New Technologies, New Futures for Mature Oil and Gas Basins

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Abstract

What opportunities remain in mature hydrocarbon basins and how reasonable is it to expect new technologies to help realise these opportunities?

This article approaches the issue from two perspectives: the nature of the opportunities themselves, and the application of new reservoir modelling technologies to evaluate them.

It is argued that finding opportunities for improving ultimate recovery by utilising CO_2 for EOR schemes offers an attractive step towards a low carbon future though the commercial construction of a CO_2 handling infrastructure which can subsequently be used for storage. Mature basins can potentially be a hub for such Carbon Capture, Utilisation and Storage (CCUS) schemes.

The requirement for technologies to support quantitative technical evaluation and the long term forecasting associated with CCUS schemes can benefit from state of the art reservoir modelling and simulation. New and emerging modelling technologies are therefore reviewed: adaptive meshes, surface-based models and the use of representative elementary volumes and multi-model techniques.

It is argued, however, that robust modelling and forecasting for complex schemes such as CCUS involves the combination of new modelling techniques with well designed workflows, and whereas new algorithms are an issue for research and development, the ability to optimise workflows is a 'technology' which is available today.

CCUS in Mature Basins

With depressed oil prices and rising costs in mature basins the finite nature of the oil and gas business becomes more immediate; in some regions, the main issue is decommissioning. The rapid growth of renewable energy supply and the vision of a green future also draw closer as the profitability of oil and gas projects decrease, and the experiences with (and efficiency of) alternative energy sources grow. These low-carbon or no-carbon alternatives are supported by wide acceptance of the contribution of historical oil and gas production to climate change and the broad consensus that we need to remove CO_2 from the atmosphere, not put more in.

These three factors - oil and gas economics, alternative energy technologies and climate change concerns - challenge traditional oil and gas projects, especially marginal ones, and combine to imply that there are limited opportunities and hence a limited future in mature hydrocarbon basins.

We suggest this is not necessarily the case. Pioneering work by several energy companies, especially in Norway and Canada, has shown that capturing carbon dioxide and putting it back into the subsurface where it came from – a process known as CO_2 capture and storage (CCS) - is a practical engineering exercise and a viable path to low-carbon fossil energy.

Over decades, oil and gas operators and service companies have built up the technical expertise in the fields of engineering and geoscience required to inject CO_2 into the subsurface, and sequestering technologies are evolving to make the process progressively cheaper and more efficient. Mature hydrocarbon basins are the most promising locations for CCS as they hold the reservoirs for which we have the greatest volume of data and hence our best technical understanding, and where there is also a history of infrastructural development which can be reused or reinvigorated for the purpose of CCS.

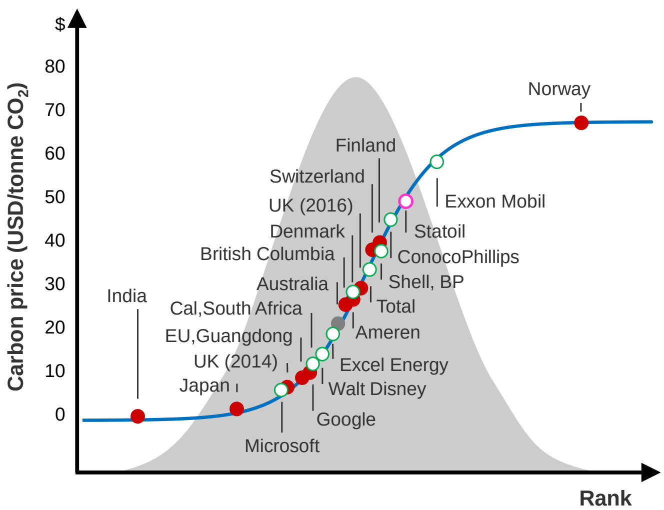

Figure 1 Carbon prices for national, regional and internal corporate markets in 2014 (modified from Cavanagh and Ringrose, 2014)

The question is cost. Carbon can be valued (in terms of avoided emmisions), either through tax or cap-and-trade mechanisms. This provides a funding source for CCS in principle but the implementation is not straightforward, and the capacity to fully cover CCS costs is not guaranteed. Figure 1 indicates the very wide range of published carbon prices for 2014; the country with the highest carbon price (based on taxation) is the one which is also home to the most successful offshore CCS projects. In countries and companies which work with lower carbon prices there is little economic incentive for CCS.

