UNECE

Application of the United Nations Framework Classification for Resources

Case studies

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Foreword

Efficient production and supply of energy and raw material resources are vital to attaining the 2030 Agenda for Sustainable Development. Ensuring that needed resources are developed sustainably has emerged as a critical challenge. Resource use has reached about 100 billion tonnes per year and is growing at a rate of 3 per cent per year. The production of raw materials and their transformation, delivery and use have significant impacts on the environment, including greenhouse gas emissions, environmental integrity, and biodiversity. While the sustainability of producing energy and raw materials has improved vastly in recent decades, there is widespread support among the sector's stakeholders for further improvement.

Having universally acceptable standards, guidelines and best practices in sustainable resource management has thus emerged as an essential requirement in the development and production of the full array of a country's resources. The United Nations Framework Classification for Resources (UNFC) is a comprehensive resource management system that incorporates social and environmental aspects, in line with the 2030 Agenda, at its core, together with the criteria of economics, technical feasibility and resource uncertainty.

UNFC is a tool for management of resources—such as petroleum, coal, gas, minerals, nuclear fuels, renewable energy, anthropogenic resources (from waste), and storage of carbon dioxide—that will improve maintenance of national inventories, aid internal company resource management, reduce risks, and create opportunities for financial markets. With due consideration of social and environmental aspects incorporated, UNFC has emerged as the only global standard that enables multi-faceted development across all energy and raw material resources. Ensuring sustainability is a process of integrating opportunities and challenges. Increasing productivity while aiming for 'zero waste' and deriving net environmental and social benefits are some of the numerous benefits that derive from the application of UNFC.

Sustainable production and use of natural resources is one of the key nexus areas of action at UNECE. I am pleased to note that, by connecting the work of economic cooperation and integration, environmental policy, forests, housing and land management, population, sustainable energy, statistics, trade and transport, UNECE's work on this nexus will unleash innovative approaches to supporting circularity in natural resource use.

The case studies presented in this publication demonstrate how UNFC can be used in different resource sectors and national contexts to assure sustainable outcomes. I recommend this publication for all those who seek not only profits, but also good social and environmental outcomes from the use of resources.

Olga ALGAYEROVA

Under-Secretary-General, United Nations
and
Executive Secretary, United Nations
Economic Commission for Europe

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Introduction

The world is witnessing a new revolution driven by various trends and technologies, and the race is on to identify and implement new transformative models in energy and material flows. These transformations are shaped by the 2030 Agenda for Sustainable Development (2030 Agenda) and the Paris Agreement on climate action. As new policies, approaches and business models emerge to reshape production, consumption, transportation and delivery systems, modernized and unified ways of managing the resulting energy and material flows are needed.

The United Nations Framework Classification for Resources (UNFC) is a global tool for consistent and coherent classification and efficient management of all resources. It applies to minerals, petroleum, nuclear fuel resources, renewable energy, anthropogenic resources and for injection projects for geological storage of CO_2. It provides a single framework on which to build international energy and raw material studies and policies, support government resource management policies, plan innovative industrial processes and allocate capital efficiently.

UNFC is a generic principle-based system in which quantities are classified by the three fundamental criteria of:

- social, environmental and economic viability (E),
- field project status and feasibility (F), and
- level of knowledge/confidence in estimates in the potential recoverability of the quantities (G).

UNFC reflects conditions in the economic, environmental and social domain, including markets and government framework conditions, social and environmental considerations, technological and industrial maturity of the projects and the ever-present uncertainties and is aligned to the requirements of the 2030 Agenda.

A key benefit of UNFC is its flexibility and ability to be adapted for diverse national and regional requirements. The European Union, African Union and countries such as the Russian Federation, Ukraine, China, India, and Mexico have national initiatives for the use of UNFC. The use of UNFC is mandatory in the United Nations System of Environmental-Economic Accounting (SEEA) Central Framework for energy accounts, which is applied globally.

UNFC is developed and maintained by the United Nations Economic Commission for Europe (UNECE), under the global mandate given by the United Nation Economic and Social Council (ECOSOC), and through the cooperation and collaboration of both UNECE and non-UNECE member countries, UN Regional Commissions, other United Nations bodies and specialized agencies, international organizations, intergovernmental bodies, professional associations, the private sector and many individual experts.

The set of case studies from minerals, petroleum, nuclear fuels and bioenergy resources included in this publication provide a broad overview of how UNFC can be applied in practice. The collection of case studies is from Argentina, Brazil, Egypt, Indonesia, Jordan, Mexico, Mongolia, Nigeria, Paraguay, Russian Federation and Venezuela. They serve to illustrate how UNFC can be tailored for national contexts.

Application of UNFC to Rare Earth Elements and Thorium Comprehensive Resource Recovery Projects in Argentina

Prepared by Luis López, National Atomic Energy Commission of Argentina (CNEA); Bradley Van Gosen, United States Geological Survey (USGS); and Charlotte Griffiths, Harikrishnan Tulsidas, United Nations Economic Commission for Europe (UNECE).

Introduction

This case study provides considerations related to the application of the United Nations Framework Classification for Resources (UNFC), and in particular, the specific Guidelines for Application of the UNFC for uranium and thorium resources [1] to rare earth elements (REE) and thorium projects/resources in Argentina.

In 2014, the oil and mining industry in Argentina contributed US$ 15,200 million to Argentina's GDP (3.2 per cent), accounting a Compound Annual Growth Rate (CAGR) of 117 per cent since 2003. Between 80 per cent and 85 per cent of that contribution to GDP corresponds to the extraction of fuel, followed by non-metallic minerals, and metallic minerals (gold, copper, aluminium, copper, silver, lithium, iron ore). Additionally, mining contributes 6 per cent of the employment, 7.4 per cent of the exports and 1 per cent of the companies based in Argentina [2] [3].

The contribution of the mining sector to the economy in Argentina is considerably low in comparison to other countries of the region, such as Bolivia and Chile, and well below the world's average. However, it is expected that the industry will gain importance, especially from larger investments that may be attracted by changes in market conditions supported by strong incentives from the national government to the mining industry. In addition to the improvement in the market conditions, the mining sector offers many investment opportunities as it is considerably underexploited compared to other countries in the region. According to the National Chamber of Mining Companies (CAEM), only 15 per cent of the mining fields have been developed [3].

This case study specifically looks into how integrated REE and associated thorium projects could contribute to the development of the solid minerals sector in Argentina. REE is widely accepted as a critical material required for renewable energy technologies [4], while thorium could be used as fuel for low-carbon nuclear power generation. A comprehensive extraction approach and application of UNFC contributes to a better understanding of such projects with co-production of commodities, and the potential contribution of such projects to the socio-economic development of Argentina.

Nuclear Power and Thorium Utilization

Similar to uranium (U), thorium (Th) can be used as a nuclear fuel. Although not fissile itself, Th-232, when loaded into a nuclear reactor, absorbs neutrons to produce U-233, which is fissile (and long-lived). Much of the U-233 will then fission in the reactor. The used fuel can then be unloaded from the reactor, and the remaining U-233 can be chemically separated from the thorium and reused as fuel [5] [6].

Argentina has three Heavy-water Reactors (HWR) in operation, namely Atucha I with a gross electrical power of 362 MW and fuelled with Slightly Enriched Uranium (SEU) (0.85 per cent U-235), and Embalse and Atucha II, both based on natural uranium fuel and with a generation capacity of 648 MW and 745 MW, respectively [7].

In connection with thorium fuel, the reactor power regulation system of the Embalse Nuclear Power Plant (NPP) has 21 adjuster rods, which are loaded with pencils of natural cobalt-59 (Co-59) powder producing cobalt-60 (Co-60) at an average rate of 3 million Curie/year. It has been proposed that in this reactor and other future Candu-6 nuclear power plants, some part or the whole of the absorbing load could be replaced by natural Th-232 to produce U-233.

A preliminary study on the feasibility and basic design for producing Co-60 in the Atucha I and Atucha II nuclear power plants has been conducted using a limited number of special fuel assemblies. These designs would have a few outer rods, where the tube would contain cobalt pencils similar to those used in Embalse NPP while the rest of the fuel assembly rods would contain slightly enriched uranium (U) fuel. In the same line, some part or the whole of the cobalt absorbing load could be replaced by natural Th-232 to produce U-233 [8].

It is important to note that beyond the potential irradiation capacities previously described, Argentina currently has no definite plans for using thorium as a nuclear fuel.

Rare Earth Elements

The REE group is composed of 15 elements that range in atomic number from 57 (lanthanum) to 71 (lutetium) on the periodic table of elements, and are officially referred to as the “lanthanoids,” although they are commonly referred to as the “lanthanides”. The rare earth element promethium (atomic number 61) is not included in discussions of REE deposits because the element is rare and unstable in nature. Yttrium (atomic number 39) is commonly regarded as an REE because of its chemical and physical similarities and affinities with the lanthanoids, and yttrium typically occurs in the same deposits as REEs. Scandium (atomic number 21) is chemically similar to, and thus sometimes included with, the REEs, but it does not occur in economic concentrations in the same geological settings as the lanthanoids and yttrium. Traditionally, the REEs are divided into two groups based on atomic weight: the light REEs (LREE) are lanthanum through gadolinium (atomic numbers 57 through 64), and the heavy REEs (HREE) comprises terbium through to lutetium (atomic numbers 65 through 71) [4].

Due to their unusual physical and chemical properties, such as unique magnetic and optical properties, REEs have diverse applications that touch many aspects of modern life and culture. REEs are used as components in high technology devices, including smartphones, digital cameras, computer hard disks, fluorescent and light-emitting-diode (LED) lights, flat-screen televisions, computer monitors, and electronic displays. Large quantities of some REEs are used in clean energy (for example, nickel-metal hydride batteries built with lanthanum based alloys as anodes, and the motors of wind turbines) and defence technologies [4].

In recent years, the aforementioned variety of high-tech applications of rare earth elements has burgeoned, especially in low-carbon technologies, and demand for them has multiplied. At the same time, there is international concern driven by the REE export restrictions of China, the world’s primary producer of REEs. Since the late 1990s, China has provided 85-95 per cent of the world’s REEs. In 2010, China announced its intention to reduce REE exports. Thus, China's reduction of REEs to the global market has caused concern about the security of the future supply of REEs, most notably the supply of HREE, as well as the costs and other product impacts this might have [4] [9].

Therefore, due to the renewed worldwide interest in REE and other critical materials, junior companies have set up different exploration projects in Argentina, such as Jasimampa, Susques, Cachi and Cueva del Chacho. These projects have shown encouraging geological prospectivety; additionally, thorium resources would be evaluated and reported.

In the past, exploratory studies of uranium and in particular thorium had already revealed the potential for rare earth minerals in Argentina. The REE interest covers vast areas of the country in the Puna, Cordillera Oriental and Pampean Ranges regions, focused mainly in Upper Jurassic-Cretaceous carbonatite rocks intruded in distensive geotectonic settings.

Legal Framework for Nuclear Minerals and REE

Since the 1950s, uranium and thorium have had the same mining legal status in Argentina. On the one hand, the Legal Framework for Nuclear Minerals from 1956 to 1997 declared uranium, thorium, and plutonium as nuclear elements [10]. On the other hand, the Argentine Mining Code (AMC), in force since 1997, considers uranium and thorium as nuclear minerals; their associated resources belong to the Provincial States under the provisions of the National Constitution (1994) [11].

Among other considerations, the Argentine Mining Code under its Title XI "On Nuclear Minerals" specifies:

(a) Nuclear minerals can be explored and exploited under a legal license by a Competent Provincial Authority.

(b) The National Atomic Energy Commission (CNEA), like any other natural or artificial person, may prospect, explore and mine nuclear minerals under the general provisions of the Mining Code.

(c) The legal owner of mines containing nuclear minerals shall supply the State with information on the reserves and production of these minerals and concentrates.

(d) The National State shall have the first option to purchase, under usual market terms, nuclear minerals, concentrates and by-products produced in the country to meet domestic needs.

(e) Exports of uranium and thorium minerals, concentrates and by-products, shall call for the prior consent of the State, and the internal supply and control of the final destination of export materials shall be guaranteed.

In general terms, under the Argentine Mining Code, mines are divided into three categories:

(a) Mines whose soil is an accessory and which belong exclusively to the State and which may only be tapped or exploited under a legal license which is granted by a competent authority.

(b) Mines which, based on their importance, are preferentially licensed to the owner of the soil; and mines which, as a result of the conditions of the deposits, are used on a shared basis.

(c) Mines which belong solely to their owner and which cannot be tapped or exploited by anybody without their owner´s consent, except in case of public benefit or good.

How metals are treated is important. According to the above classification, deposits of REE and Th associated with carbonatite rocks and pegmatites would fall into the first category, while placer deposits would fall into the second category. The eventual metal recovery from burrows and tailings of former mining works would also correspond to the second category. Under the provisions of the Mining Code, individuals are empowered to search for mineable deposits, operate mines and dispose of mines as owners.

Additionally, it should be noted that eight of the 23 Argentine provinces have legislation in place that restricts metal mining. Hence, this needs to be taken into account when studying the social viability of the projects. In connection with the location of thorium projects, in Cordoba Province, all activities related to metal mining and those specifically related to uranium and thorium production cycle are forbidden by Law 9526/2008 [12], whereas San Luis Province Law 634/2008 prohibits the use of chemicals in all forms and stages of metalliferous mining [13].

Comprehensive Resource Recovery Approach

REE, Th and U, as well as niobium and tantalum, are often associated in mineral form and occur as oxides, silicates and phosphates. At the simplest level, REE and Th are found in four main types of deposits, which are placer, carbonatite-hosted, vein-type and alkaline rock hosted deposits [14].

Due to the current low demand for Th, it has rarely been a primary exploration target. Its common association with U and/or especially REE has meant that Th resources have been identified as a spinoff of exploration activities aimed at those commodities. In current market conditions, primary production of Th is not economically viable, and the production of Th as a by-product of REE recovery from monazite seems to be the most feasible source of Th production at this time [5] [6].

Comprehensive resource recovery approaches can manage the production of REE, Th and other critical material resources in an integrated, multi-targeted manner. This approach is likely to achieve considerably higher aggregate recovery rates than a management strategy that targets only a single resource and effectively treats all other co-occurring resources as if they were contaminants or wastes. Furthermore, on the sustainability side, the premise is simpler—once the decision to break ground is taken, the ethical imperative to maximize the return from that activity is apparent according to the well-established fundamentals of sustainable development [1].

REE and Thorium Resources and Application of UNFC

Thorium in Argentina, as with the majority of the world, has not been as a general rule the subject of systematic studies. Most of the existing anomalies, showings and deposits were discovered as a result of uranium exploration, where airborne radiometric surveys played a relevant role as a prospecting technique (Figures 1 [15] and 2 [16]). REE potential was also estimated as part of the examination of high-Th radiometric records and field geological characterization.

The geological types of REE-Th deposits that have been found in Argentina are carbonatites, pegmatites and placers; the main examples can be listed as follows (for locations, see Figure 3):

a. Carbonatites, associated veins and altered zones:
   - Deposits in Puna and Cordillera Oriental (Salta and Jujuy Provinces)

– Rodeo de los Molles deposit (San Luis Province)
– Jasimampa mineralizations (Santiago del Estero Province)
– Susques mineralizations (Jujuy Province)
– Cueva del Chacho mineralizations (La Rioja Province)

b. Pegmatites:
– Cachi mineralizations (Salta Province)
– Valle Fertil Range mineralizations, Teodesia mine (San Juan Province)

c. Placers:
– III River monazite sands (Cordoba Province)
– V River monazite sands (San Luis Province).

In 2013, CNEA carried out a plan for the expeditious reexamination of the radiometric anomalies related to Th and U in the Ambargasta and Sumampa Ranges in Santiago del Estero Province. This study allowed the sites with the most mining potential to be defined, sites where high radioactivity areas were mostly related to carbonatites [17].

The only reported production of REE-Th minerals in Argentina, was the recovery of 1,010 kg of monazite, without extraction of REE and Th from the Teodesia mine (Valle Fertil Range) from 1954 to 1956.

Rodeo de los Molles REE (Th, U) Deposit/Project

This deposit was discovered by CNEA in the early 1980s while mapping and prospecting the area identified by regional airborne radiometric anomalies. The deposit is hosted in ‘fenitized’ alkaline igneous rocks (Jurassic) of the Las Chacras igneous complex. The deposit is LREE dominant. Mineralization is primarily bastnasite-synchisite, britholite and minor allanite. The geologic model is presented in Figure 4.

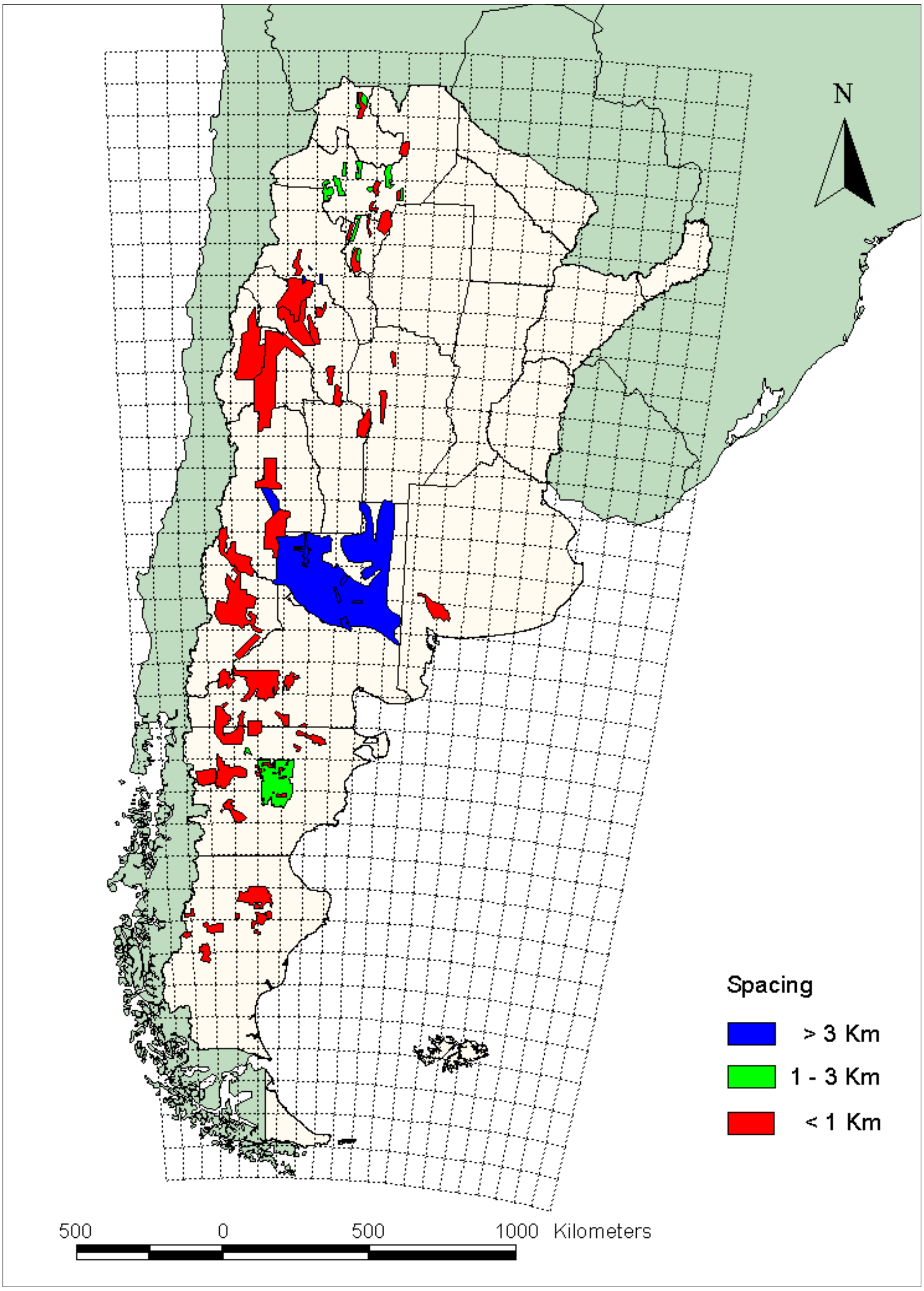
Rodeo de los Molles is the largest undeveloped REE project in Argentina with a historical geologic resource of 5.6 Mt of mineral ore, containing an estimated 117,600 tREO and 950 tU. About 10,000 tTh were estimated with a lesser degree of confidence.

The first resource estimate was prepared in 1992, including metallurgical test work that demonstrated the amenability of bastnasite to REE extraction; this estimate was based on approximately 6,000 m of rotary air blast drilling. However, resource assessments are historical in nature. Furthermore, historical exploration at the Rodeo deposit has only tested REE mineralization exposed on the surface and to very shallow depths, typically less than 35 m of depth; the limited indicated resources that have been evaluated account for 2,270 tREO at an average grade of 2.1 per cent Rare Earth Oxides (REO) [18] [19] [20]. Figure 5 shows a general view of the mineralized area.

Significant quantities of uranium could be produced as a by- or co-product from this project. About 15 tU in G2 and 950 tU in the G3 category of UNFC are estimated in this project.

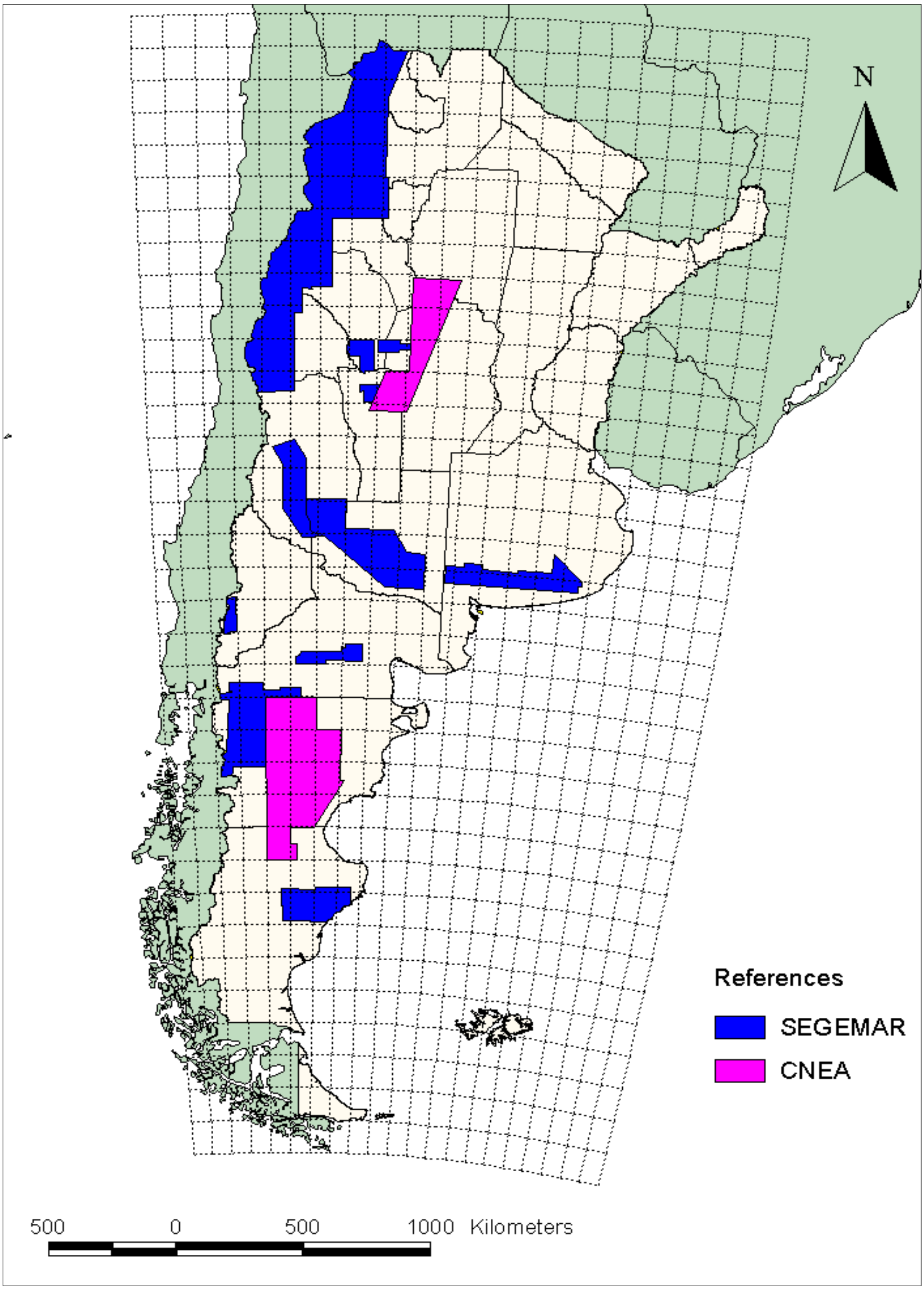
The Th resources of Rodeo de los Molles project are also considered as potential by- or co-product of the project. But the quantities are estimated with a lower level of confidence. Hence they are assigned to the G4 category. Further sampling and analytical studies are required to assign the Th quantities to higher G categories.

Figure 1. **Airborne gamma-ray total count surveys carried out by CNEA (1950-1970)**



Note: Different colours indicate the spacings of the survey flight lines [15].

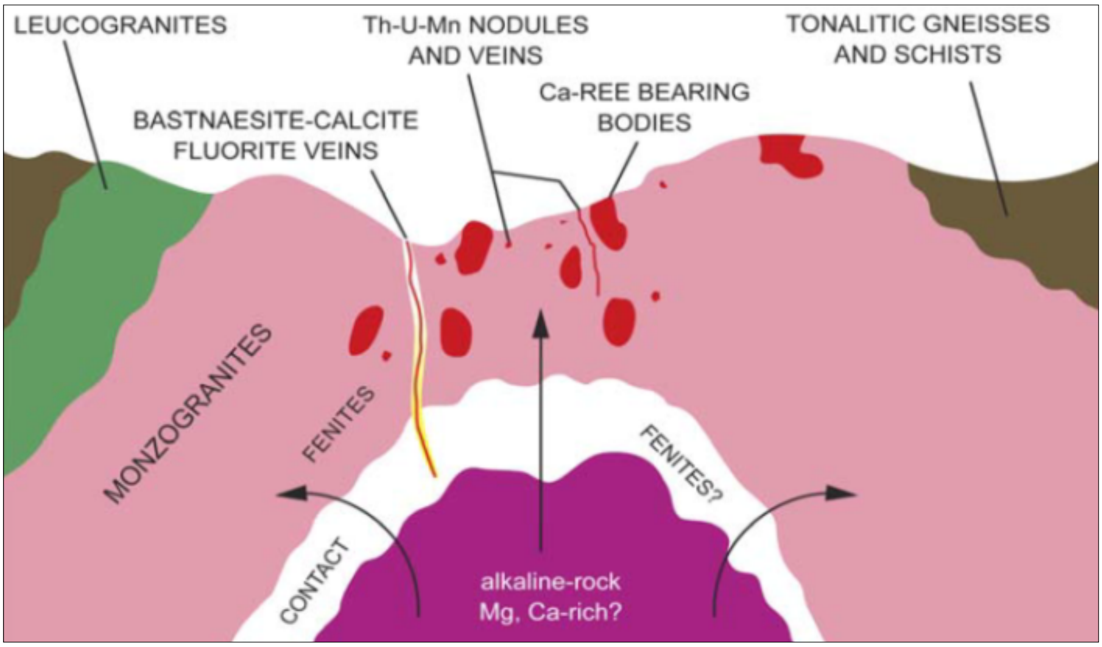
Figure 2. **Airborne gamma-ray spectrometry surveys (1978-1995)**



Note: Blocks in fuchsia were surveyed by CNEA, while blocks in blue were surveyed by SEGEMAR. Survey flight line spacing was 1 kilometre [16].

Figure 3. **Location of REE and thorium projects in Argentina**

Figure 4. **Schematic geologic model of the Rodeo de los Molles deposit [18]**



In San Luis Province, where this project is located, the Law 634/2008 prohibits the use of chemicals in all forms and stages of metalliferous mining and processing. Therefore, there are no active metal mining projects currently in this Province. However, the mineralization is primarily refractory in nature. Hence, it could be possible to mine the ore and undertake some physical beneficiation to prepare pre-concentrates, which could be shipped elsewhere for processing and recovery of REE, U and Th. Nevertheless, this possibility has not yet been discussed or tested.

Further studies are required to test the robustness of this model. The mining laws could also be amended as necessary if critical materials for clean energy projects become a priority for Argentina. Such a proposal is not currently under consideration. However that does not preclude such a change happening in the future.

Therefore, under UNFC the Rodeo de los Molles REE-U project is considered as a "Potentially Commercial Project" within the sub-class "Development On Hold" with categories E2, F2.2, G2-G3. Application of UNFC makes it very clear that if follow-up exploration activities can increase the geological knowledge of the existing inferred resources, and if detailed studies on extraction are conducted, the project could move to a higher UNFC Class.

The Th quantities are at present classified separately as an "Exploration Project". With the availability of additional data, these quantities can be transferred to higher G categories and merged with the REE-U project. In case of eventual REE production, the Th resources can be produced in the same process flow and could be stored for future use or sold in the market as required.

Figure 5. **General view of the mineralized area at the Rodeo de Los Molles [18]**

(Photo CNEA)

Puna and Cordillera Oriental Thorium (REE) Deposits

These deposits are located in the north-western region of Argentina in the Salta and Jujuy Provinces. The deposits are linked to Jurassic-Cretaceous alkaline magmatism that took place in a distensive geotectonic setting. Both magmatic carbonatites (calcite, dolomite, ankerite, magnetite, iron oxides, hypersthene, potassium feldspar, serpentine, chlorite) and metasomatic-hydrothermal carbonatites (pyrite, chalcopyrite, galena, sphalerite, magnetite, hematite, ilmenite, thorite, fluorite, monazite, strontianite, vanadinite, limonite, cerussite, thorogummite, goethite, bastnasite, parisite) can be found. All of them show a complex mineralogical composition.

In the area, at least six magmatic alkaline centres have been distinguished:

(a) Fundicion Stock (194 ± 6 Ma): syenitic facies

(b) Agua del Desierto Formation (155 ± 6 Ma): syenitic bodies

(c) Rangel Complex Laccolith (120-140 Ma): syenitic and granitic facies; radial and ring dykes

(d) Santa Julia Alkaline Complex (Cretaceous): syenite-monzonite stock; radial and ring dykes

(e) Hornillos Complex (Cretaceous): complex laccolith; subvolcanic rocks

(f) Alkaline lamprophires and phonolitic dykes (Cretaceous).

Identified resources of 23,900 tTh at a grade of 0.37 per cent Th and 35,300 tREO+Y (Rare Earth Oxides and Yttrium) at a grade of 0.58 per cent REO+Y derive from nine mineral deposits, listed in Table 1 [21] [22]. The quantities associated with these deposits have been estimated with a low level of confidence. For the REO+Y resources, the economic viability of extraction cannot yet be determined due to insufficient information and the justification as commercial developments may be subject to significant delay. Th resources, even though currently considered as not having reasonable prospects for economic extraction, can be produced as a by- or co-product along with the primary REE production. Hence, the Puna and Cordillera Oriental projects are classified as “Non Commercial Projects” with sub-class “Development Unclarified” (E3.2, F2.2, G3).

Table 1. **Main features of Puna and Cordillera Oriental Th-REE deposits [22]**

Deposit	*Width (m)*	*Depth (m)*	*Length (m)*	*Th %*	*Resources tTh*	*REE+Y %*	*Resources tREO+Y*
Rangel	0.7	70	200	0.22	58	0.45	119
El Ucu	0.3	70	200	0.08	9	0.25	28
Plateria South	0.6	130	400	0.004	4	0.03	25
Plateria North	1.0	80	250	0.02	9	0.09	49
La Barba	1.0	130	400	0.37	518	0.60	842
La Aurelia	1.1	700	2000	0.46	19001	0.65	27027
Curaca	1.0	300	1000	0.40	3203	0.60	4860
Estr. Oriente	1.0	165	500	0.40	881	0.60	1337
Isis - Osiris	1.6	300	1000	0.02	228	0.08	1037

The III River and V River Surveys

In the 1950s and 1980s, CNEA undertook a number of specific thorium recognition studies on the detrital deposits along the III River (Cordoba Province) and V River (San Luis Province) [23] [24]. Th resources in both sites and Th and REO resources in III River site were evaluated, based on raw material and monazite tonnages and monazite chemical compositions. Table 2 shows the main characteristics of these projects.

The III River and V River projects can essentially be considered as orientation surveys, and quantities are estimated based on the analytical results of 24 samples along 135 km of the river and 4 samples along 46 km of the river, respectively. Hence these quantities are assigned to the G4 Category.

The areas are densely cultivated and mining the resources may involve access to large tracts of agricultural land. Because of these constraints, the projects were deemed unattractive, and a project was not identified to potentially recover the resources. The quantities of 850 tTh and 15,500 tREO in III River and 260 tTh estimated in V River project are assumed to be currently unrecoverable, as a development project has not been identified. The quantities fall in the UNFC class of “Additional Quantities in Place”, with UNFC criteria of E3.3, F4 and G4.

Table 2. **Thorium and Rare Earths studies of the detrital material of III River and V River [23] [24]**

Study Areas	*III River*	*V River*
Length Along River	135 km	46 km
Number of Samples	24	4
Raw Material Tonnage	46.2 Mt	3.58 Mt
Monazite Tonnage	25,480 t	6,260 t
Th Grade	0.0018%	0.0072%
REO Grade	0.0335%	---
Th Resources	850 t	260 t
REO Resources	15,500 t	---

Exploration Projects

Several new REE (Th) projects are active today in Argentina. The economic viability and feasibility of extraction of these projects cannot yet be assessed due to insufficient information and limited technical data; eventual reported quantities associated with these mineralizations would be considered as undiscovered resources. Therefore, according to UNFC these projects are qualified as "Exploration Projects" (E3.2, F3, G4).

Jasimampa REE (Th) Project

The Jasimampa Property covers 60,000 ha (hectares) of ground in the Jasimampa area in the Sierra Norte de Cordoba (Santiago del Estero Province). The property lies directly east of some known small rare earth deposits.

This new project is considered highly prospective for rare earth mineralization related to Jurassic carbonatites and associated alteration, plus hydrothermal precious and base metal mineralization [25].

Susques REE (Th) Project

The Susques Property covers 41,500 ha in southern Jujuy Province, north-west Argentina. Susques is known to be prospective for a variety of rare earths elements, yttrium, and also thorium (>1000 parts per million). The economically desired higher ratio of HREE to LREE is also encouraging.

The local geology is dominated by Ordovician sediments, and Tertiary intrusives and carbonatites. Little detailed exploration has been conducted here. Rare earth mineralization that has been observed thus far is hosted in stockwork veins, which are up to 10 m wide and occur over a strike length of 6 km.

The preliminary exploration results are important first indicators of potential mineralization considering the broader geological environment in which they are hosted. More detailed work is needed to ascertain the extent and economic potential of mineralization [25].

Cachi REE (Th) Project

The Cachi property covers over 55,000 ha in Salta Province, north-west Argentina, and offers excellent opportunities for discovery, based on very favourable geology.

The geology is prospective for pegmatite-related rare earth mineralization associated with extensive granitoid intrusions, which extends for over 40 km along the strike, as well as large (up to 300 m wide) pegmatite dykes intruding Neo-Proterozoic gneiss. Worldwide, many pegmatites have been economically valuable as sources of clays and feldspars, as well as bismuth, lithium, molybdenum, rare earths, tantalum-niobium, thorium, tin, tungsten, and uranium minerals.

Reconnaissance work has been completed with stream sediment sampling and mapping completed, which identified three targets based on surface alteration halos. The sampling identified geochemical anomalies of tantalum, niobium, caesium, uranium, thorium and hafnium in the south part of the property, whereas lead and zinc were identified in the north part of the property [25].

Cueva del Cacho REE (Th) Project

The Cueva del Chacho property comprises 6,000 hectares in the semiarid valley that flanks the Sierra de Paganzo in La Rioja Province. A reconnaissance sampling of 39 slightly radioactive zones found highly anomalous REE values in massive arkosic grits, phyllites and an alaskite intrusive.

Total REE values ranged to over 0.25 per cent REO, or over 0.33 per cent if yttrium is included. Unlike many deposits, there has been little or no depletion in the HREE with respect both to chondrite and normal crustal ratios, except europium. HREE comprise an average of 29 per cent of the total REEs with a high of 71 per cent if yttrium is included, and 14 per cent of the total REEs with a high of 44 per cent if yttrium is not included. An area of anomalous uranium (as much as 551 ppm) in carbonaceous phyllites was encountered. Thorium is also present in carbonaceous shales and phylites but is not closely associated with rare earth mineralization.

A programme of further work has been recommended, on the one hand, to delineate better and evaluate the known rare earth concentrations, and on the other to determine the regional extent of these anomalies [26].

Conclusions

Although the potential for mineral resources are very high in Argentina, the mining sector plays only a minor role in the socio-economic development of the country. Most of the mineral potential of the country is under developed, which therefore offers a possible opportunity for future investments. The REE potential of the country is significant, and its potential development in the future is one that may be worth serious consideration. This case study specifically looks into how integrated REE and associated thorium and other valuable materials projects could contribute to the development of the solid minerals sector in Argentina.

Argentina currently has no plans to use Th as a nuclear fuel. However, all three existing Heavy-Water Reactor (HWR) nuclear power plants offer potential capabilities for large-scale irradiation of natural Th-232 to produce U-233. More recently, due to the renewed interest in REE worldwide, the private sector has started several exploration projects. These have shown encouraging geological prospectivity. As a result, the evaluation and reporting of thorium resources are starting. In the event of possible future production of REEs, Th and some other materials such as U, it can be assumed they will be produced as a by- or co-product. While REE has crucial applications, especially in the renewable energy sector, the Th produced can be stored for future use.

During the 1950s and 1980s, CNEA conducted several reconnaissance studies on thorium deposits that defined very limited resources, and therefore related projects were not developed. Nevertheless, thorium resource assessment in the country is far from complete, and most thorium resource estimations correspond to undiscovered resources because specific exploration and comprehensive resource estimation of REE and thorium deposits have been conducted at a very preliminary level (Table 3).

Based on the UNFC assessment conducted on a number of the deposits, such as Rodeo de Los Molles and those located in the Cordillera Oriental and Puna regions, there is potential for further development. REE resources in these deposits show a higher ranking, and Th can be produced as a by- or co-product. More studies are required for firming up the resources and progressing the projects along the project maturity pipeline. Moreover, some of the projects classified as “Exploration Projects” could have breakthroughs in discovering new additional resources.

Therefore, when classifying REE and thorium resources according to UNFC, the Argentine projects currently have neither economic and social conditions nor technical feasibility that are sufficiently matured to indicate reasonable potential for commercial recovery and sale in the foreseeable future, with the exception of the Rodeo de los Molles project which has been classified as a “Potentially Commercial Project”. However, when looking from the perspective of comprehensive extraction projects, there are projects with significant potential for future development. Thorium and other valuable materials, in that case also become significant, and could be produced without major additional investment as by- or co-products. This case study on the application of UNFC demonstrates the potential for assessing REE and Th as an integrated project, thereby increasing the project maturity of the combined project.

The application of UNFC contributes to a better understanding of the availability of reliable nuclear and associated critical material resources, especially for renewable energy in Argentina, and helps in understanding where the focus should be in the future. The role that REEs could contribute to Argentina’s GDP in the future could be reassessed with this in mind.

Table 3. **REE-Th-U projects of Argentina classified according to UNFC**

Project	*UNFC Class*	*UNFC Sub-class*	*UNFC Category*	*Resources*
Rodeo de los Molles (REE-U)	Potentially Commercial Project	Development On Hold	E2, F2.2, G2	2,270 tREO 15 tU
			E2, F2.2, G3	117,600 tREO 950 tU
Cordillera Oriental and Puna (REE-Th)	Non Commercial Project	Development Unclarified	E3.2, F2.2, G3	35,300 tREO+Y 23,900 tTh
III River (REE-Th)	Additional Quantities In Place	---	E3.3 F4 G4	15,500 tREO 850 tTh
V River (Th)	Additional Quantities In Place	---	E3.3 F4 G4	260 tTh
Rodeo de los Molles (Th)	Exploration Project	---	E3.2 F4 G4	10,000 tTh
Jasimampa (REE-Th)	Exploration Project	---	E3.2, F3, G4	Not Available

Table 3. **REE-Th-U projects of Argentina classified according to UNFC (continued)**

Project	*UNFC Class*	*UNFC Sub-class*	*UNFC Category*	*Resources*
Susques (REE-Th)	Exploration Project	---	E3.2, F3, G4	Not Available
Cachi (REE-Th)	Exploration Project	---	E3.2, F3, G4	Not Available
Cueva del Chacho (REE-Th)	Exploration Project	---	E3.2, F3, G4	Not Available

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Application of UNFC to Phosphate Rock - Uranium Resources: A Case Study of the El-Sebaeya Projects, Nile Valley, Egypt

Prepared by Mohamed Taha, Nuclear Materials Authority, Egypt; and Harikrishnan Tulsidas, United Nations Economic Commission for Europe (UNECE).

Introduction

The world is facing an unprecedented energy challenge. Global energy demand is projected to rise by over 50 per cent by 2040 [1]. The urgent need to reduce greenhouse gas emissions will require that much of this growth is supplied by low-carbon energy sources. Independent global institutions are agreed that it will be very difficult to achieve this without the significantly increased deployment of nuclear energy. The Intergovernmental Panel on Climate Change (IPCC) stresses the urgency on the need to use all available low-carbon technologies to avert climate change. Nuclear energy and renewable energy are the key elements of a low-carbon energy system, along with carbon capture and storage (CCS) [2]. The International Energy Agency (IEA) and the Organisation for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA) have projected that nuclear capacity will need to double by 2050 [3]. In tandem with the anticipated growth in nuclear energy, uranium requirements will also increase sharply in the future [4]. This will require looking at all available options for the supply of uranium – both conventional and unconventional resources.

Uranium resources are broadly classified as either conventional or unconventional. Whether uranium can be designated as conventional or unconventional is based mainly on the economics of its recovery from a given mining/extraction project. Conventional resources are those that have an established history of production where uranium is a primary product, co-product or an important by-product (e.g. from the mining of copper and gold). Very low-grade resources or those from which uranium is only recoverable as a minor by-product are considered unconventional resources [4]. In general, unconventional are resources that are of low to very low grade (10–200 parts per million (ppm) of uranium (U) on average) that cannot be mined just for uranium.

Uranium recovery from unconventional resources will need to take into account economic factors, such as cost of production and the trends in the primary uranium market. In some cases, it could be part of large-scale operations where economies of scale partly compensate for the ore's low grade. The most abundant unconventional uranium resources are seawater and phosphate rock deposits [5, 6, 7].

