DEPARTMENT OF MINERAL RESOURCES

REPORT ON INVESTIGATION OF HYDRAULIC FRACTURING IN THE KAROO BASIN OF SOUTH AFRICA
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## GLOSSARY

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<th>Term</th>
<th>Meaning</th>
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<tr>
<td>Acre</td>
<td>Unit of area (Imperial system); equivalent to 4047 m² or 0.4 ha.</td>
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<tr>
<td>bbl</td>
<td>Barrel — 42 US gallons (approximately 160 litres).</td>
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<tr>
<td>Bcf</td>
<td>Billion cubic feet (approximately 28.3 million m³).</td>
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<tr>
<td>BOE</td>
<td>Barrels of oil equivalent.</td>
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<tr>
<td>BTU</td>
<td>British Thermal Unit — equivalent to 1055 joules.</td>
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<tr>
<td>CBM</td>
<td>Coalbed Methane — also referred to in other jurisdictions as CSG.</td>
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<tr>
<td>CCGT</td>
<td>Combined-cycle Gas Turbine electric power station.</td>
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<tr>
<td>CGS</td>
<td>Council for Geoscience (South Africa).</td>
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<tr>
<td>CMG</td>
<td>Coal Mine Gas — methane accumulating in, and produced from, coal mine workings.</td>
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<tr>
<td>Completion</td>
<td>The process of preparing a well for testing or production.</td>
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<tr>
<td>Conventional</td>
<td>When applied to oil or gas reserves, ‘conventional’ indicates production from reservoirs not requiring stimulation (such as hydraulic fracturing [HF]); ‘unconventional’ correspondingly indicates a need for stimulation.</td>
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<tr>
<td>Unconventional</td>
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<tr>
<td>CSG</td>
<td>Coal Seam Gas — also referred to in other jurisdictions as CBM.</td>
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<tr>
<td>CTL</td>
<td>The process of converting coal into synthetic liquid hydrocarbons — Coal-To-Liquids.</td>
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<tr>
<td>Dry gas</td>
<td>Natural gas with minimal amounts of hydrocarbons other than methane.</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>EIA</td>
<td>Energy Information Administration (US Federal Government).</td>
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<tr>
<td>EMP</td>
<td>Environmental Management Programme as required in terms of the Mineral and Petroleum Resources Development Act.</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency (USA Federal Government).</td>
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<tr>
<td>Fracking</td>
<td>An informal contraction of ‘hydraulic fracturing’.</td>
</tr>
<tr>
<td>GTL</td>
<td>The process of converting natural gas into synthetic liquid hydrocarbons — Gas-To-Liquids.</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product — the sum of all the goods and services created or provided in a province, state or country, typically calculated or expressed as ‘per year’.</td>
</tr>
<tr>
<td>HF</td>
<td>Hydraulic fracturing.</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>A family of molecules consisting of chains, branched chains and rings of carbon atoms and hydrogen. Minor amounts of oxygen, sulphur and nitrogen may occur in the more complex molecules. The smaller and simpler molecules (e.g. methane, ethane, acetylene) are gases at surface conditions; the larger molecules (such as those in petrol and diesel) are liquids and some are solid at surface conditions.</td>
</tr>
<tr>
<td>IOGCC</td>
<td>Interstate Oil and Gas Compact Commission — a multistate (USA) government agency working to ensure that the nation’s oil and natural gas resources are conserved and maximized while protecting health, safety and the environment.</td>
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<tr>
<td>IRP</td>
<td>Integrated resource plan, as compiled and published by Department of Energy.</td>
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Karoo (Karoo) | First used as the name for a geographic region in the south and west of South Africa. Later adopted as the name for a geological basin broadly coincident in area with the geographic region. Also applied to the stratigraphic sequence of sedimentary rocks that occupy the geological basin and named the Karoo Supergroup. There are several occurrences of the Karoo Supergroup rocks further north within the Republic as well as in neighbouring countries.

<p>| LNG | Liquefied Natural Gas. |
| LPG | Liquefied Petroleum Gas — consists mainly of propane ($C_3H_8$) and butane ($C_4H_{10}$). |
| Mcf | Thousand cubic feet (approximately 28.3 m$^3$); roughly equivalent to 1 Giga Joule (GJ) of thermal energy. |
| Methane | The simplest hydrocarbon molecule, consisting of four atoms of hydrogen bonded to a single atom of carbon. |
| Mile | Measure of length in the ‘Imperial’ system = 1.609 km. |
| MMcf | Million cubic feet (approximately 28 300 m$^3$). |
| MPa | Mega Pascal — a unit of pressure (metric system). |
| (Drilling) mud | A fluid typically composed of water with some bentonite clay and chemicals to enhance various characteristics (such as gel strength and density). This multipurpose system serves the lubricate the drill bit and drill pipe, block pores and minor fractures (to minimise or prevent fluid loss and contamination of water resources) and |</p>
<table>
<thead>
<tr>
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<th>Definition</th>
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<tbody>
<tr>
<td>Natural gas</td>
<td>Hydrocarbon gas consisting primarily of methane and existing naturally in subsurface rocks (marsh gas is essentially the same, but is specific to surface deposits [marshes]).</td>
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<tr>
<td>NEMA</td>
<td>National Environmental Management Act — there are several subordinate Acts under this umbrella covering various aspects of environmental management and protection.</td>
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<tr>
<td>NORM</td>
<td>Naturally occurring radioactive material.</td>
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<tr>
<td>OCGT</td>
<td>Open-Cycle Gas Turbine electric power station.</td>
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<tr>
<td>Oil shale</td>
<td>Shale containing kerogen (the precursor to hydrocarbon formation) which has not achieved ‘maturity’ and from which oil can be generated by advancing the maturation through pyrolysis, either at surface or underground. In the MPRDA, petroleum is defined to exclude oil shale. Also see ‘Shale oil’.</td>
</tr>
<tr>
<td>Permeability</td>
<td>Describes the ability of a fluid (water, oil or gas) to move through a rock, from one pore space to the next. The unit of measure is Darcy. Very highly permeable sandstone may have a permeability of 1 Darcy. The permeability of shales is typically expressed in fractions of a milliDarcy. Also see ‘porosity’ and ‘transmissivity’.</td>
</tr>
<tr>
<td>Play type</td>
<td>A term used in the upstream petroleum industry to distinguish broad classes of exploration prospects.</td>
</tr>
<tr>
<td><strong>Porosity</strong></td>
<td>Describes the space between mineral particles in a rock. It is generally occupied by water, but can also contain oil or gas. Usually expressed as a percentage of volume. See also ‘permeability’ and ‘transmissivity’.</td>
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<tr>
<td><strong>psi</strong></td>
<td>Pounds per square inch — a unit of pressure (Imperial system).</td>
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<tr>
<td><strong>Reservoir stimulation</strong></td>
<td>A class of activities intended to improve the productivity of oil and gas wells. This includes the injection of various chemicals (depending on the nature of the reservoir) at pressures below the fracture pressure of the rock to dissolve material that may be restricting flow from pore to pore, and as a separate subset, the fracturing of reservoirs to create new flow paths by the injection of fluids at pressures above the fracture pressure of the rock and at rates sufficient to sustain the propagation of the new fracture system.</td>
</tr>
<tr>
<td><strong>RRC</strong></td>
<td>Railroad Commission of Texas — the agency of the Texas state government charged with regulating, amongst other things, the oil and gas industry in that state.</td>
</tr>
<tr>
<td><strong>SEAB</strong></td>
<td>Secretary of Energy Advisory Board (USA Federal government).</td>
</tr>
<tr>
<td><strong>Shale oil</strong></td>
<td>Oil that exists naturally in the subsurface, in the rock containing the organic matter from which it is formed. As with shale gas, given that the permeability of the shale is so low, some of the oil generated through ‘maturation’ of the organic matter has not escaped (‘migrated’) and can be extracted commercially after hydraulic fracturing of the shale. The Bakken Shale in the USA is a topical example. Also see ‘Oil shale’.</td>
</tr>
</tbody>
</table>
**SKA**  
Square Kilometre Array — internationally funded radio telescope to be constructed in the vicinity of Carnarvon, Northern Cape.

**Slick-water**  
Identifies a hydraulic fracturing system in which ‘friction-reducer’ has been added to the base fluid (water).

**Tcf**  
Trillion cubic feet (approximately $28.3 \times 10^8 \text{ m}^3$). A typical benchmark for initial assessments of the economic potential of a gas accumulation.

**Thermal maturity**  
Of organic matter acting as source for the generation of hydrocarbons. Referenced to the reflectivity of particles of vitrinite amongst the organic matter. Progresses with time and temperature from immature to the ‘oil window’, then the ‘gas window’ to overmature. The ‘windows’ are named after the main type of hydrocarbon being generated. The boundaries/edges of the windows are gradational.

**Transmissivity**  
Transmissivity is the rate at which groundwater flows horizontally through an aquifer. This measure, which is proportional to the hydraulic conductivity and the thickness of the aquifer, is expressed in $\text{m}^2/\text{day}$. Also see ‘permeability’.

**Upstream petroleum industry**  
The exploration and production sectors, as opposed to the transport, refining, and distribution sectors.

**Wet gas**  
Natural gas with appreciable quantities of higher hydrocarbons.
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EXECUTIVE SUMMARY

The Working Group of the Task Team on Shale Gas and Hydraulic Fracturing (the Working Group) was chaired by the CEO of Petroleum Agency SA and comprised representatives from the following departments and institutions: Departments of Environmental Affairs, Science and Technology, Energy, Mineral Resources, Water Affairs, the Petroleum Agency, Council for Geoscience, SKA South Africa, Water Research Commission, and ESKOM.

The terms of reference of the Working Group study are derived from the terms of reference of the Task Team and focus on evaluating both the positive and negative aspects of shale gas exploitation. The study aims to evaluate the potential environmental risks posed by the process of hydraulic fracturing as well as the negative and positive social and economic impacts of shale gas exploitation. This report and recommendations are not claimed to be fully comprehensive — new reports and technical developments continue to emerge. Further work is required in a number of critical areas.

The study comprises reports written by specialists in their various fields as well as the results of a study tour to the United States which included field trips to Pennsylvania (Marcellus Shale) and Texas (Eagle Ford Shale) and visits to the Environmental Protection Agency and the Railroad Commission of Texas, both being US regulatory organisations directly involved with shale gas exploitation.

The following major issues were considered:

The estimate of the potential resource

The United States Energy Information Administration has made a first pass estimate of a technically recoverable resource of 485 trillion cubic feet (Tcf) of gas in the Karoo Basin. The Petroleum Agency evaluated this assessment and concluded that, owing to the limited amount of available data in the area, it is impossible to quantify the resource accurately, other than to say that it is potentially very large. It is essential that additional, modern subsurface information be obtained through drilling or a geophysical survey to constrain these estimates. While the existence of a
significant gas resource in the Karoo would have implications for South Africa’s energy security by reducing national dependence on other fossil fuels, the magnitude of this potential is subject to considerable uncertainty owing to the difficulties in quantifying the resource.

**Technical aspects of hydraulic fracturing**

Hydraulic fracturing is an integral part of the production of gas from low-permeability unconventional reservoirs such as shale, tight sandstones and coal. The technique is highly specialised and comprises complex mechanical and chemical processes. Hydraulic fracturing has been used in the oil and gas industry for more than 50 years and, in the last 20 years, together with the practice of horizontal drilling, has been instrumental in making the exploitation of unconventional resources technically and economically feasible. The initial stages of exploration can be conducted without the use of reservoir stimulation. However, in order to assess the ‘productivity’ of a resource during the later stages of exploration and, finally, in order to produce the gas, hydraulic fracturing is essential. The process requires the use of significantly large quantities of a base fluid, usually water, together with a small fraction of sand and chemicals pumped into the reservoir with sufficient pressure to create artificial fractures, thereby improving the permeability of the rock and allowing the gas to be produced.

**Environmental and socio-economic implications of hydraulic fracturing**

The use of large volumes of water together with chemical additives makes it essential that the environmental and social implications of this process are considered. The present study considers the impact of shale gas exploitation on land use, water use and air pollution. Whereas existing environmental regulations adequately cover most of these factors, an immediate and important concern requiring additional attention is water usage and disposal: in particular, the volume and transportation of the water, the potential contamination of water resources and the disposal of ‘used’ fracturing fluid. The use and disposal of water in such large amounts is expected to require a water use licence under the National Water Act. Further research is required to investigate all potential sources of input water, as well
as means of water disposal. Extensive hydrological and geohydrological studies before exploration and production drilling will be required in order to minimise or eliminate potential impacts on other users. Because of the uncertainty regarding the extent, or even existence, of economically producible reserves, any assessment of the potential economic impact is subject to enormous uncertainty. However, making a moderately optimistic assumption that ultimately 30 Tcf will be produced, and using indicative pricing of US$ 4 per thousand cubic feet of gas and an exchange rate of R8 per US dollar, the gross sales value would be almost R1 trillion. Similarly, 1 Tcf was sufficient to launch PetroSA’s gas-to-liquids project in Mossel Bay which provides approximately 5% of the national demand for liquid fuels and entails 1500-1600 jobs. It is expected that the contribution of shale gas production to the growth of the economy and GDP would be enhanced by the necessary creation of service industries with all the attendant implications for sales of goods and services. Even though this process would be spread over a period of 20–30 years it clearly has the potential to have a major impact on the national economy. Although Income Tax and Royalty accruing to the fiscus depend on profitability it is expected that such amounts will run into tens or hundreds of millions of Rand, augmented by VAT. The potential long-term direct employment opportunities are likely to number in the tens of thousands, with similar numbers in the industries consuming the gas.

