Pipe-dream meets reality

Sam Davidson meets **Geoffrey Maitland,** who is contemplating taking petrochemicals production all the way down the borehole

IMAGINE if we'd never struck oil. If there was no century-long history of technology and strategies for dealing with fossil fuels. If we were starting from scratch. Starting from first priniciples and using today's technologies, and with current knowledge about the environment, how would we do it?

It sounds like an abstract piece of thinking, but it's one of the main tasks facing the Energy Futures Laboratory, a multidisciplinary research body recently launched at Imperial College,UK (see also news on p11). Combining the expertise of chemical, mechanical, systems and biochemical engineers with statisticians, social scientists, geologists, materials scientists and mathematicians, the Energy Futures Lab aims to predict how much energy mankind is going to need as the current century progresses, where it's going to be needed, and how it's to be generated.

The research effort spans many types of power generation, including renewables like solar, wind and waves; the decommissioning of the current generation of nuclear reactors and safe handling and storage of their wastes, and the design and construction of their possible replacements; the various types of biomass and strategies for extracting more of the energy content of crops; the hydrogen economy, and how it will affect power grids; new strategies for distributing energy; and how to optimise the energy generation and consumption in the new cities currently being built and populated in China.

A large part of oil processing could be relocated underground, Maitland says

Everybody agrees that the coming decades will see a much more diverse spectrum of electricity generation methods. However, today's main energy source, hydrocarbons, is still likely to be one of, if not the, major contributor to the mix well into the 21st century. A great deal of oil, gas and coal has been extracted from reserves; but a great deal still remains. The problem is that it's the easy reserves that have been recovered; the remaining hydrocarbons are in awkward locations, or in a form that is hard to recover and process.

This is where the research of Geoffrey Maitland is focused. Professor of energy engineering at the Energy Futures Lab since September, Maitland was previously with Schlumberger, where his work focused on applying modern instrumentation and control techniques to oil wells. He is continuing this work at Imperial, while also setting up collaboration with other researchers to tackle the problems of recovery and utilisation of hydrocarbons.

The first stage is to use modern sensors and instrumentation systems to see what is happening inside oil and gas wells, and then to use this information to improve the wells' performance. "The industry has moved away from post-mortem logging and matching those measurements up with the models of the reservoir and the predictions, to trying to obtain a real-time view of what's going on in there," Maitland says. "Putting permanent sensors in the wells, and eventually into the reservoir itself, is the first step towards that." This, he says, basically amounts to using technology which is well established in chemical plants – especially petrochemicals – and applying it in a much less ordered, and more arduous environment. The new generations of smaller, more advanced and cheaper sensors will allow this to happen, he says. This will allow redundancy to be built into the sensor packages, with large numbers of sensors being put in place within the well at any time, he says.

The sorts of measurement that might be made include flow rates, and especially the thermophysical properties of the crude oil and gas. This will allow engineers to use what Maitland calls a "systems approach" to the wells. Oil is recovered by injecting another fluid, usually water but increasingly supercritical carbon dioxide, into the reservoir to push the oil out to a producing platform, but currently this is a rather random process, he says. "You wait at one well to see what happens as a result of injecting something a few kilometres away. You have an injection well that you can vary the pressure in, and a production well where you suck down on that pressure to produce your crude oil."

The next phase is to take the analogy to chemical plants a little further, by installing valves inside the well to divide it up into segments. The sensor systems will monitor the conditions inside each segment, providing information on the type of fluid flowing in the section and the stability of the flow. "If you start to produce water from one section, you can shut it off or change the injection strategy," Maitland explains. "But what we're trying to do is to enable people to make these decisions well before you start to produce water, because you'll see the flow of oil is becoming unstable."

Maitland estimates that this type of technology is not too far away. "Many of the parts of the jigsaw are already in place, and we can expect to see it applied within the next decade or so, especially in wells which are approaching the late phase of their exploitation, such as in the North Sea and the Middle East," he says. But the next phase of the research is much further off, and far more ambitious.

