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Enhanced Oil Recovery—Do You Have the Right EOR Strategy?

Summary

Research and technological advancements in EOR had been growing at a high rate over the past 10 years due to growing concern that all the 'easy oil' has been exploited and result of high oil prices, which increased R&D appetite and investment into enhanced oil recovery (EOR). However, the sharp and sustained decline in crude oil prices has forced many major EOR projects to be suspended and resulted in diminished investment in EOR R&D as companies are struggling to bring down both their CAPEX and OPEX costs. But with 1 trillion barrels of potentially recoverable oil sitting in mature fields, is this right strategy? This white paper explores the trends and advancements in EOR technologies and discusses strategies of the leaders and lagers with regard to EOR.

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Do you have the right EOR strategy?

After a decade of significant strides, progress in enhanced oil recovery (EOR) is slowing. The slowdown comes as swooning oil prices have forced companies to focus on preserving cash instead of wringing every drop of oil out of their reservoirs. The result has been less spending on EOR research and development.

But is this the right strategy? Are oil prices destined to remain in the doldrums for another generation, making new EOR projects challenging at best? Or is this the time to capitalize on a temporary downturn?

One industry consultant notes that Occidental Petroleum, a leader in EOR, went on an acquisition spree in the early 2000s before oil prices rose to their highest ever late in that decade. This move positioned Occidental as the premier player in EOR worldwide, according to Val Brock, former manager of improved oil recovery/enhanced oil recovery for Holland-based Shell International Exploration and Production and now president of Bismuth Energy, a Houston energy consulting firm.

Buying when property is cheap is nothing new, and it is happening again among several oil patch players who are acquiring—at a discount—fields with potential or actual EOR operations, Brock explained.

Finding the Capital

The difficulty is finding capital for such a strategy if you don't already have some, according to Ken Holtgrieve, a former Kinder Morgan Energy Partners manager for CO_2-related EOR projects and now an independent consultant based in Conroe, Texas. Holgrieve believes that oil prices in the $65 to $75 per barrel range will be necessary before new outside capital will come into EOR projects. Right now, outside investors seem interested only in new horizontal wells in prime locations with time horizons of three to five years. By contrast the time horizon for EOR projects is often 20 to 30 years, with initial payback times of seven to eight years.

But those who have ready capital and patience can achieve superior long-term returns by buying properties at substantial discounts now for the day when oil prices return to higher levels.

However, EOR may be best the most effective and efficient strategy for optimizing returns from brownfields. According to Ahmed Hashmi, Head of Upstream Technology at BP, "Enhanced Oil Recovery, presents opportunities to access and accelerate reserves as fields mature... the world has probably reached a point globally when the potential for enhanced recovery from known hydrocarbon resources exceeds the potential from new discoveries."[1]

1 British Petroleum P.L.C., "Squeezing more from brownfields in a low oil price environment," (Transcript of Ahmed Hashmi Speech presented at CERAWeek energy conference February, 2016). Available: http://www.bp.com/en/global/corporate/press/speehes/brownfields-in-a-low-oil-price-environment.html

EOR: A Good Long-Term Investment

Short- and medium-term swings in the price of oil obscure the true prospects for EOR, even as both capital and operating costs remain significant challenges. The International Energy Agency and many professionals in the oil industry recognize that the majority of the easy-to-extract oil has been exploited. Earlier in this decade when oil prices were high, exploration units armed with record-breaking budgets were chasing ever more expensive and difficult projects in the Arctic, in ultra deepwater, and in unconventional oil deposits such as oil sands.