**The regulatory framework**

The primary conclusion reached in this report is that South Africa’s regulatory framework must be robust enough to ensure that, if hydraulic fracturing associated with shale gas exploration and exploitation were approved, any resultant negative impacts would be mitigated. This will require a comprehensive review of the adequacy of the existing framework in order to identify any shortfalls or omissions and to ensure that it is sufficiently detailed and specific. The use of existing regulations from mature regulatory environments to inform the development of South African regulations in this matter is recommended.
Astronomy research projects in South Africa

The low level of population density in the Karoo, making this area an ideal site for astronomical observation, constituted the basis of South Africa’s bid to host the Square Kilometre Array. Unmitigated radio-frequency emissions produced by the operation of heavy industrial equipment in shale gas exploration and production are expected to be detrimental to radio-astronomy operations. Although this matter requires more detailed analysis and investigation, the current study suggests that suitable mitigatory measures be established to accommodate both. It is expected that there will be a process of areas that will delineate areas where exploration and production activities of shale gas will be precluded. Site-specific analysis will be a prerequisite for operations in areas defined by the Astronomy Geographic Advantage Act.

Economic implications of a ban

While considering the implications of hydraulic fracturing, it is important to note that the effect of an extended ban, moratorium or stringent regulation can best be described as a reduction of economic opportunity (opportunity cost). Such measures would delay or prevent an improvement of the understanding of the real extent of the potential resource, hamper the development of coalbed methane and other hydrocarbon resources in low-permeability reservoirs, and remove the potential economic benefit to severely deprived communities in the Karoo.

Synthesis

In the current technological environment, any exploration for and economic exploitation of shale gas in South Africa will require the use of horizontal drilling and hydraulic fracturing.

The use of hydraulic fracturing in shale gas exploration is perceived to have the attendant risk of polluting sources of drinking water by fracturing fluids and/or methane, and induced seismic events. In the Karoo, there is the additional concern that the volumes of water required may compromise other uses and, in a large part
of the area, there is a further geological risk entailed by the presence of extensive intrusions of dolerite and kimberlite, the influences of which are not easily predicted.

The technique of hydraulic fracturing requires relatively large volumes of water which may be difficult to source in the Karoo. Groundwater pollution can be minimised through good borehole construction and the maintenance of the well bore integrity, coupled with intensive and close monitoring which can be achieved through the application of industry best practice.

The hydrogeology of the Karoo at depth is unknown, but potable aquifers are expected to be far removed from shale gas target formations and safe from contamination from injected fracking fluids, as the latter are immobile under normal conditions with no ‘drive’ once the fracturing operation has been completed. However, the effects of dolerite intrusions, kimberlite fissures and existing fracture systems are relatively unknown and further investigations and modelling are required.

Noise, dust, emissions and naturally occurring radioactive mineral (NORM) contamination levels will differ at different stages and locations and can be controlled under existing legislation.

Potential resource and energy security: Various estimates of the technically recoverable resource, ranging from 30 to 500 Tcf, have been expressed. However, there are presently insufficient data to accurately assess the size, quality and extractability of the shale gas resource and, therefore, it is not possible to accurately assess the implications in respect of energy security. Further drilling, sampling and testing will be required to improve confidence in the existence and, subsequently, extent of a resource. A large resource would have the potential to reduce national dependence on other fossil fuels and may contribute to energy security and the reduction of our carbon footprint. These factors are a powerful justification for further investigation.

The potential socio-economic impacts increase progressively through exploration and appraisal to production. In the early phases, much of the work will be done by
specialists brought in from other countries and the impact on the local economy will be slight. As confidence in the potential of shale gas increases, the training of local personnel for longer-term operations becomes viable and the impact on the local and national economy increases. In the event that a real resource is proven, it is possible that its size will be sufficient to justify proceeding to production which may be coupled with, for example, the establishment of additional gas turbine electricity generation installations or gas-to-liquids (GTL) plants with associated employment opportunities in field operations and plant operation, potentially numbering in the thousands. There would then also be significant implications for the GDP, with as much as R 960 billion added over 20–30 years. [calculated at 30 Tcf @ US$ 4/Mcf and R8/US$]

South Africa does not have the infrastructure (service industries and pipelines) in place that facilitated the success of shale gas production in the United States. However, the demonstration of a large enough resource would drive the development of the necessary infrastructure.

Astronomy research projects and shale gas in the Karoo may be mutually exclusive, but the ‘footprint’ of the astronomy installations is only a fraction of the area presently considered to be prospective for shale gas. There is scope for collaboration between government and industry on mitigating measures with a view to minimising the areas closed to exploration and production operations.

The existing regulatory framework, drawn from a number of acts, emphasises the protection of the environment covering the broad aspects of concern. It is the conclusion of the Working Group, however, that there is a need for detailed assessment and augmentation, where necessary, of the framework applicable to the upstream petroleum industry as a whole to ensure robust regulation and compliance monitoring. In order for the regulations to be effective, better co-ordination between departments and adequate resourcing of regulatory and enforcement agencies is required. Regulations relating to water usage and disposal, in particular, require in-depth study and analysis.
The published estimate of the shale gas resource potential requires further and co-ordinated investigation to expand the quantitative database required to support assessments of the inherent economic potential of the resource. Appraisals of the possible socio-economic impacts of shale gas development are of necessity based on an estimate of the resource. There is therefore an urgent need for further research on the entire Karoo Basin to reduce the uncertainty in the resource estimation and increase confidence in the associated assessments of the potential socio-economic impacts. That type of research is what oil and gas companies carry out under exploration rights.

**Options**

Based on the conclusions set out above, the Working Group considered a spectrum of options that might be recommended to the Minister, ranging from (1) an outright ban to (2) unconditional approval of hydraulic fracturing under the existing regulatory framework. Neither of these extremes was deemed suitable and, thus, the intermediate option (Option 3), specifically the ‘conditional approval of hydraulic fracturing’ (3C) was considered to be most appropriate. The options considered are tabulated in Annexure G.

**Recommendations**

The following recommendations are made:

- Allow normal exploration (excluding the actual hydraulic fracturing), such as geological field mapping and other data gathering activities (e.g. hydrological studies) to proceed under the existing regulatory framework.

- Constitute a monitoring committee to ensure comprehensive and co-ordinated augmentation of the regulatory framework and supervision of operations.

- Augment the current regulatory framework. The establishment of the appropriate regulations, controls and co-ordination systems is expected to take 6–12 months.
• Departments of Science & Technology and Mineral Resources to collaborate in developing mechanisms for the co-existence of the Astronomy Research Projects and development of shale gas in the Karoo.

• Once all the preceding actions have been completed, authorise hydraulic fracturing under strict supervision of the monitoring committee. In the event of any unacceptable outcomes, the process may be halted.

• Ongoing research to be conducted and facilitated by relevant institutions to develop and enhance scientific knowledge in respect of the development of Karoo shale gas. This includes, albeit not limited to, geo-hydrology of the prospective areas, methodologies for hydraulic fracturing in RSA and environmental impacts.

• The actions required to give effect to the proposed conditional approval must be properly resourced, incorporated into the programmes of the relevant departments and agencies and capacity developed.
1 INTRODUCTION AND BACKGROUND

The purpose of the Task Team was to investigate the full environmental, social, economic and legal implications of hydraulic fracturing as a technique for the exploration and production of oil and gas in South Africa, and to submit a report thereon for consideration by the Minister of Mineral Resources.

1.1 Terms of reference

The relevant section of the terms of reference for the Task Team reads as follows:

‘The Task Team, with the assistance of the Working Group, will investigate –

- the technical aspects of hydraulic fracturing with respect to conventional petroleum, coalbed methane and shale gas;

- possible environmental and social implications of hydraulic fracturing and related activities in respect of the different hydrocarbon play types, including but not limited to

  o land use
  o water use and pollution OR aquifer contamination
  o noise/dust pollution

- the existing regulatory framework in view of identifying possible shortfalls or omissions with regard to proposed activities;

- the potential estimates of the (unexplored) hydrocarbon resource and any constraints on these estimates;

- the implications for South Africa’s energy security;

- the economic implications of either a ban, moratorium or stringent environmental regulatory measures on hydraulic fracturing;

- Infrastructure and market limitations in respect of gas and their effect on viability of the resource; and
• Implications for astronomy research projects for South Africa.’

1.2 Process and methodology

The only region which has a significant body of experience and knowledge in respect of current use of hydraulic fracturing for shale gas development is North America. Although it has been possible to make a short study tour involving meetings with pertinent agencies and visits to operational sites, the Working Group has relied heavily on the extensive body of literature describing the method and its impacts. A selection of the more important materials is listed in the Bibliography section. However, it must be noted that new material on various aspects continues to emerge, and that it is not practical to attempt to list all the material relevant to the subject.

The work of the Working Group (Annexure H) involved these pertinent actions or events:


b) Consultations with Eskom were held on 19 and 28 July 2011. (Annexure I).

c) A study tour to key jurisdictions and regulatory authorities in the USA was carried out from 25 to 29 July 2011 (Annexure J).

d) The technical staff of Petroleum Agency SA prepared a report entitled ‘Preliminary Shale Gas Resource Scenarios for the Karoo Basin’ (Annexure A) which builds on the report of the Energy Information Administration of the USA (EIA).

e) The Council for Geoscience prepared reports on the geology of the Karoo Basin with special reference to potential shale gas resources, and on the potential for induced seismicity (Annexures B and C respectively).

f) A preliminary assessment of potential impacts on radio astronomy indicated that radio-frequency interference can be expected to arise from the exploration and production of shale gas. [This was up-dated after the
announcement of the award of the project] However, the Working Group also proposed generic mitigating measures and a more comprehensive study to be based on a more detailed understanding of the equipment and methods used in shale gas exploration and production (Annexure D).

g) The Institute for Groundwater Studies (Dr Vermeulen and Prof. Steyl) undertook a study tour to Pennsylvania and shared their experience with the Working Group through a presentation.

h) Workshops (involving scientists not previously forming part of the Working Group) were held over five days during January and February 2012 at which various options were discussed. Not all participants were able to attend on all days.

1.3 Constraints on this study

There are no known economically viable conventional onshore gas deposits in South Africa, with the consequence that there is no existing infrastructure that might have formed a springboard for gas exploration in low-permeability conventional reservoirs (tight gas). As a result, exploration for coalbed methane (CBM) in South Africa is a decade or more behind other jurisdictions and still in its infancy. However, interest in this potential resource is increasing and would require the use of hydraulic fracturing. CBM production is often dependent on hydraulic fracturing to establish economically justifiable gas flow rates. It has been established that the same formulation is used in stimulating CBM production as in shale gas. In both cases, with the possible exception of constraints on water supply in some areas, the issues surrounding the possible development of shale gas in the Karoo will also apply. Keeping these factors in mind, this report focuses primarily on hydraulic fracturing in shale gas exploration and production by means of a slick-water system.

The Working Group has, within the limits of the information available, addressed all of the avenues of enquiry indicated in the terms of reference. The paucity of reliable information on a number of key aspects is a handicap to the objective assessment of the potential benefits and risks in the possible development of shale gas in South
Africa. This hurdle is not unique to South Africa and is well expressed in the second paragraph of the executive summary in the report by Wood et al. 2011 in connection with the equivalent problem in the UK:

*It should be stressed that a key issue in assessing these issues has been a paucity of reliable data. To date shale gas has only been exploited in the US and, while initial estimates have been made, it is difficult to quantify the possible resources in other parts of the globe, including the UK. Equally, information on health and environmental aspects is of variable quality and only now is there any systematic effort being undertaken to better understand these issues. Therefore, while every effort has been made to ensure the accuracy of the information in the report, it can only be as accurate as the information on which it draws.*

The Working Group has addressed hydraulic fracturing and shale gas development from the level of principle. It must be noted, however, that just as ‘shale’ is a small word for a large and highly variable family of rocks, the term ‘hydraulic fracturing’ covers a spectrum of styles based on carrier fluids including water, liquid hydrocarbons, liquid nitrogen and liquid carbon dioxide. The style generally understood to be proposed and applicable to shale gas exploration in South Africa is referred to as ‘slick water’. Accordingly, the Working Group has accordingly given most attention to this style.

Best practice for the design and construction of petroleum boreholes is well documented and understood. The current controversy surrounding hydraulic fracturing is complicated by the fact that effects or events in the adjacent environment are often evident only some time after the petroleum operations have taken place and it is frequently not possible to directly connect petroleum operations with observed effects, especially when there has not been a preceding baseline study. See, for example, the EPA report.

The paucity of currently available information also makes it impossible to predict where within the 250 000 km² prospective portion of the Karoo such developments might take place. It is neither possible nor appropriate for the Working Group to express views as to the suitability of hydraulic fracturing and shale gas development in particular locations.
The current ‘debate’ in the media is highly polarised and this is reflected in the content of documents produced by proponents and detractors of hydraulic fracturing. As a consequence, it is hard to find analyses which develop common ground in which constructive engagement can occur. No doubt both sides are presenting information selectively to suit their causes; we are mindful of this in our consideration of the available materials. The Working Group has not been strongly polarised. However, because of the complexity of issues, our recommendations inevitably involve some degree of compromise by various members. Therefore, the recommendations represent views supported by the majority.

