FORESIGHTING REPORT
Mature Oil and Gas Assets

Addressing technologies required to extract the maximum value from oil and gas reservoirs

For Members Only

27th October 2004
V1.0

TABLE OF CONTENTS

ITI ENERGY INTRODUCTION

ITI Energy is one of three operating groups that make up ITI Scotland. Together with ITI Techmedia and ITI Life Sciences, we will be investing in excess of £450 million over the next ten years in research and development. Publicly funded, but 100% commercially driven, our collective aim is to create new technologies and stimulate business growth in Scotland.

ITI Energy will select and invest in programmes based on assessing future market needs, identifying technology opportunities, and responding to ideas, initiatives and proposals from the research and business communities. We will use our £150 million funding to commission and direct applied research projects in collaboration with partners from industry, academia and finance.

Throughout this process, we will protect the Intellectual Property (IP) that our investments generate, enhancing its competitive positioning, and helping to bring the resultant technology to market.

Participation in our activities and projects is open to all businesses and research organisations, regardless of where they are located. We are based in Aberdeen, but our scope and vision is global. We closely follow research activities in other countries, and welcome involvement and collaboration from overseas. Our success depends on being able to develop new technologies that address market needs around the world.

Further information on this foresighting study and ITI Energy may be obtained from:

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EXECUTIVE SUMMARY

This report provides a summary of ITI Energy's initial foresighting study focused on the Mature Oil and Gas Assets (MOGA) market. The report aims to:

- Provide a structured analysis of MOGA market needs and technology opportunities on which ITI Energy might focus
- Present conclusions to ITI member companies for their review and input
- Catalyse further discussion and development of MOGA technology development projects and proposals

The ITI approach to foresighting aims to consider key market trends and emerging business needs which may create market pull for new technology - using this analysis as a basis to identify and explore specific technology development opportunities. The conclusions of this study are the result of a highly consultative approach engaging over 90 companies and organisations across the oil and gas sector and involving over 150 individuals with a broad range of industry expertise and experience. This approach sought to leverage ideas and input from operators, technology users, technology suppliers and researchers from the UK, US, Norway and the Netherlands.

MOGA – A Growing Market

The MOGA market (defined as fields or reservoirs past peak production) presents a growing field of opportunity for new technology development. The following summarises some of the key factors driving this growth in opportunity for new MOGA technology:

- Increasing challenge of meeting global oil and gas demand
- Escalating O&G prices – increasing the value of unrecovered reserves
- Mature fields and reservoirs provide most of the current global oil and gas production (circa 70%) and represent a unique set of technical and commercial challenges
- New, large fields are increasingly difficult to find and expensive to develop (finding and development costs for new fields are now exceeding $7/BBL)
- Recovery factors at end-of-life remain, on average, very low for many mature fields (circa 35-37%)
- Operators' strategies toward mature areas are changing and developing:

  Super-majors appear to be viewing mature assets as increasingly important, as they find new, large fields increasingly difficult to find and expensive to exploit

  National Oil Companies are likely to become increasingly important end users of MOGA technology – applying technology to their home country assets and, in some cases, assets acquired through internationalisation strategies

  Independents are, in many cases, becoming key mature asset specialists applying a lower cost base and selective deployment of technology either focused on ageing mega-fields or rolling-up several smaller scale (uneconomic) assets.

The MOGA market also presents a range of specific business needs which are likely to shape the need for new MOGA technology in the coming 10 years. Specifically, technologies which can support:

- Locating and quantifying remaining reserves
- Accessing and producing brown field/satellite fields
- Dealing with problematic resources
- Delivering more cost effective and efficient enhanced recovery
- Achieving lowest cost base whilst sustaining operational integrity (reliability and HSE performance)
- Sustaining well/reservoir integrity of ageing assets
- Integrating and exploiting potential interactions with other energy segments e.g. possible interactions with offshore renewables
- Handling the increasing volume and complexity of data and interpretation
- Addressing the issue of ageing work-force and related issues of de-manning and loss of skilled work-force

MOGA Presents An Abundance of Technology Opportunity but no Shortage of Commercialisation Challenges

Having taken a view on market drivers and business needs, the study went on to explore a range of issues associated with the challenge of successfully developing and commercialising oil and gas technology. The following summarises some of the key insights regarding the wider context of MOGA technology development:

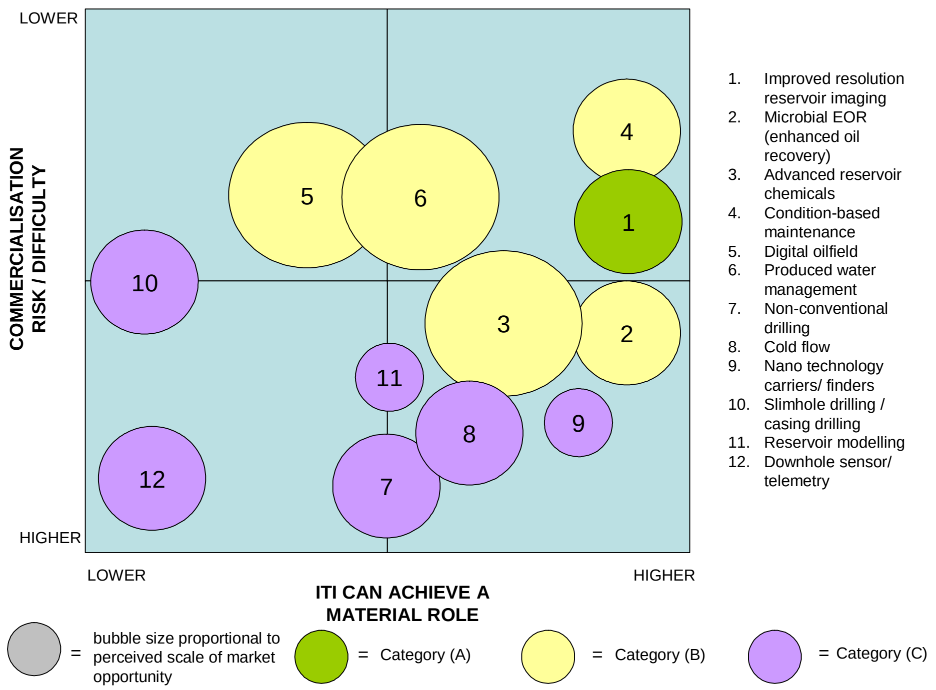
- Super majors have reduced R&D investments in the last decade and tend to look at shorter time horizons for a return on investment from R&D
- Several super majors have increasingly “out-sourced” technology development to 3rd parties: service companies for short to medium term needs and universities / institutes for longer term
- Service companies may find it difficult to maintain the scale of investment in longer term R&D given the challenge of sustaining acceptable ROI (although recent up-turn in the oil sector may soften this pressure)
- Technology has made a major contribution within the oil and gas sector and there have been considerable successes in recent years
- Small companies (according to foresighting participants) are often regarded as the engine-house of innovation – ultimately becoming acquisition targets for the larger service companies
- Many smaller independents and NOCs have limited legacy of R&D capabilities and look to others to supply new technology
- Directionally there may be significant opportunity for ITI Energy in addressing the gap between the increasing technological challenge (of maintaining supply) and the decrease in R&D investment and the reducing time horizon of remaining R&D

However, the goal of rapidly commercialising technologies in the Oil and Gas sector is particularly challenging:

- Historic analysis of the time taken for new E&P technologies to achieve significant market penetration clearly shows that the O&G sector lags well behind other sectors / industries
- Many involved in foresighting have voiced frustration that there is a long list of “good technologies” which remain on the shelf due to risk aversion and other barriers to entry
- In the context of the MOGA market - the key to successful commercialisation lies in achieving an adequate risk-reward profile for a given technology and ensuring that this profile is sufficiently well understood by key purchasers / decision makers. ITI Energy’s process for selecting projects must consider this aspect in detail and build such considerations into all stages of project development

Developing a Focused List of Opportunities

A structured process of brain-storming sessions (workshops and one-to-one meetings) and desk-top research provided an initial long-list of around 60 technology opportunities. This long-list was then filtered and prioritised to create a short-list of 12 technology areas on which to focus. Further research and analysis generated short summaries for each of these 12 technology areas (contained within the main report) and an initial prioritisation of how ITI Energy proposes moving forward in developing specific technology proposals / projects. The following diagram summarises how the 12 technologies have been prioritised:



The top right quadrant of this diagram represents technologies which are perceived as offering stronger possibility of projects where ITI Energy can play a key role and where there is a reasonable potential to achieve commercial success. The 12 technology areas have been, as indicated in the above diagram, allocated a prioritisation / categorisation as follows:

Category (A): ITI Energy will look to develop specific program or project proposals using it's own resources (e.g. conduct initial scoping / feasibility study to define specific technology gaps, estimate the scale of market opportunity for technologies to fill these gaps and assess the potential for successful capture of related IP and scope the feasibility of onward licensing and commercialisation of the technology beyond the ITI research project)

Category (B): ITI Energy will seek to engage with a targeted set of companies and researchers to explore in more depth the potential technology opportunities in this area (e.g. exploratory discussions with other parties and networking to bring interested parties together to build a clearer case for initiating more resource intensive project scoping / feasibility studies)

Category (C): ITI Energy will adopt a more passive approach looking to other parties to bring forward specific project proposals - of course 3rd parties are also open to bring forward technology proposals relating to any of the 12 technology areas.

The prioritisation of these 12 areas – as discussed above – is for the purpose of allocating ITI Energy's own resources (i.e. staff time) in proactively developing project proposals i.e. categories A and B. The 12 technology areas have all been selected from the long-list as having significant potential for new technology development. Therefore, 3rd party project proposals in any of the 12 technology areas will go through the same project screening and selection process i.e. the categorisation does not imply a pre-allocation of R&D project funding biased toward those areas categorised as A or B.

To move forward on these areas, consistent with the above prioritisation, ITI Energy is initiating a range of activities, including;

- Further one-to-one discussions with companies and research organisations
- Workshops or other forums to stimulate proposals of potential R&D projects
- Scoping / feasibility studies to develop specific proposals

However, ITI Energy remains open to 3rd parties bringing forward proposals in other areas outside the list of 12 – the prioritisation simply highlights where most of ITI Energy's time and resource will be focused in the near to medium term.

1 INTRODUCTION

1.1 Document Purpose and Structure

This report serves two broad purposes. Firstly, the document communicates the basis for ITI Energy's focus on certain areas of Mature Oil and Gas technology- allowing members to test and challenge this focus, as well as consider ideas and proposals they might wish to present to ITI Energy for consideration. Secondly, the report provides a collation of information which member companies and organisations might find useful in developing their own business and technology development plans.

In particular, the document sets out to define the objectives of ITI Energy's market foresighting exercise in the Mature Oil and Gas Assets (MOGA) market, to detail the work activities carried out as part of the exercise, and to highlight the technology priorities identified and proposed next steps. The purpose of issuing this report to members is as follows:

- To share with members a summary of the market and technology information gathered and analysed through the foresighting process
- To communicate to members what areas of technology emerged as priorities from the foresighting work
- To allow members to comment on the resulting technology priorities and to consider if they have particular project proposals or ideas they would like to bring forward for consideration

The document is arranged in five main sections:

- An introduction to ITI Energy and the foresighting process adopted
- An overview of the MOGA market
- An overview of MOGA technologies
- A description of the 12 identified technology priorities, with details on each one
- Brief conclusions and next steps

1.2 Foresighting Overview

ITI Energy has chosen to look initially at five areas of energy sector market and related technology:

- **Mature oil and gas assets**: opportunities to help operators extract maximum value from maturing assets.
- **Low-cost renewable energy**: marine energy and offshore/onshore wind with particular emphasis on how technology can drive down the cost of energy from these resources.
- **Future power networks:** grid transmission and distribution, distributed generation and demand side management.

- **Future energy storage:** the need for both large-scale and micro/portable energy storage, and the potential development of new energy intermediaries such as hydrogen and associated technologies like fuel cells.
- **Conventional power generation**: technologies that can enable conventional generation (coal, oil, gas and nuclear) to meet increasing demands such as higher efficiency, lower emissions.

This study focuses on the first of these five areas – MOGA – and has adopted a structured programme of market foresighting to identify some of the more promising technology opportunities for investment, based on anticipated medium-long term market needs and technology trends. The foresighting work has used a nominal time horizon of 2014 – i.e. what technologies will the mature oil and gas market require/ desire at this point in the future – to ensure that 'gamechanging' technologies can be nurtured, rather than purely focusing on incremental developments.

Overall, the foresighting programme has had direct engagement (through workshops and interviews) with more than 150 experts throughout the mature oil and gas sector, ranging from the USA to the UK and Norway. 93 different organisations have been involved, including 17 oil companies and 9 universities. More information regarding industry engagement is provided in Section 6 (Appendix 1)

The structure of the foresighting process is shown in figure 1, and comprised four main activities.

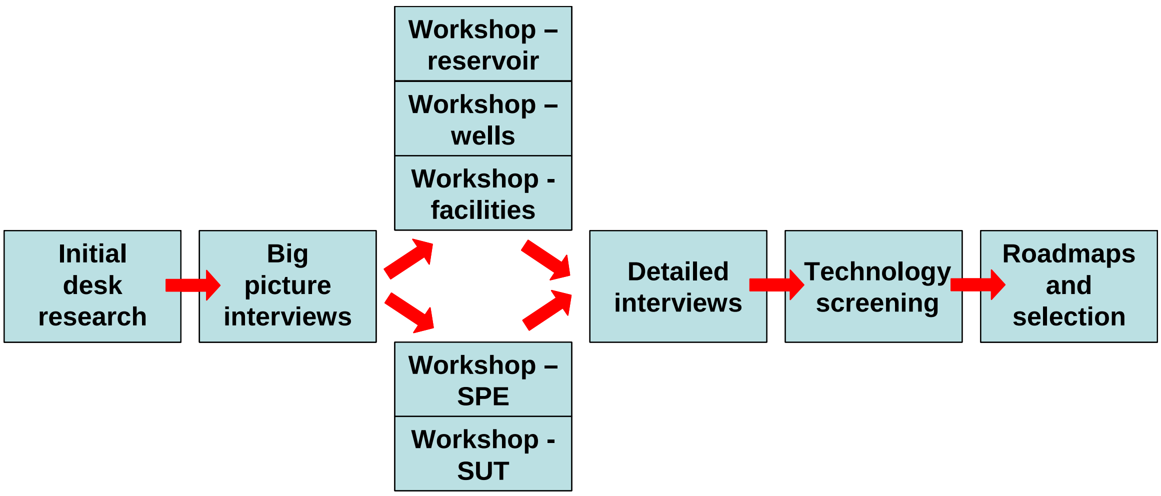


Figure 1 – MOGA Market Foresighting Process

Firstly, an initial period of desk research and 'big picture' interviews, to ensure that lessons are learnt from past and present R&D and industry initiatives, and to ensure that ITI Energy builds on the myriad of activity that has gone before, adding value as it goes.

Secondly, a series of 5 workshops with senior industry personnel were held to identify and explore future (potential) business and technology development areas of opportunity. These included 3 'closed' workshops, each comprising about 15 invited attendees representing an even split of technology users (operators) and their technology providers, covering the three main MOGA technical segments of reservoir management, drilling and wells, and facilities and subsea. There were also 2 'open' workshops, organised and promoted in conjunction with the SPE/ Institute Of Energy and SUT.

At the end of each closed workshop, delegates were asked to 'score' each of the identified technology areas of opportunity on a matrix of market size versus competitive impact, and to note down key enablers and blockers for each technology area.

These opportunities – combined with the preceding desk research - led to the clear identification of 6 key technology themes, which are described in section 3.7. The open workshops, undertaken using the Open Space format, provided an opportunity for specialist professional organisations to raise and introduce any technology opportunities and issues that they felt appropriate against the MOGA brief. These acted both to confirm some of the technologies raised in the closed workshops and introduce additional ones. In total, from the 5 workshops, 50 technology opportunities were identified.

Thirdly, a series of 35 one-to-one interviews was conducted, half face-to-face and half by telephone. These were conducted with different people to those involved in the workshops, to ensure that the views of leading industry experts in the relevant themes were gained, and also to add further input to the overall foresighting programme. In addition, interviews were held with experts from the USA, UK and Norway, to ensure a worldwide perspective.

These interviews were designed to explore and validate the choice of the 6 technology themes, to identify and characterise the niche technology opportunities within each theme, and to highlight other technology opportunities which may not have been adequately explored during the workshops. In essence, this was a further iteration on the results of the workshops. This interview process led to the definition of 34 technology opportunities, as shown in section 3.9.

Fourthly, a technology screening exercise was carried out, using the data from the desk research, workshops and interviews, to select the 'top 12' technology opportunities for further analysis. A summary proposal was developed for each of the top 12 technologies, as shown in section 4. A final stage of the study looked to develop a prioritised action plan of how ITI Energy proposes to move forward on these 12 technology areas.

2 MARKET OVERVIEW

2.1 Summary

The world faces an ever increasing challenge to maintain global oil and gas supply and demand in balance:

- The challenge is most pressing in relation to oil
- However, only a matter of time with regard to gas
- Fields and regions which fall within our definition of Mature represent the majority of current global production (~70%)
- Mature field technologies are important and the opportunities for their development and deployment are growing

The MOGA market and related technology opportunities are significant and will grow steadily over the coming 10 years and beyond:

- New large scale fields are increasingly difficult to find and increasingly costly to develop hence the existing base of mature assets will become increasingly important
- Growth in CAPEX in MOGA fields is limited but OPEX growth is substantial
- Average (oil field) recovery factors remain low, estimated average of 35-37%, this continues to represent a significant technology opportunity in mature fields
- Mature fields exist both offshore and onshore, therefore technology opportunities are not exclusive to offshore applications:
- More oil production onshore, but most growth since 1980's has been offshore
- Offshore production share will only likely increase gradually over-time
- Foresighting study sought to identify technology opportunities irrespective of whether offshore or onshore focused
- Likely that the technologies of greatest focus will be those relevant to offshore and shallower water – as these are likely to represent the MOGA areas which achieve greatest industry focus / attention in the coming 10 years

Ownership of resources and the changes in operator approach and strategy influence the opportunities for MOGA technologies:

- NOCs own the majority of global oil resources
- NOCs are likely to become increasingly important end users of MOGA technology, applying technology to their home country assets and, in some cases, assets acquired through internationalisation strategies
- Super majors remain key operators of MOGA assets (both N.Sea and GoM)
- Independents are often acting as MOGA specialists – either acquiring ageing mega-fields and applying low cost operational models or rolling up smaller reserves within a region into viable operating propositions
- Different operators have potentially different approaches and needs with regard to the development and delivery of new technologies

This study has summarised a number of key business drivers and technology challenges on which prospective technology developers might focus, in particular the MOGA technologies must focus on a range of objectives:

- Increasing recoverable reserves
- Increasing production rates
- Addressing increasing costs both CAPEX and OPEX
- Sustaining or improving H,S&E performance

The whole premise of this study is that the continuing growth and importance of the MOGA market presents technology developers / suppliers with a specific set of opportunities, quite distinct from those required for the frontier / greenfield oil and gas E&P market. Providing a range of competitive technologies which support the global MOGA market represents a key element in sustaining the Scottish supply sector, drawing on expertise and relationships developed during four decades of servicing the indigenous oil and gas industry.

2.2 Definition and Scale of the Mature Oil and Gas Assets (MOGA) market

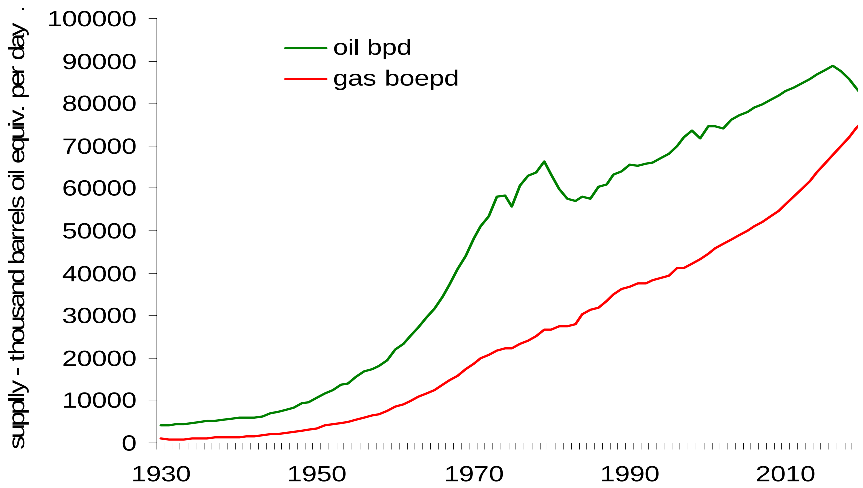


Figure 2 - A Global Oil Supply Peak before 2020?
(source: Douglas-Westwood Ltd)

There is evidence that oil supply will be stretched to meet increasing global demand.[1] This view is expressed by individuals including oil supply analysts Dr Michael Smith and Dr. Colin Campbell, investment banker Matt Simmons and Thierry Desmarest CEO of Total who recently stated “oil companies cannot discover enough new oil to ease today’s production-capacity shortage”.[2] In addition, the nature of the oil being produced is changing with the global crude slate becoming more sour and heavier. Although, predicting the exact peak and subsequent rate of decline is very uncertain it is highly probable that technology will have to play a key role in meeting the challenge of deferring the supply peak. Predicting exact peak and rate of decline is highly uncertain.

An example of this "oil peak" thinking is *"The World Oil Supply Report"* which considers four different oil demand scenarios from 2004 and concludes: [3]
Flat demand – due to supply shortfalls world oil production begins to decline in 2021
Constant 1% demand increase – world oil production begins to decline in 2017 (see figure 2 above).
Constant 2% demand increase – world oil production begins to decline in 2013
Constant 3% demand increase – world oil production begins to decline in 2013 but is unable to meet 3% demand increases from 2009.

Substitutes for oil, in particular synthetic oil from bitumens in Canada and Venezuela and oil substitutes from all forms of gas to liquids plants, could delay the onset of peak year – although at current levels of investment these will be insufficient to postpone world peak output by more than one or two years.

"The World Gas Supply Report" shows that global gas supplies have a much longer lifetime than oil.[4] However, local shortages are being experienced in the USA and even countries such as the UK, which have historically been strong net exporters, are finding it increasingly difficult to maintain supply-demand and stable pricing.

One measure of maturity – which has been used for this foresighting programme - is if a country (or field) has past peak oil or gas production. There are 58 countries in the world where peak oil production has already passed and all but the few special exceptions and very small producers empirically prove that peak year for a country occurs when between 35% and 65% of total recoverable reserves and resources have been extracted. It is estimated that:

- 58 countries are at least five years past peak (e.g. USA 1970)
- 6 just past peak (e.g. UK 1999)
- 10 at or near peak (e.g. Mexico)
- 31 more than three years until reaching peak (e.g. Saudi)

With some important exceptions (e.g. USA), gas peaks have not generally been reached.

Three issues arise from the above, all of which have a major impact on future opportunities within the MOGA market:

- Global oil demand has already pushed prices to very high levels, which might be sustained above $50/ barrel during the next 5-10 years.
- Increased oil and gas prices are likely to encourage offshore activity and maximum exploitation of assets
- Decommissioning could be implemented to the detriment of potential IOR/EOR and marginal field opportunities.

2.3 Overview of Oil and Gas Production

Schlumberger estimate that the MOGA market currently accounts for 67-72% of world production, compared with approximately 8% of world production from deepwater fields, and approximately 22% from greenfields (new field developments, prior to peak production). These figures underline the dominance of the MOGA sector within the world oil and gas industry.

In order to gauge how and where the MOGA market is likely to grow over the next 10 years – the time horizon of this foresighting exercise – one can analyse forecasts of production for different geographical regions worldwide.

Figure 3, based on figures from the US Energy Information Administration's (EIA) Annual Energy Outlook 2004, shows the forecast oil production trend until 2025 (not considering supply/ demand shortfalls). Growth in the MOGA market may be postulated as follows:

- In regions where there is decline in production (USA, Canada, Indonesia, Venezuela) the MOGA market is growing very rapidly, with typically 70-90% of production from fields in decline
- In regions where there is little or no growth in production (e.g. North Africa) the MOGA market will grow gradually, as 50-70% of production is from fields in decline
- In regions where there is still significant growth in production (e.g. Middle East, Eurasia), the MOGA market will be based around specific older fields or countries within that region that are in decline
- The consequent change in the global crude slate will provide increasing opportunities in developing heavy, sour and unconventional oil.
- In all these regions it should be noted that they each represent a combination of countries in production decline and countries in production growth, and therefore a more detailed country-by-country analysis – beyond the scope of this foresighting exercise – is recommended

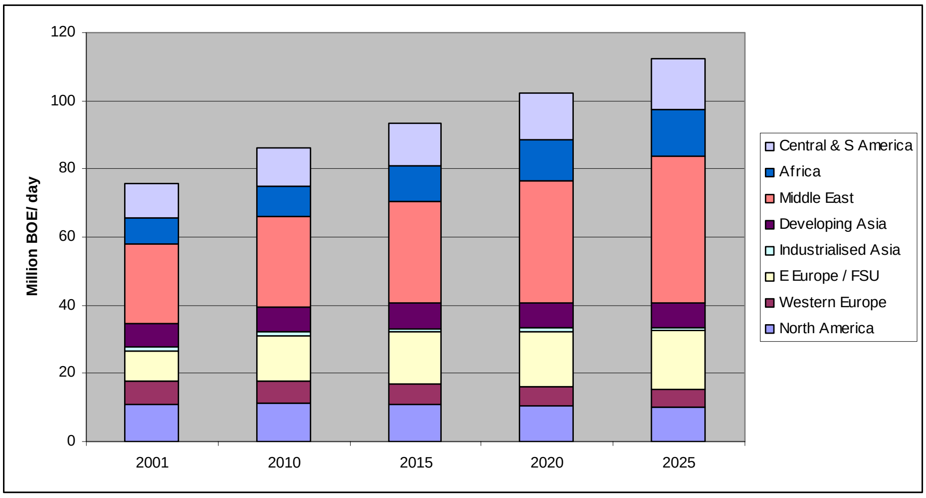


Figure 3 – Regional Oil Production Forecasts to 2025
(source: EIA International Energy Outlook 2004)

Whilst the above analysis relates to oil production, by 2014 the MOGA market will be further expanded by opportunities emerging from mature gas asset production.

