Science Action Plan
for Shale Gas in the Karoo Basin

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Science Action Plan for Shale Gas Exploration in the Karoo Basin

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The Academy of Science of South Africa (ASSAf) was inaugurated in May 1996. It was formed in response to the need for an Academy of Science consonant with the dawn of democracy in South Africa: activist in its mission of using science and scholarship for the benefit of society, with a mandate encompassing all scholarly disciplines that use an open-minded and evidence-based approach to build knowledge. ASSAf thus, adopted in its name the term `science' in the singular as reflecting a common way of enquiring rather than an aggregation of different disciplines. Its members are elected based on a combination of two principal criteria, academic excellence and significant contributions to society. The Parliament of South Africa passed the Academy of Science of South Africa Act (No 67 of 2001), which came into force on 15 May 2002. This made ASSAf the only academy of science in South Africa officially recognised by government and representing the country in the international community of science academies and elsewhere.

Foreword

South Africa's transition towards cleaner and more sustainable energy systems requires all stakeholders to understand the potential contribution and impact of the various energy resources available. The Cabinet's approval of shale gas exploration in 2014 indicated that independent scientific research should guide South Africa's understanding and exploitation of this resource. The government's view is that safeguarding the quality and availability of water and preventing environmental degradation has to take priority when alternative energy sources and their benefits are evaluated. The Square Kilometre Array (SKA) radio telescope also needs to be protected, as required by the Astronomy Geographic Advantage Act.

The Department of Science and Innovation therefore initiated consultations, convening a panel of national and international experts and holding workshops to determine what was needed to develop a shale gas industry in South Africa. The consultation process, which was coordinated by a consensus study panel appointed by the Academy of Science of South Africa, led to the development of this Science Action Plan, which provides a guiding framework to encourage independent research and mitigate the risks associated with shale gas exploration and exploitation.

The plan focuses on the development of new knowledge, governance, and engineering fields as they relate to the safe extraction of natural gas from the Karoo Basin. It acknowledges the work already being carried out, identifies gaps, and proposes a number of research areas for particular focus, including geology, the gas value chain, social science, induced seismicity, biodiversity, water and waste. Furthermore, the plan proposes a structure under the Shale Gas Monitoring Committee to coordinate research work in these areas and ensure that it informs the national approach.

Research is still required on the quantification, extraction and utilisation of resources, including the use of shale gas as a potential feedstock by repurposed coal-powered stations, to confirm the actual role of shale gas in the national energy mix. Should the shale gas reserves be confirmed, within an environmentally sustainable context, the resource has the potential to contribute to a just energy transition and minimise the impact of the move to a low-carbon economy on the livelihoods of workers and communities. Also, given the proximity of the potential gas resources to the renewable energy development zones, it may complement renewable energy resource integration.

I am pleased to present the Science Action Plan for Shale Gas Exploration, not only for its contribution to the cleaner energy future of our country, but also because it is part of a movement that will see the country increasingly embracing science and evidence-based policy making going forward.

Dr BE Nzimande, MP

Minister of Higher Education, Science and Innovation

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- Presenters and participants of the conference "The Shale Gas Industry in South Africa: Toward a Science Action Plan" held in Port Elizabeth 31 August – 1September 2017, including the late Prof Robert (Bob) Scholes of the University of the Witwatersrand

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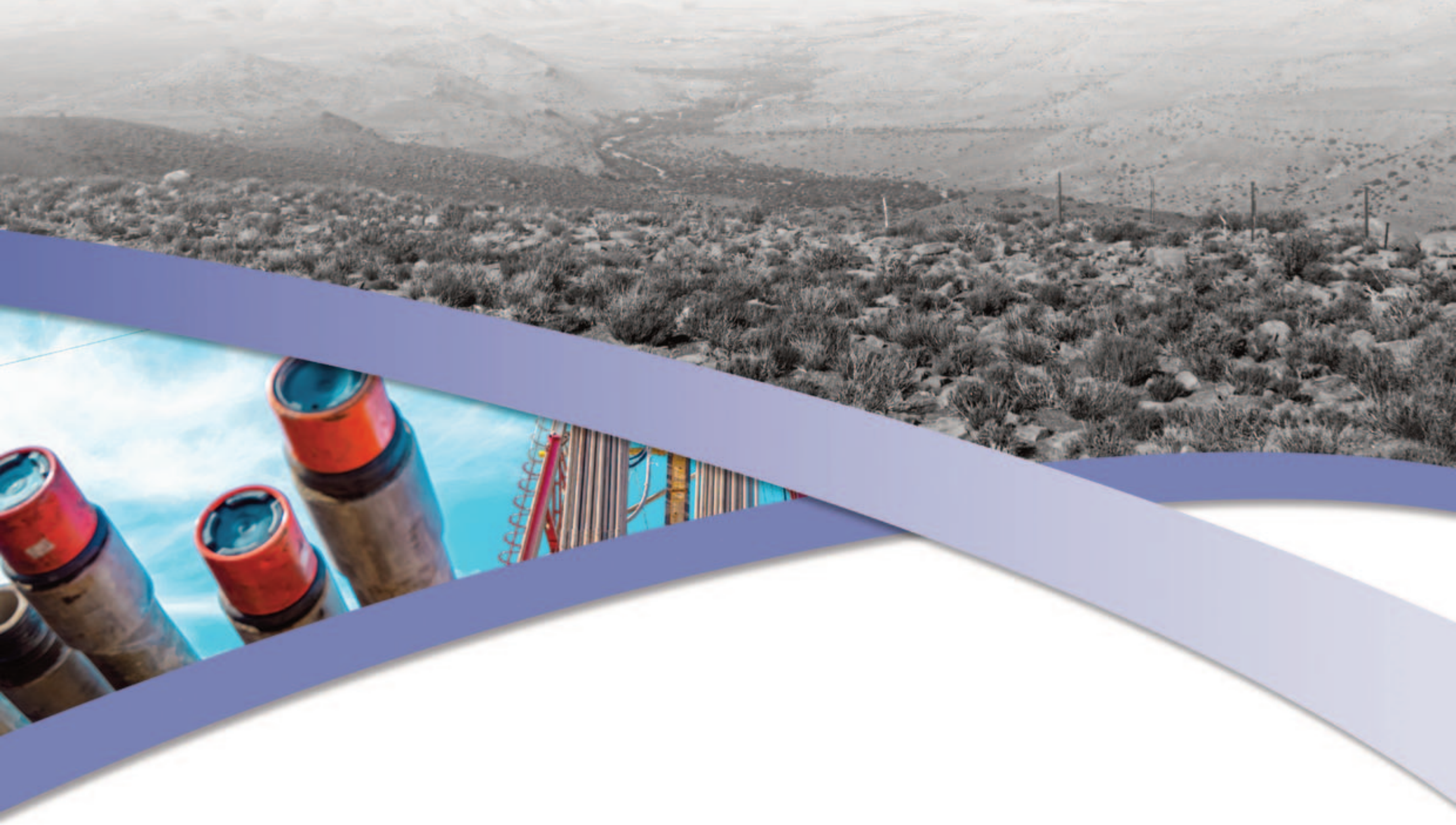
- Invaluable efforts of the ASSAf staff including Ms Nadia Algera, who also coordinated the production of the abovementioned consensus study report, Mr Ian Shendelana, Ms Patsy Scholtz and Ms Henriette Wagener



Executive Summary

This document presents the response of the Academy of Science of South Africa (ASSAf) and the South African Academy of Engineering (SAAE) to a request submitted by the Department of Science and Innovation (DSI) for a Science Action Plan (SAP) in support of an emerging shale gas industry in South Africa. As proposed in the DSI Concept Note, a researcher was engaged to develop the draft document, which was compiled jointly by ASSAf and SAAE. The report has clustered the SAP proposals into three groups:

- Proposals that focus on fundamental research that will lead to knowledge generation
- Proposals that focus on the application of current knowledge to new circumstances associated with a shale gas industry
- Proposals that relate to enabling interventions to assist in the implementation of the SAP

In order to address the critical areas outlined in the DSI Concept Note, the proposals have, in turn, been clustered into 10 topics. These topics are organised into flagship programmes, each of which falls within the ambit of competence of various government departments. The SAP has identified 36 tasks across the research topics, with 22 of these tasks requiring implementation within the next two years.

It is important to note that the tasks identified will not only benefit the shale gas industry, but will guide other unconventional gas development (such as Coal Bed Methane), as well as support other sector development proposals in the Central Karoo (such as the Square Kilometre Array, renewable energy, uranium mining and ecotourism), and promote water security, regional planning, conservation, local economic development, health and social security in the region. In preparing this document, ASSAf has consulted a number of local experts, many of whom would be able to assist DSI with the implementation and execution of the SAP.

The success of the SAP will obviously depend on the extent to which the tasks outlined are implemented. This will require coordinating the national research agenda in a manner that ensures that knowledge is effectively used in policy-level decision-making processes. It is suggested that the most urgent steps towards the implementation of the SAP are as follows:

- Appoint a suitably resourced Secretariat to initiate and manage the SAP over an initial period of around 10 years
- Appoint appropriate persons from government departments and the non-government sector to co-chair the Flagship Programmes
- Reconvene the Shale Gas Monitoring Committee
- Involve the private sector with a view to their participation in and co-funding of many of the SAP tasks, especially those that relate to exploration drilling activities and skills development
- Initiate, as a matter of urgency, the work to be undertaken on the 22 priority research tasks (0–2 years)

It is important that this SAP be read in the context of the ASSAf report "South Africa's Technical Readiness to support the Shale Gas Industry" (link), submitted to DSI in June 2015 and published in October 2016, since the SAP is a direct outcome of that study. By way of further background to the development of this SAP, the publications and events leading to creation of this document are depicted below.

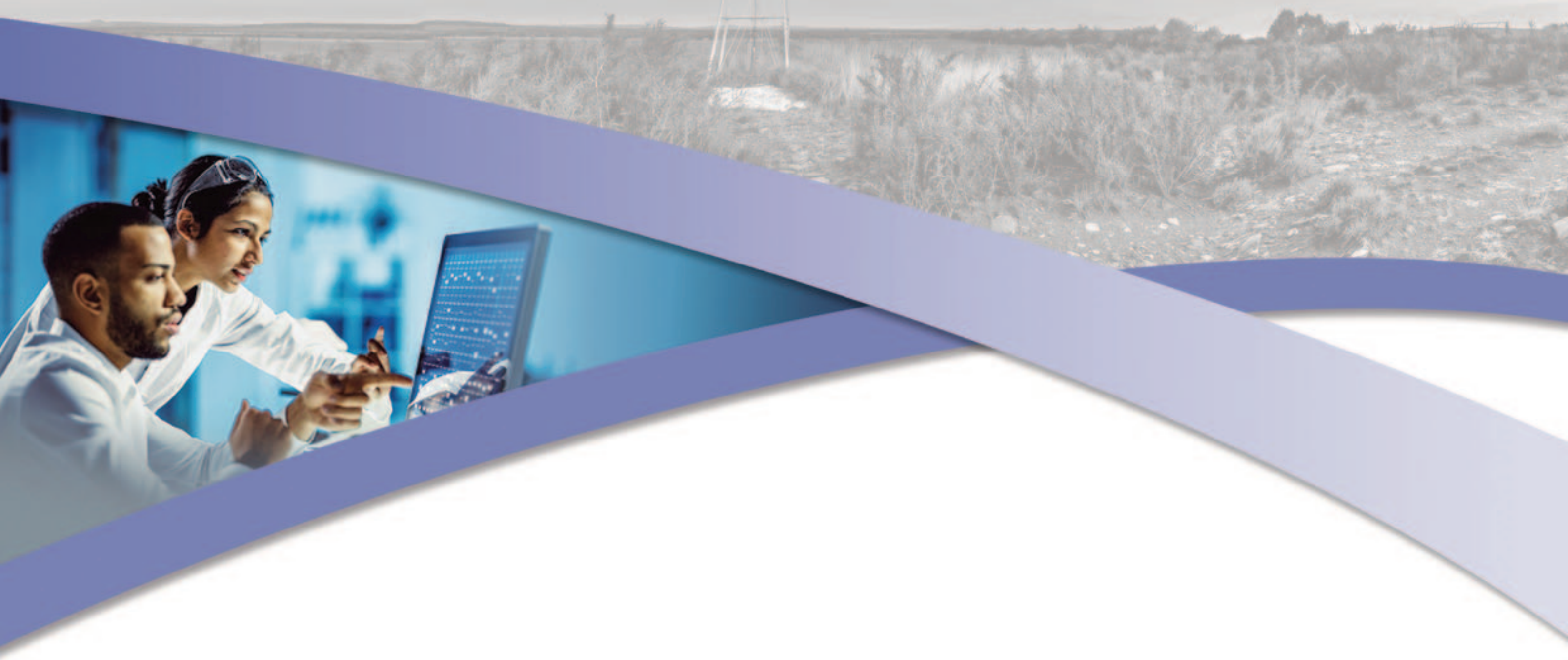
Chronology of events and publications leading to the development of the SAP:

September 2020
Shale Gas
Science Action Plan for South Africa

March 2019
ASSAf workshop
Consultative workshop on the Shale Gas Science Action Plan for South Africa

August 2017
The Shale Gas Industry in South Africa.
Towards a Science Action Plan
(https://research.assaf.org.za/handle/20.500.11911/92)

October 2016
ASSAf/SAAE report
South Africa's Technical Readiness to Support the Shale Gas Industry
(https://research.assaf.org.za/handle/20.500.11911/14)



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List of abbreviations

ASSAf	Academy of Science South Africa
BA	Basic Assessment
CBM	Coal-Bed Methane
CGS	Council for Geoscience
CoGTA	Department of Cooperative Governance and Traditional Affairs
DALRRD	Department of Agriculture, Land Reform and Rural Development
DFFE	Department of Forestry, Fisheries and the Environment
DHET	Department of Higher Education and Training
DMRE	Department of Mineral Resources and Energy
DPWI	Department of Public Works and Infrastructure
DoH	Department of Health
DEL	Department of Employment and Labour
DPME	Department of Planning, Monitoring and Evaluation
DSD	Department of Social Development
DSI	Department of Science and Innovation
dtic	Department of Trade, Industry and Competition
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
EMI	Electromagnetic Interference
EMPr	Environmental Management Programme
GDP	Gross Domestic Product
GHGs	Greenhouse Gas
GUMP	Gas Utilisation Masterplan
LNG	Liquefied Natural Gas
MIRs	Minimum Information Requirements
MW	Megawatt
GW	Gigawatt
HEI	Higher Education Institution
IRP	Integrated Resources Plan
DP	Development Plan
NDT	National Department of Tourism
NEMA	National Environmental Management Act
NGO	Non-governmental Organisation
PASA	Petroleum Agency South Africa
PM	Particulate Matter
PPE	Personal Protective Equipment
SAAE	South African Academy of Engineering
SAEON	South African Environmental Observation Network
SANBI	South African National Biodiversity Institute
SANSN	South African National Seismograph Network
SAP	Science Action Plan
SEA	Strategic Environmental Assessment
SET	Science, Engineering and Technology
SETA	Sector Education and Training Authority
SKA	Square Kilometre Array
Tcf	Trillian cubic feet
TVET	Technical and Vocational Education and Training
WRC	Water Research Commission

1 Introduction

1. Introduction

The Department of Science and Innovation (DSI) commissioned the Academy of Science of South Africa (ASSAf) and the South African Academy of Engineering (SAAE) to investigate South Africa's technical readiness to host a shale gas industry in the Central Karoo. The contents of that investigation were published in a report entitled "South Africa's Technical Readiness to Support the Shale Gas Industry" (ASSAf, 2016). One of the important recommendations from ASSAf (2016) was the establishment of a cross-disciplinary and coordinated national research agenda to guide responsible shale gas exploration activities in South Africa. Following further discussions with DSI, ASSAf and SAAE were commissioned to draft a Science Action Plan (SAP). The SAP provides an implementation framework and protocol to guide, coordinate and integrate baseline monitoring and research relevant to shale gas development.

The primary intention of this SAP is to structure a national research agenda in a manner that will assist government in making decisions regarding the exploration and development of shale gas over the next decade. To achieve this, the SAP provides the following information:

- A description of the proposed shale gas industry, explaining why new scientific, governance and technical knowledge across various functional areas is important for guiding future activities
- An overview of the regulatory and industry development trajectory, which highlights a necessity to focus research on regional baseline data collection associated with Exploration Phase I and Exploration Phase II activities (ASSAf, 2016), expected over the next decade
- The scope and range of cross-disciplinary topics and tasks recommended for research, including estimated cost scales, appropriate research vehicles, research prioritisation and the spatial extent of research activities
- The identification of Flagship Programmes, the government departments responsible for the implementation and coordination of the proposed research and the individuals from these departments and the non-government sector to co-chair these Programmes
- A review of the systems required for suitable research governance to ensure the integration and coordination of research outputs, and to promote transparency and public acceptance of these outputs
- An implementation plan for the establishment of a shale gas laboratory and intern centre, both focusing on producing indigenous scientists and engineers to facilitate the development of the industry, if suitable economically recoverable reserves are discovered.

2

Background to Shale Gas

2.1 Global and National Interest

By 2010, shale gas in the United States had sparked worldwide interest in domestic gas development. At that time, global oil prices were around $100 per barrel, and horizontal drilling and gas extraction technologies were rapidly improving (Zuckerman, 2013). Shortly afterwards, the United States Energy Information Administration issued a series of reports providing initial assessments of world shale gas resources, with South Africa's Karoo Basin ranking in the top ten globally in terms of technically recoverable reserves (Kuuskraa *et al.*, 2011) (also see notes below by ASSAf, 2016; Burns *et al*., 2016; De Kock *et al*., 2017).

Some excitement about the potential for shale gas in South Africa followed (De Wit, 2011); and while current global interest has declined somewhat, it will undoubtedly increase with rising oil prices. As such, South Africa, collectively, needs to be in a position to respond timeously when market conditions change.

2.2 South Africa's Energy System and Policy Context

Currently, the South African energy system is based mainly on coal mined in South Africa, complemented by imported oil and hydrocarbon fuels with small quantities of natural gas and one nuclear power station. Approximately 90% of electrical power in South Africa is generated by burning coal. The integration of natural gas into the energy mix is increasingly advocated in legislation (DMRE, 1998), the Integrated Resources Plan (IRP) of 2010 (DMRE, 2011a) (it should be noted that a draft of a new IRP was published for comment in 2018[1]) and public announcements (e.g. Minister of Energy, then Jeff Radebe, at the Gas-to-Power Africa Congress, 15–16 May 2018).

The National Development Plan (NDP) (NPC, 2013), the overarching guiding plan for the country, encourages increasing natural gas use in the energy mix, irrespective of whether gas is imported or sourced domestically. The IRP 2010 plans the capacity expansion programme for the power sector in South Africa until 2030 (DMRE, 2011b). The promulgated version of IRP 2010 calls for 3.9 GW of new peaking plants (gas-fired Open Cycle Gas Turbines, or similar) and 2.4 GW of new mid-merit gas-fired power plants (Combined Cycle Gas Turbines) (DMRE, 2011a). This policy objective is supported by evidence that including more natural gas in South Africa's energy mix would make the energy system more resilient, efficient, cheaper and reliable (Scholes *et al*., 2016).

2.3 The Central Karoo Social and Ecological Systems

There has been some resistance to developing shale gas. The Central Karoo is a semi-arid environment, which assigns a premium value to freshwater resources. Towns and farmers mainly rely on groundwater resources for domestic and livestock supplies and the sustenance of local economic activity, including limited irrigated agriculture and tourism. Many people experience the dry, extensive landscapes of the Central Karoo as places of austere, but compelling beauty. The region includes high levels of biodiversity, distinctive heritage features and scenic resources, which make it attractive to a growing niche tourism market with 'space, silence and solitude' being hallmarks of the tourism brand and lifestyles (Schreiner & Snyman-Van der Walt, 2018).

On the other hand, the Central Karoo is a region with high levels of poverty and limited economic opportunity for local people. The regional gross domestic product (GDP) is low when compared to the national average, and local governments have major challenges in dealing with poverty and unemployment. Many municipalities are barely able to cope with current service delivery functions, such as the provision of water, sanitation and electricity, and the maintenance of roads. Proponents of a domestic shale gas industry have promoted this as a means of enhancing energy independence, reducing the national trade deficit and promoting local economic development in this marginalised region of the country that is in need of novel growth and investment opportunities (Wright *et al.*, 2016).

[1] http://www.energy.gov.za/IRP/irp-update-draft-report2018/IRP-Update-2018-Draft-for-Comments.pdf

2.4 Petroleum Geology of the Karoo Basin

The Karoo Basin covers approximately 700 000 km2, representing more than half of the land surface of South Africa (Raseroka & McLachlan, 2008). Deep drilling during the 1960s and 1970s showed shale formations of the Karoo Basin that might contain exploitable natural gas at depths of around 2 to 3 km. However, in the absence of modern exploration data, the magnitude, distribution and economic recoverability of the gas resource is very uncertain. Even though the Karoo Basin is characterised by geological complexity, such as the presence of dolerite intrusions, the region is still considered to be a potentially attractive source of shale gas, since the target formations have a relatively high organic carbon content and occur over a large area (DMRE, 2012). More recently, Burns *et al*. (2016) suggested that technically recoverable shale gas reserves could range between 71 and 153 trillion cubic feet (tcf). On the other hand, ASSAf (2016) suggested technically recoverable ranges of between 19 and 23 tcf. Recent data from exploration drilling by De Kock et al. (2017) suggests that the Whitehill Formation and other carbonaceous shale beds are over-mature and that the technically recoverable shale gas resource may be in the region of 13 tcf[2] . Even assuming a relatively modest yield of 5 tcf[2] of economically recoverable gas, this represents a potentially significant resource for the South African energy economy and could support a 1 000 MW or 2 000 MW combined-cycle gas-fired power station supplying electricity into the national grid for 20 to 30 years. For comparison, the Mossel Bay offshore gas fields will yield a total of about 1.5 tcf over their lifetimes.

Box 1: Recoverability of resources

Technically recoverable resources are the volumes of natural gas that could be produced with current technology, regardless of petroleum prices and production costs. Economically recoverable resources are the volumes of gas that could be profitably produced under current market conditions.

2.5 Shale Gas Exploration, Development and Production

One of the foremost priorities for the shale gas industry in South Africa is the accurate determination of the quantity of potentially recoverable gas and the protection of the sensitive features that sustain life in the Central Karoo. The determination of the quantity of recoverable gas can only be achieved through modern exploration techniques (seismic surveys, vertical drilling, horizontal drilling and hydraulic fracturing), while the protection of the environment can be achieved through the regulation and effective monitoring of project implementation. With this in mind, as a means to develop the industry in a step-wise and adaptive manner, ASSAf (2016) and the Department of Forestry, Fisheries and the Environment (DFFE, 2017) recommended that the South Africa government should divide exploration licencing into two distinct Phases:

- **Exploration Phase I:** Seismic surveys, vertical drilling with limited horizontal hydraulic fracturing
- **Exploration Phase II:** Supplementary seismic surveys and vertical drilling, in support of horizontal drilling with limited multi-directional hydraulic fracturing

It is further suggested that serious consideration be given to including the private sector in these Phases since this would ensure that such instances are provided with appropriate access to information regarding the potential scale of the resource. This would obviously require that the two exploration Phases be carried out in areas that are not currently allocated to a private company. It is understood that such opportunities exist in the potential high-value areas. Licences could be issued imminently to lessees for Exploration Phase I so as to provide the necessary baseline data prior to initiating Exploration Phase II (which would include the technically complex step of hydraulic fracturing). This phased approach will provide sufficient opportunity for baseline and ongoing data collection processes to inform decision-making associated with later development stages.

[2] The De Kock et al. (2017) boreholes were drilled near Ceres and Willowvale. These areas are relatively remote from the regions of the highest gas reserve prospectivity. Thus, while they may be indicative of the petroleum geology characteristics on the extremity of the most prospective regions, they are by no means deterministic of the full shale gas resource in the Karoo Basin. Only deep drilling and potential hydraulic fracturing in the regions of high prospectivity will confirm resource estimates.