We have, as far as possible, avoided anecdotal information which cannot be tested, preferring to rely on academic papers, material published on official web sites or in reputable journals. Even in the academic domain, however, there is clear evidence of polarisation.

One of the difficulties in this debate is the inevitable lag between the adoption of a new method, the emergence of a suspicion that the method may not be risk free and the study and documentation of assumed consequences. Indeed, this whole process may take up to 10 years — see for example the report by the EPA\(^52\). In the case of shale gas and hydraulic fracturing the industry is refining its methods to reduce the potential environmental impact, and in jurisdictions where there has not been an outright ban, regulators are introducing new rules aimed at providing their constituencies with more reassurance that their interests are being protected.

Throughout the course of our research, new information and reports have continued to emerge, often casting doubt on the conclusions of earlier reports. For example, the Environmental Protection Agency of the US Federal Government (EPA) published a draft report (December 2011) finding that pollution of groundwater in the vicinity of Pavillion, Wyoming is a result of the development of the Pavillion gas field\(^52\). This conclusion supports the view that this industry sector is unsafe and casts doubt on earlier assertions that no environmental incidents were directly attributable to hydraulic fracturing\(^45\). However, the report and the methods used by the EPA have been the subject of extensive criticism.
From the IOGCC (Inter-state Oil and Gas Compact Commission) web site —

‘Although thousands of wells are fractured annually, the EPA did not find a single incident of the contamination of drinking water wells by hydraulic fracturing fluid injection. Additionally, IOGCC member states have all stated that there have been no cases where hydraulic fracturing has been verified to have contaminated drinking water’.

An analysis of the EPA report shows that the circumstances in which the Pavillion event occurred are not directly relevant to the proposed operations in South Africa. This is not to say that there is no cause for concern, but rather cautions that the pertinence of contributions to the local debate should be carefully considered.

The Working Group accepts the guiding principle that regulatory decisions should err on the side of caution, and that methods that are subject to uncertainty should not be approved unconditionally. The information that is currently available about the potential of the shale gas resource is not sufficient to support meaningful assessments of all the implications. This difficulty can only be addressed by the acquisition of additional new information which, in turn, can only be accomplished by drilling, sampling and testing new boreholes.

During the course of the investigation a new concern emerged — the potential for earthquakes arising from hydraulic fracturing operations. This concern arose as a result of two low-intensity seismic events in the vicinity of a hydraulic fracturing operation in Lancashire in the UK. This aspect is addressed as an additional risk in section 2.4.5 and Annexure C.

The shale gas production sector is best developed in the USA, where it originated, and has begun to spread across the world only in the last 3–5 years. As a consequence, the only domain with any meaningful experience of hydraulic fracturing is North America. First-hand exposure to mature operations that might represent industry best practice must then entail travelling to at least one of the active regions (e.g. Colorado, Louisiana, Pennsylvania, Texas and Alberta).
1.4 Historical perspective

Exploration for conventional oil accumulations onshore by state oil company SOEKOR (now PetroSA) began in the mid-1960s and was abandoned as having no real prospect of success in 1979. At that time natural gas was known to be venting from coal and gold exploration boreholes in the Free State and Mpumalanga, but exploration in these areas was not pursued as gas was not seen as having any commercial significance. Elsewhere in the world, natural gas was being adopted as a cheap and clean alternative to coal gas.

In the intervening decades, the use of natural gas enjoyed broader adoption across North America and Europe and, as supplies of conventional oil and gas began to deplete, unconventional sources were investigated and developed, initially exploring low-permeability rocks and, subsequently, coalbed methane.

These developments were not repeated in South Africa because there were no conventional oil and gas resources onshore and ambiguity over the ownership of gas within coal seams served only to suppress any potential interest. The latest evolution has been the convergence of the technologies of extended-reach horizontal drilling and multi-stage hydraulic fracturing with shale gas resources in proximity to well-developed infrastructure. This development has resulted in a new petroleum sector focused on the extraction of natural gas from shale (shale gas).

That new sector, generally accepted as originating in the late 1990s in the Barnett Shale around Dallas, Texas, has been astonishingly successful. It has massively expanded the gas reserves and production capacity in the USA — to the extent that rather than an impending need to import gas as LNG to meet local demand, the industry is now moving towards the export of gas (BG press release 2011.10.26). Having succeeded so dramatically in North America, the petroleum industry turned its attention to the rest of the world, including South Africa.

The promulgation of the Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) clarified the rights to methane in coal as being separate from
the right to the coal and, thus, there has been considerable interest in exploring for CBM, with 25 exploration rights focusing on coalbed methane issued so far.

The first indication of renewed interest in the Karoo was an unsuccessful application for an exploration right in October 2008. There are presently five applications for exploration rights under consideration, three of which are explicitly targeting shale gas in the Karoo Basin. The Minister of Mineral Resources has since imposed a moratorium on the receipt of new applications.

The technology enabling shale gas production has become controversial as a result of:

- the need to use large volumes of carrier fluid (usually water);
- the potential pollution of water resources resulting from surface spills or underground leakage;
- the treatment and disposal of waste fluids; and
- the potential ‘footprint’ of any development.

- In addition there are concerns relating to attendant socio-economic impacts.

Following the Cabinet decision that the matter of shale gas be investigated, the Minister of Mineral Resources directed the Director-General of Mineral Resources to form a Task Team to carry out a review and to make recommendations based thereon. The Task Team appointed a Working Group to investigate the matter and to compile a report. In the interim, finalisation of existing applications has been halted pending the outcome of this review.
2. CONSIDERATION OF SPECIFIC ISSUES FROM THE TERMS OF REFERENCE

2.1 Technical aspects of hydraulic fracturing with respect to conventional petroleum, coalbed methane and shale gas

2.1.1 What is petroleum?

The word ‘petroleum’ is derived from the Greek words ‘petra’, meaning rock, and ‘oleum’, meaning oil, and thus entails a distinction between rock-derived and vegetable oils. In modern parlance ‘petroleum’ corresponds to the term ‘crude oil’. In the Mineral and Petroleum Resources Development Act the definition of petroleum is extended, for the purposes of the Act, to include natural gas, and thus corresponds to the general chemical class ‘hydrocarbons’ (see glossary). From a regulatory perspective, the term ‘petroleum’ encompasses all forms of natural gas, including coalbed methane and shale gas. These terms thus serve mainly to identify the rock in which the gas has accumulated, associated with a consequent understanding of the different techniques required to extract the gas, and do not signify chemically distinct gases.

A generalised description of the phases of petroleum exploration is set out in Annexure L. Hydraulic fracturing of a potential reservoir is one amongst a long catalogue of operations in petroleum exploration and generally occurs near the end of the process, if indeed the process extends that far.

2.1.2 What is shale gas?

‘Shale’ denotes a class of sedimentary rocks consisting of very fine-grained particles — mainly clays but with variable amounts of quartz, other minerals, such as calcite, and organic fragments. Shales often have a laminar structure and characteristically have low porosity and extremely low permeability.

Shale gas is hydrocarbon gas extracted from shale, as opposed to conventional reservoir rocks such as sandstone or limestone, or from other unconventional reservoir rocks, such as coal or tight (very low permeability) sandstone. The
composition of the gas is essentially the same in all cases, i.e. methane (CH₄) will be
the principal component (typically 80% or more) with smaller quantities variously of
carbon dioxide (CO₂), oxygen (O₂), nitrogen (N₂), hydrogen sulphide (H₂S) and
heavier hydrocarbons (ethane (C₂H₆), propane (C₃H₈) etc.) — see
http://www.naturalgas.org/overview/background.asp

Not all shales are suitable for shale gas extraction. The extent of gas in a shale
depends on a number of factors, including the proportions and types of organic
particles deposited with the mineral grains that make up the rock, the duration and
temperature of heating of the rock during its burial (resulting in increasing ‘maturity’
of the organic matter), and the extent to which gas generated during the maturation
of the organic matter has migrated out of the shale. The best shales for shale gas
exploitation have organic contents exceeding 4%, a high proportion of quartz and/or
calcite grains relative to clay and have reached the depth/temperature window for
gas generation.

Shale gas resources are typically found between 1500 and 4000 metres beneath the
surface and are exploited by wells with long horizontal sections in the shale beds
(see Figures A and B). The lower limit is dictated by economics — richer resources
may justify drilling deeper.

For a brief discussion of the geology of the Karoo Basin with reference to shale gas,
see Annexure B.

The term ‘shale gas’ is used to identify gas produced from shales and as a general
description of an industry sector whose operations are aimed at identifying a
resource, testing its potential and developing production of gas from shale. The term
‘hydraulic fracturing’ refers to the specific reservoir stimulation operation. For a
description of the hydraulic fracturing process, refer to sections 8 to 16 in
Annexure L.
While ‘shale gas’ exploitation necessarily includes the use of hydraulic fracturing, this process is not unique to the shale gas sector. Indeed, hydraulic fracturing is used in several sectors of the upstream petroleum industry focused on, for example, coalbed methane and tight (very low-permeability) sandstones. Hydraulic fracturing is most widely used onshore, but can also be applied offshore. Hydraulic fracturing is also
used in other sectors such as the exploitation of groundwater or geothermal energy, although plain water without chemicals is used in these contexts.

While ‘shale gas’ exploitation necessarily includes the use of hydraulic fracturing, this process is not unique to the shale gas sector. Indeed, hydraulic fracturing is used in several sectors of the upstream petroleum industry focused on, for example, coalbed methane and tight (very low-permeability) sandstones. Hydraulic fracturing is most widely used onshore, but can also be applied offshore. Hydraulic fracturing is also used in other sectors such as the exploitation of groundwater or geothermal energy, although plain water without chemicals is used in these contexts.

Figure B: Schematic diagram of shale gas well construction.
2.1.3 **What is coalbed methane?**

Coal is formed almost entirely from the remains of plant-derived organic matter. Methane is commonly one of the products of the thermogenic decomposition of organic material trapped in sedimentary rocks as these are buried by subsequent layers of new sediment. Coal therefore commonly contains significant amounts of methane — this is the source of explosive gas which can adversely impact on underground coal mining operations. One of the interesting characteristics of coal is that, under suitable hydrostatic pressure, it will adsorb methane molecules. Hydrostatic pressure results from the column of water that permeates rocks below the water table. The adsorption of methane on coal is commercially significant in regions where the coal is buried too deeply to justify open-cast mining — between 150 and 500 metres beneath the surface. The removal of water from the coal faster than it can be replenished by flow within the coal or from the adjacent rocks, results in a reduction in the hydrostatic pressure. In response to the reduced pressure, the methane adsorbed on the coal desorbs and flows towards the zone of least pressure — the borehole through which the water is being extracted. The gas produced from such boreholes usually also includes minor amounts of other gases, such as carbon dioxide, nitrogen and oxygen that may have been dissolved in the water pervading the coal.

2.1.4 **What is hydraulic fracturing?**

Hydraulic fracturing is one of a class of operations referred to as reservoir stimulation. Another example is leaching of minerals through acid injection to improve the connection between the pore spaces of a rock.

Similarly, the term ‘hydraulic fracturing’ is used to describe the general procedure of breaking open rocks by applying force through a fluid medium (‘carrier’). Besides the methods using water, hydraulic fracturing also encompasses the use of other fluids, such as LPG, liquid nitrogen, liquid CO₂, diesel and other liquid hydrocarbons. Further, the sector based on water is divided into operations using plain water and those using so-called ‘slick water’. In the case of slick water, extra chemicals are
added to reduce the friction of the fluid as it is pumped through the piping and into the shale. This latter specific form (slick water) appears to be most likely to be applied if approved in South Africa. Therefore the Working Group has focused most of its attention on slick-water operations. An example of the composition of fluid for a slick-water hydraulic fracturing operation is given in Figure C. For more detail on the composition of a fracturing fluid, see Annexure M.

**Figure C: Formulation of fracturing fluid — an example.**

In all cases, solid particles (usually quartz sand) are added, to be wedged into the new fractures to hold them open when the pumping stops and the fracturing fluid is allowed to flow back up the borehole, clearing the way for the flow of gas.
The additives used in each case are different and result from a consideration of the physical and chemical properties of the shale and the carrier fluid, as well as the depth and temperature at which the fracturing will take place.

This diversity means that it is important to understand the nature of what it is that will be banned or approved, as the case may be. In the same way that it is important to distinguish between general shale gas exploration and production and specific hydraulic fracturing; the blanket term ‘hydraulic fracturing’ as short-hand for slick-water systems should be used cautiously.

The controversial aspects of shale gas production, as expressed in the USA, are equally relevant to the use of hydraulic fracturing in South Africa. These issues are compounded in the case of shale gas exploration in the Karoo by concerns about competition for scarce water resources.

**2.2 Estimates of the (unexplored) hydrocarbon resource and any constraints on the same**

There are no known viable conventional oil or gas resources onshore in South Africa. The delineation of a CBM resource in Limpopo Province is well advanced, and an application for production rights has been lodged in a highly unconventional gas field in the Welkom–Virginia region. Interest in the Karoo Basin as a potential shale gas opportunity is at a very early stage.

