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Earth Observation for Oil and Gas Geo-Information Requirements

(Deliverable 1: ESRIN/AO/1-7568/13/I-AM – Value Added Element)

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EARTH OBSERVATION FOR OIL AND GAS

GEO-INFORMATION REQUIREMENTS

(DELIVERABLE 1: ESRIN/AO/1-7568/13/I-AM – VALUE ADDED ELEMENT)

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LIST OF ACRONYMS

AV	Audio Visual
Bbl	Barrels of oil
bbl/d	Barrels-per-day
Bcf	Billion cubic feet
CAPP	Canadian Association of Petroleum Producers
CARD	Centre for Arctic Resource Development
CCS	CO_2 Capture and Sequestration
CNOOC	China National Offshore Oil Corporation
DRC	Democratic Republic of Congo
DRD	Design Requirements Document
EAGE	European Association of Geoscientists and Engineers
EARSC	European Association of Remote Sensing Companies
EIA	US Energy Information Administration
EO	Earth Observation
EOMD	Earth Observation Market Development
ESA	European Space Agency
ESIA	Environmental and Social Impact Assessment
ETM+	Landsat-7 sensor
FEED	Front End Engineering Design
GeolSoc	Geological Society of London
GIS	Geographic Information Systems
GRSG	Geological Remote Sensing Group
Hatfield	Hatfield Consultants Partnership
IFC	International Finance Corporation
InSAR	Interferometric Synthetic Aperture Radar
IPIECA	International Petroleum Industry Environmental Conservation Association
ISG	In Salah Gas
ISO	International Organization for Standardization
ITT	Invitation To Tender
KO	Kick off
LAPSSET	Lamu Port Southern Sudan-Ethiopia Transport Corridor

LiDAR	Airborne Laser Scanning
LNG	Liquefied Natural Gas
O&G	Oil and Gas
OGEO	Earth Observation Oil and Gas working group
OGP	Oil and Gas Producers Association
OPEC	Organization of the Petroleum Exporting Countries
PNG	Papua New Guinea
PRCI	Pipeline Research Council International
PS	Permanent Scatterer
RSPSoc	Remote Sensing and Photogrammetry Society
PS-InSAR	Persistent Scatterer Interferometry
PUG	Petroleum GIS Conference
RCM	RADARSAT Constellation Mission
SAR	Synthetic Aperture Radar
Sonatrach	Entreprise Nationale Sonatrach
SRC	Space Research Centre of the Polish Academy of Science
SPOT	Satellite for Observation of Earth
SWIR	Short-Wave Infrared
SWOT	Strength Weakness Opportunity Threat
TIR	Thermal Infrared
VNIR	Visible/near-infrared

1.0 INTRODUCTION

The oil and gas industry is changing dramatically with the discoveries of unconventional oil and gas, and shale gas in particular. Several new countries may enter the ranks of oil and gas exporters, which represent an important shift in oil and gas geo-politics. Major shale oil and gas resources are found across a range of geographies, but these new resources present technical challenges for their development in terms of geological complexity, water supply, infrastructure, and environmental issues.

In the context of this new era of onshore oil and gas development, the *Earth Observation for Oil and Gas* (EO4OG) project was established by the European Space Agency (ESA) and Oil and Gas Producers Association[1] (OGP) to provide a base for the potential development of earth observation (EO) guidelines for the on-shore oil and gas sector. EO technology includes satellite sensors that can provide regular, repeated observations of large areas of the Earth's surface at different spatial scales. Satellite EO data complement and extend data acquired through *in situ* observations and make an important contribution to oil and gas development across the project life cycle.

The EO4OG project commenced in March 2014 with a three-month consultation phase to assess the oil and gas industry geo-information requirements in five major thematic areas: seismic planning, surface geology mapping, subsidence monitoring, environmental monitoring, and logistic operations and survey planning. This report summarizes the preliminary **geo-information requirements** identified through a process of expert review and industry consultation through interviews and an online questionnaire. This report is accompanied by a detailed list of geo-information requirements, which are found online in the OGEO Portal[2] – comments on this report and the detailed requirements are encouraged using the OGEO Portal.

The geo-information requirements will be used in the next phase of the project to assess the existing mature and available EO-based products and services that can address industry requirements. The project will evaluate the current gap between requirements and EO capabilities, including technologies that are expected to become operational within five years. The EO4OG project findings will be presented at an **EO4OG Industry Workshop** on November 18, 2014, in London.

2.0 PURPOSE

The purpose of the EO4OG project is to establish a base for the potential development of EO guidelines for the on-shore oil and gas sector.

The purpose of this report is to document the challenges posed by conventional and unconventional oil and gas development and to establish a standard set of geo-information requirements in seismic planning, surface geology mapping, subsidence monitoring, environmental monitoring, and logistic operations and survey planning. The challenges and geo-information requirements documented are those identified based on consultation with the oil and gas industry and key service providers.

3.0 SCOPE

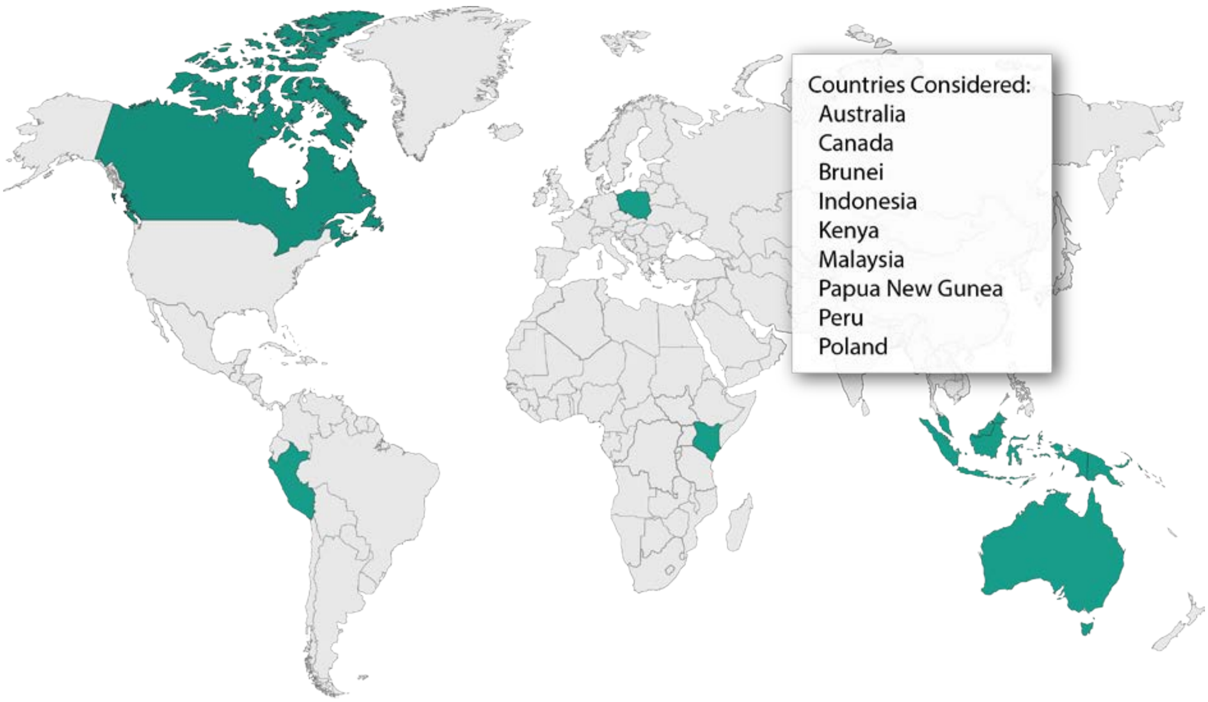
The EO4OG project addresses the complete oil and gas project lifecycle, from pre-license acquisition, exploration, development, production phases, through to the decommissioning phase.