The recommendation to split the regulatory process between Exploration Phase I and Exploration Phase II proposed in ASSAf (2016) was further detailed within the Minimum Information Requirements (MIRs) section of the Strategic Environmental Assessment that was funded by DFFE (DFFE, 2017). A summary of the proposed activity steps and regulatory process is provided in Table 1. The draft MIRs provide outlines of the baseline monitoring requirements that will need to be undertaken prior to and during the Exploratory Phases of hydraulic fracturing. (**Note:** The MIRs are draft regulations, and have not yet been gazetted.) While the focus of the draft MIRs is on baseline and ongoing data collection at site-specific level, there is no guidance in South Africa on how to implement regional social, economic and environmental baseline studies.

Table 1 An indicative typical life cycle of a shale gas project indicating the timeframes, regulatory process and nature of activities

Typical stages of a shale gas project	Exploration – Phase I		Exploration – Phase II	Development	Production	Decommis-sioning
	Part 1	Part 2				
Potential timeframes[(1)]	Year 1 to Year 3	Year 3 to Year 5	Year 6 to Year 11	Year 11 to Year 16	Year 16 to Year 36	Year 16 to Year 36
Regulatory checks	Environmental Impact Assessment (EIA)[(2)]	Commencement of site-specific baseline monitoring in preparation for Phase II	Review of exploration data from Phase I, review and consolidation of baseline data for Phase II, EIA for Phase II, ongoing monitoring	EIA for limited production (5 tcf) well field, baseline monitoring, ongoing monitoring	For 20 tcf, i.e. > 50 well pads, EIA for large-scale production, baseline monitoring, ongoing monitoring	EIA for decommissioning, continued monitoring according to closure Environmental Management Programme (EMPr) requirements
Nature of activities	Engineering method statements Planning and design 2D seismics 3D seismics Establishment of well pads Vertical wells Roads Trucks Water Waste Monitoring ***[possible exit]***		Engineering method statements Planning and design 3D seismics Vertical wells Horizontal wells Hydraulic fracturing Roads Trucks Water Waste Flaring Monitoring ***[possible exit]***	Engineering method statements Planning and design 3D seismics Vertical wells Horizontal wells Hydraulic fracturing Roads Trucks Water Waste Flaring Gas compressors Monitoring	Engineering method statements Planning and design 3D seismics Vertical wells Horizontal wells Hydraulic fracturing Roads and trucks Water and waste Flaring Gas compressors Gas-to-powe Electrical line Pipelines Monitoring	Engineering method statements Planning and design Gas flow suspension Well plugging Well closure Site clear-up Infrastructure removed Rehabilitation Monitoring

[(1)] The above information, particularly in relation to timelines, is subject to any number of variables, such as market forces and technological advances.
[(2)] EIAs in support of applications for environmental authorisation, as well as other regulatory applications.

2.5.1 Exploration Phase I

Exploration Phase I will include seismic surveys and the drilling of stratigraphic wells, as well as hydraulic fracturing activities. This Phase will enable the location of gas-bearing shales and regions of highest potential gas prospectivity to be determined. No regional or long-term baseline data collection will be required prior to undertaking the seismic surveys and the drilling of stratigraphic wells, which are standard development activities with little to no impact. An Environmental Impact Assessment (EIA) or Basic Assessment (BA) will be required in terms of the National Environmental Management Act (Act No. 107 of 1998) (NEMA). Exploration Phase I will provide an operational Environmental Management Programme (EMPr) for baseline data collection, which will need to be approved by the relevant competent authorities. This will guide the baseline data collection programme prior to Exploration Phase II.

Box 2: Hydraulic fracturing

Hydraulic fracturing entails drilling a well from a single pad with a vertical section and a number of radiating horizontal sections into a gas-bearing shale formation. Each of the sections of the horizontal well bore are selectively isolated; fracking fluid is pumped into these sections at increasing pressure using surface pumps until the pressure exceeds the shale formation's fracture gradient. Millimetre-scale fractures are created, while any existing fractures are enhanced within the shale as a result of the hydraulic pressure. The fractures act as pathways for gas to flow out of the shale and into the drilled well (Burns *et al.*, 2016).

2.5.2 Exploration Phase II

Exploration Phase II will comprise limited multi-directional hydraulic fracturing at selected well pads[3] . It will be undertaken to evaluate the shale gas retrieval process and how efficiently the gas can be extracted in order to determine its economic return and its status as a gas reserve. Exploration Phase II will include continuous ongoing baseline data collection in preparation for the development and production phases.

2.5.3 Development and Production

Following the potentially extensive hydraulic fracturing campaign of Exploration Phase II, surface equipment would be installed on the well pad in order to allow production drilling for gas to be 'produced'. During the course of initial well testing, produced gas may be flared. Activities associated with development and production would be contained within production blocks, the dimensions of which should be in accordance with the lease allocations from the Petroleum Agency South Africa (PASA). The rate and scale at which the shale gas industry will be permitted to proceed would be based on the available baseline and ongoing monitoring data and in accordance with any new authorisation processes, undertaken at key production thresholds, e.g. 5 tcf (small-scale production) and then at, for example, 20 tcf (large-scale production).

2.5.4 Decommissioning and Abandonment

On completion of the production phase, gas flow will be suspended or abandoned and surface equipment will be disconnected and removed. The decision to either suspend or permanently decommission (plug and abandon) will be based on flow results and the instruction of a closure EIA and EMPr, drafted in terms of NEMA. Post-closure monitoring will continue to trace legacy impacts over the years.

[3] A well pad is a site constructed, prepared, levelled and/or cleared in order to accommodate the equipment, material and infrastructure necessary to drill natural gas exploration or production wells. Well pads are generally in the region of 1–2 ha in size. Many individual well bores (in the region of 10–15) can be drilled from a single well pad in different directions and into different target formations.

2.6 Consensus on Levels of Risk

Since 2010, there has been some contestation regarding the scale of risk associated with shale gas exploration, development, production and decommissioning. (In this context, risks include potential or anticipated impacts.) In the last eight years, various assessments have been commissioned to investigate these questions. They include the following:

- EMPr applications developed on behalf of the industry for permitting purposes by Golder Associates (2011; 2015) and SRK Consulting (2015)
- Intergovernmental task team reports such as those developed by DMRE (2012), by the Western Cape Intra-governmental Shale Gas Task Team (Western Cape Government, 2012) and by DFFE (2017)
- Independent assessments such as those undertaken by ASSAf (2016) and Scholes et al. (2016)

Data from these diverse and inclusive assessment processes, coupled with other peer-reviewed publications, such as Schreiner and Snyman-Van Der Walt (2018), suggests that the implementation of basic risk reduction strategies and adequate planning will avoid and/or reduce the risks of shale gas Exploration Phase I and Exploration Phase II activities to within acceptable levels. This provides an evidence base that is more than sufficient for the commencement of shale gas Exploration Phase I and Exploration Phase II activities.

Box 3: Insert from Schreiner and Snyman-Van der Walt (2018: 294)

"Given the expanse of the study area (171 811 km^2) and the relatively small physical surface footprint of shale gas development activities, mitigation best practice is led through application of the mitigation hierarchy, prescribing avoidance of impacts first, largely by adjusting the exact location of well pads, roads and other structures to not coincide with sensitive surface and geophysical features. Through effective project planning, the majority of sensitive environments in the Central Karoo can be avoided, thus maintaining the social and ecological character and integrity of the region, which is so important to many stakeholders."

3

Research Needs

Publications like Bazilian *et al.* (2014) and the Federal Multi-agency Collaboration on Unconventional Oil and Gas Research (2014) from the United States outline a research agenda for the economic, environmental and social dimensions of unconventional gas. At a high level, they propose the following:

- Increasing empirical research into environmental impacts from natural gas, including fugitive emissions of methane and water contamination issues
- Providing comprehensive and integrated economic, environmental and social research in order to understand trade-offs and interactions between the different sectors and the impacts
- Developing decision support tools to convey the results of integrated modelling to decision makers in an engaging and informative fashion

In the South African context, convergence on the levels of risk associated with shale gas Exploration Phase I and Exploration Phase II activities is contingent on the assumption that adequate institutional and governance capacity is developed, suitable EIA and engineering processes are conducted prior to activities and, most importantly, that appropriate regional baseline data is collected prior to the onset of any exploration activities.

The draft MIRs (DFFE, 2017) provide some guidelines on the collection of site-specific baseline monitoring information. However, the MIRs provide no requirements for regional baseline data collection. This provides a critical research gap, which will form a major focus of the SAP. As highlighted by the various specialists that were involved in the Shale Gas Strategic Environmental Assessment (SEA) (DFFE, 2017) and in ASSAf (2016), it is essential to clearly establish baseline conditions at a regional scale before commencing the hydraulic fracturing activities associated with Exploration Phase I. Such a set of studies is a critical precursor to informed decision making and the commencement of the industry. In this regard, South Africa has a unique opportunity to provide a global exemplar, given that, to date, there is no record in the public domain that such studies have been done in countries in which hydraulic fracturing is practised. The need for such baseline information has also been one of the key concerns expressed by most stakeholders during public debates on potential shale gas development in South Africa.

3.1 The Principle of Co-beneficiary Research

Whether or not shale gas can be extracted from the Karoo Basin at economically viable rates is yet to be determined. Only following detailed exploration activities as part of Exploration Phase I and Exploration Phase II will there be a clearer indication of the true extent of the economically recoverable resources, which could be significant or of little value. During the period that exploration is undertaken to determine the real extent of resource availability, it is critical that concurrent cross-disciplinary baseline research is conducted in a coordinated and transparent manner, so that there is sufficient information available to inform regulatory decision making related to potential extensive development activities.

On account of the risk that there may not be economically recoverable gas in the Karoo Basin, the SAP research needs to be positioned as 'co-beneficiary'. In other words, even if the shale gas resource in the Karoo Basin is not economically viable, the baseline data collected and the analyses undertaken will be of use to broader society in sectors other than the shale gas industry.

For example, research into the characteristics of deep aquifers in the Karoo Basin could be developed as future water resources even if shale gas development does not occur; research into existing tourism enterprises and other socio-economic trends could help shape regional spatial development frameworks; and health surveys could help to better understand human conditions in the Central Karoo in order to improve the implementation and operations of health care systems. The key principle is that research must be designed to account for the possibility that shale gas may not proceed to development and production scale, and therefore the research should be as relevant as possible to a diversity of sectoral and societal interests.

3.2 Research Scope

The SAP focuses on the development of new knowledge in the scientific, technical and governance fields across various functional areas as it relates to the environmentally sustainable and safe extraction of natural gas from the Karoo Basin. This knowledge may be applicable to other forms of unconventional gas development, such as Coal Bed Methane (CBM). For the SAP to be useful, it has to be relevant to government decision making over the next decade. As such, the SAP must constrain its boundaries within the policy and regulatory trajectory of a realistic shale gas future in South Africa.

This means that research has to be directed by policy trends and the needs of decision makers so that, when key decisions need to be made, there is sufficient data and there are qualified personnel capable of providing the information necessary to guide government. Accordingly, it is recommended that the SAP focuses on answering quite specific research questions relevant to the next decade of shale gas Exploration Phase I and Exploration Phase II activities.

Considering this, the research will follow three broad lines of enquiry:

- What are the composition and the scale of shale gas in the Karoo Basin and how can it be explored and extracted, governed and used in a safe and environmentally sustainable manner, given that such usage will be subject to market forces?
- What regional, social, environmental and economic baseline trends should be monitored before, during and after hydraulic fracturing, potentially at scale?
- What scientific, technical and governance actions can be employed to avoid and/or mitigate future risks and enhance benefits during all phases of development – i.e. exploration, development and production, decommissioning and post-decommissioning?

3.3 Research Topics

The following research topics are proposed:

Topic 1: Geology and Gas Resources – What information is necessary to better understand the deep geology of the Central Karoo, including the development of a more comprehensive understanding of the nature and scale of shale gas reserves?

Topic 2: Exploration, Development and Production Technology and Electromagnetic Interference (EMI) – What are the key technologies required to enable the safe exploration and extraction of shale gas and how do these align with current expertise available in South Africa? What are the best technological options for risk mitigation? What is the potential impact of EMI arising from exploration technologies?

Topic 3: Induced Seismicity – What is the baseline for seismic activity in the Central Karoo?