The paucity of data available relating to the characteristics of the target shales makes it premature to try to provide a reliable estimate of the technically recoverable resource. Attempting to estimate the proportion that might be economically exploited would add a further layer of uncertainty. There is a vast range of possible outcomes, with the result that any assessment of the potential socio-economic impacts of exploration and production operations must therefore be somewhat tenuous.

The formations currently under consideration as possible sources of shale gas in the Karoo are the Whitehill, Prince Albert and Collingham Formations\(^{38}\) (also see Annexures A and B).
While the economics of production will be dictated by the price achieved, even in the USA which has the benefit of a well-developed pipeline, infrastructure shale gas wells are rarely deeper than 5000 metres.

In the absence of meaningful volumes of information about the characteristics of the target formations in the optimal location, it becomes necessary to assume that the characteristics recorded at outcrop and in the few wells for which there are records, persist laterally over great distances.

The Energy Information Administration (EIA) of the USA has published a ‘first-pass’ assessment of the technically recoverable volumes of shale gas that may be present in various geological basins in 14 countries, to provide a context for the industry. No assessment of the economics of extraction is attempted as that depends on a host of factors that are subjective and specific to each country and/or basin.

In the case of South Africa, the assessed resource is 485 trillion standard cubic feet (Tcf) of technically recoverable gas. PetroSA’s Mossgas project was initiated with a reserve of approximately 1 Tcf, so the potential of shale gas is significant at the national level. However, this assessment must be treated with some caution as it uses a small data set as the basis for assessing a large area.

Petroleum Agency SA has also carried out an assessment (Annexure A) which concluded that 30 Tcf may be technically recoverable as a minimum, with 500 Tcf as a maximum.

All such assessments are, in the case of South Africa, largely speculative and it will not be possible to reduce the associated uncertainty without specific exploration in the form of drilling, sampling of shales and testing of boreholes.

Future work: As additional information is received through new exploration, the results will be incorporated into the existing models to refine the scenarios. Such work depends on the continuation of deep-level exploration within the Karoo Basin.

The prolific dolerite sills and dykes and kimberlites which affect the Karoo Basin are complicating factors that do not occur in other shale gas basins. The subsurface
geometry of the intrusions and faults can affect the potential resource in a variety of ways. Improved tools for imaging and understanding the intensity and orientation of the intrusive rocks may need to be developed to improve the success of exploration and production and in order to minimise the risk of pollution if it is determined that hydraulic fracturing can be used.

2.3 Implications for South Africa’s energy security

2.3.1 National imperatives

Beyond the questions of whether or not hydraulic fracturing can be done safely, whether or not it can be done in the Karoo without unduly impacting on other water users, and whether or not other aspects related to hydraulic fracturing would render it, in its present form, environmentally undesirable, the scale of the potential resource is such that the development of shale gas in the Karoo must also be considered in terms of a number of other national imperatives. These include:

a) the drive to diversify sources of energy and thereby reduce our dependence on coal;

b) the commitment to reduce the ‘carbon intensity’ of our energy systems;

c) the desirability of improving ‘security of supply’ by developing indigenous resources; and

d) the immediate need to expand our national capacity to generate electricity.

Under the Integrated Resource Plan 2010 (IRP 2010\(^{18}\)) (Department of Energy), coal is expected to account for 15% of all new electricity generation, imported gas 6%, hydropower 6%, gas turbines 14% and nuclear 23%, with the balance made up by ‘renewables’. However, the continued use of coal is premised on the development and deployment of clean coal technologies such as ‘carbon capture and storage’ (CCS) as well as energy-efficiency interventions while phasing in renewable energy. Shale gas resources would enable the replacement of imported gas with indigenous
(shale) gas and the replacement of power generation from other sources (particularly coal) with gas, which is more environmentally friendly.

Bearing in mind that energy is an input cost to the economy, the IRP 2010 aims to improve South Africa’s global competitiveness, support job creation, improve management of our natural resources, and reduce and mitigate against greenhouse gas emissions in line with our international commitments. The IRP 2010 is aligned to the objectives set in the Long Term Mitigation Scenarios and the commitments made to the climate change imperatives, especially the Copenhagen Accord. President Zuma announced South Africa’s commitment to reduce carbon dioxide emissions by 34% in 2020 and by 42% in 2025, subject to the receipt of financial, capacity and technological support from developed countries. In this context, the IRP 2010 will also serve as an input to other planning functions, including economic development as well as environmental and social policy formulation.

It must be noted that the production of synthetic liquid fuels (and petrochemicals) through the employment of CTL (current capacity of ~185,000 BOE per day) and GTL (current capacity of ~45,000 BOE per day) technologies already contributes about 30% of the total liquid fuels production in South Africa. In a market where local demand has already outstripped domestic production, availability of gas may assist in replacing some of the coal used in CTL (noting that the downstream portion of a CTL plant is essentially a GTL facility), assist in sustaining the operation of the current GTL facility in Mossel Bay, and enable additional liquid fuels production from new GTL plants. In the meantime, South Africa remains critically dependent on imports of oil and refined products.

### 2.3.2 Economics of shale gas production

The development of shale gas in the USA has been so successful that gas prices have declined significantly (with supply now greater than demand). One of the consequences of this success is that it makes the economics of developing renewable energy sources comparatively less attractive. This may delay the broader acceptance of such energy sources as part of that nation’s energy mix. The further consequence then is that ‘dependence’ on carbon-based fuels, although these are
somewhat cleaner, is extended and threatens the objective of reducing global greenhouse gas emissions. In view of the current understanding of the extent of the possible shale gas resource in South Africa, similar concerns may apply here, although in South Africa’s case, our current high dependence on coal may be a mitigating factor.

The potential of shale gas became evident only after the preparation of IRP 2010\(^\text{18}\) and, subject to positive results from early exploration, it may be appropriate to reappraise the potential contribution of gas. Factors such as the time required to complete all the processes to enable exploration and to obtain those early positive results may justify a review of the IRP in 2016 or 2017.

As indicated in 2.2 above, there is considerable uncertainty regarding the extent of potential shale gas resources, so that any interpretation of the implications for national energy security must also be subject to considerable uncertainty. In the face of that uncertainty, the Working Group has elected to use 30 Tcf as the basis for assessing potential impacts, while remaining aware this is essentially an arbitrary decision. However, the main merits of implementing this benchmark are that it is plausible and can be used consistently.

There is currently a shortage of installations capable of undertaking the bulk conversion of coal into electricity in South Africa. This may only be a short-term problem (5 years) but may persist for longer, depending primarily on the economic growth of the country.

The time required to plan and commission a major coal-fired power station is significantly longer than that for a gas-fired plant. In addition, such gas-fired plants are more flexible in operation and can address the higher-cost peaks in demand.

South Africa has undertaken to reduce its carbon dioxide emissions. The carbon emissions arising from the use of gas as fuel account for a fraction of those when coal or oil is used (see Table 1\(^\text{22, 18}\)). Therefore, maximising the proportion of gas in the national energy economy could assist in meeting the objective of reducing carbon emissions.
The establishment of further gas-to-liquids plants would mitigate dependence on imported crude oil, but the carbon emissions of the production process will offset gains that may arise from increasing fuel efficiency in motor vehicles or elsewhere in the economy.

**Table 1: Pounds of air pollutants produced per billion BTU of energy.**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Natural Gas</th>
<th>Oil</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide</td>
<td>117,000</td>
<td>164,000</td>
<td>208,000</td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>40</td>
<td>33</td>
<td>208</td>
</tr>
<tr>
<td>Nitrogen Oxides</td>
<td>92</td>
<td>448</td>
<td>457</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>0.6</td>
<td>1,122</td>
<td>2,591</td>
</tr>
<tr>
<td>Particulates</td>
<td>7.0</td>
<td>84</td>
<td>2,744</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.750</td>
<td>0.220</td>
<td>0.221</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.000</td>
<td>0.007</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Notes: No post combustion removal of pollutants. Bituminous coal burned in a spreader stoker is compared with No. 6 fuel oil burned in an oil-fired utility boiler and natural gas burned in uncontrolled residential gas burners. Conversion factors are: bituminous coal at 12,027 Btu per pound and 1.64 percent sulfur content; and No. 6 fuel oil at 6,287 million Btu per barrel and 1.03 percent sulfur content—derived from Energy Information Administration, Cost and Quality of Fuels for Electric Utility Plants (1996).


The manner in which gas might be deployed in the national energy economy depends on several factors, including the extent and concentration of the resource and its location relative to infrastructure and human settlement nodes.

For example, even if a large resource (1 Tcf) is proven by exploration, if it is far from existing infrastructure (implying additional cost in extending the infrastructure to the site of the gas) or is low density (m³/ha) (implying a need for large numbers of low-productivity wells) the resource may not be economically viable.

Large deposits may support electricity generation through gas turbine plants, or gas-to-liquid plants producing liquid fuels, similar to that at Mossel Bay.

The substitution of electricity and liquid fuels derived from sustainable sources is not economically feasible in the short or medium term. To force their substitution before this is economically justified would force an increase in these input costs, reducing any competitive advantage that South Africa may have. (Another effect could be to further burden a system that is already struggling to compete). Natural gas has the merit of a reduced carbon footprint relative to coal. The extent of this reduction is
however, the subject of debate. Howarth\textsuperscript{30} has suggested that the total emissions from shale gas exploration, production and delivery negate the advantage gained at the combustion stage and may even render gas less desirable than coal. The gas production industry, through the web site www.energyindepth.org, disputes this assertion. The potential of shale gas to reduce our national dependence on other fossil fuels is significant and warrants further investigation, which can only be done by drilling, sampling and testing, as envisaged in applications for exploration rights.

Should exploration be allowed to proceed, it is estimated that the first borehole may be initiated two years after the issuing of new rights and that drilling may take 6–8 weeks per well. A site may then remain ‘active’ indefinitely if gas is discovered, firstly to enable testing (hydraulic fracturing) of the vertical well, and then to enable the drilling of an offshoot with a horizontal section. Testing of the productivity of the horizontal section may take a period of weeks or months to establish a baseline ‘decline curve’ to be used in economic modelling and the prediction of the productivity of nearby wells. The well may then be suspended pending development of a field and connection to a gathering network feeding into a pipeline to the end user. It may take ten or more years for a successful project to progress from the issuing of an exploration right, through the drilling of a discovery well, the drilling of a number of appraisal wells, the development of an economic feasibility plan, the application for and issuing of a production right, the drilling of production wells and the installation of the pipeline infrastructure before gas is delivered to the end user.

2.4 Possible environmental and social implications of hydraulic fracturing and related activities for the different hydrocarbon play types

Given the uncertainty as to whether there is indeed a commercially exploitable shale gas resource, as to where in the Karoo it might be, or the scale of development that it might support, it is not yet possible to make comprehensive assessments of the various impacts such a development might have. However, some generalisations, based on experience in the USA, are possible.
2.4.1 International experience

Simple hydraulic fracturing was introduced in the oil and gas industry in 1947 and, after a slow start, gradually became more sophisticated and reliable as a means to stimulate the productivity of wells in decline and of reservoirs that would not otherwise be economical to exploit. The ability to steer and drill horizontally is a more recent innovation. The convergence of these evolving technologies and the optimisation of fracturing fluids have resulted in the ability to economically exploit gas and oil ‘trapped’ in shales. It is reported that as many as a million wells have to date been subjected to hydraulic fracturing; the number of wells subjected to multi-stage hydraulic fracturing is now in the tens of thousands.

The only domain with a meaningful track record in the use of these methods to exploit shale gas is North America. The first economic exploitation of shale gas resources resulted from the efforts of Mitchell Energy to combine the developing technologies of extended-reach horizontal drilling with multi-stage hydraulic fracturing in the Barnett Shale field in Texas, USA. After much trial and error this technique was eventually successful in the mid-1990s, triggering the expansion of widespread interest in shale gas resources in other parts of the USA. Other factors which led to the commercialisation of shale gas were the relatively high gas price at the time, ease of access to the existing infrastructure of pipelines, and the ready availability of services for the drilling and completion of boreholes.

The composition of the fracturing fluid and the possibility of contamination and pollution of groundwater or surface water have recently been the focus of concern in respect of hydraulic fracturing in the USA. These problems were highlighted in the public consciousness through the film ‘Gasland’, although many of the claims (explicit and implied) have since been discredited. There are relatively few documented cases of pollution resulting from hydraulic fracturing operations and most of those resulted from spills during the surface handling of the constituents or the fracturing fluid, or poor well construction.

As a response to public concerns, a number of studies have been initiated and reports published and new regulations have been introduced, notably those requiring
disclosure of the composition of fracturing fluids. As with other environment-oriented regulations, these vary from state to state.

At the same time, service companies and operators have embarked upon programmes to minimise the potential environmental impacts of their operations by reducing the use of potential toxic additives or replacing them with non-toxic alternatives (as in, for example, Halliburton’s ‘CleanStim’ suite of products).

From the various reports it appears that there are a small number (relative to the number of wells treated) of incidents where fracturing fluids have migrated up the well bore as a result of poor well construction or subsequent failure of pressure integrity. At present there are, however, no documented cases of properly placed hydraulic fracturing fluids migrating through the overlying strata to contaminate groundwater.

In respect of claims of methane contamination of groundwater caused by migration from shale gas wells (in the absence of fracturing fluids) the emerging pattern is that these are generally discredited on closer examination.

There is also indirect evidence of cases of settlement of complaints accompanied by ‘non-disclosure agreements’. The nature of those agreements is such that it is not possible to account for the complaints which were settled under them.