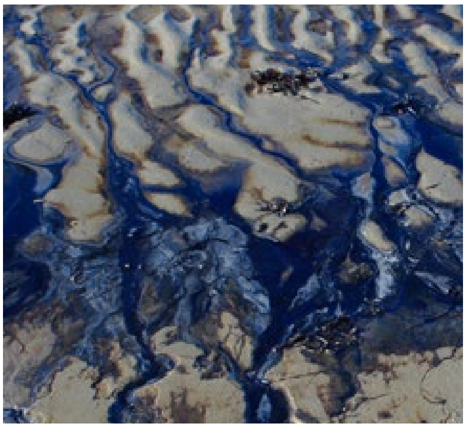
With average recovery rates around 35% there is a huge bonanza awaiting companies that can unlock the secret of low-cost EOR. An apt and succinct summary comes from Russell Ostermann, director of the Petroleum Engineering Program at The University of Kansas, as he explains the allure of oil available for EOR: "We know exactly where it is, we have wells drilled to it, and we know how to get the next 20 percent. Cost is the big issue."

For thermal recovery, the cost of fuel (primarily natural gas) heavily influences the viability of such projects, according to Vladimir Alvarado, head of the Department of Chemical Engineering at the University of Wyoming and a consultant to the oil industry. Increasingly, greenhouse gas emission caps will also influence costs for thermal projects, as is the case already in California and Alberta.

For chemical EOR, the chemicals themselves are the major expense, Alvarado explained. Expenses can mount more quickly for reservoirs with temperatures above 80 degrees Celcius that use polymer floods because special polymers for high-temperature environments may cost three times what regular polymers do.

For CO_2 injection, the CO_2 itself is expensive at the beginning of the project. Later, when wells start producing, the CO_2 can be recycled. For air and nitrogen injection, the biggest investment comes at the beginning, when setting up the plant to take in air or to extract nitrogen from the air and pressurize either for injection. After that, electricity is the major expense, Alvarado explained.

The size of the prize, however, is huge. An estimated 1 trillion barrels of oil may be ultimately recoverable from known fields using EOR, according to Gary A. Pope, a professor of petroleum engineering at The University of Texas at Austin (UT-Austin) and a consultant to the oil industry. And, this number is only for conventionally extracted light and heavy oil fields.



Unconventional Oil and EOR techniques

Unconventional oil from oil sands and other sources is not included in the 1 trillion barrel figure. These emerging sources are helping to blur the distinction between EOR and primary and secondary recovery. EOR techniques are now being applied as initial recovery methods. One example is steam-assisted gravity drainage (SAGD) which is being heavily deployed in oil sands deposits.

Moreover, major oil companies such as Royal Dutch Shell have begun to incorporate EOR into field development planning early on. This innovation is not surprising because secondary recovery methods, such as waterflooding or gas injection, are often augmented quickly with chemical EOR methods.

EOR Advances: Superior Chemicals, Combining Methods

EOR researchers report that the generally high prices in the last 10 years (before the oil price collapse) supported substantial progress that came mostly in two ways—research & development of superior chemicals for chemical EOR and inventive combinations of the three major EOR methods: thermal, miscible gas injection, and chemical flooding.[3,4]

Advances in Chemical EOR

Perhaps the most significant strides in EOR in the last decade have come from a host of new polymers, surfactants, gels, and co-solvents. For example, there have been more new surfactants created in the last 10 years than in the last 40 according to Pope, and demonstrated by analysis of trends of EOR research output and patents filed between 1980 to present according to Scopus[2].

This is significant because properly formulated and applied surfactants can raise recoveries by 20 to 30 percent of the original oil in place (OOIP). This compares favorably with about 12 percent each for both polymer flooding and CO2 injection. Because the recoveries for surfactants are in addition to recoveries using other methods, they may ultimately make a bigger difference in EOR recoveries than all other chemical methods.