Topic 4: Water and Waste – Where are important surface and groundwater sources located? How much water is available from deep groundwater sources? What regional baseline monitoring systems are required and how are these best implemented? How will waste be managed? What are the key regulatory constraints?

Topic 5: Biodiversity – What is the regional baseline condition of the biodiversity and ecological features of the Central Karoo?

Topic 6: Air Quality and Green House Gases (GHGs) – What is the quality of air in the Central Karoo? What is the current state of GHG emissions in the Central Karoo?

Topic 7: Health – What is the baseline health status of the humans and livestock in the Central Karoo? What ongoing monitoring systems are required to trace transgenerational effects?

Topic 8: Social Fabric and Local Economics – How is 'sense of place' experienced in the region? What are the baseline social and economic statuses of people living in the Central Karoo? How do communities function in the Central Karoo? What is the economic value of the gas industry versus the agriculture, tourism, renewable energy and other mining sectors? What are the best funding models to manage externality costs and decommissioned wells?

Topic 9: Development, Infrastructure and Governance – What level of institutional capacity will municipalities require in order to adequately support shale gas exploration? What is the baseline status of infrastructure and services in the Central Karoo? What is the potential for a future shale gas industry supported by regional railway networks? What are the key governance issues that need to be improved?

Topic 10:Skills Development – What science, engineering and technological skills need to be developed to promote the uptake of employment opportunities in the sector? How can interns and young professionals be integrated into the next decade of research and implementation?

3.4 Flagship Programmes

The topics will be organised into the following flagship programmes:

Flagship Programme 1:	Geology, gas resources, seismicity, exploration technology/ engineering and EMI
Flagship Programme 2:	Potential gas utilisation, energy security and macro-economic benefits (Note: this is a stand-alone programme with no subset of topics)
Flagship Programme 3:	Water quality and availability, and waste management
Flagship Programme 4:	Biodiversity, air quality, GHGs and human health
Flagship Programme 5:	Social fabric, local economics, regional development and governance capacity
Flagship Programme 6:	Skills development and integrated decision-making support systems

Each topic will be led by appointed research leaders, who report to broader Flagship Programmes (see Figure 1). The purpose of the research model is to ensure that existing technical skills in government are suitably used and that new skills are developed through research with competent authorities. It is proposed that each flagship programme be co-chaired by a representative from a relevant government department and a representative from a non-governmental sector (e.g. a university or science council). Careful attention should be given throughout the implementation of the SAP to the importance of data and knowledge management.

3.5 Research Governance

Shale gas activities require intergovernmental collaboration and the cooperation of a wide range of national government departments, as well as potentially affected provinces and municipalities. It is suggested that the Shale Gas Monitoring Committee be reconstituted (since it is an existing mandated structure) and empowered to guide research activities and shape flagship outputs into useable, policy-relevant materials. In this way, the research will remain focused, coordinated and generally useful for society.

Research governance should include relevant non-governmental role-players with an understanding of different roles and responsibilities. Such role-players may include representatives from a university, science council or civil society. This is linked to the imperative that such research information be made available to all stakeholders with the purpose of empowering them.

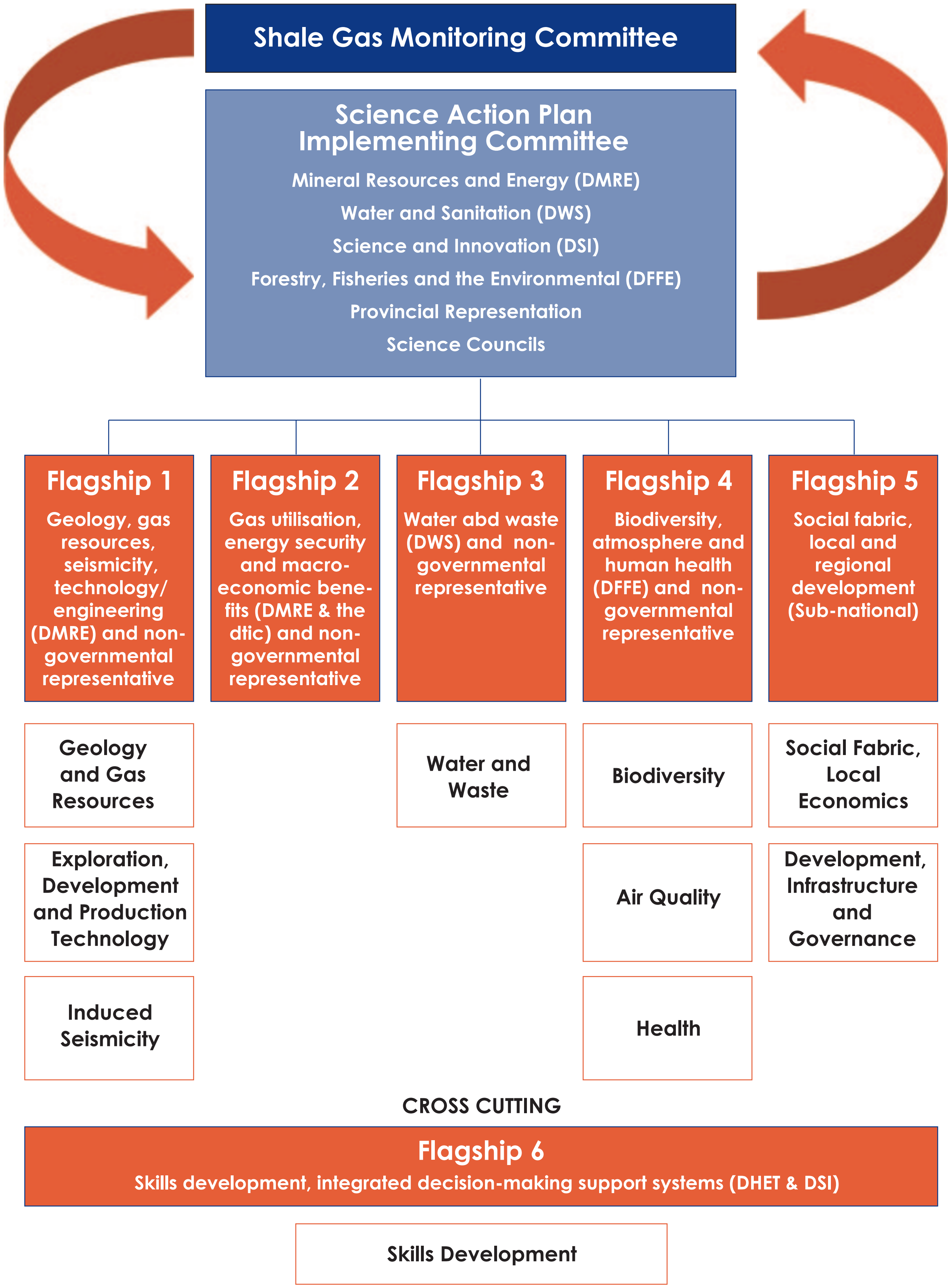

Figure 1 SAP governance structure - topics, flagship programmes and topics, and departmental reporting lines

3.6 Key Research Tasks

The following section details the specific research tasks for each research topic.

Table 2 The task characteristics, categories and explanations of the features of each research task

Task Charac-teristic	Category	Definition
Spatial scope	Local (well field)	900 km2
	Central Karoo	180 000 km2
	Karoo Basin	700 000 km2
	National	1 200 000 km2
Research 'vehicle'	Technology scan	Scan of existing work, answers very specific questions, few months' duration
	Project	Single research discipline, limited complexity, 2–5 years' duration
	Integrated programme	Multiple research disciplines, more complexity, 5–10 years' duration
	Joint venture	Collaboration with private sector, focused on drilling/ technology, 5–10 years' duration
	Independent agency	Independent third party, reports to government and stakeholders, 10+ years' duration
Timing	0–2 years	Urgent
	5 years	Needed before Exploration Phase II
	10 years	Foundation of future work, skills development through major programme
	20 years	Long-term issue, ongoing
Cost scale	◆	500 000 ZAR to 1 000 000 ZAR
	◆◆	1 000 000 ZAR to 5 000 000 ZAR, small research group
	◆◆◆	5 000 000 ZAR to 10 000 000 ZAR, large research programme
	◆◆◆◆	10 000 000 ZAR to 100 000 000 ZAR, integrated long-term regional baseline programme
	◆◆◆◆◆	> 100 000 000 ZAR, big ticket drilling campaigns, research programmes, skills development infrastructure
Departmental responsibility	**Lead department**	The department works in direct collaboration with the research leader in the coordination of research activities. Research falls directly within the department's core competency. The department has significant and relevant experience and capabilities
	Support department	The department has significant and relevant expertise, experience, personnel and potential resources

Each of the Flagship Programmes will be explored through detailed analyses of the relevant topics. The topics are presented in the following sub-sections and are reflected in (Organogram) under each Flagship Programme.

3.6.1 Flagship Programme 1 - Geology, Gas Resources, Seismicity, Exploration Technology/Engineering and EMI

3.6.1.1 Geology and Gas Resources

Why is this topic important?

Gas is known to be present in the Ecca Group shales in the Karoo Basin of South Africa (Rowsell & De Swardt, 1976). It is important to determine whether economically viable gas resources are present as this might enable South Africa to become self-sufficient in its gas needs, and possibly to supply an export market.

What research has already been undertaken?

Three organisations, the Nelson Mandela University, the University of Johannesburg and the Council for Geoscience (CGS), are undertaking research into the shale gas potential of the Karoo Basin. The results of the University of Johannesburg's recent drilling on the perimeters of the Karoo Basin have been somewhat disappointing since the shale was found to be over-mature. However, no drilling has occurred in areas of the Karoo Basin considered to have sizeable amounts of gas.

As part of the Karoo Deep Drilling and Geo-environmental Baseline Programme, the CGS plans to drill a 3 500 m deep research borehole in an area earmarked to contain shale gas in an area where it is most likely that the highest concentration of shale gas will occur in Beaufort West in the Western Cape. The deep borehole will intersect the carbonaceous shales of the Ecca Group, the Prince Albert and Whitehill formations, which are the primary targets for shale gas in the Karoo Basin of South Africa. The CGS has so far drilled five observation percussion boreholes to a depth of 169 m to monitor shallow ground water. Two monitoring percussion boreholes to a depth of 700 m are currently being drilled to monitor deeper ground water, particularly the water in the dolerite fracture zones, the primary source of groundwater in the area. Six seismograph stations have also been installed around the Beaufort West area to monitor the seismicity as part of the baseline study.

What is the research gap?

From an investigation of previous work, particularly the results of deep drilling in the Karoo Basin by Soekor, a small area was delineated between Beaufort West, Victoria West and Graaff-Reinet, which has the best potential for shale gas (Cole, 2014), whereas the University of Johannesburg's recent drilling and gas analyses took place outside areas considered most favourable for shale gas exploitation (De Kock *et al.*, 2017).

What are the specific research questions that need to be addressed?

- What is the thermal history of the Karoo Basin? What is the maturity of the Whitehill Formation in the Karoo Basin?
- If gas was once formed and has since migrated, where could it be trapped?
- What are the effects and extents of dolerite intrusions?
- Where is the high prospectivity gas area between the thermal impact of the Cape Fold Belt and dolerite intrusions?
- Is economically recoverable shale gas preserved in the Karoo Basin?
- What would be the impact of the exploration on groundwater, a critical resource in the area?

Table 3 Analysis of the tasks of the Geology and Gas Resources resource topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
1. Measure gas resource and test recoverability i. Drill deep bore-holes in high-prospectivity areas ii. Test for gas and groundwater iii. Develop Baye-sian basin models of the Karoo Basin iv. Establish a shale gas research laboratory, co-funded by industry v. Undertake core analysis of exist-ing borehole data vi. Undertake mag-netic and seismic surveys vii. Determine loca-tion of high-probability gas reserves viii. If deep borehole results are posi-tive, undertake horizontal drilling and hydraulic fracturing co-funded by industry	Central Karoo/ local	Integra-ted pro-gramme/ joint venture	**Priority =** 0–2 years **Duration =** 5–10 years (ongoing)	◆◆◆◆	**Lead:** DMRE **Support:** Petroleum Agency South Africa (PASA), Council for Geo-science (CGS), De-partment of Forestry, Fisheries and the Environ-ment (DFFE), Depart-ment of Water and Sanitation (DWS), Depart-ment of Science and Innovation (DSI),	Yes, discovery of new ground-water resources	Yes

3.6.1.2 Exploration, Development and Production Technology, and Potential EMI

Why is this topic important?