South Africa is not unique in receiving attention as a potential shale gas province. Several other countries have considered applications for shale gas exploration rights and with varying responses. Some countries, such as France and Bulgaria, have imposed outright bans whereas others, such as the UK and Poland, have acknowledged the concerns, but been confident that their regulatory systems would ensure safe operation and have allowed operations to proceed. Many countries have not yet had cause to consider the issue. A brief tabulation of responses to concern about shale gas follows, with a more complete tabulation of responses is attached as Annexure K.
## Brief list of the prominent jurisdictions

<table>
<thead>
<tr>
<th>Allow hydraulic fracturing</th>
<th>Suspend hydraulic fracturing</th>
<th>Ban hydraulic fracturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>Netherlands</td>
<td>North Rhine–Westphalia, Germany</td>
</tr>
<tr>
<td>Australia, Queensland</td>
<td>Australia, New South Wales</td>
<td>Bulgaria</td>
</tr>
<tr>
<td>Canada, Alberta</td>
<td>Australia, Northern Territory</td>
<td>Quebec, Canada</td>
</tr>
<tr>
<td>Poland</td>
<td>USA, New York</td>
<td>France</td>
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<td>Ukraine</td>
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<td>USA, Colorado</td>
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<td>USA, Louisiana</td>
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<td>USA, Pennsylvania</td>
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<tr>
<td>USA, Texas</td>
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</tbody>
</table>

Although bans or moratoria on the use of hydraulic fracturing have been imposed in a number of jurisdictions, the practice continues in at least as many others.

The following extract from the 90-day report\(^4\) of the Subcommittee on Shale Gas and Hydraulic Fracturing reporting to the Secretary on Energy Advisory Board (2011.08.18) is noteworthy:
'One of the commonly perceived risks from hydraulic fracturing is the possibility of leakage of fracturing fluid through fractures into drinking water. Regulators and geophysical experts agree that the likelihood of properly injected fracturing fluid reaching drinking water through fractures is remote where there is a large depth separation between drinking water sources and the producing zone. In the great majority of regions where shale gas is being produced, such separation exists and there are few, if any, documented examples of such migration.'

Both the EPA and the RRC were, at the time of the study tour by members of the Working Group, quite clear that where there have been environmental problems associated with shale gas exploration and production, these have been the result of surface spills or failure to establish and/or maintain the integrity of the well bore, and not directly attributable to hydraulic fracturing operations (B. Kobelski/D. Jackson [EPA] and pers. comm. - J. Tintera [RRC]).

New reports of research into such claims continue to appear. This remains an area of contention between environmentalists and the petroleum industry.

Following complaints from the citizenry of Pavillion, Wyoming, the EPA investigated the water quality of the area and confirmed that pollution indeed exists. Despite the coincidence in time and space of the development of the Pavillion gas field, the EPA was unable to unequivocally state that hydraulic fracturing used in the development of the field was indeed the cause of confirmed pollution. Nevertheless, the various threads of evidence reported were deemed to suggest compelling evidence of a link. However, the potential overlap of zones of hydraulic fracturing and underground sources of drinking water, instances of inadequate casing and/or cementing and the absence of a significant thickness of cap rock to constrain fracture development all appeared to be aggravating factors in this instance. Moreover, the gas extraction industry drew attention to a number of weaknesses in the EPA study methodology.

The aspects of concern regarding hydraulic fracturing onshore (access to water, contamination of potable water resources, visual impact) are considerably less significant in offshore operations.
2.4.2 Land use

The separation of mineral and surface rights immediately results in contention over use of the surface. Disputes between the mineral and surface right holders over the use of the land are bound to occur. The MPRDA seeks to strike a balance between the competing interests of the surface right holder and the mineral right holder by providing for payment of compensation for loss or damage suffered by the landowner, lawful occupier or surface right holder as a result of prospecting or mining operations. Compensation is determined by agreement between the parties, failing which, by arbitration in terms of the Arbitration Act, 1965 (Act No. 42 of 1965) or by a competent Court. The law prohibits unreasonable refusal by the landowner, lawful occupier or surface right holder to allow prospecting or mining operations to occur on the land and further provides for expropriation of the land as a last resort, consistent with section 25 of the constitution of the Republic of South Africa.

The geographic Karoo is not noted as a region of high-intensity industry or mining. Rather, in the section of most interest in relation to shale gas, it is a region of low rainfall (Figure D), which constrains agricultural activity. The region also has few mineral deposits of commercial significance.

Under the Mineral and Petroleum Resources Royalty Act, 2008 (Act No. 28 of 2008), royalty is payable to the State as custodian of the national endowment of minerals and petroleum, as opposed to the surface right holder (as would have been the case under the Minerals Act, 1991 [Act No. 50 of 1991]).

In the case of a conventional oil or gas field extending over more than one right, the owners of all rights encompassing a portion of the field can be required to join in the consolidation or unitisation of the field to enable optimal exploitation of the resource while also protecting the interests of all right holders. This is necessary in the case of conventional oil and gas fields because oil or gas will flow underground towards the nearest extraction point, which may not be within the area of the right from where the oil or gas will start. Although this consideration does not apply to shale gas fields, unitisation should nevertheless lead to reducing the number of surface installations and infrastructure.
In the USA (the Barnett Shale in the Dallas/Fort Worth area of Texas), even though the target shales have been found to extend under areas of human settlement, it has been possible to develop those resources.

Shale gas development would not be expected to affect the whole of the Karoo (see Figure X-1 in World Shale Gas Resources\textsuperscript{38}). Within the zone indicated as potentially prospective, the likelihood that all the shale will be suitable for development across the entire region is extremely low. In basins in the USA where shale gas is exploited extensively, the variability of the shale is such that development is focused only on the ‘richer’ areas. The proportion of the Karoo that may be suitable for shale gas can only be assessed confidently when or if further information becomes available.

However, it can be anticipated that there could be large tracts where the shale is either too shallow or too deep, or does not have suitable characteristics.

Current applications cover approximately 125 000 km\textsuperscript{2}, focused mainly in the south and west of the region and envisage between them less than 30 boreholes in their initial periods of 3 years. Each site will require approximately 2 hectares, will be occupied for only 2–3 months if exploration is unsuccessful and will be rehabilitated immediately upon abandonment. It is a common ‘rule of thumb’ that only one in ten exploration ventures is successful. The location of exploration boreholes has not yet been settled and remains subject to many considerations including logistics. It is also evident that the identity of successful projects is at this stage entirely unpredictable. It is nevertheless possible to describe likely impacts of individual drill pads and production sites by referring to those already operating in the USA.

The distribution of wells is often influenced by local regulations and the spatial extent of rights. For example, in Louisiana in the USA, boreholes must remain within ‘section’ (1 mile square) where they originate — regardless of any technical ability to cross into an adjacent section that might otherwise be legally admissible. A consequence of this requirement is that in productive areas there will be more well pads than would be required in a unitised development, namely (at least) one well...
Figure D: Mean annual rainfall for South Africa.
pad for each square mile section (as in Figure E) whereas it is technically possible to cover 3 or 4 square miles (770–1000 ha) from a single multi-well pad.

There are no restrictions of this type under South African law and the number and the density of well pads required to develop a field can be much reduced. It is becoming increasingly common (in jurisdictions where this is legally permissible) to drain larger areas from such multi-well pads. Because of the way operations are organised and sequenced, the incremental increase associated with each additional well in the space required for a multi-well pad is much smaller than the space required for a single-well pad. The largest part of the cleared sites is required to accommodate the fleets of truck-mounted equipment (Figure G) required for the fracturing process. Moreover, this space is required only once per pad and not repeated for each well to be drilled from the pad, as wells are not fractured simultaneously at a single pad (not least because of the limited availability of equipment). The greatest efficiency is achieved through zipper-frack in which pairs of wells are alternately perforated and fractured using one set of equipment. A multi-well pad for gas production will typically requires approximately 4 hectares.

The overall demand for land to develop a gas field can be managed through regulation requiring the use of multi-well pads.

The potential visual impact of the development of a (shale) gas field has been the source of some concern. Seen from ground level, the visual impact is a product of many factors. The most significant is likely to be the number of sites per unit area (square kilometre). Unlike conventional gas resources in which the extraction of gas at one point can cause flow towards that point from all other points in the reservoir, the extraction of gas from shale essentially affects only the zone of fracturing. As a consequence, it is not necessary to develop the whole of a field uniformly and each section of a field can be developed at a time suitable to the operator.

Installations on the site, particularly where only dry gas is being produced, are inconspicuous. Where liquid hydrocarbons are also produced (Figure F), some
Figure E: Visual impact, aerial view, a section of the Haynesville Shale region, Louisiana, USA. The distribution of well pads (small light rectangles in the band stretching northeast from the southwest corner) in Louisiana is influenced by the constraint that wells must remain within the ‘section’.

Additional equipment is required for separation, but in areas of high relief, the excavated sites may be more distracting. The development of a field would inevitably involve the clearing and levelling of well pads. The impact indicated in Figure E can be seen as a ‘worst case’ scenario, resulting from the specific circumstances in that location and is not applicable in South Africa.
Figure F: Eagle Ford Production facility with liquids separation. The grey tanks at the right each have a capacity of 80,000 litres (500 bbl).

Source: Chesapeake Energy Corporation, 2008

Hydraulic Fracturing of a Marcellus Shale Well, West Virginia

Figure G: An active hydraulic fracturing operation.
In considering whether or where to allow the establishment of drill sites and production facilities, account must be taken of alternative uses of the surface and their overall actual and potential benefits. For example, while the establishment of a solar electricity generation facility may preclude other uses of the surface, it is still possible to exploit gas resources underneath from well pads around the periphery. Access roads could then serve both industries.

2.4.2.1 Observations on land use

a) Multi-well drill pads make more efficient use of land surface than single-well pads.

b) The number of wells that can practically be drilled from a single drill pad partly depends on the geology of the vicinity, but six wells per pad may be used as a minimum expectation in the production phase. Single-well pads are more likely in initial exploration, but these will be widely dispersed.

2.4.3 Water use

Water security is a concern that affects much of South Africa and is particularly acute in the drier western regions, such as the Karoo.

There are three major concerns relating to the potential water use in shale gas exploration and production, namely (1) the volumes of water required in relation to the resources of the region, (2) the potential for contamination of these water resources and (3) the disposal of flow-back and produced water. The mechanisms for the delivery of large volumes of water to and from the well sites represent ancillary concerns.

2.4.3.1 Volumes of water required

a) Use and disposal of water in the volumes expected for the stimulation of shale gas wells can be expected to require a water use licence in terms of sections 21, 37 and 38 of the National Water Act, 1998 (Act No. 36 of 1998) which is administered by the Department of Water Affairs.
b) Each stage of a well to be stimulated may involve, in round terms, as much as 1.6 megalitres (10 000 bbl = 420 000 US gallons); each well may have a horizontal section segmented into 15 or more stages, indicating a gross volume of the order of 24 megalitres (24 000 cubic metres). This usage is not on going and, in the present form of the sector, is unlikely to be repeated. In other words, this is a ‘once-off’ requirement per well. This is equivalent to the volume of water required to irrigate approximately three hectares of lucerne for one year, or the volume produced by a single borehole flowing at 10 l/sec for 30 days.

c) The Karoo is a predominantly dry region which may make sourcing of the required volumes problematic. Viewed in isolation, the volumes of water required to enable the fracturing of shales for economic production seem large (millions of litres). However, when viewed against consumption by other (industry) segments the amounts involved may appear less daunting. Nevertheless, where a threshold determined by the relevant water management authority is exceeded, a water use licence will be required. In the event that hydraulic fracturing is declared a controlled activity, a water use license will certainly be required.

d) It may not be necessary to use fresh water as the basic carrier, since brackish water (for which there is no competition), or sea water may be used. The Railroad Commission of Texas (‘RRC’) stated very clearly that the use of saline water has not yet been demonstrated (pers. comm. - J. Tintera,). While the use of sea water would remove the potential burden on sources of fresh (or brackish) water, it would introduce the risk of effectively sterilising soil in the event of escape from containment systems. It is clear that further research into potential water sources is required.

e) In the event that water other than fresh water is proposed, then substantiation that suitable chemical suites are offered commercially will be required. This may prove an intractable problem, as the susceptibility of shale to an adverse reaction with brackish or salt water depends on the clay types present in the
shale in the region to be exploited and which are not necessarily the same as at outcrop.