In October 2007, the President of Egypt announced the decision to start a peaceful nuclear programme and build several nuclear reactors to diversify and secure energy resources. Based on this decision, the Nuclear Materials Authority of Egypt also started to re-evaluate Egypt's uranium resources. To date, the most significant uranium resources in Egypt are those resources that are associated with phosphate rocks.

Uranium extraction from phosphate rock

Energy, food and water security, as well as the environment, safety and health are critical challenges for sustainable development in the twenty-first century; therefore, recovering uranium as a co-product from phosphoric acid presents a particularly interesting case, with multiple pointers to sustainability issues [8].

Phosphate rocks represent one of the most important unconventional uranium resources in the world. The uranium content of phosphate rock can vary from 20 ppm to as high as 500 ppm. Several studies have reported that the average uranium concentration is generally close to 100 ppm in most phosphate rocks. In April 2015, the International Atomic Energy Agency (IAEA) World Distribution of Uranium Deposits (UDEPO) estimated there were 13.8 million tonnes (Mt) of uranium in phosphate rock deposits [9]. Phosphate deposits are classified into two main categories: igneous phosphate rocks (13 per cent) as found in the Russian Federation, South Africa, Brazil and sedimentary phosphate rocks (87 per cent) as found in Morocco, Algeria, Jordan, Egypt, and the United States of America [10]. The phosphate minerals in both types of ore are of the apatite group, of which the most commonly encountered variants are fluorapatite and francolite.

In wet chemical phosphate fertilizer production, phosphoric acid is an intermediate product. During the process, about 80–90 per cent of the uranium contained in the phosphate rock migrates to phosphoric acid. The uranium concentration in wet phosphoric acid can vary from 30 to 350 mg/L depending on the original concentration of uranium in the phosphate rocks [11, 12]. Global phosphoric acid demand is forecast to grow at an annual rate of 2.4 per cent compared with 2014, rising to 48.3 Mt P2O5 in 2019. Potential global phosphoric acid supply/demand conditions show balance in the short term and a moderately growing surplus in late 2018 to early 2019. Close to 30 new units for processed phosphates are planned between 2014 and 2019. Together, China and Morocco will account for half of these plants. Other plants will be built in Saudi Arabia, Brazil and India [13].

Uranium can be recovered from phosphoric acid by several techniques such as precipitation [14], liquid membranes [15], solvent extraction [16] and solid impregnated solids [17]. However, solvent extraction, which was widely practiced during the 1970s and 1980s is the only large-scale commercially proven method. Currently, about 72 per cent of the phosphate rock produced globally is used to produce phosphoric acid by the wet process, and uranium recovery from phosphate rock is 83.7 per cent [18]. Generally, uranium recovery from dihydrate phosphoric acid through the use of solvent extraction is a well-established technology [11].

In spite of the accident at the Fukushima Daiichi Nuclear Power Plant in Japan in March 2011, nuclear energy is still expected to play an import role in Egypt's future energy mix. To sustain nuclear power under the current state of nuclear power plant technology, it will be necessary to prospect unconventional resources because primary resources of uranium are limited [19]. Among the unconventional resources, phosphate rocks attract a great deal of attention. If properly implemented uranium recovery from the current production of phosphoric acid could provide up to 20 per cent of the annual world uranium consumption [20].

Due to falling uranium prices, by the mid-1990s operations became uneconomic and all production from phosphoric acid ceased. The price of uranium increased from around the US $10/lb U3O8 (US $26/kg U), through to a peak of US $138/lb U3O8 (US $359/kg U) in June 2007, to current long term and spot prices of approximately US $45/lb U3O8 (US $117/kg U) and US $35/lb U3O8 (US $91/kg U) respectively. Uranium recovery from phosphoric acid has many advantages, including (a) industrially proven in numerous plants (b) no mining costs, (c) easy to permit, (d) saving a resource otherwise lost forever, (e) other elements of value (such as thorium and rare earth elements (REE)) can be recovered from the same liquid [21]. Uranium recovery from phosphoric acid though faces several challenges, for example: (a) fluctuating uranium prices, (b) unfavourable public perception and political support (e.g. due to the accident at the Fukushima Daiichi Nuclear Power Plant in Japan), (c) industry fatigue to innovations, and (d) industry becoming more risk-averse.

Phosphate resources of Egypt

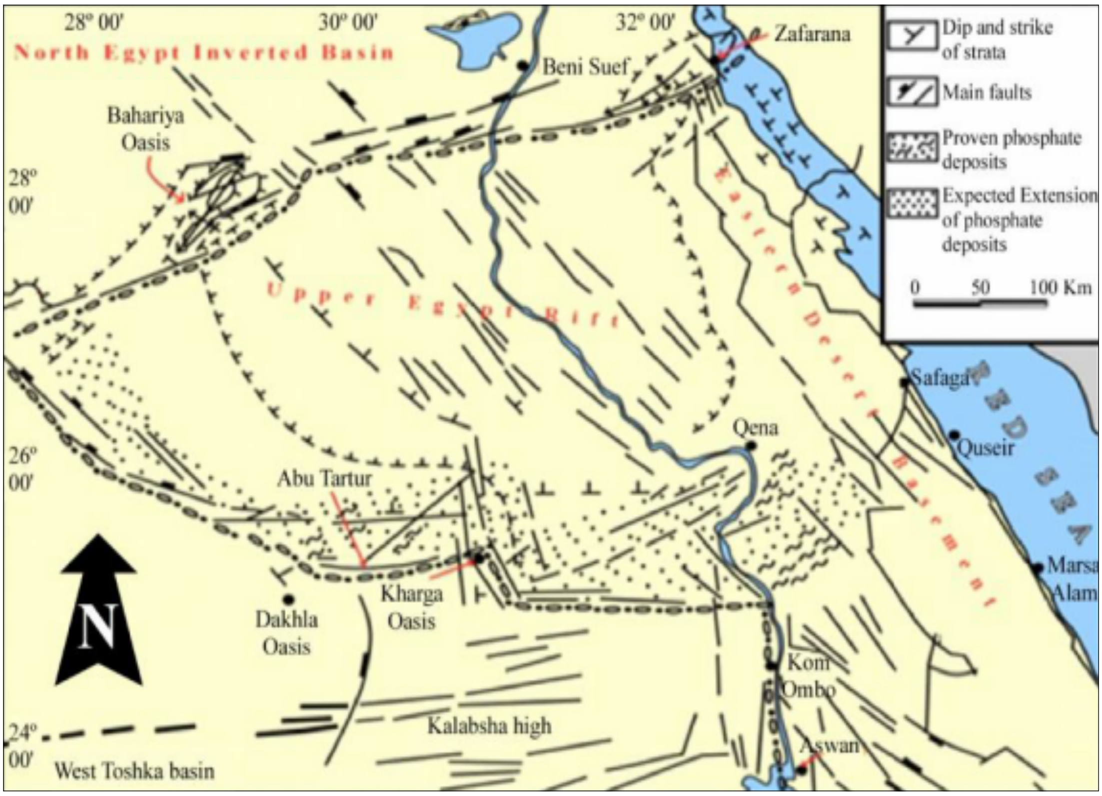
Phosphate deposits in Egypt are part of the Middle East to the North African Phosphogenic Province of the Late Cretaceous-Palaeogene age. The occurrences are divided into three east-west trending facies belts (Figure 1) [22]:

(a) Phosphorite of the northern facies belt which has no economic potential, spreading from Bahariya Oasis to Sinai as thin layers mainly of carbonate and sand facies.

(b) Phosphorite of the central facies belt represents the most economic occurrences and is confined to the following localities:
   (i) The Red Sea Coast from Safaga to the Quseir land-stretch
   (ii) The Nile Valley between Idfu and Qena
   (iii) The Western Desert on the Abu Tartur Plateau (New Valley area).

(c) Phosphorite of the southern facies belt. The rocks of these facies are associated with iron ore accumulations among shallow-water sediments.

Figure 1. **Distribution of phosphate deposits in Egypt**

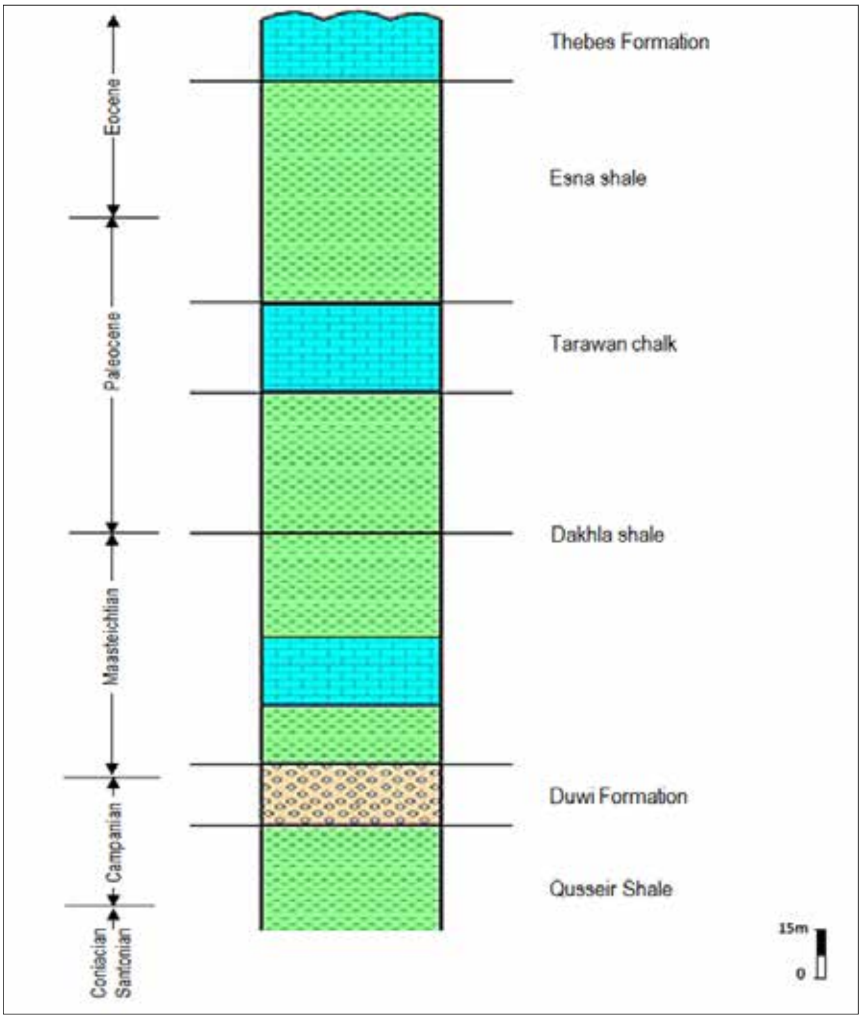


Francolite is the main phosphate mineral of the Nile Valley deposit, while fluorapatite is the principal phosphate mineral in the New Valley deposit [23].

Nile Valley phosphate deposits

The Nile Valley phosphate deposits extend between latitudes 25° 30- – 26° 30- and longitudes 32° 30- – 33° 30- on both sides of the Nile Valley [24]. Several attempts were made to classify the Upper Cretaceous-Lower Eocene succession in the Nile Valley region. The general sedimentary sequence in the Nile Valley region was classified into the formations shown in Figure 2 (from bottom to top) [25].

Figure 2. **Generalized stratigraphic section in the Nile Valley region**



The Duwi Formation in the Nile Valley region was divided into three members (from bottom to top):

(a) Mahamid Member: Composed of shale, clay, sandstone, carbonaceous shale with a few phosphatic intercalations.

(b) Sibaiya Member: Made up of siliceous-carbonate phosphorite beds intercalated with chert bands and lenses changing upwardly to shale, oyster limestone and marl.

(c) Adayma Member: Consists of marl, sandstone, and some oyster limestone and phosphate beds.

The lower part of the Duwi Formation (Mahamid Member) was assigned as the Campanian age. The Middle part was also considered as Maastrichtian age and as Campanian-Maastrichtian age. The Upper Adayma Phosphate Member has a Danian age and a Maastrichtian age [26]. The Duwi Formation in the Nile Valley region was subdivided into three members based on its lithology [27]:

(a) The lower member is composed of quartzose sandstone and siliceous shale.

(b) The middle member is built up of soft, laminated and organic-rich black shale.

(c) The upper member is mainly made up of phosphatic sandstone.

Chemical and Mineralogical Composition: The chemical composition of the phosphate beds in the Idfu – Qena region varies according to the nature of its cementing material (Table 1). The phosphorite components are represented by phosphatic pellets, and phosphatized organic remains with a predominance of the former. The grain size ranges between 0.1–2 mm with the prevailing size varying between 0.2–0.4 mm. The phosphate material in the pellets is represented by collophane, 49–60 per cent of the rock, with subordinate amounts of finely dispersed organic material and pyrite specks [24].

In the biomorphic phosphatized bones and remains, aside from the phosphate material, there are considerable amounts of organic impurities. Among the non-phosphatic grains quartz (0.05–1 mm), pyrite, and more rarely carbonate rocks, are seen. The cementing material of the phosphorite grains consists of carbonates, clays and silica mixed together in different proportions and with impurities of dolomite and ferro-dolomite. Carbonate, clay and carbonate-clay cement are syngenetic, whereas the siliceous cement was formed during later diagenetic stages [24].

Table 1. **Chemical composition (in %) of the El-Sebaeya phosphate deposit**

Compound	*Carbonate Variety*	*Carbonate-Siliceous Variety*	*Clayey-Carbonate Variety*
P_2O_5	22.7	21.24	20.28
CaO_2	48.06	38.44	40.16
SiO_2	4.80	13.05	12.07
Al_2O_3	0.32	0.42	0.95
Fe_2O_3	0.94	1.03	1.50
MgO	0.32	0.44	0.86
SO_3	0.20	-----	----
CO_2	17.70	11.10	12.06
I.R.*	4.86	14.08	12.04

* I.R. – Insoluble Residue.

Insoluble Residue

The carbonate variety of phosphorites characterizes the beds of the middle member and has a mineralogical composition which consists of phosphate mineral (52.0 per cent), calcite, (38.3 per cent), dolomite (1.4 per cent, quartz (4.2 per cent), clay (2.0 per cent), gypsum (1.2 per cent) and limonite (1.0 per cent). The carbonate-siliceous and the siliceous-carbonate varieties are very common in beds of the middle member in the localities of Serai, El Gir and Mashash and they are in general the most widespread in the region. The carbonate-clayey and clayey-carbonate varieties of the ore usually dominate in beds of the upper group [24].

Among the phosphorites which fall within the weathering zone, those which are most affected by the chemical weathering produce leached types of deposits in which P2O5 is enriched to 25–28 per cent and, which is most economically favoured in the El Mahamid area. Generally, in the zone of weathering all types of cementing materials contain supergene minerals as limonite and gypsum. Recent tests for Nile Valley phosphate reflect the importance of limonite and gypsum in advanced fertilizer manufacturing and hence make them value-added products which could be more attractive economically as opposed to exporting the phosphate rock [24].

Mining and Processing: Mining of phosphate ore at the Nile Valley locations of East and West El-Sebaeya is mostly by surface mining. The overburden is removed either by scraping or by drilling and blasting, depending on the nature of the rock. The phosphate bed is drilled, blasted, and removed by trucks to the crushing plant, where it is crushed to less than 5 cm and screened. The overburden thickness ranges from 20 to 40 metres [24].

At East El-Sebaeya, the phosphate ore used to be crushed and then attrition washed to remove the fine clayey fraction (about 10–12 per cent by weight, assaying about 12–18 per cent P2O5) and the hard siliceous coarse fraction (40–45 per cent by weight, assay 18–22 per cent P2O5). The ore is now being crushed and dry screened to remove the coarse siliceous fraction, and the marketable concentrate is the fine fraction (assaying 28–30 per cent P2O5). The control of air pollution under these circumstances is very challenging [24].

At West El-Sebaeya, there used to be a flotation plant where direct flotation and reverse flotation for upgrading the ore was carried out. However, for technical and economic reasons the flotation plant has been replaced by a crushing, screening, and de-sliming set up to remove the clayey fraction (about 20–25 per cent by weight, assaying 12–18 per cent P2O5), and the coarse fraction is rejected. Most of the production from this area is consumed locally for the production of phosphate fertilizers [24].

East and West El-Sebaeya Projects, Nile Valley: Classification of quantities using UNFC

The United Nations Framework Classification for Resources (UNFC) is a project-based system that applies to all energy and mineral reserves and resources. It has been designed to meet, to the extent possible, the needs of applications pertaining to energy and mineral studies, resource management functions, corporate business process and financial reporting standards [28].

According to UNFC, quantities are classified based on the three fundamental criteria of economic and social viability (E), field project status and feasibility (F), and geological knowledge (G), using a numerical coding system. Combinations of these criteria create a three-dimensional system. The Categories and Sub-categories are the building blocks of the system, and are combined in the form of “Classes”.

Assessment of phosphate rock quantities: Quantities of phosphate rocks in the East and West El-Sebaeya projects of the Nile Valley are classified as Proved Reserves, Indicated Resources and Inferred Resources. There are about 49.0 Mt Proved Reserves of phosphate rock (34 Mt in the East El-Sebaeya Project and 15 Mt in the West El-Sebaeya Project). Also, there are about 180 Mt Indicated Resources of phosphates in both the El-Sebaeya Projects (80 Mt in the East El-Sebaeya Project and 100 Mt in the West El-Sebaeya Project. The Inferred phosphate Resource in the two El-Sebaeya Projects is about 2,384.0 Mt. Assuming an 80 per cent recovery for the Resources, a total of 2,100.2 Mt phosphate rocks are classified according to UNFC as G1, G2 and G3 quantities. About 512.8 Mt are considered as Additional Quantities in Place.

The El-Nasr Mining Company has been mining phosphate rock from the El-Sebaeya Project for many years, and in 2013, production was approximately 3 Mt [24]. The quantities of phosphate rock mined are sold directly to the market. The quantities reported under the currently operating mine, estimated as Proved Reserves can be considered as F1.1, i.e., "extraction is currently taking place". Estimated quantities of Indicated and Inferred Resources can be considered as F2.1, i.e., "Project activities are ongoing to justify development in the foreseeable future".

The current economic and financial situation is expected to impact fertilizer demand in several ways. A return to more stable commodity prices makes it less risky for farmers to invest in fertilizers than one year ago; this is resulting in a more rapid recovery in phosphate (P) and potassium (K) fertilizer demand than had been foreseen. Supported by fairly attractive crop prices in the first half of 2014, world fertilizer consumption in 2014–15 increased by 2.0 per cent year-on-year, to 185 Mt plant nutrients (total N+P2O5+K2O).

It is anticipated that phosphorous consumption will rebound to 41.3 Mt in 2014-2015, which represents a 2.5 per cent year-on-year increase. Global phosphate rock supply is forecast to increase to 255 Mt in 2019, which is an increase of 16 per cent compared with 2014, [13]. This means that phosphate rock estimated as Proved Reserves in the El-Sebaeya projects can be assigned E1.1, i.e. "Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions". Quantities estimated as Indicated and Inferred Resources can be assigned to E2, i.e. Extraction and sale is expected to become viable in the foreseeable future. Careful consideration of the E, F and G axes of UNFC was undertaken, and these resources are designated as Commercial Project and Potentially Commercial Project as shown in Table 2.

Table 2. **Estimated phosphate rock quantities in East El-Sebaeya and West El-Sebaeya Projects, Nile Valley, Egypt (Effective date: 31 December 2013)**

Area	Project	Average P205 Content, %	CRIRSCO Template	UNFC Class	UNFC Sub-class	UNFC Categories			Phosphate rock quantities (Mt)	Estimated Phosphate rock recoverable, Mt
						E	F	G		
Nile Valley Deposit	East El-Sebaeya	29-30	Proved Reserves	Commercial Project	On Production	1.1	1.1	1	34.0	34.0
			Indicated Resources	Potentially Commercial Project	Development Pending	2	2.1	2	80.0	64.0
			Inferred Resources					3	1,674.0	1,339.2
			Additional Quantities in Place			3.3	4	1,2,3		350.8
	West El-Sebaeya	27	Proved Reserves	Commercial Project	On Production	1.1	1.1	1	15.0	15.0
			Indicated Resources	Potentially Commercial Project	Development Pending	2	2.1	2	100.0	80.0
			Inferred Resources					3	710.0	568.0
			Additional Quantities in Place			3.3	4	1,2,3		162.0
Total quantities (excluding Additional Quantities in Place)										2,100.2
Total quantities (including Additional Quantities in Place)										2,613.0

Assessment of uranium quantities: Phosphate deposits are considered to be unconventional uranium resources, i.e. uranium is recovered as a co- or by-product along with the main product, the phosphate. This means that the geological knowledge of uranium depends to a large extent on the geological knowledge of the phosphate deposits.

The El Nasr Mining Company is currently mining and the current production is about 3 Mt of phosphate rocks per annum. All the current production is sold as phosphate rock. The company completed a feasibility study in 2010 for phosphoric acid production in cooperation with an Indian partner company and acquired the licences required to construct a phosphate fertilizer complex at the El-Sebaeya site.

Due to instability in the Egyptian markets resulting from the political situation in 2011, the El Nasr Mining Company halted the construction activities of the phosphoric acid plant. At the beginning of 2015, the President of Egypt called for the construction of the phosphate complex at El-Sebaeya to re-start. The phosphate complex, which is expected to produce about 200,000 tonnes P2O5/year as phosphoric acid, should be completed by the end of 2017 with a capital cost of about US $400 million. Following the recent policy of maximum value-addition in Egypt before exporting raw material, it is anticipated that the capacity of phosphoric acid production may be progressively increased in future.

The average uranium content in the El-Sebaeya phosphate projects is about 90 ppm [24, 29–31]. It is assumed that about 70 per cent of this production could eventually be available for phosphoric acid production at the site. This assumption is based on the current global average of about 72 per cent phosphate rock being used in phosphoric acid production. It is also assumed that 90 per cent of the uranium present in the phosphate rock will report to phosphoric acid and the rest will remain in the phosphogypsum co-product. Finally, it is assumed that 90 per cent of the uranium can be extracted from the phosphoric acid using currently available technology. After applying all the above recovery factors, it is estimated that approximately 107,173.20 tonnes of uranium can eventually be recovered from the phosphate rocks. This uranium can be classified as G1, G2 and G3 based on the geological confidence determined for the phosphate rock (Table 3).

Field project status and feasibility of uranium recovery from phosphoric acid intimately depend on the feasibility of the phosphate deposit. Phosphate rock is used in phosphoric acid production, and uranium can be extracted from phosphoric acid. Generally, in the wet acid process phosphate ore must have (i) P2O5 $\geq$30 % (ii) CaO/ P2O5 ratio <1.6 (iii) MgO <1 % and Fe2O3 and Al2O3 content maximum 2.5 %. Therefore the ores which do not fulfil these specifications cannot be used directly and require some beneficiation [32].

The scoping study for uranium recovery from El-Sebaeya phosphate rock uranium extraction is being developed. Plans are also in place to start a pre-feasibility study. Therefore, uranium quantities from the El-Sebaeya phosphate rock project are classified as F2.1 “Project activities are ongoing to justify development in the foreseeable future”.

The operational expenditure (OPEX) for uranium production by this process is expected to be around the US $40-50/lb U3O8 (the US $100/kgU), assuming that the costs estimated are as those for similar operations elsewhere in the world [33], which are close to the uranium long term and spot price in August 2015 (US $35 - 45/lb U3O8 or US $90- 117/kgU). This means that uranium recovery from El-Sebaeya phosphate rock can be considered E2 – “Extraction and sale is expected to become economically viable in the foreseeable future”.

In addition to the total quantities that could be recovered with currently proven technologies, about 127,996.80 tonnes of uranium will not be recovered and can be shown as Additional Quantities in Place. This is a significant amount of uranium. With the development of innovative technologies, it could be possible to recover this uranium either partially or fully, thus improving the productivity and sustainability of the operations. The quantities of uranium available in the Nile Valley phosphate deposit are shown in Table 3.

Conclusions

The East and West El-Sebaeya Projects of the Nile Valley are some of the most important sources of phosphate rock in Egypt. The quantity of phosphate rock estimated in these projects is 2.1 billion tonnes. This is classified as Commercial Project and Potentially Commercial Project according to UNFC. Phosphate rock production is ongoing in these projects, and a major phosphoric acid and fertilizer industry complex are planned. The projects will hence provide a major contribution to the food security of Egypt, as well as the region.

Table 3. **Uranium Resources in the East El-Sebaeya and West El-Sebaeya Projects, Nile Valley, Egypt (Effective date: 31 December 2015)**

Area	*Project*	*Average U Content, ppm*	*CRIRSCO Template*	*UNFC Class*	*UNFC Sub-class*	*UNFC Categories*			*Estimated recoverable U from Phosphoric Acid, (tU)*
						E	*F*	*G*	
Nile Valley Deposit	*East El-Sebaeya*	90	Measured Resources	Potentially Commercial Project	Development Pending	2	2.1	1	1,735.0
			Indicated Resources					2	3,265.9
			Inferred Resources					3	68,339.4
			Additional Quantities in Place			3.3	4	1,2,3	87,579.7
	West El-Sebaeya		Measured Resources	Potentially Commercial Project	Development Pending	2	2.1	1	765.5
			Indicated Resources					2	4,082.4
			Inferred Resources					3	28,985.0
			Additional Quantities in Place			3.3	4	1,2,3	40,417.1
Total quantities (excluding Additional Quantities in Place)									107,173.2
Total quantities (including Additional Quantities in Place)									235,170.0

Phosphate rock is one of the most important unconventional uranium resources. As uranium is recovered from phosphates as a co- or by-product classification of uranium according to UNFC is therefore related to the classification of the phosphate resources. The total quantity of uranium estimated for the Nile Valley Deposit is 107,173 tonnes of uranium, which is currently the most significant source of uranium in Egypt. Based on ongoing project activities such as the scoping study and the pre-feasibility study, this uranium can be classified as a Potentially Commercial Project. Moreover, 127,996 tonnes of uranium are estimated as Additional Quantities in Place, at least a part of which could be recovered by innovative techniques and improving the efficiency in mining and processing.

As Egypt has stated its intention to introduce nuclear energy systems to diversify the country's energy supply, the Nile Valley phosphate projects from which uranium can be produced as a co-product can be considered as the most advanced projects for commercial uranium supply in the country. In view that to date, no other conventional resource of uranium that can be classified as a Potentially Commercial Project has been identified in Egypt, the uranium in the Nile Valley is very significant for the energy security of Egypt.

The purpose of this case study was to demonstrate the application of UNFC in classifying and reporting quantities in a multiple commodity project such as the Nile Valley Project, where phosphate and uranium could be produced as co-products. Using UNFC for classification and reporting brings greater clarity to the reporting and demonstrates that phosphate and uranium projects are critical to the food and energy security of Egypt. This will vastly aid the management of natural resources and their timely development for the socio-economic development of Egypt.

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Case study on bridging from the Oil and Fuel Gas Reserves and Resources Classification of the Russian Federation to UNFC: Field A in West Siberia, Russian Federation

Prepared by Alexander Shpilman, V.I.Shpilman Research and Analytical Centre for the Rational Use of the Subsoil, Russian Federation; Jan Bygdevoll, Norwegian Petroleum Directorate; Steve Griffiths, ERCE, United Kingdom; and Dominique Salacz, Evolution Resources SA, Switzerland.

Introduction

The case study is based on information provided from an undeveloped oil discovery in West Siberia, referred to here as "Field A". Four wells have been drilled on the Field A structure; one discovered and tested oil ("Well #2"), while the three other wells ("Well #1", "Well #3" and "Well #4") are in the water zone. The discovery is situated in Jurassic sediments (J3), with lithology well known in the area. A top structure depth map, based on interpretation of 2D seismic data and information from the wells, had been constructed (see Figure 1).

The discovery is considered to be one single pool (deposit), but the right to utilise the licence plot has not yet been transferred to an oil company. Field A is therefore situated in the unlicensed territory ("resources in open area") and is considered to be a "field under exploration", which means that a production licence has not yet been issued, and a project design document has not yet been made (reference the Bridging Document between the Oil and Fuel Gas Reserves and Resources Classification of the Russian Federation of 2013 (RF2013) and the United Nations Framework Classification for Resources (UNFC) of September 2016 (The Bridging Document is available in English and Russian on the ECE website at: http://www.unece.org/sed/unfc/rf2013bd.html) paragraph 6).

Description of the project

Based on information available at the time of preparing this case study in 2017, volumetric calculations had been made separately for two parts of the deposit; one for the area of the oil zone closest to the discovery well (Area 1) and one for the more distal part of the hydrocarbon-bearing structure (Area 2).

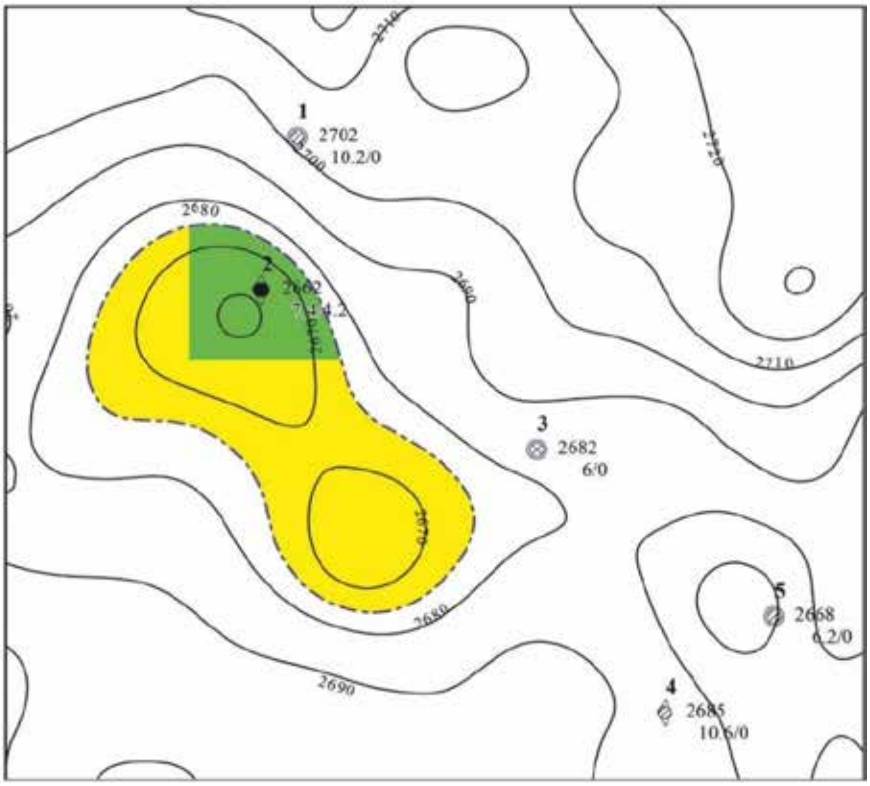
The parameters used in the calculation of oil (and gas) volumes, such as net pay, porosity, oil saturation, oil properties etc. were based on well logs and tests from the discovery well and the nearby wells lower on the structure in the water zone.

The formation test of the discovery well provided an inflow of 9 tonnes per day (tpd) of clean oil (no water) and, since it had not been directly observed in any of the wells, a common oil-water contact (OWC) had been nominally defined and assigned to the base of the lowest tested interval in Well #2, at 2,676 m true vertical depth (TVD).

Data from the discovery well indicated a net pay thickness of 4.2 metres. Test data from other wells (e.g., Well #1 and Well #4) confirmed the reservoir quality in a wider area around the discovery well. In addition to the top structure depth map, a net pay thickness map was constructed for the volumetric calculations (see Figure 2).

Figure 1. **Top structure depth map of discovery**

FIELD A

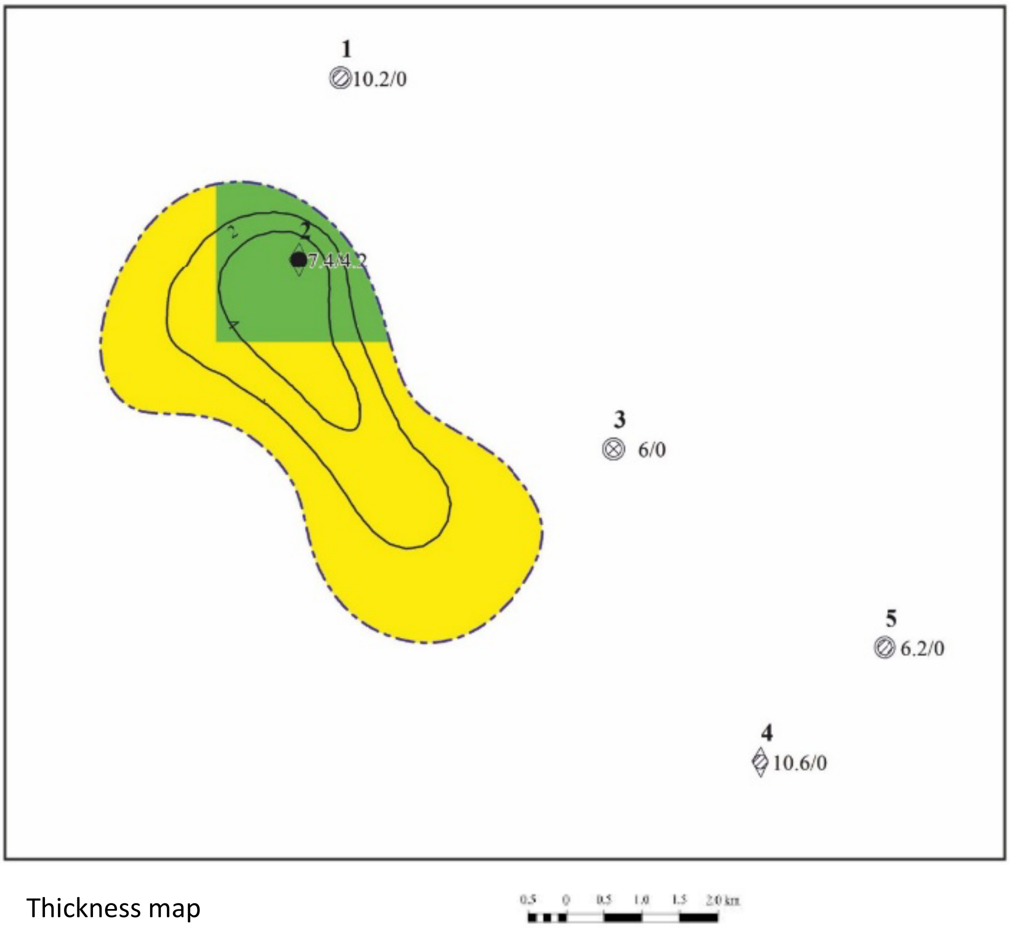


Structure map

	LEGEND
	Exploration wells with water inflow
	Wildcat wells with water inflow
	Exploration water-yielding wells by well log data
	Wildcat wells with oil inflow
	Reservoir top contour
	Outer oil pool outline
	C1 reserves area
	C2 reserves area
1	Well number
2685	Reservoir top absolute depth

Figure 2. **Net oil thickness map**

FIELD A



Thickness map

LEGEND

Isopach line

Oil water contact top

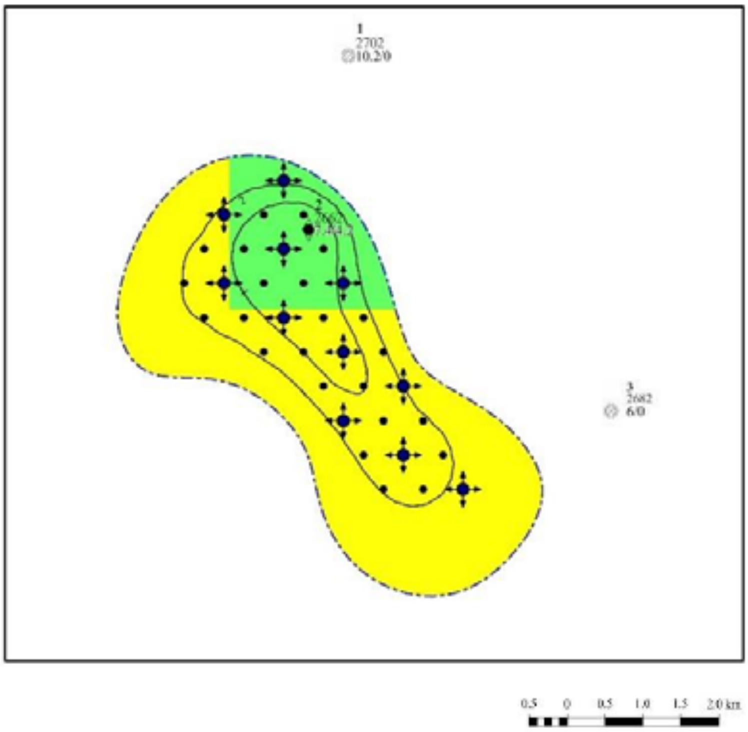
C1 reserves area (Area 1)

C2 reserves area (Area 2)

1 Well number

For the calculation of recoverable quantities, an oil recovery factor of 0.3 was applied for both areas of the deposit, based on data from analogous nearby oilfield developments and a nominal 500 m spacing waterflood pattern development scheme such as that illustrated in Figure 3.

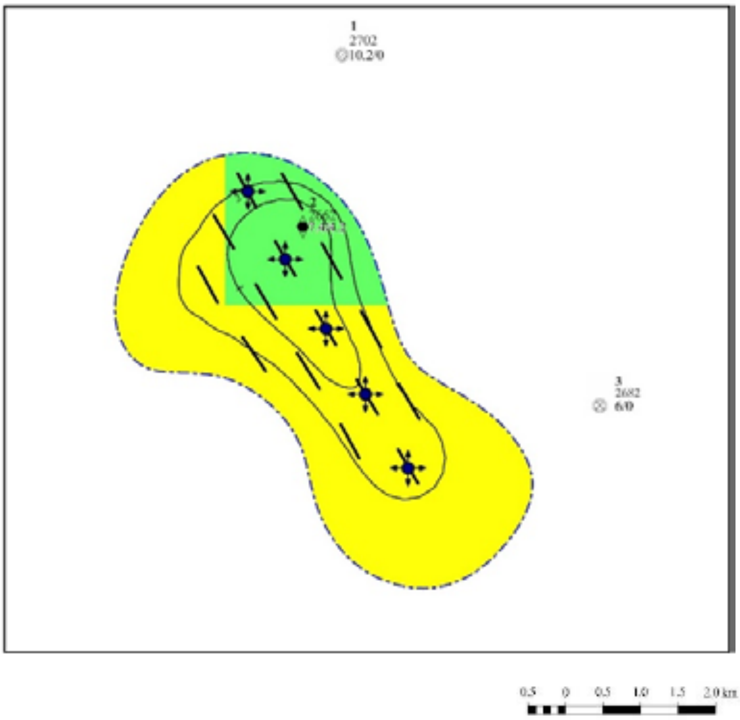
Figure 3a. **Potential future field development schemes, with either vertical or horizontal wells**



LEGEND

	Exploration wells with water inflow
	Exploration water-yielding wells by well log data
	Wildcat wells with oil inflow
	Injection wells
	Production wells
	Reservoir top contour
	Outer oil pool outline
	C1 reserves area
	C2 reserves area
1	Well number
2685	Reservoir top absolute depth
10.6/0.00	Effective thickness/Net oil thickness

Figure 3b. **Potential future field development schemes, with either vertical or horizontal wells**



LEGEND

	Exploration wells with water inflow
	Exploration water-yielding wells by well log data
	Wildcat wells with oil inflow
	Injection wells
	Production wells
	Reservoir top contour
	Outer oil pool outline
	Horizontal well
	C1 reserves area
	C2 reserves area
1	Well number
2685	Reservoir top absolute depth
10.6/0.00	Effective thickness/Net oil thickness

According to the information provided on regional infrastructure in the area around Field A, it was noted that the closest producing oil field is situated 15 km away, and the distance to the closest regional hard-top road is 18 km. The nearest oil-trunk pipeline in the area is 140 km away, and there is an inter-field oil pipeline 18 km from the discovery.

No information was available regarding why an exploration and production licence for Field A had yet to be issued, or on the likelihood of one being issued in the foreseeable future. However, it was noted that the reported Well #2 test flow rate was above the minimum of 5 tpd that is generally deemed to be commercial and cost-effective at analogous developments in the area.

Given the historical track record of oil fields being commercialized nearby, for the purposes of this case study, it was therefore assumed that future development of Field A can be considered to be technically feasible and that its associated gas sales volumes could also be commercialized.

A summary of the average reservoir property parameters and the calculated RF2013 volumetric and ultimate recovery estimates for each of the two areas of Field A is shown in Table 1.

Table 1. **Overview of reservoir parameters and calculated volumes according to RF2013**

		Category		*Category*
Area No	***1***		***2***	
Zone	***Pay zone with exploration well***		***Pay zone without exploration well***	
Oil productive area, 1,000 m^2	3,149		11,708	
Average oil net pay, m	3.86		2.39	
Net oil productive volume, 1,000 m^3	12,150		27,984	
Effective porosity, fraction	0.17		0.17	
Oil saturation factor, fraction	0.54		0.54	
Shrinkage factor, fraction	0.9		0.9	
Oil density, t/m^3	0.86		0.86	
Oil recovery factor, fraction	0.3		0.3	
Initial oil reserves in place, 1,000 t	863		1,988	
Additional quantities of oil in place	***604***	***C1*****	***1,392***	***C2*****
Initial oil reserves recoverable 1,000 t	259		596	
Cumulative oil production, 1,000 t	0		0	
Remaining oil reserves in place, 1,000 t	863		1,988	
Remaining oil reserves recoverable, 1,000 t	***259***	***C1***	***596***	***C2***
Gas factor (GOR), m^3/t	50		50	
Initial gas reserves in place, GSm^3	43		99	
Additional quantities of gas in place, GSm^3	***30***	***C1*****	***69***	***C2*****
Initial gas reserves recoverable, GSm^3	13		30	
Cumulative gas production, Gsm^3	0		0	
Remaining gas reserves in place, GSm^3	43		99	
Remaining gas reserves recoverable, GSm^3	***13***	***C1***	***30***	***C2***

Resource classification

Oil and Fuel Gas Reserves and Resources Classification of the Russian Federation

According to the Oil and Fuel Gas Reserves and Resources Classification of the Russian Federation of 2013 (RF2013), for projects still under evaluation, and having a similar commercial development status and level of geological knowledge as Field A, volumes are calculated separately for the area of the field including the discovery well and for the more remote area of the deposit with less well control.

According to RF2013, for Field A the recoverable oil volume calculated in Area 1 (259*103 tonnes) is classified as Category C1 reserves, and the recoverable oil volume calculated in Area 2 (596*103 tonnes) is classified as Category C2 reserves.

The oil volume in place calculated in Area 1 (863*103 tonnes) is also classified as Category C1 reserves, and the oil volume in place calculated in Area 2 (1,988*103 tonnes) is similarly classified as Category C2 reserves.