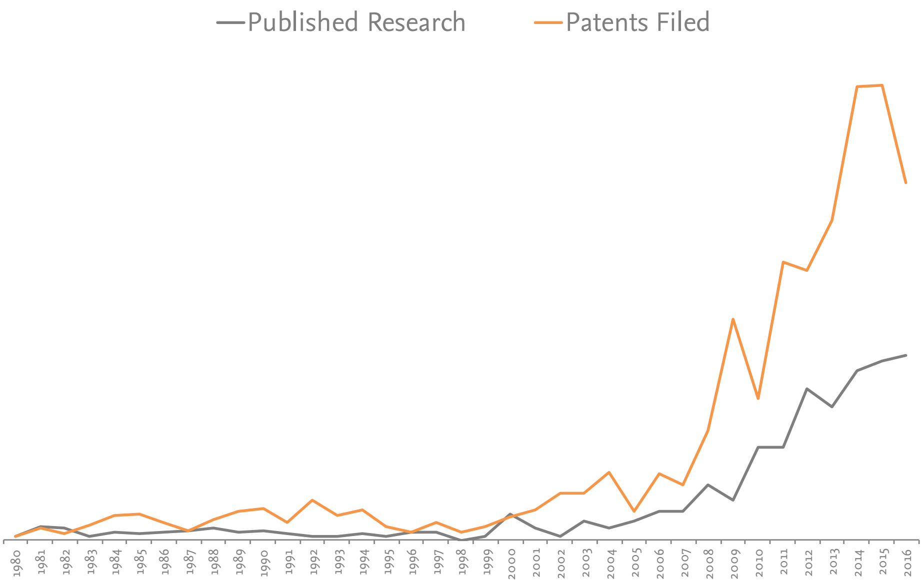


Figure 1. Published research and number of patents filed between 1980–2016. (Source: Scopus)

2 Scopus is the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings. Delivering a comprehensive overview of the world's research output by universities, research institutes and agencies and corporations with smart tools to track, analyze and visualize research (https://www.elsevier.com/solutions/scopus)

3 Much of the information and analysis in this paper comes from in-depth interviews with leading enhanced oil recovery researchers. They include Gary A. Pope, professor of petroleum engineering at The University of Texas at Austin; Vladimir Alvarado, head of the Department of Chemical Engineering at the University of Wyoming; Russell Ostermann, director of the Petroleum Engineering Program at The University of Kansas; Shahin Negahban, director of the Tertiary Oil Recovery Program at The University of Kansas; and Louis Castanier, senior researcher and lecturer, Department of Energy Resources Engineering at Stanford University. All these researchers have long experience in the EOR field—both as researchers and as consultants to, or employees of, oil companies around the world.

4 For an excellent overview of EOR methods, see Rifaat Al-Mjeni and others, "Has the Time Come for EOR?," Oilfield Review 22 (Winter 2010/2011)16-35. Available: www.slb.com/~/media/Files/resources/oilfield_review/ors10/win10/eor.pdf.

> **"We know exactly where it is, we have wells drilled to it, and we know how to get the next 20 percent. Cost is the big issue."**
>
> —Russell Ostermann, Director of Petroleum, The University of Kansas

Polymer Floods Go Offshore

Chevron has recently begun using polymer flooding in its Captain field in the North Sea. In conjunction with Finnish chemical manufacturer Kemira, Chevron developed a new polymer designed to withstand the high-temperature, high-salinity environment found in Captain field reservoirs. But there is one more important key to its use offshore. Lack of space has always been an impediment to using polymers offshore because dry polymer is normally mixed onsite with water. This new polymer comes in emulsion form and therefore does not need to be mixed, only diluted with water. That can save a lot of space that would have been devoted to additional equipment on an already cramped platform.

New Polymers for Heavy Oil

New polymers are now being applied to heavy oil in Alberta in Canadian Natural Resources' Pelican Lake Field. A 2013 SPE paper on the project explains that "Pelican Lake is the first successful application of polymer flooding in much higher viscosity oil (1,000–2,500cp) and as such, it opens a new avenue for the development of heavy oil resources that are not accessible to thermal methods."[5]

Before polymer flooding, the field yielded only about 4 percent of the OOIP. For the area currently under polymer flooding, the estimated ultimate recovery is now 23 percent. About 8 percent has so far been recovered according to Canadian Natural. The incremental operating cost is about $3 to $4 per barrel, and the capital cost is about $13 to $17 per barrel of reserves.