A new energy source to diversify the South African energy mix will build its resilience. However, strict rules must be observed not to extract gas in a manner that negatively affects the environment, communities or the water resources. Furthermore, given the proximity of the internationally acclaimed Square Kilometer Array (SKA), negative impacts on radio astronomy operations must be avoided.

What research has already been undertaken?

There has been very little research regarding best practice Exploration Phase I and Exploration Phase II activities. The most complete information regarding technology associated with the shale gas industry comes from ASSAf (2016). With regard to EMI, Tiplady et al. (2016) documented the known risk of EMI from shale gas activities on the SKA. Safe buffer distances away from the SKA infrastructure were determined and legislated.

What is the research gap?

ASSAf (2016) outlined the technological and institutional readiness mechanisms currently in place, and clearly showed the gaps.

Additional research into the specific technological and technical requirements across different functional areas to facilitate Exploration Phase I and Exploration Phase II activities is required. In terms of EMI, there is no existing data on actual measured EMI from existing shale gas industry sources.

What are the specific research questions that need to be addressed?

What are the best practices that can be implemented to avoid negative impacts, and if unavoidable, mitigate such impacts (inclusive of the adoption of buffer areas)?

Research is required in the following areas:

- The development of methods to produce cement of the correct quality in terms of appropriate international best practice.
- The development of engineering skills to ensure that when wells are developed, they are compliant with appropriate international best practice in terms of sealing/leakage properties.
- The testing of materials to be used in well construction, e.g. casings and casing materials, hangers and couplings use standards that are compliant with appropriate international standards.

This will ensure that all materials and their applications comply with appropriate international standards including, for example, proppants and hydraulic fracturing fluids.

Table 4 Analysis of the tasks of the Exploration, Development and Production Technology, and Potential EMI research topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Departments	Co-benefits	Relevant to CBM, and off-shore oil and gas
2. Develop inventory of primary technologies, processes, practices and specifications used in environmentally sustainable and safe hydraulic fracturing and gas extraction plus a gap analysis of what technology is not currently available in South Africa. Develop strategies to address technology gaps.	Central Karoo/ local	Technology scan	**Priority =** 0–2 years **Duration =** 2 years	◆◆◆	**Lead:** DSI **Support:** DWS, DMRE, DFFE	Yes, skills development	Yes
3. Monitor progress of technology used during seismic surveys and deep vertical drilling and then during horizontal drilling and hydraulic stimulation.	Local	Project	**Priority =** 5 years **Duration =** 5–10 years	**	**Lead:** DSI **Support:** DWS, DMRE, DFFE	Yes, skills development	Yes
4. Undertake EMI monitoring of existing shale gas well fields.	Local	Project	**Priority =** 0–2 years **Duration =** 2 years	**	**Lead:** DSI **Support:** DMRE, DFFE, DWS	Yes, SKA	No

3.6.1.3 Induced Seismicity

Why is this topic important?

The injection of fluids into the earth at high pressures and volumes sufficient to cause rocks to fracture and/or faults to slip will inevitably cause seismic events and, very rarely, shaking of the ground that is felt on the surface. The key issue is their magnitude. The events may range in size from microseismic events (M <3) that are barely perceptible on the surface, to events that are large enough to alarm residents and cause damage to vulnerable structures and buildings.

What research has already been undertaken?

The South African National Seismograph Network (SANSN), operated by the CGS, was established in 1971. The SANSN records both natural earthquakes and earthquakes induced by human activities, such as blasting, mining and the filling of reservoirs. In 2016/17, the CGS installed a further six stations. The Nelson Mandela University has also conducted some seismic monitoring. Mining companies have installed microseismic systems on all mines affected by mining-induced seismicity. Research has been conducted by the CGS and universities (particularly the University of the Witwatersrand) into the causes, effects and mitigation of induced seismicity. Recent studies by seismologists at CGS include a probabilistic seismic hazard assessment for South Africa and a review of the seismotectonics of the region. Papers are currently in review.

What is the research gap?

There are several significant data and knowledge gaps that should be filled to assess and mitigate the risk posed by hydraulic fracturing-induced earthquakes:

- Improve the capability to collect, analyse and interpret geological, seismic and geodetic strain data
- Improve the capability to assess building typologies and vulnerability, review building codes, and formulate guidelines for the reinforcement of existing structures

What are the specific research questions that need to be addressed?

- What are the current levels of seismicity and ground motion in the region?
- How will seismicity and ground motion change if shale gas is developed? How vulnerable are existing structures to strong ground motion?
- How can existing structures be reinforced and new structures be built to make them resilient to shaking?
- What measures can be implemented to avoid negative impacts, and if unavoidable, mitigate such impacts (inclusive of the adoption of buffer areas)?

Table 5 Analysis of the tasks of the Induced Seismicity research topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
5. Analyse data from existing seismic and GPS stations; deploy additional stations if necessary. Integrate and interpret existing geological and geo-physical data. Assess seismic hazard and identify faults.	Central Karoo	Project	**Priority =** 0–2 years **Duration =** 2 years	◆◆	**Lead:** DMRE **Support:** DSI	Partially, skills devel-opment	Yes
6. Monitor seismic activity during hydraulic fracturing.	Local	Project	**Priority =** 5 years **Duration =** 5–10 years	◆	**Lead:** DMRE **Support:** DSI	Partially, skills devel-opment	Yes
7. Undertake risk analyses of existing buildings in region.	Local	Project	**Priority =** 10 years **Duration =** 2 years	◆	**Lead:** DMRE **Support:** DSI	Yes, human safety	Yes

3.6.2 Flagship Programme 2 - Potential Gas Utilisation and Macro Economics

Why is this important?

Shale gas could play a role as a transition fuel to a low-carbon economy in South Africa's coal-dominated energy mix. Carbon dioxide emissions from coal could be reduced considerably with diversification into the use of indigenous domestic natural gas. Gas-fired power generation could provide power system flexibility which, if sourced from domestic indigenous shale gas, would improve energy security. The use of domestic indigenous natural gas is technically flexible – in addition to gas-fired power generation, it could be used in industrial processes, commercial processes and for transportation or non-energy use (e.g. fertilizers). In addition, given the unique challenges posed by the location of the gas resource and hence the potential for significant environmental impacts when the gas is exploited, a gas utilisation plan would need to be explicitly and purposefully designed.

What research has already been undertaken?

Policy research has been undertaken through various iterations of the IRP (e.g. 2010, 2013, 2018), and the Gas Utilisation Master Plan (GUMP) (DoE, 2016). Transnet SOC Ltd developed a long-term planning framework that took national cognisance of a domestic gas industry in the Central Karoo. The integration of natural gas into the South African economy was most recently investigated by Merven et al. (2017). Wright et al. (2016) provide the most synthesised and complete research on the integration of shale gas, specifically into the national electricity supply system. A number of market studies and estimates of new markets for gas have recently been completed.

What is the research gap?

While energy specialists and economists would be central to and possibly key to driving this topic, deliberations and decisions would be based on scientific findings of robust research. The activity of collating and summarising the body of work that defines the various market studies is necessary to centralise this knowledge. The explicit statements of how gas, as a power-generation fuel, would be used to complement other technologies (baseline, mid-merit and peaking) must be documented and defined so that the implications (financial, infrastructural and logistics) can be incorporated into the planning. Diversification of the energy mix and the associated economic benefits to South Africa from domestic indigenous natural shale gas needs to be explored, as well as the impact of indigenous natural gas reducing the import dependency of liquid fuels in the transportation sector. The flexibility of power grid systems to manage and integrate increased modular gas-to-power generation systems, in order to stabilise the grid during the variable effects of weather and the diurnal effects of renewable resources like solar and wind, must be tested. A better understanding of procurement approaches for domestic shale gas relative to liquefied natural gas (LNG)/pipeline imports and the associated benefits that could be realised is required, as is research into sector-coupling opportunities between electricity, heating and transportation using natural gas.

What are the specific research questions that need to be addressed?

- What would the long-term localised and national economic benefits to South Africa's energy mix be if domestic natural gas was economically feasible in the power sector, for industrial processes and/or for non-energy use?
- How much natural gas would be needed in the various end-use sectors in South Africa, i.e. the demand pull versus supply push?
- How should produced domestic shale gas be used to benefit South Africa's transition to a low-carbon economy and ensure that the country honours its international climate change commitments?

Table 6 Analysis of the tasks of the Potential Gas Utilisation and Macro Economics research

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
8. Given the unique challenges of the area under discussion, determine the gas need in South Africa across end-user sectors, identify sectors for fuel switching and determine tipping points that make gas a financially feasible option. Quantify the economic advantage of indigenous gas over other energy resources and over imported sources of gas.	National	Project	**Priority =** 0–2 years **Duration =** 2 years	◆◆	**Lead:** DMRE or Department of Trade, Industry and Competition (dtic) **Support:** DMRE, provincial authorities, municipalities	Yes, gas economy	Yes

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
9. Determine how natural gas can be integrated into the energy mix and utilised to support renewable energy and other power generation fuel.	National	Project	**Priority =** 5 years **Duration =** 2 years	◆◆	**Lead:** DMRE or dtic **Support:** DMRE, DFFE, provincial authorities, municipal-ities	Yes, gas economy	Yes

3.6.3 Flagship Programme 3 - Water quality and availability, and waste management

3.6.3.1 Water and Waste

Why is this topic important?

The typical water requirements for hydraulic fracturing are expected to be between about 1 and 6 litres per second (ASSAf, 2016). The Central Karoo is water scarce and does not have additional surface water or groundwater available for hydraulic fracturing. Water may therefore need to be imported or sourced from deep groundwater. However, it may be possible to source water from a shallow groundwater well field for the duration of the two phases, which would require the amendment of DWS's regulations. In addition, given the scarcity of water in the Central Karoo, it is imperative that the little there is and those sources yet to be established be safeguarded for use by communities.

What research has already been undertaken?

The Water Research Commission (WRC) published "State of the art: Fracking for shale gas exploration in South Africa and the impact on water resources" in 2012 (Steyl *et al*., 2012). This research surveyed the possible impacts of hydraulic fracturing in general and assessed the likelihood of artesian aquifers in the Karoo. Localised artesian aquifers exist and unexpected impacts are envisaged where such aquifers occur. The WRC also developed an interactive vulnerability map and monitoring framework to assess the potential environmental impact of unconventional oil and gas extraction by means of hydraulic fracturing (Esterhuyse *et al*., 2014). This research assessed the potential impacts of hydraulic fracturing on the biophysical and socio-economic environments. An interactive vulnerability map was developed that assessed the vulnerability of water, seismicity, vegetation and socio-economics to unconventional oil and gas extraction using fracking.

A monitoring framework was also developed for the same aspects. The report identified and assessed the potential impacts for each of the development stages of unconventional oil and gas extraction – during exploration, during production and after closure. In the scientific assessment of shale gas development in the Central Karoo, Scholes et al. (2016) undertook a scientific risk assessment of shale gas development for various aspects (water, social, economics, biodiversity, sense of place, etc.). Certain policy recommendations were made to government based on the outcome of this assessment. In 2016, ASSAf and SAAE researched South Africa's technical readiness for shale gas (ASSAf, 2016).

What are the research gaps?