[1] Geomatics Committee, EO-subcommittee

[2] http://www.ogeo-portal.eu/ (navigate to Projects -> OGEO Projects -> On-shore Project Hatfield)

While many challenges within the oil and gas sector are global and independent of climate, terrain, and remoteness, the project specifically addresses several countries with new exploration and production potential as the oil and gas industry seeks resources in new and potentially challenging regions (Figure 1).

Figure 1 Specific countries addressed in geo-information requirement assessment.



4.0 APPROACH

Geo-information requirements were established through expert review, interviews with industry members, and an online questionnaire.

The approach was to document ***challenges*** faced by the oil and gas industry, with the expectation that each challenge results in specific ***geo-Information requirements***. A specific challenge may have several geo-information requirements. For example, a challenge might be:

> *Planning a seismic survey in a mountainous, forested tropical region to reduce health and safety risks for survey staff.*

This challenge might result in the following geo-information requirements:

- Elevation and slope data to characterize topography
- Forest density and structure information
- Existing disturbance and linear corridors
- Location of existing settlements
- Distribution and status of infrastructure
- Lakes, wetlands, and flooded areas

4.1 EXPERT REVIEW

Expert review was conducted by the EO4OG project team and several key advisors that are members of the OGP Geomatics Committee (EO Subcommittee). The EO4OG team includes companies and institutions with extensive global experience providing technical services to the onshore oil and gas sector in each of the project's thematic areas:

- **Hatfield Consultants (Team Lead)** – an environmental consulting company delivering environmental and geo-spatial services to the onshore oil and gas sector. Hatfield has offices in Canada, Southeast Asia, and Southern Africa.
- **RPS Energy / RPS Group** – a global consultancy that helps clients develop natural energy resources across the complete asset life cycle, combining technical and commercial skills with an in-depth knowledge of environmental, health and safety issues. RPS Energy has major regional offices in North America, Europe, Middle East, Australia and South East Asia as well as local offices and agencies in many other areas.
- **Arup** – an independent global consultancy of designers, planners, engineers, and technical specialists offering a broad range of professional services. Arup supports the oil and gas sector regarding infrastructure and storage for exploration, production and transport. Arup also provides specialist services related to structural and geotechnical integrity of on- and offshore facilities. Arup has major regional offices in Europe, North America, Middle East, and Australia.
- **C-CORE** – provides innovative remote sensing, ice and geotechnical engineering solutions to clients in the natural resource sectors and government. C-CORE manages LookNorth, a Canadian Centre of Excellence for Commercialization and Research for sustainable resource development in harsh environments and the Centre for Arctic Resource Development (CARD).
- **Space Research Centre of the Polish Academy of Sciences** – an interdisciplinary research institute specializing in the fields of Physics and Astronomy, including remote sensing and space technology. SRC's work includes land cover and land use classification, change detection (optical and SAR data), and programing for large-scale image processing.

4.2 INTERVIEWS

Interviews were conducted with geomatics and other technical specialists in major global oil and gas companies, including subject matter experts with global responsibilities and specialists in specific countries of interest. Interviews included experts in service companies that support the oil and gas industry. Industry events were attended based on the schedule of the requirements assessment project, including:

- Petroleum Environmental Research Forum (PERF) Workshop on Environment Remote Sensing (London)
- Global Petroleum show (Calgary)
- Indonesia Petroleum Association Convention (Jakarta)
- Polish experience in the field of shale gas exploration (Warsaw)

4.3 ONLINE QUESTIONNAIRE

An **online questionnaire**[3] was used in order to reach a wide industry audience for the geo-information requirements gathering. The survey also served as a tool to prepare people for an interview by introducing participants to the type of information required. Following the survey, respondents were directed to a thank you page and encouraged to sign up and contribute to the project via the OGEO Portal.

4.4 SYNTHESIS

The information gathered was reviewed by the project team to establish the synthesis report and the first draft of the detailed geo-information requirements that are found in the OGEO Portal. All members of the OGEO were encouraged to contribute to the geo-information review process.

5.0 COUNTRY OVERVIEW AND ISSUES

Countries where the oil and gas industry operates need to be assessed based on factors that include climate (temperature, precipitation, and the seasonality of precipitation), native vegetation, water resources, topography, and remoteness. The oil and gas industry operates in all major climate zones, including tropical, arid and semi-arid, temperate, and polar.

The focus countries for the EO4OG project are representative of new exploration and production areas for unconventional oil and gas, shale gas and oil sands, as well as conventional oil and gas resources.

5.1 AUSTRALIA

About 95% of Australia's oil and gas reserves are located offshore, while its onshore basins, mostly found in Queensland, New South Wales and Victoria, account for the remaining five percent of the resources.

There are significant onshore petroleum and liquefied natural gas (LNG) processing facilities and a network of gas pipelines distributes gas to domestic customers. Energy-hungry Japan and China are eager customers, so Australia is rapidly increasing its ability to export LNG to these ready markets and, according to Wood Mackenzie[4], an energy consultancy, is expected to grow from seven percent to 25 percent of the world's liquefied natural gas by 2018. Currently, Australia operates approximately 640 km of condensate/gas pipeline, 30,000 km of gas pipeline, 240 km of pipeline for LNG, and 3,600 km for oil/gas/water products.

Australia is one of the top six or seven nations with technically recoverable oil and gas reserves from shale, according to the United States Energy Information Administration (EIA)[5] on world shale oil resources. So far, experts say, exploration for unconventional resources using hydraulic fracturing has made few inroads in Australia, but the country has positioned itself at the "forefront of shale development," because of its infrastructure, low population density and other factors, Although

[3] http://eo4og.hatfieldgroup.com/s3/survey

[4] http://www.energyboardroom.com/interviews/interview-craig-mcmahon-lead-analyst-nicholas-browne-senior-analyst-wood-mackenzie-singapore

[5] http://www.eia.gov/analysis/studies/worldshalegas/

Australia is not producing shale oil on a commercial basis, the country has technically recoverable reserves of over 17 million barrels according to the EIA study. The majority of these unconventional reserves, located in Queensland and New South Wales, face technical and environmental challenges for commercial production. Onshore reserves of unconventional oil and gas include the Canning Basin in the northern Western Australia, the Georgina and Beetaloo basins in the Northern Territory and western Queensland, and the Cooper Basin that spans northeast South Australia and southwest Queensland[6].

Unlike the situation in the United States, where private individuals own the subsurface rights to the resources beneath their land, in Australia the state government owns the rights to onshore oil and gas, potentially causing tensions between the state and its farmers.

Unconventional gas is set to play a growing role in natural gas markets, potentially accounting for almost 50 percent of the increase in global gas production to 2035, with new countries, notably Australia, emerging as important producers[7].

Australia: overview of resources, and climate, topography and environment issues:

- Proven reserves:
  - Crude oil – 1.433 billion bbl (Jan 2013 est.)
  - Natural gas – 1.219 trillion m^3 (Jan 2013 est.)
  - Shale gas (unconventional) – 17 million bbl (2013 est.)
- Pipelines condensate/gas 637 km; gas 30,054 km; liquid petroleum gas 240 km; oil 3,609 km; oil/gas/water 110 km; refined products 72 km (2013 est.);
- Climate – generally arid to semi-arid; temperate in the south and east; tropical in northern regions. There are severe cyclones along some coastal regions while severe droughts and forest fires occur throughout the country;
- Terrain – majority of the country is low plateau with deserts with fertile plains in the southeast portion of the country;
- Relatively high-cost country for exploration due to remoteness of areas;
- Land ownership regulations cause tension with farmers, who fear they will not be adequately compensated if an energy company drills on their land;
- Australia is the driest inhabited continent on the earth, and water is a critical issue for many of its inhabitants. Some fear the fracking industry may put water resources at risk.