Alkali-Surfactant-Polymer Floods

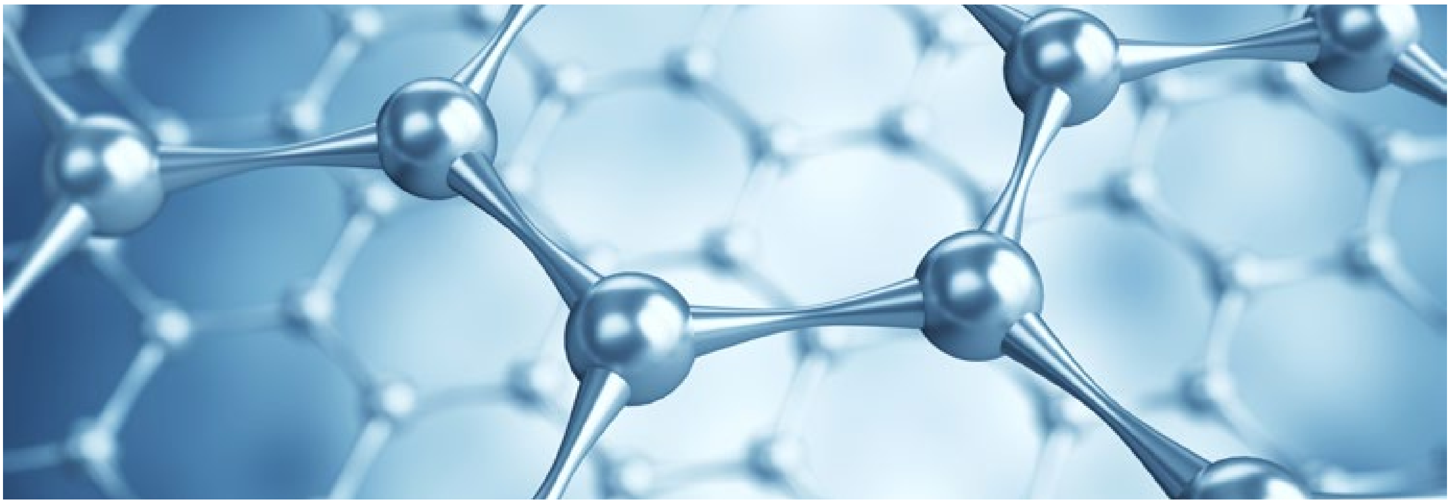
Operators in Daqing, China's most prolific oil field, have been using polymers for more than 30 years. But the explosion of new variants in polymers and other chemicals has made Daquig a hotbed of EOR field trials, including extensive trials of alkali-surfactant-polymer (ASP) combinations.[6] When suitable for the reservoir, the alkali can greatly the reduce the amount of surfactant needed, thus lowering costs.

After a highly successful trial by Cairn India in its Mangala field, ASP floods are being implemented across the entire field, one of India's largest, in order to maintain peak production.

In conjunction with Petroleum Development Oman, Shell is testing ASP on both sandstone and carbonate reservoirs in Oman.

5 Eric Delamaide and others, "Pelican Lake Field: First Successful Application of Polymer Flooding in a Heavy Oil Reservoir," OnePetro (Society of Petroleum Engineers), last revised on July 4, 2013, accessed September 22, 2016, www.onepetro.org/conference-paper/SPE-165234-MS.

6 Stephen Rassenfoss, "Daqing: An Old Field at the Center of New EOR Testing," Society of Petroleum Engineers, last revised June 5, 2014, accessed September 22, 2016, www.spe.org/news/article/daqing-an-old-field-at-the-center-of-new-eor-testing.