The primary research gaps relate to water availability, water quality and waste management. The following are the specific knowledge gaps:

- There is a paucity of reliable information regarding groundwater use (both for municipal/town water supply and for agricultural purposes).
- There is insufficient understanding of from where hydraulic fracturing water requirements would be sourced – local groundwater, deep groundwater, importing by tanker trucks. Dry fracking and gas fracking may also be options.
- A laboratory audit and technical services to support shale gas exploitation are required.
- A number of aspects related to the geology and hydrogeology interaction at depth need to be researched. These include the following:
    - The occurrence and hydraulic properties of 'aquifer' formations, as well as the quality of deep groundwater (>1 000 m)
    - The presence of potable groundwater at depth
    - The measure of interconnectivity with shallow aquifers
    - The occurrence and geometry of dolerite at depth

  These aspects are all poorly understood.
- There is limited understanding of the nature of basinal groundwater flow and its properties, geometries and controlling factors in the Karoo Basin. Therefore, at present, it is not possible to have an understanding of the basinal flow dynamics within the Karoo Basin, and specifically in the study area beyond a qualitative conceptual model.
- There is a limited understanding of the response of the Whitehill Formation and overlying strata to hydraulic fracturing.
- Knowledge of background (baseline or reference) groundwater quality is extremely sparse. This is true for shallow, intermediate and deep aquifers.
- An improved understanding of the hydrodynamics that describe the interaction of surface water and groundwater is required.
- The inter-dependence that exists between hydrology, and the ecology of temporary surface water systems is similarly poorly understood.
- The effect that additional groundwater extraction for shale gas development might have on the sustainability of temporary and ephemeral rivers and wetlands in the area is unknown.
- The volume of wastewater (flowback and produced water) that will be generated during full-scale shale gas development is similarly very uncertain.
- The risk posed by shale gas development activities to downstream dependent systems, including urban and agricultural users, as well as environmental resources, is poorly understood and inadequately quantified.

What are the specific research questions that need to be addressed?

- Where would South Africa source water from for hydraulic fracturing in a sustainable manner without impacting on existing water users and uses?
- If water cannot be locally sourced, what alternative methods could be feasibly implemented? What is the potential for dry fracking and what would be the impacts of trucking?
- Should consideration be given to amending DWS's existing regulations to permit the temporary transfer of water use licences or the sale of water from existing sources for hydraulic fracturing and would such temporary transfers or sales impact on the long-term sustainability of the water sources?

- What is the baseline of groundwater, surface water and seismicity in areas selected for exploration?
- How would one accurately verify groundwater and surface water use in proposed hydraulic fracturing areas?
- What surface water-groundwater interaction occurs in the proposed hydraulic fracturing areas?
- What is the baseflow contribution of groundwater to non-perennial streams in the proposed fracking areas?
- Are any artesian aquifers present in the proposed hydraulic fracturing areas and, if so, where?
- How would identified artesian aquifers react during hydraulic fracturing? Do they present a risk for fluid migration to shallow groundwater aquifers? Are there any deep geological structures present in the study area that present a risk for fluid migration from deep to shallow aquifers, or that present a seismic risk?
- What are the characteristics of deep aquifers in the proposed hydraulic fracturing sites? Is there any risk of fluid migration to shallow potable aquifers? What are the hydrodynamics of temporary rivers in proposed hydraulic fracturing areas?
- What technical expertise do laboratories need to assist in water analyses required for the baselines? Who would provide funding for equipping laboratories to monitor water quality during hydraulic fracturing?
- What regulations are required to protect water resources during all phases of development (i.e. exploration, production, decommissioning and post-decommissioning)?
- What are the characteristics of an independent monitoring body that should perform an oversight function? Which would be a suitable organisation to act as independent monitoring body for water resources and seismicity? Where would funding come from for such a body?
- How would South Africa ensure continuous monitoring of background water quality in fracking areas?
- What is South Africa's strategic plan for managing the cumulative effects of wastewater from multiple hydraulic fracturing sites and sources (taking into account existing stresses on governing systems to manage waste, and government's inability to handle current levels of waste generation in South Africa)?
- Should the regulations allow the disposal of flowback water in wells, or by truck to a remote toxic waste disposal site, or require further treatment such as reverse osmosis followed by evaporation before trucking to a remote toxic waste disposal site?
- How would one monitor and strategically manage decommissioned wells and minimise the long-term (intergenerational) impacts from such wells?
- What are the best practices that can be implemented to avoid impacts, and if unavoidable, mitigate surface and groundwater impacts (inclusive of the adoption of buffer areas)?

Table 7 Analysis of the tasks of the Water and Waste research topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
10. Determine baseline water quality in proposed fracking areas, groundwater water-level baseline via baseline monitoring.	Karoo Basin	Integrated programme	**Priority =** 0–2 years **Duration =** 5–10 years	◆◆◆◆	**Lead:** DWS **Support:** DFFE, DSI, provincial authorities	Yes, water supply	Yes
11. Undertake water use verification and sourcing for fracking: i. Develop a method to accurately verify groundwater and surface water use in proposed fracking areas (remote sensing coupled with ground-truthing, linked to verification of licensed and registered use) ii. Determine where South Africa can source water from for fracking in a sustainable manner, without impacting on existing water users and use iii. If water cannot be sourced locally, investigate alternative fracking methods or the availability of alternative sources of water	National	Integrated programme, joint venture for alternative fracking methods	**Priority =** 0–2 years **Duration =** 5–10 years	◆◆◆	**Lead:** DWS **Support:** DFFE, DWS, DSI, DMRE, provincial authorities	Yes, water supply	Yes, to a lesser extent
12. Surface water-groundwater interaction: i. Determine surface water-groundwater interaction in the proposed fracking areas ii. Identify the baseflow contribution of groundwater to non-perennial streams in the proposed fracking areas.	Karoo Basin, Central Karoo, local	Integrated programme	**Priority =** 5 years **Duration =** 20 years	◆◆◆	**Lead:** DWS **Support:** DFFE, DWS, DSI, provincial authorities	Yes, water supply and aquatic ecology	Yes

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Departments	Co-benefits	Relevant to CBM, and off-shore oil and gas
iii. Identify the hydrodynamics of temporary rivers in proposed fracking areas. iv. Monitor interaction, baseflow contribution and river hydro-dynamics over the long term to identify significant changes in these interactions due to fracking	Karoo Basin, Central Karoo, local	Integrated programme	**Priority =** 5 years **Duration =** 20 years	◆◆◆	**Lead:** DWS **Support:** DFFE, DWS, DSI, provincial authorities	Yes, water supply and aquatic ecology	Yes
13. Deep geological structures, deep aquifers and artesian aquifers: i. Identify deep geological structures and deep aquifers present in the study area that present a risk for fluid migration from deep to shallow aquifers, or that present a seismic risk ii. Determine how identified deep geological structures would react during fracking iii. Identify deep aquifers present in the study area at risk during fracking iv. Determine how identified deep aquifers would react during fracking v. Identify artesian aquifers present in the proposed fracking areas vi. Determine how identified artesian aquifers would react during fracking	Karoo Basin, Central Karoo, local	Joint venture	**Priority =** 5 years **Duration =** 20 years	◆◆ (along with deep drilling from Task 1)	**Lead:** DMRE **Support:** CGS, PASA, DFFE, DWS, DSI, provincial authorities, drilling companies supply drilling information during deep drilling	Yes, water supply	Yes

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
vii. Monitor seismicity of deep geological structures, the interaction of deep aquifers and artesian aquifers with geological structures and shallow aquifers over the long term to identify significant changes due to fracking							
14. Determine technical expertise required to equip laboratories, assess whether local laboratories must be upgraded. Upgrade and develop technical expertise for water quality, soil analysis laboratories (will depend on whether it is decided to outsource this to international laboratories).	National	Technology scan	**Priority =** 5 years **Duration =** 5 years	◆◆◆◆	**Lead:** DWS **Support:** DFFE, DWS, DSI	Yes, skills development	Yes
15. Assess the potential impacts of the temporary transfer of existing water uses licences and the granting of new temporary licences for the purpose of hydraulic fracturing and whether there would be a benefit in amending the DWS's regulations accordingly.	Karoo Basin, Central Karoo, local	Joint venture	**Priority =** 5 years **Duration =** 5 years	◆◆	**Lead:** DWS **Support:** DFFE, DWS, DSI	Yes, water supply	Yes
16. Assess the impacts of alternative options for the disposal of flowback water and whether the DWS's regulations should be amended to permit deep well disposal, or an option such as reverse osmosis, evaporation in lined dams and disposal by truck to a toxic waste site.	Karoo Basin, Central Karoo, local	Joint venture	**Priority =** 5 years **Duration =** 5 years	◆◆	**Lead:** DWS **Support:** DFFE, DWS, DSI	Yes, toxic waste disposal sites	Yes

3.6.4 Flagship Programme 4 - Biodiversity, Air Quality, GHGs and Human Health

3.6.4.1 Biodiversity

Why is this topic important?

The Central Karoo region includes relatively high levels of biodiversity, including highly sensitive and unique ecosystems and species. Seven different biomes and 58 vegetation types, 119 range-restricted plant species and 12 globally threatened animal species have been identified.

The Karoo is an arid ecosystem characterised by ecological processes that operate over extensive areas. The region is sensitive to disturbance, and disturbance has long-term impacts. Recovery in disturbed areas is generally not spontaneous and rehabilitation is often met with poor success. The major concern regarding shale gas is that the extensive linear infrastructure could result in fragmentation of the landscape.

What research has already been undertaken?

Holness et al. (2016) provided a high-level risk assessment of various shale gas development scenarios, which provides extremely valuable data that informs strategic and landscape mitigation and conservation management. The South African Environmental Observation Network (SAEON) is in the process of collecting landscape-level monitoring data and maintaining benchmark sites for the evaluation of shale gas development impacts.

Data is also being collected by the South African National Biodiversity Institute (SANBI) (as part of the Karoo Biogaps Project), provincial conservation authorities and DWS. It is important for shale gas development-related monitoring efforts to be coordinated.

What is the research gap?

In general, species occurrence data is fragmented across several different collection institutions (e.g. museums, the South African Institute for Aquatic Biodiversity and the Agricultural Research Council). Different formats are used for the data. For locality data, the levels of accuracy for coordinates vary. The exceptions to this are where SANBI or other threatened species projects have compiled integrated datasets across institutions, and have cleaned and geo-referenced these.

This is the case for reptiles and butterflies, as well as for threatened and restricted range plants. There is only a limited amount of data for the area in general and it is under-sampled for all taxa. There is also incomplete knowledge of the ecological requirements of many species of special concern, as well as interactions, cascading effects and impacts on processes. Should shale gas activities proceed, it will be critical to improve the comprehensiveness and coverage of data on threatened and keystone species.

What are the specific research questions that need to be addressed?

- What is the regional baseline status of species of special concern, ecosystems or habitat types, and ecological processes in the Central Karoo?
- How do Karoo systems recover from disturbances and habitat fragmentation?
- How do species respond to noise disturbance?

Table 8 Analysis of the tasks of the Biodiversity research topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
17. Complete the Karoo Biogaps Project looking at the status of species of special concern, eco-systems or habitat types, and ecological processes.	Central Karoo	Project	**Priority =** 0–2 years **Duration =** 2 years to completion	◆◆ (sup-ple-menta-ry fun-ding to existing SANBI pro-gram-me)	**Lead:** DFFE (SANBI) **Support:** DSI, provinces	Yes, regional conser-vation and decision making	Partially, different vegeta-tion types
18. Record and ana-lyse successional flora recovery around old Soekor boreholes. Model changes to ecosystems and ecological processes as a re-sult of linear infra-structure.	Central Karoo/ local	Project	**Priority =** 0–2 years **Duration =** 2 years	◆	**Lead:** DFFE **Support:** DSI, provinces, DMRE, PASA	Yes, regional conser-vation and planning	Partially, different vegeta-tion types
19. Establish baseline noise.	Central Karoo	Project	**Priority =** 5 years **Duration =** 5 years	◆◆	**Lead:** DFFE **Support:** DSI, provinces	Yes, regional conser-vation, and human health	Yes

3.6.4.2 Air Quality and GHGs

Why is this topic important?

There is a potential opportunity to reduce emissions if shale gas replaces 'dirtier' (more emissions-intensive) fuels. However, there is also a risk of increased emissions if shale gas is added to the existing energy mix, and displaces cleaner fuels for new capacity. Emissions of GHGs have global impacts, while impacts from air pollution are generally assessed at local and regional scales.

What research has already been undertaken?

As part of the scientific assessment of shale gas development (Scholes et al., 2016), the opportunities and risks with regard to air pollution and GHG emissions were examined. The highest risks assessed are due to leakage of methane, a potent GHG, prior to end-use. Even with the worst leakage rates, the 'worst shale gas' is roughly as emission-intensive as the 'best coal'. This means that the positive opportunity of introducing gas into South Africa's energy economy must avoid gas leaking to the atmosphere. Scholes et al. (2016) superseded a study commissioned by DFFE in 2014 which aimed to analyse GHG emissions throughout the shale gas life cycle. This study provided similar conclusions on emissions compared to those associated with fossil fuel combustion. The study cautions that its findings are based on international data and not site-specific measurements and that further research was required.