In addition, on the assumption that the processed associated gas from Field A will be sold (i.e. not used for fuel, or flared), the recoverable gas volume calculated in Area 1 (13 GSm3) is classified as C1 and the recoverable gas volume calculated in Area 2 (30 GSm3) is classified as C2.

Additional quantities in place are not classified in RF2013, but can be calculated by subtraction of recoverable reserves from in-place reserves, and are designated C1** and C2** in accordance with the Bridging Document.

Bridging to UNFC

In this case study, for the purposes of bridging to UNFC, the future development of Field A will be considered to be one project. Although several alternative project scenarios can also be envisaged (e.g., a further appraisal project for Area 2, a pilot project for Area 1, phased or incremental field development projects, etc.), since there has so far been one exploration project for the whole structure, it has been assumed that there also will be one future project for the development of the deposit.

Mapping E and F axes

When mapping to the E and F axes of UNFC, the quantities belonging to C1 and C2 Categories of RF2013 may correspond to any of the Codes 4, 5, 6 or 7 in Table 3 of the Bridging Document (see Tables 2 and 3).

This means that the RF2013 C1 and C2 Categories do not specify very precisely which E and F axes Categories/Sub-Categories should be used. In principle, any of the mappings outlined in blue could potentially be applicable, which implies that information other than simply the C1 and C2 annotation must be used to classify along both the E and F axes.

Table 2. **Number and colour coding for mapping of RF2013 to the E-F Matrix of UNFC (from the RF2013 and UNFC Bridging Document)**

	F1.1	F1.2	F1.3	F2.1	F2.2	F2.3	F3.1	F3.2	F3.3	F4
E1.1	1	2	3	4						
E1.2	1	2	3							
E2			4	4	5					
E3.1	12	12	12	12	12	12				
E3.2			6	6	6		8	9	10	
E3.3			7	7	7	7				11

Table 3. **Comparison of Classes and Sub-classes in UNFC with RF2013 Categories (from Bridging Document)**

Class	*Sub-class*	*Code*	*RF2013 Category*
Commercial Projects	On Production	1	A
	Approved for Development	2	B1
	Justified for Development	3	B2
Potentially Commercial Projects	Development Pending	4	A*, B1*, B2* C1, C2
	Development on Hold	5	A*, B1*, B2* C1, C2
Non-Commercial Projects	Development Unclarified	6	C1, C2
	Development Not Viable	7	C1, C2
Additional Quantities in Place		11	A**, B1**, B2** C1**, C2**
Exploration Projects	Prospect	8	D0
	Lead/High Risk Prospect	9	DL
	Play	10	D1, D2
Additional Quantities in Place		11	D0**, DL**,D1**, D2**
Produced Not Sold		12	

Note that Code 12 refers to quantities typically referred to as "fuel, flare and losses". Fuel is that portion of production consumed in operations and thus not delivered to the sales reference point.

E axis

Code 4 could potentially indicate either Category E1 (Sub-Category E1.1) or Category E2. Codes 4 or 5 could indicate Category E2. Codes 6 or 7 could indicate Category E3(Sub-Categories E3.2 and E3.3 respectively).

E1 has the following definition:

- *Extraction and sale has been confirmed to be economically viable.*

And this supporting explanation:

- *Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions. All necessary approvals/contracts have been confirmed or there are reasonable expectations that all such approvals/ contracts will be obtained within a reasonable timeframe.*

E2 has the following definition:

- *Extraction and sale is expected to become economically viable in the foreseeable future.*

And this supporting explanation:

- *Extraction and sale has not yet been confirmed to be economic but, on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic extraction and sale in the foreseeable future.*

E3.2 has the following definition:

- *Economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase).*

E3.3 has the following definition:

- *On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.*

The fact that the discovery is not in a licensed area and no owners have committed themselves to any development, precludes the use of Category E1 (and hence Sub-Category E1.1), since the timeframe for obtaining all necessary approvals/contracts is currently too uncertain.

Based on the data, analysis and interpretation provided regarding Field A, the information from analogous fields indicates that a future field development project could potentially be made economically and socially viable. This supports the assertion that the project should not be mapped as Code 7 (Sub-Category E3.3), and implies that the project currently falls into either E-axis Category E2 or Sub-Category E3.2.

While Category E2 would seem possible, to support this a company would have to be sufficiently confident of obtaining suitable licence terms for Field A and be able to demonstrate that it is currently reasonable to recognize the project as being economically viable under a feasible development plan. Alternatively, if it is considered that further information would be required in order to determine the economic viability of extraction, and/or project commerciality, then Sub-Category 3.2 would be indicated.

Given the absence of a licence (or any other formal rights for a party to continue the project), the Bridging Document suggests that the project should currently be placed in the maturity class “Non-Commercial Projects” as there is no commitment yet towards the development of Field A. The most appropriate Sub-class is “Development Unclarified” (Code 6), which implies Sub-Category E3.2. This effectively rules out Codes 4 and 5 (and therefore Category E2), as both would require that a development plan had been defined. In Russia, the exploration stage is considered to be finished when C1 to C1+C2 reserves ratio is equal to or more than 80 per cent, but in the present case, the C1 to C1+C2 ratio is about 30 per cent which means the exploration stage is ongoing. Consequently, E3.2 is the preferred Sub-category.

It is recognized that E3.2 could potentially be viewed as being too conservative, in particular when referring to UNFC definitions. This is particularly the case if further context could confirm the way that analogous projects in the region have progressed from the exploration stage in the past, and it is then considered that it can reasonably be demonstrated that (despite there being no licence or current development plans), future development is likely to be economic. In which case, this could be a “Potentially Commercial Project (Pending or on Hold)” with Code 4 or 5, and Category E2 would be justified.

However, on balance it is considered that E3.2 is the most appropriate UNFC E-axis Sub-category at this stage, given the absence of some key information required to determine unambiguous criteria for evaluation of the resources and to determine the level of confidence in their economic extraction and sales in the foreseeable future.

F axis

Table 4 shows that Code 6 (E3.2) could potentially be bridged to the F-axis Sub-Categories F1.3, F2.1 or F2.2, dependent on project feasibility and status.

The project does not currently qualify for Category F1 (confirmed development project), but it does meet the minimum necessary conditions for Category F2.

If project activities are ongoing to justify development, the most favourable position along the F axis is the Sub-Category F2.1. However, the available information for Field A does not suggest that any such activities are ongoing. Therefore, the most suitable Sub-Category currently appears to be F2.2 (Project activities are on hold and/or where justification as a commercial development may be subject to significant delay).

Taking the above-mentioned into consideration, the conclusion is that the reported RF2013 C1 and C2 hydrocarbon sales quantities for Field A in the project are classified as E3.2, F2.2.

Also, the non-recoverable reserves presented in Table 1 as C1** and C2 **, are considered to be "additional quantities in place" for Field A (Code 11) and are classified as E3.3, F4.

Table 4. **Number and colour coding for mapping of RF2013 to the E-F Matrix of UNFC (from Bridging Document)**

	F1.1	F1.2	F1.3	F2.1	F2.2	F2.3	F3.1	F3.2	F3.3	F4
E1.1	1	2	3	4						
E1.2	1	2	3							
E2			4	4	5					
E3.1	12	12	12	12	12	12				
E3.2			6	6	6		8	9	10	
E3.3			7	7	7	7				11

Mapping the G axis

According to Figure 1 in the Bridging Document, with respect to the G axis the volume classified in RF2013 as C1 reserves should be classified as G1 under UNFC. This implies that the interpretation of the well data and seismic around the discovery well is appropriate for the calculation of volumes across the whole of Area 1, and fits the criteria; "quantities associated with a known deposit that can be estimated with a high level of confidence".

Also according to the Bridging Document, the volume classified as C2 reserves in RF2013, and pertaining to the whole of Area 2, is considered to have "confidence levels ranging from moderate to low", so should be categorized as G2 + G3 in UNFC. (It should be noted that the notations G1, G2 and G3 are being used in the discrete or incremental sense, not the cumulative sense. It should also be noted that RF2013 provides best estimates and not the high (or low) cases.)

Due to the designated incremental mechanism for mapping of the RF2013 C1 and C2 reserves in the Bridging Document, it should be noted that it is not possible to report a central estimate of total reserves at the project level (i.e. covering the entire field area).

Based on the assumptions that the development of Field A is considered as one project and that only the processed oil could be sold, the UNFC resource volume estimates are as shown in Table 5.

Table 5. **Cumulative values (oil volumes)**

RF2013	*UNFC*	*Oil (1,000 tonnes)*
Recoverable	E3.2, F2.2, G1	259
Recoverable	E3.2, F2.2, G2+G3	596
Recoverable	E3.2, F2.2, G1+G2+G3	855
Non-recoverable	E3.3, F4, G1+G2+G3	1,996

There is currently no certainty that all volumes of associated petroleum gas will be sold. Depending on the details of the Field A development plan, the produced gas volumes might be (fully or partially) flared, used towards electricity production, or used directly as fuel, etc. Once the final development plan is approved, the portion of associated petroleum gas volumes that will be utilized, and how they will be utilized, will become clearer. Thus, the recoverable associated gas volumes should be mapped at this stage to Code 12. For this reason, the E-axis Category E3.1 has been applied to the RF2013 C1 and C2 gas reserves (Table 6).

Table 6. **Cumulative values (gas volumes)**

RF2013	*UNFC*	*Gas (GSm^3)*
Recoverable	E3.1, F2.2, G1	13
Recoverable	E3.1, F2.2, G2+G3	30
Recoverable	E3.1, F2.2, G1+G2+G3	43
Non-recoverable	E3.3, F4, G1+G2+G3	99

Observations and discussion

Dataset observations

Although the goal of this case study is not to challenge the evaluation of reserves presented, several technical observations can be made. These are briefly summarized in the ensuing text.

Comprehensive information on the methodologies employed for calculation of the reservoir volumetric and recovery estimates were not available (e.g. no information was provided on the relationship between the net and gross thickness). However, this was not considered important for the purpose of classification according to UNFC, although it should be noted that alternative interpretation and calculation methodologies could potentially affect the estimates of volumetrics and ultimate recovery.

The assumed field-wide OWC, based on the bottom of the tested interval in the discovery well, may be a conservative estimate.

The boundary between Area 1 and Area 2, in which the separate volumetric calculations were made, is assumed to be mainly based on the proximity to Well #2. While the map suggests that a saddle is present relatively close to the discovery well, potentially increasing the risks in the eastern part of the structure, the exact position of the boundary seems somewhat arbitrary.

Except for the net oil thickness, all the reservoir parameters and fluid properties, including the recovery factor, are estimated equal for the two areas in the calculations.

While the available data does not permit a specific probability level to be assigned to the average reservoir property values or the estimated reservoir volumes, except the OWC, the input parameters used in the volumetric calculations were understood to be based on best estimates.

The estimated recovery factor is reportedly based on data from analogous oil field development projects in similar physical and commercial circumstances. It is also resting on the assumption that a relevant number of production wells will be drilled in Field A.

Given the information that the average well spacing in this region of Russia is typically in the order of 500 m and wells are not usually drilled in the net pay thicknesses less than 2 m; it can be assumed around 34 vertical or 15 horizontal wells are needed for full development of this discovery, including the C2 area (5 km x 2.5 km) (Figure 3).

Classification observations

Since the RF2013 to UNFC Bridging Document leaves a wide range of possibilities for mapping resources in C1 and C2 to categories in UNFC, further information is needed (or has to be assumed) to select a specific mapping along the E and F axes.

It could be argued that if the parameters used to calculate the volumes are considered to be best estimates, the resulting volumes should, therefore, be classified as G1+G2 for each of the areas concerned. However, this would then be contrary to the incremental approach used as the basis for the Bridging Document mapping of C1 and C2 reserves to UNFC.

Due to the incremental approach used as the basis for mapping of the RF2013 C1 and C2 reserves in the Bridging Document, it is not easy to report a central estimate of the total Resource volumes at the full project level (i.e. covering the entire field area).

This case study can be extended to highlight some of the potential limitations associated with the workaround currently used for mapping of the G axis in UNFC. For example, it might take only one additional successful well to be drilled in the eastern area of the field, to then re-classify all the Area 2 volumes as C1 reserves. In which case the classification for Area 2 would evolve as follows (assuming, for the sake of simplicity, no changes were necessary to the current reservoir property parameters):

(a) Currently, Area 2 volumes are classified as E3.2, F2.2, G2+G3;

(b) 1 new well: Enables G3 à G1, giving E3.2, F2.2, G1 (which would still be Contingent Resources in the Petroleum Resources Management System (PRMS));

(c) Licensing and economics are then confirmed; Enables E3 à E1. This would then give E1, F2.2, G1 for the whole reservoir, with nowhere left to attribute G2 and G3 volumes;

(d) Development is then confirmed: Enables F2 à F1, giving E1, F1.3, G1. However, classification according to the G axis for E1, F1.3 and E1, F2.2 cases can be presented later in a future case study undertaken on more mature projects.

Conclusions

The RF2013 to UNFC Bridging Document has been successfully applied to a case study for an onshore Russian oil field currently at the post-discovery, pre-development stage. C1 and C2 oil reserves reported under RF2013 have been classified under UNFC as the equivalent quantities of E3.2, F2.2, G1-G3 Resources. A number of observations have been made regarding the requirement of additional information to classify C1 and C2 reserves along both the E and F axes and in mapping the G axis in this case study.

Case study on bridging from the Oil and Fuel Gas Reserves and Resources Classification of the Russian Federation to UNFC: Structure S in West Siberia, Russian Federation

Prepared by Alexander Shpilman, V.I.Shpilman Research and Analytical Centre for the Rational Use of the Subsoil, Russian Federation; Jan Bygdevoll, Norwegian Petroleum Directorate; Steve Griffiths, ERCE, United Kingdom; and Dominique Salacz, Evolution Resources SA, Switzerland.

Introduction

This case study considers estimated quantities of petroleum resources for a potential accumulation (prospect) under further exploration activities and evaluation, classified under the Russian Federation classification system (RFC). It explains how these resources can be reported according to the United Nations Framework Classification for Resources (UNFC), by use of the guidance contained in the "Bridging Document between the Oil & Fuel Gas Reserves and Resources Classification of the Russian Federation of 2013 and UNFC" of September 2016. (The Bridging Document is available in English and Russian on the ECE website at: http://www.unece.org/sed/unfc/rf2013bd.html) paragraph 6.)

The case study is based on information provided from a structure consisting of a group of four anticline traps in West Siberia called "Structure S".

There are several oil fields around the Structure S: in the Upper Jurassic deposits oil was discovered in the layers named JVn, and in the Lower Cretaceous deposits oil was discovered in the layers named BVn. The closest one under exploration is approximately 6 km from the structure. The structure has been explored by seismic comprising 3 surveys with seismic lines of grid density 1,37 km/km^2. The method used was 2D CDP and the scale is 1:50,000. The distance to the analogues is 30 km and 50 km respectively. It was recommended to drill an exploration well within the structure. Based on the interpretation of the 2D seismic, the top structure depth maps (Figures 1, 2, 3, 4) have been constructed. The structure is viewed as a combination of four traps each at a different depth and overlapping each other within the same area. There is one common Prospect Well Drilling Design Document (Figure 5).

Drilling a new prospect Well #1 (marked with red in Figures 1, 2, 3, and 4) will be designed according to an Exploration Works Design Document (in particular, a Prospect Well Drilling Design Document) in order to discover a new oilfield. The recommended TVD for the Well #1 is 2900 m, which exceeds the depth of all traps belonging to the Structure S. Mapped structural surfaces of all traps are conformal through the section and have a high level of confidence for structural imaging. Three of them are confined to the deposits where oil fields have been discovered in the immediate proximity to the Structure S. According to "Oil and Fuel Gas Reserves and Resources Classification of the Russian Federation" ("RFC"), the hydrocarbon resources of these three traps are classified as Category D0 resources. The fourth trap is confined to the deposits of the layer JV2-3; Russian Federation Classification

(RFC) defines two categories of resources in traps referred to as D0 and DL. Category D0 denotes resources of the traps prepared for exploration drilling. Resources are classified as Category DL when the traps are defined and outlined, but there are no actual plans to perform drilling, and further study is required. Category DL is also used when the defined traps are situated in a sub-district with unproved productivity within the oil-and-gas bearing complex (analogue of a play). Such a sub-district corresponds to the large tectonic units, with an area 10-90 thousand km2. The trap in the layer JV2-3 is classified with Category DL because there are no any accumulations actually discovered in the sub-district within the layer JV2-3, and particularly because this trap has a low probability of existence (0.35). After the discovery of the first accumulation in the closest proximity in this layer, all the related resources of Category DL could be upgraded to Category D0.

On the other hand, a new prospect well is planned to enter all four traps, including that in the layer JV2-3. For this reason, this trap should also be considered for further resource evaluation. All of these four traps will be drilled under the common Exploration Works Design Document (Prospect Well Drilling Design Document).

The Exploration Works Design Document proposes well logging for all traps forming Structure S and well tests for all prospective drilling targets. In view of this, the resources of all 4 traps can be regarded as prospective.

An exploration licence has not been issued and the right to study this area has not been transferred to any oil company. Structure S is therefore situated in unlicensed territory (“resources in open area”).

There is the possibility of an oil and gas discovery within the structure S, and four ready-to-drill traps in the area with proved commercial oil and gas presence. The project is regarded as exploration (ref Bridging Document, paragraph 16). A Prospect Works Design Document has not yet been made.

Figure 1. **Top BV_{10} depth map**

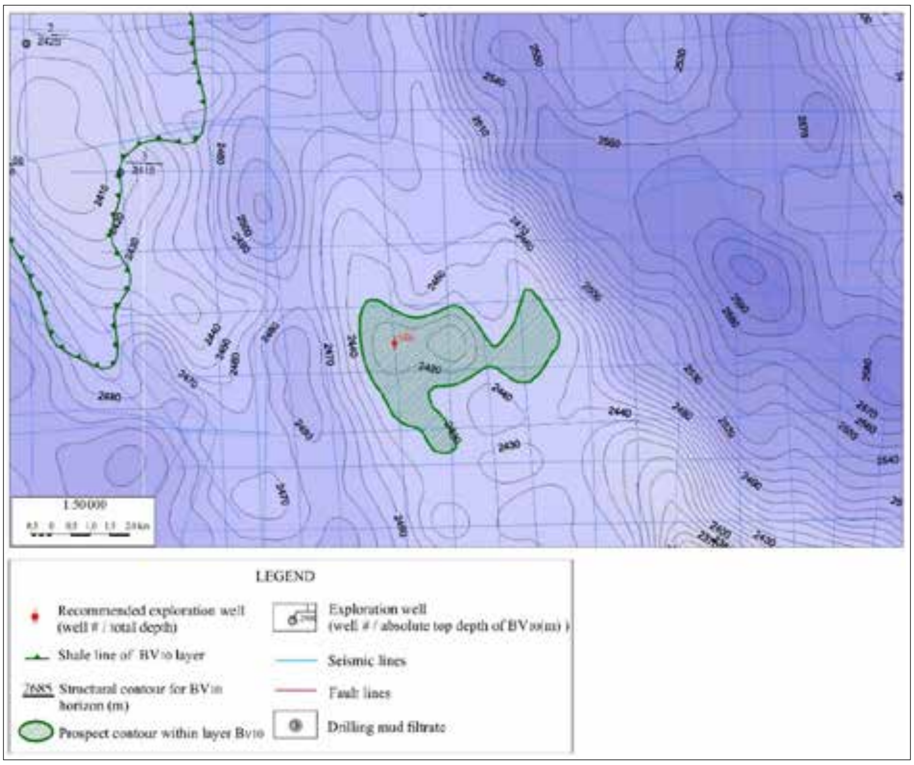


Figure 2. **Top JV_1 depth map**

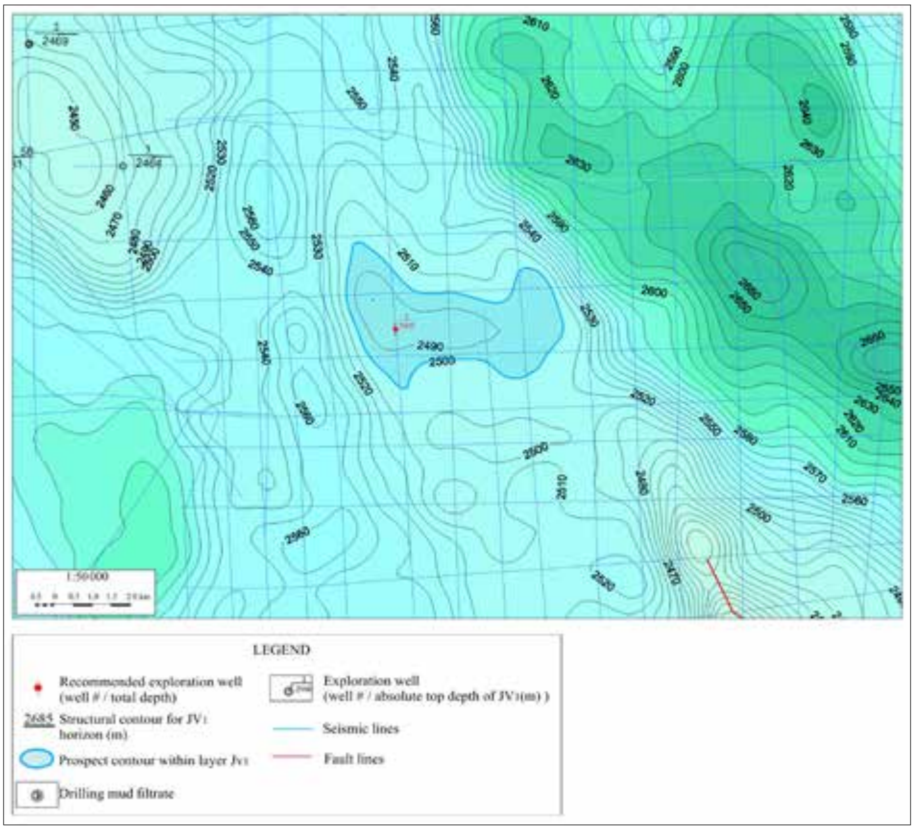


Figure 3. **Top $JV_{2\text{-}3}$ depth map**

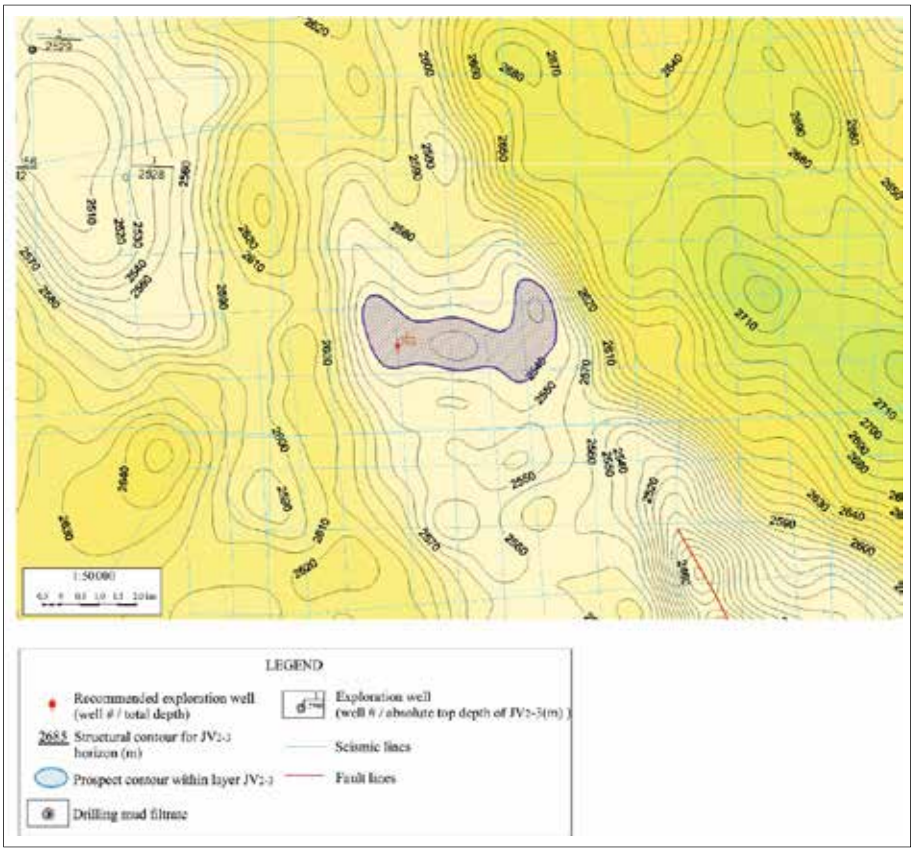


Figure 4. **Top JV_4 depth map**

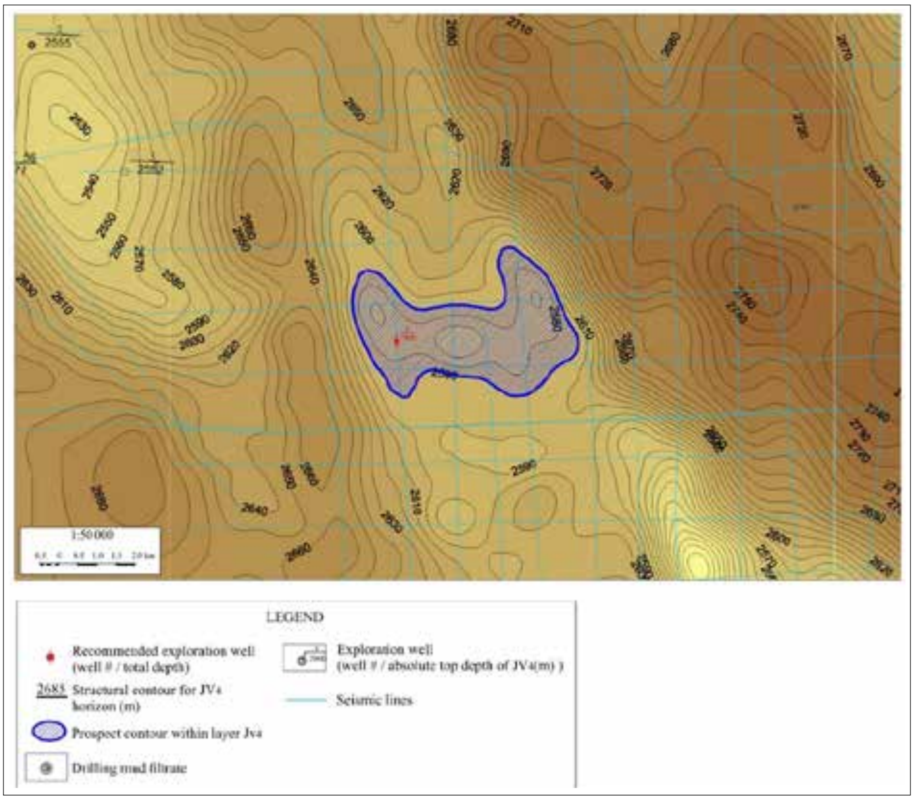
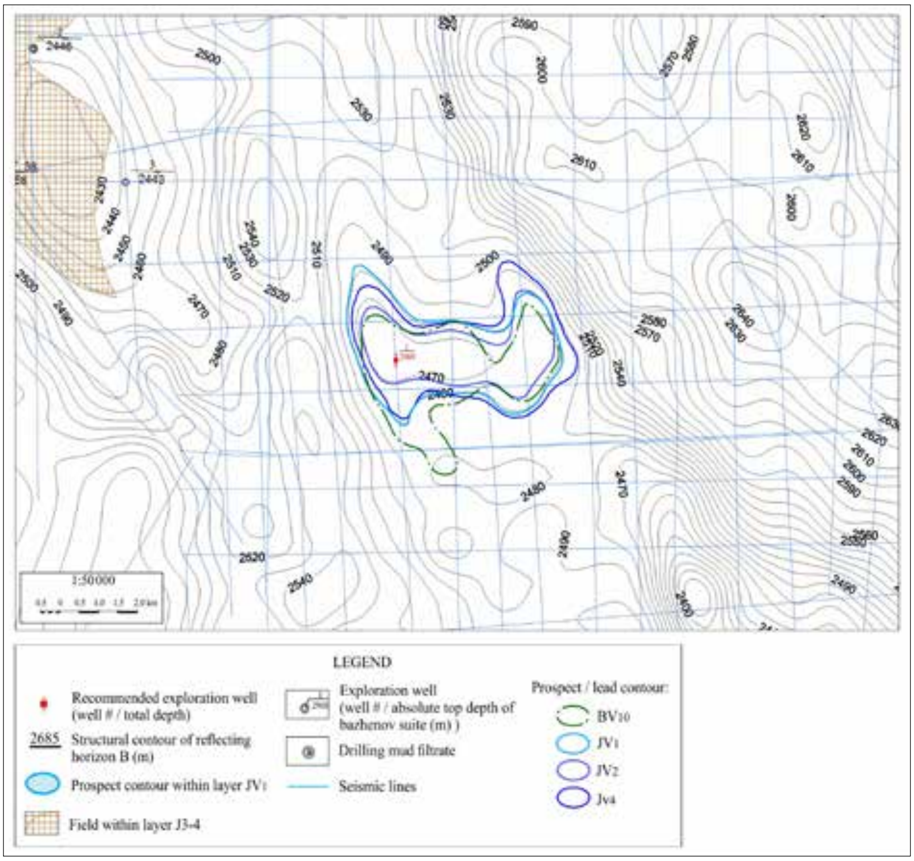


Figure 5. **Map of hydrocarbon potential**



Description of the project

Based on the information available, volumetric calculations were carried out for Structure S combining several traps. As mentioned previously, all of the four traps belonging to Structure S are intended to be drilled under the common Prospect Well Drilling Design Document. This allows all of them to be considered as prospects, even though one of the four traps is located in layer JV2-3 that is not productive within the adjacent areas.

According to information provided on the regional infrastructure in the area around Structure S, it was noted that the closest oilfield under exploration is 6 km from a discovered oilfield in the layer JV3. The closest producing oilfield is situated 23 km away; the distance to the closest regional hardtop road is 35 km. The nearest oil-trunk pipeline in the area is 213 km away, and there is an inter-field oil pipeline 35 km from Structure S.

No information is available regarding why an exploration licence for Structure S had yet to be issued or on the likelihood of one being issued in the foreseeable future.

Resource classification

Oil and Fuel Gas Reserves and Resources Classification of the Russian Federation (RFC)

A summary of the average reservoir parameters and the calculated RFC volumetric and ultimate recovery estimates for Structure S are shown in Table 1. Reservoir property parameters have been taken from two analogues in the adjacent areas.

Table 1. **Overview of reservoir parameters and calculated volumes according to RFC**

		Cat.		*Cat.*		*Cat.*		*Cat.*		*Cat.*
Trap name	*BV10*		*JV1*		*JV4*		*JV2*		*Total*	
Oil productive area, 1000 m^2	10 500		12 700		13 500		7 500			
Average oil net pay, m	2.00		3.00		3.00		3.00			
Net oil productive volume, 1000 m^3	21000		38100		40500		22500			
Effective porosity, fraction	0.18		0.17		0.18		0.17			
Oil saturation factor, fraction	0.48		0.54		0.57		0.55			
Shrinkage factor, fraction	0.920		0.800		0.935		0.923			
Oil density, t/m^3	0.891		0.873		0.886		0.882			
Oil recovery factor, fraction	0.30		0.20		0.25		0.30			
Initial oil resources in place, 1000 t	1487		2443		3442		1713		9085	
Additional quantities of oil in place	***1041***	***D0***	***1954***	***D0***	***2581***	***D0***	***1199***	***DL***	***6775***	***DL***
Initial oil resources recoverab 1000 t	446		489		861		514		2310	
Cumulative oil production, 1000 t	0		0		0		0			
Remaining oil resources in place, 1000 t	1487		2443		3442		1713		9085	
Remaining oil resources recoverable, 1000 t	***446***	***D0***	***489***	***D0***	***861***	***D0***	***514***	***DL***	***2310***	***DL***

Notes:
Totals indicated for DL are in fact totals for DL+D0.
Totals labelled DL** are in fact totals for DL**+ D0**.

According to the document "Oil and Fuel Gas Reserves and Resources Classification of the Russian Federation" (RFC), for Structure S the calculated recoverable oil volume classified as Category D0 resources is 1,796*10^3 tonnes, and the calculated recoverable oil volume classified as Category DL resources is 514*10^3 tonnes.

The oil volume in place related to resources classified as Category D0 resources is 7,372*10^3 tonnes and, similarly, the oil volume in place related to resources classified as Category DL resources is 1,713*10^3 tonnes.

Additional quantities in place are not classified in RFC, but can be calculated by subtraction of recoverable volumes from in-place volumes, and are designated D0** and DL** in accordance with the Bridging Document.

The additional oil quantities in place classified as Category D0** resources is 5576*10^3 tonnes and, similarly, the oil volume in place classified as Category DL** resources is 1199*10^3 tonnes.

Bridging to UNFC

For the purposes of bridging to UNFC, in this case study the exploration project for the whole Structure S will be regarded as one project. This is consistent with the description given in the Introduction that the whole Structure S combines four traps to be drilled under the common Prospect Well Drilling Design Document.

Mapping E and F axes

When mapping to the E and F axes of UNFC, taking into consideration previous explanations, quantities categorised as DL are treated as if they were categorised as D0. Hence, the quantities belonging to D0 and DL categories of RFC correspond to E3.2 F3.1 (Sub-class "Prospect") referred to as Code 8 in Table 3 of the Bridging Document (see Tables 2 and 3).

Table 2. **Number and Colour coding for mapping of RFC to the E-F Matrix of UNFC (from the Bridging Document)**

	F1.1	*F1.2*	*F1.3*	*F2.1*	*F2.2*	*F2.3*	*F3.1*	*F3.2*	*F3.3*	*F4*
E1.1	1	2	3	4						
E1.2	1	2	3							
E2			4	4	5					
E3.1	12	12	12	12	12	12				
E3.2			6	6	6		8	9	10	
E3.3			7	7	7	7				11

Table 3. **Comparison of Classes and Sub-classes in UNFC with RFC Categories**

Class	*Sub-class*	*Code*	*RFC Category*
Commercial Projects	On Production	1	A
	Approved for Development	2	B1
	Justified for Development	3	B2
Class	*Sub-class*	*Code*	*RFC Category*
Potentially Commercial Projects	Development Pending	4	A*, B1*, B2* C1, C2
	Development on Hold	5	A*, B1*, B2* C1, C2

Table 3. **Comparison of Classes and Sub-classes in UNFC with RFC Categories (continued)**

Non-Commercial Projects	Development Unclarified	6	C1, C2
	Development Not Viable	7	C1, C2
Additional Quantities in Place		11	A**, B1**, B2** C1**, C2**
Exploration Projects	Prospect	8	D0
	Lead/High Risk Prospect	9	DL
	Play	10	D1, D2
Additional Quantities in Place		11	D0**, DL**,D1**, D2**
Produced Not Sold		12	

Note: Code 12 refers to quantities typically referred to as “fuel, flare and losses”. Fuel is that portion of production consumed in operations and thus not delivered to the sales reference point.

E axis

According to the RFC Bridging Document, the project is in the maturity class “Exploration Projects”.

Further information would be required in order to determine unambiguous criteria for evaluation of the resources and to determine the level of confidence in their economic extraction and sales in the foreseeable future, that means that Sub-Category E3.2 is appropriate.

In UNFC, the E3.2 category is used for the classification of Exploration Projects. Code 8 unambiguously indicates Category E3 (Sub-Category E3.2).

Category E3 has the following definition:

- Extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability.

E3 also has the following supporting definition:

- On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future; or, economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase). Also included are quantities that are forecast to be extracted, but which will not be available for sale:

Subcategory E3.2 has the following definition:

- Economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase).

F axis

Table 2 shows that Code 8 can be bridged only to the F-axis Sub-Category F3.1.

F3 has the following definition:

- Feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data.

And this supporting explanation:

- Very preliminary studies (e.g. during the exploration phase), which may be based on a defined (at least in conceptual terms) development project or mining operation, indicate the need for further data acquisition in order to confirm the existence of a deposit in such form, quality and quantity that the feasibility of extraction can be evaluated.

F3.1 implies that:

- Site-specific geological studies and exploration activities have identified the potential for an individual deposit with sufficient confidence to warrant drilling or testing that is designed to confirm the existence of that deposit in such form, quality and quantity that the feasibility of extraction can be evaluated.

Taking the above-mentioned into consideration, the conclusion is that the reported RFC D0 and DL oil resources for Structure S in the project are classified as E3.2, F3.1.

In addition, the non-recoverable volumes presented in Table 1 as D0** and DL**, are considered to be "Additional quantities in place" for Structure S (Code 11), and are classified as E3.3, F4.

Mapping the G axis

According to Figure 1 in the Bridging Document, the volumes classified in RFC as D0 and DL should be both categorised as G4 under UNFC. This implies that the interpretation of well data on the adjacent analogues and seismic around Structure S is appropriate for the calculation of volumes across the Structure S area, and fits the criteria "Estimated quantities associated with a potential deposit, based primarily on indirect evidence".

Also according to UNFC, the volumes classified as G4 should be regarded as G4.1 + G4.2.

According to the text of Section III of UNFC, "the quantities may be estimated using deterministic or probabilistic methods". This implies that UNFC does not require use of a particular method for evaluation. A probabilistic method for estimation is not implied and supported by RFC. Resources in Russia are estimated using the deterministic method.

Based on the assumptions that Structure S is regarded as one exploration project, the UNFC resource volume estimates have been calculated and are provided in Table 4.

Table 4. **Cumulative values (oil volumes)**

	Classification	*Oil (1000 tons)*
Recoverable	E3.2, F3.1, G4	2310
Non-recoverable	E3.3, F4, G4	6775

Chance of discovery of Structure S

In the case reviewed, there is a chance of discovering a commercial accumulation and this can be estimated using historical data.

The chance of discovery can be estimated based on the exploration well drilling results in this play over previous years (approximately 10 years). A total of 386 prospects have been drilled (first exploration wells) in this area, during this period, and 129 of them were productive, so the well success ratio is 0.33.

A success ratio could also be estimated based on the number of discovered accumulations. There are 714 traps (levels under closure) that have been drilled and tested in this area. These resulted in discovery of 200 accumulations across the whole section, which implied a discovery ratio of 0.28. When designing a prospect well, all target levels – which are prospective based on the well log results of the analogues – should be tested. Some traps could be empty but the resources confirmation factor, which is the ratio of reserves in discovered accumulations to resources in associated traps, is close to 1.0 in this area. This conclusion is based on the results of previous studies (Russia Resources Evaluation performed in 2012).

Chance of commerciality

According to the Russia Resources Evaluation performed in 2012, the minimum economic field size in the area of Field B is $0.3*10^6$ tonnes. There are now 84 oilfields with oil reserves less than $1*10^6$ tonnes discovered in the area, 16 of them are under development. The reserves of 4 developing oilfields are less than 0.3*106 tonnes.

Hence, if there is only 1 discovered accumulation from 4 initial traps (experience shows that JV1 can be regarded as the most favourable level) then given that its estimated recoverable resources are more than $0.3*10^6$ tonnes ($0.489*10^6$ tonnes), it can be assumed that, if successful, the development will be economic.

Observations and discussion

Dataset observations

Although the goal of this case study is not to challenge the evaluation of resources presented, a number of technical observations can be made. These are briefly summarised below:

- Comprehensive information on the methodologies employed for calculation of the reservoir volumetric and recovery estimates were not available. However, this was not considered important for the purpose of UNFC reserves/resource classification, although it should be noted that alternative interpretation and calculation methodologies could potentially affect the estimates of volumetric and ultimate recovery.
- The estimated recovery factor is reportedly based on data from analogous oil field development projects in similar physical and commercial circumstances.

Classification observations

The RFC to UNFC Bridging Document provides a very straightforward solution for the mapping of the exploration project. Although the exact maturity level of a potential reservoir might always be debated, this was not the purpose of this document.

Considering all the major uncertainties such as net pay (only based on seismic) and fluid contacts, the range of outcomes might have a major impact on project economics, and it is somewhat counter-intuitive to have only one estimate for an exploration project.

The purpose of exploration teams is to assess the risks and to validate the presence of hydrocarbon resources through the exploration process. In this context, it can be detrimental to be too pessimistic (missing opportunities), and the teams often provide a high side for volume estimations. In the absence of a full range of volumes (in place and recoverable resources), it could be considered whether the data provided by RFC is likely to tend toward the G4.1+G4.2+G4.3 category.

The incremental approach was used as the basis for evaluation and classification of D0 and DL hydrocarbon resources according to RFC. According to the terms, conditions and the logic used in UNFC, D0 and DL volumes have been treated as the prospect under one exploration project. Despite the fact, that RFC to the UNFC Bridging Document presumes mapping of DL resources category of RFC only to Code 9 of UNFC, this case study suggests mapping both D0 and DL resources categories of RFC to Code 8.

Conclusions

The new RFC to UNFC Bridging Document has been successfully applied to a case study in the Russian Federation for an onshore anticline Structure S, including several traps currently at the early exploration stage.

D0 and DL oil resources reported under RFC have been classified under UNFC as the equivalent quantities of E3.2, F3.1, G4.

While the mapping appears straightforward, the only missing point is the range of uncertainty that would be expected in any exploration project.

Pilot project for the classification of Mexico's petroleum resources and reserves based on UNFC

Prepared by Fidel Juárez Toquero, Eduardo Simón Burgos, Eduardo Meneses-Scherrer, Elaine Angélica Arellano Sánchez, Mauro Ivan Weimann, Josué Salazar Juárez, Francisco Fuentes Pacheco, Guillermo Guerrero Olivares, Miguel Ibarra Rangel, Alma América Porres Luna and Ulises Neri Flores, National Hydrocarbons Commission, Mexico; Francisco Pacheco Román and Mayelli Hernández Juárez, Ministry of Energy, Mexico; and Guillermina Mera Avecias and José León Mella, Safety, Energy and Environment Agency, Mexico; and Satinder Purewal, Chair, Petroleum Working Group of the Expert Group on Resource Management.

Introduction

This case study presents the results of a large-scale project (pilot project) to apply the United Nations Framework Classification for Resources (UNFC) to projects in nineteen hydrocarbon exploration and extraction blocks in Mexico. The pilot project was led by the National Hydrocarbons Commission (CNH) of Mexico in collaboration with the Ministry of Energy (SENER) and the Safety, Energy and Environment Agency (ASEA).

According to the proposal included in document ECE/ENERGY/GE.3/2018/9,[1] Mexico implemented a pilot project under the auspices of a regulator (CNH).

The primary purpose of the pilot project was the implementation of UNFC to evaluate the value and applicability in Mexico, with particular regard to describing the social and environmental project risks.

The collaboration between the institutions involved allowed the holistic identification and visualization of all aspects involved in the evaluation of oil and gas projects.