Alkali-Co-Solvent-Polymer Flooding
UT-Austin is pioneering a new combination known as alkali-co-solvent-polymer (ACP) flooding. The co-solvent in ACP is small, simple, and non-ionic, and it functions more effectively than alcohol, something that has been used as a solvent for more than 40 years. No surfactant is required, which reduces costs. ACP has been tested successfully on heavy oils.[7]

Hope for Fractured Carbonate Reservoirs
Half the carbonate reservoirs in the world are fractured and tend to resist EOR techniques. But the new class of surfactants holds out hope that higher recoveries can be achieved. Those fractured reservoirs represent 20 to 30 percent of the world's oil resources. With recoveries hovering around 10 percent, there is much to be gained if the new surfactants can increase recoveries by another 20 to 30 percent of the OOIP. Small-scale tests suggest that they can, but no large-scale trials have yet taken place. Mexico's supergiant Cantarell field represents one of the prime targets for such new surfactants.

CO_2 with Surfactant
Not long ago UT-Austin researchers, with help from Dow Chemical, achieved something that others had failed to achieve in 40 years of trying. They found a surfactant that will dissolve in supercritical CO_2. The combination is designed to improve the sweep efficiency for carbon dioxide in high-salinity environments up to 120 degrees Celcius.[8]

Low Salinity Waterfloods
Many years ago water was just water. Operators did not think very much about the composition of that water and its effect on recoveries. Now, a new area of research has opened up as experiments with low salinity waterfloods yielded promising results. The best way to think about this research is as ion modification.

Under the umbrella of "smart water," researchers and companies are partnering to explore new electrolyte combinations that work better than existing sources of unmodified water. These new water chemistries by themselves yield unspectacular results—a few percent increase in recoveries—but do so at very low cost. And, they can be combined with other methods to make both more cost-effective.

Delayed-Action Particles
In conjunction with Chevron and Nalco (a division of Ecolab), BP has developed a proprietary product called BrightWater.® It contains thermally activated particles that target injection water thief zones so that the waterflood flows to where the oil is.

7 Robert Patton Fortenberry and others, "Use of Co-Solvents to Improve Alkaline-Polymer Flooding," OnePetro (Society of Petroleum Engineers), last revised October 2, 2013, accessed September 22, 2016, www.onepetro.org/conference-paper/SPE-166478-MS.

8 Yunshen Chen and others, "Switchable Nonionic to Cationic Ethoxylated Amine Surfactants for CO_2 Enhanced Oil Recovery in High-Temperature, High-Salinity Carbonate Reservoirs," OnePetro (Society of Petroleum Engineers), last revised April 2014, accessed September 22, 2016, www.onepetro.org/journal-paper/SPE-154222-PA.

Evolution and maturity of EOR

Source: Gary A. Pope, Professor of Petroleum Engineering, The University of Texas at Austin

New Directions in Thermal Recovery

Thermal recovery methods, such as steamfloods and in-situ combustion, have a long history. The basic approaches have not changed much in decades. But one thing that has changed recently is a new source of energy for steamfloods. It is a simple marriage of renewable energy with EOR.

California-based GlassPoint Solar has been a leader with solar thermal installations to power steamfloods in Oman, Kuwait and California. The company claims to reduce fuel costs and carbon emissions by up to 80 percent. Interest in this approach is due in no small part to increasing restrictions on greenhouse gas emissions. But rapid advances in the technology are raising efficiencies and lowering costs to make it ever more competitive with operations that burn natural gas.

Regarding in-situ combustion, improved pumps with tolerance for high temperatures coming out of SAGD development may help revive a practice that produces very hot gas/oil combinations in production wells.

Future Directions for EOR R&D

Future directions for EOR R&D range from the exotic (for example, nanoparticles) to the surprisingly simple (for example, carbonated water). Right now EOR projects contribute a mere 2 million barrels per day to world production. Of that amount, about 400,000 barrels come from polymer floods, between 300,000 and 500,000 barrels from CO_2 flooding, and about 1 million barrels from thermal recovery. This total is larger than some other published estimates because many projects remain under wraps while development proceeds.