2.4.3.2 Contamination of water resources

There is very little information relating to the hydrogeology of the Karoo at depths greater than 500 m. The hydrogeology of the first 200–300 m can be summarised as follows:

a) The sedimentary pile and the dolerite intrusions have a strong influence on groundwater occurrence and dynamics and will have an impact on hydraulic fracturing operations (also see Annexure B). The Karoo sediments consist of sandstone, mudstone and shale which may be metamorphosed locally in the vicinity of contact with the dolerites and water is expected to be present as a mobile phase in the more porous, coarser-grained rocks, such as sandstone. The dolerite sills and dykes, as well as kimberlites that have intruded the Karoo basin, adopt very complex structures and may variously represent barriers to, or fractured conduits for, the movement of groundwater. The western Karoo Basin, where shale gas exploration is envisaged, can be divided into a northern section, intruded by dolerite and kimberlite, and a southern section, devoid of dolerite and kimberlite, but intersected by faults (see Annexure B).

b) The sedimentary rocks are commonly fractured at the contact with the dolerites and water permeates into the fracture spaces. The transmissivity and permeability of these rocks are enhanced where fractures occur — certainly in the near-surface region. As a result, Karoo aquifers are generally classified as ‘fractured rock’ aquifers.

c) In the context of geological time, the fluid column permeating the sedimentary rocks is generally continuous and self levelling, with pressure increasing uniformly with depth. The water nearest the surface is generally ‘fresh’ as a result of replacement or recharge from the surface. With increasing depth, the content of dissolved minerals generally increases, decreasing the utility of
the water as a resource for human consumption. Economic water extraction depends on the yield of a borehole and therefore on the transmissivity of the aquifer (e.g. fractured sandstone). As a consequence, although water is present throughout the system, extraction from aquifers for human use is generally limited to depths of a few hundred metres and zones of enhanced porosity and permeability (transmissivity).

d) The hydraulic fracturing of a reservoir involves the injection of fluids into the reservoir rock. In the case of shale gas, that rock will typically be a carbon-rich shale lying between 1500 and 4000 m below surface. The target zone then is normally at least 1000 m below any known groundwater resources. The proportion of the injected fluid which flows back after the fracture system has been created is very variable but is often less than 50%, implying that the larger proportion remains in the fracture system so created. The induced fractures represent the path of least resistance for the flow of any fluid in their vicinity — the alternative path, through the overlying strata, would present greater resistance for the remaining injected fluid to find its way upward to contaminate an aquifer. This aspect is treated in some detail in a report by ICF International\(^{32}\) as one of the enquiries by New York State government in its assessment of the likely environmental impacts of shale gas development in the state. The section on subtask 1.2 ‘Subsurface mobility of Fracturing Fluids and Additives’ is particularly pertinent.

e) There are two possible exceptions to the above scenario in the case of the Karoo, namely (1) the uncertain effect of dolerite and kimberlite intrusions (see 2.4.2.(b)), and (2) pre-existing fractures related to the Cape Fold Belt tectonics. Such fractures may either be open or closed owing to the confining pressure of the overlying and adjacent rocks. One of the properties and functions of the ‘mud’ (see glossary) used in drilling is to fill and block minor fractures. In the case of major open fractures, their presence will be detected by loss of drilling mud from the system, and remedial measures will be taken to block them. It is also possible that the pressure of hydraulic fracturing can re-open such fractures to accept the fluid and trigger movement (minor
tremors) or, in more severe cases, preclude the build-up of pressure to the point where new fractures are initiated. The pressure of the injected fluid is monitored constantly during fracturing for indications of such anomalies. Microseismic monitoring is also useful for observing the development of the fracture network as it happens.

f) The targeted shales in the Karoo are overlain by very thick and tight, less carbonaceous shale deposits, such as the Tierberg Formation (see Annexures A and B), which are up to 800 m thick in places and are likely to minimise the vertical migration of natural gas. However, the possible existence of fracture systems that may facilitate gas migration, as described in (e), cannot be overlooked.

g) Exploration in the northern, dolerite affected sector (see 2.4.2.4 [b]) will present additional challenges. There is sparse information on the structure of deep dolerite intrusions and associated deep groundwater and water strikes. Groundwater exploration at shallow depths has shown that open fractures can extend laterally for hundreds of metres at the base of dolerite sills, at least to a depth of 250 metres\(^{13}\). These semi-deep aquifers are confined and not directly linked to the overlying shallow fractured aquifers. However, vertical and horizontal drilling may create an artificial connection between these aquifers and leaking of hydraulic fluid or gas in the event of, for example, improper grouting of casing. This problem may be overcome if sufficient investigation is carried out on these intrusive structures at depth.

h) Extended-reach horizontal drilling, as practiced in shale gas extraction, commonly exceeds 1500 m. In the case of the Karoo, such wells might therefore intercept a dolerite dyke, a kimberlite dyke or a fault, which raises the question ‘Could such a dyke or fault act as a conduit for deep hydraulic fracturing fluid to the surface?’ Dykes are primary targets for groundwater exploration at very shallow depth (30 m in the weathered zone) or semi-shallow depth (200 m) where multiple water-bearing fractures may be intersected. At depths greater than 1500 metres, the hydrogeological characteristics of dykes and faults are unknown and would require
investigation and/or careful consideration during the preparation of a well for fracturing.

i) There are about 16 naturally occurring warm water (thermal) springs (26–41°C) in the main Karoo Basin south of latitude 28°S. Only a few deep fractures exceeding 700 m in depth propagate to the surface, as evidenced by these warm springs. For the main Karoo Basin, none are known from depths exceeding approximately 1000 m. Hydraulic fracturing will only be undertaken below these depths, so the possibility of fracturing fluids propagating to the surface through the sedimentary pile will be negligible.\textsuperscript{32}

2.4.3.3 Disposal of flow-back and produced water

a) The proportion of fracturing fluid recovered (‘flow-back’) is often significantly less than 100\%\textsuperscript{49} and occasionally zero (pers. comm. - Paloma Resources,) but may nevertheless represent hundreds of thousands of litres of liquids that are unlikely to be suitable for discharge into the surface run-off system which is, in any event, largely dry. Re-use is increasingly being embraced by the industry. Surplus frack fluid must be disposed of in a manner that will not affect freshwater resources. The discharge and disposal of flow-back fluids will be subject to the provisions of the National Water Act.

b) The low return rate of frack fluid to the surface (as low as 0\%, pers. comm. - Paloma Resources,) in the Eagle Ford play in Texas is attributed to imbibition of water by the shale. This may also be a factor in other plays.

c) In recognition of the desirability of reducing the risk associated with frack fluids, at least one major service provider is offering a system that utilises components with reduced environmental impact\textsuperscript{26}. The introduction of systems with reduced environmental impact is a process that can be expected to continue.
2.4.3.4 Observations (water use)

a) The volume of fluid required for the fracturing of fully developed shale gas production wells is in the order of millions of litres.

b) There are alternatives to the use of potable water as the base fluid.

c) The dolerite and kimberlite intrusions in the northern part of the western Karoo Basin do not have uniform characteristics and may act either as conduits fracturing fluids or as barriers to flow. Their attributes at depths greater than 500 m is unknown.

d) The southern part of the western Karoo Basin has a different structural framework which is characterised by listric faults.

e) Extra care should be taken to understand these aspects in any exploration for shale gas in the Karoo Basin.

f) The volumes of flow-back (a short-term issue) are likely to be millions of litres.

g) The volume and chemistry of produced water (a long-term issue) remain be determined. The rate of produced water flow is expected to be only a fraction of the flow-back rate.

h) Experience in the USA suggests that treatment facilities for flow-back and produced water may need to be purpose built.

i) Pollution of surface water is a risk in any industrial process and can be minimised by the implementation of industry-specific regulation.

j) The risk of the pollution of groundwater can be minimised by enforcing best-practice regulations in the construction of the wells.

2.4.3.5 Regulation and monitoring

a) The need to minimise or eliminate the potential impact on other users suggests a need for extensive hydrogeological studies (in collaboration with
the Department of Water Affairs) before exploration and production activities begin.

b) Deep hydrogeological investigations and groundwater modelling will need to be completed during the initial exploration phase in order to improve understanding of the potential mobility of subsurface fluids, and particularly the influence of intrusives (dolerites and kimberlites) and fractures.

c) It is proposed that the regulation and supervision of all oil and gas operations be improved to more effectively preclude the possibility of environmental incidents.

d) In the event that hydraulic fracturing is approved, the Working Group proposes that it be made a requirement to disclose all additives to the regulatory agency before the commencement of each job.

e) It is clear that the rigorous adherence to construction practices ensuring the integrity of the well bore (including isolation of sources of groundwater) will minimise the potential for pollution incidents. This can be achieved by encoding industry best practice in the regulations (such as the isolation of fractures, high transmissivity zones or any natural or artificial conduits for groundwater). Equally, if hydraulic fracturing could effectively be done using water to which no potentially toxic substances or chemicals inappropriate to a source of potable water have been added, a large part of the current concern would be eliminated. The service industry recognises the importance of this imperative and is working towards achieving this goal (see for example CleanStim\textsuperscript{28}).

2.4.4 Noise/air pollution

Hydraulic fracturing does not directly give rise to noise. The noise associated with the process arises from the operation of an array of high-pressure pumps powered by internal combustion (diesel) engines.
Typically, all equipment and materials are delivered to the site by road. This can result in several hundred individual transits by heavy trucks over a period of weeks or months, depending on the number of wells at the particular site. Existing roads will need to be improved and it is possible that new roads to specific sites may need to be developed.

The following observations are based on visits to operating sites during the study tour (Annexure J). On-going production generates almost no noise. The pressure of produced gas is generally sufficiently high to preclude the need for compressors to increase the pressure up to the operating levels of the transmission pipelines (in contrast to CBM where the gas pressure is generally low). Drilling, fracturing and completion operations are noisier, but are generally short term (6-8 weeks per well). However, noise levels may become problematic in the case of multiwell (6 or more) pads. Although the industry is accustomed to 24 hour operation, continuous operation is not essential to success or safety and is primarily informed by economic factors. Drilling and completion operations visited were not, from our subjective point of view, regarded as likely to be intrusive. The sparsity of vegetation (necessary for noise screening and absorption) in the Karoo may be off-set by the low population density. Moreover, a review of specific regulations in other jurisdictions may be fruitful.

Dust control is a normal part of the operation of drilling and production sites. In Pennsylvania, where the working area is required to be covered by a dual-purpose membrane (absorbent upper layer and impermeable lower layer), dust control is minimised. The nature of the methods and waste handling procedures used is such that dust arising from operations is limited (there are no large piles of waste rock fragments or spoil heaps as are the case in mining). Dust arising from vehicular movement on un-sealed roads may be the greatest challenge. In cases where water must be delivered to the operational site by road tanker, it is likely that hundreds of trips over a period of weeks will need to be made. This, as well as the associated noise and social disruption, may require special consideration.

Fugitive emissions: Quantities of various gases, including methane, carbon dioxide, oxides of nitrogen and volatile organic compounds, may be vented to the
atmosphere from well completions, flare stacks, transport vehicles, operating equipment etc. The nature of the gaseous emissions depends on factors such as the extent of the fracturing job, the equipment used and trucking requirements. The EPA appended updated estimates of greenhouse gas emissions attributable to the completion and work-over of unconventional gas wells as Appendix B to a published technical support document on revised reporting requirements\textsuperscript{53}. Regulatory controls for application in South Africa must be further investigated.

2.4.4.1 Observations (noise/air)

a) Noise, dust and damage to dirt roads arising from the numerous transits by heavy vehicles bringing equipment and materials to an operational site are potential problems, but mitigating measures may be imposed through the EMP.

b) Emissions from exploration drilling and completion operations will normally be limited to the exhaust from internal combustion engines providing power for the various mechanical and hydraulic processes. Any methane produced during testing of exploration wells would be flared.

2.4.5 Naturally occurring radioactive material (NORM)

In production, a limited amount of formation water flows to the surface with the gas. That water is expected to be somewhat saline and to contain a variety of dissolved minerals which will precipitate out under surface conditions. The dissolved minerals, which vary from field to field, can include trace amounts of NORM, with the consequence that scale and sludge build-up inside the pipework, tanks etc. of the production infrastructure may result in a concentration of radioactive materials. (See for example the web site \url{www.world-nuclear.org}). Most oil and gas production activities are affected by this problem to varying degrees, from region to region. Exposure to sources of high radioactivity can be damaging to human health. This risk has been identified\textsuperscript{26} and research to date indicates that although NORM may accumulate in this manner the intensity of radiation remains below safe limits and procedures have been developed to manage this risk. Bearing in mind that this
industry segment (shale gas production) is relatively new, it is recommended that the issue be re-visited when there has been more time for the effect to become pronounced.

There are, however, published guidelines for the management of NORM in the oil and gas industry\textsuperscript{37} where monitoring indicates that there has been a potentially toxic build up. These precautions form part of the standard provision of care in the oil and gas industry and are usually necessary only during the production stage. Requirements for baseline and on-going monitoring would be imposed on the explorers.

\textit{2.4.5.1 Observations (NORM) }

a) The risk that radioactive material may accumulate in the facilities used in oil and gas production can easily be managed through routine monitoring and facilities maintenance.

\textit{2.4.6 Induced seismicity and subsidence}

During the course of our investigations a new concern emerged — the potential for earthquakes arising from hydraulic fracturing operations. This possibility, (that the high-pressure injection of fluids underground may activate existing fractures enabling release of pre-existing stresses in the rocks thereby giving rise to seismic events) came into focus as a result of reports of two low-intensity seismic events (measuring less than 3 on the Richter scale) in the vicinity of a hydraulic fracturing operation in Lancashire in the UK. While events of this magnitude will frequently go unnoticed, the scale of events arising from such a mechanism will depend on the regional stress regime. The operator commissioned an independent study\textsuperscript{17} which concluded that (1) the events were real but not of sufficient magnitude to cause danger to health or property and (2) the circumstances that gave rise to them were very unusual and unlikely to be repeated. The study also concluded that the amount of energy injected into the earth through fracturing operations is not in itself sufficient to cause significant seismic events, but may be sufficient to trigger events in areas already subject to natural stresses and which are therefore predisposed to the occurrence of...
earthquakes, even very minor ones. This study and its conclusions are discussed in more detail in Annexure C, but the overriding conclusion is that in a region of low natural seismic activity, such as the Karoo, the risk of hydraulic fracturing triggering seismic activity possibly posing a risk to health or property is extremely low.