Mexico has large discovered hydrocarbon volumes and significant undiscovered hydrocarbon potential; as of 1 January 2018, the estimated 2P[2] reserves were approximately 16.2[3] billion barrels of oil equivalent (BBOE) and 112.8[4] BBOE for the prospective resources (risked mean values) in conventional and unconventional resources.

Currently, hydrocarbon volumes in Mexico are classified according to the Society of Petroleum Engineers (SPE) Petroleum Resources Management System (PRMS).[5] PRMS (briefly) notes environmental and social aspects among other considerations for the classification of hydrocarbon projects. UNFC uses similar principles to PRMS but explicitly differentiates social and environmental risks, with some granularity, to better describe the level of project maturity.

1 Petroleum Working Group of the Expert Group on Resource Management (formerly known as the Expert Group on Resource Classification), 2018, ECE/ENERGY/GE.3/2018/9, United Nations Economic Commission for Europe

2 2P is a term in the Society of Petroleum Engineers (SPE) Petroleum Resources Management System (PRMS) and denotes the best estimate of reserves (sum of proved plus probable). In UNFC, this is equivalent to G1 + G2 for commercial projects

3 https://portal.cnih.cnh.gob.mx/downloads/es_MX/estadisticas/Reservas%20por%20campo%202018.pdf

4 https://portal.cnih.cnh.gob.mx/downloads/es_MX/estadisticas/Recursos%20Prospectivos.pdf

5 SPE, 2007, Petroleum Resources Management System and 2011, Guidelines for application of PRMS

The pilot project involved evaluating hydrocarbon projects with different levels of commercial maturity, legal and contractual terms, development risks and technical uncertainty, trying to obtain a representative sample of the different types of hydrocarbon projects in Mexico.

The key social risks identified in the pilot project include the approval and acceptance (often referred to as 'social license') of the projects by local communities, agrarian cores, indigenous people, among others; negotiation of the use, affectation or acquisition of land, property or rights to carry out activities, and for the specific case of unconventional resources, social acceptance of hydraulic fracturing.

The key environmental risks identified in the pilot project include the loss of natural protected areas, water use, and reduction in biodiversity due to deforestation.

This document summarizes all the experiences, lessons learned, tools and considerations made in the implementation of the pilot project, including classification of all the projects using UNFC.

Description of the Pilot Project

The pilot project comprised four main stages (see Figure 1):

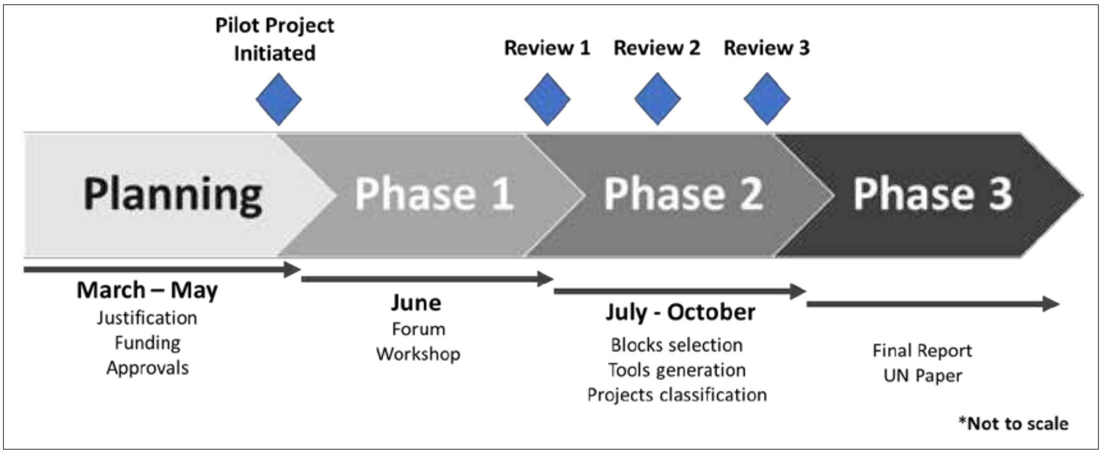
a. Planning: Justification and Funding;

b. Phase 1: Forum and workshop on UNFC;

c. Phase 2: Project selection, tools generation and classification using UNFC;

d. Phase 3: Final Report.

Figure 1. **Pilot Project Phases**



A detailed project schedule, including all the activities and the specific dates, is shown in the Annex to this case study.

Planning

An agreement was established with the United Nations Development Programme (UNDP) office in Mexico for Mexican institutions to conduct the UNFC pilot project with the support of experts in the field. All necessary internal procedures were followed to obtain the funds and the corresponding approvals.

Phase 1

A forum and a workshop were conducted to outline the scope and objectives of the pilot project, including the benefits of applying UNFC within the context of the Sustainable Development Goals (SDGs). Multiple stakeholders within the oil industry, including oil and gas exploration and production entities, regulators and government, and relevant non-governmental organizations participated in the forum.

During the workshop, a team was formed comprised of representatives from CNH, SENER, ASEA, and members of the Expert Group on Resource Management (Expert Group). The purpose of this workshop was to understand the technical, economic, social, environmental, and regulatory conditions to classify the projects using UNFC.

During Phase 1, UNFC was better understood, and a selection of new blocks was needed, given that those initially selected (before the workshop), did not have committed associated projects. The definition of the project was re-assessed as well, to ensure agreement with UNFC.

Phase 2

The selection of blocks was made, taking into account certain criteria in order to meet the goal of having a representative sample of hydrocarbon projects to analyze.

The blocks selection criteria included the existence of an operator exploration, appraisal or development plan, different project maturity, fluid type, resource type, location, social, environmental, technical and legal risks. This resulted in a set of nineteen blocks to evaluate.

Subsequently, the team identified the projects in each of the selected blocks, resulting in a total of seventy-five projects.

All the variables to be considered in the E and F axes of UNFC were outlined and assessed in the classification of the projects with a specific focus on the local social and environmental risks.

As part of this process, two tools were created to assist in mapping to UNFC categories. For the evaluation of the E axis, a matrix that identifies the key social, environmental and legal risks, as well as the main economic assumptions for each project. Likewise, for the F axis case, a project feasibility evaluation tool was created based on the existing regulatory processes of oil and gas projects approvals.

For the G-axis evaluation, as no volumes were estimated by the team, the team instead used values provided by existing estimates that were made according to the regulatory framework[6,7] and validated by CNH.

The projects were then evaluated and classified based on UNFC.

Phase 3

Phase 3 consisted of the documentation of the pilot project, including:

(a) a report provided to the participating institutions for internal usage. This report included a detailed analysis of each of the seventy-five projects, the evaluation undertaken and their classification under UNFC;

(b) a summary report (herein) for wider distribution.

6 http://dof.gob.mx/nota_detalle.php?codigo=5508418&fecha=20/12/2017

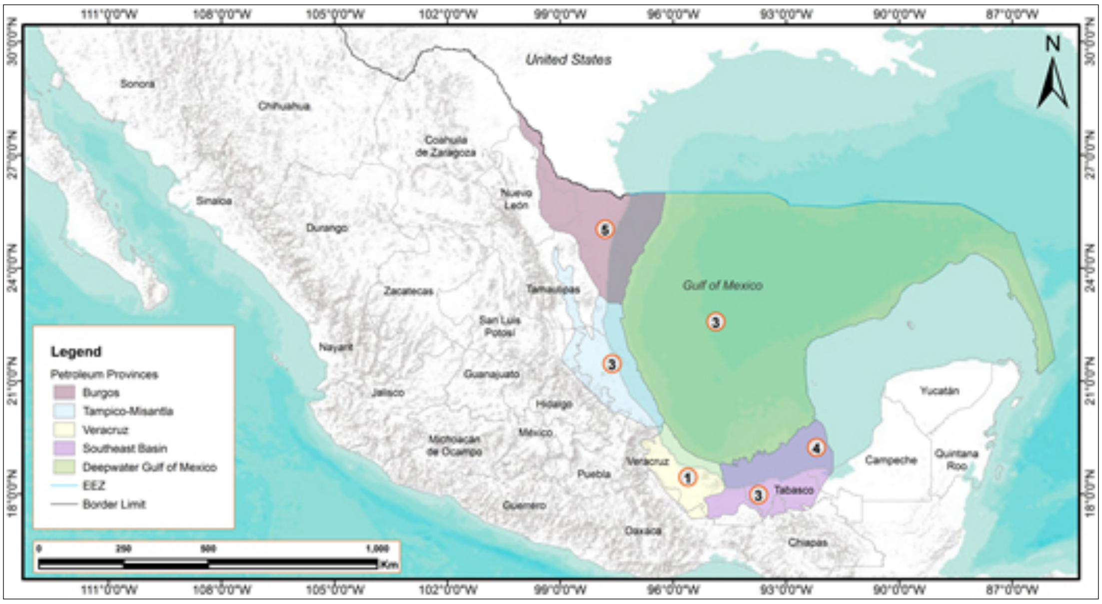
7 http://dof.gob.mx/nota_detalle.php?codigo=5324529&fecha=05/12/2013

Pilot project execution

Project definition and considerations

A map showing the location of the nineteen blocks evaluated during the pilot project is shown in Figure 2, located in the five most important petroleum provinces of Mexico, which include five blocks in Burgos, three in Tampico-Misantla, one in Veracruz, three onshore and four offshore in the Southeast basins, and three in Deepwater Gulf of Mexico.

Figure 2. **Pilot project blocks location map**



The operator exploration, appraisal or development plans for each block were assessed to define the individual projects based on project maturity. This included a review of the committed activities (base scenario) and incremental activities (incremental scenario) within each plan.

The assessment identified the conventional and unconventional resources potential. Potential volumes come from the estimates included in the National Leads Database (managed by CNH), as well as from a regional study carried out by the state-owned petroleum company (Petróleos Mexicanos (PEMEX)). These volumes are not committed to being developed by any current block operator. Otherwise they would be included in an exploration plan. The decision of considering these volumes was made to evaluate the full potential of the whole geological column of the blocks.

The status of regulatory approvals was undertaken and considered in the classification.

Based on the above considerations, it was possible to identify seventy-five projects (see Figure 3) and catalogue them into nine different project groupings with similar project attributes in each (see Figure 4). The project groupings included:

(a) Unconventional Prospective Resources (UPR);

(b) Conventional Prospective Resources (CPR);

(c) Exploration Plans (Incremental Scenario) (EPI);

(d) Exploration Plans (Base Scenario) (EPB);

(e) Appraisal Plans (Base and Incremental Scenarios) (AP);

(f) Migration Proposal (MP);

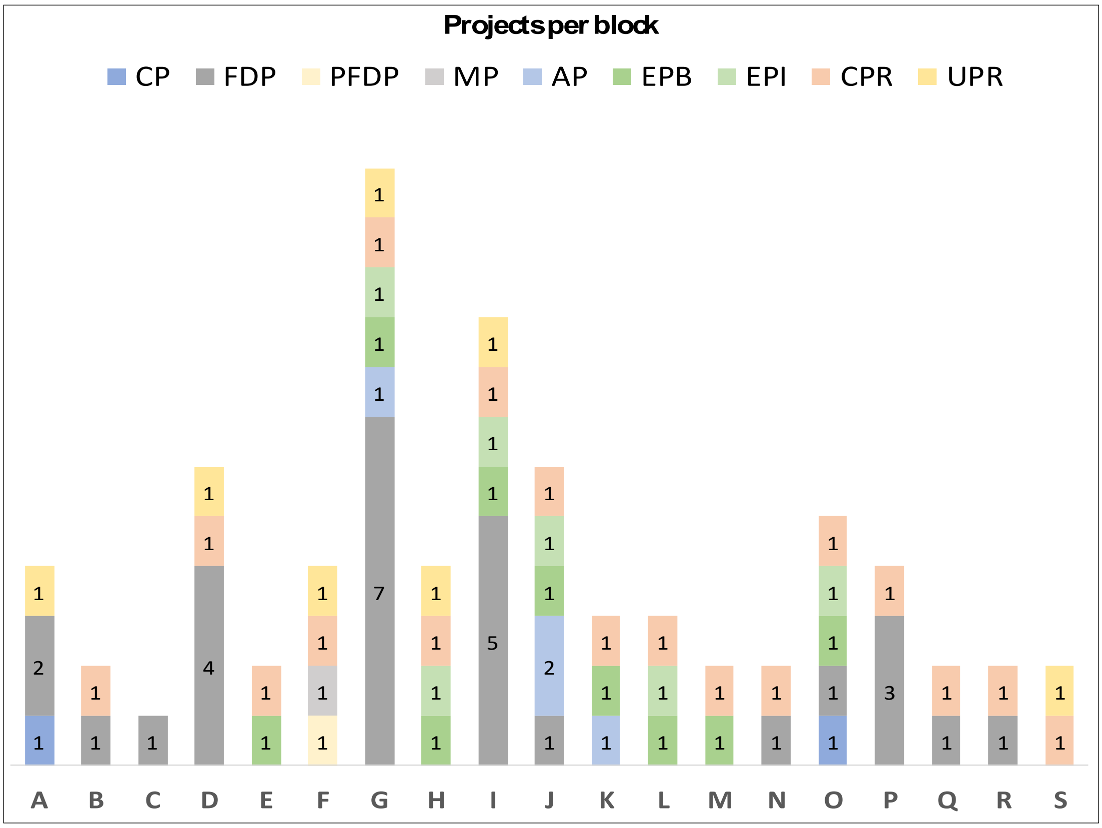
(g) Provisional Field Development Plan (PFDP);

(h) Field Development Plans (FDP);

(i) Current Production (CP).

Each project (project groupings) included in the 19 blocks (Blocks A to S), is displayed in Figure 3. For example, in Block A, one project of Current Production type (CP), two projects of Field Development Plan type (FDP), and one project of Unconventional Prospective Resources type (UPR) are included, adding four projects in total for that specific block.

Figure 3. **Projects identified**



Mapping tools

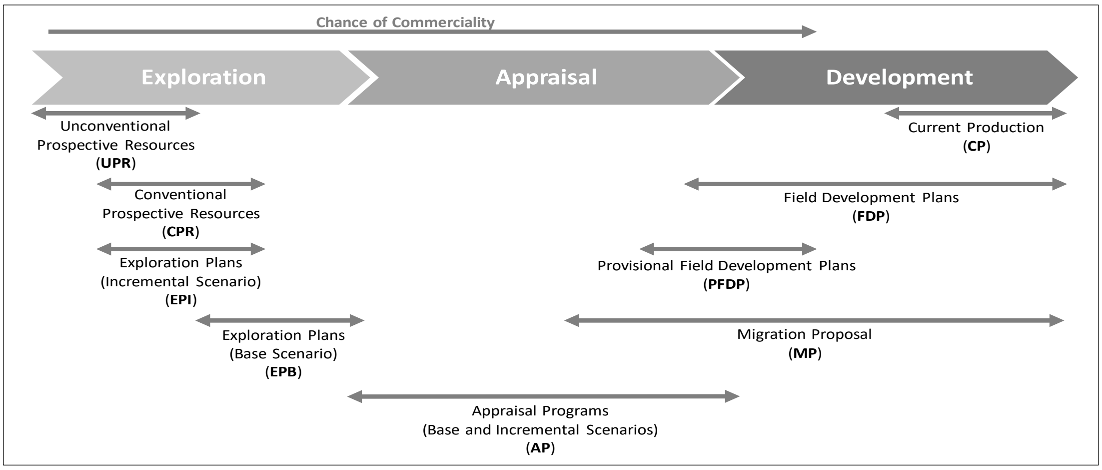
In evaluating the socio-economic viability of the E axis, a matrix was created to better describe the project-specific risks. For the case of the F axis, a flow diagram (gate process) was generated.

The matrix (for E-axis evaluation) considered the Mexican legislation regarding socio-organizational and environmental factors, required by the government in two documents: the "Social Impact Assessment"[8] (MIA) and the "Environmental Impact Assessment"[9] (EVIS). Thus, the matrix contains the relevant information required by the country´s legislation.

8 https://www.semarnat.gob.mx/temas/gestion-ambiental/impacto-ambiental-y-tipos/contenido-de-una-mia

9 https://www.gob.mx/tramites/ficha/evaluacion-de-impacto-social/SENER2561

Figure 4. **Types of projects**



The socio-organizational factors included the presence of communities with indigenous people, urban and rural land use, the values of the marginalization index and the index of human development, the local economic activity and water use, among other variables.

The environmental factors included the existence of safeguard zones, protected natural areas, wetlands of international importance (called Ramsar[10] sites), species of flora and fauna protected by legislation and the zoning of critical land use in the area.

The project team used a multivariate geospatial analysis (map algebra[11]) to identify and evaluate the socio-organizational and environmental factors. This tool allows the identification of the spatial distribution of the variables and interaction between variables within the blocks.

The map algebra considered both quantitative and qualitative variables. Each variable had different weights or values based on its importance considering the vulnerability, fragility, sensitivity or protection and conservation, as established in the respective legal framework related to the protection of property, environmental services, indigenous communities, archaeological zones, safeguard zones, and protected natural areas, among other considerations.

Legal and regulatory conditions were also considered including those contained within the MIA and EVIS, in addition to the "Environmental Baseline" (LBA), "Change of Land Use in Forest Land", "Safety and Environmental Management System" (SASISOPA), and the acquisition of insurance policies or guarantees to cover environmental contingencies.

For economic factors, the evaluation considered the economic indicators Net Present Value (NPV) and the Internal Rate of Return (IRR).

Table 1 presents the proposed matrix which uses three levels of viability for the development of the projects, considering the environmental, social, legal and economic variables used to classify the projects on the E axis: (1) high or most likely, (2) best or likely, and (3) low or unlikely. This matrix can be used by experts, with extensive knowledge of the project area, as a qualitative tool and judgment should be used to identify key social, environmental, legal and economic risks in order to assess the likelihood of project execution.

The matrix presents the environmental and social factors separately for practical reasons. However, the final evaluation assumed that both factors are cross-linked and equally important to determine the economic viability of a project.

10 https://www.ramsar.org/

11 Tomlin, C. D. (1990). Geographic information systems and cartographic modeling (No. 526.0285 T659) Prentice Hall

The F-axis flow diagram generated fits appropriately with the definitions of the categories and sub-categories of UNFC, in accordance with the regulations issued by CNH in terms of planning approvals.

Considering the above, it was concluded that the processes of submission and approval of plans are consistent with the definitions of the F axis. Therefore the classification was considered "direct".

The flow diagram (see Figure 5) consists of binary responses (yes or no) and gate type, which leads to a direct categorization on the F axis.

For the specific case of F1.2 classification, there are two ways possible to evaluate it. The first one is to consider that the Final Investment Decision (FID) of the operator is unknown by CNH, as it is not a legal requirement for FDP approval, and it is implied that the operators will meet the committed activities (once FDP is approved) as they have demonstrated previously their financial capacity. The second way is to consider FID disclosure by the operator. These two ways indicate that there are no impediments to the project proceeding and that the project is underway.

For other purposes or stakeholders, this process can be modified, improved and adjusted to adapt it to the specific regulatory conditions or the processes established by governments, companies or general users of UNFC.

Table 1. **E axis evaluation matrix**

Environmental variables	*High (Most likely)*	*Best (Likely)*	*Low (Unlikely)*	*Spatial support*	*Legend*
Is the project located in a restricted area?	No	Partially	Yes		
• Natural protected area? • Ramsar Site? • Safeguard zone…? – Lacandon Jungle – Yucatan Platform and Mexican Caribbean – Coral reef: Gulf of Mexico and Mexican Caribbean. – Californian Gulf and Baja California Peninsula	***Comments:***				
Is there flora and fauna listed in the NOM-059-SEMARNAT-2010?	No	Maybe	Yes		
• Species at risk (endangered, threatened, special) – Amphibians? – Birds? – Fungus? – Invertebrate? – Mammals? – Reptiles? – Fish?	***Comments:***				
Is there a critical ecological land-use planning?	No	Partially	Yes		
• General? • Regional? • Specific? • Local?	***Comments:***				
Is there critical land use?	No	Partially	Yes		
• High jungle? • Wetland? • Forest? • Other? consider the rest of existing categories	***Comments:***				

Table 1. **E axis evaluation matrix (continued)**

Socio-organizational variables	*High (Most likely)*	*Best (Likely)*	*Low (Unlikely)*	*Spatial support*	*Legend*
Presence of indigenous communities? (Communities > 50 people)	No	Partially	Yes		
• Communities with less than 40%? • Communities with more than 40%? • Communities of interest?	***Comments:***				
Is there an indigenous region?	No	Partially	Yes		
• Mayo-Yaqui? • Tarahumara? • Huicot o Fran Nayar? • Purépecha? • Huasteca? • Sierra Norte de Puebla & Totonacapan? • Otomí de Hidalgo & Querétaro? • Mazahua-Otomí? • Other? Consider 17 more existing regions	***Comments:***				
Is there a social land ownership?	No	Partially	Yes		
• Ejidal land (Ejido)? • Communal Land?	***Comments:***				
Is there marginalization? As measured by the marginalization index	No	Partially	Yes		
• Very high? • High? • Medium? • Low? • Very low?	***Comments:***				
Is the project interfering with an economic activity?	No	Maybe	Yes		
• Agriculture? • Mining? • Tourism? • Other?	***Comments:***				
Is there a concern with water?	No	Partially	Yes		
• Hydrological basins? • Aquifers? • Water wells? • Other?	***Comments:***				

Legal variables	*High (Most likely)*	*Best (Likely)*	*Low (Unlikely)*	*Spatial support*	*Legend*
Is there any concern with the legal status of the project?	No	Partially	Yes		
• Contract? • Migration? • Entitlement?	***Comments:***				
Are there environmental approvals and permits?	No	N/A	Yes		
• Environmental base line? • Environmental Impact Assessment? • Industrial, Operational, and Environmental Safety Administration System (SASISOPA)? • Insurance policy? • Any other applicable: • Change of land use in a forest area?	***Comments:***				

Table 1. **E axis evaluation matrix (continued)**

Legal variables	*High (Most likely)*	*Best (Likely)*	*Low (Unlikely)*	*Spatial support*	*Legend*
Are there social assessments presented?	No	N/A	Yes		
• Social Impact Assessment? • Others?	***Comments:***				

"Pure" economic variables	*High (Most likely)*	*Best (Likely)*	*Low (Unlikely)*	*Spatial support*	*Legend*
Is there an economic evaluation?	Yes	N/A / Maybe	No		
• Acceptable Net Present Value (NPV)? • Acceptable Internal Rate of Return (IRR)?	***Comments:***				

As mentioned previously, the estimates considered on the G axis were those made by the operators in accordance with the existing regulation regarding resources and hydrocarbon reserves, which is based on PRMS.

Block I Project Case Study

The project is located inside the "I" block (Entitlement), and it is an EPB. It considers the drilling of six exploratory wells targeting unconventional reservoirs. Five of the six wells are proposed on the southeast portion of the block while one of them is proposed on the northern portion. The drilling of the six wells is supported by an operator exploration plan approved by CNH.

The surface area associated with this project has a "high" value for the socio-organizational factor. This flags a high risk for potential development and for the activities related to the exploration, appraisal and production of hydrocarbons, so special attention should be given to the relation between the socio-organizational variables and the viability of the hydrocarbon projects. It should be noted that high marginalization can be seen from two points of view, one negative considering that the development of projects could be affected by unsatisfied communities or from a positive point of view, where it represents a good opportunity to improve their living conditions along with hydrocarbon projects development.

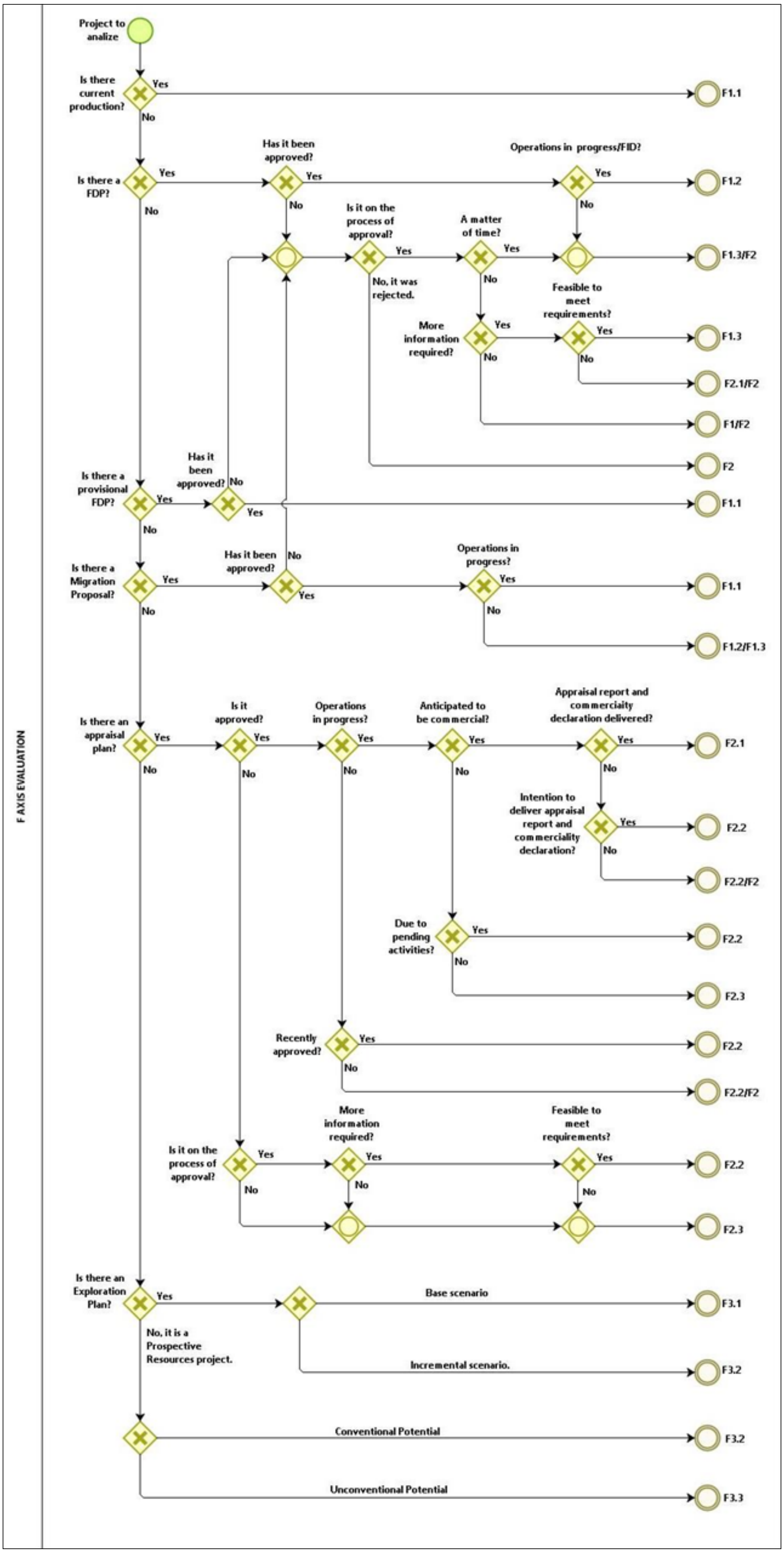
There are 23 human settlements and one indigenous region (Sierra Norte de Puebla-Totonacapan) within the project area. There are five communities that have more than 40 per cent of the indigenous population, which indicates that they should be consulted by SENER according to the standards adopted by the National Commission for the Development of Indigenous Population (CDI).[12,13] Concerning social land ownership, there are 30 communal lands (ejido) dispersed in the area.

The main land use in the area is for agricultural purposes, and the value of the marginalization index is high.

The main water use comprises urban public use (64 aquifers) and to a lesser extent for livestock (two aquifers). The entire block is under a regulation that prohibits the uncontrolled extraction of underground freshwater. The drilling, completion and development of unconventional reservoirs must meet the strict regulations managed by the National Water Commission, ASEA and CNH.

12 http://www.diputados.gob.mx/LeyesBiblio/pdf/LHidro_151116.pdf, Art. 120
13 https://www.gob.mx/cdi/documentos/indicadores-de-la-poblacion-indigena

Figure 5. **F axis evaluation process**



It should be noted that this is an Entitlement block, and thus, no Social Impact Assessment had to be presented to the authorities.

The project area does not affect any Protected Natural Area of a federal, state or municipal nature, nor does it have an impact on Ecological Territory Ordinance Programmes. There is no incidence of wetlands included under an international Ramsar sites agreement.

Given the nature of the Entitlement, authorizations are not mandatory in terms of environmental impact, nor SASISOPA (Sistema de Administración de Seguridad Industrial, Seguridad Operativa y Protección del Medio Ambiente) or insurance and guarantees for compliance with the authorizations related to security and protection of the environment.

An economic evaluation was not conducted given the level of maturity of the project.

The E axis evaluation matrix helped to assess the social, environmental, legal and economic aspects to determine the potential viability of development; additionally, the evaluation must be compliant with UNFC definitions, so this project was classified as an E3.2 (Exploration Project). The E axis evaluation is shown in Table 2.

Table 2. **E axis evaluation, case study**

"Economic viability": evaluation of the components considered in the E axis

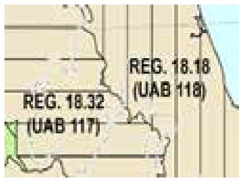
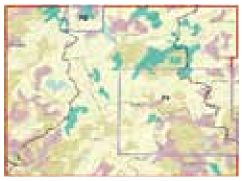
Assumptions:

Environmental and social factors are equally important for the "economic viability" of the project
The components of the E axis are crosslinked, especially the environmental and social factors
The purely "economic factor" is relevant but not decisive.

Block I:		***Project***	***Description***	***"E" Classification***
Location:	Hidalgo, Puebla and Veracruz	2	Exploration Plan Base Scenario	3.2
Category:	Onshore unconventional			

Environmental variables	***High (Most likely)***	***Best (Likely)***	***Low (Unlikely)***	***Spatial support***	***Legend***
Is the project located in a restricted area?	No	Partially	Yes		Block Area of the project
• Natural protected area? • Ramsar Site? • Safeguard zone…? – Lacandon Jungle – Yucatan Platform and Mexican Caribbean – Coral reef: Gulf of Mexico and Mexican Caribbean. – Californian Gulf and Baja California Peninsula	***Comments:*** There are no restrictions.				
Is there flora and fauna listed in the NOM-059-SEMARNAT-2010?	No	Maybe	Yes		
• Species at risk (endangered, threatened, special) – Amphibians? – Birds? – Fungus? – Invertebrate? – Mammals, reptiles, fishes?	***Comments:*** There is a possible existence of critical vegetation and species listed in the legislation.				

Table 2. **E axis evaluation, case study (continued)**

Environmental variables	***High (Most likely)***	***Best (Likely)***	***Low (Unlikely)***	***Spatial support***	***Legend***
Is there a critical ecological land-use planning?	No	Partially	Yes		Karst Huasteco Sur (32%) and Lomeríos de la Costa Golfo Norte.
• General? • Regional? • Specific? • Local?	***Comments:*** The area has a general land-use plan with policies of environment restoration and sustainable use?				
Is there critical land use?	No	Partially	Yes		Rainforest agriculture 58% Grassland 24% Shrubby Sec. Veg. 14% Herbaceous Sec. Veg. 4%
• High Jungle? • Wetland? • Forest? • Other? consider the rest of existing categories	***Comments:*** There is no critical land-use.				

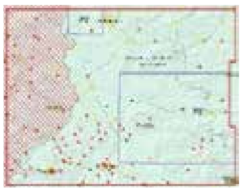
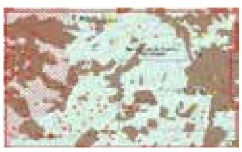
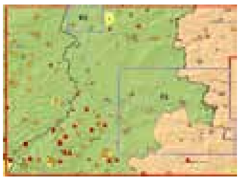
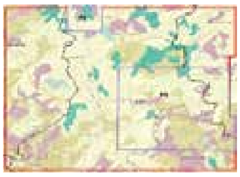
Socio-organizational variables	***High (Most likely)***	***Best (Likely)***	***Low (Unlikely)***	***Spatial support***	***Legend***
Presence of indigenous communities? (Communities > 50 people)	No	Partially	Yes		Communities > 40% Communities < 40% Comm. of interest
• Communities with less than 40%? • Communities with more than 40%? • Communities of interest?	***Comments:*** 5 communities >40% (1,144 people) 8 communities <40% (541 people) 11 communities of interest (2,278 people)				
Is there an indigenous region?	No	Partially	Yes		Huasteca Sierra Norte de Puebla y Totonacapan
• Mayo-Yaqui? • Tarahumara? • Huicot o Fran Nayar? • Purépecha? • Huasteca? • Sierra Norte de Puebla & Totonacapan? • Otomí de Hidalgo & Querétaro? • Mazahua-Otomí? • Other? Consider 17 more existing regions	***Comments:*** There are 2 indigenous regions, but only one region within the area of the project.				
Is there a social land ownership?	No	Partially	Yes		0 irrigation districts 30 Ejidal lands
• Ejidal land (Ejido)? • Communal Land?	***Comments:*** Yes, dispersed in the surface.				

Table 2. **E axis evaluation, case study (continued)**

Socio-organizational variables	*High (Most likely)*	*Best (Likely)*	*Low (Unlikely)*	*Spatial support*	*Legend*
Is there marginalization? As measured by the marginalization index	No	Partially	Yes		23 rural comm. (2,524 hab.) 0 urban communities
• Very high? • High? • Medium? • Low? • Very low?	***Comments:*** The value of the marginalization index is high.				
Is the project interfering with an economic activity?	No	Maybe	Yes		Rainforest agriculture
• Agriculture? • Mining? • Tourism? • Other?	***Comments:*** Yes, probably with agriculture.				
Is there a concern with water?	No	Partially	Yes	The entire block is under a regulation that prohibits the uncontrolled extraction of underground freshwater.	The development of unconventional reservoirs will have to meet the regulation of CONAGUA, and the one of ASEA and CNH
• Hydrological basins? • Aquifers? • Water wells? • Other?	***Comments:*** There is availability of water. 2 hydrological basins. 66 aquifers (64 urban use & 2 livestock use)				

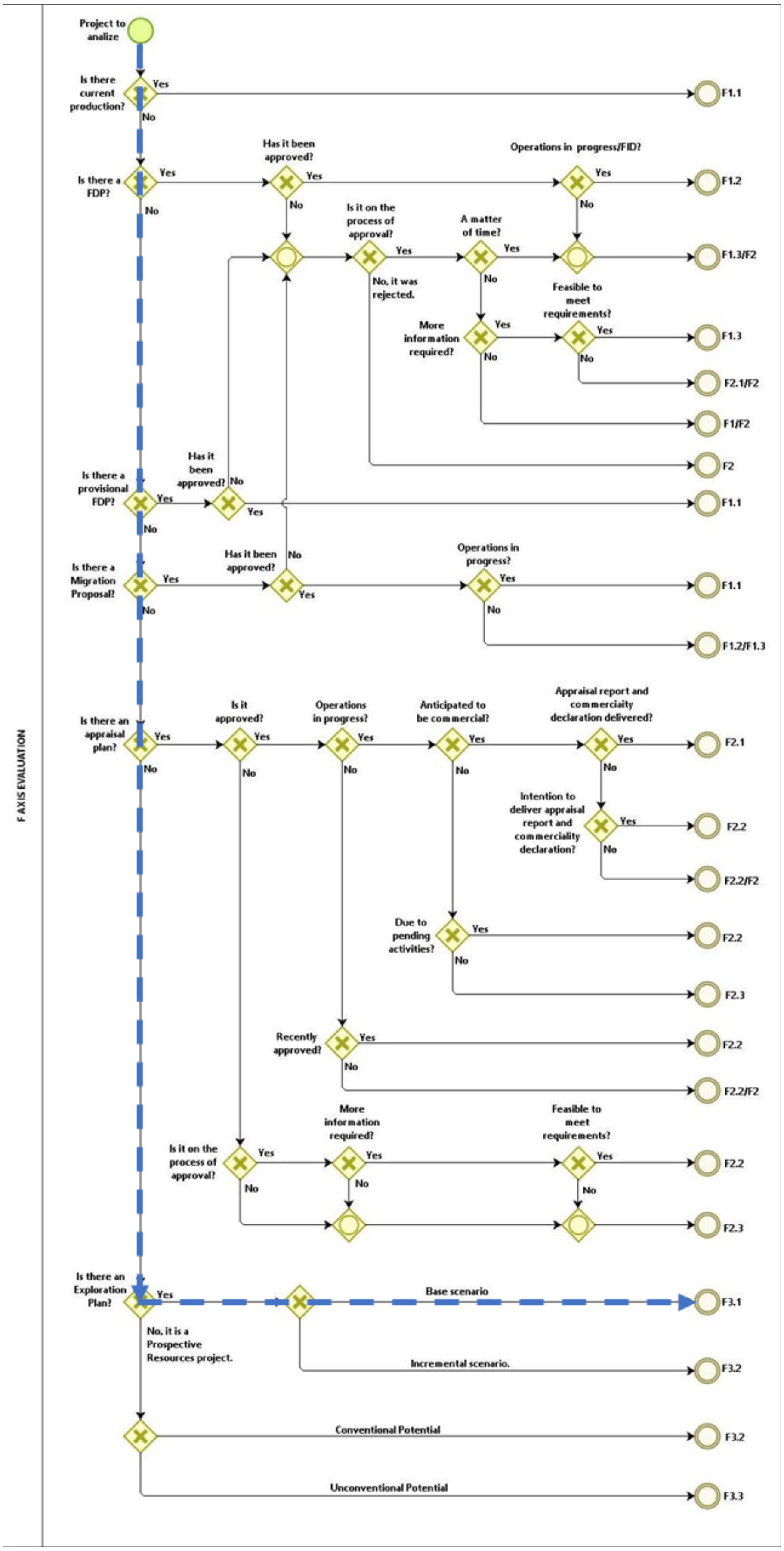
Legal variables	*High (Most likely)*	*Best (Likely)*	*Low (Unlikely)*	*Relevant information*	*Additional information*
Is there any concern with the legal status of the project?	No	Partially	Yes	Start date: 27 August 2014. Duration: 22 years.	
• Contract? • Migration? • Entitlement?	***Comments:*** The project is part of an Entitlement				
Are there environmental approvals and permits?	No	N/A	Yes		
• Environmental base line? • Environmental Impact Assessment? • Industrial, Operational, and Environmental Safety Administration System (SASISOPA)? • Insurance policy? • Any other applicable: • Change of land use in a forest area?	***Comments:*** It has environmental authorization conditioned.				
Are there social assessments presented?	No	N/A	Yes	There is no Social Impact assessment presented to the authorities.	
• Social Impact Assessment? • Others?	***Comments:***				

Table 2. **E axis evaluation, case study (continued)**

"Pure" economic variables	*High (Most likely)*	*Best (Likely)*	*Low (Unlikely)*	*Relevant information*	*Additional information*
Is there an economic evaluation?	Yes	NA/ Maybe	No		
• Acceptable Net Present Value (NPV)? • Acceptable Internal Rate of Return (IRR)?	***Comments:***				

Following the process established to evaluate the F axis, classification F3.1 was obtained. The project is supported by an approved exploration plan, and there is a strong commitment from the operator of the block to drill the planned wells. Therefore it is possible to categorize them as Prospects. Figure 6 shows the F axis evaluation process for this project.

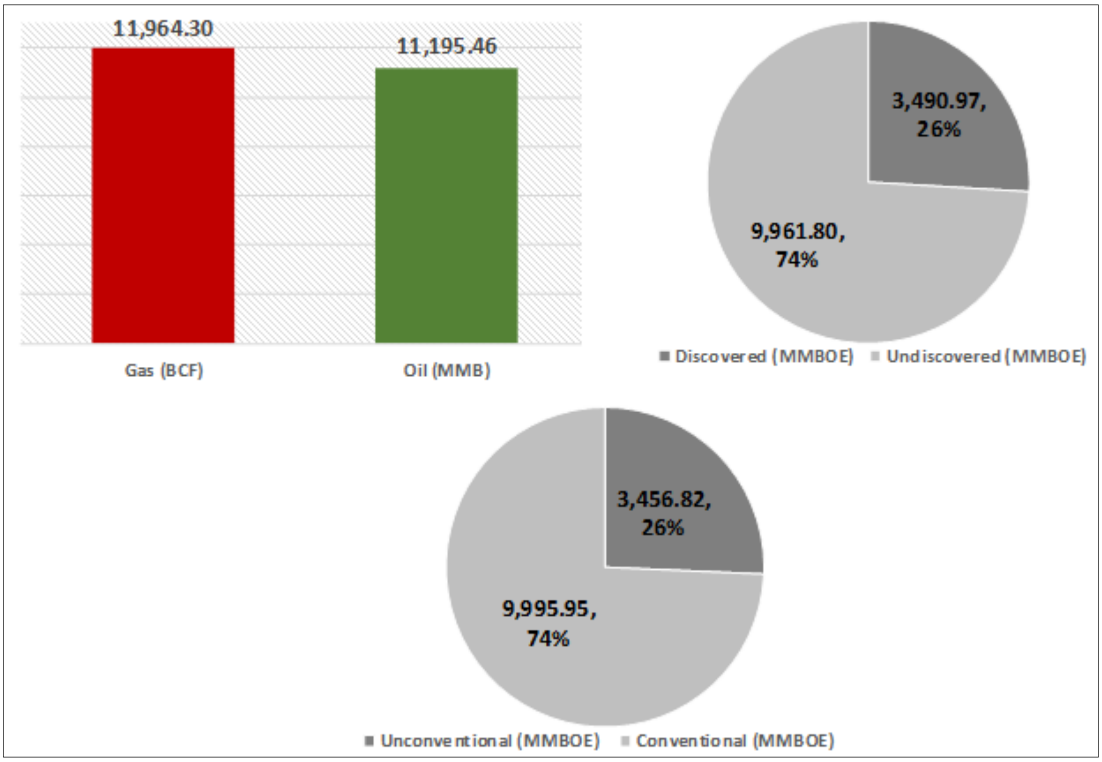
Figure 6. **F axis evaluation, case study**



Results

The total discovered and undiscovered hydrocarbon volumes (P50) associated with the seventy-five projects were considerable, estimated to be 11.9 Trillion cubic feet of gas (TCF) and 11.2 Billion barrels of oil. These volumes represent approximately 13.4 BBOE, this being the volumes associated with undiscovered and conventional hydrocarbons (see Figure 7). For comparative purposes, the volume of discovered hydrocarbons classified (this may include commercial, potentially commercial and non-commercial projects) represents 21 per cent of the country's 2P reserves as of 1 January 2018 and in the case of undiscovered hydrocarbons represents nine per cent of the country´s total prospective resources.

Figure 7. **Classified volumes**



Fifty-eight of the seventy-five projects were located on land while seventeen were located offshore. Most of the analyzed projects (fifty-nine) are associated with exploration, appraisal or development of conventional hydrocarbons. The legal situation of the evaluated blocks and thus of the projects were varied, with forty-six projects included in Entitlement areas, twenty-seven in contractual areas and two in non-assigned blocks (see Figure 8).

