal well permits will be granted in the restricted zone, and operators must curtail fluid injections into existing wells by 40% of their 2014 average rate. Based on last year's figures, that means a reduction of fluid injection of approximately 300,000 B/D.

Because water disposal is a necessary component of oil and gas operations, the immediate scarcity of disposal wells may drive up fees at sites operated by third parties. Recycling or trucking the water outside of the restriction zone are expensive options that few operators can afford right now.

If there are no feasible alternatives, ongoing production declines may accelerate in the Mississippian Lime, the most significant play affected by the order. The play is a carbonate formation, and unconventional techniques are used to recover oil and gas from it. Last year, production in the Mississippian Lime was estimated to be around 100,000 B/D, which accounted for a quarter of the state's overall production.



Scientists and regulators in Oklahoma have concluded that the high-volume injections into the subsurface are increasing the pore pressure inside the rock along the faults, which creates a greater risk of the faults slipping. *Graphic courtesy of Steven Than/Stanford University.*

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From Lanny's Review

Emphasize these Priorities

- Ensure new carbon regs do not impact existing EOR
- Avoid rules which incent premature abandonment of old fields
- Maintain flexible transport options for new supply
- Codify liability rules

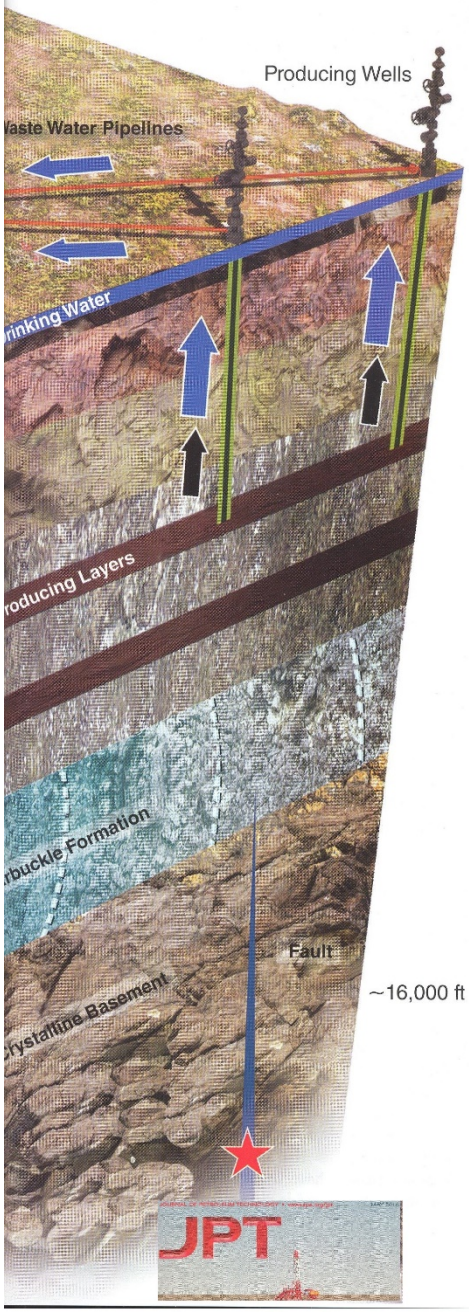
Thank you

I'd Like to Take this Opportunity to Recognize Bill Lemay – Former OCD (NM) Director, a Wonderful IOGCC and Regulation Community Contributor who Passed Away Last Month

www.melzerconsulting.com

See also www.residualoilzones.com

JPT Article on Induced Seismicity (page 2)



The play is notable for being the leading water producer in the state. To handle all the produced water, along with much smaller fractions of drilling and fracturing fluids, operators have spent millions of dollars on drilling a vast network of disposal wells.

As they do around the world, disposal wells in Oklahoma allow companies to efficiently and cheaply dump billions of barrels of waste water a year deep into the ground. In most locations, this is a safe and standard practice.

But when the volume of water being injected in Oklahoma soared to new levels, so did the rate of earthquakes—now 600 times higher than it was before 2008, according to the Oklahoma Geological Survey (OGS). The consensus among regulators, scientists, and many industry experts is that wastewater injections are the root cause of the earthquakes, a process termed induced seismicity.

It could take several months for regulators to decide if their current plan has worked. If it fails, then some experts expect to see even tighter rules or an outright moratorium on injections. There are also those who believe that reductions are not the solution; instead, a better understanding is needed of where disposal wells will have little or no chance of triggering fault slips.

Mississippian Lime in Trouble

Only 4 years ago, the Mississippian Lime was hyped up as the next Bakken Shale, a bold prediction that missed the mark by a wide margin. Operators have struggled to make the play a commercial success and though the latest restrictions seem to cast more dark clouds over the Mississippian Lime's future, low oil and gas prices are likely to mask any immediate impact.