The potential for subsidence resulting from the extraction of material from the subsurface has also been raised. There are well-documented examples of subsidence associated with the extraction of oil and gas. See for example, ‘Chapter 8 — Reservoir compaction and surface subsidence’ in the North Sea Ekofisk Field, in Developments in Petroleum Science, Vol. 41, 1995. However, such occurrences are relatively unusual. Subsidence may be expected to occur uniformly across an area which is susceptible to this hazard. Moreover, subsidence is limited in vertical extent and not disruptive or dangerous the integrity of surface structures.

According to Wiborg and Jewhurst (1986)\textsuperscript{54}, reservoirs where substantial subsidence has been reported produce from around 1500 m or shallower.

\textit{2.4.6.1 Observations (Induced seismicity and subsidence)}

a) Hydraulic fracturing operations may trigger earth tremors in areas that are already prone to such events, but the increased risk of seismic events of sufficient magnitude to constitute risk to health or property arising from these operations is negligible.

b) The risk of considerable compaction and subsidence resulting from the extraction of gas during shale gas operations is very low and the risk that such subsidence may be sufficiently abrupt or uneven to constitute a serious risk to health or property is negligible.

\textit{2.4.7 Socio-economic considerations}

Consideration of the potential socio-economic impacts of a proposed course of action is essential in the decision-making process. South Africa is presented with applications for exploration rights focusing on shale gas over large parts of the Karoo which can eventually lead to a requirement for hydraulic fracturing operations to
determine the commercial viability of any discoveries. At this stage, the existence of commercially exploitable reserves of shale gas in the Karoo is nothing more than a theoretical possibility — an interpretation based on a small number of imperfect data points. The area covered by the applications is approximately 125 000 km² and encompasses the towns of Aberdeen, Beaufort West, Cradock, Graaff-Reinet, Noupoort and Sutherland, as well as vast tracts with very low population density. Although there is no way to predict whether, or indeed where, economically exploitable reserves might be located in this large area, some economic modelling has been done. Econometrix has considered two scenarios, i.e. 20 and 50 Tcf of economically exploitable reserves, whereas the Working Group has used 30 Tcf. These estimates all indicate that such developments would be economically significant on a national level, materially affecting income tax and royalties payable to the fiscus, GDP and the balance of payments, as well as providing several thousands of permanent jobs. The societal implications of such developments are more difficult (impossible) to assess at this stage precisely because the location of these possible developments is as yet unknowable. Nevertheless, some high-level comments have been made in this regard. Prof. Pretorius of Nelson Mandela Metropolitan University has provided supporting commentary in respect of hydraulic fracturing (Annexure E) and Associate Professor Leiman of University of Cape Town has provided a critique of the work by Econometrix. In addition, Professor Leiman has concluded that if the modelled volumes of gas were to be proven, and taking the gross economic activity of the region as R200 million per annum then, if reduced to its most abstract level (total sterilisation of other economic activity by shale gas production), then the shale gas production would have greater benefit to the nation (Annexure F).

Potential applications of gas: The specific outcomes for the deployment of commercially produced gas depend upon a host of factors, but the easiest to deal with are the location of the producing field relative to infrastructure and the scale of the reserve. While the gas-to-liquids plant at Mossel Bay was launched with a reserve of approximately 1 Tcf of gas, it is entirely feasible that smaller fields could be developed economically. Based on the optimistic assumptions set out above, development of shale gas may, for example, facilitate the addition of the equivalent
of 30 GTL plants to the national economy (perhaps 48 000 jobs in GTL plants, several thousand more long-term jobs in the drilling and field maintenance industries).

Another common use of bulk gas is electricity generation. Open- or combined-cycle gas-turbine generators (almost a commodity in themselves) could be used individually or in groups to tap fields of various sizes starting from considerably less than 1 Tcf. Proximity to the power line corridor from Welkom in the Free State through De Aar and Beaufort West to Cape Town would suggest that power generation may be a highly propitious venture. Other high-intensity energy users may be persuaded to convert from electricity to gas if the discovered reserves present the probability of long-term supply on terms sufficiently attractive to justify the cost of conversion.

Co-ordinated policy development between the Departments of Mineral Resources, Energy, Water Affairs and Environment Affairs, the National Planning Commission (and possibly the National Treasury) can be used to guide the use of gas to meet national priorities.

2.4.7.1 Societal impacts

The socio-economic impacts during the exploration phase will be minor, temporary and localised. If and when a discovery is confirmed, uncertainties about the location and scale of potential production operations will quickly be removed at which point a meaningful socio-economic impact assessment must be undertaken.

South Africa as a whole is a water-stressed country, especially in the western part of the potentially prospective area. Water availability may be a constraint for not only drilling and completion operations but also for the operation of facilities consuming gas in the immediate vicinity of the Karoo. This may lead to the transmission (by pipeline) of gas to areas where water is more readily accessible, such as the coast. Employment opportunities arising from the development of shale gas may then not be focused exclusively on the immediate vicinity of the producing field. Gas piped to PetroSA’s GTL plant could extend the life of this installation considerably.
Although potential employment opportunities are recognised, most jobs (directly from shale gas exploration and production) are likely to require specialised skills and knowledge which may not be available locally (since onshore exploration is not yet well developed in this country and hydraulic fracturing even less so) and therefore planning around the enhancement of local skills in the upstream petroleum sector is crucial for the country to avoid operators having to ‘import’ all skilled labour.

An influx of population to drilling and production areas may result in significant demands for housing and this may initially be seen as a positive impact owing to the concomitant revenue generation and potential economic growth for the Karoo region. However, in the long term, and taking into account the current demographics of the region, the local community (particularly the less advantaged component) may find themselves priced out of the accommodation market. This has already been experienced in fast-growing mining towns such as Rustenburg and Lephalale where there has been a trend of escalating property prices. Currently the trend is affecting North Dakota in the USA where a boom in shale oil production is underway. As a result, an increase in informal settlements may occur, exacerbating disparities which are already a major social issue in South Africa. In addition to the demand for accommodation and related facilities, other amenities such as water supply and sewage facilities may require upgrade and hence limited access to services may occur.

Over and above potential employment opportunities, the state would benefit from taxes and royalties. Revenue (sales and sales tax) may also be generated from direct and indirect supplies from the retail industry (although the majority of drilling and production equipment would inevitably be sourced from abroad), food services, hospitality and the housing industry.

Trucking activities associated with shale gas development would lead to an increase in traffic and may also result in the disruption/deterioration of public and private roads and associated infrastructure such as bridges. Although no in-depth evaluation of the capacity of the existing roads in the Karoo has been done, it is seen as unlikely that these components were designed to carry the volumes of traffic (including mass) associated with shale gas development. Roads are currently seen
to deteriorate in coal mining areas where trucking is used intensively for distribution. An increase in traffic may also result in an increase in accidents (as a result of potholes and damaged roads) and noise pollution.

The Karoo region is known to have potential for tourism owing to its aesthetics, heritage and natural resources and therefore an influx of population to the area as a result of gas exploration and production may result in a perceived loss of a sense of community, not only for the potential tourists but also among the local population. This generally applies to any development that has the potential to change or tarnish the characteristics and scenic beauty of an area. This was also one of the issues that were raised during the survey on socio-economic analysis for the Marcellus Shale Development in the USA in 2010. However, with proper planning and avoidance of certain areas, such a potential impact can be mitigated without negatively impacting on tourism.

Public health associated with water quality (from potential migration of methane to water resources, surface spillages and the management of waste water) and gaseous emissions is a key social issue that needs to be addressed by enhancing legislation governing site infrastructure, well design and construction, and ensuring the regular monitoring of site activities.

2.5 The existing regulatory framework to identify any shortfall or omission with regard to proposed activities

The consideration by the Working Group of hydraulic fracturing as a technique for the exploration for, and production of, oil and gas in South Africa was guided by the Constitution. Section 24 of the Constitution provides that everyone has the right to “secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development”, and that legislative and other measures must be enacted to ensure this fundamental right.

It is not unusual in other countries or states for different aspects of exploration to require separate permitting. The number of separate approvals, each with its own requirements, varies from one jurisdiction to another, depending on the arrangement
of regulatory responsibility across Departments, and levels of decentralisation (national, provincial, municipal).

### 2.5.1 Legislative framework

In South Africa, exploration for, and production of, oil and gas is regulated by the following key legislative instruments, all of which are geared to give expression to this fundamental right.

a) **Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) (MPRDA)**

Section 39 of the MPRDA provides that any person who applies for an exploration or production right must conduct an environmental impact assessment and/or submit an environmental management programme. Such a right becomes valid only on approval of the associated environmental management programme.


NEMA establishes a general framework for environmental law by, *inter alia*, prescribing national environmental management principles that must be applied by state institutions when making decisions that may have a significant impact on the environment. Section 2(1) of NEMA provides that the principles set out therein apply throughout the Republic to the actions of State that may significantly affect the environment.


The purpose of this Act is to ‘ensure that the nation’s water resources are protected, used, developed, conserved, managed and controlled’ taking into account, *inter alia*, the basic human needs of present and future generations, equitable access to water, social and economic development, the public interest, the growing demand for water, ecosystems and biological diversity and international obligations.

d) **Waste/waste water Management**
With the exception of nuclear and mining waste (residue deposits and stockpiles), waste management in South Africa is generally regulated by the National Environmental Management: Waste Act, 2008 which is administered by the Department of Water and Environmental Affairs (DWEA). This statute provides norms and standards for regulating the management of waste by all spheres of government, licensing and control of waste management activities, remediation of contaminated land, compliance and enforcement measures, etc.

Waste management activities associated with hydraulic fracturing that may require a waste management licence include, but are not limited to, the following:

a) Storage, including the temporary storage of general and hazardous waste;
b) Re-use, recycling and recovery of general and hazardous waste;
c) Treatment of general and hazardous waste including effluent, waste water or sewage; and
d) Construction of facilities and associated structures and infrastructure.

Concern has been raised that the existing regulatory framework may not be adequate to deal with all the implications of the process. An initial analysis has been carried out and gaps identified — see Annexure N.

The existing regulatory framework of the upstream petroleum industry in South Africa operates at a high level and relies to a large extent on (1) the principle that administrative decisions should err on the side of caution and (2) reference to other Acts (National Environmental Management Act, Mine Health and Safety Act, National Water Act, Astronomy Geographic Advantage Act) administered by other Departments as well as the right of the regulator to require submission of documents not otherwise specified in regulation.

Regulation can be divided into several areas, the most obvious being concerned with environmental protection. However, regulation does not function in isolation; rather it is closely linked to operators’ practices. Regulation may stipulate requirements in respect of workers’ health and safety, well planning and construction and the optimal extraction of hydrocarbons.
Several jurisdictions with mature regulatory systems governing the upstream oil and gas industry have had no difficulty embracing hydraulic fracturing in shale gas exploration and production mainly because these practices are not revolutionary, but rather have evolved from established procedures. In order to address public anxiety regarding pollution risks, rules requiring disclosure of the composition and volume of fracturing fluid are being introduced.

There are several jurisdictions with mature regulatory systems governing (onshore) oil and gas operations which may be adapted for application in South Africa. (Colorado, Louisiana, Texas, Pennsylvania in the USA, Alberta in Canada, and possibly Queensland in Australia). This will have the dual benefit of providing assurance to the public and predictability for investors.

It is suggested that a comprehensive review of the adequacy of the existing regulatory environment as it applies to oil and gas exploration and production generally, and hydraulic fracturing specifically, be undertaken. Based on our understanding of the regulatory system in Texas, for example, it is recommended that a more detailed and specific system of regulation be put in place together with mechanisms for co-ordination between the various interested Departments to ensure integrated and consistent enforcement.

Any plan to augment the regulation of the subject activities must include provision to augment capacity for enforcement within the relevant agencies, as regulation without capacity for enforcement serves only to undermine the credibility of regulatory systems in general.

2.5.2 Observations (regulatory framework)

The South African regulatory regime requiring separate permits from a variety of regulatory bodies dealing with different aspects of the exploration and production process is not unusual.

There are areas of regulation that would benefit from augmentation.
There are several well-developed and readily accessible regulatory systems which could be referenced in a bench-marking exercise and as a source of material for new regulations.

A programme to research and implement a more detailed and specific system of regulation will be initiated as a priority. (See Annexure N).

2.6 The economic implications of a ban, moratorium or stringent environmental regulatory measures on hydraulic fracturing

Hydraulic fracturing is an essential activity in the production of unconventional petroleum. A more reliable estimate of the potential resource in the Karoo is therefore essential in order to evaluate the implications of a total or partial ban on hydraulic fracturing.

The effects of a ban, moratorium or stringent regulation can most effectively be expressed as reduction of economic opportunity balanced against the saving of costs arising through avoidance of risk (associated with environmental hazards).

Based on current estimates of the scale of the resource, it can be said that shale gas has the potential to make a major contribution to the national energy economy and consequently to GDP. The potential technically recoverable reserve has been assessed at as much as 500 Tcf: PetroSA’s GTL project, which meets approximately 5% of the national liquid fuel requirement, was launched based on a reserve of 1 Tcf. However, the ultimate economic potential depends on many factors including scale of proven reserve, depth to the shale, productivity of each well, distance from end user and the ultimate use for the gas.