In terms of local air pollution, the greatest risk is the exposure of workers to air pollutants on the well pad. Both workers and the local and regional communities may be exposed to local air pollutants (see list below). Activities that lead to air pollutant emissions include well pad and infrastructure preparation (i.e. trucking of equipment), vertical and horizontal drilling, hydraulic fracturing, well completion, transportation (e.g. transportation of water and waste materials), production stage distribution of the gas, and the associated end-use of the gas. The risk of exposure to air pollution is driven by the increase in ambient particulate matter (PM) concentrations, which already occasionally exceed national ambient air quality standards. For ozone and PM, no concentration limit has been determined below which there is no impact on human health.

What is the research gap?

The most important gap is to establish baseline information before Phase II appraisal takes place. This applies to both GHGs and local air pollutants. While control technologies and systems exist, their effective implementation depends on good governance, transparency and strong regulatory and enforcement frameworks. Based on initial baselines, ongoing monitoring and enforcement needs to be put in place. More regional information on local air pollutants (including measurements and photochemical modelling) is needed to establish ambient concentrations. International experience on GHGs regarding leakage rates deserves further study for South Africa, with both top-down modelling and bottom-up ground-truthing of 'super-emitters' – low-frequency but high-consequence events.

What are the specific research questions that need to be addressed?

- What are the baseline emissions in the Central Karoo where shale gas development may occur with regard to the following:
  - GHGs: carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O)
  - Local air pollutants: nitrogen oxide (NOx), carbon monoxide (CO), volatile organic compounds (VOCs), diesel exhaust, PM (PM2.5, and PM10), hydrogen sulphide (H2S), ozone (O3) and respirable crystalline silica
- What governance, institutional and skilled human capacity needs to be put in place for the effective monitoring of the impacts of shale gas development, and the enforcement of measures to mitigate risks required by government?

- What are the ambient concentrations of particulate matter and ozone in the Central Karoo?
- What does the literature on super-emitters in the USA suggest for South Africa, what leakage rates should be assumed now (prior to shale gas development) and what research and monitoring would be required after shale gas development (if any)?
- What are the best practices that can be implemented to avoid both GHG and more localised air pollution impacts, and if unavoidable, mitigate such impacts (inclusive of the adoption of buffer areas)?

Table 9 Analysis of the tasks of the Air Quality and GHGs research topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
20. Determine regional baseline concen-trations for local air quality and GHG.	Central Karoo	Project	**Priority =** 0–2 years **Duration =** 5 years (ongoing)	◆◆	**Lead:** DFFE **Support:** DSI, DMRE, Depart-ment of Health (DoH), provinces, munici-palities	Yes, regional health and environ-mental quality	Yes
21. Using data from the USA, use top-down and bottom-up modelling to deter-mine leakage rates in South Africa. Monitor leakage rates to calibrate models.	Central Karoo/ inter-national data	Project	**Priority =** 5 years **Duration =** 0–2 years	◆	**Lead:** DFFE **Support:** DSI	Yes, to gas industry in South Africa	Yes

3.6.4.3 Human Health

Why is this topic important?

Research suggests that the people in the Central Karoo are generally less healthy than those in the rest of South Africa, making them potentially vulnerable to negative environmental impacts (Genthe *et al*., 2016). Furthermore, although data is sparse, there are concerns that individual chemicals used in hydraulic fracturing may have short- and long-term impacts (Genthe *et al*., 2016). While very low concentrations of such chemicals are utilised for hydraulic fracturing, there is nevertheless the chance of potential health impacts via various exposure pathways, i.e. air, soil and food contamination. Hence, the probability of potential impacts needs to be investigated.

What research has already been undertaken?

To date, desktop reviews of international studies on the impacts of shale gas development have been the focus in South Africa, since fracking has not previously taken place in the country. These included various reports (e.g. DMRE, 2012; ASSAf, 2016), as well as a national scientific assessment (Scholes *et al.*, 2016) under the auspices of various government departments. A public health survey associated with potential shale gas exploration and production in the Central Karoo has been undertaken (Willems, 2015) to determine the knowledge levels of people residing in the Central Karoo regarding the possible impacts of hydraulic fracturing on their health, their thoughts regarding these potential impacts, their health risk perceptions and what formed their perceptions, their main sources of information regarding shale gas development, as well as their trust in government regarding shale gas exploration and production.

What is the research gap?

The health impacts associated with the shale gas industry, especially longer-term community health impacts, are largely unknown and have not been assessed internationally in any detail.

What are the specific research questions that need to be addressed?

- What metrics need to be used to determine the regional health baseline of the Central Karoo?
- What is the current status of health in the Central Karoo and what is the status of the health infrastructure and skills?
- What are the short- and long-term health impacts and associated financial implications?
- What are the most suitable personal protective equipment (PPE) measures and engineering solutions to mitigate human health impacts?
- What are the noise impacts of shale gas activities and how can they be mitigated?

Table 10 Analysis of the tasks of the Human Health research topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Departments	Co-benefits	Relevant to CBM, and off-shore oil and gas
22. Initiate a baseline regional health monitoring programme and vulnerability assessment.	Central Karoo	Integrated programme	**Priority =** 0–2 years **Duration =** 5 years (ongoing)	◆	**Lead:** DoH **Support:** DSI, DWS, DFFE, Department of Employment and Labour (DEL), provinces, municipalities	Yes, health status	Yes
23. Assess the potential short- and long-term health impacts of hydraulic fracturing and estimate the cost of these impacts to the public health system in South Africa. Determine the effectiveness of PPE and engineering solutions to mitigate impact and reduce costs.	Central Karoo/ international data	Project	**Priority =** 5 years **Duration =** 0–2 years	◆	**Lead:** DFFE **Support:** DSI	Yes, to gas industry in South Africa	Yes

3.6.5 Flagship Programme 5 - Social Fabric, Local Economics, Regional Development and Governance Capacity

3.6.5.1 Social Fabric and Local Economics

Why is this topic important?

Shale gas development will have a significant effect on local towns and communities – these will be both positive and negative. Positive impacts include job creation and regional investment from the private and public sector. Negative impacts include the influx of people and pressures for public spending, e.g. housing, streets, health, water, wastewater and solid waste disposal, electricity and policing. The crucial point is that any mining investment, which is typically of a 'boom and bust' nature, requires effective government planning and balancing throughout the mining period. This includes ensuring financial mechanisms for ongoing and post-closure activities so that municipalities and communities are not financially responsible for damaged ecological services or infrastructure.

What research has already been undertaken?

A fair amount of research has been done on the boom or bust nature of mining, e.g. in the Welkom (Free State) and Sishen (Northern Cape) areas. Estimates on the economic value of and number of jobs in the shale gas industry have been reported in, for example, Econometrix (2012). Van Zyl *et al.* (2016), as part of the national scientific assessment (Scholes *et al*., 2016), which provides a synthesis of these reports and estimates the number of jobs and value shale gas development would add to the local economy versus current land uses, such as agriculture and tourism (based on assumed 5 tcf and 20 tcf economically recoverable scenarios). The information from municipal and provincial planning documents provides a good indication of the social and economic baseline trends in the area.

What is the research gap?

From a social fabric perspective, not enough is known about the way shale gas exploration activities are perceived by local communities and how this activity either enhances or diminished their 'sense of place'. Sense of place is intrinsically linked to important social and economic activities in the region, such as tourism. If shale gas is developed at scale, there are no clear guidelines for the financial compensation of municipalities bearing the brunt of operational and post-closure impacts.

What are the specific research questions that need to be addressed?

- What are the senses of place and how are they impacted upon by industrial development in the Central Karoo?
- How sensitive are tourists to shale gas development activities? At what spatial scale?
- What are the micro- and macro-economic costs and benefits of shale gas development?
- What is an effective framework for the long-term monitoring and management (including rehabilitation and the mitigation of impacts) of abandoned or decommissioned wells and other infrastructure?
- What economic model(s) can be implemented to ensure cost recovery related to service delivery and optimising local and regional economic opportunities related to shale gas development (including taxes, levies, development contributions, social corporate investment and application levies)?
- How should produced domestic shale gas be used to benefit South Africa's transition to a low carbon economy and to ensure that the country honours its international climate change commitments?

Table 11 Analysis of the tasks of the Social Fabric and Local Economics research topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Departments	Co-benefits	Relevant to CBM, and off-shore oil and gas
24. Determine 'senses of place' in the Central Karoo and the responses to proposed shale gas development activities.	Karoo Central	Project	**Priority =** 0–2 years **Duration =** 5 years	◆	**Lead:** Department of Social Development (DSD) **Support:** Provinces, municipalities	Yes, relevant to all development projects in the Central Karoo	Yes, but different regions
25. Investigate the nature of tourism in the Central Karoo and internationally to determine its sensitivity to shale gas development activities.	International data/ Central Karoo	Project	**Priority =** 5 years **Duration =** 5 years	◆	**Lead:** Department of Tourism (DT) **Support:** dtic, dtic, provinces, municipalities	Yes, relevant to enhancing the tourism performance of the Central Karoo	Partially relevant to tourism in the Waterberg
26. Scan international (boom and bust) literature for case studies of financial models designed to cater for potential long-term impacts and infrastructure damages liability. Recommend best models for the South African shale gas industry.	Global	Project	**Priority =** 5 years **Duration =** 2 years	◆	**Lead:** National Treasur **Support:** DFFE, DMRE, provincial authorities	Yes, relevant to the entire mining sector	Yes
27. Undertake a full cost-benefit analysis based on seismic and deep vertical drilling results that account for externalities (undertaken within the Socio-Economic Impact Assessment System developed under the Department of Planning, Monitoring and Evaluation (DPME))	National	Integrated programme	**Priority =** 5 years **Duration =** 5 years	◆◆	**Lead:** PME **Support:** National Treasury, DFFE, DMRE, Department of Agriculture, Land Reform and Rural Development (DALRRD), DT, DWS, provincial authorities	Partially relevant to other development programmes in the Central Karoo	Yes

3.6.5.2 Development, Infrastructure and Governance Systems

Why is this topic important?

Small- and medium-sized towns play a significant role in South Africa. Within a context of ongoing urbanisation, but also town ward concentration, many of these towns face major challenges in terms of increased vulnerabilities, rising unemployment, increased service delivery demands, and resource- and skills-strapped local municipalities. The need to support municipal spatial and integrated settlement and infrastructure planning, as well as aligned intergovernmental planning and governance between the various spheres and sectors involved have been identified as critical.

What research has already been undertaken?

Monitoring is mostly geared towards tracking job creation and tangible targets. The monitoring of unintended consequences, impact on local economies and social cohesion have been highly fragmented and anecdotal. Local case studies do not exist, even though learning from other large-scale infrastructure and mining-related initiatives could be highly relevant.

What is the research gap?

A priority is to identify relevant case studies, design a coherent research programme and implement real-time monitoring and evaluation of the intended and especially the unintended consequences of large-scale investments in small towns. A programmatic approach to track implications over the lifetime of projects, but especially beyond that, making use of innovative and scalable qualitative and quantitative data, will add incredible value. Such learning can support decision-support systems, feed into the modelling of scenarios and serve as a probe to feed into local and intergovernmental planning forums.

What are the specific research questions that need to be addressed?

- What is the status quo and functionality of existing infrastructure, service delivery and existing governance systems in the Central Karoo that will be influenced by shale gas exploration? Which government departments are responsible for which specific tasks and how resourced are they to undertake their jobs?
- What are the intended and unintended consequences of large-scale externally induced investment on the livelihoods, economies and service delivery needs of small towns and surrounding hinterlands?
- Is there value in the real-time monitoring of such consequences to inform municipal, as well as intergovernmental short-term adaptation, as well as longer-term forward planning?