The projects analyzed allowed the evaluation of many classes and sub-classes defined by UNFC. Based on the analysis, commercial, potentially commercial, non-commercial projects were identified, as well as those exploration projects. It should be noted that in this pilot project, the additional quantities on site of both discovered and undiscovered accumulations were not considered. Table 3 shows the number of projects classified based on the category defined for each of them (primary classes).

Figure 8. **Evaluated projects**

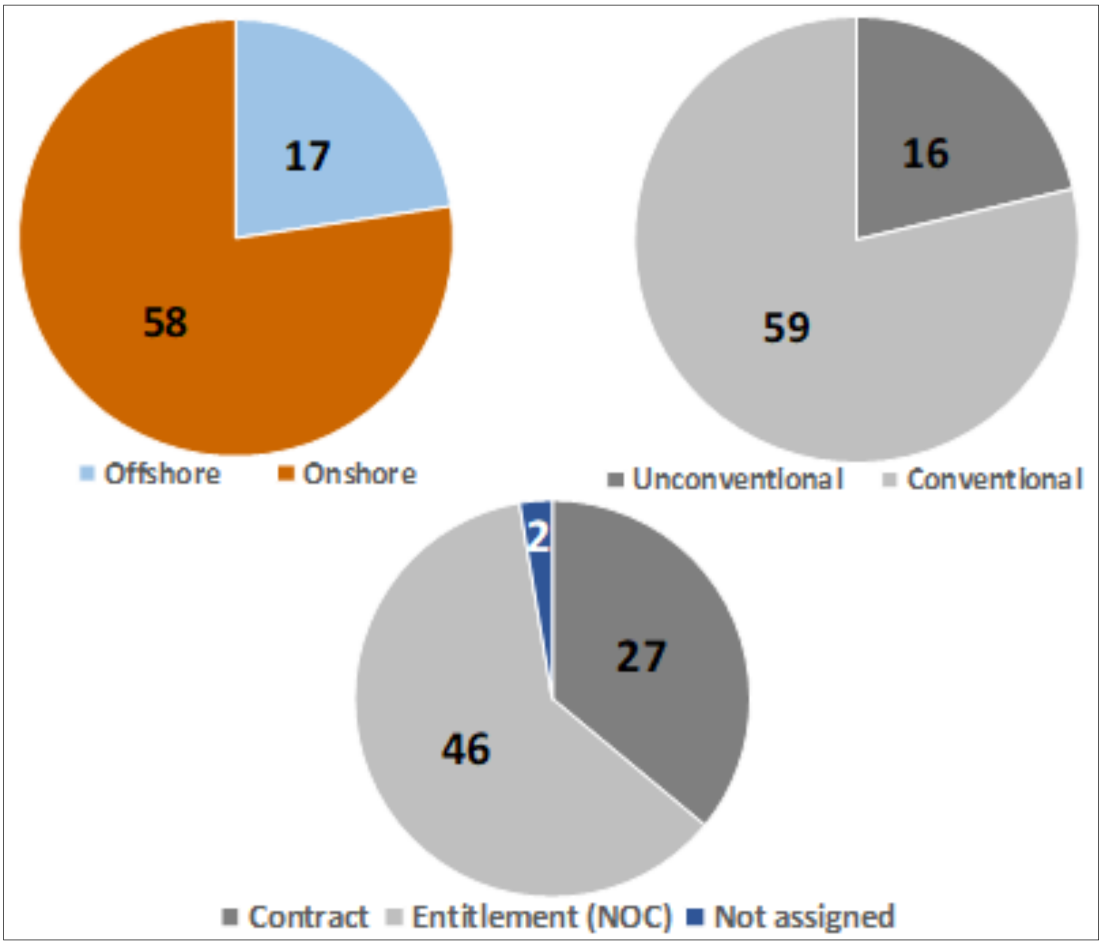


Table 3. **Classification of projects, primary classes**

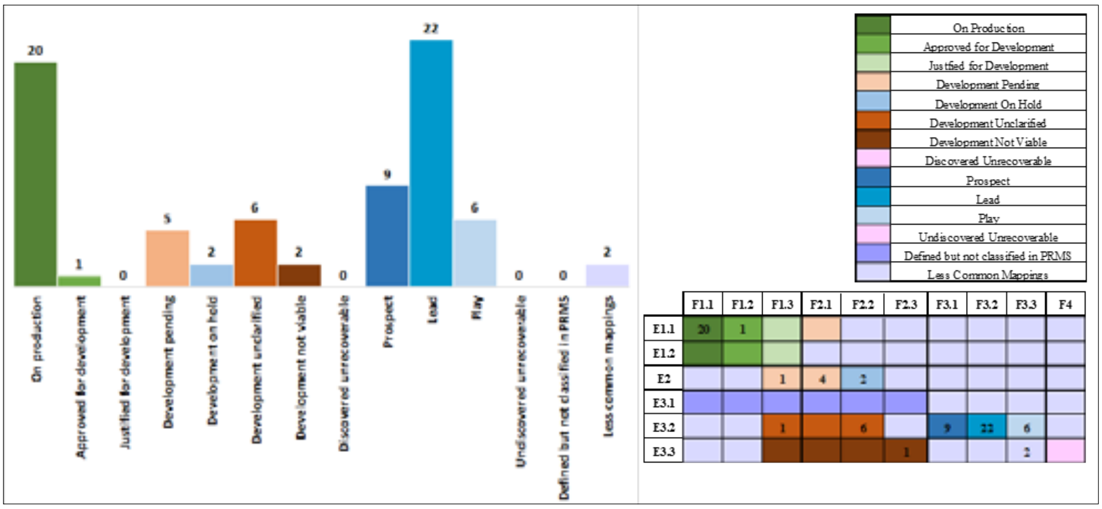
Projects classified (E vs F)				
Classes	*F1*	*F2*	*F3*	*F4*
E1	21	0	0	0
E2	1	6	0	0
E3	1	7	39	0

Application of UNFC to the seventy-five projects added granularity to their classification. The Sub-classes defined in UNFC were used in the pilot project, and the distribution of the classified projects based on these Sub-classes is shown in Figure 9.

Twenty-one projects were classified as Commercial Projects, seven projects as Potentially Commercial Projects, eight as Non-Commercial Projects, thirty-seven as Exploration Projects and two projects as less common mappings.

For projects associated with discovered hydrocarbon volumes, the volumes associated with the Commercial Projects were approximately 1,769.9 million barrels of oil equivalent (MMBOE), for the case of the Potentially Commercial Projects approximately 1,455.7 MMBOE, and 265.4 MMBOE in the case of the Non-Commercial Projects.

Figure 9. **Classification of projects, including Sub-classes**



For projects associated with undiscovered hydrocarbon volumes, the volumes classified were approximately 9,961.8 MMBOE. The distribution of the classified hydrocarbons volumes associated with discovered and undiscovered accumulations is shown in Table 4.

Table 4. **Volume distribution by Sub-classes (MMBOE)**

	G1	*G1+G2*	*G1+G2+G3*
E1.1, F1.1	986.4	1,357.4	1,384.4
E1.1, F1.2	122.4	412.5	706.1
E2, F1.3	128.7	187.2	187.6
E2, F2.1	1.0	1,197.8	1,247.3
E2, F2.2	68.8	70.7	554.7
E3.2, F1.3	0.0	0.0	54.6
E3.2, F2.2	57.9	265.4	798.4
E3.3, F2.3	0.0	0.0	979.3
	G4.1	*G4.1+G4.2*	*G4.1+G4.2+G4.3*
E3.2, F3.1	708.0	2,193.2	4,518.4
E3.2, F3.2	1,010.8	4,715.0	10,606.2
E3.2, F3.3	814.9	2,852.1	6,519.1
E3.3, F3.3	56.6	201.4	456.0
			**G (MMBOE)*

Capturing added value with UNFC

The pilot project found that application of UNFC requires a multi and interdisciplinary approach. The collaboration and interaction between CNH, SENER and ASEA allowed for identification and evaluation of all factors that influence the development viability of hydrocarbon projects.

The formation of the integrated team allowed the consolidation of disparate data sets managed by each institution and that in other situations, it would not be easy to analyze independently. The consolidation of social, environmental, technical, legal, economic information, under a single lens, allowed a holistic evaluation of the feasibility of the projects.

Formats and diagrams created for the evaluation of the E and F axes represented a uniquely important milestone in the pilot project and can be used as valuable tools for the classification of projects for different sectors in the future based on UNFC.

Further development of the pilot project outcomes with the inclusion of other stakeholders represents an area of opportunity for better evaluation of the feasibility of the projects.

Detailed inclusion of the social and environmental considerations for the classification of the projects assists project financial investment decision-making through a comparative assessment of objectives and priorities of national, regional and local stakeholders.

Use of UNFC in Mexico for the classification of not only oil and gas resources, but other types of resources such as renewables, nuclear fuels, minerals, among others, could establish an effective platform for the country´s energy and regulatory policy decision-making.

Conclusions

Application of UNFC allowed the project team to understand and visualize in different dimensions and perspectives, the development likelihood of the hydrocarbons resources in Mexico, taking into consideration the international standard developed by the United Nations Economic Commission for Europe.

The use of UNFC allowed the identification of the social, environmental and legal factors, related to each other that directly and indirectly influence the development of oil and gas projects and will be useful to identify the impacts and relationships with the Sustainable Development Goals.

The consideration of aspects other than purely technical ones allowed the team to identify barriers or obstacles to be overcome to avoid delays, suspensions or even cancellations of projects.

The tools used for the evaluation of the E and F axes were generated considering the local conditions, highlighting the main social, legal, environmental and economic variables present, as well as the approval processes of oil and gas projects. Both tools are only applicable to Mexico; however, they can be modified or adapted for use and implementation in other parts of the world.

The main social aspects identified that could represent a barrier to the execution of oil and gas projects within the evaluated blocks are the presence of indigenous localities or regions, rural communities, high rates of marginalization, the economic activity of the locality, availability and restriction of water use, as well as the lack of Social Impact Assessments.

Environmental approvals were highlighted as a key project risk.

Key social and environmental risks were identified to facilitate discussion with key stakeholders.

Future work could be undertaken to identify the impacts and relationships with the SDGs for each block or groups of them, according to the document: "Mapping the oil and gas industry to the Sustainable Development Goals: An Atlas[14]" (UNDP, the International Finance Corporation (IFC) and IPIECA, the global oil and gas industry association for environmental and social issues, partnered to develop this Atlas), prioritizing the analysis and development of the resources with considerations on energy security, climate change and economic growth among others.

The results of the pilot project support the objective of UNFC as a standardized system that helps to link and analyze the SDGs. UNFC can serve as an effective platform to make decisions on energy policy and regulatory actions and will facilitate the interaction with other government institutions and stakeholders.

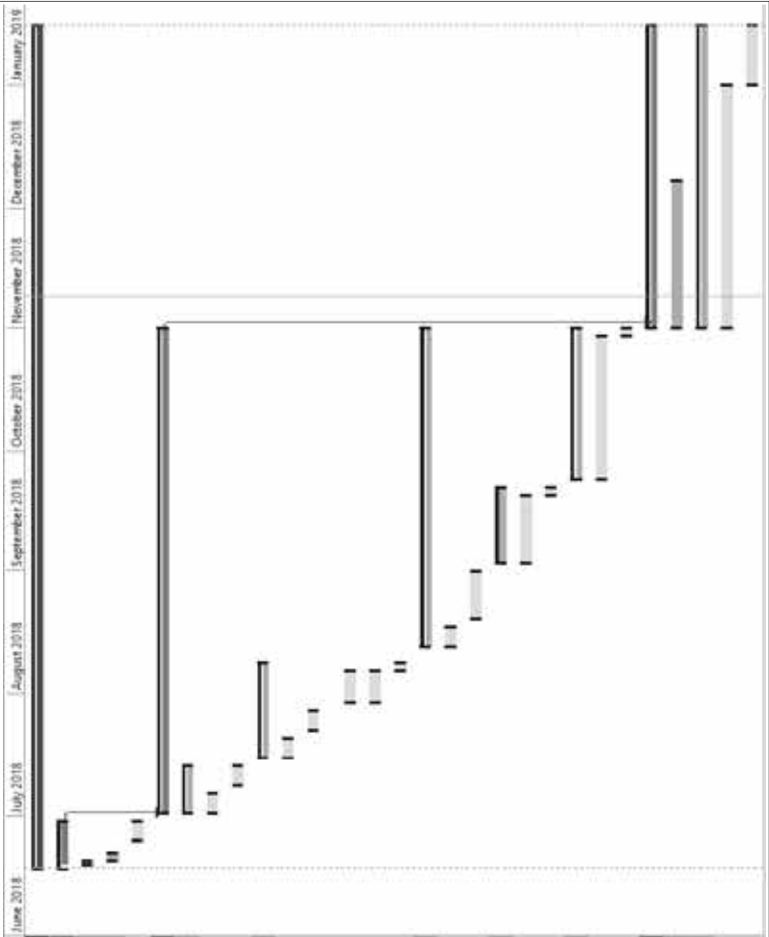
Acknowledgements

The technical review of the case study was carried out by Karin Ask, Equinor, Norway; Alistair Jones, Chair, Technical Advisory Group of the Expert Group on Resource Management; Barbara Pribyl, Santos Ltd, Australia; and Claudio Virues, Alberta Energy Regulator, Canada. The comments of the review team have been included.

Bizagi Modeler, QGIS, ArcMap and Microsoft Office Suite were used in this project.

14 UNDP, IFC, IPIECA, 2017, http://www.undp.org/content/undp/en/home/librarypage/poverty-reduction/mapping-the-oil-and-gas-industry-to-the-sdgs--an-atlas.html

Annex: Detailed Project Schedule



Name of Task	Start	Finish	Duration
Pilot Test	Mon 18/06/18	Tue 15/01/19	152 days
Phase 1. Forum and Workshop	Mon 18/06/18	Fri 29/06/18	10 days
Forum	Tue 19/06/18	Tue 19/06/18	1 day
Workshop	Wed 20/06/18	Thu 21/06/18	2 days
Phase 1 Outcomes	Mon 25/06/18	Fri 29/06/18	5 days
Phase 2. Implementation of UNFC	Mon 02/07/18	Wed 31/10/18	88 days
Work Strategy Redefinition	Mon 02/07/18	Fri 13/07/18	10 days
Work Team Definition	Mon 02/07/18	Fri 06/07/18	5 days
Work Program Definition	Mon 09/07/18	Fri 13/07/18	5 days
Blocks and Variables Definition	Mon 16/07/18	Wed 08/08/18	18 days
Blocks Selection Criteria	Mon 16/07/18	Fri 20/07/18	5 days
Blocks Selection - Data Compilation	Mon 23/07/18	Fri 27/07/18	5 days
Projects Identification	Mon 30/07/18	Mon 06/08/18	6 days
Variables Definition	Mon 30/07/18	Mon 06/08/18	6 days
Visit UNDP Expert (Review 1)	Tue 07/08/18	Wed 08/08/18	2 days
Projects Evaluation and Classification	Mon 13/08/18	Wed 31/10/18	58 days
Classification Tools Creation	Mon 13/08/18	Fri 17/08/18	5 days
Projects Classification	Mon 20/08/18	Fri 31/08/18	10 days
First Classification Report	Mon 03/09/18	Fri 21/09/18	15 days
Report Generation	Mon 03/09/18	Wed 19/09/18	13 days
Results Presentation (Review 2)	Thu 20/09/18	Fri 21/09/18	2 days
Final Classification	Mon 24/09/18	Wed 31/10/18	28 days
Comments Consideration	Mon 24/09/18	Mon 29/10/18	26 days
Visit UNDP Expert (Review 3)	Tue 30/10/18	Wed 31/10/18	2 days
Phase 3. Conclusions and Recommendations	Thu 01/11/18	Tue 15/01/19	54 days
Final Report Development	Thu 01/11/18	Fri 07/12/18	27 days
UN Paper Development	Thu 01/11/18	Tue 15/01/19	54 days
UN Paper Generation	Thu 01/11/18	Mon 31/12/18	43 days
UN Sending	Tue 01/01/19	Tue 15/01/19	11 days

Glossary

Agrarian cores. An organized population that has been awarded with an area that is under a special legislation that promotes communal land use without having direct ownership, or ability to transfer it to third parties. Usually, this land is used for farming.

Entitlement. The legal act through which the Federal Government grants exclusively to PEMEX or any other state-owned company, the right to carry out activities of exploration and extraction of hydrocarbons in a specific area and duration.

Environmental Impact Assessment (MIA). This is the document where it is made known (by the operator), based on studies, the significant and potential environmental impact that a project or activity would generate, as well as the way to avoid or mitigate it if it is negative.

Expert Group on Resource Management (Expert Group). Formerly known as the Expert Group on Resource Classification and prior to that the Ad Hoc Group of Experts on Harmonization of Fossil Energy and Mineral Resources Terminology. The Expert Group is responsible for the promotion and further development of the United Nations Framework Classification for Resources (UNFC) and the United Nations Resource Management System (UNRMS).

Marginalization Index. This is a multidimensional indicator that measures the intensity of deprivation suffered by the population through nine forms of exclusion grouped into four dimensions: education, housing, population distribution and monetary income.

Ministry of Energy (SENER). SENER is the institution in charge of conducting the country's energy policy, within the current constitutional framework, to guarantee a competitive, sufficient, high quality, economically viable and environmentally sustainable supply of energy required for the development of national life.

National Commission for the Development of Indigenous Population (CDI). The mission of CDI is to be an institution that guides public policies for the integral and sustainable development of indigenous peoples and communities, which promotes respect for their cultures and the respect of their rights.

National Hydrocarbons Commission (CNH). CNH regulates the upstream sector of hydrocarbons in Mexico. Its mission is to regulate in a reliable and efficient way the exploration and extraction of hydrocarbons in Mexico to promote investment and economic growth.

National Water Commission (CONAGUA). The mission of CONAGUA is to manage and preserve in quantity and quality the national waters and their inherent public goods, with the participation of users and society, and with the linking of the management of the three orders of government, to achieve the sustainable use of the resource.

Safety and Environmental Management System (SASISOPA). This is the integral set of interrelated and documented elements whose purpose is the prevention, control and improvement of the performance of a facility or group of them, in terms of industrial and operational safety and environmental protection.

Safety, Energy and Environment Agency (ASEA). The mission of ASEA is to guarantee the safety of people and the integrity of the environment with legal, procedural and costs certainty in the hydrocarbon sector. It is part of the Ministry of Environment and Natural Resources (SEMARNAT).

Social Impact Assessment (EVIS). This is the document that contains the identification of the communities and villages located in the area of influence of an energy sector project, as well as the identification, characterization, prediction and assessment of the consequences to the population that could be derive from it, the mitigation measures and the corresponding social management plans.

Study of Environmental Base Line (LBA). The study (made by the operator) that identifies the environmental conditions in which the habitats, ecosystems, elements and natural resources are found, as well as the relations of interaction and environmental services existing in the area, prior to the beginning of the oil and gas activities.

Uranium projects of Argentina according to UNFC: An update

Prepared by Luis López, National Atomic Energy Commission of Argentina (CNEA); Harikrishnan Tulsidas, United Nations Economic Commission for Europe (UNECE); and Adrienne Hanly, International Atomic Energy Agency (IAEA).

Introduction

This case study provides an updated classification of Argentina's uranium resources according to the United Nations Framework Classification for Resources (UNFC) [1]. This assessment was made by applying the UNFC Bridging Document between the Organisation of Economic Co-operation and Development (OECD)-Nuclear Energy Agency (NEA)/ International Atomic Energy Agency (IAEA) classification scheme and the specific Guidelines for Application of the UNFC for uranium and thorium resources [2] to uranium and associated critical materials projects/resources in Argentina.

This paper was based on a case study previously described in 2014 and published in 2015 [3] and presents a comprehensive vision of uranium projects, updated resources, and project statuses including exploration projects and non-conventional sources for the supply of nuclear raw material in Argentina.

Nuclear Power Generation in Argentina

Argentina has three heavy water reactors, namely Atucha I with a gross electrical power of 362 MWe that is fuelled with Slightly Enriched Uranium (SEU) (0.85% U-235), and Embalse (CANDU) and Atucha II, both based on natural uranium fuel with generation capacities of 648 MWe and 745 MWe, respectively. At present, Atucha I and Atucha II, located in Buenos Aires Province, and Embalse, located in the Province of Cordoba, are in commercial operation. It should be noted that Embalse was out of the generation system for two years for successful refurbishment tasks designed to extend its useful life for a term of 30 years, which included an increase in its power by an additional 35 MWe [4].

With an approximate installed capacity of 1.7 GWe, nuclear power sources have a 10% share in the national electricity mix, with natural uranium requirements of about 220–250 tU per year.

Additionally, at the Atucha site the Argentine prototype small modular reactor CAREM (27 MWe net/32 MWe gross) is under construction and is planned to come into criticality in 2022-2023. There is the potential to increase the scale of the unit to a higher capacity of possibly 120 MWe, while the commercial nuclear power plants would be made of four units accounting for 480 MWe.

As part of nuclear development in Argentina, China and Argentina signed an agreement for the installation of the fourth (CANDU Pressurized Heavy Water Reactor) and fifth (Hualong One Pressurized Water Reactor) nuclear power plants in the country, with construction planned to start in 2018 and 2020 respectively. The committed investments were around USD 15 billion, with China contributing 85% of the required financing. This programme has been delayed and partially canceled and it is expected to be reformulated and renegotiated in the near future.

Based on various nuclear growth scenarios, it is estimated that by 2030 there will be a generation capacity of some 3,092 GWe for the reference case. In that scenario, the raw material needs would be 486 tU, which is about double current consumption.

Legal Framework of Nuclear Minerals in Argentina

The Argentine Mining Code, in force since 1997, considers uranium and thorium as nuclear minerals; their associated resources belong to the Provincial States under the provisions of the National Constitution (1994) [5].

Among other considerations, the Argentine Mining Code in its Title Eleventh, so-called “On Nuclear Minerals”, specifies:

- Nuclear minerals can be explored and exploited under a legal licence by a Competent Provincial Authority.
- The National Atomic Energy Commission (CNEA), like any other natural or artificial person, may prospect, explore and mine nuclear minerals under the general provisions of the Mining Code.
- CNEA is empowered to make a decision on the mining or retiring of Sierra Pintada (Province of Mendoza) and Cerro Solo (Province of Chubut) nuclear deposits.
- The legal owner of mines containing nuclear minerals shall supply the State information on the reserves and production of these minerals and concentrates.
- The National State shall have the first option to purchase, under usual market terms, nuclear minerals, concentrates and by-products produced in the country to meet the domestic needs.
- Exports of uranium and thorium minerals, concentrates and by-products shall call for the prior consent of the State, and the internal supply and control of the final destination of export materials shall be guaranteed.

In general terms, and as for the rights recognized and conferred by the Argentine Mining Code, mines are divided into three categories:

1st: Mines whose soil is an accessory and which belong exclusively to the State and which may only be tapped or exploited under a legal license which is granted by a competent authority.

2nd: Mines which, based on their importance, are preferentially licensed to the owner of the soil; and mines which, as a result of the conditions of the deposits, are used on a shared basis.

3rd: Mines which belong solely to their owner and which cannot be tapped or exploited by anybody without their owner´s consent, except in case of public benefit or good.

With regard to the metals treated in this contribution, according to the above classification/three categories, the deposits of uranium (U), vanadium (V), thorium (Th), rare-earth elements (REE), copper (Cu) and phosphates associated with different geological types of uranium deposits would fall into the first category, while the eventual metal recovery from workings and tailings of former mining works would correspond to the second category. Under the provisions of the Mining Code, individuals are empowered to search for mineable deposits, operate mines and dispose of mines as owners.

Also, it should be noted that 8 of the 23 Argentine provinces have legislation in place that restrict metal mining, which needs to be taken into account when studying the socio-economic viability of the projects. The currently identified uranium resources are mostly located in the provinces of Chubut and Mendoza, where legislation is in place that restricts uranium production. In Chubut, open-pit mining is not allowed, and projects need to wait for the implementation of provincial territory zoning provisions of Law 5001/2003, as well as the introduction of a mining regulatory framework for this jurisdiction [6].

Any new operation of uranium mining and processing in Mendoza Province will require significant changes to the legislation, such as permitting the use of sulphuric acid, among other chemicals, which is currently forbidden by Law 7722/2007 [7]. It must be noted that after many years of discussion, in 2015 the Supreme Court of Justice of Mendoza confirmed that the rule that prohibits the use of chemical substances in the development of metal mining is constitutional [8].

Moreover, in San Luis Province, Law 634/2008 prohibits the use of chemicals in all forms and stages of metalliferous mining [9], while in Cordoba Province, all activities related to metal mining, and those specifically associated with a uranium and thorium production cycle, are forbidden by Law 9526/2008 [10].

Comprehensive Resource Recovery Approach

The main geological types of uranium deposits in Argentina are intrusive, granite-related, volcanic-related, sandstone, surficial and phosphate [11] [12]. In most of these deposits, not only is the uranium resource of importance, but additionally, other critical minerals of potential value may co-occur, such as Rare Earth Elements (REE), niobium (Nb), tantalum (Ta), molybdenum (Mo), vanadium (V), phosphate (P), and thorium (Th). In case of future commercial operation of these projects, a comprehensive extraction design could potentially recover multiple valuable resources in the same process flow, which could be sold in the market as required or could be stored for future use, as in the case of Th.

Thus, comprehensive resource recovery approaches can manage the production of U (as primary, co- or by-product) and other critical material resources in an integrated, multi-target manner. This approach is likely to achieve considerably higher aggregate recovery rates than a management strategy that targets only a single resource and essentially treats all other co-occurring resources as if they were contaminants or wastes. Furthermore, on the sustainability side, the premise is simpler—once the decision to break ground is taken, the ethical imperative to maximize the return from that activity is grounded in the well-established fundamentals of sustainable development [2].

Argentina’s Uranium Resources and Associated Critical Materials and Application of UNFC

Main Uranium Projects

Historically, uranium resources in Argentina have been classified and reported according to the NEA/IAEA classification and resource reporting scheme. This system consists of a biaxial classification that considers the degree of geological knowledge and the production costs of uranium concentrate. Additionally, considerations about the status of the production centre related to the resources are taken into account [13]. Since 2003–2004, junior mining companies that set up uranium projects have reported exploration results and resources through the Canadian National Instrument 43-101 (NI 43-101).

More recently, resources for nuclear fuel and related projects have been assessed under the United Nations Framework Classification for Resources (UNFC). This assessment has allowed documentation and reporting of the uranium resources of the country, which includes information on the project maturity, consideration of social and economic issues, analysis on resource progression and regulatory, legal and market conditions imposed by governments and markets, domestic demand, technological and industrial progress and the ever-present uncertainty [3].

In 2017, CNEA reported about 19,000 tonnes of uranium (tU) as identified resources (Reasonably Assured Resources + Inferred Resources) for the production cost category <130 USD/kgU in the OECD-NEA/IAEA classification scheme [17]. Approximately 19,370 tU of Canadian National Instrument 43-101 (NI 43-101) certified resources have been reported in recent years by the public mining company named U3O8 Corporation [14] [15] and Blue Sky Corporation [16] [17] and the private mining company named UrAmerica Limited [18].

The total uranium resources of Argentina are thus 38,740 tU in the aforementioned Identified Resources category and belong to seven projects whose main characteristics are described in Table 1. It can be highlighted that if the higher production cost category of <260 USD/kgU is considered, there is no substantial variation and Identified Resources account for 39,790 tU [19].

Table 1. **Uranium Identified Resources in Argentina according to the NEA/IAEA Classification Scheme (as of 1 January 2019)**

Deposit (Ownership)	*Type*	*RAR tU ≤ USD 130/kgU*	*IR tU ≤ USD 130/kgU*
Sierra Pintada (CNEA)	Volcanic-related	3,900	6,110
Cerro Solo (CNEA)	Sandstone	4,420	3,760 (4,810)*
Don Otto (CNEA)	Sandstone	180	250
Laguna Colorada (CNEA)	Volcanic-related	100	60
Laguna Salada (U3O8 Corp)	Surficial	2,420	1,460
Meseta Central (UrAmerica Ltd)	Sandstone	–	7,350
Ivana (AG) (Blue Sky Corp)	Sandstone/suficial	–	8,730
Sub Total		***11,020tU***	***27,720 tU (28,770 tU)****
Total			***38,740 tU (39,790 tU)****

RAR – Reasonably Assured Resources
IR – Inferred Resources
* tU for production cost category of <260 USD/kgU

For the uranium resources of different projects of CNEA and mining companies, the criteria of UNFC concerning social and economic viability (E), technical feasibility (F) and geological knowledge (G) were redefined and updated at the Sub-Category level and then grouped into the major Classes considered in UNFC.

Cerro Solo Project

In the Cerro Solo Deposit (Chubut Province), the tonnage and grade estimated are expected to ensure sustained uranium production in the future. Since the discovery of this blind deposit in 1971, exploration and evaluation drilling programmes have amounted to 100,700 metres of drilling. The deposit occurs in Cretaceous fluvial sandstones and conglomerates of the Chubut Group. In this paleochannel structure, the mineralized zones are 0.5-6 metres wide and 50-130 metres deep [20].

The identified resources are 9,230 tU at approximately 0.1 to 0.2 per cent U, which are included in the <US$260/kg U production cost category (cost category as applied in [19]). The reported resources correspond to the most studied mineralized bodies, and the available geological knowledge indicates the excellent potential to develop new uranium resources in this mining property.

In connection with pre-feasibility studies, in 1997 CNEA retained NAC International to complete the Preliminary Economic Assessment (PEA) of the Cerro Solo uranium deposit, which included a geological model revision and ore reserves estimate, consideration of mining and milling methods and their costs, cash flow, and risk analysis [21].

Recently, a programme to complete the feasibility study of the Cerro Solo Deposit was formulated. Several laboratory-scale tests have been carried out to determine the most economically competitive milling process. Also, conceptual engineering design has been defined based on geological modelling, tonnages, grade, geotechnical, geostructural and hydrogeological data. Currently, governmental and private funds are intended to be used to carry out the basic engineering of both the mining operation and also the processing plant. Also, the social-environmental baseline is being surveyed in cooperation with national universities and research councils.

Regarding potential co- and by-products, the recovery of coexisting molybdenum has not been examined by a systematic evaluation; inferred resources amount to 870 tMo. Although technical viability to recover of molybdenum has not been defined, the potential socioeconomic benefits of income from this process justify further research and evaluation in both the extent of molybdenum resources and its recovery. Also, anomalous assays of rhenium (up to 50 ppm Re) were detected in Cerro Solo, and its potential should be the subject of further research.

Besides technical considerations, a Chubut Provincial Law 5001/03 that prevents open-pit mining is still in effect, and mining projects must wait for the introduction of a mining regulatory framework for this jurisdiction, as well as the Chubut provincial territory zoning provisions of the law above. It is thought that the proximity of Cerro Solo to Navidad project—one of the most significant silver projects worldwide—could play a decisive role in establishing provincial zones for mining activities.

Therefore, under UNFC, Cerro Solo U project is considered as a “Potentially Commercial Project” within the Sub-class “Development Pending” with categories E2, F2.1, G1-3. The quantities of molybdenum are currently classified separately as “Non-Commercial Project” with “Development Unclarified” and categories E3.2, F2.2 and G3. With additional, comprehensive recovery studies and data availability, these quantities may be augmented and transferred to higher UNFC categories and merged with the U project. In the event of future U production, the molybdenum resources have the potential to be produced in the same process flow and could be sold in the market for multiple uses.

Laguna Salada Project

The Laguna Salada Project (Chubut Province) corresponds to a surficial uranium-vanadium deposit and includes the Guanaco and Lago Seco areas with 82% and 12% of the resources respectively. Mineralization occurs within 3 metres from the surface in soft, unconsolidated gravel. Uranium identified resources have been evaluated at 3,880 tU at grades ranging between 55 and 72 ppm U, while vanadium identified resources have been assessed at 21,330 tV at grades ranging from 308 to 330 ppm V.

The NI 43-101 Preliminary Economic Assessment (PEA) for the Laguna Salada Deposit was recently issued and it reinforces the U-V comprehensive recovery concept. Test work shows that the removal of the pebbles and coarse sand from the gravel increases the uranium grade by 11 times from the in-situ grade of the Guanaco gravels and seven times those of the Lago Seco gravels. Vanadium grades in the residual fine material increase 3.7–3.8 times relative to the grade of the in-situ gravel from Guanaco and Lago Seco, respectively. The fine material being fed to the hydrometallurgical plant would then have grades of 720-740ppm U on average. These grades are similar to the mill feed grade of operating surficial uranium deposits in other parts of the world. Fine material from the gravel would have an average grade of 1,310–1,330ppm V. Uranium and vanadium would be extracted from the fine material by alkaline leach, in which the reagents are sodium carbonate (washing soda) and sodium bicarbonate (baking soda) at an optimal temperature of 80°C [22].

Among other issues, the uranium business model of the company takes into account in its customer segment both domestic uranium sales in-country for fuel fabrication and vanadium sales to steel or battery/renewable clean energy.

The Laguna Salada U-V project is currently evaluated as a “Potentially Commercial Project” within the sub-class “Development Pending” (E2, F2.1, G2-3). Additional studies include augmentation of resource knowledge, proof of concept uranium and vanadium extraction from bulk samples, and pilot plant test work to refine operational and capital cost estimates in advance, in combination with better both market conditions and legal framework at Chubut province. If these studies prove economically viable, the project could move to the UNFC Class “Commercial Projects”.

Amarillo Grande Project (Ivana)

Blue Sky Uranium is actively exploring its Amarillo Grande (AG) Project in the Central Rio Negro Province. Defined mineralization at Amarillo Grande is found in three target areas (Ivana, Anit, and Santa Barbara) along a 145 kilometre trend. Mineralization at all three areas occurs at or very near the surface, in unconsolidated to weakly-cemented host rocks.

Surface exploration, ground geophysics, pit sampling and more than 9,000 metres of reverse circulation (“RC”) drilling were completed at the project since the beginning of the revitalized work program in 2016. In 2018, the Company announced its first mineral resource estimate for the Amarillo Grande Project, on the Ivana uranium-vanadium deposit. The Ivana deposit has characteristics of both surficial and sandstone-hosted style of deposits.

In 2019, the first PEA for Ivana, as well as an updated resource estimate was announced. The inferred resource estimate includes 8,730 tU at a grade of 0.031 %U and 2,920 tV at a grade of 0.011 %V (100 ppm uranium cut-off). The PEA for Ivana includes a $135M NPV with a 29.3% internal rate of return (IRR), for a surficial mining operation with a simple 2-step processing and 13 years of uranium and vanadium production [17].

The Amarillo Grande (Ivana sector) U-V project is currently evaluated as a “Potentially Commercial Project” within the sub-class “Development Pending” (E2, F2.1, G3).

Sierra Pintada Project

The Sierra Pintada Uranium Deposit (Mendoza Province) belongs to the volcanic-related model, where mineralization is localized in Permian formations associated with synsedimentary acid volcanism [23, 24].

The level of uncertainty in the estimation of remaining resources in Sierra Pintada is medium to high. The resources are evaluated to be 10,010 tU Recoverable Identified Resources at a production cost below US $130/kg U [19]. This deposit has been the focus of the most significant uranium production in the country, with a total of 1,600 tU produced from 1975 to 1997 after which the mining-milling facility was put on standby status for economic reasons. Therefore, the feasibility has been partially demonstrated by the fact that this deposit was previously in operation using an acid heap-leaching mining method. Other alternatives have been considered for possible future production, including the use of alkaline leaching [25], bioleaching [26] and vat leaching [27]. Also, given the possibility of the reopening of the mining-milling complex all available data have been processed to redefine the geological model and formulate a more suitable mining design.

Current activities at the complex are mainly focused on remediation of former mining and milling liabilities and radiological and environmental monitoring of the site and surrounding areas. Environmental liabilities include mine water, solid waste, precipitates, tailings, low-grade material, and barren material. The monitoring programme comprises air radon surveys, soil sampling, and stream and groundwater studies.

Although this project would be the most viable technical alternative for a return to the production of uranium concentrates in the country, the lack of social licence including the provisions of Law 7722/2007 previously discussed makes it inconceivable to put this project into operation in the foreseeable future. Under UNFC, Sierra Pintada was assessed as a "Potentially Commercial Project" within the sub-class "Development On Hold" (E2, F2.2, G1-3). No other critical materials have been associated with this project.

Meseta Central Project

Meseta Central Project (Chubut Province) is located in the vicinity of Cerro Solo and comprises the Graben, Plateau West and Plateau East deposits. Uranium mineralization is hosted by siltstones, sandstones and conglomerates of the fluvial and lacustrine Cretaceous-aged Los Adobes Formation. Mineralized layers lie between 40 and 140 metres beneath the surface, are flat-lying or very gently dipping, and are up to 15 metres in thickness. The total inferred resources for the project are 7,350 tU at an average grade of 260 ppm U. These resources were based on data from two drilling campaigns comprising 178 boreholes for a total of 21,450 metres of drilling. Boreholes were mostly on a 200 by 200 metres grid. As reported by UrAmerica Ltd., about 75% of the uranium resources evaluated occur in confined aquifers layers [28]. Therefore, further geological and hydrological studies will be undertaken to determine amenability to in-situ leaching mining. The results of these studies could play a relevant role regarding the socio-economic viability of this project. Hence, the Meseta Central project is classified as "Non Commercial Project" with Sub-class "Development Unclarified" (E3.2, F2.2, G3).

Don Otto Project

The Don Otto (Salta Province) uranium deposit is a tabular U-V subtype hosted in sandstones of Cretaceous Yacoraite Formation of the Salta Basin; this basin covers approximately 150,000 ha, and is also known for its oil and gas potential. Don Otto was in operation from 1963 to 1981 and produced 201 tU at 0.1 to 0.2 per cent U grade [29, 30].

When mapping to the E, F and G axes, the Don Otto U project is classified as a "Non-Commercial Project" with Sub-class "Development Unclarified". However, it should be highlighted that because this deposit was previously in operation and current exploration/evaluation studies yielded very encouraging results; it could be possible in the future for the project to move to a higher UNFC class.

Additionally, enlargement of the mining property and resource augmentation are considered key factors to ensure project feasibility. A comprehensive study that includes updating environmental impact assessment (EIA) reports, block-leaching research and development studies, feasibility of underground extraction, use of a mobile ionic exchange plant, hydrogeological studies to define in situ leaching amenability, vanadium resource evaluation and extraction feasibility, and uranium recovery from the former heaps and remediation of the site, are all factors that would aim to increase project viability [31, 32].

Despite the high vanadium content recorded in the Don Otto deposit as well as other deposits in the Salta Group basin, this metal has not been subject to systematic studies, and the resource estimates have a low level of certainty. Therefore, with respect to vanadium resources, the Don Otto project can be classified as an "Exploration Project".

Laguna Colorada Project

Laguna Colorada (Chubut Province) deposit belongs to the volcanic-related type, synsedimentary subtype, and is located in the San Jorge Basin (Cretaceous) with evaluated resources of 160 t U at 660 ppm U [33]. The limited resources of the project make it difficult to envisage extraction at present unless the characteristics of the ore would allow treatment in a plant that may in the future be located in the area of Cerro Solo. According to UNFC, Laguna Colorada is classified as a "Non-Commercial Project" within the Sub-class of "Development Not Viable" (E3.3 F2.3 G1-3). Due to the low geological interest, no further exploration activities have been programmed for this site.

Uranium Exploration Projects

Exploration and development of uranium resources in Argentina began in the 1950s. Since then, as a result of systematic exploration several types of deposits have been discovered: volcanic-related, sandstone, granite-related, surficial and intrusive using the NEA/IAEA uranium deposit classification scheme [12].

In recent years, junior and provincial (Chubut, La Rioja, Salta, Santa Cruz) mining companies, senior producers, and CNEA have been carrying out several uranium projects that have different degrees of development. As a general rule, most of the resources have been assessed with a low confidence level as undiscovered resources.

This case study briefly lists the main projects that have the potential to contribute to the uranium resource inventory of the country, and which are defined as "Exploration Projects" under UNFC with criteria E3.2, F3 and G4.

San Jorge Basin Projects

In the Chubut Province, the San Jorge Basin extends over about 180 000 km2 and contains Jurassic and Cretaceous continental sediments, hosting not only important uranium deposits but also oil and gas resources. Between 1974 and 1980, two small sandstone uranium deposits named Los Adobes and Cerro Condor were in operation producing 120 tU and 56 tU respectively [20].

There are several projects in this region, mainly located in the Cerro Solo, Sierra Cuadrada and Mirasol areas [34], belonging both to the Government and the private sector. The main focus of these projects is on sandstone (paleochannel, tabular, and possible roll-front) but also on volcanic-related (synsedimentary) and surficial (fluvial valley, lacustrine-playa) uranium deposits.

The exploration surveys carried out include aerial geophysics, geological prospecting, geochemical and geophysical surveys, car-borne and ground gamma-ray spectrometry, mining labours, and limited drilling estimated to total 30,000–40,000 metres.

It is understood that the integral study of the San Jorge basin is a pending matter, and to the extent that the exploratory efforts are strengthened there are very favourable expectations to define new and important uranium resources.

Neuquen Basin Project

Neuquen Basin is a vast area of about 200 000 km^2 that is also considered a sedimentary energy basin because of its potential for oil, gas and uranium. The Basin is well-known because of the Vaca Muerta Formation, one of the most significant unconventional sources of hydrocarbons worldwide.

CNEA owns two significant mining properties in the Neuquen Basin: Tres Nidos and Gobernador Ayala located in the Rio Negro and La Pampa Provinces respectively. Tertiary sandstone units are being studied in these properties with a focus on sandstone-type uranium deposits with prospects of being exploited by in-situ leaching (ISL) technology [30].

A compilation of information from the oil industry managed by the National Fuel Secretariat, including field geological reconnaissance, petrophysical determinations, and petrological studies led to the delineation of the main areas of interest. The studies in the Tres Nidos and Gobernador Ayala sites included the application of geophysical techniques of audio-magnetotelluric (AMT) and vertical electrical sounding (VES), geochemical and radon emanometry surveys, and semi-regional geological profiles surveys. To obtain more in-depth knowledge about subsoil geology and identified uranium anomalies, a drilling programme has been implemented in the Tres Nidos site covering 1,110 metres distributed in six drill holes [35].

Alipan Project

This CNEA project is located in the La Rioja Province and belongs to the granite-related type of uranium deposits and perigranitic sub-type.

The central area of interest is called Alipan, where mineralization is hosted by Middle Ordovician metamorphic rocks in discontinuous meridian belts as disseminations mainly in the oxidized/weathered zone that extends from the surface to a depth of 40–50 m. The Huaco granite (350-358 Ma, U/Pb age of monazite) located in the proximity of the deposit is considered to be the source of uranium [36].