Given the estimated 1 trillion barrels thought to be ultimately recoverable using EOR from existing conventional light and heavy oil fields, there is considerable value available—anywhere from around $40 trillion at current prices to over $100 trillion if the high prices of the early part of this decade return. Of course, if oil prices remain low, EOR costs would have to come down significantly for this value to be realized.

The Simple Ideas

Almost all EOR methods already in widespread use have been designed with vertical wells in mind. Today, drilling horizontal wells is routine, and the industry continually increases its skill in doing so. But drilling horizontal wells to advance EOR is just in its beginning phase. This one simple idea could greatly increase the oil available for EOR. The indications are that all existing technologies will work better in horizontal wells. Of course, for existing fields without horizontals, there is the extra cost of drilling them just for EOR operations. But often new wells must be drilled anyway for most types of EOR.

Another simple idea, carbonated water, seems too obvious and simple to be considered part of the future of EOR. In fact, the idea has been around for decades, and a body of research already exists. With the proliferation of smart water technologies, however, carbonation might now be taken seriously as part of a list of desirable traits for water used in future waterfloods. The incremental gain may be small, but the cost would be correspondingly paltry.

Nanoparticles

Perhaps one of the most exotic areas of EOR research is in nanoparticles. In general, the idea is that nanoparticles could make current EOR chemicals more robust, for example, make them less subject to degradation and adsorption. In the case of surfactants, nanoparticles could help create more stable foams.

Nanoparticles could also pave the way for timed-release additives to EOR fluids. With timed-release chemicals, well operators could not only get the effects they want but also get them when they want them.

The timing of release is not the only consideration. In some cases releases might be better keyed to pressure, temperature, and pH and other fluid characteristics.

CO_2 Floods and Carbon Sequestration

With the new emphasis on reducing carbon emissions, government funding has shifted away from fossil fuel research. What little research there is tends to be related to sequestering carbon in existing reservoirs. Some CO_2 is already being sequestered by current reservoir floods. Research that demonstrates how more CO_2 can be sequestered might receive government support in the future.

Look for any progress in this area from the major players in CO_2 flooding including Occidental Petroleum, Denbury Resources, and Kinder Morgan.

More Stable Chemicals

As companies drill in deeper and hotter formations, the EOR chemicals they use will have to withstand temperatures up to 150 degrees Celcius Companies will also be drilling in formations that will be increasingly saline, another challenge to those chemicals. Though not revolutionary, incremental advances in stability brought about through research will lower costs and expand the number and type of reservoirs that can be targeted for EOR. Major players in this area include French giant SNF; Shell Chemicals, a division of Royal Dutch Shell; and U.S.-based Stepan Company.

EOR and the Shale Revolution

The so-called "shale revolution" has put U.S. oil production definitively on an upward trend for the first time since Alaska's Prudhoe Bay field began producing in earnest.

Along with that revolution comes a whole new area of research for EOR. Recovery rates from these shale deposits are very low, in some cases only a few percent. Little EOR research has been done on these deposits, in part because their exploitation has been so recent. But the potential is huge—and so is the major challenge: extremely low permeability.

Low oil prices have kept investors and companies focused on drilling new wells in the most economical areas of shale plays. Until these sweet spots are exhausted and prices head higher, any progress on EOR in shale is likely to be stalled. But with 95 percent or more of the oil left behind, shale will remain a tempting target.

In-Situ Upgrading

If oil, especially heavy oil, can be upgraded while in the reservoir, companies can avoid the expense of an upgrading facility on the surface. In addition, an operator can upgrade the oil where and when it chooses, possibly even in smaller reservoirs that would never have justified the building of surface upgrading facilities. The big advantage is being able to wait for high prices before proceeding with upgrading—and being able to stop if prices fall without worrying about servicing debt often associated with a large capital investment in surface upgrading facilities.