When oil and gas are extracted from their subterranean resting places, they are under high pressure and at high temperature. They are transported through many kilometres of piping to the surface, where the pressure and temperature are reduced, then they are pumped to terminals and onward to processing sites – where, in order for them to be refined and converted into useful products, they are heated and pressurised. This, Maitland points out, is hardly an efficient use of resources. Why pay, and use valuable fuel, to put energy into a substance that already possesses that energy in its natural state? And why leave all those kilometres of conduit as merely a transport system? "What we have," Maitland says, "is a

high-pressure, high-temperature plant or reactor system. And it's currently empty."

The goal of Maitland's long-term work is to carry out some of the transformations that are currently done on the surface while the oil is still "down the hole". Current research on process intensification systems is producing compact equipment, such as reactive distillation columns and combined heat exchanger/reactors, which can perform the functions of several pieces of conventional chemical engineering equipment within a very confined space. Why not install such equipment within the pipelines that bring the oil to the surface?

"The most extreme example of this is the processes we do in refineries," Maitland says. "We could do some of the catalytic processes on the way to the surface, and produce not the raw hydrocarbon, but some processed version. Then, we'll be addressing several issues, including controlling the carbon dioxide, because we'll be producing it at the point of generation." This, he says, could make the proposed techniques of carbon sequestration, where supercritical CO_2 is used as the injection fluid to force the oil to the surface, and then stored within the gas-retaining structures of the reservoir, much easier.

The goal is to have the oilwell producing a hierarchy of products. "What you really want for the power sector is electricity, so ideally, you'd want some down-hole power generation. Then, you'd want to produce a clean fuel, preferably hydrogen, but possibly something like clean diesel. And then you'd want something that would act as a chemical feedstock, possibly olefins, or possibly something like methanol, which can act as a fuel or a chemical feedstock." This can only be done by treating the reserves as a complete, integrated chemical plant, and will take careful monitoring and controlling of all stages of the process, from the materials within the reservoir to the emerging products. "You might have the same systems producing fuel, power and chemicals, or you might have some wells producing mainly fuels and so on. These details are still to be worked through," he says.

Such systems are likely to be increasingly important once oil exploration and production switches its attention to sources which are currently considered marginal. These include undersea coal deposits which, Maitland says, are unlikely to be mined, but could be gasified *in situ*. Other sources include tar sands and oil shales, and heavy oils, which are currently seen as too difficult to exploit. "Currently, you have to use fairly crude methods, like steam injection to reduce the viscosity of the oils, and physically get them to flow," Maitland explains. "But if you had the alternative of saying that we won't actually produce all the hydrocarbon there – we'd selectively process it, so we can convert it into things which have a higher value – it would make their exploitation much more viable. So you produce the high-value stuff, and leave the low-value stuff in the ground."

Maitland stresses that this picture of hydrocarbon production is several decades off, probably not practical until the second half of the 21st century. "It's going to be achieved by people who are concerned with the chemicals end of this: catalysis, new materials design, combined with the process engineers at the well level and the systems engineers who would integrate all this into a controlled process."

Other aspects of the technology will also require a multidisciplinary approach, particularly the concept of carbon capture and storage. If the fossil fuel deposits are being converted directly into hydrogen or clean fuels, then much of their carbon content will be stripped away on site. This, as Maitland says, is far more convenient for their sequestration in the reservoir as it becomes depleted, but the issue isn't quite that simple. Many disciplines need to come together, he comments.

The reservoir, with its complex structure of cracks, pores and fissures, has to be mapped accurately. The properties of all the rock formations have to be understood, especially in terms of how they'll interact with the highly-solvent nature of supercritical carbon dioxide. And sealing materials will have to be devised to cap off the well, and ensure that the sequestered CO_2 does not escape. "You have to restore the seals to the natural condition of the cap rocks that were there before you started drilling into the reservoir," Maitland says. "It's an interesting match of geology and some innovative materials science, to make seals that have to withstand conditions that are rather different from the ones that were faced when it was just oil and gas in the reservoir."

The strength of the Energy Futures Lab is that all the disciplines needed to work on such a large-scale vision are in place, within a few square kilometres of South Kensington, London. What Maitland and his colleagues hope is that their work will bear fruit at the time when the exploitation of the remaining fossil fuel reserves, and the implementation of safe, environmentally-friendly methods of dealing with the residues, are at their most crucial. **tce**

Sam Davidson is a freelance journalist