Richard Zeits, founder of Zeits Energy Analytics, researches shale operators for investors and said a number of producing wells are likely to be shut in as a result of the new constraints. But he also noted that production in the area is already on course to decline by 20% or more by the end of this year.

"Even without regulatory restrictions," he said, "there are many questions with regard to what threshold oil price might be required for [the Mississippian] Lime to be a profitable play."

Initially, the Mississippian Lime was seen as a "perfect application for horizontal drilling," according to an OGS report written in 2012 when activity levels were starting to ramp up. A year later drilling activity peaked and several companies sold off their entire positions at fire-sale prices.

The play's largest producer and operator of a number of disposal wells, Oklahoma City-based SandRidge Energy, doubled down around that time and acquired more core acreage leases. In March, the company said it may not survive for much longer. If that is the case, SandRidge would be the largest shale producer to file for bankruptcy protection since the downturn began.

Operators competed for large swaths of the play that spans both Oklahoma and Kansas knowing it had higher than normal water cuts. In addition to high oil prices, they believed the water handling costs would be offset by lower drilling and completion costs. Many areas of the Mississippian Lime are considered shallow compared with other plays (between 1,600 ft and 7,000 ft) and since it is a carbonate as opposed to a shale, it is

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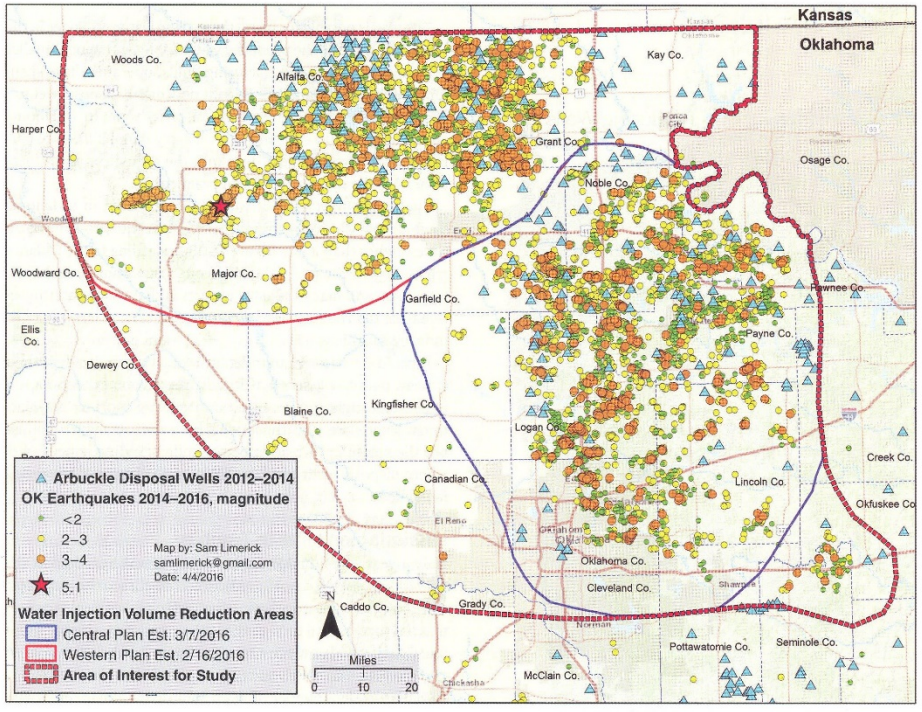
JPT Article on Induced Seismicity (page 3)



After a 5.1 magnitude earthquake in February, the Oklahoma Corporation Commission has taken its biggest steps yet to mitigate the growing earthquake problem in the state. *Graphic courtesy of Sam Limerick.*

easier to drill through and requires lower horsepower rigs.

But the more operators got to know the Mississippian Lime, the less they liked it. Wells depleted too quickly and due to its remoteness, companies faced spending tens of millions of dollars on power lines needed to run pumps for lifting and disposal.

And the water cuts were not just higher than normal, they were often extraordinarily high. Newly completed oil wells have been known to pump out as much as 98% water at a rate of thousands of B/D. Those who have worked the Mississippian Lime sometimes quip that it is really a water aquifer with just a little bit of oil sitting on top.

Even if prices rise enough to make the play profitable, the disposal limits will essentially act as a cap on future oil production. And as bad as things are now, they could always get worse if further limits are put in place. Zeits said the biggest risk facing operators is the uncertainty about how the situation will play out and whether the response plan meets its objective.

"If there are more big earthquakes, the regulators may have little choice but to impose even stricter rules," he said. "I am not saying this will happen, but if it did, the impact on production and cash flows would be potentially a lot more severe."