A bridging solution lies in CCUS: CCS with Utilisation incorporated. The use of carbon dioxide in EOR projects combines the need for CO_2 disposal with the wish to optimise ultimate recovery from old fields. The objective is to turn carbon intensive oil and gas projects into low-carbon energy projects to support the global transition to reduced emissions of greenhouse gases.

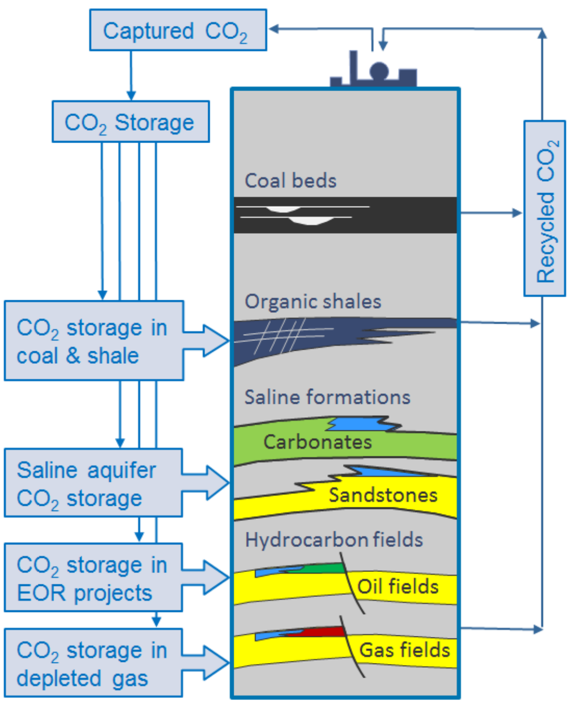

Figure 2 Options for CO_2 Capture, Utilisation and Storage (Cavanagh & Ringrose, 2014)

Cavanagh & Ringrose (2014, Figure 2) summarise options for CCUS. The image combines storage-only projects, either in saline aquifers, coal and shale layers or depleted gas fields, with utilisation schemes for Enhanced Oil Recovery (EOR). The notion is to combine multiple schemes around a single sequestering hub, typically a power station, to maximise the efficient use of the sequestering project. Basins with multiple EOR opportunities would be favoured as the utilisation: storage ratio in the overall CCUS scheme increases.

EOR schemes in themselves involve the production of more oil, the consumption of which produces more CO_2 and the question arises as to the degree of offset of this CO_2 by storage (Durusut et al. 2014), Estimates of the ratio of CO_2 stored compared to CO_2 emitted from EOR schemes are a factor less than 1, depending of the type of project (Cavanagh & Ringrose 2014). The long-term benefit comes in the construction of CO_2 handling infrastructure, partially financed by the EOR scheme, which can then be used for storage over the longer term once the EOR element is complete (Figure 3). Hence the concept of the sequestering hub and the benefit of identifying a basket of storage and usage schemes which can be viewed economically as an integrated CCUS project.

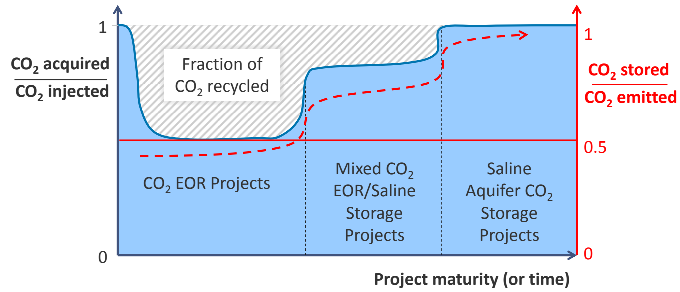

Figure 3 Greenhouse Gas Management in CO_2, EOR and CO_2 Storage Projects (Cavanagh and Ringrose, 2014)

CCUS therefore offers a path to support the transition to a low carbon future, but the schemes need to be evaluated technically and this involves reservoir modelling technologies which are more sophisticated than the current norm. Moreover, storage schemes are more long term in nature than typical oil and gas projects, and the ability to forecast robustly is therefore at a premium.