The anomalous zone is 2.5 km discontinuous length with a maximum width of 300 m. Primary mineralization is composed of sooty pitchblende and coffinite associated with pyrite, calcite and quartz; the dominant supergene mineral is uranophane. Potential resources range from 1,500 to 2,500 tU at grades between 0.04 and 0.15 per cent U.

This site has been the subject of geological, geochemical and geophysical studies, including 2,353 metres of exploration drilling distributed over 14 drilled holes. There are also an additional 15 drill holes programmed for completion. However, these have not been executed as a result of anti-mining actions implemented by local authorities and non-governmental organizations since 2013.

Towards the north of the Alipan project, a new area of interest for uranium exploration called Lucero has been found and this is also under investigation. Preliminary results have been very encouraging, and three zones with anomalies and evidence of hexavalent uranium minerals have been defined [37].

Mina Franca Project

This project is located in the Catamarca Province and belongs to the granite-related deposit type, perigranitic subtype. Vein/stockworks occur in the Neoproterozoic-Paleozoic metamorphic basement, which encloses high potassium calc-alkaline granites. The Mina Franca Deposit is located in the periphery of the Los Ratones granite (335-340 Ma) in the Sierra de Fiambala (North-western Pampean Ranges) [38] [39].

The mineralisation is mainly controlled by north- to north-east-trending fractures zones adjacent to the west and north-west border of the pluton; the mineralization dominantly consists of pitchblende and hexavalent uranium minerals. The prognosticated resources have been evaluated in the range of 1,000–1,500 tU at a grade of 0.2–0.3 per cent U.

Geological, structural, geophysical and geochemical studies have been completed that allowed the detailed delineation of the mineralized structure at surface level and the formulation of a drilling programme.

Water and sediment geochemical sampling has been implemented simultaneously as part of the environmental baseline survey. Moreover, communication programmes related to exploration activities in the region and nuclear technology applications have been conducted in neighbouring populations and provincial governmental offices. Activities of the project have been delayed on several occasions due to social issues.

Laguna Sirven Projects

Uranium-vanadium deposits of the surficial type have been discovered in the modern covered area of Laguna Sirven (Santa Cruz Province). Mineralized layers, consisting mainly of carnotite and non-pedogenetic sulphates and carbonates, are about 30 cm wide and occur at depths between 20 cm and 3 metres, within the calcrete level that serves as cement to a polymictic matrix.

Mining properties of the area belong to Fomicruz S.E. and CNEA, with potential resources of 2,000–2,500 tU at 150 ppm U and 4,000–6,000 tVat300 ppm V [40] and to Sophia Energy S.A., with potential resources of 3,000–3,800 tU at 70 ppm U and 9,000–10,000 tV at 300 ppm V [41]. Total potential resources of the deposit, which covers an area of roughly 600 km^2, have been estimated at 5,000 tU and 14,500 tV.

Initially, the site was discovered by a regional airborne radiometric survey that was conducted by CNEA from 1978 to 1979. Since 2004, car-borne and ground gamma-ray surveys and Landsat 7 ETM+ and ASTER image processing defined areas of interest; some of these areas became the target of detailed studies by trenching and shallow drilling.

Amarillo Grande Project

Exploration continues in the aforementioned properties Ivana, Anit and Santa Barbara of the Amarillo Grande U-V project to focus on expanding the mineralization proximal to the Ivana deposit. Plans include additional pit and auger sampling, with a 6km-long Induced

Polarization ("IP") geophysical survey and up to 4,500 metres of reverse circulation (RC) drilling.

Achala Batholith Projects

The Achala Batholith in the Sierra Grande de Cordoba (Cordoba Province) is a significant intrusion of Devonian to Early Carboniferous age. In this complex, several areas of interest have been the subject of exploration studies.

Episyenites with disseminated U mineralization hosted by the peraluminous leucogranites represent one of the types of endogranitic deposits found in the Achala projects (e.g., the La Negra site).

Besides the vein-type U mineralization that has been defined, it is thought that in the Schlagintweit deposit ore exploited would correspond to the supergene zone (700 m long, 300 m wide, 60 m deep) product developed from the shallow portions of the primary hypogenetic vein and/or disseminated mineralization, which is hosted by ferruginous chalcedony breccias and controlled by magmatic shear planes. The deposit was in operation during 1982 to 1989 with cumulative production of 207 tU at an average grade of 0.0152 per cent U.

These granites and the related deposits of Achala are comparable to those from the Middle European Variscan chain and have encouraging prospects to define new uranium resources [11] [42] [43] [44]. However, all uranium projects at Cordoba Province stopped in 2008, when the Law 9526/2008 which prohibits all activities related to nuclear mining came into force [10].

Other Potential Sources of Uranium

In this section of the case study, prospective unconventional uranium from REE deposits, phosphates, porphyry copper deposits, coal and sea/lake water are summarized.

Uranium from Rare Earth Elements (REE)

Rodeo de los Molles is the largest undeveloped REE (U, Th) project in Argentina with a historical geologic resource of 5.6 Mt of mineral ore, containing an estimated 117,600 t Rare Earth Oxide (REO) and 950 tU. About 10,000 tTh were determined but with a lesser degree of confidence.

The first resource estimate was prepared in 1992, including metallurgical test work that demonstrated the amenability of bastnasite to REE extraction; this estimate was based on approximately 6,000 m of samples obtained from rotary air blast drilling. From REE mineralization exposed on the surface and to very shallow depths, typically less than 35 m of depth, a limited amount of indicated resources have been evaluated, showing 2,270 tREO at an average grade of 2.1% REO [45]. Significant quantities of uranium could be produced as a by- or co-product from this project. About 15 tU in G2 and 950 tU in G3 categories are estimated in this project.

In San Luis Province, where this project is located, Law 634/2008 prohibits the use of chemicals in all forms and stages of metalliferous mining and processing [9].

Hence under UNFC, the Rodeo de los Molles REE-U project is considered as a "Potentially Commercial Project" within the Sub-class "Development On Hold" with categories E2, F2.2, G2-3. The Th quantities are at present classified separately as an "Exploration Project" [46].

Uranium from phosphates

Systematic prospecting studies of phosphates in sedimentary basins were carried out during the 1970s by the Argentine Geological Survey. This programme delineated eighteen areas in several marine basins with phosphate potential, occupying a total area of about 640,000 km^2 [47].

Follow-up studies in recent years led to discoveries in the Patagonia Region. New data, together with published information about phosphates have been compiled, and principal phosphate occurrences and their correlation with the global phosphogenetic events have been defined (Cambrian, Ordovician, Jurassic-Cretaceous, Cretaceous-Paleocene, Miocene and Modern) [48].

At present, CNEA in cooperation with the Buenos Aires University and the National University of Salta, is carrying out the project “Assessment of the uranium potential of phosphate rocks and testing low-grade phosphate ores extraction” in the framework of cooled reactor (high-temperature gas-cooled reactor (HTGR)) applications for energy-neutral sustainable comprehensive extraction and mineral product development.

The purpose is to assess the unconventional U (Th and REE) resources related to phosphate rocks, involving studies in three sedimentary basins (Ordovician North-western Basin, Upper Jurassic – Lower Cretaceous Neuquen Basin, and Paleocene - Miocene Patagonia Basin), where low-grade phosphate mineralization and uranium anomalies (up to 135 ppm U) have been detected. Exploration and beneficiation/extraction studies are being conducted, which would allow evaluation of the economic potential of the study areas.

The IAEA Coordinated Research Project (CRP) on neutral uses of HTGRs would allow accounting for a better understanding of heat processing of low-grade phosphates. This process would help to increase the socio-economic viability and technical feasibility to set up productive projects in the long term by providing positive implications for food and energy security [49].

It should be noted that to date economic phosphate deposits have not been found nor has production been carried out in Argentina. Phosphate identified resources, which belong to restricted sites of the North-west and Neuquen Basins, have been evaluated at 1 M t of P_2O_5 with grades ranging from 2.5 to 6.3 per cent P_2O_5 [50].

However, the existence of favourable basins and different mineralization models suggest promising conditions to set up new projects to develop the phosphate potential in the country, taking into consideration the perspective of uranium recovery from this unconventional source of nuclear raw material.

At the current level of knowledge, uranium quantities linked to phosphates are evaluated as “Additional Quantities In Place Associated with Potential Deposits”, where a portion of these quantities may become recoverable in the future.

Uranium from porphyry copper

In recent years, Argentina ranged from the fourteenth to the twentieth largest copper producer in the world, totalling 180,000 tCu per year during 2004 to 2007. This production came from only one operation – a project called “Bajo de la Lumbrera” in Catamarca Province.

Other potential production projects are Agua Rica (Cu, Au, Mo, Ag) in Catamarca Province, El Pachon (Cu, Mo, Ag), Jose Maria (Cu, Au, Ag), Los Azules (Cu, Au, Ag) and El Altar (Cu, Au) in San Juan Province, San Jorge (Cu, Au)in Mendoza province, and Taca Taca (Cu, Au, Mo, Ag) in Salta Province [51].

Taking into account both the identified and potential copper resources, evaluated at 81.5 and 500 Mt of Cu respectively, additional efforts should be devoted to delineating an inventory of U tonnages and grades related to this metallogenic typology to evaluate the feasibility of uranium recovery. However, at present there are no prospects for U recovery from copper production and thus potential uranium resources are assessed as “Additional Quantities in Place Associated with Potential Deposits”.

Uranium from coal

Rio Turbio (Santa Cruz Province) is the leading coal deposit in Argentina. It has been in operation in an intermittent manner since the middle 1950s. Resources of the deposit account for 750 Mt – its carbon types range from high volatile bituminous C to Sub-Bituminous A (A.S.T.M.).

Taking into account an estimated average grade of 5 ppm U in raw material, it can be assumed that the existence of undiscovered resources is in the order of 3,750tU.

Furthermore, the carboniferous zones in Argentina extend throughout the Precordillera region and in parts of the Andean region, mainly in the provinces of Catamarca, La Rioja, San Juan, Mendoza, Neuquén, Río Negro, Chubut and Santa Cruz, however, there are also known Carboniferous formations in Salta and Jujuy.

Also, peatlands have been the object of exploratory work, especially those peatlands that are located in Tierra del Fuego, where 90,000,000 tons of mineral peat are calculated on a dry basis [52].

At present, there are no prospects for U recovery from coal in the country and potential resources constitute “Additional Quantities in Place Associated with Potential Deposits”.

Uranium from sea/lake water

Improved adsorbent materials for the recovery of uranium from sea/lake water are being investigated in Japan, United States of America and China [53]. Argentina has an extensive continental shelf, which has been recently augmented to include more than 2,800,000 km^2 by a resolution of the United Nations. In this vast area, Argentina has sovereign rights for commercial recovery of metallic-ore, non-metallic ore, and hydrocarbons [54]. According to several provincial legal restrictions to metal mining, it is important to note that the provinces shall only exercise jurisdiction over the territorial sea adjacent to their coasts, up to a distance of 3 nautical miles measured from the line of the lowest tides (Law 18.502) [55]. Also, internal salt lakes could be evaluated for comprehensive mineral recovery.

Uranium and other metals resources associated with such a project are evaluated as “Additional Quantities in Place Associated with Potential Deposits” under UNFC. It is considered that recovery from salt waters constitutes a sustainable option for uranium supply in the foreseeable future in Argentina.

Conclusions

Despite the apparent growth prospects of the use of nuclear energy for the generation of electricity in the country, which would lead to double the uranium needs by 2030, there are no immediate prospects for the provision of nuclear raw material for fuel fabrication from the local production of uranium oxide concentrates at Argentine deposits.

In 1992, due to the low prices in the international market, the import of uranium concentrates began from South Africa, a situation that gradually led to the closure of local production in 1997. Since then, there has been no production of uranium in the country, while the uranium needs from operating nuclear power plants have been met with raw materials imports from abroad (i.e. Uzbekistan, Czech Republic, Kazakhstan and Canada).

Even though the international uranium market has been depressed in recent years, the Free On Board (FOB) prices that the country has paid for the purchase of yellowcake in the spot market have not been insignificant. In large part due to the increases in transportation charges, insurance premium and taxes, in 2015 Argentina paid an average FOB price of USD 172/kgU, while the uranium price on the spot market was USD 81/kgU [56].

Furthermore, to define the economic feasibility of the CNEA's projects, uranium prices in the international market should be taken as a reference, not as a determining factor, considering that the raw material has a bearing of 5 to 7 per cent in the total cost of nuclear energy in the country, which is USD 80–100/MWh. So far, Argentina has not pursued the objective to obtain dividends from the sale of uranium in international markets, nor has it considered eventual local production by the private sector for domestic use. It would be socio-economically viable to put into production in the short term the identified resources evaluated in the country, notably the uranium available from the Cerro Solo, Laguna Salada, Amarillo Grande (Ivana), Sierra Pintada and Meseta Central projects.

One main concern is that the identified uranium resources in Argentina are mostly located in the provinces of Chubut and Mendoza. These are areas where no metallic mineral mining projects are in operation, and also, the provincial legislations markedly restrict uranium production. These factors need to be taken into account when studying the socio-economic viability of the projects. However, it could also be assumed that the mining laws could be amended as necessary if a requirement of uranium and other critical materials for clean energy projects becomes very important to Argentina.

Also, projects with a higher degree of maturity must complete technical feasibility studies for the recovery of uranium. In the case of possible future production of U, other valuable materials such as V and Mo can be assumed to be produced as a by- or co-product, contributing to the mineral sector development in Argentina. While U is used for nuclear fuel, V and Mo have critical applications, especially in the renewable energy and steel industry sectors.

At the exploration level, there are several projects within the basins of great interest in the country that are carried out by both the private sector and the government. However, as a general rule, the integral exploration at basin level has not been carried out, and the evaluated resources are meagre compared to the country's uranium potential. Also, these resources have generally been evaluated with a low level of confidence.

The most advanced exploration projects, such as Golfo San Jorge, Amarillo Grande, Alipan, Mina Franca and Laguna Sirven, have a high potential of transforming to a higher degree of maturity as classified in the UNFC system. Initially, it will be necessary to advance the delineation of resources and raise their level of confidence through preliminary economic assessments of these projects. In sedimentary environments, particular attention should be given to those sandstone-type deposits that are amenable to in situ leaching to recover uranium.

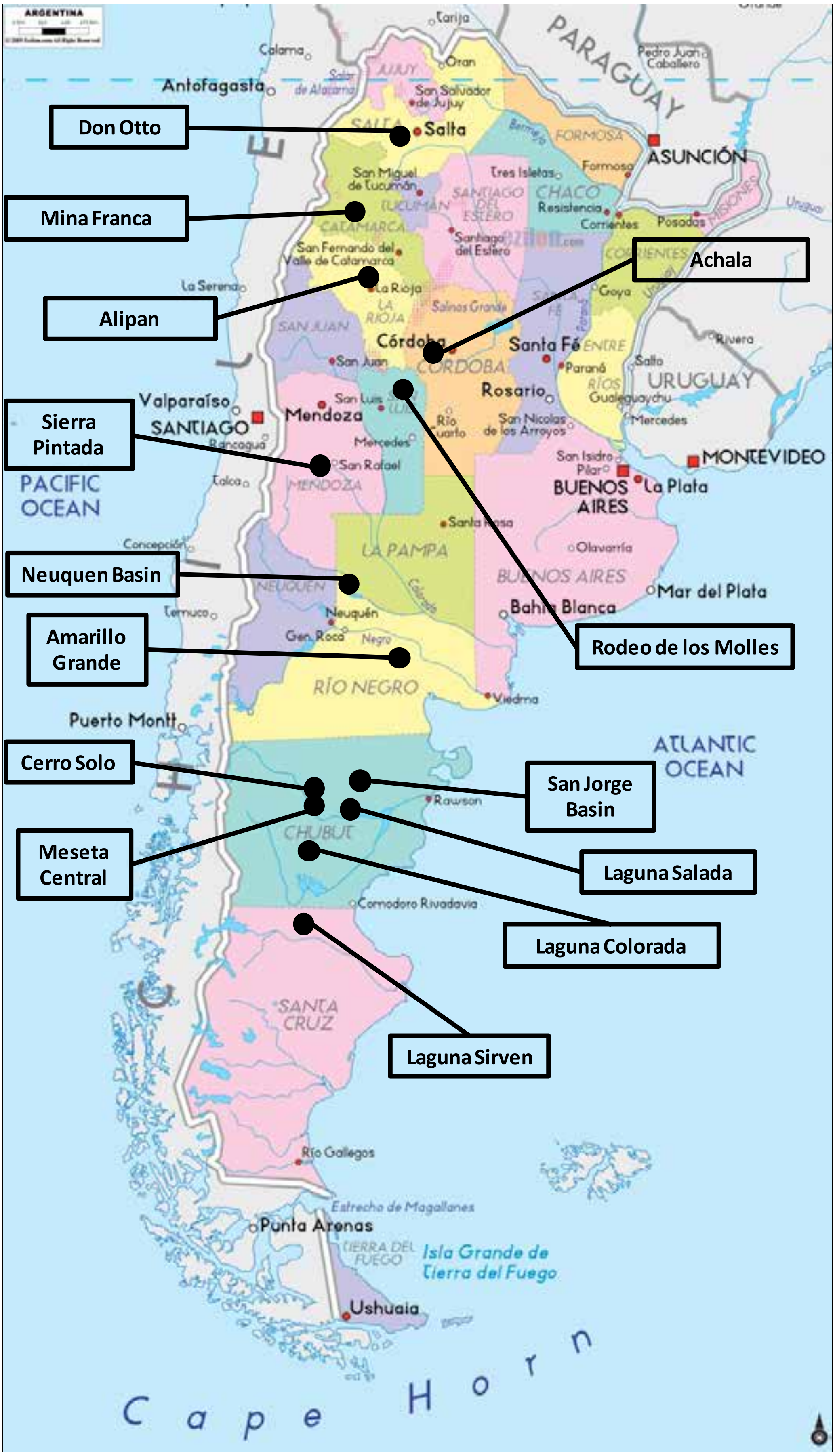
Also included in this report are some unconventional sources of uranium that could provide sustainable alternatives for nuclear supply in the foreseeable future, such as rare earth projects, phosphates, and lake and sea waters.

Currently, uranium is imported for domestic use in Argentina, which has implications for supply and energy security. For this reason, this report has tried to outline different possibilities for the sustainable domestic production of uranium, especially considering the world situation of the uranium market where the commodity-driven model seems to be weakening. In this general context, the application of UNFC contributes to both a better understanding of the availability of reliable resources in Argentina as well as demonstrate how these resources can contribute to the national nuclear energy programme and the mining sector (Table 2; Figure 1).

Table 2. **Uranium projects of Argentina classified under UNFC (Effective date: 1 January 2019)**

Project	*UNFC Class*	*UNFC Sub-class*	*UNFC Category*	*Resources*
Cerro Solo (U)	Potentially Commercial Projects	Development Pending	E2, F2.1, G1	2,420 tU
			E2, F2.1, G2	2,000 tU
			E2, F2.1, G3	4,810 tU
Cerro Solo (Mo)	Non-Commercial Projects	Development Unclarified	E3.2, F2.2, G3	870 tMo
Laguna Salada (U-V)	Potentially Commercial Projects	Development Pending	E2, F2.1, G2	2,420 tU 14,500 tV
			E2, F2.1, G3	1,460 tU 6,830 tV
Ivana (AG) (U-V)	Potentially Commercial Projects	Development Pending	E2, F2.1, G3	8,730 tU 2,920 tV
Sierra Pintada (U)	Potentially Commercial Projects	Development On Hold	E2, F2.2, G1	2,700 tU
			E2, F2.2, G2	1,200 tU
			E2, F2.2, G3	6,110 tU
Meseta Central (U)	Non-Commercial Projects	Development Unclarified	E3.2, F2.2, G3	7,350tU
Don Otto (U)	Non-Commercial Projects	Non-Commercial Projects	E3.2, F2.2, G1	100 tU
			E3.2, F2.2, G2	80 tU
			E3.2, F2.2, G3	250 tU
Don Otto (V)	Exploration Project	---	E3.2, F3, G4	Not Available
Laguna Colorada (U)	Non-Commercial Projects	Development Not Viable	E3.3, F2.3, G1	80 tU
			E3.3, F2.3, G2	20 tU
			E3.3, F2.3, G3	60 tU
San Jorge Basin (U)	Exploration Project	---	E3.2, F3, G4	Not Available
Neuquen Basin (U)	Exploration Project	---	E3.2, F3, G4	Not Available
Alipan (U)	Exploration Project	---	E3.2, F3, G4	1,500 - 2,500 tU
Mina Franca (U)	Exploration Project	---	E3.2, F3, G4	1,000 - 1,500 tU
Laguna Sirven (U,V)	Exploration Project	---	E3.2, F3, G4	5,000 tU 14,500 tV
Amarillo Grande (U,V)	Exploration Project	---	E3.2, F3, G4	Not Available
Achala Batholith (U)	Exploration Project	---	E3.2, F3, G4	Not Available
Rodeo de los Molles (REE-U)	Potentially Commercial Project	Development On Hold	E2, F2.2, G2	2,270 tREO 15 tU
			E2, F2.2, G3	117,600 tREO 950 tU
Uranium from phosphates	Additional Quantities In Place	---	E3.3, F4, G4	Not Available
Uranium from porphyry copper	Additional Quantities In Place	---	E3.3, F4, G4	Not Available
Uranium from coal	Additional Quantities In Place	---	E3.3, F4, G4	Not Available
Uranium from sea/lake water	Additional Quantities In Place	---	E3.3, F4, G4	Not Available

Figure 1. **Location of the main uranium projects of Argentina**



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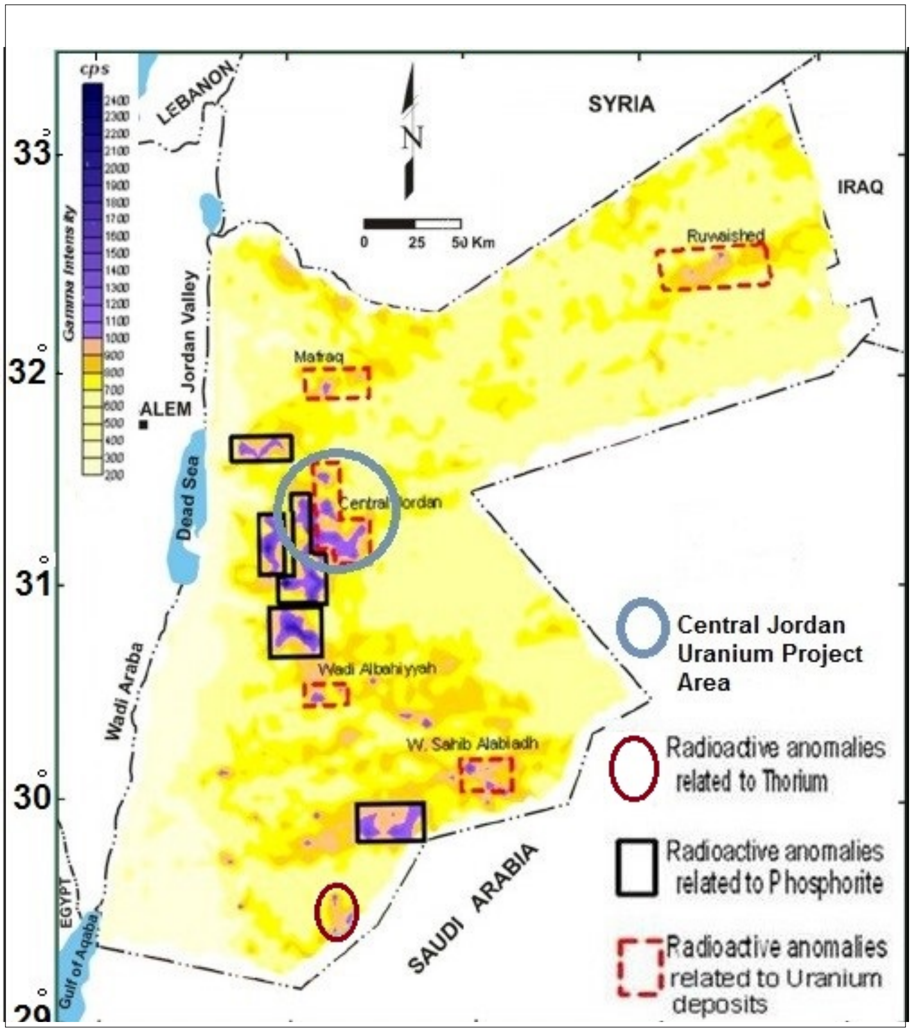
Application of UNFC for monitoring the project maturity of the Central Jordan Uranium Project

Prepared by Ahmad Al Dajani, Hussein Allaboun, Jordan Uranium Mining Company (JUMCO), Jordan; and Harikrishnan Tulsidas, United Nations Economic Commission for Europe (UNECE).

Introduction

Since 1992, uranium ore deposits have been discovered in several locations in Jordan by the Jordanian Natural Resources Authority (NRA) (Figure 1). Discoveries relied on measurements obtained from several data resources, including airborne radiometric surveys, geological surveys, radiation measurements collected by car and by foot, radon gas measurements, and from the results of sample analyses obtained from drilled boreholes and excavated trenches.

Figure 1. **Airborne Radiation Survey, Jordan**

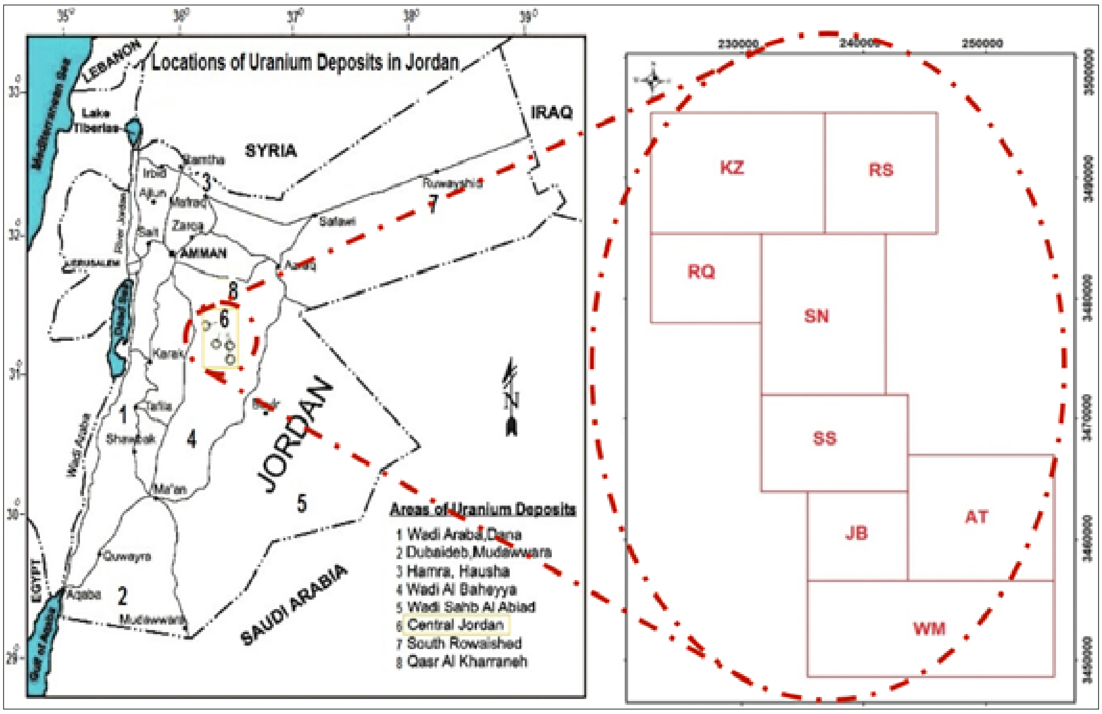


The Central Jordan Uranium Project (CJUP) is located some 60 km south of Amman along the Amman-Aqaba highway and occupies an area of 875 km² (Figure 2, left). The project's licensed area was divided into several zones, as shown in (Figure 2, right) to facilitate planning and monitoring of exploration activities.

Uranium exploration and resource estimation were performed over two phases. In Phase, I, the uranium mineralization in the CJUP that is hosted in the Muaqar Chalky Marl (MCM) Formation was estimated and reported as an Inferred Resources according to the 2012 Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves ('the JORC Code') principles (JORC 2012). Intense exploration activities were continued in Phase II with the objectives of further increasing the uranium resource base and upgrading the existing resource to the Indicated Category.

This case study demonstrates the advantages of using UNFC to monitor the project maturity of CJUP over different phases of exploration [1] [2]. The project progressed from a "Potentially Commercial Projects/Development on Hold" project in Phase I to a more mature "Potentially Commercial Projects/Development Pending" in Phase II.

Figure 2. **Location of the Central Jordan Uranium Project within Jordan and its exploration zones**



KZ: Khan AZ Zabib
RS: Rujm Al Sheed
RQ: Rujm Qiyal
SN: Siwaqa North

AT: Attarat
WM: Wadi Maghar
JB: Jabal Al Bayda
SS: Siwaqa South

Regional Geology

The general geology of Jordan can be summarized as follows:

(a) Precambrian rocks, south-western part of Jordan, comprise metavolcanic, metasedimentary, gneiss and migmatite belts.

(b) Palaeozoic rocks, southern Jordan, comprise limestone, dolomite and fine-grained sandstone.

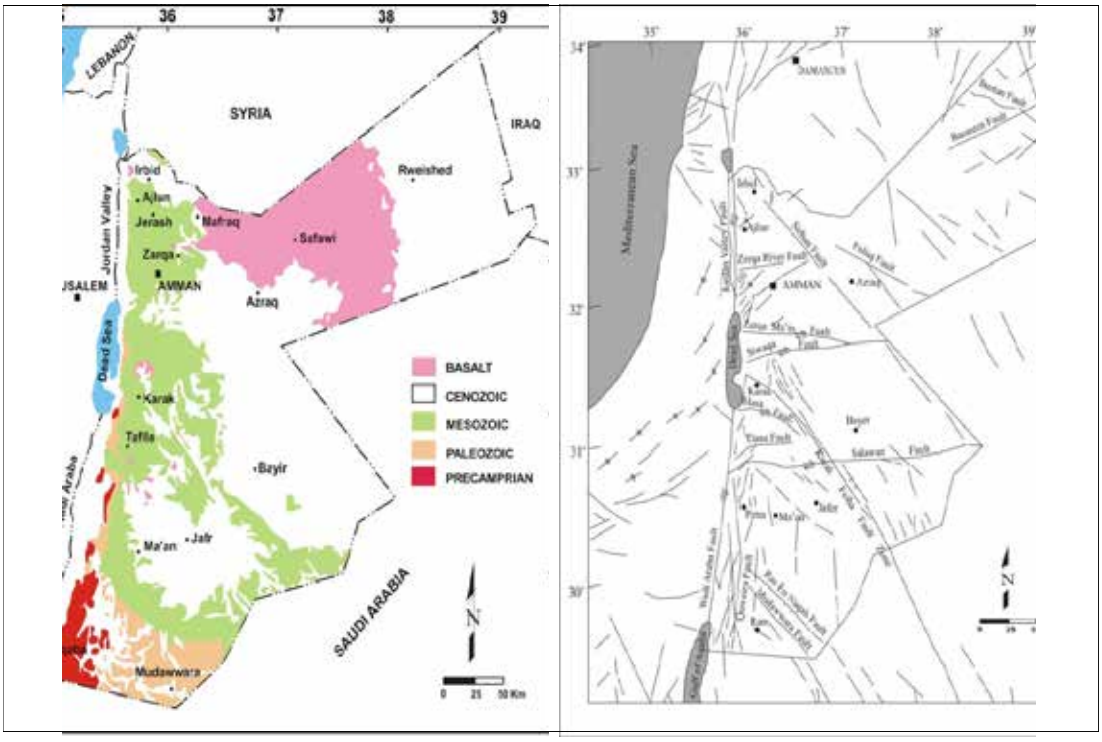
(c) Mesozoic rocks, the western and southern margin of Jordan. Upper Cretaceous rocks have the dominant distribution; they are considered sources of oil shale, phosphate, limestone, and marble.

(d) Cenozoic rocks, northeastern Jordan. These are shallow marine deposits, mainly composed of chert, limestone, chalk, marl, conglomerate and evaporates.

(e) Neogene basalts.

The general dip direction of strata in Jordan is to the north-east. The overall trend is rock formations towards the north-east (Figure 3, left) [3].

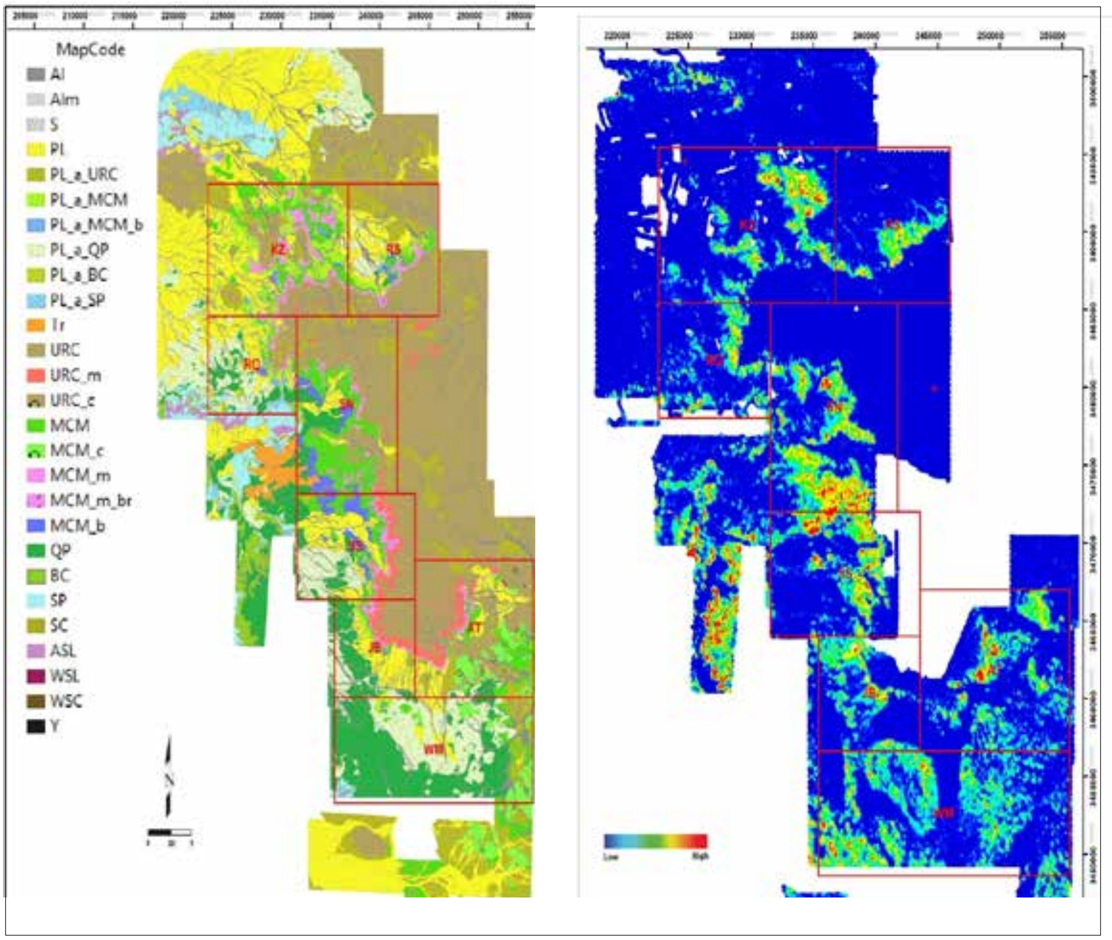
Figure 3. **General geology and structural trends of rock units in Jordan**



Geology of Central Jordan

In Central Jordan, the sedimentary sequence is composed of rocks of Upper Cretaceous (Turonian) to Paleogene in age (Figure 4, left). Locally, these rocks are overlain by beds of travertine and alluvial sediments of the Pleistocene age. The area of the CJUP was surveyed by a car-borne radiometric study (Figure 4, right). Figure 5 provides an explanation of rock units in the legend on the left.

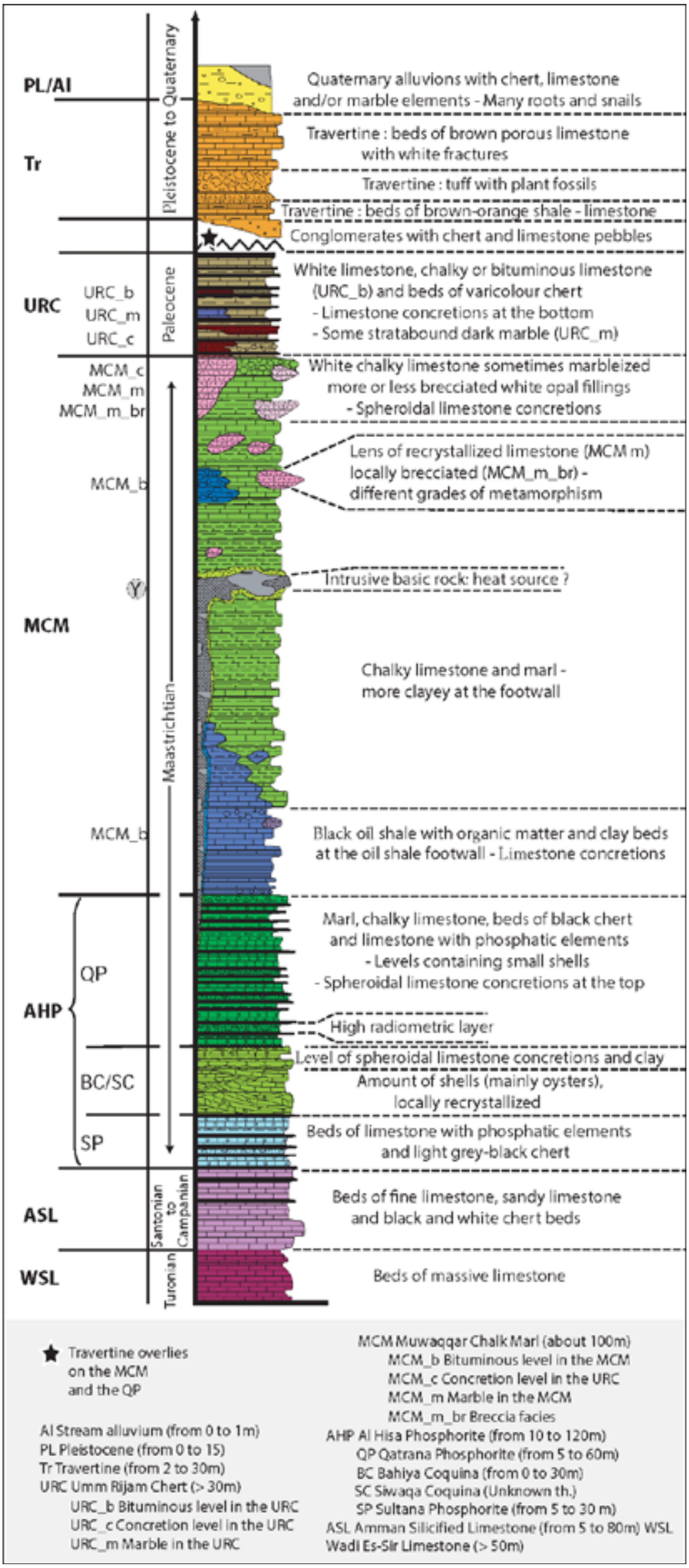
Figure 4. **Geology (left) and gamma-ray intensity (right) maps of the Central Jordan Uranium Project area**



Lithology and stratigraphy of the mineralized zone

The uranium deposits in the CJUP are primarily hosted by the Muaqar Chalky Marl (MCM) Formation of the upper Maastrichtian age, part of the Upper Cretaceous to lower Tertiary Belqa Group (Figure 5).

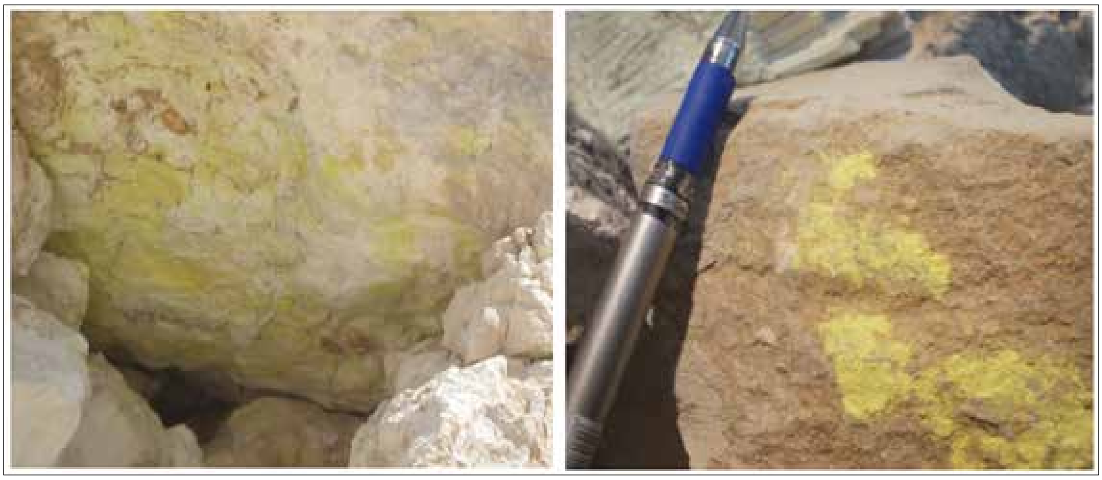
Figure 5. **Litho-stratigraphic section of Central Jordan**



Uranium mineralization occurs in two zones. Surficial uranium mineralization occurs as a thin layer from near-surface to a depth of around 4 to 5 m, and an underlying interval of mineralization occurs from 5 m to 20 m depth. The upper part of the surficial mineralization layers tends to be weathered and fractured chalky limestone (saprolite), while the lower part is more intact but constitutes fractured rock [4].

Yellow secondary uranium minerals are the dominant uranium phases, which are mainly fine-grained uranium vanadates (carnotite group). These include the minerals strelkinite and tyuyamunite [5], which occur as thin discontinuous layers on fractures and joints and as irregular patches and disseminations that impregnate the most porous and friable sediments (Figure 6).

Figure 6. **Shows of uranium mineralization (uranium vanadate minerals)**



(Photo JUMCO)

The main features of uranium mineralization in the area are:

a. The uranium deposits are surficial (average overburden is about 0.5 m) and can be mined by shallow open-pit methods, hence at relatively low cost and with less technological complications. Uranium mineralization is amenable for mining using free digging technologies while excavating trenches.

b. Infrastructure is already well established, including roads, power lines, water and energy.

c. The uranium ore requires minimal crushing due to the friable nature of the host rock.