Figure 2 showed that world gas production will peak about 12 years after world oil production, implying that by 2014 a large number of gas fields will be 'mature'. Figure 4 below, also based on figures from the US EIA's Annual Energy Outlook 2004, shows the forecast gas production trend until 2025.

The view of a strong growth in world natural gas production shown in figure 4 is supported by forecasts contained within the EIA International Energy Outlook 2004. World production estimated at 45 million BOE/ day in 2001 is expected to increase to 75 million BOE/ day by 2025 - a growth of 66%. The largest increases are expected from the Former Soviet Union and Middle East. Gas growth is being driven in part by the burgeoning global LNG market that is making gas an internationally traded commodity, particularly as gas becomes the dominate fuel source for the world power market.

In 2001 gas production accounted for 37% of total (oil and gas) production. By 2025 the gas share of total production is forecast to increase slightly to 40%.

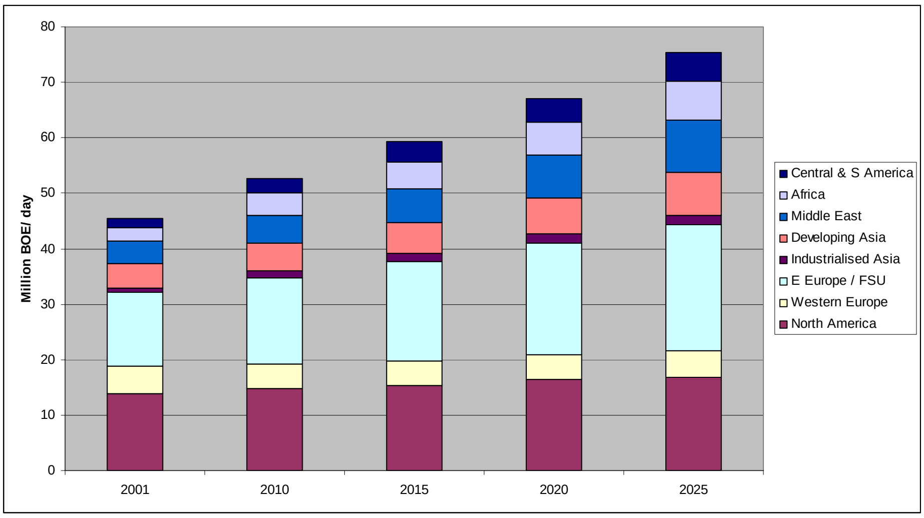


Figure 4 – Regional Gas Production Forecasts to 2025
(source: EIA International Energy Outlook 2004)

2.4 Increasing Challenge of Finding and Developing New Fields

New field opportunities – in terms of quantity and size – are now in decline, and there is an increasing global challenge to find and economically exploit new fields. Figure 5 shows that since peaking at 80 billion barrels of oil equivalent (BOE) in the mid-1960s, reserve additions from new discoveries have fallen dramatically and are now averaging 10 billion BOE per year, a decline of 83 percent. Illustrating this point further, over the last 40 years in the Gulf of Mexico, the average size of a new discovery has fallen from 250 million BOE to under 10 million BOE, a reduction of 96 percent.

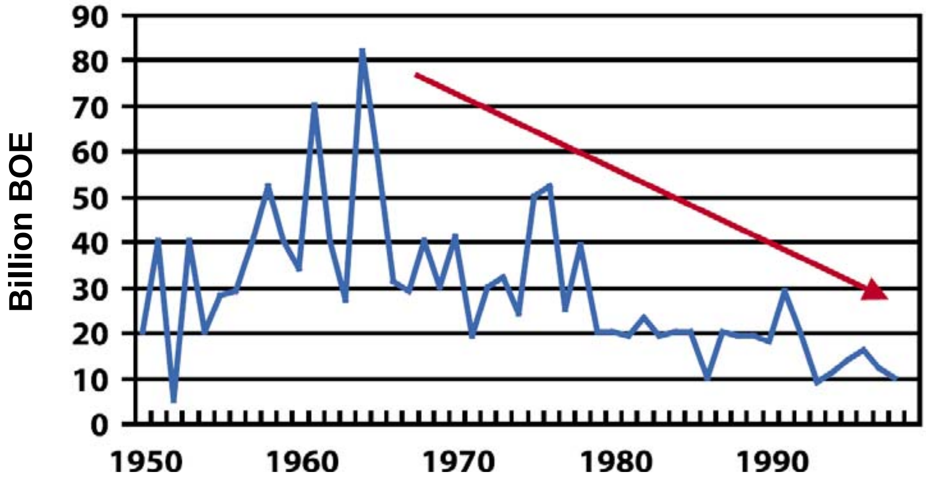


Figure 5 – Annual Reserve Additions from New Discoveries Worldwide
(source: US Geological Survey)

This global challenge - to find and economically exploit new fields – also needs to be seen against the backdrop that F&D (finding and development) costs are now constantly increasing, at a rate of approximately 15% per year [2,3]. This is partly as a result of the scarcity of new field opportunities, and the increasing technical complexity (e.g. ultra deepwater in Gulf of Mexico and West Africa, sour gas at Kashagan etc) of the opportunities that exist.

Figure 6 shows the rise in global F&D costs, which bottomed out at $3.50/ barrel of oil equivalent in 1997, but may top $8/ barrel in 2004 according to ExxonMobil [5, 6].

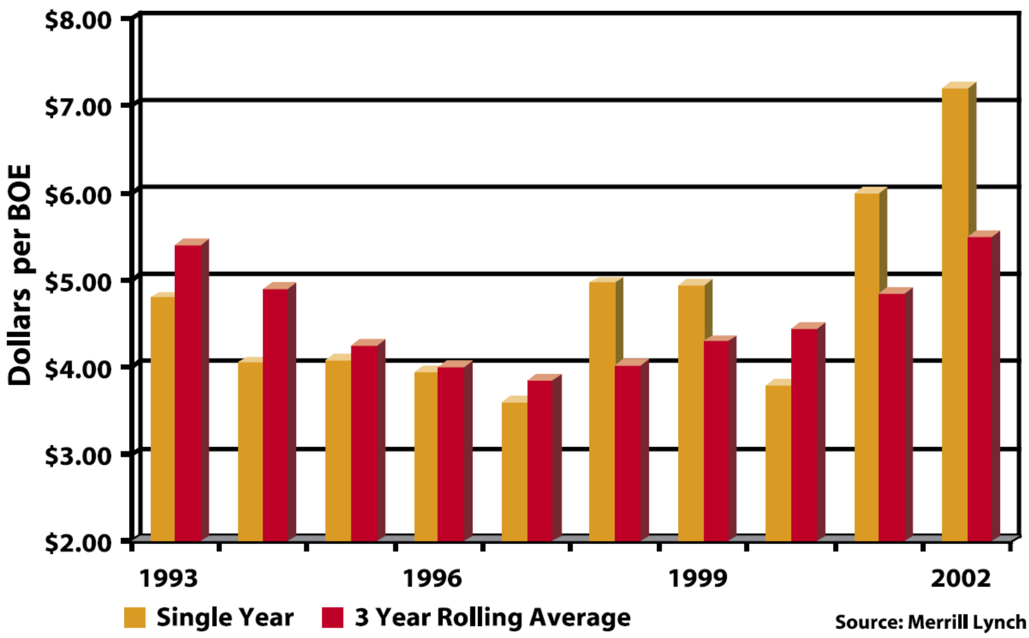


Figure 6 – Rising Finding and Development Costs
(Source: Merril Lynch)

The rise in F&D costs provides additional stimulus to oil companies to improve returns from mature assets in their portfolios, where they have already made the capital investment in finding and development.

This issue also leads to the increasing trend amongst oil companies to re-organise their asset portfolios, a trend which is discussed more fully below.

2.5 Recovery Factors

While the MOGA market accounts for the majority of production, the recovery factors (i.e. the proportion of total hydrocarbons which can be economically recovered) are still surprisingly low. The average recovery factor for oil fields is generally agreed to be 35-37% , and 50-60% for gas fields.

These figures lead to two conclusions. Firstly, that recovery factors will need to be dramatically improved in order to meet the anticipated increase in world hydrocarbon demand over the next 10 years. Secondly, that there is a tremendous opportunity to realise huge extra value, even by increasing recovery factors in mature assets by just a few percent.

2.6 Onshore versus Offshore

There is substantially more oil production from onshore areas than offshore. Approximately 34% of world oil production in 2003 came from offshore fields and 66% came from onshore. This is hardly surprising since onshore areas have been exploited for so much longer and there are far more fields in production. However, onshore oil production peaked in 1979 and since then the main increase has been from offshore. Intuitively one might expect that the share offshore production takes will gradually increase in the future especially as deepwater developments come onstream.

Figure 7 shows historic & forecast onshore and offshore production. The proportion of offshore oil production is forecast to increase, assuming 1% growth in demand.

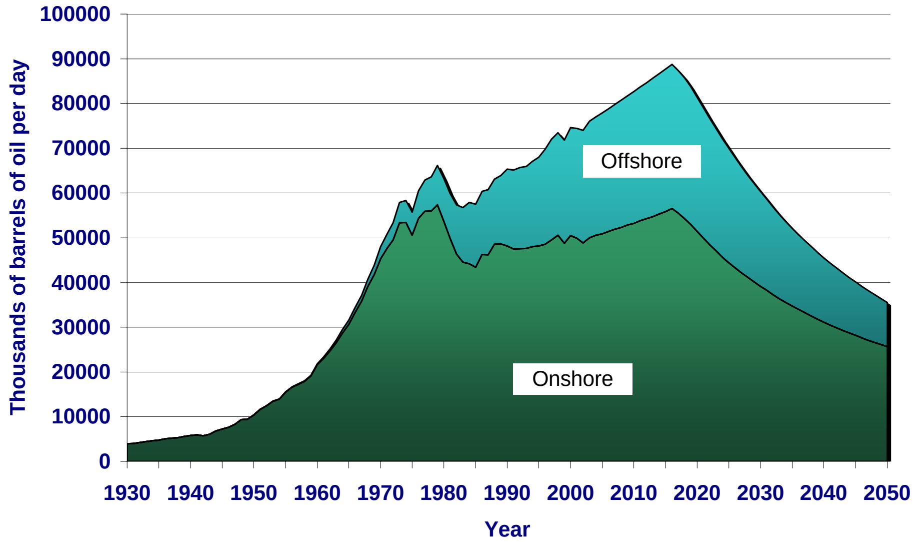


Figure 7: Global onshore and offshore oil production forecast
(source: Douglas-Westwood Ltd)

However, offshore areas have less estimated total oil reserves and resources compared with onshore – 25% lie offshore and 75% lie onshore. There are significantly more onshore reserves because onshore has much greater sedimentary areas. It should be noted that although two thirds of the world's surface area is covered by water the vast majority of this is underlain by oceanic crust, which is non-prospective for oil.

Offshore oil production share will increase as shown above but only marginally, especially since large remaining reserve volumes located in Saudi Arabia, Iran and Iraq are mostly in giant onshore fields. However, the bulk of 'yet to find' resources outside the Middle East and Russia are believed to lie offshore.

The split of gas production onshore versus offshore is more difficult to assess. There is a general shortage of statistics giving the onshore/ offshore segmentation of current and forecast gas production and reserves (although a new study is currently underway[7]). In addition, the picture is complicated in areas such as the Middle East where there is considerable use of gas for re-injection to boost oil production and in addition very large volumes are flared worldwide.

Nearly 57% of world gas reserves are in three countries, Russia, Iran and Qatar and large investments are ongoing to more fully exploit these reserves.

In short-to-medium term there will be a major growth in offshore gas production, with developments ongoing or planned in Sakhalin, the Caspian, West Africa, Egypt, and the Australian NW Shelf. In addition, with USA onshore gas production declining attention is again focused in the Gulf of Mexico.

In the longer term there is major potential for 'yet to find' onshore reserves in Saudi Arabia, and many of the longer term offshore prospects for yet to find gas lie within the Arctic regions (so called 'polar gas'), in particular the Barents Sea, Russia and Alaska.

Looking out to 2014, then as now, the majority of mature offshore fields will be in shallow water and, by then, have massively depleted reserves. However, it is not possible to sensibly generalise on what levels of reserves will remain in place as each field is an individual case and dependant upon its own economics. These shallow-water fields will progressively be joined by deepwater ones and there is a probability that the first major deepwater area - Brazil - could be a mature region!

The conclusion is that technology investment in the MOGA market needs to consider both onshore and offshore opportunities, with the emphasis for offshore in the next 10 years in shallow water.

2.7 Oil company Segmentation

In order to understand the MOGA market, it is important to understand the key 'market-makers' in the industry – the oil companies.

The oil and gas industry supply chain can at it's most basic form be split into three groups, with oil companies – the end users of products, services and related technologies - procuring from a small (decreasing) number of integrated service companies (ISCs), who in turn procure from a myriad of tier 1 and other suppliers. The ISCs are dominated by Schlumberger, Halliburton and Baker Hughes, who between them account for 33% of total worldwide oilfield expenditure (which was approximately $144 billion in 2003)[8]. However new players are emerging from Asia, for example China Offshore Service Ltd a subsidiary of CNOOC. The supply chain is further illustrated by analysis of the technology value chain in section 3.4.

Figure 8 below shows liquid reserves by oil company, as an indicator of relative scale.

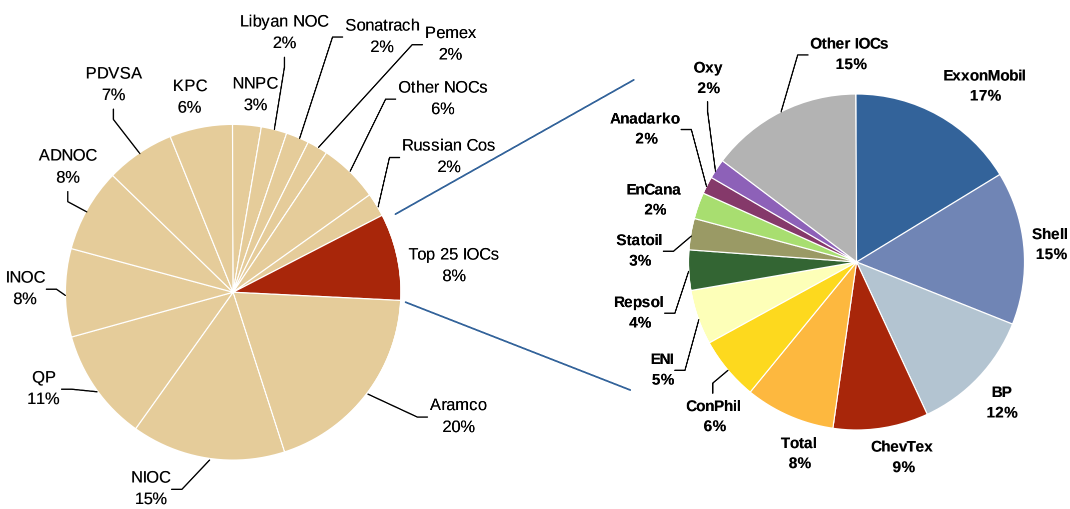


Figure 8: Oil and Gas Reserves by Oil Company at start-2003
(source: Oil & Gas Journal, 09/03)

Figure 8 shows that OPEC and national oil companies control much of the world's proved reserves, whilst the the top 25 IOCs control less than 10% of reserves.

Figure 9 shows the geographical distribution of oil and gas resources, and illustrates how the Middle East continues to dominate the oil map, and FSU gas.

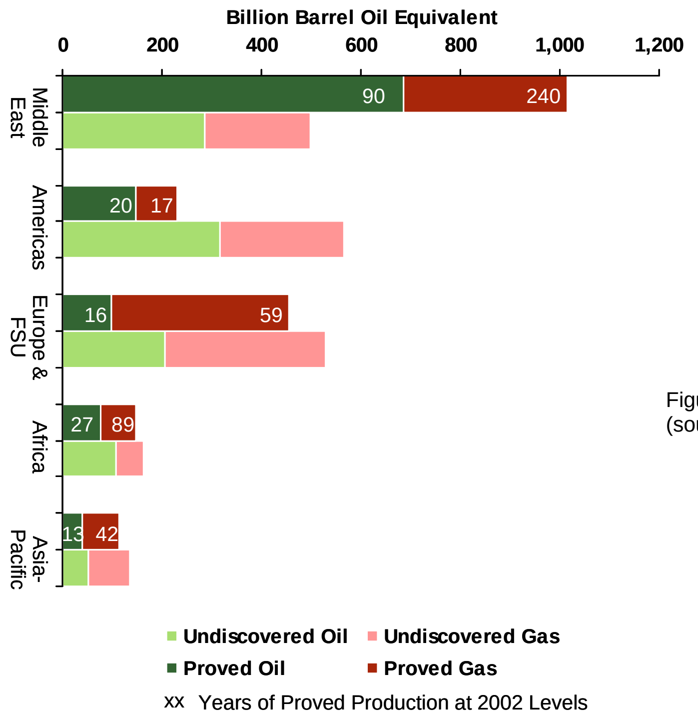


Figure 9: Geographical distribution of oil and gas resources (source: BP, SEC, USGS, IHS, CRA)

In practice very little meaningful data exists regarding future field development plans out beyond 2008 (and in many instances even this is difficult to achieve with reasonable confidence). Anything associated with reserves is now a very difficult subject charged with major uncertainty following the recent downwards revisions.

Assuming any technological development that ITI Energy invests in takes some five years to bring to commercial acceptance, then logically it will be applied outside the period of sensible statistically-based forecasting. However, as mentioned earlier, the trends by country are readily discernable.

2.8 Changing Nature of Operators

As new field opportunities decline (see above), so the asset portfolios of oil companies (operators) in the mature oil and gas sector are changing. It can be seen from figures 10 and 11 below that US Gulf of Mexico operatorships are dominated by smaller 'independent' oil companies (e.g. Apache, Union Oil, Murphy, Forest Oil etc). This trend started in the early 1990's when the major oil companies started divesting many of their shallower water GoM assets, and started to pursue new large field opportunities (e.g. deepwater GoM/ West Africa, and in Russia).

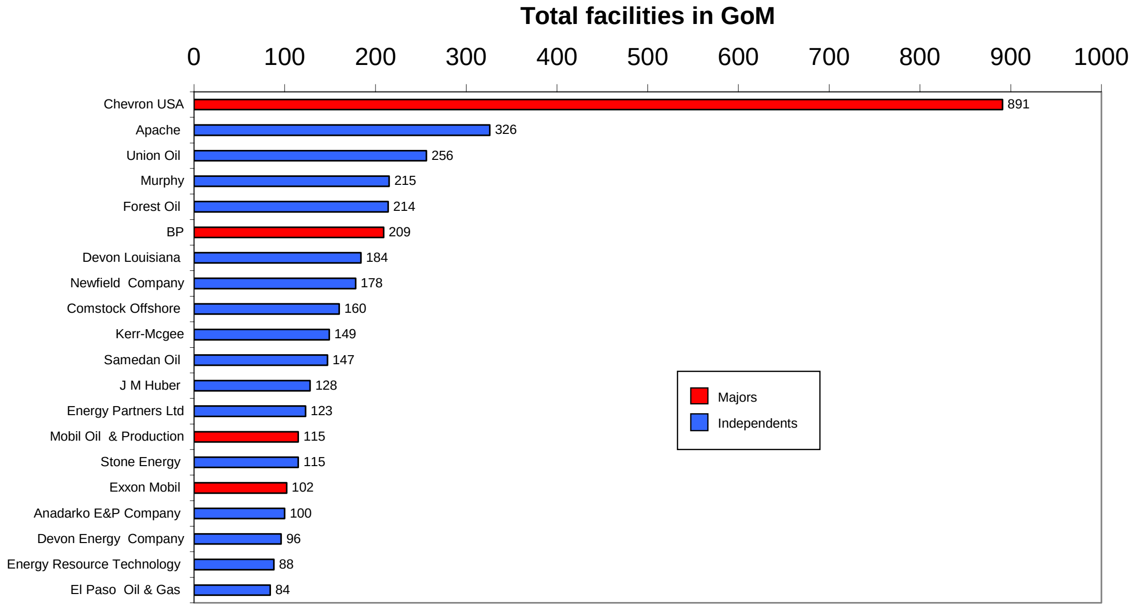


Figure 10 – US Gulf of Mexico facilities by operator

By contrast, UKCS (UK Continental Shelf) assets remain dominated by major oil companies, with ownership of UK platforms dominated by BP, Shell and ConocoPhillips who together operate 65% of all UK offshore surface facilities. This is shown in Figure 11.

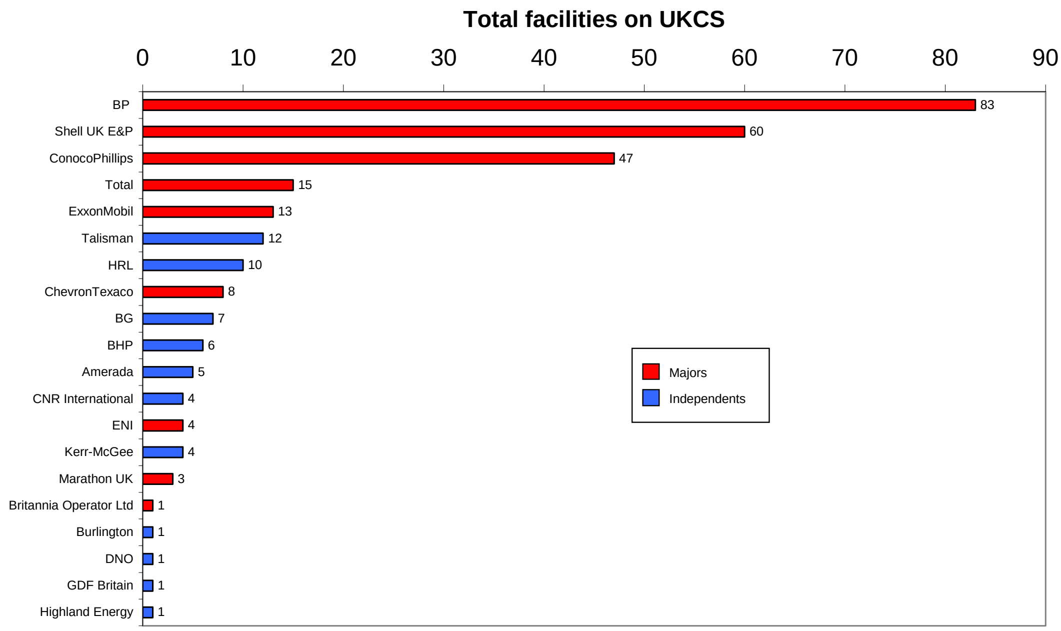


Figure 11 – UKCS facilities by operator

Clear signs are emerging that a similar trend is taking place now in the North Sea to the trend in the GoM 10 years ago, as smaller independents acquire mature assets from majors. This has a significant bearing on the overall MOGA market, as one seeks to characterise MOGA ‘customers’. Figure 12 highlights recent acquisitions / divestments in the UK sector:

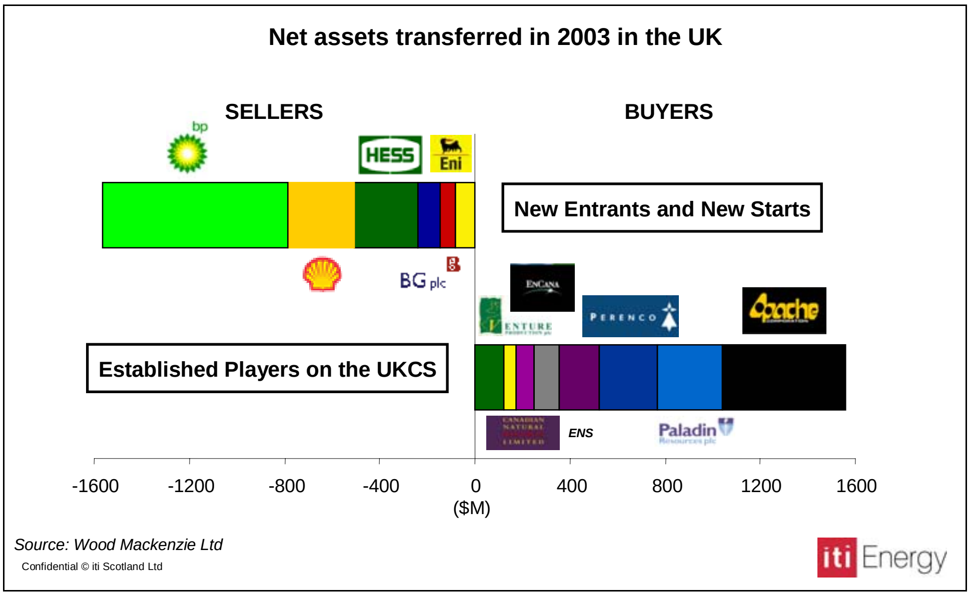


Figure 12 – Acquisitions/ divestments in UK sector

However, whilst the role of independents is of growing importance, it should not be forgotten that majors and national oil companies (NOC) still play the major role overall – and this is likely to remain the case, partly as a result of a diminishing number of new field opportunities for them to divert attention towards.