A ban on hydraulic fracturing would (1) prevent improvement of the understanding of the real extent of the potential resource, (2) have the potentially unintended side effect of hampering the development of coalbed methane resources elsewhere in the country, and hydrocarbon resources in low-permeability reservoirs other than shale, and (3) remove the potential economic benefit to severely deprived communities in the Karoo. Without a more robust assessment of the extent of the resource, it is not feasible to assess the potential economic impact meaningfully.
The potential cost to the people of South Africa and the national economy of the environmental hazards that may be associated with hydraulic fracturing cannot be assessed at present. It is not clear that there is a body of reliable risk data based on current practices, even in the USA which has the longest history of use of this method. Industry practices are changing in the face of public pressure, largely reflected in the increase of regulations, as in Texas, Ohio and Colorado. If the method is to be allowed in South Africa then it must be subject to current industry best practice embodied in regulation under one or more statutes — certainly the MPRDA, probably the National Water Act and possibly the NEMA.

A moratorium on the use of the hydraulic fracturing may be justified for a limited period, pending (1) a decision by the Minister in consultation with other members of Cabinet on whether to allow or ban the technique and (2) the promulgation of a more detailed regulatory regime. The negative effect of this measure is unclear, but it may lead some applicants to abandon applications or rights on the basis that it would not be prudent to begin or continue investment in exploration when there is no certainty that the technique, which is crucial to the exploitation of resources in low-permeability reservoirs, will eventually be allowed. This may have a short-term effect; if hydraulic fracturing is indeed eventually banned no loss will have occurred and if eventually approved then the new certainty is expected to attract new applicants.

With regard to the regulation of oil and gas operations generally, and hydraulic fracturing in particular, there is no reason why South Africa should be expected to allow less rigorous regulation of these activities than in jurisdictions with a mature industry. Regulation as outlined above should not be seen by the industry as unduly restrictive — generally it is expected to represent the codification of industry best practice.

2.6.1 Observations (economic impact of ban or moratorium)

a) There would be no direct cost to a ban on hydraulic fracturing.
b) Such a ban may, however, damage South Africa’s image as a destination for investment.

c) The failure to investigate the potential of shale gas would remove the possibility to provide relief from dependence upon imports, etc. The extent of this ‘opportunity cost’ is unquantifiable.

2.7 Infrastructure and market limitations in respect of gas and their effect on the viability of the resource

One of the factors that enabled the success of shale gas production in the USA was the existence of an extensive network of pipelines into which the gas could be delivered with the minimum of investment in additional infrastructure (see, for example, Figure H22). At present this is not, however, true for the area where exploration for shale gas in South Africa is proposed. In fact there are no gas pipelines in or near the area. The only significant infrastructure in the region is the series of electricity transmission lines that connect the Western Cape to the generating hubs in Mpumalanga (Figure I). This suggests that, given sufficient resources, the establishment of gas-fired open- or combined-cycle gas turbine (OCGT or CCGT) power stations would be the first logical application of any gas discovered. Such power installations would have the additional advantage of relieving the capacity constraints coupled with the flexibility of operation of gas turbine systems. For higher volumes of gas, pipeline transmission systems to the larger coastal markets will be economically feasible, enabling the siting of CCGTs in areas with access to sea water for cooling.
Figure H: Major natural gas transportation corridors in the United States and Canada, 1997.

However, if the EIA assessment is even remotely accurate, the extent of the resource would probably justify extensive infrastructure development. The SASOL, iGas and CMG joint venture has found it economic to pipe gas from Pande/Temane in Mozambique to the SASOL CTL plant in Secunda, somewhat further than the distance from almost anywhere in the Karoo to PetroSA’s GTL plant in Mossel Bay. Foreign direct investment can be attracted to fund gas infrastructure under a liberal regulatory system.

Once the infrastructure has been developed for core projects, smaller, incremental projects can be commercialised for a wide variety of markets, such as simple heating fuel or, as in the proposed development in the Welkom area, as alternative fuel for motor vehicles operating in a limited range. Such incremental developments can typically be executed by smaller companies with lower overhead operating costs.
Figure I: Trans-Karoo power-line corridor, application areas and areas protected by the Astronomy Geographic Advantage Act. Power lines are shown in turquoise.

### 2.7.1 Observations (market and infrastructure limitations)

a) The minimal development of infrastructure in the prospective region represents a potential hurdle to development.

b) At the same time, this could present an opportunity for public investment in infrastructure to facilitate further development.
c) Further work: In order to assess the potential market for shale gas, Eskom has offered to provide a scenario-based market analysis as part of the cost benefit studies of shale gas, including key driving factors such as market regulation, government policy, global energy prices, climate change initiatives, evolution of emerging technologies, skills availability, water scarcity and access to finance.

2.8 Implications for astronomy research projects for South Africa

The low level of development and population density in the Karoo makes it ideal as a site for astronomical observation. This fact formed the basis of South Africa’s bid to host the ‘Square Kilometre Array’, an international project of great scientific importance and with considerable financial implications for the region. In order to preserve this advantageous state, Parliament has enacted the Astronomy Geographic Advantage Act, which provides the Minister of Science and Technology with the power to restrict or prohibit a variety of activities, including prospecting (exploration) and mining (production).

Although not clearly defined at this very early stage in the process, it is suggested that the impacts of shale gas exploration and production on radio astronomy (Square Kilometre Array etc.) can be managed to accommodate both, though it is expected that there will be some areas (e.g. up to 30 km radius from an SKA station) where it may not be possible to make provision for both activities, in which case petroleum exploration and production activities will be precluded. A more detailed analysis is required but can only be carried out when a more complete understanding of the equipment and methods to be used is available (Annexure D).

2.8.1 Observations (astronomy research projects)

a) The award of the major portion of the Square Kilometre Array project to South Africa need not lead automatically to the preclusion of shale gas operations across the whole of the potentially prospective area.
3 SYNTHESIS

The full impact of shale gas production in the areas of the USA where it is most intensively practiced is the subject of on-going evaluation. Because the process is still relatively new (10 years, see for example Figure J from a proprietary report by Wood MacKenzie), the methods and materials used are still evolving to meet economic and public demands. This condition will almost certainly persist for some time so that any regulatory adjustments should be structured to accommodate a certain measure of evolution.

Figure J: Evolution of shale gas plays in the USA.

Although there is some evidence of the pollution of water sources with industrial chemicals from surface spillages and/or migrating gas resulting from poor well construction or failure to maintain well bore integrity, these problems are not specific to hydraulic fracturing, but apply to the upstream oil and gas sector generally.
It would therefore be helpful to augment the regulatory framework applicable to the upstream petroleum industry as a whole. Additional regulation may be required under several statutes, not all of which will be administered by the Department of Mineral Resources.

In the absence of an operative industry, any assessment of cumulative impacts must depend either on the use of proxies or data from other jurisdictions which, in effect at this stage, are those in North America.

Any assessment of the environmental and economic risks and opportunities that may arise from shale gas development in South Africa is necessarily tenuous at this time. More quantitative data on the distribution and richness of the target shales, as well as the complications arising from dolerite and kimberlite intrusions, is required to reduce these uncertainties. Such data can only be acquired by drilling boreholes and collecting and analysing samples of the shales. It is possible that such further data would show that there is no resource that is suitable for commercial exploitation. If, however, it becomes clear that there is real potential, as that potential is clarified, it will be possible and necessary to evaluate the potential socio-economic impacts in a more meaningful way.

There is a need to augment the regulatory framework on several fronts, and such augmented regulation will include provisions applicable to the upstream petroleum industry generally, possibly extending to the general regulation pertaining to the drilling of boreholes and the introduction of foreign material into the subsurface.

Provided that there is appropriate collaboration by the industry on mitigating measures, the existence of the Astronomy Geographic Advantage Act and the Square Kilometre Array project need not represent cause to prohibit the development of a shale gas industry across the region generally. It is emphasised that the potential radio-frequency interference profile of each site must be assessed for its likely effect on radio astronomy, and that no general approval should be expected.
A summary of concerns and possible mitigatory measures is tabulated in Annexure O.

4 OPTIONS CONSIDERED BY THE WORKING GROUP

There is a spectrum of possible actions on hydraulic fracturing and shale gas available to the Minister, ranging from an outright ban to unconditional approval. These are termed Options 1 and 2 respectively. Neither of these extremes is deemed appropriate.

The Working Group has therefore considered a number of intermediate options under the general heading of Option 3 — Qualified Approval. The options considered are set out in Annexure G and include:

3A Postpone hydraulic fracturing for a fixed period of time to learn more from international experience;

3B Postpone hydraulic fracturing for a defined period to allow experimental work;

3C Approve hydraulic fracturing under augmented regulation and close control;

The possibility of commissioning a joint venture (Option 4A) to investigate the implications of hydraulic fracturing to be executed by academia, funded by industry and co-ordinated by government subject to the controls set out in option 3C was considered, but despite certain advantages, did not appear likely to yield the required data in a workable time frame.

The desirability of a Strategic Environmental Assessment (SEA) was also considered (Option 4B). While it is recognised that an SEA would be desirable in the event of significant discoveries, such an assessment would be premature at this time because of a lack of clarity regarding the scale and location of any possible production projects. If exploration proves successful then the data necessary to inform an SEA will begin to accrue.
The potential positive and negative aspects, including different opinions of members and invited experts relating to each option, were considered and are set out in Annexure G. It must be noted that the invited experts only attended one or two of the meetings of the Working Group, and further wished to record that their opinions did not necessarily represent the institutions from where they are currently operating.

After consideration on how best to achieve with the least risk the increased certainty regarding the existence and extent of a potential economically exploitable resource, the Working Group has settled on recommending Option 3C.

Any negative outcome at any time or stage in the processes envisaged in the conditions can result in an immediate decision to suspend or cancel this proposed conditional approval. Some elements of the sub-options are not mutually exclusive and may be added or substituted in the decision of the Minister.

In the event that it is decided to ban hydraulic fracturing in its present form it should be remembered that this technology continues to evolve and there should be provision for a review of the decision in the event that the causes giving rise to such a ban have been significantly addressed by new developments in the technology.

The fiscal implications of the need to increase capacity within the various regulatory agencies to enforce new regulation have not been quantified.

In the event that the recommendation section 5 below is adopted and if, following the conditional approval phase, it is decided to allow shale gas development, then it is expected that there will be a significant requirement for skills development involving a long-term, nationally co-ordinated programme of capacity development.

In all cases, other than a ban on hydraulic fracturing, there is scope in varying degrees for research and development activities, which may best be focused in a cluster of research institutions to facilitate communication between disciplines, giving rise to a ‘centre of excellence’. These include, amongst others:

   a) the evolution of a ‘most appropriate style’ of hydraulic fracturing for use in South Africa;
b) the understanding of the deep geohydrology of potentially prospective areas;

c) support services, such as analytical laboratories; and

d) the evaluation of the resource potential.

e) studies on environmental impacts.

5 RECOMMENDATIONS OF THE WORKING GROUP

The following recommendations are made:

- Allow normal exploration (excluding the actual hydraulic fracturing), such as geological field mapping and other data gathering activities (e.g. hydrological studies) to proceed under the existing regulatory framework.

- Constitute a monitoring committee to ensure comprehensive and co-ordinated augmentation of the regulatory framework and supervision of operations.

- Augment the current regulatory framework. The establishment of the appropriate regulations, controls and co-ordination systems is expected to take 6–12 months.

- Departments of Science & Technology and Mineral Resources to collaborate in developing mechanisms for the co-existence of the Astronomy Research Projects and development of shale gas in the Karoo.

- Once all the preceding actions have been completed, authorise hydraulic fracturing under strict supervision of the monitoring committee. In the event of any unacceptable outcomes, the process may be halted.

- Ongoing research to be conducted and facilitated by relevant institutions to develop and enhance scientific knowledge in respect of the development of Karoo shale gas. This includes, albeit not limited to, geo-hydrology of the
prospective areas, methodologies for hydraulic fracturing in RSA and environmental impacts.

- The actions required to give effect to the proposed conditional approval must be properly resourced, incorporated into the programmes of the relevant departments and agencies and capacity developed.

A timeline for the implementation of this option is attached as Annexure P.

The co-ordination of the monitoring by the various interested Departments will be formalised to ensure comprehensive assurance that upstream petroleum operations are conducted within acceptable standards. This will require the formalisation of, *inter alia*, the composition of the co-ordinating body, terms of reference, and determination of limits of authority. The objectives of this exercise are to ensure that all appropriate permits are in place prior to the commencement of operations and that operations comply with all aspects of relevant statutes and regulations.
REFERENCES AND BIBLIOGRAPHY

The table below lists documents relevant, at least in part or peripherally, to the task of the Working Group. This list is not presented as definitive of all the material that may be relevant — the internet is a vast and wonderful system. The list has been posted on the web site of Petroleum Agency SA and will be updated periodically as new material emerges.

The documents are arranged in alphabetical order of the name of the author or organisation responsible for their publication.

Some documents are referred to specifically in the text of the Working Group’s report, by means of superscripts. These superscripts correspond to the numbers in the left-hand column.

For more information on the geology of the region and hydraulic fracturing, the reader is invited to refer to the references and bibliography included in Annexure B.

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