We already know that enough heat in the reservoir can cause some upgrading. But so far, this has not proven practical for widespread application. The addition of catalysts might enable in-situ upgrading to reach commercial viability. Just what those catalysts would be and how they would be delivered to the reservoir are research subjects that could provide rich returns.

Microbial EOR

Microbial EOR, either through introducing novel microbes into the reservoir or inducing certain native microbes to grow preferentially, has been a topic of research for decades. But, there are few compelling results. A breakthrough here would be significant because of the potentially low cost—existing infrastructure could end up being largely sufficient—and low environmental impact.

Obstacles and Opportunities for EOR

Several obstacles are slowing EOR research and development, chief of among them low oil prices. While there is little anyone can do about prices, other obstacles are largely institutional.

Major EOR opportunities include building onto the existing CO2 infrastructure in the U.S. to expand CO2 flooding; offshore areas such as the Gulf of Mexico that offer new frontiers for EOR; and the Middle East, where national oil companies are now requiring contractors and partners to provide an EOR strategy as part of new field development plans.

However, EOR research is fragmented. Researchers working in different areas—thermal, miscible gas, chemical and microbial—do not communicate with one another well. If the last decade of successes in EOR has demonstrated anything, it is that combining approaches from different areas can produce outsized, synergistic results, and significant progress in this field is made through collaboration and partnerships, which often bring the best minds together, reduces total R&D costs and commercialization investment costs in short-term and long-term; a win-win for a company's bottom line, academia and research institutes, and industry.

When oil prices rise again, those companies with a long-term outlook that have developed an EOR strategy based on collaboration and partnerships, and positioned themselves properly will be able to reap the rewards that EOR can provide. And as BP, Occidental and others such as Pioneer Natural Resources are proving through their success with EOR, the benefits do not come by chance and are the result of incremental improvements and optimization over time. Therefore, the benefits can only be reaped by companies who are prepared to rethink their short-term and long-term strategies and incorporate sustained discipline and commitment to invest in research, development and scaling of EOR technologies. With a prize of 1 trillion barrels of oil and expected increase in future demand, perhaps the time to invest is now.