[6] http://www.ga.gov.au/scientific-topics/energy/province-sedimentary-basin-geology/petroleum/onshore-australia

[7] http://www.abo.net/en_IT/flip-tabloid/oil_25_eng/

5.2 CANADA

Canada's large territory is endowed with an exceptionally rich and varied set of natural resources, which enables it to rank among the five largest energy producers in the world. Its energy industry is highly sophisticated and is both an importer and exporter of oil and refined products. Oil production in Canada comes from three principal sources: the oil sands of Alberta, the conventional resources in the broader Western Canada Sedimentary Basin (WCSB), and the offshore oil fields in the Atlantic. Activity within Western Canada's unconventional resources will play an increasingly important role in years to come.

According to the National Energy Board[8], western Canada is responsible for almost 95 percent of Canadian oil production, while Eastern Canada contributed the remaining five percent of national output.

Canada's unconventional oil sands are a significant contributor to the recent and expected growth in the world's liquid fuel supply and comprise the vast majority of the country's proven oil reserves (expected to provide approximately 85% of Canada's production by 2017), which rank third globally. Environmental issues around oil sands production are unique in some respects, particularly regarding land disturbance, water use, water quality, air quality, and aquatic and terrestrial wildlife impacts.

Shale oil and gas production in Canada is currently limited but quickly gaining momentum while the shale gas basins in eastern Canada (Quebec and New Brunswick) are in early stages of exploration and development. There are a number of general challenges regarding shale oil and gas exploration and development, which include technical challenges of recovery as a result of geological complexity, water supply, infrastructure, and environmental issues. The process of hydraulic fracturing has received considerable attention, including environmental and water resource impacts, land stability, and subsidence.

In Western Canada, there is an abundance of tight light oil (also known as shale oil) formations, both surrounding conventional oil reservoirs, like the Cardium Pembina oil field, and entirely new regional resource plays, like the Exshaw (often referred to as the Alberta Bakken) and the Duvernay/Muskwa formation, also in Alberta. In the WCSB, there are a variety of formations in four provinces that contain tight light oil including the following:

- Bakken/Exshaw Formation (Manitoba, Saskatchewan, Alberta, and British Columbia)
- Cardium Formation and the Beaverhill Lake Group (Alberta)
- Viking Formation (Alberta and Saskatchewan)
- Lower Shaunavon Formation (Saskatchewan)
- Montney/Doig Formation (B.C. and Alberta)
- Duvernay/Muskwa Formation (Alberta)
- Lower Amaranth Formation (Manitoba)
- Canol (Northwest Territories)

8 http://www.neb-one.gc.ca/clf-nsi/rnrgynfmtn/sttstc/crdlndptrlmprdct/stmtdprdctn-eng.html

As a result of previous exploration activity in the 1970s and 1980s, it's estimated that Canada's Arctic region holds billions of barrels of oil and gas both onshore and offshore, but logistical problems and extremely high costs have kept exploration and production sporadic, despite government support. Industry has drilled hundreds of wells over the last 40 years but despite this exploratory success, much of the discovered resources remain in the ground[9].

Now, improvements to drilling technology has contributed to a rekindled interest in the region among the world's largest oil companies (e.g. ConocoPhillips Canada, Husky Energy, Royal Dutch Shell, and Imperial Oil Ltd.) that are making plays to explore for reserves in the Canol shale play in the Sahtu region of the Central Mackenzie Valley are in the Northwest Territories.

Trading arrangements between Canada and the United States (US) are such that Canada's natural gas pipeline system is highly interconnected with the US pipeline system. TransCanada operates the largest network of natural gas pipelines in North America, including thirteen major pipeline systems and approximately 60,000 km of gas pipelines in operation, over 40,000 km of those pipelines operate within Canada. Development of heavy oil pipelines is receiving particular public interest.

Canada: overview of resources, and climate, topography and environment issues:

- Proven reserves:
  - Crude oil – 173.1 billion bbl (Jan 2013 est.) – 13% of global reserves
  - Natural gas – 1.93 trillion m^3 (Jan 2013 est.)
  - Unconventional oil – 506 million bbl (2014 est.)
- Climate – varies from temperate in south to subarctic and arctic in north. Harsh winter climate in most areas, including continuous permafrost in far northern areas which is a serious obstacle to development;
- Terrain – central Canada is mostly plains with mountains in the west and lowlands in southeast;
- Almost 10% of the Canadian territory is water (two to three million lakes est.);
- Much of the territory is remote and lacks infrastructure while 90% of population lives within 200 km of the US border;
- Resources in remote locations with high operating costs;
- Extensive environmental information required to meet licensing and regulatory requirements. Extensive consultation with Aboriginal Peoples and Communities;
- Resources and pipeline infrastructure crosses range of natural landscapes and human land uses; and
- Concern regarding cumulative impacts on water resources and wildlife management issues.

[9] http://www.theglobeandmail.com/news/national/the-north/fracking-and-climate-change-canadas-far-north-gets-an-energy-boost/article16396953/

5.3 INDONESIA, MALAYSIA, BRUNEI

5.3.1 INDONESIA

Energy self-sufficiency is a long term goal for Indonesia, which left the Organization of the Petroleum Exporting Countries (OPEC) in 2008 when it became a net importer of oil.

Indonesia is the most populous country in Southeast Asia and ranks as the 24th-largest crude oil producer in the world. Indonesian oil production continued to decline in 2013 as recent discoveries have not yet reached full capacity. Aging infrastructure and oil fields suggest the country will likely continue to struggle to meet production targets in the short term. While the majority of production is derived from offshore basins, Chevron operates Indonesia's two oldest, largest producing onshore fields, Duri and Minas, located on the eastern coast of Sumatra in the South Sumatra Basin. Total operates onshore production and facilities to support offshore production in East Kalimantan. Onshore exploration occurs throughout the archipelago's major islands including Sumatra, Borneo and Papua, and Sulawesi.

With an estimated 547 tcf of recoverable shale gas resources and Indonesia's energy production threatening to become a significant drag on its economy, the benefits of once again becoming a net energy exporter are extensive. Yet the momentum now appears to have stalled, with Indonesia facing uncertainty over the future of shale gas as it struggles to attract sufficient investment.

5.3.2 MALAYSIA

Malaysia is the second largest oil and natural gas producer in Southeast Asia, the second largest exporter of LNG globally, and is strategically located amid important routes for seaborne energy trade. Its oil reserves are the fifth highest in Asia-Pacific and one of the top 30 highest reserves in the world. ExxonMobil, Shell, and Murphy Oil are the largest foreign oil companies by production volume, and Shell is the largest foreign investor in Malaysia's oil sector.

Malaysia continues to focus on offshore production as over half of the country's natural gas reserves are in its eastern areas, predominantly offshore Sarawak, where the gas reserves are associated with oil basins. There is also renewed onshore development activity. In 2013, deposits of crude oil and gas were discovered in the vicinity of Miri City in northern Sarawak. The discovery by Petronas and Nippon Oil, the first onshore discovery in over 20 years, is poised to open up new frontiers in inland oil and gas exploration. To-date, three discoveries have been made within Sarawak; the Miri, Asam Paya, and Adong Kecil West fields.

Malaysia has a relatively limited oil pipeline network and relies on tankers and trucks to distribute products onshore. The networks that connect offshore production to onshore are currently expanding following the launch of several infrastructure development projects. For Sarawak, there are a few other oil pipelines connecting offshore fields with the onshore Bintulu oil terminal. The majority of oil pipelines are operated by Petronas, while Exxon Mobil also operates a number of pipelines connected with its significant upstream holdings located offshore Peninsular Malaysia.