Estimation History and Application of UNFC

Uranium quantities for the Central Jordan Uranium Project were estimated using two sets of data generated during two phases of exploration. The surficial mineralization was estimated based on the channel sample data set, and for deep mineralization, downhole gamma logs were used [5].

Quantities were estimated originally with JORC 2012 compatible standards and then transferred to UNFC using the Bridging Document between the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) Template and UNFC.

UNFC is a project-based classification system in which quantities are classified by three fundamental criteria: (1) socio-economics; (2) project feasibility; and (3) geological knowledge. Hence, UNFC provides a more granular data categorization of the quantities reported. The aforementioned Bridging Document was used to transfer quantities from the CRIRSCO Template to UNFC, together with an independent evaluation of the information based on UNFC principles (Table 1) [1].

Table 1. **Mapping of the CRIRSCO Template to UNFC [2]**

CRIRSCO Template		*UNFC "minimum" Categories*			*UNFC Class*
Mineral Reserve	Proved	E1	F1	G1	Commercial Projects
	Probable			G2	
Mineral Resource	Measured	E2	F2	G1	Potentially Commercial Projects
	Indicated			G2	
	Inferred			G3	
Exploration Results / Exploration Target		E3	F3	G4	Exploration Projects

E: Social and economic viability
F: Technical feasibility
G: Geological knowledge

Channel samples data

Starting in 2013, the Jordanian Uranium Mining Company (JUMCO) initiated a detailed exploration programme for uranium mineralization in the CJUP area using excavated trenches and chemical analysis of collected samples. These samples were the main set of data to estimate the surficial uranium mineralization (0 m to 5 m depth). By using chemical analysis for the surficial layers, a higher accuracy level was obtained, and the effects of the secular disequilibrium on the assayed results were eliminated.

Borehole data

Equivalent uranium (eU) assays obtained from the down-hole gamma logs were used in the estimation of the resources below 5 m, referred to as the deep mineralization layers within the CJUP (5 m to 20 m depth). The database for this deep mineralization contains 5,691 drilled holes carried out by the Jordanian French Uranium Mining Company (JFUMC) from 2009 through 2012.

Phase I Estimation

In Phase I (April 2014) of the project [5], the resource estimation was based on the data of 1,967 trenches and 19,685 channel samples. These trenches were excavated in several zones of the central JCUP area at grid distances of 200 m by 200 m. The surficial mineralization (0 m to 5 m depth) was constrained and separated from the deep mineralization (5 m to 20 m depth) by wireframe, and the two mineralization styles were estimated separately.

Based on the study by the international team of Competent Persons, the mineralization in CJUP was estimated and reported as an inferred mineral resource category. Central Jordan was estimated to contain approximately 269 Mt of uranium ore containing 30,857 tU at an average grade of 114 ppm U. This was estimated using a cut-off grade of 78 ppm U applied to Selective Minable Unit (SMU) blocks of dimensions 50 m x 50 m x 0.5 m. This estimate is classified as an Inferred Resource of the JORC Code (JORC 2012). These quantities are classified as G3 in UNFC.

Table 2. **Data grid spacing (m) for G axis classification of uranium resources in the central Jordan resource study area**

	Measured (JORC) / G1 (UNFC)	*Indicated (JORC) / G2 (UNFC)*	*Inferred (JORC) / G3 (UNFC)*
Central Jordan Area	25-50 x 25-50 m	100 x 100 m	200 x 200 m

To assess and categorize project feasibility, the extraction by a defined development project or mining operation was subject to further evaluation in Phase I. During this phase, preliminary studies demonstrated the existence of a deposit in such form, quality and quantity that the feasibility of extraction by a mining operation can be evaluated. However, further data acquisition and studies may be required to confirm the feasibility of extraction. Thus, this project can be classified as UNFC category F2.

Since 2009, the Jordan Atomic Energy Agency has conducted an International Atomic Energy Agency (IAEA) supported Technical Cooperation project (TC project code, JOR2009) to develop the uranium deposits of the country. This project was carried out in parallel with a nuclear energy programme that is envisaged for Jordan. It was intended that the supply of uranium fuel could be procured locally and surplus uranium, if any, could be sold on the international market. Several studies on ore characterization and extraction from a surficial carbonate ore were investigated at the laboratory level during this phase [6] [7] [8]. Since the project activities are at an early stage, justification as a commercial development will require more data and investigations, especially bulk ore testing and pilot-scale experiments focused on the efficiency of uranium extraction. The F axis sub-category was hence designated as F2.2 in this phase.

Since Jordan foresees demand for domestic utilization of uranium and also possible exports internationally, further studies would be addressed to determine the extraction and sale feasibility, which are expected to become economically viable in the predictable future. Hence, an E axis criteria of E2 has been assigned to this project in Phase 1.

In summary, the project in Phase I could be designated as E2, F2.2, G3 with calculated resources of 30,857 tU, at an average ore grade of 114 ppm U (Table 3). This project will fall in the Class of a Potentially Commercial Project and Sub-class of Development on Hold.

Table 3. **Uranium resource in the CJUP area as reported in Phase I Estimation (Effective date 2014)[a]**

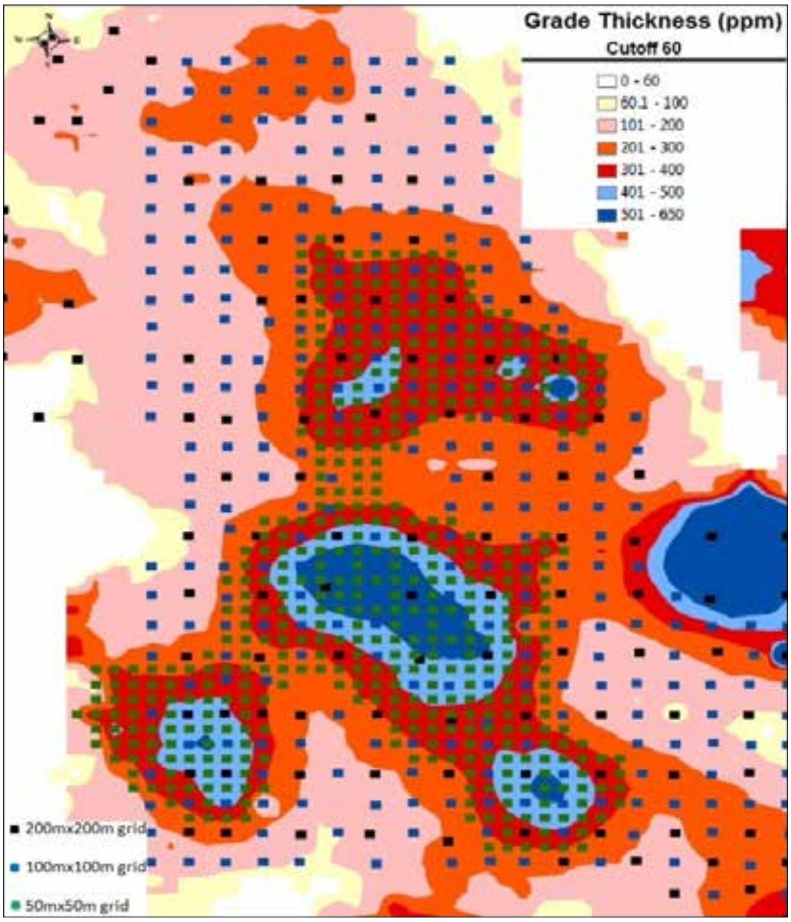
Region	*UNFC Criteria*	*Ore tonnage (Mt)*	*Grade (ppm U)*	*Metal (tU)*
Surficial Mineralization		67.5	135	9,100
Deep Mineralization	E2,F2.2,G3	201.7	108	21,757
Total		269.2	114	30,857

[a] Cut-off grade of 80 ppm U.

Phase II Estimation

To improve the categorization of the Potentially Commercial Project/Development on Hold project, JUMCO continued an intense exploration programme to further increase and refine the resource base and upgrade inferred portions of its resources to the indicated category. By the end of 2015, over 5,000 trenches had been excavated and sampled by JUMCO [9]. Detailed metallurgical tests of bulk samples, density tests, coordinate measurements, and other special studies were carried out by JUMCO.

Figure 7. **Trenching grid at the Khan Az Zabib uranium deposit**

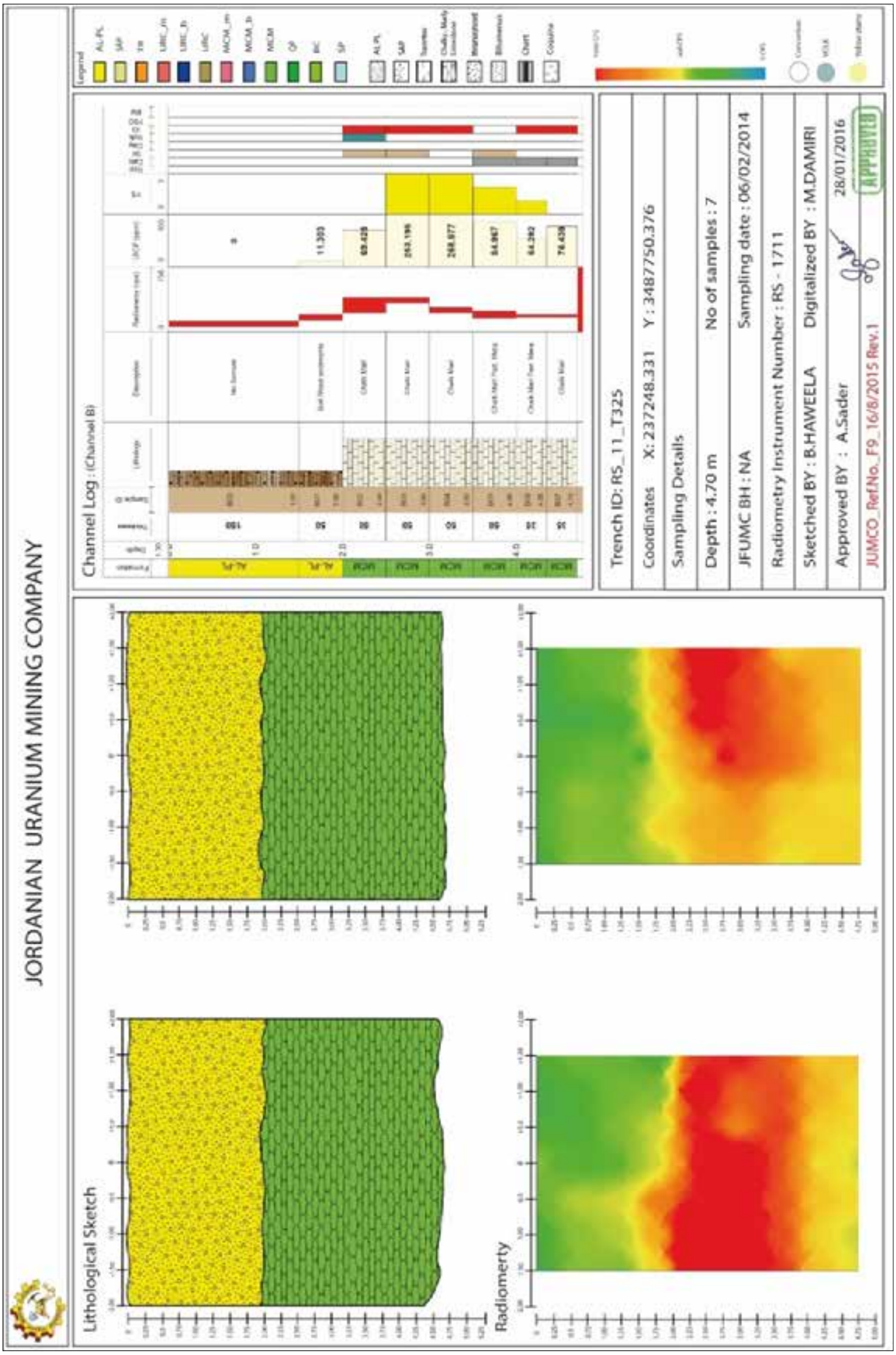


As shown in Figure 7, in selected parts of the deposits (for example, Khan Az Zabib (KZ), see Figure 2) the exploration trenching grid was infilled from 200 m x 200 m to 100 m x 100 m grids. Subsequently, additional denser 50 m x 50 m grids were adopted. However, the 50 m x 50 m infill trenches were not included in the revised mineral resource estimation.

All the data records collected for each excavated trench were compiled into one final digitized layout to represent individual trench data comprehensively. These data include lithology, radiometry, as well as general information and details for the collected channel (Figure 8).

Uranium resources for the CJUP deposit, according to JORC 2012, are estimated and reported as mineral resources in both the Indicated and Inferred categories [9]. The deposit was estimated to contain approximately 289 Mt of uranium-bearing mineralization at an average grade of 115 ppm U (136 ppm U_3O_8) containing 33,398 tU (Table 4). The estimate is based on a cut-off grade of 80 ppm U (94 ppm U3O8). Since the resource estimation included data from trenches excavated at grids spaced at 100 m x 100 m and 200 m x 200 m, the resource estimate was upgraded to G2, G3 quantities according to UNFC. Some of the remaining quantities were designated to G3. Currently, selected areas within the KZ exploration zone are being infilled with trenches at a grid of 50 m x 50 m as an attempt to upgrade the quantities to the G1 category.

Figure 8. **Example of digitalized trench data**



Extraction of uranium from the ore is being tested by an alkaline leaching process by the principle of irrigation in six-metre long columns (Figure 9). The leaching agent consists of sodium carbonate and bicarbonate. Temperature, flow and slump are monitored daily. The samples collected daily are sent to the Jordan Atomic Energy Commission for analysis. Following the conclusion of a given test, the recovery of the uranium is calculated together with any other needed elements. Metallurgical studies so far have shown that uranium is easily recovered by conventional alkaline leaching. Uranium recovery of 80 per cent to 90 per cent was achieved during the metallurgical test [10] [11] [12].

Because the feasibility of extraction by a defined development or mining operation is subject to further evaluation, the project can be designated as F2. In Phase II, project activities continue to evaluate and justify development in the foreseeable future; thus, the F axis Sub-category has been designated as F2.1.

Figure 9. **Columns used in the metallurgical testing**

(Photo JUMCO)

The uranium resources are located close to the surface and hosted by soft, friable sediments. The resource can be effectively mined using free gigging techniques with relatively low mining costs. A preliminary economic evaluation, based on extraction and sales estimates, suggests that uranium mineralization of the Central Jordan Uranium Project is expected to become economically viable in the foreseeable future. Hence the project can be designated as E2.

In summary, the classification of CJUP in Phase II has been upgraded to an E2, F2.1 and G2, G3 project, which falls in the UNFC class of Potentially Commercial Project and the Sub-class of Development Pending. The estimated quantities of uranium are 33,398 tU (39,380 tonnes U_3O_8) from ore with an average grade of 115 ppm U (Table 4) [9].

Table 4. **Uranium resource classification of Phase II Estimation (Effective date 15 December 2015)[a]**

UNFC Class	UNFC Sub-class	UNFC Criteria (E,F,G)	JORC 2012 Category	Surficial Mineralization			Deep Mineralization			Both Mineralizations		
				Tonnage (Mt)	Grade (U ppm)	Metal (tU)	Tonnage (Mt)	Grade (U ppm)	Metal (tU)	Tonnage (Mt)	Grade (U ppm)	Metal (tU)
Potentially Commercial Project	Development Pending	2,2.1,2	Indicated	20.5	148	3,058	34	113	3,830	54.5	126	6,888
Potentially Commercial Project	Development Pending	2,2.1,3	Inferred	67.2	127	8550	167.7	107	17,960	235.0	113	26,510
Total quantities				87.8	132	11,608	201.7	108	21,790	289.5	115	33,398

[a] Using cut-off of 80 ppm U (94 ppm U_3O_8)

Conclusions

In Phase I of the Central Jordan Uranium Project, the uranium quantities were estimated with a low level of confidence; thus all of the calculated resources of 30,857 tU were designated as G3 quantities. Project feasibility studies were initiated at this stage at a laboratory level, indicating the F criteria as F2.2. Since Jordan has embarked on a nuclear energy programme that envisages domestic demand for uranium as well as the sale of excess uranium on the international market, extraction and sale is expected to become economically viable in the foreseeable future. Hence a category of E2 was designated for the project. Under UNFC, the project was classified as a “Potentially Commercial Project” with Sub-class “Development on Hold”.

Since the initial exploration and laboratory investigation data were encouraging, the project was pursued with greater vigour in Phase II. More exploration data based on closer-spaced sampling intervals were generated in Phase II. Further, bulk ore testing was initiated on a pilot scale by JUMCO.

In Phase II of the study of uranium resources in the CJUP, the results of the exploration operations and the development of extraction processes are classified according to UNFC as E2 F2.1 G2, G3. On the G axis, separate quantities are designated as G2 and G3, reflecting that the estimates have moderate and low levels of confidence, respectively. Further investigations are ongoing to designate part of the quantities with a high level of confidence, i.e., G1. With regard to the project feasibility criteria, the project is designated as F2.1, where extraction is being evaluated with a pilot-scale study. Further data acquisitions and studies are required to confirm the visibility of the study.

The project is now designated as E2 because extraction and sale is expected to become economically viable in the foreseeable future based on current market conditions and realistic assumptions about future market conditions. The uranium price at which the project breaks even at a 7 per cent discount rate, i.e., a net present value (NPV) of zero, is US$ 45.4 /lb U_3O_8 (US$ 118 /kgU). This is a realistic forecast of uranium prices in the foreseeable future. Utilizing the estimated 88 Mt of ores reserves in surficial mineralization containing 11,617 tU, the capital expenses could be fully repaid during seven years of production [9]. According to UNFC, CJUP can be classified as a "Potentially Commercial Project" with Sub-class "Development Pending" (E2 F2.1 G2, G3).

The application of UNFC to the CJUP study in Jordan demonstrates the advantage of tracking the project from a lower maturity level of assessment (Phase I) to a higher level (Phase II). Therefore, classification and reporting of uranium resources using UNFC have clear advantages for policymakers in Jordan, as well as for internal company requirements for monitoring the progress of a project over time. UNFC is thus an effective tool for making decisions on whether or not to make further financial commitments in order to demonstrate the continued viability of the project.

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Case study on application of UNFC to the uranium deposits of Mexico

Prepared by V. E. Badillo-Almaraz, J.R. Ramírez-Sánchez, J.C. Palacios-Hernández, National Institute of Nuclear Research, Mexico; and R. Alexandri-Rionda, Ministry of Energy, Mexico.

Introduction

Mexico has uranium deposits throughout the country, but none have been mined to date. Domestic uranium demand has been low; the country has two boiling water reactors with a total installed capacity of 1.62 Gigawatt electrical (GWe) net in operation at the Laguna Verde Nuclear Power Plant. To satisfy the uranium demand for fuel, Mexico has been importing processed nuclear fuel, rather than uranium oxides concentrates. In the longer term, Mexico may look to expand its nuclear capacity, and a new evaluation of uranium deposits is therefore needed. This case study provides considerations related to the application of the United Nations Framework Classification for Resources (UNFC) to estimates of uranium resources that correspond to the most studied uranium deposits of Mexico, which are situated in the western and northern parts of the country. This estimate and classification of the country's uranium resources will contribute a better understanding of the availability of reliable resources in Mexico, as well as demonstrate how these resources can contribute to the national nuclear energy program. The series of four case studies included in this report demonstrate that UNFC can be applied to nuclear fuel resources.

Uranium exploration in Mexico

Uranium exploration began in Mexico in 1957 by both ground and aerial prospecting with geological and radiometric methods. Later, from 1957 to 1972, other exploratory works were performed in several states of the country, executed mainly by the National Commission of Nuclear Energy (CNEN, initials in Spanish) through the private Company GEOCA. Then in 1975, the National Institute of Nuclear Energy (INEN, initials in Spanish) performed studies in several regions. In order of importance the areas explored are in the states of Chihuahua, Nuevo León, Tamaulipas, Sonora, Coahuila, Zacatecas, Querétaro and Puebla. The Government-owned company Mexican Uranium (URAMEX, acronym in Spanish) which was created in 1979 undertook intensive exploration in the late 1970s and found some large deposits, but with low grades (less than about 0.10 per cent U_3O_8). This discouraged economic development. URAMEX resumed the studies carried out by CNEN and INEN by performing additional preliminary assessments of the resources. Uranium exploration ended in 1983 and URAMEX was dissolved in 1985. The Regulatory Law of Article 27 of the Constitution on Nuclear Matters, passed on 1985, regulates all nuclear activities in Mexico, grants to the Comisión de Fomento Minero (CFM) responsibility for uranium mining and milling which will not be subject to any concession or contract. Accordingly, CFM will continue the activities of the now dissolved URAMEX. Since 2010, the Federal Commission of Electricity (CFE, initials in Spanish) through the Mexican Geological Survey (SGM, initials in Spanish) has conducted a programme to reevaluate resources according to international standards. The analysis, reinterpretation of existing data and additional fieldwork was undertaken in the most favorable areas in the northern states of Chihuahua, Nuevo León, Sonora and Durango (Figure 1) and reported in the *Compendium of Uranium Deposits in Mexico* [1].

Historically, uranium resources in Mexico have been classified according to the resource reporting scheme of the Organization for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA)/IAEA (the 'Red Book') [2]. The total amount of identified conventional resources in Mexico reported being as in situ is **3,818** tonnes of uranium (tU). Of this total, **2,035** tU are classified as reasonably assured and **1,783** tU are classified as inferred resources.

Figure 1. **Map showing uranium resources/projects of Mexico**

In recent years, an increase in exploration efforts in Mexico has led to a significant increase in reported uranium resources (see Figure 1) as well as on their level of knowledge, especially in the Sierra Peña Blanca uranium deposits. This district hosts not only important uranium deposits but also molybdenum resources.

In addition to uranium deposits, mineral deposits that are rich in the rare earth elements (REEs) have been reported in Mexico [3]. This case study describes the resources that correspond to the most studied uranium deposits in Mexico. The four case studies included in this study on application of UNFC to the uranium deposits of Mexico demonstrate that UNFC can be applied to nuclear fuel resources and its application provides an understanding as to how the resource projects could be progressed from the current Potentially Commercial Project or Non-Commercial Project classes to the Commercial Project class. The appraisal using UNFC methodology also considers comprehensive recovery of potential by-products with uranium, as well as possible exploration and production scenarios with oil & gas in some of the projects.

In 2012, uranium resources in Mexico had been updated by federal institutions, the Mexican Geological Service and the Federal Commission of Electricity (CFE) and reclassified according to the NEA/IAEA Classification (the 'Red Book') [2] (Table 1).

Table 1. **Uranium Identified Resources (updated by CFE [1], according to NEA/IAEA Classification [2]).**

District	Deposits	Deposit Type	RAR tU	IR tU	per cent U
Sierra Peña Blanca	Margaritas	Volcanic-related	517		0.0787
	Puerto III	Volcanic-related	151		0.0672
	El Nopal I	Volcanic-related	293		0.0861
	Other occurrences	Volcanic-related	466		0.0296-0.1272
La Sierrita	La Coma	Sandstone		1 117	0.1484
	Buenavista	Sandstone		1 065	0.1356
	Diana	Sandstone		797	0.0435
	El Chapote	Sandstone		715	0.0457
	Peñoles-Presitas-Trancas	Sandstone		430	0.0559
Los Amoles	Los Amoles district	Volcanic-related	583	357	0.0201
Durango	La Preciosa	Carbonate	1,495		0.053
	Coneto-Buenavista	Carbonate		478	0.0167
SubTotal			***3,505***	***4,959***	
Total			***8,464***		

Note: RAR, reasonably assured resources; IR, inferred resources.

Sierra Peña Blanca Project

The Chihuahua State is one of the federal entities of highest importance with respect to uranium deposits. Uranium prospecting work began in this region in the early 1950s. In recent years, the Mexican Geological Survey, estimated the uranium resources of this region through analysis and reinterpretation of existing data and additional fieldwork [4]. As a result, the resources of Chihuahua State were estimated to be 1,934 tU. This amount represents an estimate of nine uraniferous locations, which were not though classified according to the "Red Book") [2]. In this work, only the Sierra Peña Blanca deposit estimated at 1,427 tU was reported.

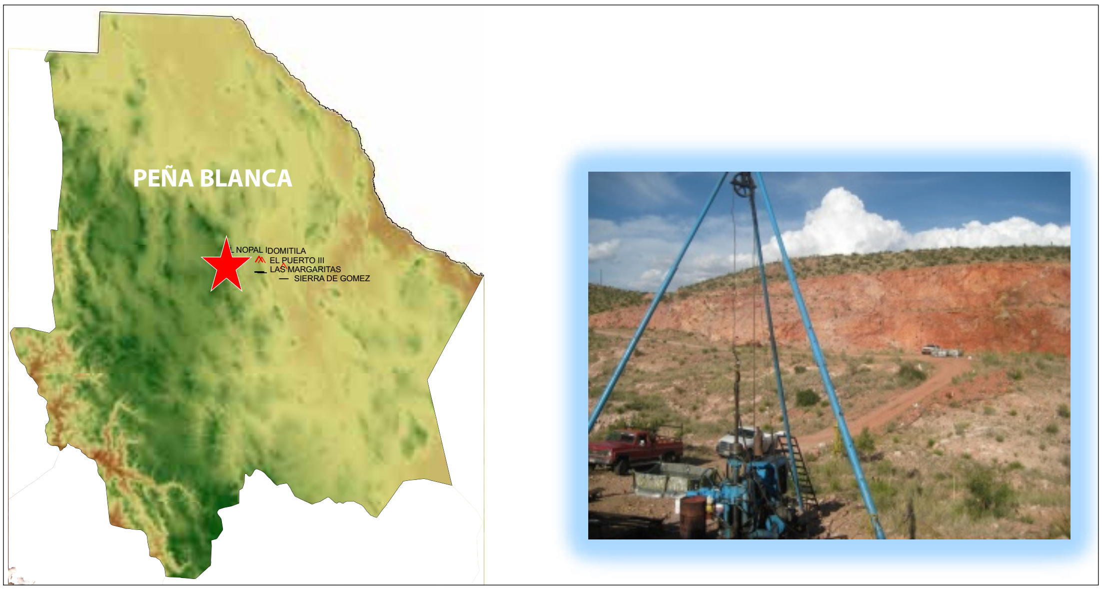
The Peña Blanca uranium mining district (see Figure 2), located in the Sierra Peña Blanca, in the Aldama area in the north of Chihuahua City, is the most significant in the Chihuahua State. These uranium deposits conform to a volcanic-related model, located within the physiographic province of Sierras and Plains of the north, inside the sub-province of Bolson of Mapimi. More than 100 radioactive anomalies were detected in volcanic and sedimentary rocks. The uranium ore bodies are mostly hosted in the conglomerates of the Pozos Formation — Las Margaritas, Puerto III and el Nopal — located in the mid portion of the Sierra [5]; the Sierra Peña Blanca resources were estimated to be 1,427 tU with a grade of 0.0848 per cent U, including 446 tU from other minor deposits at variable grades.

Only the Margaritas deposit which has the greatest volume of uranium mineral, but with low concentration, was classified as RAR (*Reasonably Assured Resources*); the deposit's resources are estimated at 517 tU with a grade of 0.0787 per cent U. Economically recoverable molybdenum (Mo) has been defined for the Margaritas deposit at approximately 1,017 t of Mo; the potential of this by-product should be subject to further research. The Margaritas deposit appears to be the most promising uranium project in Mexico. It is one of the most studied mineralized bodies, and the available geological knowledge indicates very good potential for development.

The second deposit in the Peña Blanca uranium mining district is Puerto III; the tonnage and grade of the deposit have been estimated. The identified resources are approximately 151 t of U with a grade of 0.0672 per cent U. In terms of operation, an underground mining system room and pillar) was proposed.

The El Nopal I deposit is low volume but higher grade; its uranium resource was estimated as 293 tU with a grade of 0.08615 per cent U. An open-pit mine was developed for this deposit but the workings were not completed.

Figure 2. **Peña Blanca Project [6]**



(Photo Geological Survey of Mexico (SGM))

In 2012, a technical report that complies with the Canadian National Instrument (NI) 43-101 and the Australasian Standard (JORC Code) was prepared by CFE [6]; the report included an updated resource estimated for the Sierra Peña Blanca Project. Measured resources were calculated based on 40 radiometric anomalies within a radius of 8 km from the deposit. A three-dimensional block model was constructed and modelled using inverse distance techniques and data input from drill holes that were chemically assayed and whose drill orientation was known. A more detailed block model was constructed, and kriging was used to incorporate geochemical data into the model. The results of this resource estimate are summarized in Table 1. The indicated resources used cut-off grades of 0.0929, 0.0793 and 0.1016 per cent U_3O_8 for the Margaritas, Puerto III and Nopal I deposits respectively.

In the Peña Blanca uranium-mining district, other minor uraniferous occurrences have been evaluated since 1981 by URAMEX; the tonnage and grade were estimated at 466 tU at grades varying from 0.0296 to 0.1272 per cent U.

The resource estimates of the Sierra Peña Blanca deposits are compliant with the Canadian National Instrument (NI) 43-101 and the Australasian Standard (JORC Code) and deemed reliable. From this analysis, the resource estimated, for the three main deposits, is classified as **G1** in UNFC [16], because it is derived from detailed exploration that involved detailed three-dimensional delineation of the deposit. Because of its specific application of the JORC Code, the Sierra Peña Blanca inventory combines JORC categories 'Measured resources' and 'Indicated Resources'; an Identified Resource (RAR and IR) under the NEA/IAEA system corresponds to Potentially Commercial Projects under UNFC categories **E2** and **F2**. A mining report and pre-feasibility study indicates a preliminary assessment of the economic viability and demonstrated the extraction of the reported quantities to be justified (**F2.1**) for the resource deposits (Table 2). Hence, these quantities are in the UNFC Sub-Class – Development Pending.

As these resources are found in three small deposits such as Margaritas (517 tU), Puerto III (151 tU), El Nopal I (293 tU) and other minor occurrences (466 tU), a viable approach for small-scale commercial production that can supply uranium for domestic uses may have to be devised. The commercial viability of U production could be supplemented by 1,017 t of Mo. Detailed studies for the comprehensive recovery of U and Mo needs to be carried out to progress the project to the next class, i.e., Commercial Project – Justified for Development.

La Sierrita Project

These deposits are located in the central-north part of the Burgos Basin at the Coastal Plain of the Gulf of Mexico. This basin experienced several superimposed tectonic events. The complex basement contains both metamorphic and igneous rocks, affected by rifting during the opening of the Gulf of Mexico. In this basin, more than 220 onshore gas fields in Cenozoic and Mesozoic rocks as well as uranium deposits have been discovered [7].

The first discovery of these deposits occurred in 1964 in particular in La Coma and Buenavista – the main deposits of the region – using radiometric exploration programmes (see Figure 3). The next uranium deposits that were defined were Diana, El Chapote and Presita-Trancas-Peñoles [8]. In recent years, the Mexican Geological Survey updated exploration in detail and semi-detail in the La Sierrita project area.

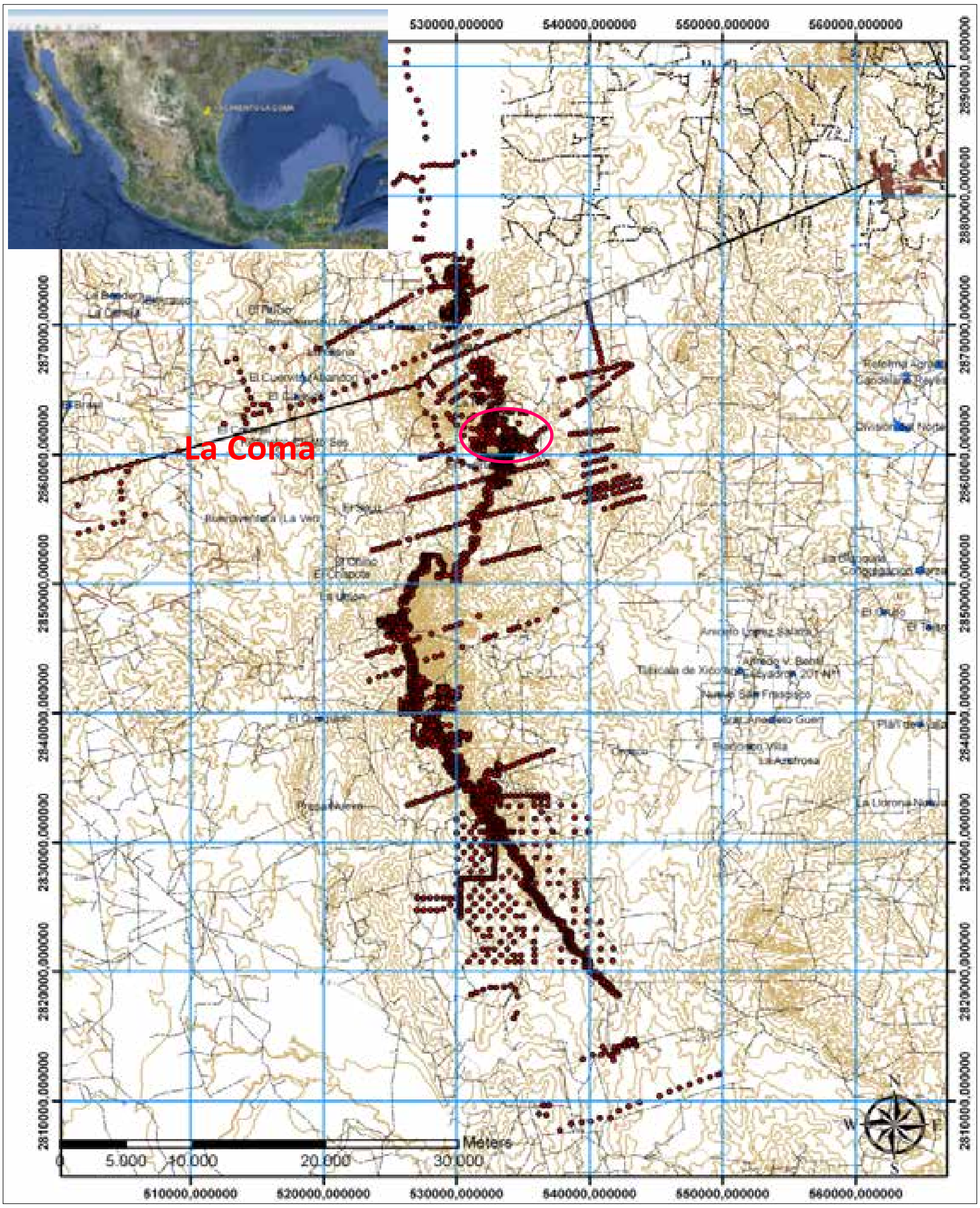
La Coma is a deposit with the most exploration infrastructure. It is considered a large tonnage deposit, but with low grades of U_3O_8. The grades vary from 0.050 to 0.70 per cent of U_3O_8. The mineralization occurs in sandstone, which contains a horizon of uranium mineralization with a thickness from 0.55 to 0.92 m.

With regard to resource evaluation, Castillo [9] estimated the La Coma deposit at 1,117 tU with 0.148 per cent U, the Buenavista deposit at 1,065 tU with 0.135 per cent U, the La Diana deposit at 797 tU with 0.0435 per cent U, and the El Chapote deposit at 715 tU with 0.0457 per cent U. Exploration of the Peñoles-Presitas-Trancas deposits was not completed; however, the uranium resources have been estimated at 430 tU, which is the sum of all three deposits with grades varying from 0.0425 per cent to 0.0836 per cent with a mean grade of 0.0534 per cent U [8]. The total uranium resources in the La Sierrita deposits are estimated to be 4,124 t**U**.

Due to the level of exploration (drills and cuts), and the geologic knowledge of mineralization, these deposit estimates can be classified as inferred resources.

The sandstone-type uranium deposits in the Burgos Basin in the state of Tamaulipas State are of a low uranium grade. National economic considerations could permit extraction in the future, subject to favourable findings in feasibility studies. These Identified Resources have been defined as Inferred Resources (IR) under the NEA/IAEA system; this corresponds to a Potentially Commercial Project under UNFC categories **E2** and **F2**, and may be sub-classified on the F axis as UNFC "Development on Hold" **F2.2**. When considering geologic certitude, inferred resources are moderately well-understood based on projections made from limited drilling and an incomplete understanding of the continuity of mineralization, and hence would be classified as **G3**. Hence, a UNFC classification of **E2**, **F2.2**, **G3** is proposed for the uranium resources of the La Sierrita deposits (La Coma, Buenavista, Diana and El Chapote).

Figure 3. **Plan view of drill holes at La Sierrita Project (La Coma, El Chapote deposits) From: Mexican Geological Survey, SGM [6]**



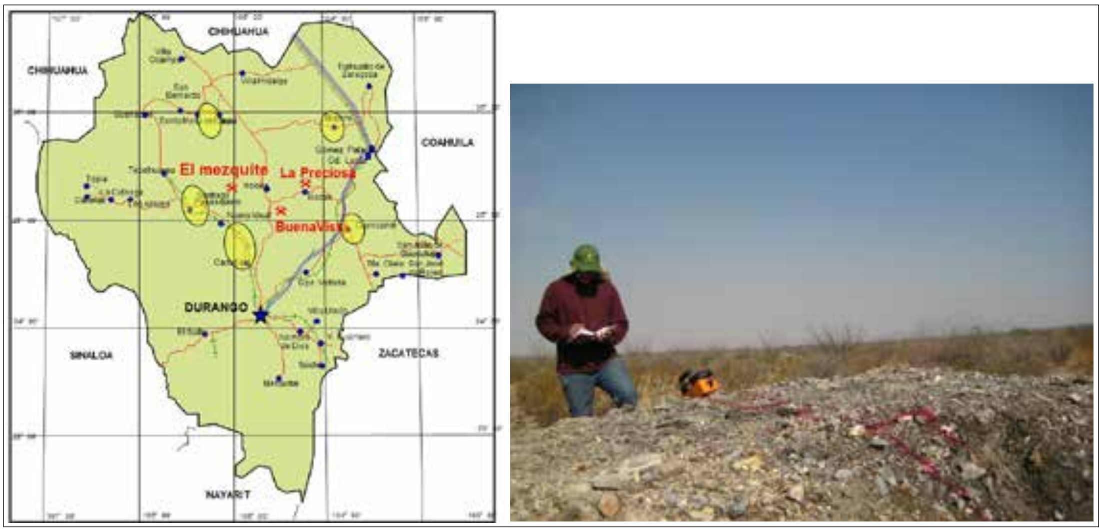
The Burgos Basin has also been proven to significant oil and gas. The possibility of In-situ Leach (ISL) production of the deposits needs to be studied. At present (February 2018) in Mexico, there are no ISL uranium mining projects. All conventional uranium mining ended in 1983 with the permanent closure of pit mines. Low-cost production from these deposits could though potentially become commercially viable.

Further feasibility studies could progress the project to E2, F2.1, i.e., Development Pending. The pace of uranium mining will depend largely on the outcome of the current reform initiatives as well as exploration and strategies. Further exploration to increase the resources could be coordinated with petroleum exploration in this basin.

Durango uranium Project

The uranium deposits in Durango State are divided into two groups. In the first one, the mineralization is hosted by Cretaceous sedimentary rocks (Cuesta del Cura Formation) lutites, sandstone and limestone (Caracol Formation). The second group occurs in Tertiary volcanic rocks altered by intrusive and volcanic bodies. The most important deposits in Durango are the La Preciosa and the Coneto-Buenavista deposits; the uranium resources are summarised for each location in terms of uranium recoverable as follows: 1,495 tU with 0.053 per cent U for the La Preciosa deposit and 478 tU with 0.0167 per cent U for the Coneto-Buenavista deposit which together contain a total of 1,973 **tU**.

Figure 4. **La Preciosa Project [6]**



(Photo SGM)

The La Preciosa mine is located in the Nazas municipality in the southern part of La Cal Sierra. The deposit is located on the eastern flank of the Cretaceous to mid-Tertiary age Sierra Madre Occidental (SMO), a north- to south-east-trending mountain range in north-western Mexico. This mountain range is part of an island arc assemblage of early Mesozoic age, consisting of metamorphosed, deep-water sedimentary rocks (Cuesta del Cura Formation), and island arc volcanic rocks. Uranium mineralizations of La Preciosa are secondary uranium minerals such as carnotite, uranophane, autunite and torbernite. The deposit consists of a tectonic mineralized breccia of 131 m thickness and 100 to 150 m width with a length of at least 1,800 m with high values of U_3O_8; the mining works have an extension on the surface of 550 m; eleven levels and four access shafts with seventeen galleries were developed in the La Preciosa mine. In 2010, based on data from previous studies [13], the Federal Commission of Electricity reassessed the deposit [14] including material not accounted before and estimated a total of 3,167,116 tonnes of mineralized rock with a grade of 0.0625per cent U_3O_8.

The Coneto-Buenavista uranium deposit is located in the central-northern part of Durango State, within the physiographic sub-province of Sierras Transverses, inside the province of Sierra Madre Occidental. Different federal institutions have evaluated the resources in the Coneto-Buenavista deposit on a number of occasions. In 2005, Munguía-Aizpurúa [15] used information recovered from INEN and URAMEX to reevaluate the Coneto-Buenavista uranium deposit. They performed a geostatic assessment by *kriging* normal and lognormal methods. The first method produced an estimated amount of 2,866,306 t of mineralized rock with a grade of 0.0197 per cent (197 g/t) of U_3O_8. The second method produced an estimate of 2,140,018 t of mineralized rock with a grade of 0.0127 per cent (1,227 g/t) of U_3O_8. The mineralization of the Coneto-Buenavista uranium deposit is commonly associated with uraninite, molybdenum, violet fluorite, quartz and to a lesser extent torbernite.

The carbonate-related type uranium deposits in Durango State are of low grade. An Identified Resource (RAR and IR) under the NEA/IAEA system corresponds to Potentially Commercial Projects under UNFC categories **E2** and **F2**. The quantities of mineralized rock are based on a mining report, demonstrated extraction of the reported quantities to be justified in the near future, and may be sub-classified on the F axis of UNFC as "Development on Hold" **F2.2**. The uranium resources are subdivided in order of increasing geological confidence into indicated categories **G2** for the La Preciosa mine and inferred categories **G3** for the Coneto-Buenavista deposit.

Classification of the uranium resources of the Mexican deposits was undertaken according to UNFC, as shown in Table 2.