Legal Faults Widening

The spike in Oklahoma's seismic activity prompted the US Geological Survey to recently issue its first 1-year forecast for earthquake hazards in the continental US. The federal agency, whose seismic risk assessments are used to develop building codes and guide policy makers, said Oklahomans face a 5% to 12% chance of incurring minor home damage "such as fallen plaster or cracks in the walls" due to an earthquake induced by injections. It is the same risk level assigned to naturally occurring earthquakes in the seismically active state of California.

Keith Hall, a professor and director of the Mineral Law Institute at Louisiana State University, presented a technical paper on the legal risks associated with induced seismicity at last year's SPE Hydraulic Fracturing Technology Conference. He said that since then, there have been more earthquakes, more regulations, and more lawsuits filed by homeowners. "The one thing I am seeing less of is skepticism about whether there is really a problem," he said.

Hall added that environmental groups have begun using the issue as a legal wedge that may affect future permits,

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especially for those on federal lands. And so far, two class-action lawsuits have been filed in state court against disposal well operators in Oklahoma.

While most of the earthquakes have caused little damage, Hall said if enough homeowners report small cracks and too many sleepless nights, "then you could get significant [monetary] damages, even though no particular plaintiff suffered that much."

Behind the Oklahoma Earthquakes

- Earthquake swarms are occurring over approximately 15% of the state where injections of produced water have risen significantly in recent years.
- The majority of produced-water injections are taking place in the Arbuckle formation that overlies the crystalline basement rock.
- Most of the earthquakes are happening within the crystalline basement rock that is much deeper than oil and gas operations.
- "High-bulk" permeability sections within the Arbuckle allow pressure from injections to be transmitted several miles away from a disposal well.
- The high density of disposal wells in central and north-central Oklahoma and the geologic characteristics of the Arbuckle make attributing specific wells to specific seismic activity difficult.

Source: Oklahoma Geological Survey

Research Looking for Details

The latest research has moved past proving that the earthquakes are induced and is focusing on unanswered questions such as why some areas with lower injection volumes have more seismic activity than areas with higher injection volumes.

"There is a lot more than just injection that is needed to cause earthquakes—you might think of it as a perfect geologic storm," said Rall Walsh, a PhD candidate at Stanford University's department of geophysics.

At the center of that storm is the deepest sedimentary rock layer in Oklahoma called the Arbuckle formation, the primary target for most of the state's disposal wells. Walsh published a widely circulated study last year that found that between 1997 and 2013 injection volumes doubled to 160 million bbl per month, most of which went into the Arbuckle.

"Much in the way that accountants will follow the money, we followed the water through Oklahoma," he explained.

The Arbuckle lies below the hydrocarbon layers and just above the fault-laden basement rock. It has been described as the ideal formation for disposal. Due to its low pressure, it eagerly vacuums up incredible volumes of water, and vast networks of natural fractures, vugs, and caves provide plenty of extra real estate for the injected water to reside in. Or so it was thought.

Because the formation is not hydraulically isolated, Walsh and other researchers believe excess fluid pressure is migrating into the basement layer where, in some cases, it spreads out for a mile or more. And when the pressure on a fault exceeds the pressure holding it in place, it slips, causing an earthquake. Walsh is now analyzing the known faults in Oklahoma to determine "which are close to slipping and which ones you couldn't make slip if you tried."

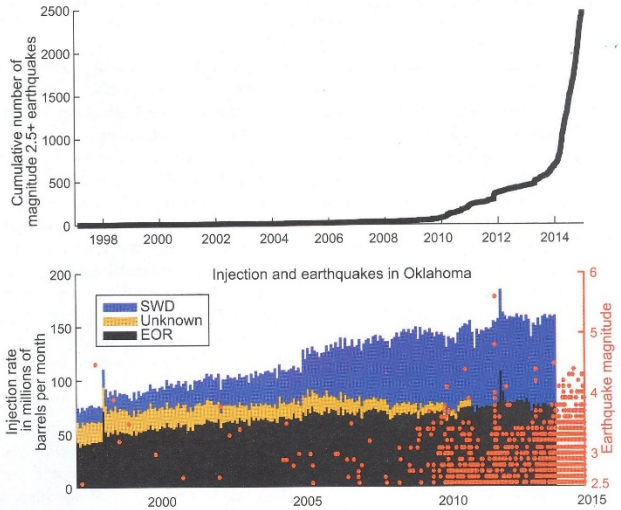
He added that through his research it is becoming increasingly clear that the problem in Oklahoma is not about individual wells but a combination of many wells that all contribute to pushing sensitive faults past their limits.

"One thing we've told the operators is that it is no longer just about what they are injecting down the well," he said. "It's what all of your neighbors are injecting down their wells too that matters."

New Modeling Efforts

One way to observe the pressure regime in the Arbuckle would be to use decommissioned disposal wells as monitoring wells. The first person to lead such an effort is Kyle Murray, a hydrogeologist at OGS.