Malaysia does, however, have one of the most extensive gas pipeline networks in Asia. A 2,500 km network of pipelines connect offshore gas fields to gas processing facilities and link Sarawak's offshore gas fields to LNG shipping facilities. Because of Malaysia's extensive natural gas infrastructure and its location, the country is a natural candidate to serve as a hub in the ongoing trans-ASEAN gas pipeline system (TAGP).

5.3.3 BRUNEI

Brunei, an energy-rich Sultanate on the northern coast of Borneo in SE Asia lodged between the Malaysian states of Sabah and Sarawak, lies at the heart of the Northwest Borneo Basin. Exploration for oil and gas in the onshore areas of Brunei started more than a century ago when the first recorded well, Ayer Berkunchi, was drilled in Brunei bay.

Today, Brunei is a substantial producer and exporter of crude oil and natural gas for Asia with resource estimates exceed 10 bbl/d of oil and 46 tcf of gas. Through its long-standing joint venture with Royal Dutch Shell (Brunei Shell Petroleum) Brunei has produced oil and natural gas for several decades, primarily from two large, mature fields – Seria and Champion – in the offshore Baram Delta. With the exception of some coastal wells, no onshore oil or gas has been produced since 1962[10].

According to Brunei National Petroleum Sendirian Berhad (PB), Brunei's national oil company, revenue from oil and gas exports accounts for 90 percent of Brunei's GDP. After reaching a recent peak of 220,000 barrels per day (bbl/d) in 2006, Brunei´s petroleum and other liquids production has declined to 134,000 bbl/d in 2013[11] and the Sultanate is faced with maturing petroleum assets. Despite evidence of significant accumulations of hydrocarbons and nearby world class oil and gas export/refinery facilities onshore Brunei, there has been little concentrated, onshore exploration efforts since 1988. Currently, two large on-shore blocks (Block M and Block L) are being explored following awards to two Australian companies; Melbourne-based AED Oil, and Perth-based Tap Oil. Serinus Energy (formally Kulczyk Oil), a Canadian oil and gas company, is also active in Brunei where it owns working interests to produce oil and gas from Blocks L and M.

[10] http://www.ft.com/cms/s/0/f9bf5474-4d68-11df-9560-00144feab49a.html#axzz37CNEpboL

[11] http://www.eia.gov/countries/country-data.cfm?fips=BX

***Indonesia, Malaysia*, and Brunei: overview of resources, and climate, topography and environment issues:**

- Proven reserves (Indonesia):
  - Crude oil – 4.03 billion bbl (Jan 2013 est.)
  - Natural gas – 3.07 trillion m^3 (Jan 2013 est.)
- Proven reserves (Malaysia):
  - Crude oil – 0.64 million bbl (Jan 2012 est.)
  - Natural gas – 2.35 trillion m^3 (Jan 2013 est.)
- Proven reserves (Brunei):
  - Crude oil – 1.1 billion bbl (Jan 2013 est.)
  - Natural gas – 390.8 billion m^3 (Jan 2013 est.)
- Climate – three countries have similar climates; hot and humid tropical climate with two distinct wet seasons and persistent cloud cover in some areas. Highland areas have a more moderate climate;
- Terrain – mostly coastal lowlands and plains rising to highlands and interior mountains on larger islands and land masses;
- Archipelago of islands with sensitive coastal environment and local communities dependent on natural resources;
- Rich biodiversity and areas of tropical forest and mangrove;
- Poor infrastructure, particularly in Indonesia;
- Seismically active region, particularly in Indonesia;
- Dense population and relatively poor communities in some regions; and
- Increasing pipeline development for transportation of oil and liquid natural gas.

5.4 KENYA

In the past, doubts about the amount of recoverable resources in the East Africa region, along with regional and civil conflicts, presented challenges and risks to foreign companies. Consequently, exploration activities in East Africa have evolved at a much slower pace relative to other African regions. However, the pace of exploration activity has recently picked up in Kenya after foreign oil and gas companies made a series of sizable discoveries. According to a report by Deloitte in 2013, more hydrocarbons have been discovered in East Africa in the past two years than anywhere else in the world. In Kenya, UK-based Tullow, in partnership with Vancouver-based Africa Oil Corp., announced in 2013 that it had discovered oil in the South Lokichar Basin within the Turkana region (commercial viability is yet to be determined). The Turkana discovery has led to major international interest in Kenya's remaining oil exploration licenses, including from Total, China National Offshore Oil Corporation, ExxonMobil, Apache, Statoil and Chevron, though no other companies have yet announced commercially viable discoveries. Kenya has 46 blocks, of which 44 are licensed to 23 exploration companies. The Kenyan government plans to create and auction seven new blocks in the near future.

While most of the international focus has been on oil exploration, Kenya has enormous natural gas potential. Gas exploration has lagged, however, partly because the government's exploration licenses failed to clearly address gas rights. To rectify matters, Kenya's Ministry of Energy and Petroleum has stated it is drawing up new terms for gas explorers, which should help boost interest[12].

Infrastructure development is also planned, including a new reversible product pipeline to Uganda and replacement of the Mombasa to Nairobi product pipeline, as well as improvements to Mombasa Port. Finally, there is the Lamu Port Southern Sudan-Ethiopia Transport Corridor (LAPSSET) project.

Kenya plays a critical role as a transit country in East Africa since its neighboring countries depend on crude oil and petroleum products imported through Kenya's Mombasa Port. Although Kenya currently produces no crude oil or natural gas, it has one of the largest crude oil refineries in East Africa, the 80,000-barrels-per-day (bbl/d) Mombasa refinery (nameplate capacity). The refinery typically operates below capacity and processes Murban heavy crude from Abu Dhabi and other heavy Middle-Eastern crude grades.

The African Rift Valley forms a dominant geological feature within Kenya. Seismicity, faulting, surface movements (uplift and subsidence) and volcanism related to tectonics provide a range of active geohazards in the region.

***Kenya:* overview of resources, and climate, topography and environment issues:**

- Proven reserves:
    - Crude oil – no proven reserves (Jan 2013 est.)
    - Natural gas – no proven reserves (Jan 2013 est.)
- Climate – varies from tropical along the coast to arid in the interior;
- Terrain – consists of low plains that rise to central highlands bisected by the Great Rift Valley. Western plateaus are fertile.
- Majority of activity in the exploration and development phases;
- Substantial pipeline infrastructure to transport oil to other neighboring countries, and need to understand geohazards and subsidence issues;
- High poverty and illiteracy rates within specific regions have potential for security issues with site safety due to difficulties with communication, underemployment and social inequalities; and
- Environmental baseline and habitat data are required.

[12] http://www.oxfordbusinessgroup.com/economic_updates/recent-discoveries-kenya-highlight-oil-and-gas-potential

5.5 PAPUA NEW GUINEA

There is interest by major global energy companies in the Papua New Guinea's substantial oil and gas resources and there numerous petroleum prospecting licenses[13]. Projects include the Papua New Guinea liquefied natural gas (PNG LNG) project by Esso Highlands Limited (EHL), a subsidiary of ExxonMobil Corporation, which is an important infrastructure development to realize the potential of three large gas discoveries in the southern and western highlands of the country. The integrated project includes gas production, processing and liquefaction facilities, as well as offshore and onshore pipelines. According to the PNG Chamber of Mines and Petroleum, LNG shipments are due to start by the end of 2014.

In addition to the PNG LNG project, Talisman Energy and joint-venture partners such as Mitsubishi are very actively targeting a group of licenses covering large parts of Western Province. With substantial proven oil and gas reserves, Western Province is experiencing a large increase in exploration activity from additional companies such as, Nippon Oil, Sasol, InterOil, Eaglewood Energy, New Guinea Energy, and Horizon Oil. Exxon Mobil and Oil Search are focused on the Fold Belt in the central part of the mainland. However, little supporting infrastructure exists outside Port Moresby and the hilly, densely forested terrain makes logistics and moving assets and personnel around very difficult and costly.

