

# Well recovered

## [ Key Facts ]

- Estimates of worldwide oil recovery factors range from 27% to 40%.
- Developments using EOR could contribute 10% of Shell's equity production within a decade, up from 2% today.

119



The world's remaining oil reserves are plentiful but often difficult to access. Shell has increased its focus on enhanced oil recovery (EOR) to make the most of what's left, explain the company's Val Brock, Peter Christman, Jose Morell and Gordon Shahin.

We are faced with an exciting but challenging future in the energy industry as we work to meet the global energy demand. In the context of the world energy challenge, there has been heated debate about peak oil, or at least a peak in 'easy oil'. This does not mean that the world is running out of oil, as there are trillions of barrels yet to be produced. The underlying reality, however, is that the remaining oil is more difficult to access, requiring technology and innovation to recover these barrels economically and sustainably. One of the ways that Shell is meeting these energy challenges is through an increased focus on enhanced oil recovery (EOR).

The intriguing aspect of EOR is that we already know where the barrels are, so it is a matter of applying the right technologies to get the oil out of the ground. Statistical estimates of worldwide oil recovery factors range from 27% (Laherrère) to 40% (the United States Geological Survey [USGS]). This means that on average only about a third of the oil in place is recovered via conventional means, an arguably unacceptable figure in the face of the global needs. By the accelerated application of improved recovery technologies, we will recover more from existing fields and basins.

EOR has been identified as an enabling theme to support delivery on the exploration and production roadmap. Shell has a proud legacy in EOR, with early steam trials in the 1930s in California, US, that grew into today's Aera JV, one of the industry's first CO<sub>2</sub> injection projects in the 1970s in the US Permian, installing the world's largest CO<sub>2</sub> flood in the 1980s in the Wason Field, and early leadership in chemical EOR research and development. Shell's objective now is to deliver a long-term, sustainable EOR business that grows the

hydrocarbon resource base through increasing recovery of profitable barrels from existing assets and leveraging the capability into new business. With the numerous projects online or in execution or maturation stages, developments that make use of EOR technologies could contribute about 10% of Shell's equity production within the next decade, up from about 2% today.

## EOR techniques

The term EOR covers a wide range of techniques for increasing recovery of the more difficult barrels that are often left behind by conventional methods. Historically thought of as tertiary processes that follow waterfloods, EOR processes can be applied earlier. They should be considered an integral part of field development and management, a full lifecycle approach to maximise oil recovery.

There is no silver bullet in EOR, as each field and reservoir tends to have its own unique characteristics and complexities that cause oil to be left behind. Success will therefore require a full EOR toolkit in order to apply the ideal technique for each field. Technical-limit thinking enables us to assess each reservoir according to various complexity factors, and how we might overcome them with infill drilling, facility modifications or EOR. In reservoir engineering terms, enhanced recovery aims to unlock those barrels mainly by improving volumetric sweep and/or displacement efficiency, addressing the physical challenges of oil-water interfacial tension (the beading-up effect that traps oil in the rock pore space) and

viscosity contrast (making it difficult for thicker crudes to flow to producing wells). The plot of oil viscosity versus reservoir depth illustrates the three main families of EOR:

- Thermal, most commonly steam injection
- Miscible or immiscible gas injection
- Chemical, which include polymer and surfactants



The three techniques have different applications and success factors, and some are more mature than others, so each requires its own approach and area of technology focus.

### Thermal EOR

Thermal EOR involves heating up the oil to reduce its viscosity and enable it to flow more easily to the producing wells, typically accomplished by steam injection. It requires effective heat placement and operating/development efficiency. Shell's approach here is an extension of proven steam technologies and industry-leading operations in Canada and its Aera JV in California, to new and more challenging reservoirs such as fractured carbonates in Oman and ultra-heavy oil and bitumen in Canada. Aera's application of lean manufacturing techniques, borrowed from the auto industry and applied in the oil field, has proven to be a world-class approach to operational excellence and well and reservoir management.