Indeed the role of the NOC is, in some regions, changing from host to competitor, with increasing numbers internationalising. Petronas of Malaysia now operates in 35 countries with Chinese NOCs, PetroChina and Sinopec, willing to invest significant capital to obtain a position overseas. NOCs can leverage strong intergovernmental relationship and lack the constraints shareholders can exert.

An important issue amongst oil companies is their willingness and ability to deploy new technology. Attitudes vary considerably from company to company, along with resources available for technology development and assessment and overall attitude to risk, and to partnering with a technology provider. Perceptions of technology risk are undoubtedly a major problem and in some cases they present a far more significant challenge than developing the technology. As a generalisation:

- Majors generally have all the in-house capabilities to be able to assess technology risk but their own asset managers may resist early adoption or trialling of new technologies
- National oil companies vary from “reserve holders” (e.g. Nigerian NOC) to active technology adopters (e.g. Statoil). NOCs are likely to become increasingly

important end users of MOGA technology – applying technology to their home country assets and, in some cases, assets acquired through internationalization strategies
- Independents may be less able to assess the risk and employ others to do this for them and/or avoid employing new technology totally, although exceptions exist such as Unocal.

2.9 Overall Global Expenditure

As already noted, technology investment in the MOGA market needs to consider both onshore and offshore opportunities. The most recent pan-industry annual survey of E&P spending trends carried out by Citigroup Smith Barney forecasts that total global upstream oil and gas spend in 2004 will be $149 billion, representing an increase of 4.4% over 2003 totals. This 2004 spending figure includes both onshore and offshore spending.

Detailed breakdowns of onshore spending are generally not available due to lack of data from a number of national oil companies who dominate onshore spending. However, data exists for offshore spending, in particular from Scottish Enterprise's E&P Spends and Trends 2004[9]. Total estimated 2004 spending offshore – both capital expenditure (CAPEX) and operating expenditure (OPEX) – is $81 billion, representing 54% of Citigroup Smith Barney's total upstream oil and gas spend forecast.

2.10 Offshore Global Expenditure

Levels of forecast offshore capital expenditure are perhaps the greatest macro indicator of an offshore region's maturity. Figure 13 and Table 1 show offshore CAPEX decline in UK, Norway and the Gulf of Mexico.

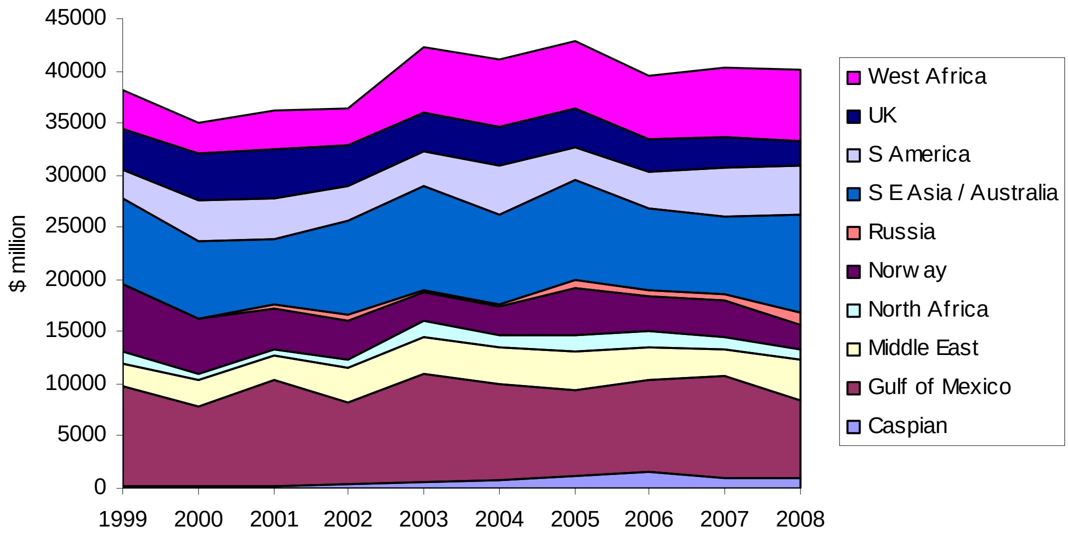


Figure 13 – Global offshore CAPEX forecast
Source: Scottish Enterprise Spends & Trends 2004/ Douglas-Westwood Limited

CAPEX ($ million)	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*99-03*	*04-08*
Caspian	216	206	246	310	661	731	1213	1481	974	1063	1641	5462
Middle East	2197	2556	2478	3235	3597	3466	3804	3209	2617	3885	14062	16982
North Africa	1190	576	598	847	1457	1315	1526	1540	1117	962	4668	6460
Norway	6347	5225	3809	3764	2712	2675	4499	3338	3607	2265	21857	16384
Russia	93	46	490	558	248	281	821	701	487	1220	1435	3509
S E Asia	8169	7374	6181	8913	9906	8571	9495	7699	7594	9389	40542	42748
South America	2713	3869	3951	3368	3390	4574	3208	3618	4688	4634	17289	20722
UK	4024	4548	4727	3812	3666	3820	3673	3154	2905	2476	20777	16028
US GoM	9542	7654	10065	7970	10278	9206	8119	8801	9712	7401	45509	43239
West Africa	3599	2994	3592	3609	6273	6540	6486	6039	6523	6733	20067	32321
Total	38090	35048	36137	36386	42188	41179	42844	39580	40224	40028	187847	203855

Table 1 – Global offshore CAPEX forecast
Source: Scottish Enterprise Spends & Trends 2004/ Douglas-Westwood Limited

Comparing the past five years and next five years – as shown in Figure 14 - the forecasts of CAPEX identify the North Sea and the shallow water US Gulf of Mexico as the main mature offshore regions.

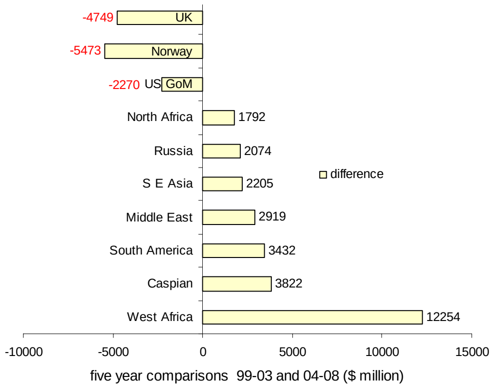


Figure 14 - The North Sea & GoM are the Main Mature Regions
(source: Douglas-Westwood)

Also considerable numbers of mature fields exist in SE Asia and W Africa. New CAPEX in the US GoM is mainly associated with deepwater developments. Since 1992, active deepwater leases have grown from 27% to 54% of the 7,800 GoM leases.

As shown in Figure 15 and Table 2, total offshore OPEX is forecast to increase at approximately 11% per annum, from $40 billion in 2004 to $60 billion in 2008.

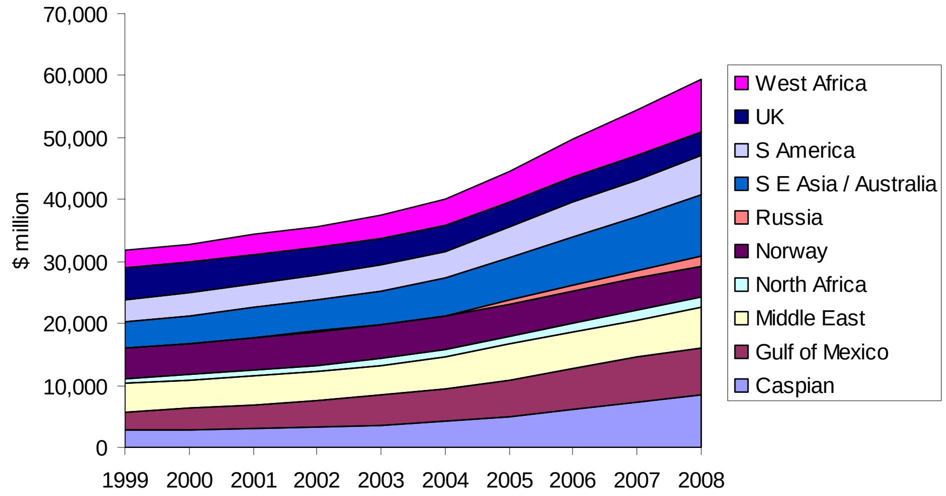


Figure 15 – Global offshore OPEX forecast
Source: Scottish Enterprise Spends & Trends 2004/ Douglas-Westwood Limited

OPEX ($ million)	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	99-03	04-08
Caspian	2,775	2,833	3,132	3,289	3,651	4,234	4,976	6,175	7,418	8,540	15,680	31,344
Gulf of Mexico	2,980	3,431	3,786	4,221	4,758	5,231	5,940	6,546	7,129	7,582	19,176	32,428
Middle East	4,567	4,592	4,614	4,819	4,892	5,197	5,700	5,843	6,060	6,580	23,484	29,380
North Africa	791	846	930	949	1,060	1,117	1,265	1,402	1,575	1,679	4,575	7,038
Norway	4,804	5,107	5,250	5,442	5,434	5,405	5,332	5,216	5,062	4,873	26,037	25,888
Russia	36	36	36	36	60	62	583	919	1,206	1,574	205	4,344
SE Asia/ Australia	4,407	4,485	4,804	4,971	5,391	6,019	6,773	7,829	8,762	9,835	24,059	39,217
S America	3,427	3,575	3,948	4,017	4,156	4,414	4,968	5,590	5,991	6,430	19,123	27,393
UK	5,147	4,986	4,716	4,659	4,311	4,222	4,107	3,995	3,886	3,759	23,819	19,970
West Africa	2,775	2,833	3,132	3,289	3,651	4,234	4,976	6,175	7,418	8,540	15,680	31,344
Total	31,709	32,724	34,348	35,694	37,363	40,137	44,620	49,691	54,506	59,391	171,838	248,346

Another important trend is the growing dominance of OPEX, as shown in Figure 16. This dominance of OPEX is even more pronounced in mature regions such as the North Sea and the Gulf of Mexico.

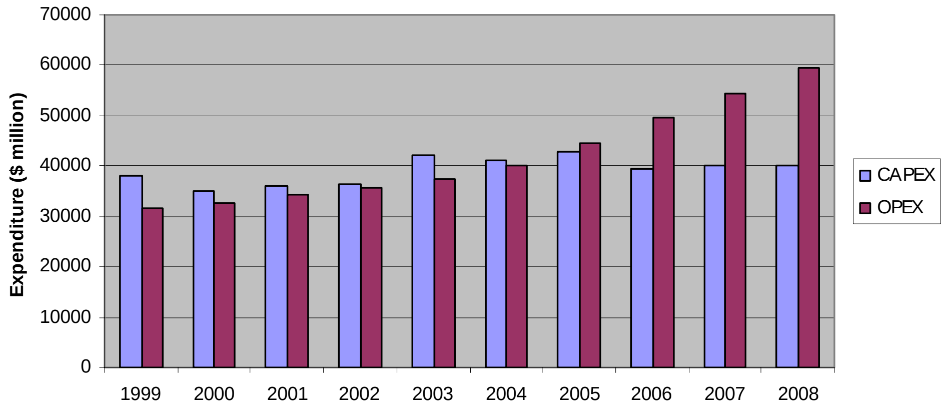


Figure 16 – Global offshore CAPEX/ OPEX comparisons
Source: Scottish Enterprise Spends & Trends 2004/ Douglas-Westwood Limited

A segmentation of offshore OPEX is shown in Figure 17. However it should be noted that this segmentation can vary dramatically from country to country and field to field. Operations can sometimes include significant amounts of pipeline tariffs, and modifications to field installations may in whole or part be accounted for as CAPEX.

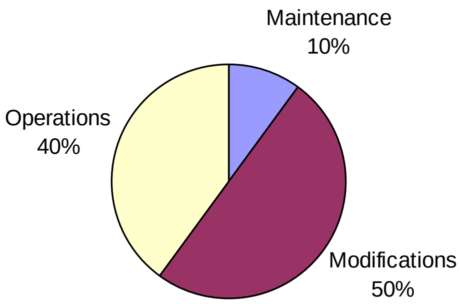


Figure 17 - OPEX Segmentation is Often Unclear
(source: Douglas-Westwood)

Over the next five years abandonment expenditure will be low, but it will become of increasing significance towards the end of the decade.

2.11 Overview of Key Business Drivers / Needs

In the course of this study a number of workshop based activities and one-to-one interviews focused on the question, “what are likely to be the key business challenges facing mature fields in 10 years time (2014)?”. The range of views and perspectives expressed are summarised in Figure 18.

Explore — Develop — Produce — Decommission

Locating and quantifying remaining reserves	World Class Inventory of non-proven reserves Improved HC detection techniques Accurately quantify hydrocarbon reserves
Accessing and producing brown field/satellite fields	Locating remaining oil pockets, attic oil Tie in satellite fields Low cost solutions to satellite fields
Dealing with problematic resources	Heavy Oil Sour or high TAN crudes HP/HT
More cost effective and efficient enhanced recovery	Address overall technical complexity Integration of reservoir model over time with drilling/AI technologies
Sustaining operational integrity (reliability and HSE performance)	Increasing environmental demands Application of low cost operations which continue to meet HSE criteria
Achieving low cost base operation	Design for abandonment (flexibility on facilities to match aging infrastructure Changing regulations on use of pipelines
Sustaining well/reservoir integrity	Reliability of well, over life cycle Well integrity, blow down – reconfiguration/ compression
Integration and interaction within the wider context of energy supply	Alternative use for platforms and infrastructure Defer abandonment of infrastructure CO2 reduction, sequestration

Business Issues

Changing business models and approaches	Bridge divide between supplier and operator regarding technology Changing competitive landscape – NOCs Internationalising, Indies operating legacy
Improving decision processes (e.g. improved / increased information, modelling to reduce risks and improve asset optimisation)	Workflow model improvement Permanent monitoring Maximum use of increased information levels to anticipate and lessen downtime
Altering Industry Demographic (ageing workforce degradation of skills base)	Ageing workforce Need to make industry more attractive Perception of a declining industry

Figure 18 – MOGA Business Challenges in 2014

In many instances, those participating in the study believed that the challenges or needs of the future would be similar to those which are facing operators and suppliers today, only the extent and severity of some of the challenges would increase over the coming 10 years.

2.12 Conclusions Regarding MOGA Market Trends and Drivers

Based on the market analysis in the preceding sections, a number of summary conclusions regarding the MOGA market may be drawn:

The MOGA market is strong and is likely to show consistent growth

- Subject to global economic growth, there is likely to be continued growth in oil and gas demand, in which case prices will remain strong, favouring increased investment.
- The MOGA market is growing in its dominance of the upstream oil and gas market worldwide, accounting for ~70% of worldwide production, and increasing steadily.
- A decline of new field opportunities coupled to an ongoing increase in finding and development costs will further drive this market growth.

Oil companies are showing increased commitment to this sector

- As a result of increased interest in MOGA, there has been a rapid increase in mature field re-development and associated technologies over the last ten years [10].
- In addition, there has been a spurt of interest across the industry in effective technology collaboration to ensure mature asset exploitation becomes increasingly effective, as evidenced by several major pan-industry events convened by bodies such as SPE on this exact subject [11, 12]. This foresighting exercise has reviewed outputs from these recent SPE forums, and incorporated the conclusions from these within this foresighting exercise.

Opportunities for suppliers of MOGA product and services are growing both domestically and worldwide, although the challenges associated with maintaining strong margins are considerable even when the offering is technologically advantageous:

- In the North Sea, small-field and mature-field opportunities have attracted new independent (often relatively small) oil & gas companies and we expect a stream of small-field developments (e.g. step-outs/ tiebacks) to form the future for the UKCS. Worldwide, National Oil Companies (NOCs) are becoming increasingly open to international oil companies (IOC), and nations with abundant oil and gas reserves that were previously closed to IOCs (e.g. Saudi Arabia, Former Soviet Union) are now opening up their fields, many of which may also be categorised as 'mature' [13].
- NOCs are internationalising and increasingly present themselves as competitors to IOCs.

Significant opportunities exist for new technology

- The mature oil and gas sector has been focused on cost reduction and the implementation of technology in new ways. The opportunity now is for new technology, emphasising value creation as well as cost reduction, applied with expertise.
- Low recovery factors (currently averaging ~35% for mature oil fields) present a huge opportunity for production growth.
- Global OPEX is expected to now exceed global CAPEX, highlighting the importance of OPEX-attacking technologies (e.g. produced water handling averages $0.50/ bbl water).
- The oil produced will become sourer and heavier, leading to difficulties in recovery and challenges for the downstream / refining sector.
- Further reductions in cost (including demanning) are feasible and likely but must be achieved whilst maintaining or improving H, S&E performance. Technology has a vital role to play in achieving the dual goals of lowest cost operation at highest H,S&E performance.

3 TECHNOLOGY OVERVIEW

3.1 Summary

The foresighting study aimed to select a number of MOGA related technology areas on which ITI might focus attention. This section summarises both the wider context of Oil & Gas technology development and the approach used to develop a “long-list” of technology opportunities - which formed the basis for selecting a short-list of technologies discussed more fully in Section 4.

The key conclusions regarding the context for O&G technology development are as follows:

Technology adoption in upstream O&G sector is difficult but potential opportunities exist:

- Super majors have reduced R&D investments in the last decade and tend to look at much shorter time horizons for a return on investment from R&D
- Several super majors have increasingly “out-sourced” technology development to 3rd parties: service companies for short to medium terms needs and universities / institutes for longer term
- Service company’s may find it difficult to sustain scale of investment in longer term R&D given the challenge of sustaining acceptable ROI
- Technology has made a major contribution within the oil and gas sector and there have been considerable successes in recent years
- Small companies (according to foresighting participants) are often regarded as the engine-house of innovation – ultimately becoming acquisition targets for the larger service companies
- Many smaller independents and NOCs have limited legacy of technology development capability and look to others to supply new capabilities
- Directionally there may be significant opportunity for ITI in addressing the gap between increasing technological challenge (of maintaining supply) and the decrease in R&D investment and the reducing time horizon of remaining R&D

However, technology commercialisation in O&G is problematic with many challenges and barriers to rapid adoption:

- Historic analysis of the time taken for new E&P to achieve significant market penetration clearly shows that the O&G sector lags well behind other industry sectors / industries
- Many involved in foresighting have expressed the view that there are a long list of “good technologies” which remain on the shelf due to risk aversion and other barriers to entry
- The key to successful commercialisation would appear to lie in achieving an adequate risk-reward profile for a given technology and ensuring that this profile is sufficiently well understood by key purchasers / decision makers

Most aspects of MOGA technology are relatively mature with major global companies holding strong positions. There is significant ongoing R&D. Therefore, any new R&D activities must be carefully considered in relation to the existing incumbents and ongoing activities, particularly:

- Consideration of the technical segmentation and technology value chain
- Awareness of ongoing or planned global technology initiatives
- Recognition of existing key research organisations – who might compete or collaborate with ITI Energy

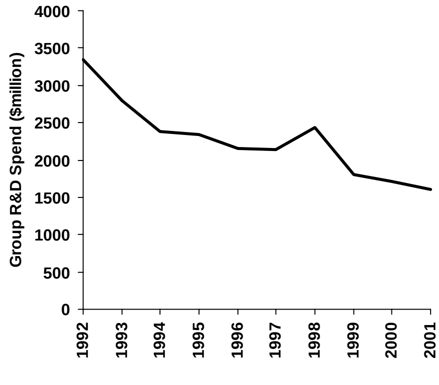
ITI Energy has adopted a systematic process to selecting areas for potential development, including:

- Application of a gate process and associated selection / prioritisation criteria
- Development of a "long-list" of technology opportunities
- Short-listing of 12 technology areas for further consideration

In summary, the MOGA market presents several opportunities for ITI Energy participation in technology development. However, the barriers to commercialisation and the existing competitive intensity are significant issues. The foresighting process to date has helped identify a group of technologies on which to initially focus, each of which appear to offer a combination of sizeable market opportunity and a degree of new territory where ITI Energy might make a material difference.

3.2 The Opportunity and the Challenge of MOGA Technology Development

The level of R&D investment by major oil companies has declined through the 1990's:



"R&D investment by major global oil companies has dropped 50% in the 1990's "
- Shell Tech Ventures

Figure 19 – Trend in Top 5 Oil Companies' R&D Expenditure (source:Charles River Associates)

As a result, many of the major oil companies have increasingly out-sourced technology development to 3rd parties, both service companies and universities / research institutes. However, service companies are also under pressure to cut costs and are therefore questioning whether their longer term R&D investments can achieve adequate returns.

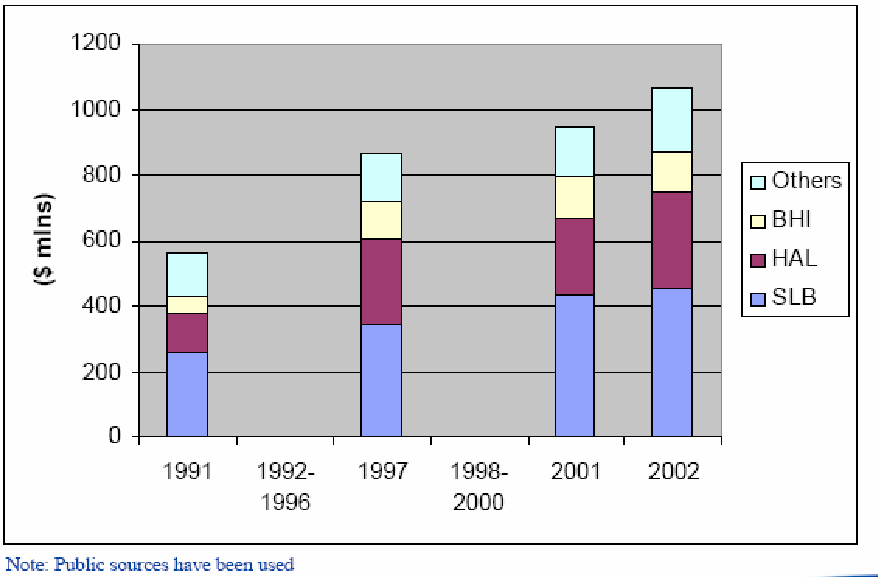


Figure 20 – Trend in Service Company R&D
(source:Shell)

In addition, there are many challenges associated with commercialising new E&P technology as Figure 21 illustrates.

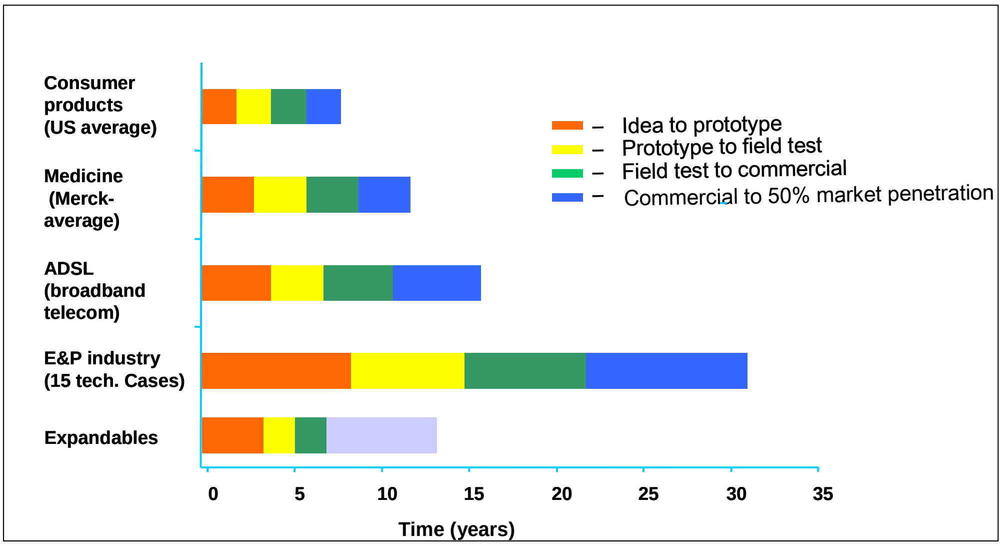


Figure 21 – Time to Market Comparators
(Source: McKinsey)

The above analysis uses the time for new technologies to achieve 50% market penetration (from the point of first conceptualising the idea) as a key indicator of an industry's pace of innovation. This analysis provides a stark contrast between oil and gas exploration and production and other sectors. On a sample of 30 E&P technologies, 50% penetration took ~30 years, compared to 7-15 for other sectors.