PNG is made up of several thousand separate communities, and has a long-running history of tribal conflict. That lawlessness has been made worse by an influx of weapons and capital into urban areas.

As part of its Biodiversity Strategy, which outlines how PNG LNG manages terrestrial biodiversity in its main project area, EHL has defined biodiversity values at various geographic scales (large, medium, and local) to support its mitigation efforts to maintain the area's ecological intactness[14].

Papua New Guinea: overview of resources, and climate, topography and environment issues

- Proven reserves:
  - Crude oil – 154 million bbl (Jan 2013 est.)
  - Natural gas – 155 billion m^3 (Jan 2013 est.)
- Climate – tropical climate with distinct monsoon seasons and persistent cloud cover in some areas;
- Terrain – mostly mountainous landscape, remote with dense tropical forest cover, coastal lowlands and rolling foothills;
- Most activities are in the exploration and development phases;
- Increasing interest in pipeline development for transportation of liquid natural gas;

[13] http://pngchamberminpet.com.pg/petroleum-in-png/

[14] Uncharted Wilderness: a detailed program for protecting biodiversity while developing LNG gas infrastructure in one of the world's least explored regions (Esso Highlands Limited, 2013)

- Strategies to manage terrestrial biodiversity, i.e., conserve priority ecosystems, protect focal habitats, and maintain ecological intactness;
- Lack of infrastructure increases operating costs;
- Some security concerns exist as there is evidence of amplified unrest in PNG as rival groups seek capitalise on the increased capital flowing into the country; and
- Potential for land use conflicts between multiple sectors, i.e., forestry, mining, oil and gas, and between industry and subsidence farming (approx. 85% of population).

5.6 PERU

Peru is the eighth-largest crude oil reserve holder in Central and South America. Much of Peru's proved oil reserves are onshore, and the majority of these onshore reserves are in the Amazon region. Proven natural gas reserves in Peru are the fourth-largest in Central and South America.

Natural gas production in Peru has grown rapidly since the largest energy project went on-stream in 2004. In 2009, unconventional gas was found in the Devonian shale beneath the Santa Rosa 1X well, which was drilled by Maple Energy in its Block 31E. Significant work however, is required to determine if this shale gas reserve can be developed to produce gas in commercial quantities. The Camisea gas project, situated in the San Martin reservoir in the south-eastern Amazon Rainforest, is expected to have a reserve of 13 trillion cubic feet of gas and 482 million barrels of natural gas liquids[15].

Camisea is Peru’s most important source of energy, producing 45 million cubic metres of gas a day. Since 2004 it has provided the government with more than $6 billion in royalties. Camisea’s Block 88 has the biggest probable gas reserves in the Peruvian Amazon, however, most of the block lies in the Kugapakori-Nahua-Nanti reserve, an Amerindian reserve created by the government in 1990. Pluspetrol has drawn up plans, recently approved by the government, to conduct seismic tests and develop new well-sites in the block. Camisea has become a hotspot[16] as well as a test of whether hydrocarbon exploitation can coexist with fragile environments and native peoples. In particular it could be a model for Ecuador, which recently agreed to allow oil exploration in the Yasuní national park.

Environmental stewardship issues are raised by the influx of exploration drilling activity apply across much of the Amazon basin. In Peru, as elsewhere in Latin America, the state owns the subsoil, and any oil, gas or minerals it contains. From 2005 to 2008 the proportion of Peru's rainforest earmarked for oil and gas exploration had expanded from 15% to 72%, much of it on lands claimed under Indian title. Peru’s government has recently announced controversial plans to loosen the social and environmental checks on companies exploring for oil and gas[17] which may have contribute to the issue.

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[15] Camisea Gas Project, Peru (http://www.hydrocarbons-technology.com/projects/camisea/)

[16] http://www.economist.com/news/americas/21601267-energy-extraction-can-coexist-native-peoples-and-forests-drilling-wilderness

[17] http://www.theguardian.com/environment/andes-to-the-amazon/2014/mar/08/peru-eliminate-environmental-rule-oil-gas-minister

Peru: overview of resources, and climate, topography and environment issues:

- Proven reserves:
  - Crude oil – 579 million bbl (Jan 2013 est.)
  - Natural gas – 360 billion m^3 (Jan 2013 est.)
- Climate – varies from tropical in the east to dry desert in the west. The Andes are temperate to frigid;
- Terrain – coastal plains in the west (costa), high and rugged Andes in the centre (sierra), and eastern lowland jungle of the western Amazon Basin (selva);
- Activities in the exploration, development and production phases;
- Concern over environmental stewardship since most of the onshore reserves are in the Amazon Rainforest, often on reserves;
- River shipments of crude oil are planned until adequate pipeline infrastructure is in place; and
- Densely vegetated eastern region with persistent cloud cover.

5.7 POLAND

Poland produces small quantities of crude oil and natural gas and is a net importer of oil and natural gas. With reserves of shale gas estimated at 346-768 billion m^3, Poland has ambitions to replicate the US shale boom and is keen to develop shale gas resources as a way to lower energy costs and reduce its dependency on imports. The Polish government appears intent on moving forward with its unconventional resources in spite of difficulties encountered in 2011 when Exxon Mobil abandoned its projects and Marathon Oil Corporation and Talisman Energy Inc. withdrew amid regulatory constraints and plans to increase taxation. The geological setting also appears to be more complicated and difficult to interpret than anticipated.

More recently, and as a potential turnaround, San Leon, a junior oil & gas player that took over Talisman's operations, announced it had positive results with one of its test wells (vertical) in the Baltic Basin in northern Poland, prompting the drilling of a more productive horizontal well in July 2014. The company hopes to bring the well to commercial production in October 2014. This play, if successful within Poland, has the potential to open other EU countries to exploration and drilling for unconventional oil and gas.

Gas companies drilled over 50 shale wells as of May 2014 (13 were drilled in 2013) and there needs to be at least 200 in total to determine whether large-scale commercial production of shale gas within the Baltic Basin is viable, according to Poland's Environment Minister. With the development of operational hubs by United Oilfield Services and Halliburton, it is expected there will be an increase in exploration and drilling activity in the short term. Even if the production of unconventional oil and gas in Poland is small compared to the US output, there is progress in Poland's shale gas exploration.

Poland imports crude oil primarily from Russia through the Druzhba pipeline, which has a capacity of approximately 1 million barrels per day (bbl/d). Poland imports most of its natural gas from Russia, Norway, and Germany. Russia transports its natural gas to Poland through the Yamal pipeline. As of 2013, Poland operates over 14,000 km of gas pipeline, 1,300 km of oil pipeline, and about 775 km of pipelines carrying refined products.

Poland: overview of resources, and climate, topography and environment issues:

- Proven reserves:
    - Crude oil – 156 million bbl (Jan 2010 est.)
    - Natural gas – 92 billion m^3 (Jan 2013 est.)
    - Unconventional gas – 346-768 billion m^3 (2014 est.)
- Climate is temperate with cold, cloudy, moderately severe winters with frequent precipitation while summers are generally mild.
- Terrain is mostly flat plains with mountains along its southern border
- Strong debate taking place on environmental concerns that have been linked to shale gas extraction (i.e. hydraulic fracturing), namely:
    - Water pollution;
    - Methane leakage; and
    - Induced seismicity;
- Difficult geological setting;
- Land use issues (i.e. access for seismic exploration or well pad siting) and some un-exploded ordnance issues remain from the second world war;

6.0 OPERATIONAL CHALLENGES

Overall, **more than 70 challenges for the oil and gas industry** were identified across the five main thematic areas of seismic planning, surface geology mapping, subsidence monitoring, environmental monitoring, and logistic operations and survey planning. These challenges are defined in detail online in the OGEO Portal – comments are encouraged via the OGEO Portal. The challenges titles are listed in Appendix A of this synthesis report.