Emerging Reservoir Modelling Technologies

Reservoir and simulation models integrate knowledge, allow us to forecast futures, quantify value and hence help make significant commercial decisions. For unusual schemes such as CCUS-related EOR, the modelling is more complex than the norm and the need to build reliable long term forecasts is high. The drive to make best use of the 'already found' hydrocarbon resources also requires optimisation which is can be supported by high-quality integrated reservoir models. Models therefore have an increasingly significant role to play in the evaluation of major strategic schemes; we therefore review current model developments in this context and see two big areas of development: the emergence of new algorithms and an understanding of how to make iterative workflows both unbiased and more efficient.

New Modelling Algorithms

Arguably the most significant current area of research is the move away from grid-centric modelling. Conventional reservoir simulators use a finite-difference gridding scheme where only small deviations from an orthogonal grid can be accepted. The modelling approach is governed by the demands of the flow simulator (e.g. computational limits on the number of grid cells, and convergence of the numerical flow solutions) and generally results in distortion and over-simplification of the geological features the flow model is attempting to represent. Handling of structural features, such as faults and fracture zones, is particularly problematic. Moreover, the construction and update of a fixed corner-point grid is typically time-consuming and tends to be the 'efficiency bottleneck' in most modelling projects. Current research seeks more efficient alternatives and although the nature of the next generation of modelling tools is not fixed, one vision incorporates surface-based modelling with adaptive meshes and the wider application of REV logic (discussed below).

Surface-based modelling. Commonly, methods for geological reservoir modelling are either object-based, beloved of sedimentologists, pixel-based, such as indicator simulation, focused on geostatistical estimation (exploiting two-point spatial statistics) and more recently texture-based approaches using multi-point geostatistics, the latter requiring the use of training images (see Mariethoz & Caers, 2014, for further discussion). All these techniques require the allocation of rock properties to a pre-defined 3D grid which remains fixed for the duration of the modelling project.

A different approach is to consider depositional process in an attempt to re-create geological history and built a rock architecture using the sequential build-up of 2D surfaces and 2D structural frameworks. Some such tools are available now such as SBED for small-scale clastic depositional architectures (Wen et al. 1998; Nordahl et al. 2005) and 3DMove for creating or recreating structural architectures (Zanchi et al. 2009). The chief merit of these process-based methods is geological realism, but the level of detail required makes significant demands on flexible, hierarchical, gridding algorithms. An integrated numerical description of the subsurface is captured by the GeoChron model (Mallet, 2014) and represents an important step towards building these algorithms.

A step towards making this process more nimble is captured by the Rapid Reservoir Modelling initiative, with sketch-based techniques drawn from advances in 3D digital graphics (Jackson et al., 2015b). If you can sketch it, you can model it.

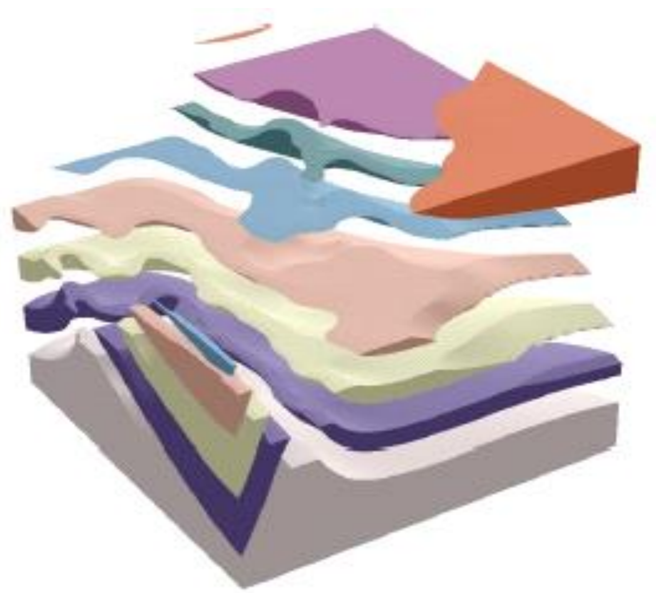

Figure 4 Rapid Reservoir Modelling Using Surface-based Modelling Techniques (Jackson et al., 2015b)

The disposable grid (grid independence). More grid flexibility can be achieved by moving away from the relatively regular grids favoured by finite-difference simulators. Finite-volume flow simulation methods allow more grid flexibility and are being developed and applied to multi-scale reservoir systems including complex structural architectures (e.g. Jenny et al. 2006; Geiger et al. 2004; Coumou et al. 2008). By applying more flexible gridding algorithms to the reservoir flow simulation problem, not only can detailed geological features such as fracture zones be more explicitly including in the flow simulation (Matthäi et al. 2007) but also the possibility emerges for adaptive gridding schemes (Jackson et al. 2015a). The latter (Figure 5) is the most radical option as the grid is not only flexible, it is also disposable and hence the step away from 3D grid-centric modelling is finally made.