However, over the last 30 years in the North Sea, technology has undoubtedly contributed significantly to the industry's development. For example, the development and adoption of various innovations has enabled average oil recovery factors of 30% to 35% for some fields – as discussed in section 2.5 - to increase to between 50% and 60%. This increase has been attributed by some[14] to what may be called 'technology creep'.

New technology is not itself an instant panacea, however. For many years the case has been clearly made that whilst 'cutting edge' technology is considered by many to be a panacea for mature field development, it is the judicious use of old ('classical') and new technology which provides new life for old reservoirs, for 'the basics, as provided by classical technology, will always be important.'[15]

Smaller operators appear to have become very successful at identifying mature field technologies – such as sidetrack and infill drilling – to realise incremental value from assets that may have become stranded by the more traditional approach and techniques of the super-majors [16].

These smaller operators have also realised benefits from improved supply chain efficiencies and generally leaner operations, and it is not clear how much of their mature field successes can be attributed to technology alone.

It is clear however that the independent, smaller operators can in some cases be significant 'early adopters' of new technology. This has recently proven to be the case with a new proprietary seismic imaging technology, where many of the early adopters were independents[17]. However, many independents often describe their approach to new technologies as one of "fast followers".

Equally, SME's are often the source of new innovations, for example Shell Technology Ventures has developed a portfolio of investments which include a number of smaller companies leading development and delivery of innovative new technologies, as shown in Figure 22.

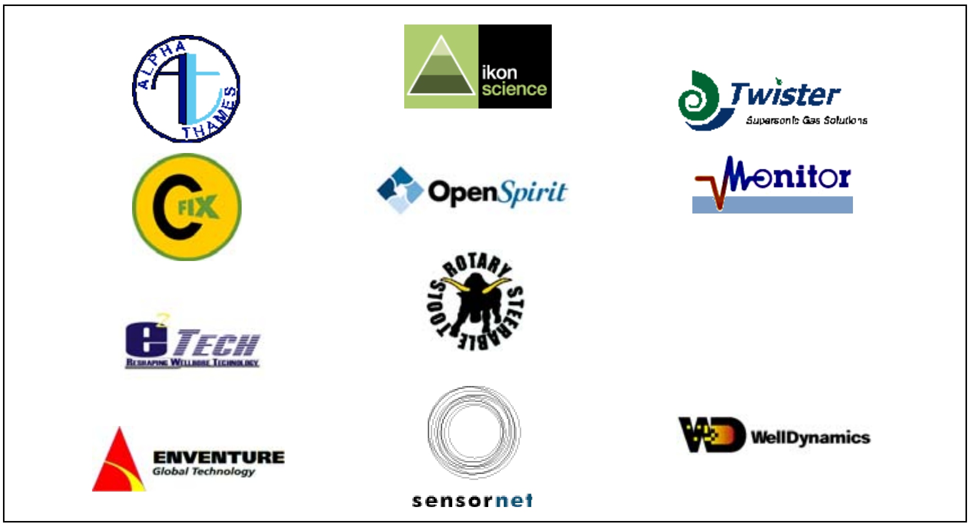


Figure 22 – Examples of Companies in Shells Technology Ventures' Portfolio

It appears, however, that many technologies cited (by participants in this study) as 'the future' for mature asset exploitation are already well proven and in many cases rigorously tested for their ability to either increase production or recoverable reserves. Case studies abound of the application of technologies – for example drilling technologies such as slim well technology, under-balanced drilling, casing drilling, through-tubing technology, multilaterals, extended reach drilling (ERD) and coiled tubing – which have already been successfully deployed on a number of live fields[18] and of their proven ability to 'add reserves' or accelerate production[19, 20]. It is clear that many drilling technologies relating to mature asset exploitation are driven by the need to introduce more wells in a field to access additional reserves, whilst constrained by well slots on a production platform[21]. Other advances such as 4D seismic, enhanced oil recovery techniques (EOR – such as steam assisted gravity drainage – SAGD), multiphase pumping and separation, sand control, and long-distance subsea tiebacks utilising technologies such as subsea multiphase metering and high-integrity pressure protection systems (HIPPS)[22, 23]. The emphasis in many of these references appears to be both the judicious application of technology and the need to push forward the boundaries of their application once proven (e.g. the limits of ERD).

Many leading practitioners in the industry cite technologies such as these as the way forward, when asked 'what breakthrough technologies are required to meet the business challenges of mature asset exploitation in 2014'. Since these technologies in many cases already exist, this calls into question whether the requirement lies more with technology adoption than with technology development, or whether there is a general lack of vision across the industry for what could be achieved through innovative technology.

Therefore ITI Energy - in identifying optimum technologies for investment - needs to consider:

- Are there opportunities to package existing components / capabilities into a more integrated product or service offering?
- Are there pieces of enabling technology which can significantly enhance the effectiveness of existing technologies or which can enable existing technologies to be more rapidly / effectively commercialised?
- Are there enabling technologies which cut across traditional boundaries of the energy sector (e.g. condition monitoring is an issue applicable to oil&gas, power generation and wind / marine energy) or cut across the energy sector and other industries (e.g. technologies to handle large volumes of data handling and analysis are relevant in oil & gas, power generation and the financial sector)?
- Can ITI Energy act as a catalyst to enable pursuit of more radical or step-out solutions?
- Where can new investment make a material difference – where are the opportunities for pursuing novel or niche developments not already saturated by competitive activity?

Technology has done a good job in maintaining production from mature assets but this has often been at the expense of accelerating production decline[24]. Overall there is an increasing shift to 'brownfield' or mature oil and gas assets exploitation, as described in Section 2, and this brings with it a new set of technical challenges and required solutions[25]. Specifically, there are four key business needs which MOGA technology must target:

- Increase or maintain production rates (nearer term priority, particularly given current oil prices)
- Increase recoverable reserves (the priority in the medium to longer term)
- Reduce or maintain Capital and Operating costs – particularly the latter
- Maintain or improves H, S&E performance whilst achieving cost objectives

3.3 MOGA Technical Segmentation

The MOGA market may be segmented into five main areas of activity, as shown in figure 23. These activities include reservoir description and dynamics, drilling and completions, facilities and construction, production and operations, and health, safety and environment.

Within each of these areas of activity, the figure shows the main systems or services required – and therefore gives an overview of the specific areas in which technology may be able to deliver an improvement or breakthrough. It should be noted that the systems and services within each area of activity are not strictly sequential, so care should be taken with the use of this figure.

Within the MOGA foresighting programme, three main technical segments have been used to provide focus – reservoir, drilling and wells, and facilities. The fit of the five areas of activity in the figure below, into these three segments, is broadly self-evident, however production and operations has been included within drilling and wells, whilst H,S&E has been included within all segments.

Reservoir description and dynamics	Drilling and completions	Facilities and construction	Production and operations	Health, safety and environment
Reservoir geology Reservoir geophysics Formation evaluation Fluids characterisation Recovery processes Enhanced oil recovery Reservoir simulation Reservoir monitoring	Drilling equipment Operational envir't Downhole operations Perforating Sand control Horizontal/ multilateral completions Permanent monitoring & intelligent completions Completion equipment	Control system Tree system Flow gathering system Pipeline system Riser system Surface platform Processing facilities Surface export system	Artificial lift Oilfield chemistry and corrosion Multiphase flow Well life cycle Production performance evaluation Production & injection systems Fracturing and acidizing Production enhancement	Environment Management Health Safety Partnership & communication Decommissioning & abandonment

Figure 23 – Technical segmentation of the upstream mature oil and gas sector (source: OTM/ SPE)

3.4 Technology Value Chain

As well as understanding the technical segmentation of the MOGA market, it is also important to understand the technology value chain, particularly in order to understand how technologies in which ITI Energy may invest may yield value. There was some discussion in earlier sections regarding the deployment of technology and specific blockers, and this is explored in more detail for specific technologies in section 4. Of particular relevance to ITI Energy is the way in which SMEs (small medium enterprises) can create value from new technologies. This is illustrated in Figure 24, which shows the interlinkages between technology users/ oil companies, systems integrators/ service companies, and technology suppliers/ SMEs. The connecting arrows show vital lines of communication, without which value cannot be delivered through the supply chain.

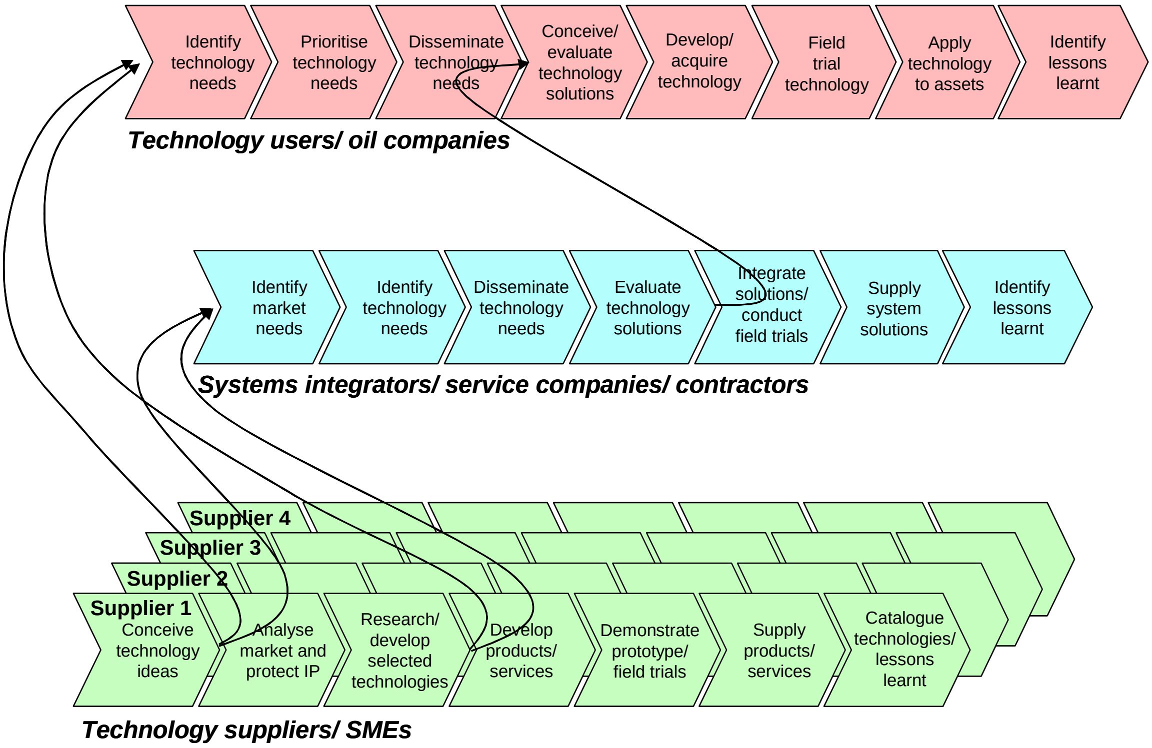


Figure 24 – The MOGA technology value chain (sources: DTI OGID, OTM)

Figure 24 shows the vital connection between operators, service companies and suppliers, and the feasibility of these connections have been analysed in the analysis of shortlisted technology opportunities in Section 4.

3.5 Global Technology Initiatives

A number of historic and ongoing R&D/ technology initiatives have been analysed through desk research, both to identify ongoing technology priorities and trends, and to ensure that ITI Energy does not end up duplicating existing industry efforts. The key initiatives analysed include:

- Oil and Gas Industry Task Force (OGITF[26]), UK, 1999
- Industry Technology Facilitator[27], Aberdeen, UK – several ongoing initiatives including ‘brownfield wells’ and ‘subsea tiebacks’
- Department of Trade and Industry Foresighting Initiative, UK, 1994-2004 - Energy and Marine panels [28]
- EPSRC (Engineering and Physical Sciences Research Council, UK) - Research Priorities and Opportunities[29]
- Scottish Enterprise Energy Group, Aberdeen, UK, 2001 - Technology needs of the Oil & Gas Sector[30]
- EUROGIF (European Oil and Gas Innovation Forum) – Thematic Networks[31], Technology Master Plan[32], 2002-2004
- European Union, DGXII/ DG XVII – analysis of programmes by SREA, 1999
- OG21[33] Task Force, Ministry of Petroleum and Energy (MPE), Norway, 2001-2004 - national technology strategy for value creation and enhanced competitiveness in the oil and gas industry[34]
- Demo 2000[35] initiative, Norway, 1997-2004 - 6th call for technology proposals
- Citigroup Smith Barney, USA, 2004 - annual survey of E&P spending trends[36]
- Research Council of Norway (NFR), Norway, 2001 - VERTEKS study[37] analysing R&D for value creation in the petroleum industry
- Schlumberger, Houston, USA, 2004 - ‘White Paper’ on Brownfields[38]
- Baker Hughes, Houston, USA, 2004 – ‘In Depth’ newsletter[39] on production optimisation theme
- DeepStar technology development programme, Houston, USA – technology priorities[40]
- Completion Engineering Association[41] (CEA), USA, 2003 - technology needs review
- SPE conferences and workshops worldwide, 1980-2004 [11,12,15,19-23,42,43]
- Journals, including Oil and Gas Journal, World Oil, World Energy, Business Briefing – E&P, Journal of Petroleum Technology (SPE), Drilling Contractor (IADC)

Two key points emerging from this analysis are the results of the pan-industry annual survey of E&P spending trends carried out by Citigroup Smith Barney, and a summary of key recurring technology needs across all the initiatives analysed.

Firstly, the most recent version of Citigroup Smith Barney's annual survey of E&P spending trends[42] showing technology trends was in Jan 2004, and included survey results from 224 oil companies around the world. This survey has been carried out since the 1980s, and the statistics in Table 3 show what percentage of respondents have nominated each of the technologies shown, when asked to identify the top 3 technologies/ trends impacting their spending levels.

Area of Innovation	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Seismic/ Computer Aided Exploration	72	75	67	64	58	74	71	76	67	57	75
Horizontal/ Directional Drilling	42	53	35	48	27	54	37	46	57	44	60
Drilling Technology-Other	2	11	5	10	17	29	41	40	46	55	58
Fracturing Technology	5	5	8	3	5	13	10	16	29	36	31
Completion/ Coiled Tubing	6	5	7	--	14	16	17	13	17	16	29
Subsea/ Floating Sys/ Deepwater	8	7	9	16	21	12	27	11	6	8	6
Federal Regulation	--	7	9	4	5	4	2	4	--	--	--
Steam Assist Gravity Drainage	1	2	8	6	5	1	--	--	--	2	--

Table 3 – Technologies having the most impact on E&P spending plans – all figures are percentages
(source: Citigroup Smith Barney)

The most significant rising trend here would appear to be the category 'drilling technology – other', which includes downhole tools, logging, drilling fluids, reservoir description / optimisation, and drill-bit technology.

Secondly, analysis of the desk research highlighted a number of common technology themes relevant to MOGA from ongoing initiatives, which include:

- Enhanced oil recovery (EOR)
- Improved imaging, including high-resolution seismic acquisition and visualisation
- Reservoir modelling
- New drilling concepts
- Infill drilling
- Chemical water shut-off
- Digital oilfield/ e-field – communication, automation, real time data, remote operations, 'smart reservoirs'
- Miniaturisation and nanotechnology
- More reliable downhole instrumentation
- Integrity/ reliability
- Low cost subsea tiebacks
- Multiphase flow/ flow assurance
- Produced water and sand management

3.6 Key Research Organisations

It is clear from the analysis of historic and ongoing initiatives that there are a number of key research organisations active in the MOGA technology area. Whilst this list is by no means exclusive, these include the organisations shown in table 4 (one for UK and one for worldwide), a number of whom were directly involved in workshops and interviews for this study. These organisations (amongst others) should be considered as a source of; innovative ideas, competing programs or projects and (potentially) contracted research.

Aberdeen University	UK
Cambridge University	UK
Cranfield University	UK
Edinburgh University	UK
Heriot-Watt University, Edinburgh	UK
Imperial College, London	UK
Qinetiq	UK
Robert Gordon University	UK
Strathclyde University	UK
TUV NEL	UK
Sintef	Norway
Rogaland Research	Norway
NTNU	Norway
IFP	France
TNO	Netherlands
CSIRO	Australia
SWRI (South West Research Institute)	USA
GPRI (Global Petroleum Research Institute)	USA
Texas A&M/Offshore Technology Research Centre (OTRC)	USA
Louisiana State University	USA
MIT	USA
Colorado School of Mines	USA
Gas Research Institute	USA

Table 4 – Key research organisations

3.7 ITI Energy Approach to Opportunity Identification & Prioritisation

Following the desk research and initial high level interviews, the study progressed to a structured process of engagement/ discussion with organisations in the MOGA market. This process is illustrated in Figure 25, and included workshops, and interviews. The next sections describe these activities in more detail.

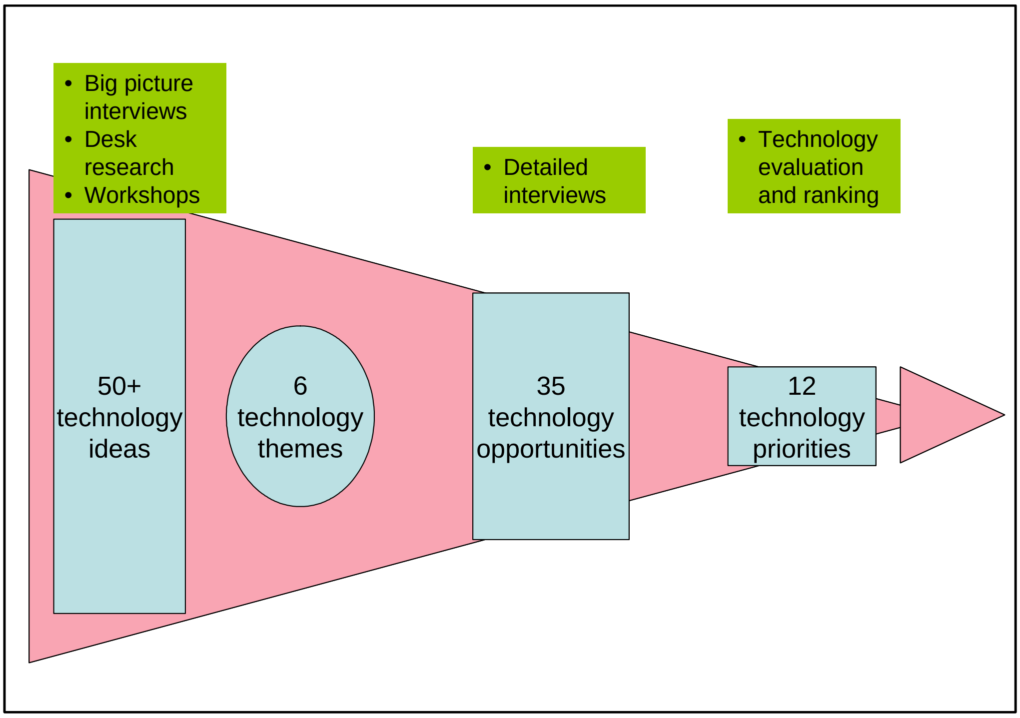


Figure 25 – Technology identification and screening process

For clarification, the 50+ "technology ideas" generated in the early phase of foresighting were very raw concepts or, in some instances, simply statements of a particular need. These were used as the raw material to develop the 35 more specifically defined technology opportunities which could be screened and prioritised. "Raw" output from the workshops is also accessible via the ITI Energy members web-site.

3.8 Key Technology Themes from Workshops

As described in Section 1.2 and summarised in Appendix 4, a large number of technology opportunity areas were identified by attendees at the 5 foresighting workshops. These were then clustered into the following technology themes, to enable further validation and investigation during the subsequent one-to-one interviews:

- Enhanced oil recovery
- In-well imaging

- Low-cost finders (both finder wells and other reservoir-invasive types of finders, such as nano-robotic sensors, homing microbes etc)
- Elimination of well casing
- Low-cost subsea tiebacks
- Corrosion management

3.9 Generating the Long-List of Potential Technology Opportunities

During the 35 interviews carried out after the workshops, the technology themes were investigated further, to identify specific technology opportunities, to identify additional technology opportunities which had not been surfaced earlier in the foresighting exercise, and to validate the overall direction of the foresighting. This process resulted in the identification of 34 specific technology opportunities, as described in Table 5 below.

Ref	Technology opportunity	Related theme
1	Microbial EOR	EOR/ IOR
2	CO2 EOR	EOR/ IOR
3	Flow diversion chemicals	EOR/ IOR
4	Miscible fluid chemicals	EOR/ IOR
5	Downhole gas compression	EOR/ IOR
6	Nano-robotic carriers	EOR/ IOR
7	In-place conversion into electricity	EOR/ IOR
8	In-place conversion into e.g. methane	EOR/ IOR
9	Non-seismic sensors	In-well imaging
10	Improved seismic sensors	In-well imaging
11	Sensor networks (e.g. X-well tomography)	In-well imaging
12	Reservoir modelling	In-well imaging
13	Data processing/ data mining	In-well imaging
14	Non-rotary drilling	Low-cost finders
15	One-trip casing drilling	Low-cost finders
16	Brilliant mole systems	Low-cost finders
17	Nano-robotic finders	Low-cost finders
18	Composite drilling/ casing fluid	Elimination of casing
19	Novel installation techniques	Low-cost tiebacks
20	Cold flow techniques	Low-cost tiebacks
21	AUVs	Low-cost tiebacks
22	Subsea processing	Low-cost tiebacks
23	Composite materials for linepipe	Low-cost tiebacks
24	Low-cost reliable pumps	Low-cost tiebacks
25	Plastic lining	Low-cost tiebacks
26	Subsea autonomous power	Low-cost tiebacks
27	Low-cost reliable multiphase flowmeters	Low-cost tiebacks
28	Carrier chemicals for ring main pipelines	Low-cost tiebacks
29	Wellbore monitoring and refurbishment	Corrosion management
30	Decommissioning and abandonment	Others

Ref	Technology opportunity	Related theme
31	Condition-based maintenance	Others
32	Produced water handling	Others
33	Digital oilfield	Others
34	Downhole sensor/ telemetry reliability	Others

Table 5 – Technology opportunities identified during interviews

3.10 Technology Evaluation and Ranking

These potential technology opportunities were then evaluated and ranked to produce a shortlist of 12. The prioritisation process used both a qualitative and semi-quantitative ranking using the following eight parameters: market size, market growth, compelling benefit, technical feasibility, technology ‘openness’, commercial feasibility, Scottish fit, and overall industry interest and desirability.

The definition of these parameters is shown in Table 6. The scoring was based on the cumulative results and findings from the desk research, workshops and interviews.

Parameter	Definition
Market size	High = largest market forecasts relative to other technologies assessed, low = smallest market forecasts
Market growth	Estimate of market growth (high = >10% per annum, low = GDP)
Compelling benefit	High = compelling benefit expressed by industry (e.g. 'gamechanger', 'huge potential' etc), low = interesting but not a must-have
Technical feasibility	High = widely accepted feasibility of making technical progress, low = doubts expressed about technical feasibility
Technology ”openness”	High = virgin territory and lots of space for new technology, low = lots of technologies already competing in this area
Commercial feasibility/ risk	High = minimal barriers to entry/ technology likely to be adopted/ supported by whole supply chain, low = operators express concerns re deployment/ service companies may resist implementation etc
Scottish suppliers/ universities	High = Scottish companies/ universities recognised/ regarded as internationally competitive in this area of technology
Overall industry interest/ desirability	High = interviewees and attendees clearly stated the importance of this technology as a ‘must have’, low = technology regarded as ‘nice to have’

Table 6 – Screening parameters used for technology ‘shortlisting’

This scoring identified 12 technology opportunities which were clearly ranked ‘ahead’ of the rest of the technology opportunities, as follows:

- Cold flow
- Non-conventional drilling
- Casing drilling/ slimhole drilling

- Improved resolution reservoir imaging
- Condition-based maintenance
- Downhole sensor/ telemetry reliability
- Microbial EOR
- Advanced reservoir chemicals
- Reservoir modelling
- Digital oilfield
- Nanotechnology
- Produced water handling

These opportunities are described and discussed more fully in section 4.

4 TECHNOLOGY PRIORITIES

4.1 Overview

The 12 short-listed technology areas address five key operational priorities to differing degrees, as follows:

Technology priority	Increased recoverable reserves	Increased production rates	Reduced CAPEX	Reduced OPEX	Improved H,S&E
Cold flow	High	Low	High	Medium	High
Non-conventional drilling	High	Medium	Medium	Medium	Medium
Casing drilling/ slimhole drilling	High	High	High	Low	Medium
Improved resolution reservoir imaging	High	High	Low	Low	Low
Condition-based maintenance	Medium	High	Low	Medium	High
Downhole sensor/telemetry reliability	Medium	High	Low	Low	Low
Microbial EOR	High	High	Low	Low	Low
Advanced reservoir chemicals	High	High	Medium	Medium	Medium
Reservoir modelling	High	High	Low	Low	Low
Digital oilfield	High	High	Low	High	Medium
Nanotechnology	High	Low	Medium	Low	Medium
Produced water handling	Low	High	Medium	High	High

= High Impact = Medium Impact = Low Impact

Table 7 – Overview of 12 shortlisted technologies and related end-user business cases

As Table 7 illustrates, most of the prioritisation has focused on technologies with potential to increase recoverable reserves or increase production as these are areas which generally represent the highest "value-adding" opportunities. However, they are also, as a result, areas likely to have the highest amount of competitive activity. Hence, the foresighting has specifically attempted to identify critical issues or technology gaps which are not yet being addressed or novel approaches that are perhaps still too far from market for operators or service companies to vigorously pursue.