6.1 LAND SEISMIC SURVEY

Effective planning is critical to the onshore seismic acquisition process. Operational, environmental and regulatory aspects must be studied before any project commences. The objective of planning is to ensure quality data are obtained through cost effective operations, especially with regard to drilling, data acquisition and processing. There is a variety of different mapping scales, terrain characteristics and vegetation cover needs that need to addressed in planning land seismic survey.

Land seismic surveys are completed using mechanized equipment or man-portable operations, depending on terrain and vegetation. Steep topography, soft terrain, and dense vegetation pose operational and safety risks for mechanized equipment and crews. Near surface terrain characteristics can also degrade the seismic signal (e.g. signal scattering, attenuation, and point loading) and affect data quality.

Onshore exploration projects frequently have complex surface geology because of the variations in erosion, overburden, and water content, which leads to complex environments that can affect surface velocities. Improved subsurface characterization leads to a better image of the reservoir. The main challenges related to planning seismic surveys are:

- **Terrain conditions and topography related to safety and logistics.** Surveys may occur in challenging terrain and topography. Planning requires maps of potentially hazardous terrain in a range of environments, such as arid desert, tropical forests, to permafrost regions. The challenges include:
    - Elevation data are lacking and airborne methods are costly, time-consuming, or unsafe.
    - Steep slopes need to be identified, as well as other hazards such as cliffs and ravines.
    - Low-lying areas that are susceptible to seasonal change in water bodies or flooding.
    - Soft terrain that can be hazardous to vehicles.
    - Dense vegetation, especially tropical forest/jungle.
- **Terrain conditions associated with risk of poor coupling between the ground and a seismic source or receiver**. Surface velocities are affected by different landforms or geomorphologic units such as soft sandy depressions, escarpments, swampy ground or sandy substrate. Discontinuous permafrost area is an issue in northern environments.
- **Environmentally-sensitive areas.** To minimize the environmental impact of seismic acquisitions, environmentally-sensitive areas must be identified. The most common are:

  - Ensuring suitable setbacks for features such as water bodies habitat for important flora and fauna.
  - Wildlife habitat such as caribou winter ranges, calving grounds, and summer ranges.
  - Reducing damage to agricultural land.
- **Reduce the amount of time crews are in the field**. To minimize field survey time and de-risk operations, improved desktop planning is required through better data (e.g. support route planning by identifying and reducing river crossings).

6.2 SURFACE GEOLOGY CHARACTERIZATION

The combined analysis of topography, geomorphology and geology is required at different stages in the oil and gas lifecycle, with particularly strong benefit at pre-license, exploration, pre-FEED and FEED (Front End Engineering Design) stages.

Many of the areas with active exploration lack existing geological mapping at suitable scales and accuracy and there is a need for assessment and interpretation of large, remote geographic areas with difficult and costly field access. Surface geology characterization using EO data should typically be verified using field-based analysis. Verified data can then be incorporated into different workflows at different stages in the oil and gas project lifecycle (e.g. seismic planning and project/logistics de-risking).

The main challenges related to surface geology characterization are:

- **Lithological discrimination.** Information on rock types such as limestone, sandstone, clay, basement rocks. During exploration lithological discrimination is key to mapping formation types in a basin and assessing characteristics of source and reservoir rocks should they outcrop in the region. Mineral alteration by hydrocarbon seepage can be used as an exploration tool. Surface lithology information helps assess potential impacts on land seismic surveys or rates of excavatability (impacting cost of infrastructure) for pipeline trenches.
- **Geological information to build geological models.** Information is required at various mapping scales before any geophysical data are acquired. This information can assist in defining potential basins and reservoirs. Once the outline and characteristics of a basin are identified, structural imaging focuses on potential geological structures. An improvement to geological models leads to better basin and reservoir characterization. At the site development scale geological models are required to inform site selection for facilities, pipeline routeing and developing risk registers for engineering design of facilities such as CPF and LNG plant.
- **Structural interpretation.** Lineament identification including faults, folds (bedding) and shear zones for 3D structural analysis for detailed geological understanding to support exploration, field campaigns, seismic data acquisition and infrastructure siting and design.
- **Geomorphology characterization and geohazard identification.** Information on topography, relief, terrain type, drainage, surface lithology and soil / weathering can be obtained from remote sensing. Visualization of geomorphological features can help with identification of geohazards, which allows for mitigation measures to be considered. Examples of important features and hazards include sabkha, claypans, moraine ridges, sand dunes, wadis, solution features, landslides, faulting, river migration, erosion.

6.3 LAND SURFACE DEFORMATION

Monitoring of land surface deformation is an important activity to support oil and gas production, infrastructure planning and management, and environmental management. Surface movements can impact not only production outputs but also infrastructure such as pipelines and well pads. Surface deformation is also an important environmental and health and safety priority.

The main challenges related to land surface deformation monitoring are:

- **Land-motion relating to fault lines**. Determining active areas to support site selection and situational awareness.
- **Infrastructure monitoring.** The integrity of pipelines can be affected by land surface deformation. Much attention is being focused on northern permafrost, especially the boundary of discontinuous permafrost. Thawing of permafrost in northern regions has a direct effect on pipeline route planning and existing infrastructure.
- **Reservoir management**. Monitoring of reservoirs and modelling to support enhanced recovery techniques and compliance.
    - Improve production rates by identifying areas exhibiting surface response to extraction and reduce the risk of dry wells.
    - Continual monitoring of extraction activities to meet environmental regulations and standards. Activity can produce subsidence at the surface potentially affecting infrastructure or have environmental impacts such as changes in surface water and ground water interactions.
    - Carbon capture and storage projects. Monitoring subsidence and uplift related to CO_2 injection. Long-term monitoring of ground displacement patterns over CO_2 sequestration sites.
- **Methane and light gases leakage**. As part of shale gas development, unexpected emissions of methane and other light gases. Potential need for extensive air monitoring before and after gas drilling to determine how hydraulic fracturing may impact natural leakage rates.
- **Permafrost areas impacted by climate change.** In these areas it can be difficult to separate the degradation in permafrost conditions due to changes in air temperature or due to project developments. Seasonal monitoring provides an indication of the changes due to the active layer. Trends extracted from annual monitoring programs, combined with permafrost models that integrate temperature and moisture with surface/subsurface formations and climate models that provide temperature trends into the coming decades, can provide a baseline of naturally occurring degradation. These models also provide insights into the future impacts of surface projects on the permafrost.

Interferometric Synthetic Aperture Radar (InSAR) is a monitoring technique that continues to develop and improve, although some specific challenges were reported with InSAR. Persistent scatterer Interferometry (PS-InSAR) is a technique that measures differences of permanent scatterers (PS) or point targets. A suitable PS will provide a stable SAR signal return over time; small microwave signal changes that occur at this PS can be measured and analyzed. A typical PS would be a building, transportation/communications infrastructure, dam, or other man-made feature[18]. Natural features

[18] Ferretti, A., Prati, C., Rocca, F., & Colesanti, C. 2004. Validation of the Permanent Scatterers Technique in Urban Areas.

such as exposed rocks can also provide suitable conditions to produce a PS. Under the best conditions, land-surface elevation changes on the order of several centimeters or less can be determined. However, challenges were noted in several regions regarding the availability of point targets and the need to install PS targets. The timeliness of information delivery was also reported as a challenge, as the oil and gas industry seeks to acquire, process and utilize land deformation products.

6.4 ENVIRONMENTAL MANAGEMENT

Oil and gas activities can occur in a range of sensitive environments, such as arid desert, wetlands, and forests. The oil and gas industry aims to minimize its environment footprint across the entire oil and gas project lifecycle. Potential environmental impacts and risks are assessed and avoided or mitigated. An environmental management and monitoring plan ensures that impacts are detected by a company and can be addressed through adaptive management.