The adaptive mesh can be combined with the surface-based techniques described above, as the mesh requires some underlying description of the subsurface, and that can be encapsulated in the hierarchical surface-based model. In this scenario the ‘fixed’ aspect is the underlying surface database and the conceptual understanding of the reservoir, both of which evolve steadily through a field life cycle. The grid itself becomes a variable, to be built and discarded quickly once a decision has passed and is a fundamentally different workflow from the traditional building of a detailed full-field grid (Jackson et al., 2014).

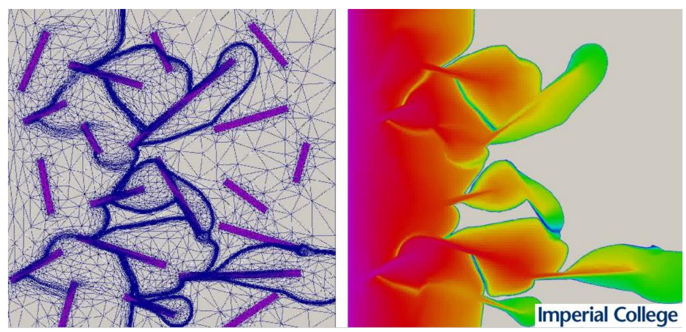

Figure 5 The Ultimate Disposable Grid – Adaptive Meshes for Finite Element Reservoir Simulation (Imperial College, research in progress)

The REV – intelligent averaging. Combining adaptive, unstructured meshes and an underlying surface-based description of the reservoir leaves one major gap to be filled: the availability of appropriate properties for the volumes in between those surfaces.

This requires a consideration of the scales at which the reservoir is being represented and a decision on what aspects of the reservoir (from the microscopic to the macroscopic) need to be included. In addressing this question, Ringrose and Bentley (2015) have demonstrated the benefits of a using a multi-scale Representative Elementary Volume (REV) approach, e.g. Figure 6.

The REV concept seeks to identify the smallest volume over which a measurement can be made that will yield a statistically representative value. This has been widely applied to flow in porous media (e.g. Bachmat & Bear, 1987). Nordahl & Ringrose (2008) demonstrated how the concept could be used at multiple scales in heterogeneous rock media, leading to a framework for using intelligent averaging over a wide range of length scales. Reservoir modelling studies should be focussed on the scales where the heterogeneity present has the highest impact on the flow process and the flow process itself acts as a filter for deciding which heterogeneities matter. For example, waterflood schemes are more influenced by small-scale heterogeneities while gas depletion schemes may notice only the large-scale connectivity.

The surface-based approach to reservoir description implicitly calls on the identification of hierarchical REVs, and we therefore see the REV concept as a link in the chain of these new grid-independent modelling technologies.

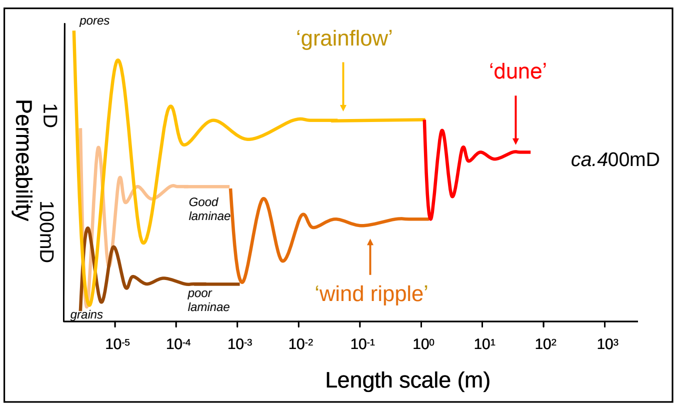

Figure 6 The Hierarchical Arrangement of Representative Elementary Volumes - REVs – for an Aeolian reservoir outcrop analogue (Bentley & Ringrose, 2015)

New Model Design Workflows

The modelling algorithms described above are research work in progress but considerable progress can be made immediately by adjusting the workflows commonly in use in the industry. It isn't necessarily what you do – it's the way that you do it. Four areas for workflow optimisation are outlined below.