There are many potential approaches to tackling any one of the five key operational priorities highlighted above. The 12 short-listed technology areas on which ITI proposes to focus, have varying degrees of interdependence or inter-relatedness. The following diagram, Figure 26, illustrates how 10 of the 12 areas all relate to the key drivers of “increased recoverable reserves” and “increased production rates”.

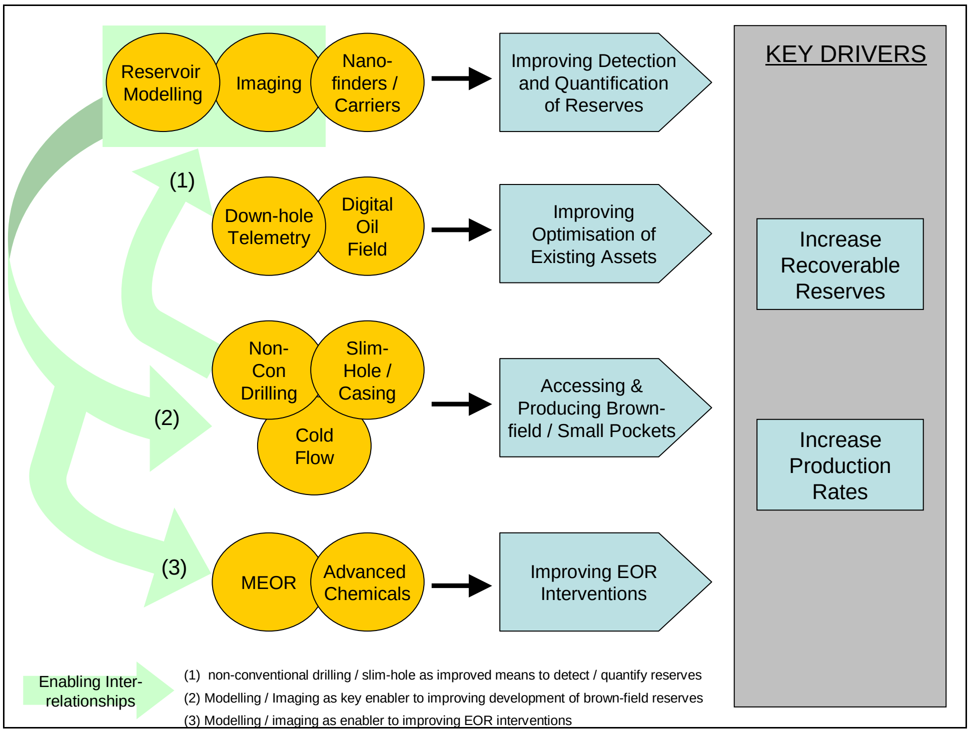


Figure 26 – Inter-dependence of short-listed technologies

Our selection and further exploration of these 12 areas reflects this set of inter-dependencies both in assessing key technology gaps and estimating the related scale of market opportunity each technology might represent.

In addition, ITI Energy’s foresighting activities look to identify enabling technologies which may be the key to unlocking value in a number of different applications – in oil and gas or across several segments of the energy market. Table 8 is a provisional assessment of enabling technology opportunities across the 12 technology areas. A similar “mapping” exercise will be conducted across the other foresighting themes – and this will be used to look for common or related opportunities. The colour coding in Table 8 is summarised below:

Technologies likely **critical** to enabling overall success	Technologies likely to **contribute** to overall success

For example, developments in the following enabling technologies are all potentially critical in achieving improved reservoir imaging; reservoir modelling, electromagnetic imaging, data modelling, advanced control and sensors/instrumentation.

ENABLING TECHNOLOGY	Improved resolution reservoir imaging	Microbial EOR (enhanced oil	Advanced reservoir chemicals	Condition-based maintenance	Digital oilfield	Non-conventional drilling	Produced water management	Cold flow	Nano Technology	Slimhole drilling / casing drilling	Reservoir modelling	Downhole sensor / telemetry
Specific:												
Reservoir injection / delivery systems												
Chemical formulation & testing												
Acoustic imaging												
Electromagnetic imaging												
Reservoir modelling												
Improved imaging/characterisation												
Enzyme formulation & testing	(1)											
Plasmas												
Mud Chemistry												
Optical Fibres												
Generic:												
Machinery												
Mechanical / structural												
Materials												
Data Modelling / Adv. Control												
Sensors / instrumentation												
Communications												
Filter / separator technologies												
Automation / robotics												
Electrical / power												
Miniturisation												
Nano technology	(1)											
Lasers	(2)											
AI / Learning Systems												
Molecular Biology												
Polymer (Reology) Properties												
Positioning of Fluids / Chemicals												
Process Engineering												
Standardisation / interfaces												
Microchips/switches/solid state physics												
Production / manufacturing												

Table 8 - Summary of enabling technologies

Notes:

(1) For example, enzyme's or nano devices acting as "tracers"

(2) For example, as a low cost, slim-hole "finder" well

The remainder of this section provides a more detailed summary of each of the 12 'short-listed' technology opportunities. Each of these summaries covers the following:

Introduction:
- Technology description
- Industry insights / requirements

Technology Assessment:
- Existing / previous R&D
- Technical development needs
- Technical feasibility
- Alternatives / substitutes

Market Assessment:
- Size of market
- Potential Growth Rate
- Barriers to Entry / commercialisation risks
- Compelling Benefit
- Routes to Market

IP Assessment
- Technology "openness"
- IP management feasibility

Strategic Fit:
- Potential economic benefit to Scotland
- Scottish suppliers / universities

These summaries include a number of parameters (as detailed in table 9 below) which are in addition to those used for short-listing (as described in Section 3).

Parameter	Definition
Alternatives/ substitutes	High = no/ few alternatives identified, low = many other emerging competing/ alternative technologies
IP management feasibility	High = IP can be generated and easily protected/ managed, low = segment already crowded by IP and any new IP may be hard to protect
Scale of economic benefit to Scotland	High = major economic impact on Scotland e.g. jobs/ new companies/ world-class cluster development, low = minimal impact on Scotland
Increased recover-able reserves	High = significant increase in recoverable reserves, low = no impact
Increased production rates	High = significant increase in production rates, low = no impact
Reduced CAPEX	High = greatly reduced CAPEX, low = no impact
Reduced OPEX	High = greatly reduced OPEX, low = no impact
Improved H,S&E	High = significant improvement in H,S&E, low = no impact

Table 9 – Additional parameters used for technology definition

4.2 Cold Flow

INTRODUCTION	
Technology description	COLD FLOW TECHNIQUES: Progress is being made towards significantly improving the understanding of mechanisms which result in the formation of hydrates and waxes. At the same time, and to some extent due to this improved understanding, it is possible to improve the efficiency of low dose 'kinetic' chemicals to manage transport, either through acting as inhibitors, or through management of the solids created in the process. Other 'cold flow' technologies may be mechanical rather than chemically-based, with solutions such as specialist pigs/ macerators, or continuous circulation of materials likely to be disruptive to hydrate/ wax formation (e.g. gravel). Benefits arise from greatly simplifying pipelines (e.g. reduction/ removal of thermal insulation). Within this technology area ITI Energy could identify platforms, i.e. analytical tools and modelling to be able to manage on a bespoke basis problem products, through to identifying/ developing groups of new chemicals for inhibition or control, or mechanical systems.
Industry insights/ requirements (gleaned during foresighting exercise)	Mechanical systems would avoid cost of chemicals but CAPEX and OPEX not well known. Internal pipe coatings may also have role to play. A much better understanding is now being obtained of chemical processes which cause hydrate formation and wax formation. In case of hydrates the thermodynamic approach of changing the phase diagram by injection of high volumes of chemicals can now be replaced by low dose kinetic chemicals (or in the case of the Sintef/ BP Cold Flow program, without use of chemical additves at all), which attack the problem chemically. This approach is apparently new so there is good potential. Over and above cost reduction from using un-insulated lines there is potential to share lines if a ring main picking up output from several small prospects could be established. Ring main allows potential for pigging. Significant commercial factors to overcome but potentially large cost savings. There is a well established program at Sintef in Norway (run in collaboration with BP) with one view being that UK would be starting five years behind the position achieved on that project, and should look for alternative technologies to that being pursued by Sintef. There appears good scope for an alternate technology to Sintef's.

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	Advantica – long standing R&D focused on the chemistry of hydrate formation and mitigation SINTEF / BP - Cold Flow project IFE / Scandpower Petroleum Technology - Horizon, the solution to long distance transport of well-stream fluids NTNU / Aker Engineering / Operators - Natural gas hydrate slurry process The University of Tulsa's Hydrate Flow Performance Loop Facility / BP / BHP / Champion Technologies / Marathon / MMS - hydrate flow performance in deep waters DeepStar - Hydrate Performance Flow loop - Cold Flow Program

Technical development needs	Most likely to be in the area of understanding chemical processes causing the problem, then the development of chemicals, and development of low cost means of producing chemicals. Mechanical solutions are emerging (e.g. Pigasys) and scope exists for fresh innovation here.
Technical feasibility	Estimated to be high for identifying mechanisms and appropriate chemicals. Challenges around cost of production and possibly environmental issue
Alternatives/ substitutes	Low cost insulation or heating of lines, but unlikely for small accumulations due to costs. Similarly mechanical methods at the well head but these involve potentially costly intervention.

MARKET ASSESSMENT	
Size of the market	Operators think ~ 1% of operational budget expended on flow assurance issues. World offshore oil & gas expenditure is ~ $90 billion in 2004, of which OPEX is 44%. So flow assurance could be a $0.4 billion market. CAPEX - Estimated CAPEX on facilities is ~$10 billion in 2004, so a 10% impact would suggest a market of $1 billion. Cold flow technologies could therefore have an offshore industry 'market' value of $1.4 billion. This accords well with a recent industry study of the US oilfield chemicals market (ref Freedonia Group), which suggests a market for flow assurance chemicals of ~$0.4-0.6 bn/ annum in 2007.
Potential growth rate	Medium. Flow assurance is a mature, well-established market segment, but growth is likely to occur from the opportunities to reduce pipeline CAPEX.
Barriers to entry/ commercial risks	There seem to be no significant barriers beyond usual first mover issue. If a field development is dependant on performance of a new chemical to inhibit hydrate or wax there will be risk for first mover unless new chemical can be trialled on an existing development which again may mean CAPEX issues. May be difficult to develop genuinely original ideas or approaches.
Compelling benefit	Significantly reduced CAPEX, and OPEX, and potential for developing stranded fields. Ultimately very significant impact if it allows much longer tiebacks, possibly to the beach
Routes to market	Some basic research around chemical processes and identifying inhibiting low dose kinetic chemicals. Involvement of one or more chemical producers and engagement with one or more oil companies, with existing fields where new chemicals could be trialled, or with adjacent undeveloped fields as potential for cluster development (e.g. North Sea ETAP). Consider links with Subsea UK.

IP ASSESSMENT	
Technology "openess"	Subject of active research by Sintef for example but, distinctly different approach proposed at least by Heriot Watt. Not many researchers/ technologies active in this area currently.
IP management feasibility	Probably moderate given level of activity at present. May be higher if comments by some UK researchers can be confirmed

STRATEGIC FIT	
Scale of econ benefit to Scotland	Direct benefit likely to be to chemicals companies (Scottish capability in chemicals production not known but Scottish Chemical Industries is one such company), with follow on and ultimately significant benefits to Scottish based subsea marine construction companies through increased tieback construction when the technology is applied
Scottish suppliers/ universities	Heriot-Watt substantial expertise and capability. HW currently partner with Warwick University on this subject. Also capability at Cambridge University. Scottish Chemical Industries Ltd. A strong Scottish capability also exists in mechanical solutions to cold flow, such as Pact Engineering's development of the Pigasys contra-flow pig with Aberdeen and Edinburgh Universities.
What can ITI bring to the table?	Funds and contacts and introductions
Funding scale requirements	Heriot Watt advise that \$200-300k programme could identify new approach and capture IP. However, project funding levels are likely to be generally in the range \$500-800k.

END-USER BUSINESS CASE		
Increased recoverable reserves	High. Can play a major role in reducing cost of subsea tiebacks, enabling many small pools of reserves close to existing infrastructure to be developed. UKOOA report is quoted as showing 135 incremental reserves (reachable from existing facilities) available in the North Sea alone and a further 200 potential new developments	
Increased production rates	Low. Small contribution	
Reduced CAPEX	High. Goal is a large cost reduction for pipelines through not requiring insulation, and ultimately, possible sharing of upstream lines via development of clusters	
Reduced OPEX	Medium. OPEX should be reduced via removal of need for bulk 'thermodynamic' chemicals such as methanol and glycol and use of low dose 'kinetic' chemicals	
Improved H,S&E	High. Potentially easier and marginally safer construction of pipelines. Environmental effect of chemicals will need to be considered	

4.3 Non-Conventional Drilling

INTRODUCTION	
Technology description	NON CONVENTIONAL DRILLING (This includes Non Rotary Drilling and Enhanced Resonant Drilling). Alternative techniques to rotary drilling, and techniques to radically enhance conventional rotary drilling have been studied by a number of universities and research institutes. Techniques have included enhanced resonant (sonic) drilling for enhancing conventional drilling, and non rotary techniques in addition to coiled tubing drilling have included plasma drilling, electrical discharge and lasers. The area of application is not necessarily as a replacement for drilling main sections of wells but as methods e.g. for simplifying sidetracks, or significantly increasing the distance that can be reached by multilaterals. There are proposals from various organisations to move some of these technologies forward. Within this area there is scope for supporting individual technologies but probably also for creating some synergies combining certain approaches.
Industry insights/ requirements (gleaned during foresighting exercise)	Potential "game-changing" technology area. Check out Strathclyde University plasma drilling. Can be used in thru-tubing mode so very attractive for sidetracks (currently e.g. $4 mn each) Sounds fantastic, step on the road to brilliant moles as well Challenges of steerability and position-sensing. Sounds like a good idea. Plasma drilling/ laser drilling for sidetracks/ infill drilling etc are a sensible step towards more ambitious goal to have a more realistic chance of reaching useful targets Lots of good proposals via OG21 in Norway (e.g. Badger) Interfaces with MWD (measurement while drilling) and LWD (logging while drilling) also need to be included within scope

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	Strathclyde University - Plasma channel drilling Aberdeen University - Enhanced resonant drilling Laser drilling - Los Alamos Laboratory Laser drilling - Gas Technology Institute, Colorado School of Mines, US DoE, Halliburton - plus acquisition of military/ NASA laser patents from Boeing Rogaland Research - Badger
Technical development needs	For enhanced resonant drilling includes: building and proving of larger scale systems and on to full scale, plus industrialisation of current lab based systems. For plasma channel drilling includes: field trials, industrialisation of lab based equipment, development of a method of, and systems for, delivery and operations - probably a modified modular rig
Technical feasibility	Scale models have been shown to operate successfully and in some cases theoretical rock mechanic models have been developed that explain the processes. Good feasibility of at least increasing scale of models.
Alternatives/ substitutes	Conventional rotary drilling advances, although unlikely to be an alternative to enhanced resonant drilling. Coiled tubing advances

MARKET ASSESSMENT	
Size of the market	Over the last five years 15,531 new wells were drilled offshore. 70% were development wells of which 10% were close to horizontal and less than 1% were slimholes and multilaterals – a total of 1,762 wells; Assuming 600 wells per year at an average offshore well cost of $12 million, this totals $7.2 billion. Assuming that 'non-conventional drilling' could capture 20%, a potential of $1.4 billion is suggested.
Potential growth rate	Medium. There is great potential for growth in this area, but there is also an initial requirement to build credibility and confidence in using an entirely different approach to drilling.
Barriers to entry/ commercial risks	Resistance from established drilling contractors. Reluctance of operators to be first-adopters
Compelling benefit	Versatility of use (e.g. in thru-tubing mode) and cost-effectiveness (could be deployed from very simple rig) make this a gamechanger
Routes to market	Apparent clear need for delivery via a well services company, or drilling contractor, but not necessarily needing to be a huge one and not one that necessarily is rig owner

IP ASSESSMENT	
Technology "openess"/ crowding	Few, if any competing technologies at present
IP management feasibility	High - based on complex hardware and physics-derived know-how, and in some situations university based

STRATEGIC FIT	
Scale of econ benefit to Scotland	Potentially high - niche spin-out company/s could be formed to work in alliance with larger service companies. Drilling is a large and global market, and there is potential beyond oil and gas
Scottish suppliers/ universities	Strathclyde University programme, Aberdeen University programme Abbot Group/ KCA Deutag is a major international drilling contractor Industrialized mechanical and power equipment could be manufactured in Scotland
What can ITI bring to the table?	Funds and contacts Given nature of drilling industry would be important to have a drilling industry partner involved from the beginning
Funding scale requirements	First step would be to review all previously researched systems. Proposals for enhanced resonant drilling and plasma channel drilling from respective universities are for circa $600-800k over three years but this is based on university-pace development using PhD students. A faster approach would probably be appropriate. Ultimately, full scale prototype equipment would require a guesstimated $4-6 million

END-USER BUSINESS CASE		
Increased recoverable reserves	High. Lower-cost development of other reservoir zones etc	
Increased production rates	Medium. Potentially significant if drilling more and or longer reach multilaterals is achieved.	
Reduced CAPEX	Medium. Yes if ERD successful arising from single trip drilling and faster drilling	
Reduced OPEX	Medium. Potentially strong impact on drilling costs, for example for sidetracks	
Improved H,S&E	Medium. Potentially less rotating equipment, and potential for reduced loads, pressures and mud flows, with overall small reduction in HS&E risk. Also less tripping therefore less making and breaking connections - reduced human interaction	

4.4 Casing Drilling/ Slimhole Drilling

INTRODUCTION	
Technology description	CASING DRILLING/ SLIMHOLE DRILLING: Casing drilling provides a means of drilling with reduced materials, reduced tripping time and the ability to reduce circulation losses in pressure depleted zones. The latter problem is particularly appropriate to mature reservoirs. Application has primarily been onshore. Progress is required to make the technique more widely applicable and to realise its wider benefits (i.e. not just in pressure depleted zones) particularly offshore and in situations where higher angle deviations are appropriate. There is the potential to combine the technologies of under-balanced drilling with casing drilling which would have the overall effect of reducing costs and increasing value. The challenges and rewards are considerable. Ultimately this could prove to be an area which may be difficult for ITI Energy to have an impact because of the size of investment required. Slimhole drilling technologies are at an earlier stage of development with possibly greater potential for ITI and Scottish-based industry involvement. This has been the subject of previous UK JIPs for example and there is scope for building on this.
Industry insights/ requirements (gleaned during foresighting exercise)	Primary exponents of casing drilling (Tesco and Weatherford who offer distinctly different systems) claim widespread applications and cost savings, similarly with under-balanced drilling which proponents say can be used in conjunction with casing, adding increased value with decreased costs. Comments from operators and drilling companies include: Technology is still at an early stage and will need time to become widely applicable. At present it is cheaper to use conventional drilling over certain sections of the well. Casing drilling only applicable through unstable formations and in pressure depleted regions (although other operators challenge this and say that opportunities can be far more widespread) Future developments will be around improving techniques and know-how. Technology improvement most likely to be incremental. Significant cost required to modify drill rig before casing drilling or under-balanced drilling can be used. Slim hole drilling is at an earlier stage. Has the potential for universal application, 50% reduction in material costs required to build the well, and reduced rig time. Can be used (introduced to the industry as low risk route) as retrofit to existing wells allowing increased capacity wells.

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	Scottish company BBL developed much of the technology for casing drilling before it was sold to Weatherford. Scottish entrepreneur Bob Appleton sold his top drive design for casing drilling to Tesco A JIP developed a concept of slim hole drilling now owned by Scottish SME Caledus Ltd (which has VC funding from Lime Rock Partners) Novatek Inc, USA (http://www.novatekonline.com/ids.html)

Technical development needs	Incremental for casing drilling. For slim hole basic concept needs to be moved on from where left by JIP involving detailed design and development of new associated technologies
Technical feasibility	Feasibility of slim hole drilling is estimated to be at least moderate based on commitment by entrepreneurial team in establishing a start up company to take it forward and small venture capital input to date. If casing drilling does require only possibly incremental technologies then feasibility of these would be high.
Alternatives/ substitutes	Expandable casing drilling probably direct alternative, although ability of slim hole technology to use in retrofit operations is unique

MARKET ASSESSMENT	
Size of the market	Casing operations are estimated to average 13% of total offshore well costs as a function of the type of well. Global offshore drilling expenditure is estimated at $37 billion in 2004 giving a total casing services expenditure of $4.8 billion. Assuming a 30% cost reduction due to combined drilling/ casing a value of $1.4 billion is suggested. The market for slim hole drilling, if successful, is argued to be larger than for casing drilling due to its wider applicability and potential for retrofit operations
Potential growth rate	High, due to projected increases in drilling activity, and casing drilling is already becoming established in the market
Barriers to entry/ commercial risks	There would be high barrier to entry for ITI Energy into casing drilling and cost of modifying rigs is further barrier. For Slim hole drilling barrier will be acceptance by oil companies and possibly drilling contractors. Has the advantage over casing drilling and under balanced drilling of not needing modifications to drill rigs Casing drilling is largely in the hands of major service companies/ suppliers, so more difficult for SMEs to impact
Compelling benefit	Estimated to be high given the importance of reducing drilling costs Reducing well construction costs, particularly for in-fill drilling has huge potential. This can stimulate activity for wells searching for pockets of smaller recoverable reserves not economic at the investment case level at present. One supplier has noted: ‘Reduce the well cost, increase the productivity, and increase the net present value (npv) and mature province operators will invest in these assets’
Routes to market	In the case of casing drilling this requires steady progression and acceptance by the market and improvements in techniques and know-how. For slim hole drilling the path is further 'D', use in retrofit applications for diversion wells, and on to building complete new wells. Important element will be engagement of oil co and possibly drilling contractor from early stage

IP ASSESSMENT	
Technology “openess”/ crowding	Poor for casing drilling Potentially good for slim hole
IP management feasibility	IP from UK JIP on slim hole drilling now fully vested in a Scottish start up company (Caledus) who believe there are other associated technologies with IP potential

STRATEGIC FIT	
Scale of econ benefit to Scotland	Reducing cost of drilling will have high impact by increasing in fill and step out developments
Scottish suppliers/ universities	Abbot Group, Caledus
What can ITI bring to the table?	There are not many options around drilling although possible that slim hole developments may provide an area suitable for ITI support
Funding scale requirements	As focus is on development rather than research, the scales of funding required are likely to be relatively high

END-USER BUSINESS CASE		
Increased recoverable reserves	High. Cheaper drilling will encourage more development in MOGA areas	
Increased production rates	High, with applications in retrofit operations	
Reduced CAPEX	High. Claimed to be very significant. Slimmer well construction will reduce flat time, leading to faster construction, and perhaps lower generation rigs can do higher end wells, getting the lower cost fleet back into utilisation	
Reduced OPEX	Low. Not targeted in this area	
Improved H,S&E	Medium, via reduced rig time and less heavy equipment.	