Many countries where oil and gas companies operate have well-developed environmental laws and regulations, and companies also refer to the International Finance Corporation (IFC) Performance Standards that define responsibilities for managing environmental and social risks.

The main challenges related to environmental management and planning activities with reduced impact/footprint are:

- **Baseline mapping of environment.** In general environmental baseline issues must be addressed, which include:
    - Identify ecosystem components using data such as land cover, land use, forest density and biomass, and biodiversity (flora and fauna), soils, geology, and elevation.
    - Establish water quality for lakes and rivers and lakes levels and river discharge. Establish groundwater baselines.
    - Air quality and background emissions.
    - Identify historical flooding patterns.
- **Habitat mapping for key species of flora and fauna.** Habitat mapping that can be linked to issues such as biodiversity, including:
    - Habitat fragmentation and quality.
    - Temporal and spatial extent of aquatic habitat.
- **Environmental monitoring**. Effective monitoring of activities supports adaptive management and regulatory reporting, including:
    - Monitoring ecosystem components, particularly land cover, land use, forest density and biomass, and biodiversity (flora and fauna).
    - Surface water quality and quantity.
    - Air quality and emissions.
    - Monitoring progression of vegetation succession, e.g., within pipeline right of way.
    - Monitoring of induced environmental impacts based on opening access to an area for third parties.
    - Remediation monitoring following rehabilitation of sites.

- **Situational awareness**. Routine updates and situational awareness is required to help to monitor compliance and environmental risks:
  - Weather information such as rainfall intensity.
  - Forest fire risk and activity.
  - Lake and river ice and snow extent for northern regions.

6.5 LOGISTICS PLANNING AND OPERATIONS

Logistics planning and operations covers a wide range of activities and challenges related to environmental and social risk management and infrastructure planning and management. An important challenge and responsibility is occupational health and safety management to ensure the safety, health and welfare of employees and local communities. The main challenges related to logistics planning and operations are:

- **Baseline information and updates.**
  - Existing conditions at site and along access routes to site for personnel, plant and consumables.
  - Selection of suitable sites for infrastructure development.
  - Water resources and potential for groundwater exploitation.
- **Infrastructure planning.** Developing capital assets, including transportation system, utility networks and buildings requires extensive baseline information including the identification of existing infrastructure and sub-surface features.
- **On-going monitoring of operational infrastructure and assets.**
  - Mapping locations of crews, camps and equipment to ensure health and safety during exploration and later stages of project.
  - Monitoring rights of way and other corridors for encroachment, erosion, stability, and security. Identify unauthorized activities near pipelines that can lead to damage and interrupt production.
  - Monitoring buildings and other assets for potential encroachment by local communities or the environment.
- **Emergency response preparedness.** Baseline data of natural terrain and operational assets required for the formulation of emergency response plans and monitoring during and post incident using real time or post-incident data.
  - An emergency response will be required following natural hazards (earthquake, volcanic, flood, significant storms, etc.), operational incidents (spills, leaks, etc.), or security incidents (terrorist attack, civil disturbance, etc.).
  - The response required ranges from incident monitoring to crew evacuation based on the likelihood of the emergency developing.
  - Damage assessment for insurance claim quantification and rehabilitation.

7.0 SYNTHESIS: OIL AND GAS INFORMATION REQUIREMENTS

Across the oil and gas project lifecycle and within the range of environments around the globe where the oil and gas industry operates, the challenges faced are generally consistent and ultimately focused on obtaining information needed to reduce environmental, health and safety, and economic risks. Reliable information can help industry make better informed and timelier decisions regarding oil and gas development.

Based on our assessment, addressing the challenges requires information from a set of **base geo-information requirement categories.** These are listed in Table 1.

Table 1 Base geo-information requirements.

Base geo-information requirement	Description
Air quality and emissions	NOx, SOx, CO_2, particulates emissions and concentration. Methane emissions.
Distribution and status of assets	People, equipment, buildings.
Distribution and status of infrastructure	Pipelines, roads, and railways and their condition.
Distribution of habitat and biodiversity	Critical habitat for important flora and fauna. Distribution of important flora and fauna.
Land cover	General land cover information and specific thematic classes such as forest types and parameters.
Land use	General land use information and specific thematic classes such as urban and agricultural land use, as well as other industrial development.
Lithology, structural geology, surficial geology	Surficial geology, geo-hazards
Base images	Multi-spectral images that typically have precise ortho-correction to support multiple uses.
Sub-surface features	Evidence of sub-surface infrastructure.
Surface motion (horizontal and vertical)	Land surface deformation related to seismic activity or production, as well as environmental change such as permafrost degradation.
Terrain information	Stability, surface properties and characteristics
Topographic information	Elevation, slope, and other derived measures.
UXO hazard	Estimates of UXO contamination.
Water quality	Water quality information for rivers and lakes, such as nutrients, sediment concentration, temperature, metals, etc.
Water quantity	Water distribution, including extent of lakes, streams, and wet areas, flood extent, snow and ice cover extent and conditions.

It is not surprising that the most the most frequent geo-information requirement across the challenges identified in the different themes are land use, land cover, topographic information, ortho-base images, and water quantity. A matrix showing the relationships between the geo-information requirements and the themes is shown in Figure 2.

Figure 2 **Base geo-information requirements required by theme (based on a total of 82 documented challenges).**

Base Geo-information Requirement

Theme	Air quality and emissions	Distribution and status of assets	Distribution and status of infrastructure	Identify critical habitat	Land cover	Land use	Lithology, structural geology, surficial geology	Ortho base images	Sub-surface features	Surface motion (horizontal and vertical)	Terrain information	Topographic information	UXO hazard	Water quality	Water quantity
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Seismic Planning			●	●	●	●		●	●		●	●	●		●
Surface Geology Mapping					●	●	●	●				●		●	●
Susidence Monitoring					●	●				●	●				●
Enironmental Monitoring	●		●	●	●	●		●		●	●	●		●	●
Logistics Planning & Operations		●	●		●	●	●	●		●		●			●

The base information requirements are consistent throughout all phases of the oil and gas project lifecycle, but the "demand" in terms of data volume, resolution, precision, frequency, and coverage changes can vary. For example, various environmental data are required throughout the entire oil and gas project lifecycle. The most intensive period in terms of demand and rigour is during an environmental impact assessment as part of the development phase. Subsequently, an environmental monitoring and management plan during production will result in an ongoing demand for environmental data. In contrast, surface geology mapping is most extensively practiced during the pre-license and exploration phases, with demand afterwards related to engineering and construction.

The importance and value of **baseline data and information** is noted, since historical and baseline information is required prior to oil and gas activities. Baseline information can be used throughout subsequent phases to understand and manage the impacts of oil and gas activities, as well as to manage potential external effects on infrastructure and assets.

Several respondents noted that a standardization in how geo-information products are developed would be a great benefit to the oil and gas industry allowing existing and potential customers to easily compare between products and select the most appropriate product or service based on the business need. Currently, it was felt that there was a degree of over-complication in the specification of the products and services leaving customers confused by the number of available parameters and configurations.

8.0 NEXT STEPS AND CANDIDATE SOLUTIONS

The oil and gas sector has used EO technologies for more than 30 years, including satellite-based EO when data became commercially available from the Landsat and SPOT programs. Research and development by oil and gas companies and services providers has led to the application of EO-based products that are relevant to, or specific to, the oil and gas sector. In particular:

- EO enables a unique synoptic view of the land surface and provides timely, consistent, and repeatable observations for oil and gas projects. Many of the environmental and geophysical factors important to oil and gas development and operation can be measured by EO;
- EO provides a range of data that can complement and extend data available from ground-based or airborne sensors and measurements;
- Recent EO advances have enhanced the ability to describe and understand natural resources, facilitate exploration and planning of oil and gas development, and support environmental impact assessments and monitoring:
    - Development of long time-series of EO data and advances in data processing mean that weekly, monthly, and seasonal geo-information products are now possible;
    - Improved spatial and spectral resolution with new frequencies/wavelengths and enhanced information from radar polarization and phase;
    - More frequent observations through increased selection of satellite platforms, flexible imaging geometries;
    - Timely access to data and information products through new communications and web-based technologies.