As part of an agreement between SandRidge and Oklahoma regulators, Murray will have access to five nonoperating disposal wells. He plans to install pres-



Using statewide data, researchers have shown a correlation between the number and rising strength of earthquakes and disposal well injection volumes in Oklahoma (data available up to 2014). SWD–saltwater disposal; EOR–enhanced oil recovery. *Graphic courtesy of Rall Walsh/Stanford University.*

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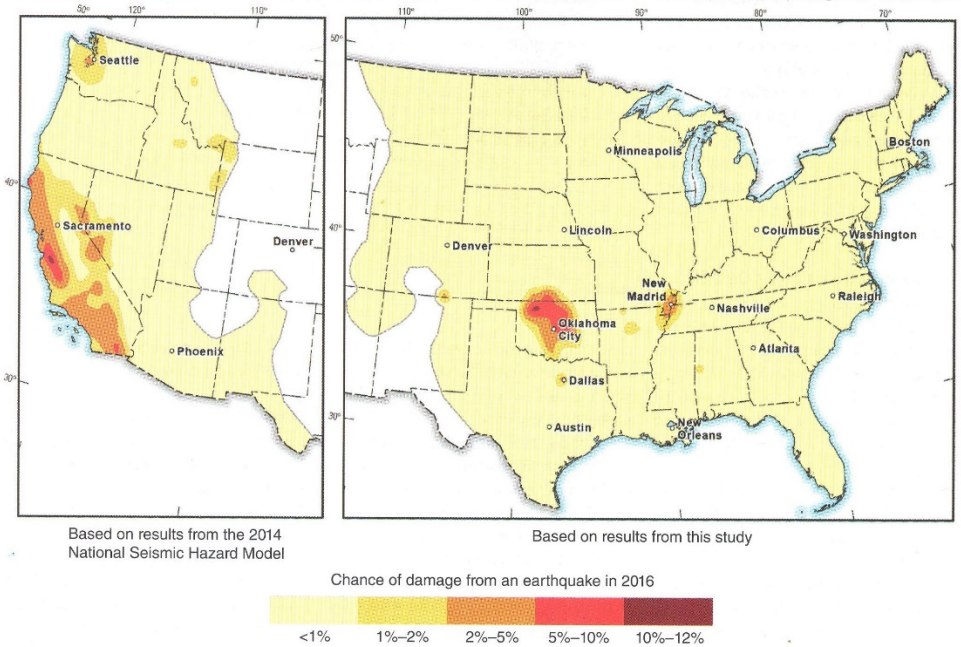
Chance of damage based on the average of horizontal spectral response acceleration for 1.0-second period and peak ground acceleration



The US Geological Survey (USGS) issued a map showing parts of Oklahoma are now considered as seismically hazardous as areas of California where natural earthquakes occur regularly. ***Graphic courtesy of USGS.***

sure transducers just below the fluid line inside the wells to take measurements on a second-by-second basis and build hydrogeological models with the data.

He is hoping that the transducers will identify a "pressure front" moving through the Arbuckle formation and said such information could help operators find safer locations to drill disposal wells in the future, as well as where it would be a bad idea.

"This is the raw data that has been missing," he said. "We think that the Arbuckle disposals are related to seismicity—we think that it is pressure propagating away from those wells and reaching basement faults—but until someone starts measuring that pressure in the Arbuckle, and possibly in the basement rock, we won't ever be able to document it."

The project is being funded by industry partners and emergency funds released by Oklahoma's governor to address the earthquake situation. Murray said his ultimate goal is to establish a network of at least 12 monitoring wells.

Another modeling approach to the seismic situation is to take emerging geomechanical modeling technology designed to predict the effects of hydraulic fracturing at the wellbore level and use it to predict fault behavior on a regional level.

Ahmed Ouenes, chief executive officer of the geomechanical modeling firm FracGeo, believes that injection reductions alone will not solve the problem. "The problem is not about injection" volumes only he said. "It's really all about where you inject."

He recently coauthored an SPE paper outlining how his company's software can identify the existing stresses involved with regional fault networks and put them into two categories: those with low induced-seismicity potential, and those with a high induced-seismicity potential. The difference between the two categories could help explain why some areas with high injection volumes observe few earthquakes and others that have low injection rates experience many earthquakes.

"Geomechanically, it is very simple," Ouenes said. "When we see these high injection volumes happening in the low induced-seismicity potential areas, and we don't see earthquakes, that confirms that the location is more important than the volume." **JPT**

For Further Reading

SPE 173383 On Liability Issues Concerning Induced Seismicity in Hydraulic Fracturing Treatments and at Injection Disposal Wells: What Petroleum Engineers Should Know *by Keith Hall, Louisiana State University et al.*

SPE 180461 The Effects of Faults on Induced Seismicity Potential During Water Disposal and Hydraulic Fracturing *by Nick Umholtz and Ahmed Ouenes, FracGeo.*

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