4.5 Improved Resolution Reservoir Imaging

INTRODUCTION	
Technology description	IMPROVED RESERVOIR IMAGING: The potential for achieving higher resolution and shorter time base 4D reservoir imaging exists through both seismic and non seismic survey techniques. New systems for increasing the frequency of 4D seismic for better control of reservoir management, use of downhole seismic arrays for improved resolution, and better interpretation by filtering geotechnical stress from seismic signals can all be addressed to improve seismic surveying. Use of alternatives to seismic survey, such as gravity, electromagnetic resistance measurement, magnetic and nuclear sensors, working alone or in conjunction with seismic surveys also offers potential for improvement. This a large area with an anticipated large scope for innovation still, even in the seismic areas
Industry insights/ requirements (gleaned during foresighting exercise)	If more and better data is to be produced then better reservoir models are also needed to be able to use the data. There is beginning to be progress in electromagnetic survey as complement to seismic, with UK and Norwegian companies quoted as having systems at advanced stages. Resolution would ideally be to 5m, and if from wellbore should have a range of >1km from wellbore itself. A major step forward can be achieved if sensor capable of direct detection of hydrocarbon could be achieved - this is claimed to be the case for electromagnetic. Early work taking place on magnetic sensing systems for direct sensing of HCs Use of 4D concepts with in-well recording (seismic or alternative techniques) has great potential to produce better control of reservoir management. Key focus areas are improved resolution and repeatability: • Increase the frequency of 4D seismic by downhole seismic arrays for improved resolution and seabed source. (Note : Some of the major oil companies have been working this area for the last couple of years - downhole receivers and seabed arrays to monitor changes in fluid saturation within the reservoir) • Computation of additional data from gravity, electromagnetic resistance measurement, magnetic and nuclear sensors will increase resolution in subsurface modeling and decrease risk. Non unique however, so these techniques must be used in conjunction with seismic. Innovation is regarded as important. These techniques have existed for a long time. Breakthrough is possible with development in: • Processing and imaging of large data volumes quickly • Software development. eg Improvement of signal to noise ratio e.g. incorporation of Neural Network technology to detect and/or alert if any changes occur in the reservoir (ie fliud saturations). • Transmitters and receivers of different types. Size - slim hole designs? • Lower cost of high end equipment. We are seeing many advances and new equipment - not really being matched by reduction in costs for utilization. Should be a focus area

Industry insights/ requirements (gleaned during foresighting exercise *Contd./*	• Higher end computer for advanced modeling. Should be able to do everything at the wellsite. This was difficult to do before due to hardware limitations. Vision would be to undertake reservoir imaging real-time while drilling - leading to real-time update of reservoir models. • Reliability, particularly in high BHT situations Problems to be overcome include: • Model will be key. Non unicity of interpretation specially for non seismic methods. • Need to consider a range of projects with a range of feasibilities. • Range of reservoir types eg channel systems (rapid lateral facies changes), highly faulted reservoirs, layered reservoirs. Also, importantly - carbonates and fractured reservoirs, both of which are much more complex and predicability is very difficult. Development of carbonate reservoirs will become an increasingly important part of the global industry over the next few years. • Those techniques will improve resolution only in specific geological conditions – need to consider rock physics, sea bed conditions etc • It will be challenging to keep the overall cost down - we haven't yet seen evidence that costs are coming down • Tool maintenance issues Specialised and limited crews

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	DOE/ Paulsson Geophys. Services - Borehole seismic imaging of gas reservoirs Centre for Technical Geosciences - Electric and electromagnetic imaging, inversion and characterisation methods Earth Resources Laboratory - Improving the ability to estimate reservoir properties that impact production Colorado School of Mines -The Reservoir Characterisation Project (RCP) DOE / NETL - Advanced Diagnostics and Imaging Systems - tools and technologies that will provide higher resolution and more precise rock and fluid properties for reservoir targets in U.S. basins Berkeley National Laboratory - Identification, imaging and monitoring of fluid-saturated underground reservoirs Qinetiq, UK Offshore Hydrocarbon Mapping (OHM), Aberdeen, UK (electro-magnetic survey technology) Imperial College, London – Combined seismic/ in-well electro-kinetic sensors Edinburgh University, (Electro-magnetic imaging technology) Heriot-Watt University, Edinburgh Strathclyde (high resolution gravity analysis) ExxonMobil R&D - Downhole seismic arrays for improved resolution and seabed source (work ongoing for a couple of years) Foster Findlay Associates, Aberdeen/ Newcastle, UK

Technical development needs	This is a large subject area covering: transmitters and receivers of different types, and processing and imaging of data, and there will be significant areas for development. Examples would be: Heriot-Watt proposal for software development to filter geomechanical stress from seismic signals to remove a source of inaccuracy, Mecon's proposal for seabed seismic source for increased frequency and lower cost 4D seismic, various suggestions for system for acoustically 'listening' to the reservoir, Heriot Watt's magnetic survey tool which has just received 'proof of concept award' and would be a candidate as a complimentary survey tool with potential for direct detection of hydrocarbons
Technical feasibility	Will range from high to low depending on specific project identified, but reasonable to assume that there will be a range of projects with a range of feasibilities, and range of lead times for development. Would need to be assessed for fit with ITI
Alternatives/ substitutes	Will need to be assessed against selected projects

MARKET ASSESSMENT	
Size of the market	Major service company estimates that 4D and in-well seismic will have value of $450m per annum within 3-4 yrs, which is believed to be a conservative estimate.
Potential growth rate	High. As described below, improved resolution imaging is high on many operators' shopping lists, and this is likely to be a major area of attention and growth. Growth will be driven by the ability of improved imaging to provide higher confidence levels in reserves location and magnitude.
Barriers to entry/ commercial risks	Comments have been made that this is an area dominated by the major service companies and therefore would be difficult for ITI to enter. Other view is that it is a large area with large appetite from client base and niche opportunities will arise, together with possibilities in areas which the service companies may be missing or ignoring
Compelling benefit	Improved resolution imaging is close to the top of the 'most wanted' list of technologies for oil companies for both reservoir management and identification of increasingly small pools of oil. This is very important to MOGAs. Therefore compelling overall subject area with potential for finding compelling niches
Routes to market	Will depend on specific technology selected and predicted time scale for development. Given dominance of major service companies and ITI's financial capability, an ITI-led 'partnership' would have some advantages

IP ASSESSMENT	
Technology "openess"/ crowding	A large area in which there will always be space. Will need to review this when a specific project is identified
IP management feasibility	Within the sorts of project so far identified, there are likely to be projects that would fit ITI's criteria

STRATEGIC FIT	
Scale of econ benefit to Scotland	Estimated to be high. A number of SMEs are currently established in the closely related reservoir management area. The right technology would find a large market with potentially modest start up costs as would be the case for software or small tools (e.g. transmitters and sensors) technology
Scottish suppliers/ universities	A number of Scottish SME's are active in the area of reservoir management and in cutting-edge alternative techniques (e.g. OHM, see above). Heriot-Watt have specific proposals in this area and Aberdeen University has relevant expertise
What can ITI bring to the table?	Likely project selected in this area will be software or small scale hardware which is probably in ITI's comfort zone. The major contribution from ITI will be selection of a candidate technology and assisting in finding industrial partners at the appropriate stage and in appropriate proportion
Funding scale requirements	There would appear to be projects which can be considered currently at an early stage (e.g. Heriot-Watt's magnetic survey tool currently at Proof Of Concept Stage and proposals for improved 4D seismic systems) requiring initially relatively modest funding. A small supplier has a proposal for a system for allowing seabed mounting of both seismic sources as well as detectors and would allow for much reduced cost and shorter time lapse 4D seismic survey. An initial budget of $150k is sought which apparently would achieve new IP. Heriot Watt guesstimates circa $400-500k budget to explore magnetic sensors for interwell scale survey with objective of direct sensing of hydrocarbons

END-USER BUSINESS CASE		
Increased recoverable reserves	High. If improved resolution survey gives greater confidence to reservoir management issues, this will allow greater confidence in considering use of EOR techniques with consequent increased recoverable reserves. Additional reserves e.g. 'small pools' via improved resolution survey.	(green)
Increased production rates	High. Potentially significant through better reservoir management	(green)
Reduced CAPEX	Low. Increased CAPEX, but modest.	(red)
Reduced OPEX	Low. OPEX may increase due to increased survey activity - challenge is to provide improved resolution and at a lower cost	(red)
Improved H,S&E	Low. Limited positive impact, except if technologies provide improved early detection of gas pockets.	(red)

4.6 Condition-Based Maintenance

INTRODUCTION	
Technology description	CONDITION BASED MAINTENANCE: The combined issues of reliability/ uptime of equipment, corrosion management, and integrity monitoring which are all concerned with maximising uptime, reducing OPEX and life extension for physical assets, represent an important technology challenge. Improved integrity monitoring of platforms and major plant can benefit from advances in acoustic signal sensing and conditioning. Similarly advances in corrosion technology are believed to have more potential than is currently being employed in offshore oil and gas to extend life and reduce downtime. These and other technologies may be available to ITI Energy to further develop, and move forward to commercial products and services.
Industry insights/ requirements (gleaned during foresighting exercise)	Over and above extending life of facilities, improving the reliability of offshore mechanical plant from typically 85% would have a large impact on economics. Contrast is made with the aerospace industry and even refineries where reliability is close to 100%. For successful exploitation of all remaining assets in mature areas such as the North Sea, operating life will need to be doubled. This requires full understanding of life cycle management of all equipment and components involving high performance Maintenance Management System, Root Cause Analysis capability and integration with components supplier systems. There are opinions that there is a large gap between what is known by corrosion engineers and scientists and what is applied by the offshore industry with similar comments being made about the use of coatings. Application of known techniques to subsea facilities requires improved communication and power systems. Increasing HS&E regulation is helping to drive the market. Exploitation of existing technology is a big area of opportunity, what is done today is largely the same as was done 10-15 years ago and has not taken cogniscence of technological advances such as on-line systems

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	Robert Gordon University (RGU), Aberdeen, UK (Centre for Condition-Based Maintenance) EA Technology, Chester, UK TWI, UK Swansea University, UK South West Research Institute (SWRI), Texas, USA Aberdeen University, UK Southampton University (Institute of Sound and Vibration Research), UK University of Manchester, UK
Technical development needs	This is a wide subject area covering issues of corrosion and condition based monitoring/ maintenance both topside, subsea and downhole. Typical development proposals include: new and improved continuous monitoring systems for jacket structures, improved subsea communication systems to support subsea condition based monitoring, wireless based integrity monitoring equipment for topsides, subsea packages for

	integration with AUVs
Technical feasibility	Will range from high to low depending on specific projects identified but reasonable to assume that there will be a spread of potential projects with a range of feasibilities, and range of lead times for development
Alternatives/ substitutes	Will depend on the project selected

MARKET ASSESSMENT	
Size of the market	Estimated expenditure on maintenance of offshore installations totals $6.1 billion worldwide (excluding modifications & operational expenditure). Assuming that condition-based maintenance could take 10% of the sector, a market of $600 million/ annum would ensue. An established specialist company in the market gives the breakdown of the $6.1 bn as 25% admin and scheduling by operators, 15% integrity management, 48% maintenance operations, 12% integrity monitoring
Potential growth rate	High. As increasing numbers of fields and related facilities worldwide become mature, this market segment is well placed for ongoing growth. This driver is supported by the ongoing drive amongst operators for continuous improvements in uptime/ system availability, and reductions in OPEX.
Barriers to entry/ commercial risks	In the offshore oil and gas area this subject is not the domain of US based integrated service companies (ISCs) and is not as fully developed or as widely applied as some technologies. Depending on subject(s) chosen there should be only limited barriers to entry, and there does not appear to be strong defensive or predatory activity from the ISCs. As well as hardware/ software challenges, there are big barriers to realising the full benefits of CBM because of a lack of understanding, management, implementation etc. – the whole area of business processes. In particular, condition based maintenance technologies often require investment of money now to extend life or improve reliability later – any technology proposition will have to be sufficiently compelling to overcome this inherent barrier.
Compelling benefit	Possibly the most compelling from all short listed subjects, due to criticality of maintaining physical infrastructure in place in MOGA areas for as long as possible
Routes to market	Will vary depending on project selected. Some of those so far identified may leverage funds from large companies such as Wood Group, who in turn could help bring to market the technologies of smaller companies which fit as part of their overall remit

IP ASSESSMENT	
Technology “openess”/ crowding	Good prospect for identifying projects in this area with sufficient “openess”

IP management feasibility	Example projects so far identified in foresighting work (and not a complete list) have come from range of companies including small SME's where IP management would reasonably be expected to be manageable, through to partly developed technologies in larger (Scottish) companies where IP management would be more of an issue. Technologies span from niche hardware systems (e.g. monitoring systems) to software tools and processes for integrity management.

STRATEGIC FIT	
Scale of econ benefit to Scotland	This is significant on standalone basis, and particularly noting role of Scottish companies in platform maintenance, but there is multiplier effect as well in that the greater the life extension of facilities the greater the scope for infill drilling and tiebacks etc
Scottish suppliers/ universities	There is a large and well-established world-class cluster of Scottish companies in this segment, particularly around Aberdeen. Strathclyde, Aberdeen, RGU, and Northumbria Universities have capability. Scottish suppliers include iicorr, Clampon, Wood Group and AUV/ ROV developers. Also of note is the Centre for Condition-Based Maintenance at RGU which has recently established an Aberdeen-based industry forum focusing on this subject area. There is also cross-over with the sensor community as described in 'downhole sensors', which embraces another large and well-established cluster
What can ITI bring to the table?	Funds and introductions between companies. Nurture of Scottish cluster.
Funding scale requirements	As examples: An ongoing first phase (EU) project to develop low cost wireless systems for integrity monitoring on topsides has a budget of $3m over three years. Project to develop subsea systems and interface with AUVs to support subsea condition monitoring is guesstimated to be of the order of $5-6m. Proposal for developing a novel system for permanent condition monitoring of jacket structures has a first phase budget of $300k. Good prospect of establishing IP in the software for data analysis, and in hardware for monitoring.

END-USER BUSINESS CASE		
Increased recoverable reserves	Medium. The longer the life of physical infrastructure the more oil fields / pockets will be developed	
Increased production rates	High, due to increased uptime/ reliability of plant	
Reduced CAPEX	Low, small increase in CAPEX due to integrating more monitoring systems.	
Reduced OPEX	Medium. Increase in OPEX due to operating maintenance management systems, but will be more than offset by reduced costs from unplanned failures and breakdowns and increased production	
Improved H,S&E	High. Reduction in unplanned equipment failures potentially very significant for H,S&E. Indeed increasing H,S&E regulation is helping to drive the market for improved maintenance and condition monitoring	

4.7 Down-Hole Sensor/ Telemetry Reliability

INTRODUCTION	
Technology description	DOWNHOLE SENSOR / TELEMETRY RELIABILITY: The reliable permanent measurement of reservoir flow parameters downhole, including: pressure, temperature, flow velocity, has the potential to very significantly advance reservoir and production management. New ranges of optical sensors for both point, and distributed arrays within a well bore/ producing zone, and optical fibres for data transmission are currently providing main areas for development. Alternative technologies (ultra low frequency electromagnetic) using data transmission through the casing offer potentially more reliable systems but with a penalty in data transmission rates. In-well imaging using seismic and non-seismic sensors add further general demand in this subject area particularly with regard to reliability.
Industry insights/ requirements (gleaned during foresighting exercise)	If basic flow, pressure, and temperature data can be collected from several regions of a producing formation and can be used in conjunction with reservoir models there is scope for much improved reservoir management. For some operators there is a large question over reliability of both sensors and data transmission systems. Data transfer can be through fluid, tubing/ casing, optical fibres. Sensors able to listen to the formation are also expected to produce valuable data. Use of self-powered sensors and associated flow control, including artificial intelligence, with no downhole cables and 100% reliability Halliburton, Schlumberger, Weatherford (fibre optics) and Expro (electromagnetic) are typical companies now offering systems and services in this area For additional data to be gained from additional sensors and techniques it is essential to have a means of managing it and using it in models which give improvement to reservoir understanding and management While optical and electromagnetic data transmission systems are being developed the principal data transfer method is still cable

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	Sintef, Norway Surrey University, UK (plus spin-out company Polarmetrix) University of Barcelona (Intelligent Signal Processing Group), Spain Robert Gordon University (opto-electronics), Aberdeen, UK University of Strathclyde (physics), Glasgow, UK University of Glasgow, UK University of Southampton, UK Qinetiq, UK IFP, France Sensa (part of Schlumberger), UK Insensys, Southampton, UK Sensornet, London, UK

Technical development needs	Principal areas are: sensors, downhole autonomous power systems, and transmission systems. Re sensors there are improvements needed particularly regarding flow metering Re autonomous power systems, this is the area probably requiring most development Re transmission systems, probably only incremental steps for fibre optics. Need and scope for advances in electromagnetics is greater. Radio and acoustic systems have been tried but so far without success
Technical feasibility	The fact that development of downhole autonomous power systems is not progressing, after being established as a requirement for some time, is an indication of difficulty if not feasibility. If (and it is not necessarily the case) there was a common technology between autonomous downhole systems and autonomous subsea power systems for instruments and controls this may add to the feasibility of a program having a successful result. Some in the industry believe however that downhole is significantly different. Feasibility of new sensors is a separate issue. Possible to argue that it may be easier since in principle there is wider scope. The Heriot-Watt magnetic sensor currently at proof of concept stage is a case in point.
Alternatives/ substitutes	Power will continue to be supplied by batteries or hard wired from surface until autonomous downhole system is available. Again existing sensors will suffice while new systems are developed

MARKET ASSESSMENT	
Size of the market	Downhole sensor devices can be permanent and are applicable to high-cost wells. The highest cost wells are offshore where we expect 2,200 development wells (candidates for downhole sensors) to be drilled in 2004. At say $150,000 per well this would give a total opportunity of $330 million p.a. Subject to the appropriate technology sensors and transmission systems/methods, the technology could be fitted to existing wells with order of magnitude number being 100,000. If 10% of these were targeted this represents a further market of $1.5 bn. Some major service companies have identified this technology area within the foresighting program as a key market.
Potential growth rate	Medium. Enhanced downhole instrumentation presents great potential, especially in the digital oilfield arena, but the existing market – for example in intelligent wells – is not growing at originally-predicted levels. Some in the industry believe that with good investment the growth rate of this segment could be lifted to 'high'.
Barriers to entry/ commercial risks	A successfully developed technology/ device/system may need to be marketed and produced on a large scale to compete with major service companies who are also active in this area. However, small suppliers are also active in this market, but it should be noted that some successful ones have been acquired by big service companies (e.g. Sensa by Schlumberger). Sensornet has received investment from Shell Technology Ventures providing an additional vision of how technology may progress to market.
Compelling benefit	Compelling drive for the basic technology e.g. new data transmission system or autonomous power unit. Less clear for the incremental steps.

Routes to market	Since a Scottish company (Expro) is becoming established in this area first position would be to discuss with them. It would also be advantageous to discuss with industry networks of users and providers in this area such as IWIS (Intelligent Well Interface Standardisation group).

IP ASSESSMENT	
Technology "openess"/ crowding	Initial evidence is that this may be limited, but should be confirmed. Significantly less limited in area of autonomous power systems and sensors, or if new transmission methods such as acoustic or radio frequency were to be attempted
IP management feasibility	Probably good in areas of autonomous power systems.

STRATEGIC FIT	
Scale of econ benefit to Scotland	Technology represents a major step in management of mature oil and gas assets and therefore of benefit to North Sea
Scottish suppliers/ universities	Expro Group, Omega, Aker Kvaerner Oilfield Products (Aberdeen). Many of the Scottish Universities (see R&D section above)
What can ITI bring to the table?	As examples could support development of autonomous power system, flow sensor, or alternative acoustic or radio frequency transmission systems. Some service companies have suggested that autonomous power systems may be a good initial focus area.
Funding scale requirements	Estimated budget for developing an autonomous downhole power system is suggested as $1.5 mn. As an indication, the cost of developing ultra low frequency electromagnetic system (Expro) to date is circa $20 mn, which may be indicative of budget for alternative acoustic or radio frequency systems

END-USER BUSINESS CASE		
Increased recoverable reserves	Medium. Some impact, via improved reservoir management, but possibly only marginal if without introduction of EOR	
Increased production rates	High. This is where the main benefit form the technology arises	
Reduced CAPEX	Low. Will increase CAPEX but will provide extra revenue through higher production rates	
Reduced OPEX	Low. Probably small increase in OPEX	
Improved H,S&E	Low. No Impact	

4.8 Microbial EOR

INTRODUCTION	
Technology description	MICROBIAL EOR: The ability now exists in specialist companies to identify and engineer enzymes that will solve industrial process problems. Within the EOR process, enzymes can work either in a miscible function or in a function to reduce viscosity (or both). Complimentary to the identifying of the enzyme is the identification of appropriate bacteria for creation of enzymes, and or nutrient for helping sustain bacteria. Within this technology area, and possibly in combination with ITI Life Sciences, ITI Energy can explore platforms or individual technologies within the suite of enzyme/ bacteria/ nutrient 'products' using latest techniques, or refine techniques which specifically address the processes required for reducing viscosity and surface energy
Industry insights/ requirements (gleaned during foresighting exercise)	Early work saw field trials undertaken on Beatrice with some positive results and some negative. Overall ambiguous, and program was not continued Tertiary discovery has got stuck in its progress. Needs new technologies to better sweep the hydrocarbons as part of water flooding. Maybe stalling due to costs. Several oil companies regard this as 'very large potential and definitely the one to back'. Need to break down the long chain hydrocarbons and also precipitate out the sulphur without blocking reservoir, plus potentially generate CO2 to pressurise the reservoir. Could have more impact than horizontal wells.' Many regard the missing jigsaw piece as being a reservoir model that will clarify how to run and manage Microbial EOR operations. Well spacing for offshore wells is major issue in applying any form of EOR. In some cases nutrient enhanced bacteria used as blockers (rather than to reduce surface energy or viscosity) where the temperature change in non oil bearing regions causes intense 'blooming' of the bacteria, sufficient to block the formation. Some concerns regarding whether the bugs can be removed at the refining stage

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	Mississippi State University (A Valdie) / Hughes Eastern Corporation, USA (Field trial of selective plugging using indigenous micro-organisms) Exeter University, UK (apparently made large strides in developing solutions but could not establish a dialogue with the oil companies to take it forward) Concordia University, Montreal, Canada Reservoir Management Ltd, UK (JIP - Use of residual oil as nutrient for MEOR) Statoil, Norway (utilised MEOR on Norne development) Titan Oil Recovery, California, USA Commercial Microbiology, Aberdeen, UK NCIMB Ltd, Aberdeen, UK

Technical development needs	Current programs concentrate on developing and delivering selected nutrients in water flood operations, and use this route to increase microbial activity and the rate at which surface energy is broken down by the enzymes associated with bacteria. Progress has been made recently by Statoil although used an aerobic process. Since this process may be unsuitable for the lower grades of steel used in most facilities in the UK sector (because high O2 content causes corrosion) there is a need to identify anaerobic nutrients to achieve the same effect. An alternative approach is to concentrate first on the enzymes and their action rather than supplying nutrient to the bacteria since it is the enzyme which does the work of breaking down the long chain hydrocarbons. This starts at understanding how the enzyme works and then finding the most efficient enzyme. This would be a longer term program. Within this approach it is theoretically possible to find an enzyme that would ultimately produce hydrogen, although the means of delivering would also need to be developed - blue sky category For either approach there is also a need for suitable reservoir models for understanding and managing the Microbial EOR programs in any given reservoir. Without these the application of Microbial EOR will not gain momentum.
Technical feasibility	There will undoubtedly be progress in the near to medium term and hence progress is feasible. What is not so clear from information gained to date is the extent to which this will be based on new technology based solutions. UK based JIPs for example seem to simply mimic, or propose demonstration programs based on work done by Statoil around development of nutrients and understanding a little the process by which they work. The feasibility of a more fundamental approach described as "An alternative approach", which has the potential to be a game changing but longer term approach is more difficult to judge. More investigation is needed to make this judgement. ITI Life Sciences could assist.
Alternatives/ substitutes	Use of miscible chemicals is a substitute for part of what can potentially be achieved with Microbial EOR for lowering surface energy. Similarly other chemicals are proposed for providing "blocking" chemical to manage water based sweep operations. Based on industry comment these alternatives are not sufficient to stem interest in a major push for developing Microbial EOR

MARKET ASSESSMENT	
Size of the market	A recent industry study of the US oilfield chemicals market (ref Freedonia Group) estimates demand advancing 6.1%/ annum through 2007 to $4.2 bn/ annum, of which we estimate 2.5% may be attributed to the types of chemicals/ solutions used for MEOR. Scaling-up this US market (15% of global oil and gas production) gives a global market forecast of $0.7 bn/ annum.
Potential growth rate	Low. The uptake of microbial EOR is still uncertain so a conservative measure for growth is proposed.
Barriers to entry/ commercial risks	The technique is only minimally applied at present onshore and even less so offshore, and there are few players and little work in progress on the subject in the UK at least. Medium to high commercial risk in obtaining oil co take up based on past experience. May be improving with higher oil

	prices
Compelling benefit	The potential to improve recoveries by several percentage points is a highly compelling benefit. Successfully developed, could extend life of existing fields and improve economics of fields still to be developed.
Routes to market	Routes to market are likely to flow from initial research (R rather than D) projects, moving in to development/ testing work and subsequent field trials, unless specific new research can be identified (e.g. enzyme research) which can move more rapidly to development phase

IP ASSESSMENT	
Technology "openess"/ crowding	It seems possible that in the nutrient base approach that technology "openess" may be more limited although in the case of Statoil program this is based on use of aerobic processes, whereas it is argued (not completely persuasively apparently) that in the UK an anaerobic nutrient based development would need to be found which may open more space for IP. The alternative approach of concentrating development on the enzymes appears novel and hence more space would be expected
IP management feasibility	Statoil have established IP but are quoted as indicating a willingness to share subsequent IP if developed in joint programs. There is no known IP base for this work in the UK other than what may exist in Exeter University so ITI funded work may be starting from a zero base in establishing within UK and within approaches different to Statoil's. Overall management will be more difficult in nutrient-based programs but potentially better in principal, in enzyme based programs - if judged to be feasible

STRATEGIC FIT	
Scale of econ benefit to Scotland	In the short term possibly small. However based on the probable increasing attention to be given to this area (EOR in general) because of diminishing worldwide reserves and increasing oil prices the longer term benefits could be considerable if new IP can be established
Scottish suppliers/ universities	Some university capability identified in Scotland to date – for example, Aberdeen and Paisley University both have ongoing work in this or related areas. Aberdeen has also one spin-out company (Remedios) which focuses on bio-remediation technology, some aspects of which may relate to the challenge of MEOR. Is or has been a significant capability at Exeter University. Reservoir Management Ltd (RML) have an interest and enthusiasm in this area and are used by DTI in attempts to get programs launched. RML quote sources of expertise in Scotland and at least one company offering microbiological services (treatments) called Commercial Microbiology Ltd
What can ITI bring to the table?	In the UK there seems to be no 'standard bearer' for microbial EOR. DTI push quite hard on overall EOR/IOR but there is scope for an organisation to champion Microbial EOR in particular at least to the extent of catalysing the initiation of a planned program of work. At present there appears to be risk that nothing will happen with two failed JIP initiatives in the recent past being indicative of this. The most recent of these (submitted by RML to ITF) failed at the time for the want of one more participant to sign up.