### Miscible gas

Miscible gas, including CO<sub>2</sub> EOR, is widely applied; the challenge is often matching an affordable gas source with a viable candidate field. Miscible flooding is based on the injection of solvents, such as CO<sub>2</sub>, at the ideal temperature and pressure to mix with oil in the reservoir without interface as with water, thereby reducing residual saturations and increasing recovery.

Shell's approach is to build upon its past experience in designing and operating the largest CO<sub>2</sub> EOR project in the world (Permian Basin – McElmo Dome/Denver Unit). Having operated CO<sub>2</sub> floods for more than 25 years, Shell exited the Permian in 2000 with technologies and experience that can be applied in new CO<sub>2</sub> EOR developments around the world. One crucial difference is that these future developments will often involve man-made CO<sub>2</sub>, through the application of pre- and post-combustion capture technologies that Shell is also applying. In this way CO<sub>2</sub> EOR can contribute to sustainable solutions for reducing the world's CO<sub>2</sub> emissions. CO<sub>2</sub> EOR won't fully solve our greenhouse gas problem but it can play a significant niche role in carbon storage and associated infrastructure development.

### Chemical EOR

Chemical EOR is the least well proved of the three but it offers great potential. Polymer flooding works by increasing the viscosity of the injection water, enabling it to better push slightly thick oil. Surfactant flooding, which can be thought of as putting soap into the injection stream, reduces the oil-water interfacial tension and dissolves oil, sweeping trapped oil out of the rock pore spaces.

A novel technique invented and successfully piloted by Shell is Enhanced Alkali Flooding (also known as ASP, or Alkali-Surfactant-Polymer), where a cheap alkali is injected, reacting with acids in the crude to form petroleum soaps in-situ, and combined with surfactants to tune the chemistry. The polymer component provides mobility control for effective displacement of the cocktail. The key to this R&D focus area is accelerating deployment of polymer and ASP technology through demonstration in the field, riding on the back of successful waterfloods. Surfactant manufacture and supply will be a vital part of growing chemical EOR and Shell is fortunate that its sister company Shell Chemical offers differentiated and high-performing surfactants and manufacturing know-how that complements its E&P field.

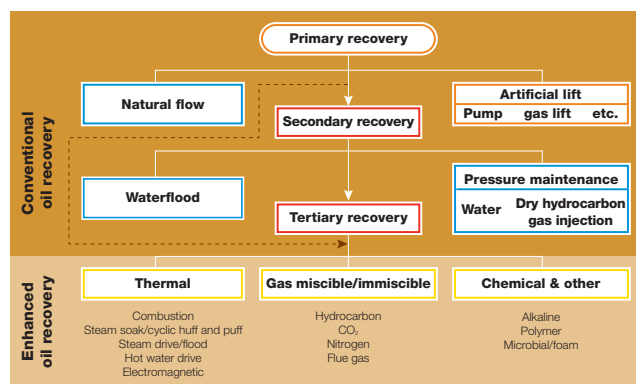


Figure 1: Oil production processes.

### EOR portfolio overview

In order to supplement the regional identification of hydrocarbon recovery opportunities, a global EOR screening study was undertaken in 2007, covering existing assets and possible new business targets. The aim was to develop a more holistic and consistently evaluated ranking of EOR opportunities, to further fill the funnel and better focus resources to drive delivery.

Shell has EOR opportunities widely distributed across its assets. The thermal opportunities are primarily in EPW (Canada, California) and EPM (Oman), plus the Schoonebeek field in the Netherlands. Steam operations continue in numerous fields in Aera, Shell's California JV, plus Peace River and Orion in Canada, and several projects are post-FID in execution phases in PDO as well as at Schoonebeek. Miscible gas injection projects are being implemented at the Kashagan Field in Kazakhstan, and at Harweel in PDO, with several more identified and in various stages of maturation in the Middle East, Asia, the North Sea and California. The Marmul polymer project in PDO will be the first field scale application of Chemical EOR in the Shell portfolio, with first injection expected before year-end. Projects are being matured in Brunei, Oman and Russia to deploy and demonstrate the viability of ASP. Many more opportunities are in the identify stage, positioned to further fill out the funnel. Ultimately growing Shell's EOR business will be about delivering these projects.