EO provides several essential elements to support the implementation of oil and gas activities during the project lifecycle. The research carried out for EO4OG project and synthesized in this report are intended to support ongoing efforts to promote increased EO awareness throughout the oil and gas sector, generate a more wide-spread use of existing and new EO technologies, and to maximize the benefits of EO technologies to the sector in general.

Task 2 of the EO4OG project will document the existing mature and available EO-based products and evaluate the extent that these products meet the challenges and geo-information requirements gathered in Task 1. The upcoming assessment will evaluate issues such as demand, utilization, and availability of EO products and services.

APPENDICES

Appendix A1

Industry Geo-information Challenges and Requirements

Seismic Planning – Areas of poor coupling

HCP-1101	Identify areas with soft sediments to avoid strong attenuation.
HCP-1102	Identify rock-strewn areas to avoid point loading.
HCP-1103	Identify soft and hard ground as areas of potentially poor source and receiver coupling.
HCP-1104	Identify lake, river and coastal ice grounding status for data quality.
HCP-1105	Identify permafrost zone for data analysis.

Seismic Planning – Identification of adverse terrain for trafficability

HCP-1201	Identify up-to-date general land use patterns to plan access and apply safe setback distances.
HCP-1202	Identify rivers, lakes and wet areas to apply safe setback distances.
HCP-1203	Identify areas with soft sediments to plan access and assess hazards.
HCP-1204	Assess forest characteristics to plan access and assess hazards.
HCP-1205	Identify steep slopes to assess potential constraints to access in forested areas.
HCP-1206	Identify steep slopes to assess potential constraints to access.
HCP-1207	Identify claypan surfaces to be avoided.
HCP-1208	Identify optimal seasonal land use to reduce permitting costs - in particular commercial and subsistence farming practices.
HCP-1209	Identify land parcel boundaries for impact compensation.
HCP-1210	Identify soft ground to reduce environmental impacts.
HCP-1211	Planning bridging through a tropical forest.
HCP-1212	Identify sabkahs / salt lake areas.
HCP-1213	Identify ice thickness and status for travel safety.
HCP-1214	Identify restricted areas that must be avoided.
HCP-1215	Identify UXO related hazards.

Seismic Planning – Identification of environmentally sensitive areas

HCP-1301	Identify sensitive habitat to minimise and manage impacts of activities.
HCP-1302	Assess and map forest fire risk and provide situational awareness of fire occurrence.
HCP-1303	Planning heliports, camps, and drop zones in forested areas.

Surface Geology Mapping – Mapping geological features

HCP-2101	Lineament mapping.
HCP-2102	Understanding hydrogeology.

Surface Geology Mapping – Structural interpretation

HCP-2201	Identify geological structure through landform.

Surface Geology Mapping – Lithological discrimination

HCP-2301	Identify discreet lithology.

Surface Geology Mapping – Terrain evaluation and geo-morphology characterisation

HCP-2401	Identify geohazards and landscape change rates.

Surface Geology Mapping – Engineering geological evaluation

HCP-2501	Characterization of surface/near-surface structural geological properties for infrastructure planning.
HCP-2502	Identification of problem soils.
HCP-2503	Assessment of duricrusts and rock excavability.
HCP-2504	Identification of slope instability.
HCP-2505	Identify geophysical properties of the subsurface.

Subsidence monitoring – Land motion relating to fault lines or other causes

HCP-3101	Baseline and monitoring of areas with active faults and subsidence.

Subsidence monitoring – Infrastructure monitoring

HCP-3201	Assessment of infrastructure placement and effects to the surrounding environment.
HCP-3202	Monitoring pipeline stability in discontinuous permafrost.
HCP-3203	Management of surface impacts due to ground deformation from operations.
HCP-3204	Monitor stability of surface reservoirs such as settling ponds.

Subsidence monitoring – Reservoir management

HCP-3301	Monitoring carbon capture storage reservoir leaks.
HCP-3302	Assessing ground deformation to support enhanced recovery operations.
HCP-3303	Monitoring effectiveness of steam assisted gravity drainage (SAGD) operations.

Environmental management – Baseline historic mapping of environment and ecosystems

HCP-4101	Assess fragmentation of natural habitat and cumulative disturbance.
HCP-4102	Land cover and land use for environmental baseline and/or impact assessment.
HCP-4103	Social baseline information to support compensation and/or resettlement.
HCP-4104	Mapping of forest extent and quality for environmental baseline and/or impact assessment.
HCP-4105	Identification of cultural heritage and archeology assessment.
HCP-4106	Air quality monitoring on an airshed and site specific basis.
HCP-4107	Detection of unexpected methane leakage on a regional basis.
HCP-4108	Assess habitat quality for key species for environmental baseline and/or impact assessment.
HCP-4109	Understand temporal and spatial extent of usable fish habitat to maintain acceptable levels.

Environmental monitoring – Continuous monitoring of changes throughout the lifecycle

HCP-4201	Remediation and reclamation monitoring.
HCP-4202	Map coastal habitat and built environment/settlement sensitivity to strengthen tactical oil spill response and preparedness.
HCP-4203	Monitor "induced access" corridors to assess indirect impacts or effects as a result of project development.
HCP-4204	Monitoring local communities and land use in the project area.
HCP-4205	Remediation monitoring related to agriculture impacts.
HCP-4206	Monitoring lake and wetland levels and recharge rates following water use for exploration/operations.
HCP-4207	Understanding and predicting changes in hydrological processes.
HCP-4208	Identification of groundwater table to reduce potential issues during seismic activity.
HCP-4209	Monitor onshore pipeline right of way (RoW) to evaluate successions of vegetation communities.

Environmental monitoring – Natural Hazard and Risk Analysis

HCP-4301	Map and monitor induced seismic hazards
HCP-4302	Floodplain mapping and understanding flood extent and flood frequency
HCP-4303	Understand extent of lakes and wet areas for hazard assessment.
HCP-4304	Situational awareness information on water levels and lake extents and potential flooding.
HCP-4305	Monitoring air quality related to seasonal fires.
HCP-4306	Assess and manage forest fire risk to facilities and infrastructure.
HCP-4307	Coastal elevation data for tsunami risk analysis.

Logistics planning and operations – Baseline mapping of terrain and infrastructure

HCP-5101	Obtaining baseline land use for pipeline route planning.
HCP-5102	Assess potential project site for historical use.
HCP-5103	Identify subsurface infrastructure for planning of pipeline crossings.
HCP-5104	Baseline elevation data for project planning and design.

Logistics planning and operations – Support to surveying crews for planning surveys and H&S

HCP-5201	Monitoring assets for risk management.

Logistics planning and operations – Facility siting, pipeline routing and roads development

HCP-5301	Planning and assessing borrow pits as source of aggregate material.
HCP-5302	Terrain stability for route planning.
HCP-5303	Mapping land cover trends over the project area.
HCP-5304	Baseline imagery for project planning and design.
HCP-5305	Identify existing linear routes for co-location of pipelines in wilderness areas.
HCP-5306	Assessing terrain stability for infrastructure planning in permafrost environments.
HCP-5307	Assess coastal environment for infrastructure planning.

Logistics planning and operations – Monitoring of assets

HCP-5401	Monitor pipeline corridor hazards
HCP-5402	Detection of oil contamination and oil seeps.
HCP-5404	Monitoring of pipeline right of way for third party mechanical damage.
HCP-5405	Monitor potential pipeline corridor encroachment by communities.