	ITI could also bring some improved planning and focus to JIP proposals
Funding scale requirements	Recent JIPs have had first phase programs with estimates ranging between $400-600k although it is understood that in neither of these cases would new IP have been produced. Concordia University, Montreal advise regarding program based on first identifying appropriate enzymes that 'Basic analytical components and validation of candidate enzymes may be in the order of $350,000'

END-USER BUSINESS CASE		
Increased recoverable reserves	High. Increased recovery of reserves is the primary objective of MEOR	
Increased production rates	High. In most cases this would happen later in the life of the field	
Reduced CAPEX	Low. CAPEX could potentially increase if e.g. it became necessary to line pipe or replace tubing to deal with injecting aerobic solutions where O2 content results in corrosion	
Reduced OPEX	Low. OPEX would increase due to cost of procuring/ injecting solutions, but treatments would not be frequent	
Improved H,S&E	Low. No impact	

4.9 Advanced Reservoir Chemicals

INTRODUCTION	
Technology description	ADVANCED RESERVOIR CHEMICALS: This area includes both miscible fluids to reduce surface energy/ improve mobility of hydrocarbon particles, and flow diversion chemicals to improve water flood management and effectively shut-off produced water. The use of surfactants, either as liquids, or gases such as CO2 and hydrocarbon gas, to act as miscible fluids for reducing surface energy at pore scale to improve recovery is established. Barriers are cost of chemicals, particularly liquids, and availability of gases most particularly CO2. Technology opportunities could arise through more chemically efficient chemicals, or through reducing cost of chemicals which are generally oil based, as well as improved reservoir models in order to manage the application of miscible techniques. More efficient chemicals may be designed through improved analysis and understanding of the mechanism of surface energy reduction, and cost reduction may be achieved through alternative manufacturing processes involving microbial or nano techniques. Advances in flow diversion/ water shut-off chemicals are being made in improving conformance during water flood and in reducing produced water, by use of more advanced and in some cases intelligent fluids. Techniques such as those based on heat sensitive polymers and pressure sensitive foaming agents provide potential platforms for more developments, and chemicals using other mechanisms are being investigated. Because of the volumes involved cost is a primary issue and part of the technology opportunity will include development of technologies which allow cheaper bulk production of the appropriate chemicals, as well as the actual development of the required chemicals.
Industry insights/ requirements (gleaned during foresighting exercise)	There was a wave of technology developments in 70s/ 80s, which provided the chemicals still being used today. Research has slowed down considerably since then, partly due to concerns over cost. This is a readily deployable, low-capital-intensive “game-changer” needing a complete reassessment as there’s potentially lots of opportunity in this area. Many technologies out there but it takes years to get sufficient field trials to prove if they work or not. Trials are often 1 or 2 wells meaning that promising technology is often dropped before it can get a proper chance. Candidate wells need to be decent wells i.e. something less than 95% water cut before considering it a candidate. Cost of manufacturing small batches of chemicals is also high which has to be recouped. Because there are few trials the cost needs to recouped in the first few tests and therefore it becomes expensive. Commitment to larger numbers of wells would result in lower costs. New generation of flow-improving technology needed to increase recoverable reserves by 10% at <$2/bbl (i.e. lower cost) and ultimately reduce the cost of water handling to zero. Also need to solve current perceived 'problems' relating to where to inject, how to shut-off fluid paths that do not contribute to sweep, and better understanding of processes involved. This responds to current concerns regarding possible damage to formation/ reservoir structure, and potential 'lost' production. Ideas cited for technology opportunities include:

Industry insights/ requirements (gleaned during foresighting exercise) *Contd./*	Smart fluids Use of nanotechnology - in chemicals production and in chemicals themselves Conversion of in-situ fluids to fluids you need/ want There is probably scope for technology transfer from other sectors, such as blood thinning technologies. This illustrates good synergy with ITI Life Sciences.

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	Nalco/ ExxonMobil/ BP (Brightwater programme - see SPE paper 89391) Heriot-Watt University, UK ICI, UK Delft University of Technology (Dietz Lab), Netherlands Petroleum Technology Research Centre, Regina, Saskatchewan, Canada University of Texas at Austin, USA (pH triggered gels for water shut-off and conformance control) New Mexico Tech (Petroleum Recovery Research Centre), USA Cleansorb, Guildford, UK WaterWeb – new relative permeability modifier (RPM) Thermatek (Licensed by Halliburton not owned) - Annular seal Rogland Research, Norway - RPM – Polymer/ oil emulsion Downhole water separation
Technical development needs	Firstly, a new generation of flow-improving chemical technology to increase recoverable reserves by 10% at <$2/bbl (i.e. lower cost) and ultimately reduce the cost of water handling to zero Secondly, improved modelling and analysis processes
Technical feasibility	Medium. Technical feasibility of use of chemicals for flow-improvement and water shut-off is already well proven. However, it is difficult to gauge the feasibility of the required 'new generation' of chemicals.
Alternatives/ substitutes	Other forms of EOR (e.g. thermal, microbial), other approaches to improved recovery such as artificial lift (downhole pumping etc), acceptance of status quo due to uncertainties about impact on reservoir

MARKET ASSESSMENT	
Size of the market	A recent industry study of the US oilfield chemicals market (ref Freedonia Group) estimates demand advancing 6.1%/ annum through 2007 to $4.2 bn/ annum, of which 15% may be attributed to the types of chemicals described in this summary. Scaling-up this US market (15% of global oil and gas production) gives a global market forecast of $4.2 bn/annum.
Potential growth rate	Medium. In mature assets, declining reserves and production coupled to the drive to increase recovery of what hydrocarbons remain in place, will provide an increasing incentive to use chemical EOR techniques, manage waterflood more effectively, and limit water production. This is also supported by ongoing Government determination to increase use of this technology in, for example, the USA and Europe.
Barriers to entry/ commercial risks	Market blockers include potential/ perceived production losses, uncertainty regarding what will actually happen. Concerns exist amongst a number of operators regarding possible damage to formation/ reservoir structure, and potential 'lost' production, and the complexity of modelling and knowing what's going on in the reservoir. In addition, the benefits from the use of chemicals for improving mobility of hydrocarbon particles are often longer-term, and the current short-termist culture mitigates against this.
Compelling benefit	Cited by many of those consulted as a readily deployable, low-capital-intensive gamechanger, where minimal R&D has been carried out since 70s/80s
Routes to market	The required 'new generation' of chemical technology would suggest the need for new research (R rather than D), which would be followed by small scale tests and eventual field tests, perhaps over a 5-6 year period. Improved modelling and analysis processes will be quicker to market

IP ASSESSMENT	
Technology “openess”/ crowding	Good. Minimal R&D carried out since 70s/80s, and few players in this market, but dominated by major service companies.
IP management feasibility	High. New chemical technology IP will be straightforward to protect and manage, whilst modelling and analysis processes will be harder to protect.

STRATEGIC FIT	
Scale of econ benefit to Scotland	High. There are few companies active in this market segment in Scotland, and therefore there are good opportunities for growth. Economic development prospects from manufacturing and associated technical development/ support are high.
Scottish suppliers/ universities	Low. The main suppliers of reservoir chemicals currently include Aqueolic (Canada), BJ Services (USA), Clariant (Switzerland/ UK), Halliburton (USA), Schlumberger (France/ USA), Tiorco (USA), ExxonNalco (USA). There does not appear to be a strong technology base in Scotland in this technology area, with the exception of Heriot-Watt University, Reservoir Management Ltd (RML - Consultants), and active Aberdeen-based branches of foreign-owned companies (especially Clariant and Halliburton).

What can ITI bring to the table?	Stimulation of technology transfer from other sectors, particularly life sciences (synergy with ITI Life Sciences).
Funding scale requirements	Medium. Several previous and proposed JIPs have budgets in the range $500-800 k.

END-USER BUSINESS CASE		
Increased recoverable reserves	High. A key use of chemicals in the reservoir is for EOR.	● (green)
Increased production rates	High. 'Release' of residual reserves, coupled to reduction in produced water will increase hydrocarbon rates.	● (green)
Reduced CAPEX	Medium. Effective water shut-off in the reservoir will remove the need for significant separation and water handling facilities at the surface.	● (amber)
Reduced OPEX	Medium. Effective use of chemicals will reduce produced water handling costs, but the chemicals themselves are currently regarded as expensive.	● (amber)
Improved H,S&E	Medium. Water shut-off will reduce environmental impact.	● (amber)

4.10 Reservoir Modelling

INTRODUCTION	
Technology description	RESERVOIR MODELS AS MANAGEMENT TOOLS: In order to benefit from the capabilities of such technologies as: EOR, improved understanding of water flooding, sand control etc there is need for improved understanding of the reservoir, in order that these technologies can be applied with more confidence in what they will achieve. New holistic reservoir models will focus on being management tools rather than pure geophysical reservoir interpretations which are then subsequently adapted. Models will be based on a combination of basic physics, and to some extent be phenomenological or empirically based parameters. A "workbench" or suite of models which are adaptable are needed for management of different reservoir management processes (e.g. EOR, sand control, water flood). Such models will also be needed to use most effectively the increasing volumes of data currently being generated but not always used.
Industry insights/ requirements (gleaned during foresighting exercise)	Reservoir models to date have concentrated on exact geological interpretations of the reservoir with obtained data being used to validate the model for the models sake. Industry needs models as management tools. The three aspects, data, model, and management decisions need to be treated holistically to provide models that are useful in reservoir management and management decision making. We need a modelling tool that is easily adaptable and more user friendly, with an ongoing incentive for the supplier to improve the product on a continuous basis.

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	RF-Petroleum - Reservoir characterisation and steering University of Calgary, Canada Heriot-Watt University, Edinburgh, UK Imperial College, London, UK ExxonMobil, USA (new release - 'Empower') Schlumberger (GeoQuest)/ ChevronTexaco, USA AEA Winfrith, UK (which became ECL and is now owned by Reslab)
Technical development needs	Model would build from basic physics and incorporate statistical methods, process engineering, chemical engineering and worked as a multi-discipline project. There needs to be link with oil companies to understand the nature of the required management decisions and input of real data sets, and software company/s for interfaces (input/output, data management, and imaging)
Technical feasibility	Feasibility estimated to be moderate to high
Alternatives/ substitutes	Alternatives are management models already offered by major service companies and the improvements doubtless being made on these.

MARKET ASSESSMENT	
Size of the market	All fields today have models to assist in reservoir management. The cost to populate and initially set up a model with data specific to a field may be of the order of $300-500k. Annual costs for operations could reasonably be $2mn per year if the model is proving beneficial in reservoir management issues e.g., water floods, EOR, sand control, management of smart wells etc. Hence represents an annual market of $0.5-1 bn and possibly beyond.
Potential growth rate	Medium, supported by digital oilfield initiatives.
Barriers to entry/ commercial risks	There is a view that this is a novel approach, and could provide some advantages over traditional approaches, however it is currently very much the domain of the major service companies who in the past have acquired SMEs who develop reservoir management tools/ expertise, and who are believed to keep a "close and jealous eye" on developments. Hence barrier/ commercial risk which could possibly be managed by engaging with one of them.
Compelling benefit	General acknowledgement that good models which can accept appropriate data and be an aid to management decision-making are lacking. Will probably be important and possibly even essential for improvement in this area for take up of tertiary recovery techniques
Routes to market	As noted above, a combined team of mathematicians/ geophysical modellers, plus oil company, software company, and possibly also engagement with a company such as Landmark or Schlumberger

IP ASSESSMENT	
Technology “openess”/ crowding	Believed to be a new approach therefore some space
IP management feasibility	Again believed to be a new approach thus far only about in research institutions and universities (though wider check would be appropriate). Would indicate good potential for IP management with source being in areas such as database design, algorithms, imaging etc

STRATEGIC FIT	
Scale of econ benefit to Scotland	As primarily software, successful product could be easily 'established' in a new or existing Scottish company
Scottish suppliers/ universities	Heriot-Watt have capabilities in this area – as does Edinburgh University. Also, there may be suitable software companies with capabilities required for an integrated project/program approach
What can ITI bring to the table?	Facilitating the building of a group with possible introduction of oil co and major service company. ITI Tech Media could also have role in such a project
Funding scale requirements	Ball park estimate from Imperial college is $1-2 mn for core new model before interfacing, but IP established at this point. Total cost may be double this.

END-USER BUSINESS CASE		
Increased recoverable reserves	High. This is one of the primary objectives of the tool in that it will support application if EOR techniques to better effect	● (green)
Increased production rates	High, through better reservoir management decision making	● (green)
Reduced CAPEX	Low, possibly marginal increase	● (red)
Reduced OPEX	Low. Possibly, due to fewer 'surprises' during reservoir production	● (red)
Improved H,S&E	Low	● (red)

4.11 Digital Oilfield

INTRODUCTION	
Technology description	DIGITAL OILFIELD AND DATA MANAGEMENT: Digital Oilfield is all about making better decisions regarding the future of an asset, and reducing cycle time in the decision-making process (e.g. moving from decisions based on daily / monthly data to much shorter duration measure-analyse-react time-periods of hours (or even minutes)). One operator's vision is that data will flow from reservoirs, wells and process plant, onshore or offshore, to the desks of their experts anywhere in the world. Opportunities are significant including increased recovery, de-manning, efficiency improvements and reduced operating cost. Potential for 10% increase in recovery and 30% reduction in operating costs – OLF (Norwegian Oil Industry Association) quote these benefits from a study entitled “eDrift”. This is a hot area of development which may offer significant opportunities for ITI Energy and Techmedia involvement. However there is much existing activity by operators, service companies and niche solution providers and much of the required technology may already be available – it may be more a question of making integration and use of technology much easier. Areas of focus for further investigation include: - Key technological barriers which are holding back more rapid development of e-field capabilities e.g. disparate sources of data, lack of standard operating systems and architectures i.e. oil industry equivalent of Microsoft NT - Robust, cost effective, high-bandwidth comms. technologies e.g. fibre-optics - Improved reliability sensors, instruments and data acquisition - Technologies which provide real solutions to data overload e.g. processing speed, data integration, analysis algorithms Significant opportunities for technology transfer may also exist from other sectors, such as defence (e.g. real-time battlefield planning/ monitoring/ control), as oil and gas is not traditionally a data and software intensive business – the emphasis has been on hardware and more traditional aspects of operational excellence. BP has a major programme entitled Field of the Future, embracing aspects of Digital Oilfield such as: - Permanent seabed and in-well seismic arrays - Real-time, down-hole, multi-phase fluid, temperature and pressure measurement

Technology description *Contd./*	- Real-time facilities fluid, equipment performance and integrity measurement - Data transmission from field to office and digital support architecture - Real-time well surveillance and facilities fluid/equipment performance data to expert's desktop ('data to desktop', D2D) - New generation reservoir simulation to allow fast updates and decision making - Downhole flow control/ intelligent wells - Visualisation and collaboration tools - Production optimisation and automation - Remote facility operations and performance management - Standardised digital architecture - Integrated system modelliing

Industry insights/ requirements (gleaned during foresighting exercise)	Industry visions in this area include: 3D/4D monitoring, back to control room, real-time management, 1m3 resolution visualisation, short turn-round time (1 hour) Real-time measurement of temperature/ pressure/ flow-rate/ salinity - 1% accuracy, frequency 1 minute Downhole sensing of water-oil %, frequency 1 day Technology to integrate full dataset efficiently into full range of realisations, with reduced cycle time to generate new models, truly covering phase space of possible outcomes, and intelligent integration Inclusive decision tool, incorporating business model & integrated reservoir data Models that can cope with multiple data (wells/ sources) and risk/ uncertainty and learning – building on improved models data Improved link from 4D to flow simulation and prediction Re-designed subsurface modelling workflow – reduced cycle time, more scenarios, better decisions Moving control rooms onshore - e-field vision of reduced manning and lifting cost reduction, better HSE (roving management crew) Also need to provide data back to suppliers and manufacturers Could ITI Energy get bogged down in the wide-ranging complexities of this segment - and should they leave this to the big service companies unless a breakthrough technology presents itself?

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	BP Field of the Future programme Chevron iField programme Shell Smart Field programme – Partnership with Schlumberger (IBM) University of Southern California/ ChevronTexaco (CiSoft - centre for interactive smart oilfield technologies), USA Imperial College, London, UK University of Houston (Centre for Intelligent Oilfield Operations), USA Heriot-Watt University, Edinburgh, UK
Technical development needs	Linkage of real-time data to optimisation and simulation models. Use of wireless technologies (RFIDs, Moles etc) for offshore application. Intelligent analysis of complex data volumes. Chevron Texaco has major i-Field programme. They note the need to move from the current state (reservoir management not systematically integrated, facilities management separate from subsurface management, SCADA weakly exploited, 60-80% of time spent finding or managing data, data not merged or managed consistently, no direct link between real time data and numerical geological models) to a future state (could new / emerging technologies change the way assets are managed?, what technology already available and how get operating assets to implement it?, anything to learn from downstream with regard to automation?, what challenges do we face in data integration & database management?, how to afford and manage retrofit of enabling technology components to mature assets?).
Technical feasibility	Medium. Many of the technologies already exist (e.g. advanced controls, optimisers..) but have not been widely used upstream. The integration and analysis of complex data from multiple data sources is a difficult problem, and presents challenges to technical feasibility. However, this is an area where opportunities exist and market demand is high, which may result in significant pull-through of promising technology solutions from the marketplace. Business process changes to allow successful adoption of the technologies is probably the biggest challenge.
Alternatives/ substitutes	Threat from alternatives/ substitutes is regarded as high, as promising technologies may rapidly establish themselves across the market, and operators are likely to standardise on a single approach. Type and nature of alternatives/ substitutes will depend on the specifics of the data integration/ analysis technologies proposed.

MARKET ASSESSMENT	
Size of the market	A recent study has estimated that if the industry had the ability to monitor and manage all operational activities in real-time regardless of location, the world's oil & gas recoverable reserve base could be increased by 125 billion boe (more than the proved reserves of Iraq) over the next 5-10 years, facility costs by 5-10% (3-5 years) and overall output de-bottlenecked by a further 2-6% (*Offshore Engineer'* pp 32-33 July 2004). On this basis, increased oil production of say 5% may be achieved, giving a value of $58 billion.
Potential growth rate	High. The digital oilfield era is just dawning, driven by demand for increased recoverable reserves and reduced OPEX, increasing geographic challenge (operator experts becoming fewer and based in one global location), and ageing/ declining workforce demanding increasing automation/ de-manning.
Barriers to entry/ commercial risks	Barriers to entry are low. Technology (AI, SCADA, real-time applications) is available but change management is cited as the key to successful implementation. Effective uptake of this technology is dependent on major changes in practises within operators, but even a small uptake of this technology will create a major market. Commercial risks therefore based on competition (see below).
Compelling benefit	R&D costs likely to be relatively low, whilst impact on recoverable reserves and OPEX is identified as being high. This technology area features in 'top 5 priorities' of most major operators.
Routes to market	This is a technology which will become fundamental to the heart of an operator, and therefore likely to present straightforward routes to market for all sizes/ types of company. Relationships with operators will be significant to demonstrate potential of technologies, as will be ability to support software and provide related consultancy worldwide.

IP ASSESSMENT	
Technology "openess"/ crowding	Poor. There appears to be significant ongoing activity in all of the areas described above, by operators e.g. BP (field of the future) ChevronTexaco (i-Field), ConocoPhillips (Onshore Drilling Centre), and also by solution providers e.g. DecisionTeam, Invensys (ArchestrA) application and architecture which enables integration of diverse data sources into an object based environment. Any path forward for ITI Energy in this area is likely to depend on the identification of a niche area, such as data integration. Note that about one-third of Shell Technology Ventures' portfolio companies are focused on technologies related to digital oilfield - such as vMonitor, Open Spirit, and Sensornet.
IP management feasibility	Poor. IP related to software is notoriously hard to manage, unless clear algorithms/ processes can be identified and protected. IP around integration and decision making processes is a significant concern to the operators.

STRATEGIC FIT	
Scale of econ benefit to Scotland	Poor. Data integration and analysis may be a successful niche for ITI Energy, but this essentially software-based technology area will not yield similar wealth-generation potential to manufacturing/ hardware technologies such as chemicals or equipment. Economic benefit will derive from software sales and associated consultancy. Also has the potential to extend field life and increase recovery - impact of this could be significant.
Scottish suppliers/ universities	Medium. As described above, this area embraces a huge range of technology sub-sets. It would appear that the strongest angle for Scottish companies may lie more in software areas such as data integration, than in hardware, where for most of the areas described Scotland does not appear to have a particular lead. Conversely there are areas of hardware technology (e.g. well monitoring) where universities such as Heriot-Watt have significant strengths, but these are areas where there are already significant numbers of competing companies/ technologies worldwide. Companies providing remote monitoring/ data analysis capabilities will benefit from this technology change. There will be a skill shift in the industry and Universities could be well placed to help lead this.
What can ITI bring to the table?	The best direction for ITI Energy appears to be technologies related to data integration and analysis. ITI Energy can provide funding for research, and possibly catalyse a Scottish network of expertise and solutions. Proximity to BP's Field of the Future programme office (Dyce) is an additional benefit. Development of industry standards via pilot projects
Funding scale requirements	Funding requirement is likely to be relatively low, due to proposed approach being mainly focused on software development.

END-USER BUSINESS CASE		
Increased recoverable reserves	High. Recent OLF 'eDrift' study identifies potential for 10% increase in recoverable reserves	
Increased production rates	Medium. BP quote improved production from Schiehallion of 1,000 bbls/ day attributable to digital oilfield. This is a major driver - optimisation of production is probably the key financial driver.	
Reduced CAPEX	Low. CAPEX reduction not identified as a primary driver of this technology	
Reduced OPEX	High. Recent OLF 'eDrift' study identifies potential for 30% reduction in operating costs	
Improved H,S&E	Medium. Onshore operating centres are reducing the number of trips for people offshore - taking them away from the hazard. Increasing equipment efficiency should also lead to increased energy efficiency and reduced emissions.	

4.12 Nanotechnology

INTRODUCTION	
Technology description	NANOTECHNOLOGY: Nanotechnology is at a very early stage. Its future impact on industrial processes is difficult to determine but first signs of progress are being made. Nano carriers are used in medicine for delivering specific drugs (other chemicals) to specific sites, new 'smart' coatings made up from nano size elements are beginning to be used for industrial applications, and MEMS which are built up from nano size elements are finding applications. Against this background the concept of looking for nanotechnology based opportunities for example, for more efficient reservoir management (data collection, oil sensing, and EOR), and corrosion resistant coatings is reasonable. Noting that ITI Energy is interested in a balanced portfolio, including potentially 'game changing' technologies with a ten year delivery, at least a detailed assessment of areas of potential application for nanotechnology is appropriate. In addition, there is clear potential for synergy with ITI Life Sciences.
Industry insights/ requirements (gleaned during foresighting exercise)	Interest expressed during foresighting in the role of MEMS (micro-electromechanical systems) and nano-technology includes: • Sensing and identification/ de-lineation of pockets of reserves • Chemicals for enhanced oil production (see separate technology summary on miscible fluid chemicals) • Metering systems, employing tiny sensors, to provide improved information about reservoir performance • Nano-carriers, a new breed of nano-robots which can locate and retrieve hydrocarbon particles A leading nanotechnology research centre in Scotland suggests potential applications in: • Nanocomposites: modest improvement in the strength/weight ratio of materials would make a huge difference to the design of oil platforms • Nanocatalysts: Engineering catalysts at the nanoscale with different pore sizes and shapes. Also catalysts for reducing viscosity and sulfur content. • Nanofiltration and separation • Nanolubricants and nanotribology: lubrication by nanoscale thin films (thin coating of liquid lubricant by condensing a gas onto surfaces) • Nanoparticles: surface-modified nanoparticles in fluids used to recover hydrocarbon from underground formations for oil recovery • Nanotubes: create lighter, stronger and more corrosion-resistant structural materials in platforms for offshore drilling

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	Institute of Nanotechnology, Stirling, UK Heriot-Watt University, Edinburgh, UK (Electrical, Electronic and Computer Eng Dept) Edinburgh University, UK (Institute for Integrated Micro and Nano Systems) Nanoscience Centre, University of Cambridge, UK MEMS/ Nanotechnology Group, Qinetiq, Malvern, UK Schlumberger Research Centre, Cambridge, UK INSAT (The Institute for Nanoscale Science & Technology), University of Newcastle, UK Funmat Consortium, Norway (Sintef, NTNU, Oslo Univ, Inst for Energy Technology) - to gauge efforts, the associated Nanomat programme has R&D funds of NOK 108 million for 2002-06 Rice University, Houston, USA (Dr Richard Smalley)
Technical development needs	This such a new area, the key needs at this stage are to identify some promising niche applications, and to provide evidence of success to build industry interest and credibility
Technical feasibility	A credibility issue exists regarding what can be achieved in a 10-year period with nano-technology, and a clear demonstration of opportunity and paths to market will have to be demonstrated early, but several technology providers indicate that the realisation of much of the vision outlined above can be achieved in that time-frame. In addition, MEMS are already being deployed (for example as accelerometers detecting ground vibrations, in Input/ Output's latest generation seismic system)
Alternatives/ substitutes	This depends greatly on the specifics of each application

MARKET ASSESSMENT	
Size of the market	Most nanotechnology commentators estimate that this emerging market will be worth trillions of dollars. This does not provide a very good guide regarding the MOGA market, and a better guide may be obtained by looking at specific applications. The size of the nanotechnology market for sensing, enhanced oil recovery chemicals, and carrier-robotics, may be estimated as part of the current reservoir imaging and specialty chemicals markets, which together we estimate at $2 bn/ year globally (ref OTM, Spears & Associates). By 2014 we estimate that nanotechnology might account for 10% of this market, i.e. $200 mn/ year, based on technology introduction in 2010-12.
Potential growth rate	Medium growth to 2014, due to technology relative immaturity. High growth beyond 2014, as the main adoption phase of the technology kicks in, resulting in rapid growth, reaching perhaps 25% of the reservoir imaging and specialty chemicals markets by 2020.
Barriers to entry/ commercial risks	Nanotechnology is a complex area of technology, and clearly a high level of understanding of this new area of technology is required in order to make any commercial progress. Barriers to entry are therefore regarded as being high. Commercial risks include current concerns regarding the credibility of what can be achieved (and therefore few oil companies saying 'we need this now'), and the fact that application of the technology in the reservoir is fraught with commercial risks - cf the slow take up of EOR technology generally.