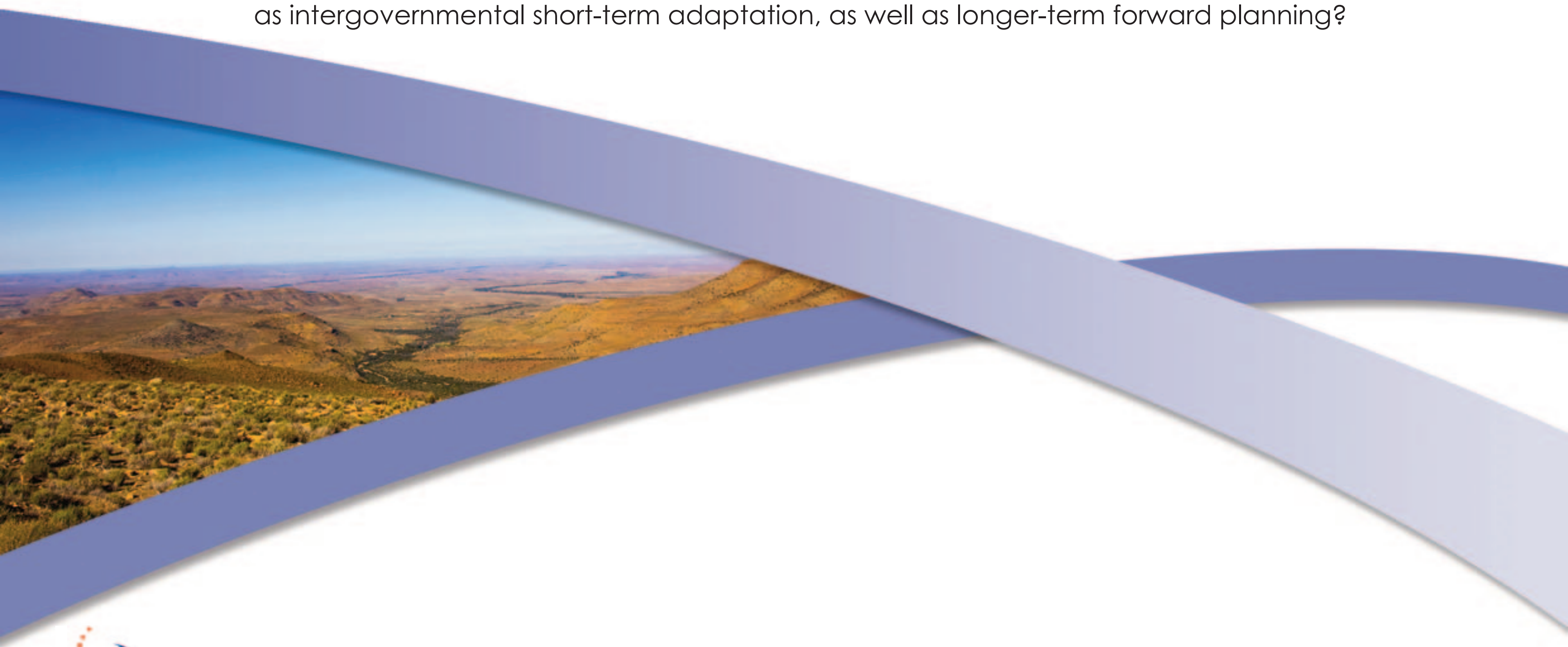

Table 12 Analysis of the tasks of the Development Infrastructure and Governance Systems research topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
28. Undertake a status quo assessment of key municipal infra-structure. Couple assessment with mining case studies from southern Africa looking at intended and unintended consequences. Develop systems to model financial and spatial risk.	Central Karoo/ Southern Africa	Project	**Priority =** 0–2 years **Duration =** 2 years	◆	**Lead:** Depart-ment of Cooper-ative Gov-ernance and Tradi-tional Affairs (CoGTA) **Support:** DFFE, National Treasury, Depart-ment of Public Works and Infrastruc-ture (DPWI), DALRRD, provinces, municipal-ities	Yes, relevant to municipal planning	Yes
29. Determine levels of governance capacity in national, provincial and local government depart-ments responsible for the monitoring and enforcement of shale gas.	National/ Central Karoo	Project	**Priority =** 0–2 years **Duration =** 2 years (ongoing)	◆◆	**Lead:** CoGTA **Support:** DFFE, National Treasury, DPWI, DALRRD, provincial authorities, municipal-ities	Yes, relevant to national and local govern-ment	Yes
30. Review water and waste regulations, taking into account existing reports of impacts in the South African context. Review the suitability of the regulations to c reate an enabling environment for shale gas explora-tion.	National	Project	**Priority =** 0–2 years **Duration =** 5 years	◆	**Lead:** DWS **Support:** DFFE, DMRE, DSI, provincial authorities	No	Yes

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
31. Propose terms of reference of an independent shale gas exploration monitoring body with appropriate governance structures and reporting lines.	National	Inde-pen-dent agency	**Priority =** 0–2 years **Duration =** 5 years (ongoing)	◆	**Lead:** DMRE **Support:** DWS, DSI, provincial authorities	No	Yes
32. Establish appropri-ate shale gas local or district govern-ance structures to monitor real-time impacts on infrastructure and services.	Central Karoo	Project	**Priority =** 5 years **Duration =** 10 years (ongoing)	◆	**Lead:** CoGTA **Support:** DFFE, Na-tional Treasury, DPWI, DALRRD, provincial auth-orities, munici-palities	Yes, relevant to munici-pal plan-ning	Yes

3.6.6 Flagship Programme 6 - Skills Development

Why is this topic important?

A shale gas industry requires the availability of a wide range of skills, from artisans to reservoir engineers. These skills, mainly in the upstream sector, are currently either in short supply or unavailable, but have the potential to create jobs in South Africa. As such, South Africa needs to be in a position to capitalise on the resource and create the skills base required to fill employment opportunities. The country thus needs to implement programmes as a matter of some urgency to address this matter.

What research has already been undertaken?

ASSAf (2016) investigated the technical readiness of South Africa to support the shale gas industry. It was found that South Africa is in urgent need of enhancing its skill base if employment opportunities for local people are to be realised.

What is the research gap?

There is a need to understand the type and extent of skills necessary to support a shale gas industry.

What are the specific research questions that need to be addressed?

- What types of skills are required to support the shale gas industry and which of these are not currently being developed in higher education institutions (HEIs) (universities, universities of technology, and technical and vocational education and training (TVET) colleges?
- What is the scale of the skills required across the different sectors?
- How can we implement skills development training programmes to support science, engin-eering and technology (SET) in South Africa, which would benefit the shale gas industry in particular?

Table 13 Analysis of the tasks of the Skills Development research topic

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Depart-ments	Co-benefits	Relevant to CBM, and off-shore oil and gas
33. Model and quantify specific skills requirements (i.e. job descriptions) through the private and public sector for drilling activities, monitoring and responsible decision making (model based on different resource scenarios, e.g. 5 tcf and 20 tcf). Undertake a gap analysis of skills currently available or not available in South Africa. Plot the difference between potential industry requirements and current outputs of the Department of Higher Education and Training (DHET).	International data/ national	Project	**Priority =** 0–2 years **Duration =** 2 years	◆	**Lead:** DHET **Support:** DSI, DFFE, DWS, DMRE, provinces, municipalities	No	Partially
34. Launch a shale gas laboratory, co-funded by industry and potentially either through the DSI and/or the relevant Sector Education and Training Authority (SETA). The facility will be linked to both Exploration Phases and will serve as a training centre for entrants to the industry. Interns are also employed at the laboratory and seconded to research topic leaders in the implementation of the SAP.	Central Karoo/ local	Integrated programme / joint venture	**Priority =** 0–2 years **Duration =** 5–10 years (ongoing)	See Task 1 in Section 3.6.1.1 (Geology and Gas Resources)	**Lead:** DMRE **Support:** DSI, DFFE, DWS, DMRE	Yes, skills development	Yes

3.6.7 Research Integration Task

The diversity and complexity of information coming out the research will make it challenging for government to interpret and thus make decisions. As such, integration tools that provide the latest expertise in collaborative, computing and display technologies for the data integration, visualisation, modelling and simulation of shale gas exploration impacts are needed. The intention will be to integrate data sets from across disciplines in order to facilitate streamlined decision-making processes (see Flagship Programme 6).

Table 14 Analysis of the Research Integration task

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Departments	Co-benefits	Relevant to CBM, and offshore oil and gas
35. Develop, test and run integrative modelling systems to streamline decision making for project development.	Central Karoo	Integrated programme	**Priority =** 0–2 years **Duration =** 5 years	◆◆◆	**Lead:** DSI **Support:** DMRE, DFFE, provinces, municipalities	Yes, relevant to all development decision making	Yes

3.6.8 Programme Coordination Task

The scope of research topics proposed in the SAP crosses many disciplines and skills sets. Carrying out the SAP tasks in an integrated and efficient manner will require oversight from a sufficiently skilled and resourced Secretariat. The responsibilities of the Secretariat should include overall coordination, the development and management of an open-source online data repository (including, among others, coordinating the collection of data, data quality checks, warehousing and data analyses), the appointment of programme chairs, the management and distribution of funds and taking responsibility as the primary liaison point with the Shale Gas Monitoring Committee. It will be the responsibility of the Secretariat to plan and resource an annual two-day workshop where topics are presented, objectives are re-established and the direction of the research is measured against policy needs. In a similar tone, it should be the role of the Secretariat to establish a mechanism or a number of mechanisms to communicate the science emanating from the research to ensure that all stakeholders (especially decision makers, policy makers and local communities) are suitably informed and empowered.

It is again emphasised that data and knowledge management needs careful attention by all parties involved so as to ensure that there is proper and professional dissemination of all such data and knowledge to all interested parties and that such information is in the public domain.

Table 15 Analysis of the Programme Coordination task

Task	Spatial Scope	Research Vehicle	Timing and duration	Cost Scale	Lead & Support Departments	Co-benefits	Relevant to CBM, and offshore oil and gas
36. Establish a Secretariat to manage the implementation of the SAP over a 10-year period.	National	Independent agency	**Priority =** 0–2 years **Duration =** 10 years	◆◆◆	**Lead:** DSI **Support:** DMRE, DFFE, DWS, provincial - authorities	Yes, skills development	Yes

4
Conclusions

Various national research initiatives have provided meaningful contributions to the knowledge base on issues relevant to a domestic shale gas industry in the Central Karoo, particularly in the last eight years. These include the establishment of dedicated shale gas research programmes at the University of Johannesburg, the Nelson Mandela University, the University of Cape Town, the University of the Western Cape and the University of the Free State.

In addition, cross-disciplinary assessments have been undertaken within the private and public sector to advance our understanding of shale gas, as well as reports and evidence presented by non-governmental organisations (NGOs), civil society and trade unions. All these programmes and initiatives have produced commendable research, but there is a need to develop a coordinated approach to addressing the issues raised by these programmes. The proposals contained in this document outline an action plan to address this matter.

The success of this SAP, over the next decade, will depend on the extent to which the proposals outlined in this report are implemented. This will require coordinating the national research agenda in a manner that ensures that knowledge is effectively used in policy-level decision-making processes. The SAP has identified 36 tasks across the different research topics, with 22 tasks of eight research topics requiring implementation within the next two years. From an analysis of the research tasks, there is a high degree of cross-relevance to other economic sectors.

In other words, the tasks identified here will not only benefit the shale gas sector, but will guide other unconventional gas development in South Africa (such as Coal Bed Methane), support developments proposed in the Central Karoo (such as the Square-Kilometre Array (SKA), renewable energy, uranium mining and ecotourism), and promote water security, regional planning, conservation, local economic development, human health and social security in that region. It should also be noted that, in preparing this document, ASSAf has developed a list of people that it believes have the necessary expertise to assist in the execution of the SAP. This will be made available to DSI should it so wish.

The most critical urgent steps toward the implementation of the SAP are as follows:

- The appointment of a suitably resourced Secretariat to initiate and manage the SAP over its 10-year duration
- The appointment of appropriate persons from government departments and the non-government sector to co-chair the Flagship Programmes
- Continued meetings of the Shale Gas Monitoring Committee, possibly with increased frequency
- The involvement of the private sector with a view to its participation in and co-funding of many of the SAP tasks, especially those that relate to exploration drilling activities and skills development
- The initiation, as a matter of urgency, of the work to be undertaken under the priority research topics (0–2 years)

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