The big model. Single, detailed full-field models are currently the industry default, supported by more nimble, widely-available software and ever-increasing computing power. These allow the 'big model' to be achievable, albeit at often considerable manpower cost.

Sometimes, the 'big single model' is necessary but often it isn't, yet the models get built anyway out of an assumption that this is the right thing to do technically. This is frequently not the case and is simply 'modelling for comfort' (Bentley, 2016). Our suggestion is to think twice before embarking on a big detailed model; these models are often not necessary, and the alternatives below may be both quicker and better.

Increasing determinism ('support'). A subtle subtext to the 'big model' is that the properties in these models are not distributed meaningfully, and rely too heavily on geostatistical defaults. This issue relates to our expectation of geostatistical methods, which has changed considerably over the last 20 years with a growing awareness that statistical algorithms require considerable support. This is not an issue with geostatistics itself, but simply the way it is often applied, especially by new practitioners.

The fundamental issue is data density and statistical insufficiency. A 'sufficient' data set, rich and regular, such as 3D seismic data, lends itself well to geostatistical techniques. Sparse well data do not without 'support' for the algorithms which in non-statistical terms means adding more concept-based, deterministic control.

Direct personal experience of the authors has been that useful models tend to be those which are more firmly rooted in deterministic guidance in the form of reservoir concepts (even just simple sketches) which often look beyond the data set itself.

Non-linear workflows – resource models vs. decision models. Acceptance of the disposable grid and model, with or without surface-based or adaptive components, opens the door to multi-size and multi-scale modelling workflows which have been explored over recent years but have not become established as common tools.

This is most notably the case in mature fields where there is a need for handling production data, and current multi-model software tools are premised on assisting the user in repeating the single full-field model approach multiple times. These tend to neglect multi-scale options although this need not be the case.

Rather than building one large model, or generating stochastic permutations of a single full-field model, an alternative is to distinguish between 'resource' and 'decision' models. The *resource* model is necessarily full-field, used for holding field-wide data such as surfaces and contacts, and used for static volumetric estimates of additive data which can be readily upscaled to coarse cells. The *decision* models are focussed at the scale of the development question, which is often not full-field, and here the more intensive data-handling and finer-scale reservoir representations and simulations can be conducted efficiently. These may take many forms: sectors, mechanistic models, cross-sectional or single well models – the choice depends on the issue at hand. The common characteristic is that they are resolved at the scale of the question, not simply assumed to be full-field, full-data exercises. The full-field resource database lives on; the decision models can be disposed of ('archived') once the decision itself has been made.

Uncertainty and behavioural bias. Also founded on attitude, this concerns our awareness of cognitive bias and its impact on quantification of uncertainty and forecasting. This issue is emergent in the social and cognitive sciences, but is only just beginning to find its way into practical reservoir modelling workflows.

Of the items above we would argue that an awareness of bias (‘heuristics’) in workflows for uncertainty-handling is key (Ringrose & Bentley, 2015). Heuristics of representativeness, availability, overconfidence, affect and anchoring (see Kahneman 2011, for definitions) cause us to build models which unintentionally mislead.

These are biases which cannot be removed automatically by the application of geostatistical algorithms, but are resolved more effectively by conceptual thinking and multi-deterministic modelling (Bentley & Smith, 2008). Attempts to remove bias also benefit from open-minded discussion, and are a motivation to support constructive peer reviewing.

Conclusion – the road ahead

This article reviewed two aspects which can be brought to bear to operations in mature basins: the application of enlightened, low-carbon tertiary field management, and the development of new technologies and novel workflows for modelling and forecasting aimed at supporting those activities.

The fluctuating oil price and the long decline tail in mature fields, especially in onshore basins, make it likely that commercial margins will be achievable at least periodically for some decades to come. Truly fit-for-purpose reservoir modelling and simulation exercises can help quantify these late-life conventional options; in our view, ‘fit-for-purpose’ means adapting thoughtful, unconventional workflows in place of defaulting to detailed full-field simulations and lengthy history-matching exercises.

A particularly exciting view of the end game in mature basins is the application of EOR-based CCUS technologies. These serve as a bridge to a low-carbon future, allow the last hydrocarbons to be extracted with reduced environmental impact and lead the way to cost-effective carbon capture schemes. Getting CCUS schemes right makes an even greater call on the robustness of the technical tools used for modelling and forecasting.

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