Compelling benefit	This is a young area of technology which has tremendous promise. Whilst it is unlikely to yield commercial returns in the 5-8 year period, it presents ITI Energy with an exciting gamechanger opportunity.
Routes to market	A combination of research projects (to generate technology) and market engagement activities (to create relationships/ technology links/ early market pull) is proposed. Technology development is further off, at this stage.
IP ASSESSMENT	
Technology "openess"/ crowding	There are many efforts getting underway worldwide in nanotechnology, but few focused initiatives in upstream oil and gas. The opportunity still exists to create a world-class network in Scotland.
IP management feasibility	Whilst nanotechnology is in its early days, it appears that most of its constituent technologies can be well protected as IP, and that this IP can be managed effectively in any subsequent licensing arrangements.

STRATEGIC FIT	
Scale of econ benefit to Scotland	High. On the world stage, Scotland has a strong emerging nanotechnology base which can be developed in conjunction with the pre-eminent indigenous oil and gas industry to provide a terrific economic opportunity for Scotland in the 7-15 year timeframe.
Scottish suppliers/ universities	Medium. On the world stage, Scotland has a very strong nanotechnology foundation, including centres such as Institute of Nanotechnology, Stirling, UK, and Heriot-Watt and Edinburgh Universities. In addition, significant new UK government funding was announced in early 2004 (including $160 mn (£90 mn) funding over 6 years) into UK nano-technology research, and a new UK Micro and Nanotechnology Network (MNT Network) has been set up.
What can ITI bring to the table?	Encouragement and incubation of R&D and commercialisation efforts over the longer term as this market develops. The develop of niche positions for Scottish companies, in association with oil companies. The creation of a Scottish oil and gas nanotechnology network.
Funding scale requirements	Medium. UK Government has just made R&D grant funding awards totalling $27 mn (£15 mn) for 25 projects, an average of $1.08 mn/ project.

END-USER BUSINESS CASE		
Increased recoverable reserves	High. This is an EOR technology.	
Increased production rates	Low. This technology is not aimed primarily at increased production rates.	
Reduced CAPEX	Medium. The benefit here is indirect, in that effective use of nanotechnology in the reservoir will reduce surface processing requirements and therefore investment in facilities.	
Reduced OPEX	Low. This technology is not aimed primarily at reduced OPEX.	
Improved H,S&E	Medium. This technology will have some beneficial H,S&E spin-offs.	

4.13 Produced Water Handling

INTRODUCTION	
Technology description	PRODUCED WATER HANDLING: All fields produce a mixture of oil, water and gas, presenting 3 water-related challenges: avoidance of blockages in pipelines caused by water/ hydrocarbon reaction to form hydrates, reduction in the volume of hydrocarbon that can be transported or processed due to need to transport/ process produced water simultaneously, and the need to clean-up separated water prior to discharge. As fields age/ mature, the proportion of water produced steadily increases, and the removal of water from the wellstream can become the limiting factor in production. Produced water is removed from the oil and gas using separators - either downhole, on the seabed or on a surface platform. Typical separation technologies include gravity separators (more recently including inlet cyclones to improve efficiency), cyclone separators, and centrifugal separators. Prior to disposal of separated water, clean-up/ treatment is required. The final (fine) droplets of oil have to be removed to meet increasingly stringent environmental criteria, often through coalescence by coagulation/flocculation chemicals or fibrous media or through the use of electrostatic fields. If water is to be disposed of by reinjection, care needs to be taken to ensure that the water does not react in the reservoir to form scale or sour the remaining hydrocarbons. It may require sulphate removal to prevent barium/strontium scale formation and/or treatment for other chemicals present in the water (O2, CO2, fatty acids, cations, etc). As well as the actual separation and treatment of water, monitoring technologies such as oil-in-water monitoring are becoming increasingly important technologies. Note: this summary focuses on methods for removing water from the wellstream and subsequent clean-up
Industry insights/ requirements (gleaned during foresighting exercise)	Managing water has been a drumbeat for 20 years and is becoming an increasing challenge as volumes of produced water continue to increase Challenge of increasingly stringent environmental demands Cost of handling produced water demands major initiative to reduce OPEX Need more flexibility to know when to restrain prod. water and when to produce Seek to handle increased volumes of produced water at no net cost Separate and dispose of produced water downhole or on seabed, although downhole may be unnecessarily complicated and some R&D programmes (e.g. H-SEP) appear to have stalled Focus to date has mainly been on dispersed oil droplets, but increasing focus now on dissolved organic and certain inorganic components.

TECHNOLOGY ASSESSMENT	
Existing/ previous R&D	Aker Kvaerner, Norway (H-SEP) Aker Kvaerner – also launching new JIP on coalescence technology Weir Pumps, UK (H-SEP) TEA Group, Italy (GLAS, other separator technologies) Colorado School of Mines, USA (Produced water treatment techniques) TUV NEL, UK Robert Gordon University, UK (Chemical reactor development) Delft University of Technology, Netherlands Loughborough University/ Micropore Technologies, UK Clean Water Systems, UK (Aquapurge) University of Queensland, Australia (nanocrystalline photocatalysis) Scotoil Services Ltd, Aberdeen, UK (awarded $2 mn R&D grant in 08/04 for Nanotechnology for Sustainable Water Purification) Statoil/ Epcon Offshore, Norway (e.g. CTour/ Epcon technologies)
Technical development needs	Development needs tend to be focused on 'pushing the limits', i.e. water management solutions that are more compact, cheaper to build/ purchase, lower operating costs etc. See operator visions for this segment above. A key challenge is to reconcile the drive to reduce costs (especially OPEX) with the drive to improve performance. Increased performance is often now leading to greatly increased technical complexity.
Technical feasibility	High feasibility. Even though many technology solutions already exist, feasibility of further breakthroughs is high, and the technical challenges are generally not insurmountable.
Alternatives/ substitutes	Breakthroughs in successful water shut-off within the reservoir itself, using injected chemicals (see 'miscible fluid chemicals' technology summary), could reduce volumes of produced water and therefore reduce the produced water management market. However, it is likely that the ongoing solution to produced water management will be a combination of water shut-off at the reservoir and water separation/ treatment/ disposal at the surface or downhole.

MARKET ASSESSMENT	
Size of the market	It is estimated that industry expenditure on water production averages 50 cents per barrel amounting to an annual total of $40 billion. This is direct costs and an even greater cost occurs through loss of hydrocarbon production (say $60 billion). Environmental legislation is expected to further increase disposal costs. So perhaps at present the total water “opportunity cost” could exceed $100 billion**.** Produced water management has just become a major focus of US R&D funded by the Dept of Energy.
Potential growth rate	Growth is high due to the combination of increasing levels of produced water as more fields mature, increasingly stringent environmental criteria, and increasingly demanding operator economic targets (e.g. to reduce production cost/ barrel)

Barriers to entry/ commercial risks	Low barrier to entry for ITI Energy, as R&D can be conducted at relatively low-cost, on a well-established research base in Scotland. Low-medium commercial risk in obtaining field trial opportunities (ref Clean Water Systems on-going field trials in North Sea) and subsequent deployment. Risk may exist that a successful small company in this area would be an attractive acquisition target by a larger service company/ group.
Compelling benefit	High, given the need to reduce the huge cost of handling produced water, and the increasing quantities of produced water itself.
Routes to market	A combination of new-commissioned research project/s to create fresh ideas/ technology, accompanied by development of promising and nearer-market technology/s which also exhibit existing market interest.

IP ASSESSMENT	
Technology "openess"/ crowding	Poor for primary separation, good for secondary separation/ clean-up, medium for monitoring devices,
IP management feasibility	High. Most produced water mgt technologies are based on specific processes (e.g. chemical reactors) or hardware (e.g. opto-acoustic oil-in-water monitoring) which is simple to protect and manage. Some aspects e.g. incremental separator improvement, may be harder to differentiate clearly and therefore protect.

STRATEGIC FIT	
Scale of econ benefit to Scotland	With a cluster of technology providers already based in Scotland (see below), increased research funding in this area could catalyse a world-class centre of excellence in produced water management, which could also find opportunities in other market sectors such as drinking water supplies, environmental remediation etc. Breakthroughs in produced water management could create fresh opportunities for oil and gas production on the UKCS, mitigating decline in domestic oil and gas market.
Scottish suppliers/ universities	A strong cluster of Scottish companies already exist (e.g. Expro, Weir Group, NEL, Clean Water Systems, Robert Gordon University) several of whom are world-renowned in this field
What can ITI bring to the table?	Funds, and stimulation of bolder new research in the area of separation and treatment. This has become a technology area of somewhat incremental advances, especially in separation. Few technology opportunities such as micro-fluidics, advanced chemical treatment (e.g. hydrophobic chemicals), and nano-technology (e.g. nanocrystalline photo-catalysis, see above) have been strongly explored in the MOGA sector. Water treatment may have synergies with ITI Life Sciences.
Funding scale requirements	Medium. New research will not have high funding requirements (e.g. <$900 k/ project), but commercialisation of existing technology will be more capital-intensive (e.g. $1.5-3 mn) due to testing/ prototyping/ field trialling of hardware.

END-USER BUSINESS CASE		
Increased recoverable reserves	Low	
Increased production rates	High, both through reduced hydrostatic head caused by water in well/ pipeline/ riser, and through de-bottlenecking of processing facilities	
Reduced CAPEX	Medium. Some impact through the introduction of new-generation, lower-cost separation/ treatment facilities	
Reduced OPEX	High, through the reduction of per-barrel water handling costs	
Improved H,S&E	High, as this technology enables stringent new environmental criteria for produced water discharge to be met	

5

CONCLUSIONS AND WAY AHEAD

This study has identified and considered a wide number of technology needs and opportunities through extensive engagement with companies and research organisations. This foresighting exercise has involved more than 150 experts throughout the mature oil and gas sector worldwide. 93 different organisations have been involved, including 17 oil companies and 9 universities. The process of active consultation with industry has developed a focus on 12 technology areas – which are directed at 5 critical industry objectives:

- Increasing recoverable reserves
- Increasing production rates
- Reducing operating costs
- Reducing capital costs
- Improving H,S&E performance

Each of these 12 areas has significant associated market potential and distinct areas of further required technology development. However, ITI Energy has limited resources, particularly given a remit to look right across energy – not just oil and gas. Therefore, further prioritisation is required to develop a realistic approach to driving forward development of specific project proposals in any of these 12 areas. Further prioritisation is largely driven by consideration of:

- Scale of market opportunity in each of the technology areas (e.g. appreciable increase in recoverable reserves versus marginal improvement in cost or H,S & E)
- Feasibility of finding and developing projects with real commercialisation potential (particularly given the significant barriers to energy sector technology adoption)
- Materiality of the proposed ITI Energy involvement (i.e. the particular area in question offers real potential for ITI Energy to play a pivotal role in delivering the technology)

Figure 27 summarises this final phase of prioritisation:

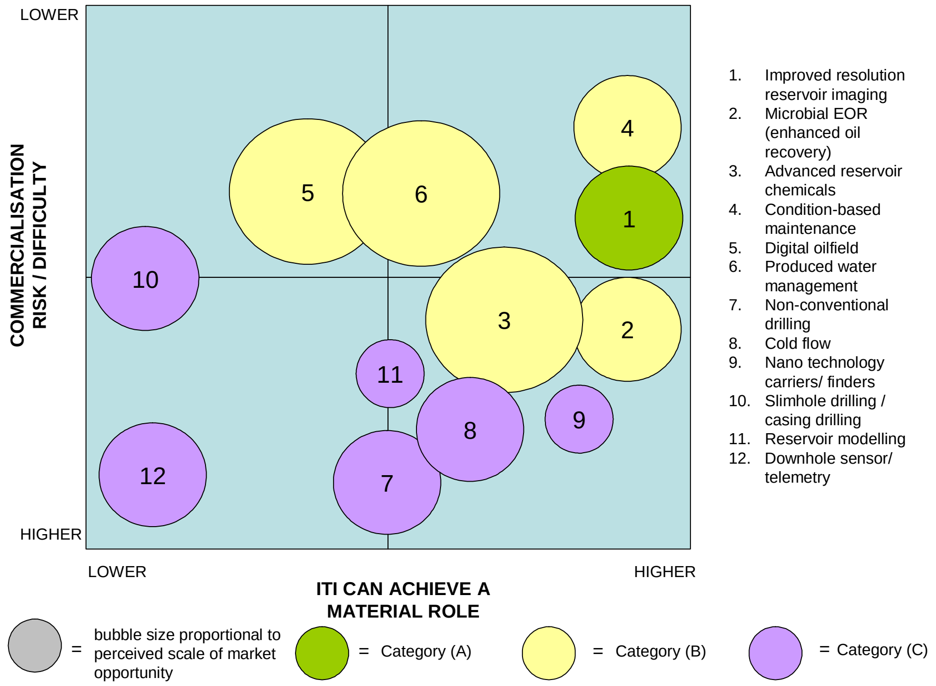


Figure 27 – Technology prioritisation

The top right quadrant of this diagram represents technologies which are perceived as offering stronger possibility of projects where ITI Energy can play a key role and where there is a reasonable potential to achieve commercial success. The 12 technology areas have been, as indicated in the above diagram, allocated a prioritisation / categorisation as follows:

Category (A): ITI Energy will look to develop specific program or project proposals using it's own resources (e.g. conduct initial scoping / feasibility study to define specific technology gaps, estimate the scale of market opportunity for technologies to fill these gaps and assess the potential for successful capture of related IP and scope the feasibility of onward licensing and commercialisation of the technology beyond the ITI research project)

Category (B): ITI Energy will seek to engage with a targeted set of companies and researchers to explore in more depth the potential technology opportunities in this area (e.g. exploratory discussions with other parties and networking to bring interested parties together to build a clearer case for initiating more resource intensive project scoping / feasibility studies)

Category (C): ITI Energy will adopt a more passive approach looking to other parties to bring forward specific project proposals - of course 3rd parties are also open to bring forward technology proposals relating to any of the 12 technology areas.

Figure 28 summarises this initial categorisation:

	PRO-ACTIVE		REACTIVE
	A) Pursue Specific Projects	B) Explore possibilities	C) Seek 3rd Party Proposals
• Improved resolution reservoir imaging	■		
• Microbial EOR (enhanced oil recovery)		■	
• Advanced reservoir chemicals		■	
• Condition-based maintenance		■	
• Digital oilfield		■	
• Produced water management		■	
• Non-conventional drilling			■
• Cold flow			■
• Nano technology carriers/ finders			■
• Slimhole drilling / casing drilling			■
• Reservoir modelling			■
• Downhole sensor/ telemetry			■

Figure 28 – Categorisation of actions by ITI Energy

The prioritisation of these 12 areas – as discussed above – is only for the purpose of allocating ITI Energy's own resources (i.e. staff time) in proactively developing project proposals i.e. categories A and B. The 12 technology areas have all been selected from the long-list as having significant potential for new technology development. Therefore, 3rd party project proposals in any of the 12 technology areas will go through the same project screening and selection process i.e. the categorisation does not imply a pre-allocation of R&D project funding biased toward areas categorised as A or B.

To move forward on these areas, consistent with the above prioritisation, ITI Energy is initiating a range of activities, including;

- Further one-to-one discussions with companies and research organisations
- Workshops or other forums to stimulate proposals of potential R&D projects
- Scoping / feasibility studies to develop specific proposals

However, ITI Energy remains open to 3rd parties bringing forward proposals in other areas outside the list of 12 – the prioritisation simply highlights where most of ITI Energy's time and resource will be focused in the near to medium term.

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www.otmnet.com

Boreas Consultants Limited, 3 Bon Accord Square, Aberdeen AB11 6DJ

6 APPENDIX 1 – ORGANISATIONS INVOLVED IN FORESIGHTING

Organisations

ABB Vetco Gray
Abbott Group
Acona
Acorn Oil & Gas
Aker Kvaerner
Albagaia
Amec Process & Energy
Apache Corporation
APEC
Arup Energy
Baker Hughes Inteq
Benchwhistler Associates
BG Group
BGS
Boreas Consultants
BP
Caledus
Cambridge University
CDL
Century Subsea
ChevronTexaco
Commercial Microbiology
Concordia University, Montreal
ConocoPhillips
Cranfield University
DES
DNV
Downhole Fluid Solutions
DTI
Energy Development Partners
Energy Institute
Expro Group
Exxon Mobil
Forest Oil
Fugro Survey
Generics Group
Global Petroleum Research Institute
Gyrodata
Halliburton
Helix RDS
Heriot Watt University
iiCorr
Ikon Science
Imperial College, London
Institute of Nanotechnology
ITF
ITI Techmedia
KCA Drilling
LOGIC
Marathon Oil
Mecon
METOL
M-I Production Chemicals
Mike Kettle Associates
Nautronix
Ocean Design Europe
OTM Consulting
Paladin Expro
Petro-Canada
PGL
Pipistrelle
Proneta
Qinetiq
Ramco Energy
Reservoir Management Ltd
Robert Gordon University
ROXAR
SAIC
SAMS
Schlumberger
Scottish Enterprise
Shell
SLP Engineering
SPE
Statoil
Stolt Offshore
Strainstall
Strathclyde University
Subsea 7
Subsea UK
Surrey Satellite Technology
Talisman Energy
Technip Offshore
Technosphere
Total
Tritech International
UKOOA
University of Aberdeen
Venture Production
Weatherford
WellDynamics
Wood Mackenzie

Job functions of people involved in foresighting

Account Manager - Aberdeen
Advanced Technologies Director
Advisor, Reservoir Engineering
Applications Support
Bus. Dev. Manager, Intelligent Wells
Business Development Manager
Business Unit Leader, Mature Fields
Chairman
Chief Engineer, Subsea
Chief Operating Officer
Chief Reservoir Engineer
Chief Technical Professional
Commercial Manager
Consultant Reservoir Engineer
Decline Management Team Leader
Deputy Principal
Development Engineer
Development Engineering Team Leader
Director
Director of Engineering
Director of Offshore Technology
Director of Resources
Director, Technology and Markets
Drilling Engineering Superintendent
Dvpmt Bus. Improvement Leader -EP Europe
Engineering Manager
Engineering Technology Manager
Exec VP, E&P Technology
General Manager, Reservoir
Global Technology Manager
Group Mktg Dir, Cased Hole Services
Head of Contracted Research
Head of Energy
Head of Petroleum Engineering Institute
Honorary Secretary
IP Manager - Expandable Technology
Manager, Continental Shelf & Margins
Manager, E&P
Manager, Instrumentation
Manager, Offshore Engineering Dept
Manager, Projects
Managing Director
Market Analysis Manager
New Technology Well Engineering
North Sea Technology Manager
Operational & Bus. Dvpmt Director - Guidance Drilling
Principal - New Technology, Well Engineering
Principal Partner
Principal Reservoir Engineer & Comm Mgr.
Production Engineering Manager
Production Technology Broker
Production Technology Manager
Production Technology Superintendant
Professor of Petroleum Engineering
Professor of Economics
Professor of Production Geoscience
Project Manager
R&D Manager
Reader
Regional Director, Europe
Regional Director, North West Europe
Reservoir Engineering Supervisor
Sales Manager - North Sea
Senior Investment Manager
Senior Pipelines Engineer
Senior Production Engineer
Senior Reservoir Engineer
Senior Technical Advisor
SPU Subsea Operations Manager
Strategic Marketing Manager
Subsea Tiebacks Programme Leader
Subsurface Technology Broker
Technical Director
Technical Director
Technical Manager
Technical Sales Manager, Optronics
Technology Alignment Manager
Technology Analysis Manager
Technology Analysis Manager
Technology Director
Technology Initiatives Consultant
Technology Manager
Technology Manager North Sea
Technology Team Leader
Theme leader, low-cost reservoir access
Theme Manager, Brownfields
UK Representative
Upstream Technology Manager Aberdeen)
VP Worldwide Drilling
VP, Corporate Reservoir Engineering

6 7 APPENDIX 2 - GLOSSARY OF ABBREVIATIONS AND TERMS

AUV	Autonomous underwater vehicle
Bbl	Barrel
Bn	Billion
BOE	Barrel of oil equivalent
CAEX	Computer aided exploration
CAPEX	Capital expenditure
DGXII	Directorate General XII of the European Commission
E&P	Exploration and production
EOR	Enhanced oil recovery
ERD	Extended reach drilling
EU	European Union
F&D	Finding and development
GoM	Gulf of Mexico
HC	Hydrocarbon
H,S&E	Health, safety and environment
HIPPS	High integrity pressure protection system
IOC	International oil company
IOR	Improved oil recovery
IP	Intellectual property
ISC	Integrated service contractor
JIP	Joint industry project
Km	Kilometre
MEMS	Micro electro-mechanical systems
MEOR	Microbial enhanced oil recovery
Mn	Million
MOGA	Mature oil and gas assets
NOC	National oil company
OGJ	Oil and Gas Journal
OPEX	Operating expenditure
R&D	Research and development
ROV	Remotely operated vehicle
SAGD	Steam assisted gravity drainage
SME	Small-medium enterprise
UKCS	UK Continental Shelf
ADNOC	Abu Dhabi National Oil Company
KPC	Kuwaiti Petroleum Company
INOC	Iraqi National Oil Company
NIOC	National Iranian Oil Company
NNPC	Nigerian National Petroleum Company
PDVSA	Venezuelan National Oil Company
QP	Qatar Petroleum

8 APPENDIX 3 – TECHNOLOGY OPPORTUNITIES IDENTIFIED DURING FORESIGHTING

Automated moveable subsea unit
Autonomous downhole power/comms/sensing
AUVs/ ROVs - to support subsea processing
Brilliant mole systems
Carrier chemicals for ring main pipelines
CO2 EOR
CO2 injection / capture
Cold flow techniques
Composite drilling/ casing fluid
Composite materials for linepipe
Condition-based maintenance
Corrosion management
Data collection system for control etc
Data processing/ data mining
Data visualisation (realtime, hi-res)
Decommissioning and abandonment
Digital oilfield
Downhole explosives
Downhole gas compression
Downhole intelligent autonomous flow control
Downhole real time measurement (hi-res, fast, P/T/Q)
Downhole sensor/ telemetry reliability
Downhole water flood management chemical
Extended reach drilling using laser/sonics
Flexible concrete coating for pipes
Flow assurance and cold flow
Flow diversion chemicals
High integrity sand control
High resolution survey (incl non-seismic)
Hi-performance casing/ production tubing system
Improved 4D/4C capability/ cost
Improved CO2 handling for EOR (corrosion etc)
Improved fluid saturation measurement
Improved seismic sensors
Improved under-balanced drilling
In well non-seismic imaging tool
In-place conversion into eg methane
In-place conversion into electricity
Intelligent drilling
In-well robot intervention
Local GTL production vessel
Long distance pipeline transport
Low-cost reliable multiphase flowmeters
Low-cost reliable pumps
Microbial EOR
Miscible fluid chemicals
Moving control room onshore
Nano-robotic carriers
Nano-robotic finders
Non-rotary drilling
Non-seismic sensors
Novel installation techniques
One-trip casing drilling
Packaging of existing technology solutions
Pipeline rehabilitation
Plastic lining
Produced water management
Real time downhole sensing
Reliable 3 phase measurement
Reservoir flow improvement (chemical/ biological etc)
Reservoir management integrated tool
Reservoir modelling
Ring main pipeline for transport
Risk based intervention / access points in pipelines
Self forming casing
Self sealing ultra slim finder conduits
Sensor networks/ deployment (e.g. X-well tomography)
Sensors in rock while drilling
Smart miscible fluids
Smart production conduit
Spiral well
Subsea autonomous power
Subsea processing
Subsea robot drill rigs
Technology proving system
TFL well maintenance robot for step-outs
Virtual reality reservoir/prod
Wellbore monitoring and refurbishment

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