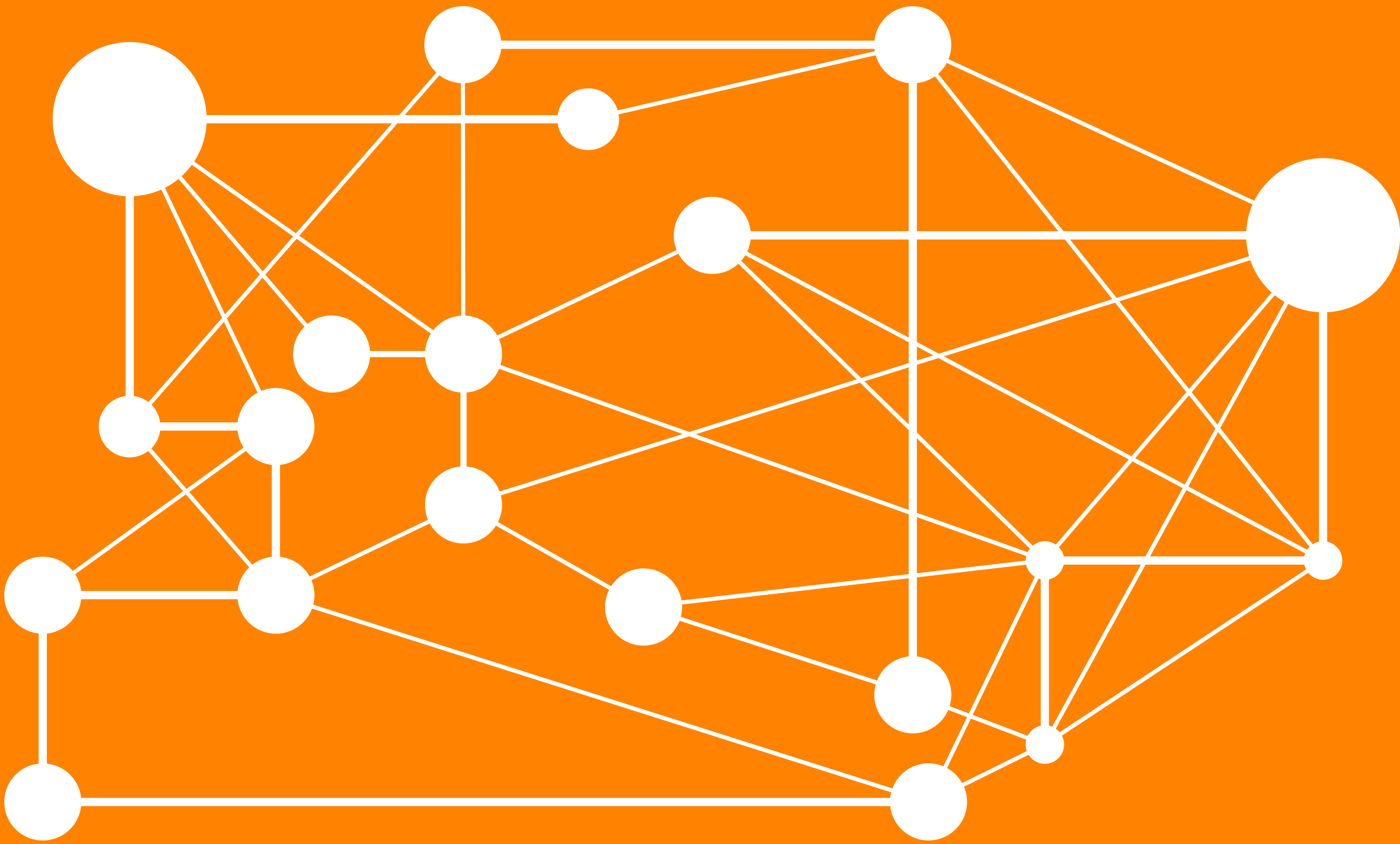
EOR Method		Pressure Support	Sweep Improvement	IFT Reduction	Wettability Alteration	Viscosity Reduction	Oil Swelling	Hydrocarbon Single Phase	Compositional Change[1]	Incremental Recovery Factor
Waterflood	Waterflood									Base case[2]
	Engineered water									Low
Gasflood: immiscible	Hydrocarbon									Moderate
	CO_2									High
	Nitrogen or flue gas							3	3	Moderate
Gasflood: miscible	Hydrocarbon								4	High
	Hydrocarbon WAG								4	Very high
	CO_2									High
	CO_2 WAG									Highest
Thermal	Steam									High
	High-pressure air									High
Chemical	Polymer									Low
	Surfactant									Moderate
	ASP									High

IFT = interfacial tension
WAG = water-alternating-gas
ASP = alkali-surfactant-polymer

1. Change of composition of liquid hydrocarbon.
2. Waterflooding provides the base case for comparison of other methods.
3. Oil stripping occurs as miscibility develops.
4. Condensing and vaporizing exchange.

^ **Physical effects of EOR methods.** EOR methods generate various physical effects that help recover remaining oil (shaded boxes). The incremental recovery factor (*right*) has a large range of values when compared with waterflooding, which is typically not considered an EOR method.

Figure 2. Physical effects of EOR methods. © Schlumberger. Reprinted with permissions from Schlumberger from Rifaat Al-Mjeni et. al., "Has the Time Come for EOR?," Oilfield Review 22 (Winter 2010/2011) 16-35. Available: http://www.slb.com/~/media/Files/resources/oilfield_review/ors10/win10/eor.pdf.



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