It is worth highlighting that by 2010, Oman will be an EOR showcase, with projects in all three EOR families – gas (Harweel), thermal (Mukhaizna, Qarn Alam, Fahud, Amal) and chemical (Marmul polymer and possibly ASP). Canada is also an important and growing hub for Shell's thermal operations. Other growth areas noted above will be close behind.

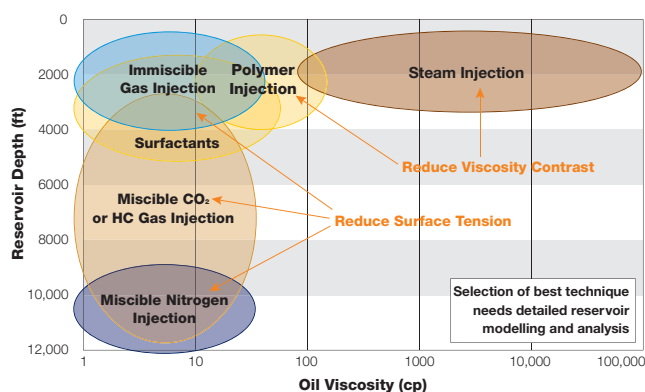


Figure 2: EOR processes.

### The future in EOR

Shell is not alone in its pursuit of EOR; a number of competitors are showing interest in the deployment of EOR technologies. Where Shell differentiates itself is in the integrated technologies offered, backed by global breadth and a strong R&D program.

The EOR technology pipeline can be thought of as a maturation curve, with some well-proved techniques already in operation, several evolved to demonstration stage, and many more in research and development. EOR isn't only about the subsurface either, as facilities, wells, surveillance and supply technologies all come into play to make a successful integrated project.

Competitive advantage is also about people and the capability to deal with complexity and integration challenges through science and technology. Development of the next generation of EOR experts is critical. Winning will mean moving quickly and demonstrating in the field, with mini-trials and other fast-track deployment approaches. It will require keeping an eye on costs and operating excellence as we apply EOR technologies, working to further increase the efficiency of EOR, and commercial elements including supportive fiscal terms that accommodate the riskier cost and return nature of EOR. Getting the most out of Shell's existing resources will be essential if the world is to meet the future energy challenge – there is no alternative, and that will not change with the inevitable ups and downs of oil prices. Resource holders will demand getting every barrel we can out of every reservoir, even the difficult ones, and that underpins the commitment to EOR. The key success factors for EOR are a strong and prioritised opportunity inventory, a technology deployment programme linked to the portfolio

challenges, an organisation with the skills and capabilities to drive the projects through maturation to successful delivery, and excellence in reservoir management and surveillance to deliver the barrels. ●

#### [ Val Brock ]

As the business development manager for EOR, Val Brock serves as Shell's global lead in delivering enhanced recovery opportunities from existing assets and new business. He joined Shell in 1983 and has held various line and leadership positions.

#### [ Peter Christman ]

Peter Christman is the technical excellence manager in the Americas region and the principal technical expert for CO<sub>2</sub> and Miscible Gas Injection. He been with Shell for more than 26 years and has held positions in research, technical service and development engineering in the US and Europe.

#### [ Jose Morell ]

Jose Morell has held various technical positions at Shell, mainly focused on EOR, dynamic modelling and software development. He is currently the miscible theme leader in Shell's EP Technology Solutions.

#### [ Gordon Shahin ]

Gordon Thomas Shahin Jr is a senior staff reservoir engineer with Shell's International Exploration and Production technology organisation in Houston. He holds more than 60 patents in thermal recovery and related technologies, and has authored numerous papers in his 20-year career with Shell.

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