Table 2. **Uranium Resources in Mexico as classified under UNFC**
Effective date 31 December 2017

Project	*UNFC Class*	*UNFC Sub-class*	*UNFC Classification*	*Resources (tU)*	*Resources (tMo)*	*Total (tU)*
Sierra Peña Blanca	Potentially Commercial Projects	Development Pending	E2 F2.1 G1	517		1,427
			E2 F2.1 G1	151		
			E2 F2.1 G1	293		
			E2 F2.1 G2	466		
			E2 F2.1 G2		1017	
La Sierrita	Potentially Commercial Projects	Development on hold	E2 F2.2 G3	1117		4,124
			E2 F2.2 G3	1065		
			E2 F2.2 G3	797		
			E2 F2.2 G3	715		
			E2 F2.2 G3	430		
La Preciosa	Potentially Commercial Projects	Development on hold	E2 F2.2 G2	1495		1,973
Coneto-Buenavista			E2 F2.2 G3	478.2		
Los Amoles	Non Commercial Projects	Development unclarified	E3.2 F2.2 G2	583		940
			E3.2 F2.2 G3	357		
Total						***8,464***

Los Amoles uranium district

In 1958, the Los Amoles uranium deposit was discovered in the central part of Sonora State. It is considered the most important uranium deposit of the region; it is comprised of the mine called Los Amoles I, and the delimited areas of Los Amoles II and Los Amoles III. These deposits are located in the occidental flank of Sierra Aconchi within the physiographic sub-province of Sierras and Valleys of the north, inside the province of Sierra Madre Occidental. The Aconchi granitic batholith represents an intrusive complex that is lithologically simple, consisting almost exclusively of alkali granites, including abundant pegmatites. Lithologies vary from granites to quartz monzonites, granodiorites and diorites. These rocks are of great economic importance because of their well-known association with porphyry copper (Cu-Mo) deposits, as well as W (tungsten) and Fe (iron) skarn deposits [10].

The exploration works in the Los Amoles I mine consist of a vertical shaft with five levels (+30, +15, 0+0, -15 and -30). The different levels are connected by several wells and counter wells as well as small crossroads. Whilst mineral was extracted, the U was processed. Systematic sampling was executed inside the mine together with a detailed radiometric geological survey at the levels 0+30, 0+15 and 0+00.

Further exploration work with pneumatic drilling allowed delimitation of other areas: Los Amoles II and Los Amoles III. Different federal institutions have evaluated the resources in the Los Amoles deposit on a number of occasions. In agreement with the most recent assessment performed by the Federal Commission of Electricity [11] and from previous information [12], the resources from the Los Amoles I mine were classified as “measured”: 2,694,494 tonnes of mineralized rock with a grade of 0.0216 per cent U representing 583 tU. For the Los Amoles II deposit, the resources are estimated at 1,920,655 t of ore with a grade of 0.0185 per cent U, which represents 357 tU. The Los Amoles III deposit does not contain significant resources. The uranium resources for the Los Amoles district have been estimated as 940 **tU** which is the sum of the first two deposits with a mean grade of 0.02013 per cent U.

The volcanic-related type uranium deposits in the Los Amoles district in Sonora State are of low grade. Even if a detailed three-dimensional delineation of Los Amoles deposit had been made, measured and inferred, resources are only moderately well-understood based on projections made from a limited drilling and an incomplete understanding of the continuity of mineralization. The uranium resources are subdivided in order of increasing geological confidence into indicated categories **G2** for Los Amoles I and inferred categories **G3** for the Los Amoles II deposit. A UNFC classification of **E3.2**, **F2.2**, **G2** and **E3.2**, **F2.2**, **G3** are proposed for the uranium resources of the Los Amoles deposits.

Conclusions

The application of UNFC as a complement to the NEA/IAEA classification contributes to both a better understanding of the availability of reliable uranium resources in Mexico, as well as providing insights on how these resources can contribute to the national nuclear energy programme. Currently, all the projects fall in either the Potentially Commercial or Non-Commercial classes. Further detailed studies on producing uranium from small-scale projects or through potential ISL operations can progress these resources to higher classes. In some of the deposits, uranium can be co-produced with other valuable materials. In some of the sandstone type deposits, further, exploration can be coordinated with petroleum exploration.

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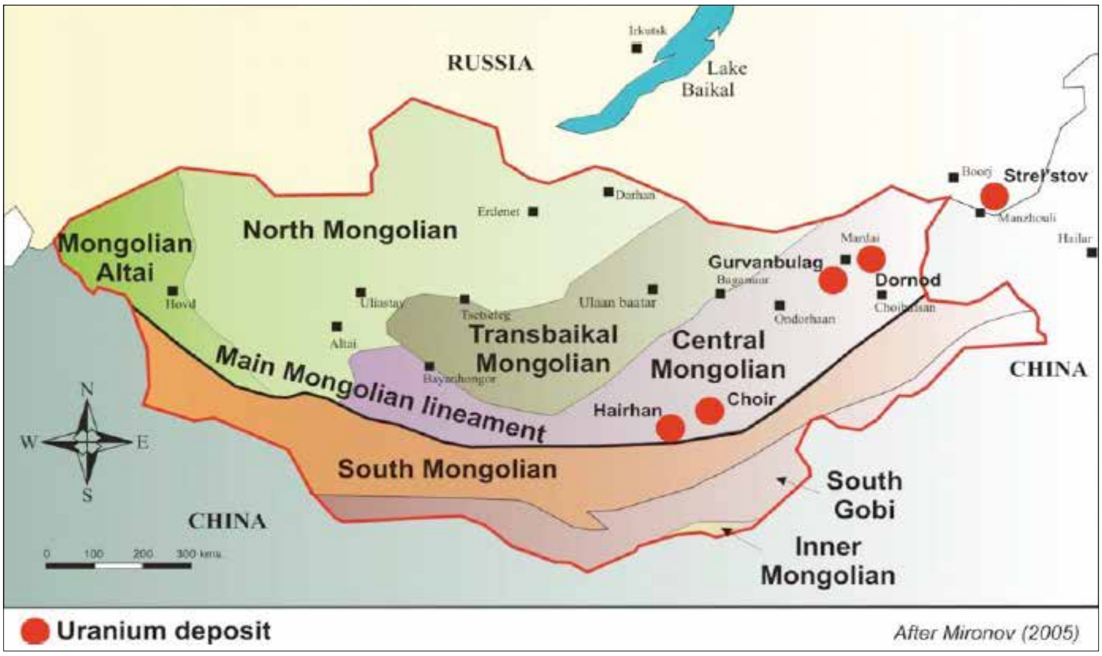
Application of UNFC to the uranium resources of the Gurvanbulag Deposit, Mongolia

Prepared by Shengxiang Li, China National Nuclear Corporation; and Harikrishnan Tulsidas, United Nations Economic Commission for Europe (UNECE).

Introduction

The Gurvanbulag Uranium Deposit lies within the Saddle Hills property, which is located in Dornod Aimag in north-eastern Mongolia, approximately 100 km from the border of Mongolia with Russia to the north, and 100 km from the border with China to the east. The deposit lies approximately 780 km north-east of the capital Ulaanbaatar with coordinates 49°03'N and 114°00'E. Geologically, the Gurvanbulag Uranium Deposit is located in the Central Mongolia metallogenic belt (Figure 1).

Figure 1. **Regional location map of the Gurvanbulag Uranium Deposit**
After [1]

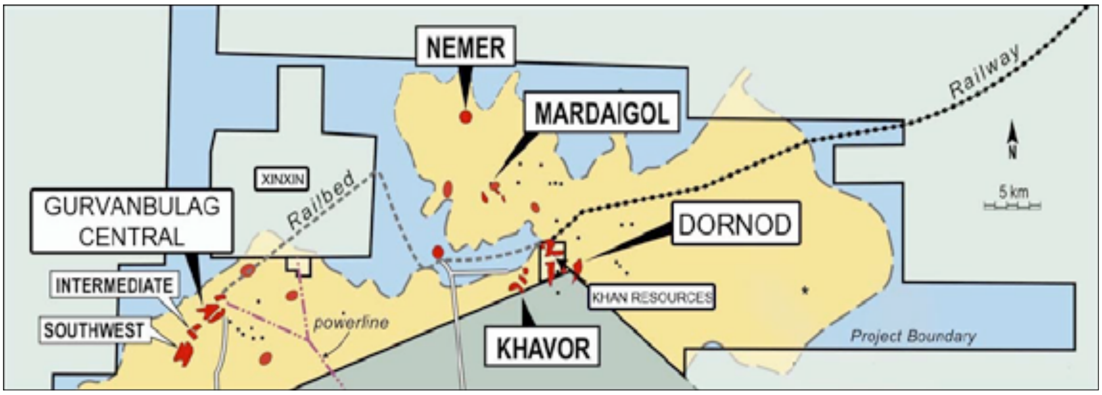


The Gurvanbulag Uranium Deposit comprises three parts, namely, the Central Zone, Intermediate Zone and South-west Zone (Figure 2).

The deposit was discovered and developed by the Ministry of Geology of the Former Soviet Union (FSU). Exploration work was conducted by FSU geologists between 1944 and 1989. Polymetallic mineralization was identified in 1945.

Prospecting for uranium in the Choibalsan area began in 1971 with the first reference to uranium occurrences in the district in 1975, when radiometric surveys identified uranium anomalies. After these surveys, several regional and local exploration programmes were conducted, including geological mapping at 1:50,000 and 1:200,000 scales, airborne and ground spectrometric surveys, geochemistry and trenching.

Figure 2. **Location map of the Gurvanbulag Uranium Deposit within the Saddle Hills Property After P&E Mining Consultants Inc. (2009) [2]**



The Gurvanbulag Uranium Deposit was explored and developed in the 1970s and 1980s. Initially, surface drilling was drilled at 200 x 100 m^2 spacing with detailed follow-up of 100 by 50 m^2 grids in areas identified as mineralized. All holes were radiometrically logged.

Underground development at the Gurvanbulag Deposit comprised three vertical shafts with the deepest descending to approximately 287 metres (m), with limited development on the 140 m (+920 FSU level) and 200 m levels (+860 FSU level) and with most development on the 260 m level (+800 FSU level).

Underground diamond and percussion drilling at the Gurvanbulag Deposit targeted a grid of 25 by 25 m^2 but in many areas as holes fanned out from levels above and below, the zone spacing along the sections was closer to 10 m.

In 1973–1987, FSU geologists conducted a significant amount of geological and geophysical work in the Gurvanbulag Deposit and its neighbouring area, including 654,000 m of drilling, 258,100 m^3 of trenching and generation of over 5,000 samples [3].

In the early 1990s, the property was abandoned with the withdrawal of all personnel from Mongolia following the collapse of the FSU. All surface facilities relating to the development of the Gurvanbulag Deposit were removed, and all shafts were capped with concrete.

In 2004, Western Prospector Group Limited (Western Prospector), a Canadian company based in Vancouver, British Columbia, acquired the property. The property was operated by Emeelt Mines LLC. The Gurvanbulag Mine was dewatered in the second half of 2006, and underground exploration and sampling were initiated.

In 2004–2008, Western Prospector Group Limited carried out a large amount of geological work in the property area to verify the FSU geologists' exploration results, to carry out infill drilling which upgraded the resources and to undertake a feasibility study, including 68,625 m of drilling and the generation of 3,464 samples.

Following underground exploration and further surface drilling, the company P&E Mining Consultants Inc. (P&E) was engaged to prepare a new mineral resource estimate. This was completed in November 2008 [2].

In 2009, CNNC International Limited, which is a subsidiary company of the China National Nuclear Corporation (CNNC), acquired the property and became the operator of the project. This study attempts to unify the resource estimates under the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) Template and the FSU Classification of Reserves for Solid Minerals of 1981 through the application of the United Nations Framework Classification for Resources (UNFC).

Geology and resource estimates

Geology

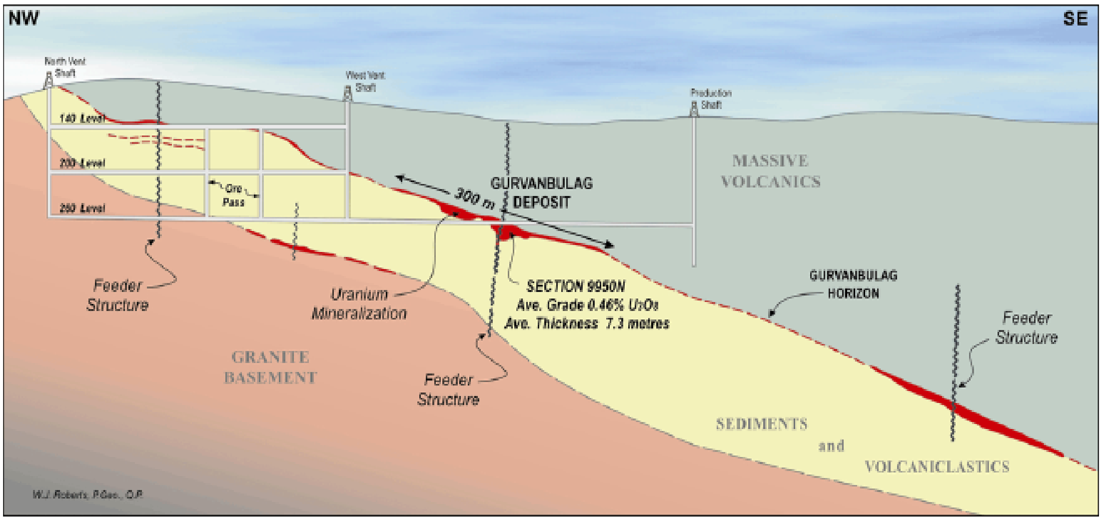
The Gurvanbulag Deposit occurs in Mesozoic volcanic rocks located within a uranium province that extends into Russia (Figure 1) and includes the uranium deposits of Strel'tsov in Russia. The Gurvanbulag Deposit shares many similarities with the Strel'tsov deposits but differs in that the majority of the mineralization shows strata-bound characteristics.

The deposit falls within the broad classification of a volcanic-related uranium deposit with a uranium-molybdenum-fluorine (U-Mo-F) association. Common to all uranium deposits in volcanic rocks is their occurrence in a bimodal suite of rocks consisting of large amounts of high silica rhyolites which overlie intermediate and basaltic units. The deposit differs from other volcanic-related uranium deposits by being associated with a laterally extensive volcanic glass horizon and extensive bedding conformable mineralization.

Uranium mineralization at the Gurvanbulag Deposit occurs in extensively altered, hydro-mica rich clays occurring immediately above and below the obsidian horizon underlying massive felsitic ignimbrites, dipping 5–20 degrees to the south-east (Figure 3). Minor localized mineralization occurs in steeply dipping faults in the overlying ignimbrites and as small strata-bound deposits below the main Gurvanbulag horizon.

The coefficients of variance in the grade of the ore bodies in the Gurvanbulag Deposit range between 1.83 and 2.7 (% U)^2, indicating a high complexity of the Deposit.

Figure 3. **A schematic profile of the Gurvanbulag Deposit**
After [4]



Resource estimates

Three significant uranium resource estimations were conducted previously for the Gurvanbulag Deposit.

The first resources estimation was completed by FSU geologists in 1988 [3]. The in-situ resource was estimated using the polygonal estimation method at a cut-off grade of 0.04% U and a minimum minable thickness of 0.7 m. Table 1 summarizes the C1 and C2 category resources of the Gurvanbulag Deposit (Central, Intermediate and South-west) defined by the FSU. These estimates are not entirely compatible with Mineral Resources and Mineral Reserves as defined under the CRIRSCO family of codes and standards, such as the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (‘the Joint Ore Reserves Committee (JORC) Code’) or the Canadian Institute of Mining, Metallurgy and Petroleum (CIM) Definition Standards on Mineral Resources and Mineral Reserves as incorporated into Canadian Securities Administrators (CSA) National Instrument 43-101 (NI 43-101).

Table 1. **Uranium resources of the Gurvanbulag Deposit according to the FSU Classification of Reserves for Solid Minerals as of July 1987 [3]**

Area	*Category*	*Ore (kilotonne (kt))*	*% U*	*tU*
Central Zone	C1	4,214	0.208	8,761
	C2	3,204	0.118	3,788
	Subtotal	***7,418***	***0.169***	***12,549***
Intermediate Zone	C2	2,690	0.104	2,800
South-west Zone	C2	451	0.16	724
Total	C1	4,214	0.208	8,761
	C2	6,345	0.115	7,312
	C1+C2	***10,560***	***0.152***	***16,073***

The Russian Code for the Public Reporting of Exploration Results, Mineral Resources and Mineral Reserves (NAEN Code) [5] provides a mapping of the current 2008 Russian Mineral Reporting Standards (which is derived from the FSU Classification of Reserves for Solid Minerals of 1981) and the CRIRSCO Template, which indicates that C1 in deposits of the 1st, 2nd and 3rd complexity groups can be equivalent to Measured Resources, and C1 in deposits of the 4th complexity can be equivalent to Indicated Resources. C2 in the Russian system is also considered equivalent to Indicated Resources. Inferred Resources are mapped to P1 resources of the Russian system [5]. However, this study, based on the application of UNFC principles and specifications, conservatively assigns the category C2 resources reported in the FSU classification system as being equivalent to Inferred Resources.

In November 2006, on behalf of Western Prospector, SRK Consulting (Canada) Inc. prepared an NI 43-101 compliant Mineral Resource estimate for the Central Zone of the Gurvanbulag Deposit. [4]. The primary objective of the SRK Consulting report was to prepare an independent estimate of uranium resources that is compliant with the CIM Definition Standards on Mineral Resources and Mineral Reserves. The estimate of SRK Consulting was based on a dataset that combined both FSU data and new data collected by Western Prospector/Emeelt Mines in the 2005–2006 drill programme; the drill data included holes drilled by Western Prospector/Emeelt Mines to mid-March 2006 [4]. The previous FSU data was largely supported by an additional 110 confirmation diamond drill holes completed by Western Prospector.

SRK Consulting reported mineral resources for the Central Zone of the Gurvanbulag Deposit at a cut-off grade of 0.07% U_3O_8 (0.059% U) and a minimum minable thickness of 1.5 m, based on a long-term uranium price of US $47 per pound U_3O_8 and its own internal estimate of potential operating costs for underground mining. Using conservative criteria only, a part of the C1 resources were considered as Indicated Resources, and the rest were classified as Inferred Resources. The resource estimates under different categories are shown in Table 2.

Since the SRK Consulting resource estimation parameters (higher cut-off grade and thickness) are more conservative than the previous FSU estimate, the total resources of the Central Zone of the Gurvanbulag Deposit estimated by SRK Consulting are somewhat smaller.

Table 2. **Uranium resources of the Gurvanbulag Central Zone Effective as of November 2006 [4]**

Area	*Category*	*Ore (kt)*	*% U*	*tU*
Central Zone	Indicated	2,830	0.186	5,249
	Inferred	2,670	0.125	3,327
	Total	***5,500***	***0.156***	***8,576***

In November 2008, P&E Mining Consultants Inc., in conjunction with Aker Solutions (Aker), at the request of Western Prospector Group Ltd, conducted an updated resource estimation for the Gurvanbulag Central Zone and prepared an NI 43-101 compliant Technical Report and Definitive Feasibility Study on the Gurvanbulag Central Deposit, Saddle Hills Property [2].

A total of 2,220 FSU and Western Prospector drill holes including 40,457 m of diamond drilling and 8,360 m of reverse circulation drilling on the surface, underground channels and gamma logged drill holes, were used in the resource modelling area.

The resource estimate was derived by applying a 0.08% U_3O_8 (0.068% U) cut-off grade and a 1.4 m minimum mineable thickness to the block model, and reporting the resulting tonnes and grade for potentially mineable areas. In this estimate, more exploration data were made available, especially from underground channel sampling. Channel sampling on the 260 level was initiated in November 2006 and continued to March 2007. The objective of the underground sampling programme was to channel sample existing underground workings to fill a gap in the available FSU information and to provide a substantial quantity of new assay information for incorporation into an NI 43-101 compliant resource estimate. Underground geological mapping was also carried out to better understand the structural geology and nature of the ore body. Radiometric (gamma) logging was undertaken in the FSU-era diamond and percussion drill holes on the 260 level of the mine workings.

Additionally, 62 reverse circulation (RC) drill holes were drilled, totalling 8,360 m, out of which 54 were gamma logged. These are mainly infill drilling designed to convert the Inferred Resources of the SRK Consulting resource report (2006) to Indicated Resources by increasing the drill hole density. Additional exploration data and infill drilling promoted a part the SRK 2006 Indicated Resources to Measured Resources and a large part of Inferred Resources to Measured Resources. Table 3 shows the resource estimate results prepared by P&E for the Central Zone of the Gurvanbulag Deposit, effective as of 15 October 2008.

The Gurvanbulag Deposit will be mined by underground mining techniques. The known potentially economic mineralization extends from the surface to approximately 500 m below surface elevation. A mining recovery of 95% and dilution of 20% were considered when P&E estimated the reserve for the Gurvanbulag Central Zone. Further, the Definitive Feasibility Study (DFS) converted the Measured and Indicated Resources into Proved and Probable Reserves based on mine geotechnical inputs and economic analysis. Inferred Resources were not considered in the DFS.

Table 3. **Uranium resources of the Gurvanbulag Central Zone Effective as of 15 October 2008 [2]**

Area	*Category*	*Ore (kt)*	*% U*	*tU*
Central Zone	Measured	774	0.205	1,579
	Indicated	3,510	0.151	5,313
	Measured & Indicated	4,284	0.160	6,892
	Inferred	795	0.107	847
	Total	***5,079***	***0.152***	***7,739***

The process plant that has been designed for the Gurvanbulag operation is based on a Resin Extraction Process (REP). The first stage of processing is the sorting stage. This is followed by grinding, leaching, then the resin extraction process and elution, product precipitation, and finally calcining and packaging. The processing recovery considered was around 95%. Table 4 shows the reserve estimate provided by P&E for the Central Zone of the Gurvanbulag Deposit, effective as of 15 October 2008.

Table 4. **P&E Uranium reserves of the Gurvanbulag Central Zone Effective as of 15 October 2008 [2] (after P&E, 2009)**

Area	*Category*	*Ore (kt)*	*% U*	*tU*
Central Zone	Proved Reserves	914.5	0.168	1,538
	Probable Reserves	4,128.5	0.130	5,346
	Total Reserves	***5,043***	***0.137***	***6,884***

Uranium resource reporting: aligning the Gurvanbulag Deposit to UNFC

UNFC is a project-based system that applies to all energy and mineral reserves and resources. It has been designed to meet, to the extent possible, the needs of applications pertaining to energy and mineral studies, resource management functions, corporate business process and financial reporting standards [6]. The transfer of quantities from the estimates reported previously to UNFC has been helped by the UNFC principles, Generic Specifications and the Bridging Document between the CRIRSCO Template and UNFC. Further, the uranium guidelines were also considered in the exercise [7].

According to the information previously detailed, there are a total of 11,255 tU of uranium resources, which is inclusive of 6,884 tU reserves in the Gurvanbulag Deposit. The Central Zone of the Gurvanbulag Deposit has 6,884 tU of Proved and Probable Reserves and 847 tU of Inferred Resources, the Intermediate Zone has 2,800 tU of C2 resources, and the South-west Zone has 724 tU of C2 resources (Table 5). The C2 resources of the FSU classification system have been conservatively assigned as Inferred Resources in this study.

In the Central Zone of the Gurvanbulag Deposit, 1,538 tU of Proved reserves can be classified as E1.1, F1.3, G1 (Table 5), and 5,346 tU of Probable Reserves can be classified as E1.1, F1.3, G2 using UNFC since detailed studies for demonstrating the feasibility of extraction have been completed and approved by CNNC and the Mongolian Government and their geological confidence level is high (for Proved Reserves) or moderate (for Probable Reserves). About 847 tU of inferred resources can be classified as E2, F2.1, G3 using UNFC since their geological confidence level is relatively low and project activities are ongoing to justify development in the foreseeable future.

There are an estimated 2,800 tU of C2 resources in the Intermediate Zone and 724 tU of C2 resources in the South-west Zone. The 3,524 tU of C2 resources can also be classified as E2, F2.1, G3 according to UNFC. Table 5 shows all the uranium quantities according to UNFC.

Table 5. **Uranium reserves and resources of the Gurvanbulag Deposit classified according to UNFC (Effective date: 15 October 2008)**

Area	*tU*	*% U*	*NI 43-101 or FSU Classification*	*UNFC*	*UNFC*	*UNFC Categories*		
				Class	*Sub-class*	*E*	*F*	*G*
Central Zone	1,538	0.168	Proved Reserves	Commercial Projects	Justified for Development	1.1	1.3	1
	5,346	0.13	Probable Reserves			1.1	1.3	2
	847	0.107	Inferred Resources	Potentially Commercial Projects	Development Pending	2	2.1	3
Intermediate Zone	2,800	0.104	C2	Potentially Commercial Projects	Development Pending	2	2.1	3
South-west Zone	724	0.16	C2	Potentially Commercial Projects	Development Pending	2	2.1	3

The definitions of the UNFC Categories used are as follows:

E1.1 Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions.

E2 Extraction and sale is expected to become economically viable in the foreseeable future.

F1.3 Sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development project or mining operation.

F2.1 Project activities are ongoing to justify development in the foreseeable future.

G1, G2, G3 Quantities associated with a known deposit that can be estimated “with a high level of confidence” (G1), “with a moderate level of confidence” (G2) and “with a low level of confidence” (G3).

Conclusions

The key conclusions from the case study are provided as follows:

(a) This case study presents the historical progression of estimates, during the different Effective Dates and discusses the factors responsible for changes in the estimates over time. Three uranium resource estimations conducted at different development stages of the Gurvanbulag Deposit, by FSU geologists, SRK Consulting and P&E Mining Consultants, are based on significant drilling, analytical data and exploration work. The uranium resources estimated by P&E Mining Consultants [5] for the Gurvanbulag Central Zone are less than the earlier FSU estimates. The differences are due to the use of a higher cut-off grade and thickness and additional data made available as a result of the exploration carried out during 2004–2008. Application of UNFC principles and specifications makes the comparison of estimates consistent and reliable.

(b) For the Gurvanbulag Deposit, the category C1 resources of the FSU classification system can be viewed as equivalent to Indicated Resources of the CRIRSCO Template and the category C2 resources can be viewed as equivalent to Inferred Resources.

(c) The case study of the Gurvanbulag Deposit demonstrates that quantities reported under the FSU classification system and the CRIRSCO Template can be unified and classified under UNFC. Moreover, the granularity offered by UNFC is useful to describe the project more precisely, especially in relation to project status, feasibility and socio-economic viability.

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Uranium mineralization in the Nigerian Basement and sedimentary basins: Case study of North-Eastern Nigeria—Application of UNFC as a standard for sustainable energy in Nigeria

Prepared by Alex Nwegbu, Oluwole A Oyedeji, Akinlolu Funmilayo, Tunde Muritala Arisekola, Stanley Maspalma Samson, Nigerian Geological Survey Agency.

Introduction

The exploration efforts related to uranium ore in Nigeria date back to the end of World War II in 1945. In an attempt to deploy its nuclear sovereignty, all the major powers competed in a search for uranium ore to provide sources of raw materials for generating energy. The Nigerian territory, being part of the British Empire, became a hive of exploration activities for western nations. According to Ogedengbe (1984), the first documented record of uranium exploration was by Beer (1952). The British Geological Survey, Atomic Energy Division, published a classified report of uranium mineralization in Nigeria.

Uranium exploration efforts in Nigeria have been conducted so far by the Federal Government of Nigeria. Analogue airborne radiometric surveys were conducted over the Nigerian Territory from 1974 to 1976. The radiometric data for 1974 to 1976 was executed using flights lines with 2 km nominal line spacing, 20 km-apart tie-line spacing, and a nominal flight altitude of 500 feet (152 m) above the terrain. The areas covered by the surveys include the lower Benue Trough (Figure 1) and adjoining regions, and the Ugep–Cross River State, Niger/Benue River Confluence (Kogi State), as well as the Sokoto and Dange areas. The airborne radiometric anomaly map between 1974 and 1978 is shown in Figure 2.

The Nigerian Uranium Mining Company was established in Technical Partnership with TOTAL Compagnie Minière (TCM) of France, primarily to explore, develop and mine uranium deposits in Nigeria. Between 1976 and 1978, the Nigerian Uranium Mining Company (NUMCO) started the exploration campaign in the north-eastern part of the country in collaboration with BGRM Ltd. The prospecting was in two stages: (1) a reconnaissance survey of the basement and sedimentary areas in 1976 and 1977, and (2) detailed lithological/structural mapping, geochemical soil sampling, and radiometric scintillometer surveys of anomalies of mineralized occurrences during 1977 and 1978. The exploration work led to the discovery and identification of 100 radiometric anomalies, with some delineated areas of uranium mineralization within indicated geological settings (Figures. 1 and 2).

From 2003 to 2009, the Federal Government of Nigeria, through the Nigerian Geological Survey Agency and the Ministry of Mines and Steel Development, performed a high resolution airborne geophysical radiometric survey of the entire country (Figure 3). The survey was completed between 2003 and 2010. This survey was conducted to enhance and complement the earlier exploration activities. The data have identified many anomalous areas and targets for further exploration. UNFC has been adapted for the classification of the level of uranium resource studies completed in these areas and presented here as a Nigerian case study.

Uranium deposit discoveries

The uranium anomalies that were identified in north-east Nigeria occur in basement rocks around the Gumchi, Gabrunde, and Mika areas, and sedimentary rocks in Mayo-lope and Zona areas of the Benue Trough sedimentary area (Figure 1). Most of the anomalies and mineralized occurrences of most interest are located in basement rock areas and are associated with rhyolite dykes.

Uranium Mineralization in Basement Rocks

Gumchi Prospect

In the Gumchi area, the rocks that host the uranium anomalies are fine-grained porphyritic granite and mylonitized sheared and brecciated quartzites. The brecciated zone extends for over 15 km and is associated with lamprophyres. The breccia is highly silicified. The uranium anomaly is mostly associated with silica cementing the breccias. A very-low-frequency (VLF) survey was carried out in the area. A total of 65 holes were drilled in the area; a total of 5,679 m of drill samples were recovered and logged. The Reasonably Assured Resource (RAR) for the deposit was determined to be 100 t of U oxide. The geochemical analysis indicated an average uranium concentration of 2000 parts per million (ppm). The Gumchi area is the best prospect among the different mineralized areas underlain by the basement areas.

Gabrunde Prospect

In the Gabrunde area, uranium mineralization is hosted by Pre-Cambrian granites. Reportedly, the largest deposit is composed of uraniferous pyrochlore, an ore of niobium with small amounts of U and Th, hosted within peralkaline granite. The uranium concentration was at 215 ppm. The Reasonably Assured Resource (RAR) is estimated at 60 t U oxide.

Mika Prospect

In the Mika area, the mineralization is associated with Pan-African tectonized granites within a major northeast-southwest-trending shear zone. A total of 14,173 line-km of airborne (by helicopter) gamma-ray spectrometric radiometric survey was conducted. Additionally, 15 total-count scintillometers (Spp2), two GR 410 spectrometers, and one Scintrex spectrometer were used for ground radiometric surveys.

Uraniferous rhyolites of Jurassic age occur as dykes, which were emplaced within Pan African Granite. The uranium resource in the Mika deposits was estimated based on the drilling results of 23 holes, with a total of 434.8 m of drill cores samples collected and logged. The geochemical analysis showed that the average uranium concentration is 540 ppm over 130 m in thickness. The Reasonably Assured Resource (RAR) estimate for the deposit is 52 t U oxide.

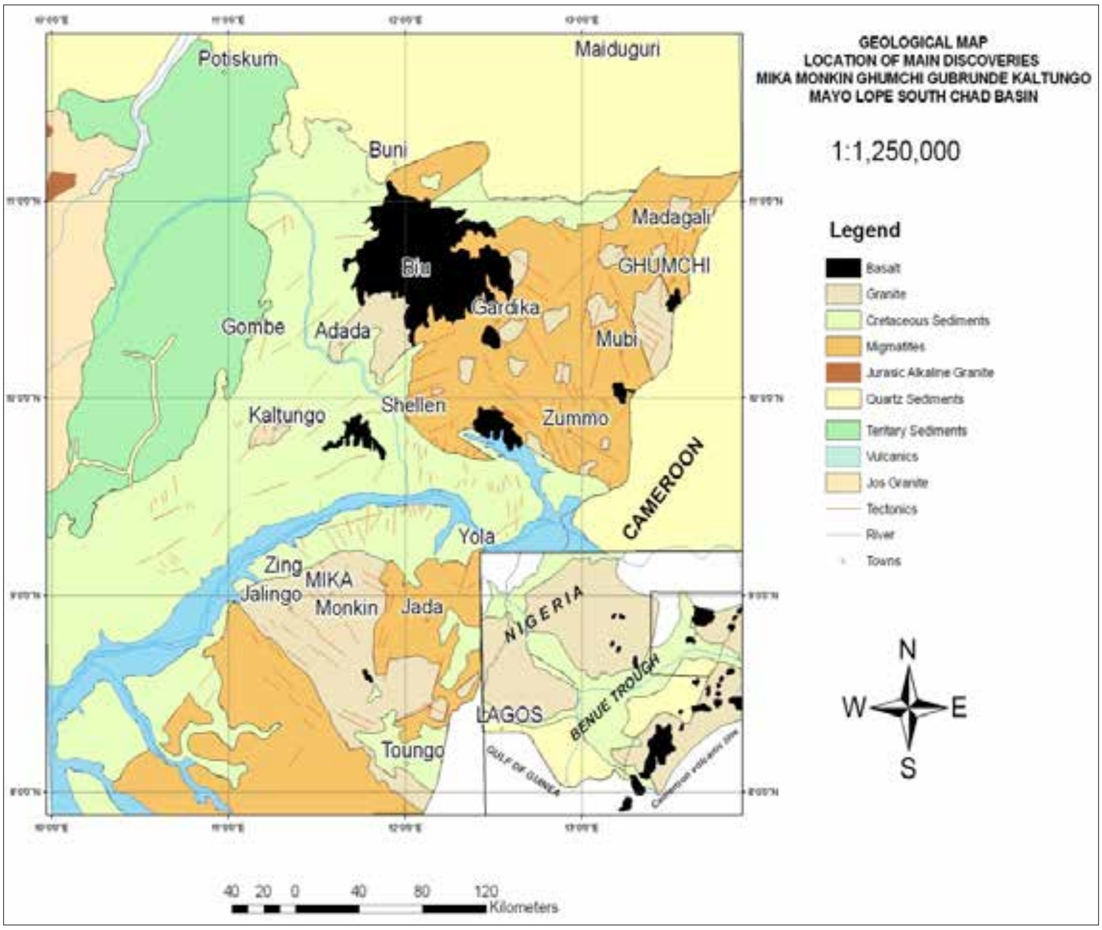
Sedimentary Unconformity-Related Uranium Mineralization

Mayo-Lope and Zona Prospects

The Benue Trough sedimentary area is located in the southern and northern limbs of the Mayo-lope Syncline (Ogedengbe, 1984). Uranium mineralization in the Mayo-lope and Zona areas is associated with the Cretaceous Bima Sandstone, which lies directly and unconformably on the Precambrian basement rocks. The anomaly is hosted around Bille and Passam Hills, both located in the southern and northern limbs of the Mayo-lope Syncline (Ogedengbe, 1984). The Bille anomalous uranium concentration is essentially channel-fill. Geochemical analyses indicated a U concentration of 1826 ppm. The Passam Hill anomaly is also in channel fill. The analyses of samples showed a concentration of 2375 ppm U. The mineralization occurs in both sections of hills as ferruginized conglomerates lying on top of the Lower Bima Sandstone. The Bille and Passam Hills contain a layer that shows evidence of a break in sedimentation. The deposition of uranium in the area was not traced to any fracture since both deposits occur in the same formation. Stratiform occurrences of uranium lie at 200–350 m of depth. A hydrogeochemical survey was conducted. Three holes were also drilled (a combined depth of 257.86 m). The Bima Sandstone uranium deposit (the Mayo-lope Syncline) has the best potential as a viable uranium resource within the sedimentary rocks.

The Zona uranium deposits also occur within Bima Sandstone in the Mayo-lope Syncline. It is a structurally-controlled deposit, unlike the Mayo-Lope. The Zona mineralization is hosted near a vertical fault line cutting across three types of Bima Sandstone—fine-grained brecciated, medium-grained, and coarse-grained arkosic sandstones (Ogunleye and Okujeni, 1993). Chemical analysis indicated U concentrations between 0.01 and 128 ppm. The Reasonably Assured Resource (RAR) estimated in the Zona deposit is 130 t U oxide.

Figure 1. **Generalized geologic map of the Benue Trough sedimentary area, showing uranium discoveries in North-Eastern Nigeria**



Note: Uranium discoveries are indicated in upper case

Figure 2. **Airborne radiometric survey of parts of Nigeria flown during 1974 to 1978**

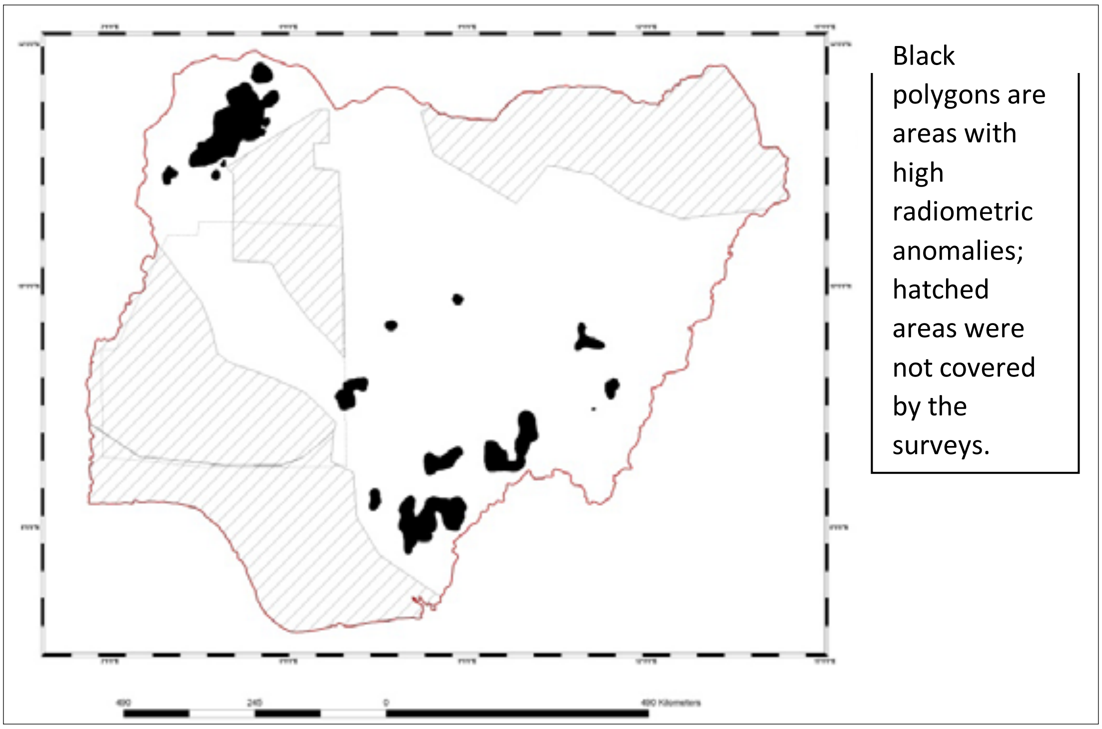
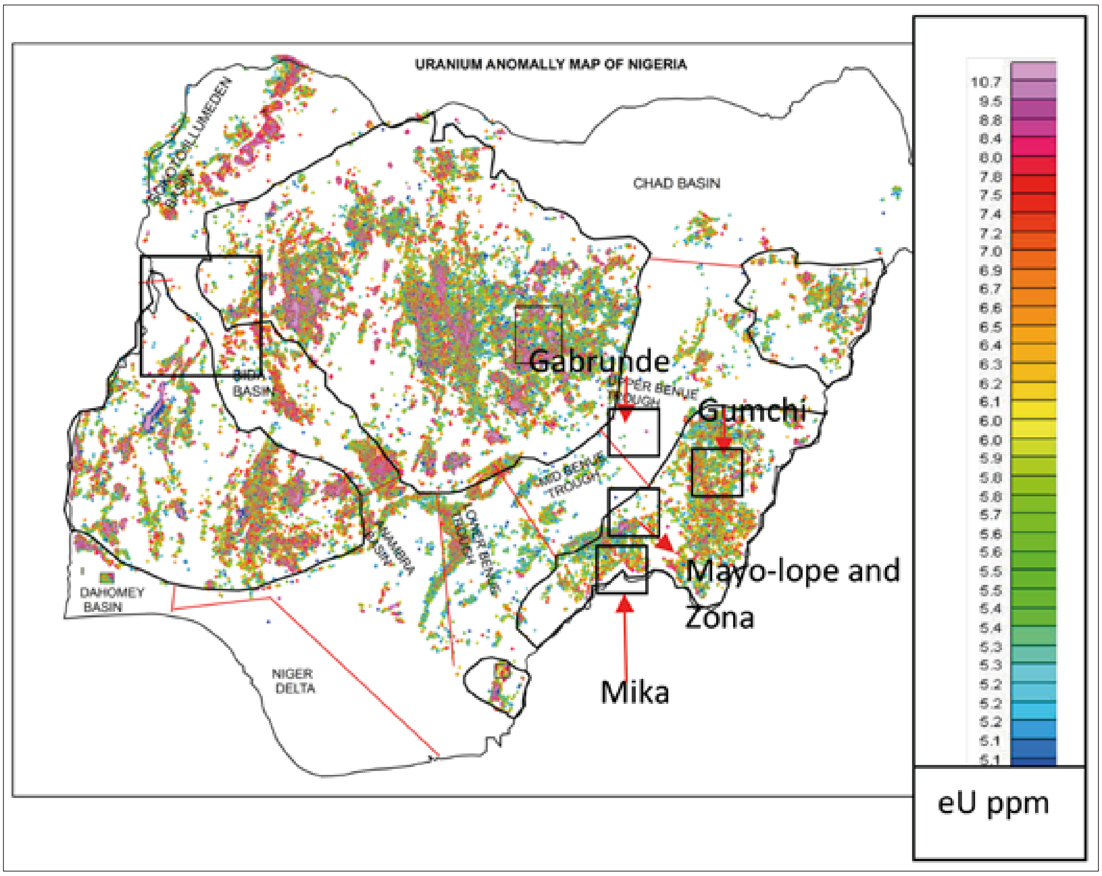


Figure 3. **High resolution airborne radiometric data recorded between 2003 and 2010**



Note: Boxes indicate prospective areas described in this report.

Table 1. **Application of UNFC for uranium resource classification to the basement- and sedimentary basin-hosted uranium deposits in North-Eastern Nigeria**

	Project and location	*Geology*	*Quantity of U resource*	*Average U grade in ppm*	*UNFC Class*	*E*	*F*	*G*	*Remarks*
1	Gumchi prospect, North-East Nigeria	Uranium in anomalies in brecciated, silicified and mylonitized porphyritic granites	100 t U	2000 ppm	Non-Commercial Project	3.2	3.1	3	Priority 1 It has the best uranium grade and best geological potential in this region.
2	Mayo- lope syncline—Zona prospect, North-East Nigeria	Uranium in Cretaceous Bima Sandstone	130 t U	1826 ppm and 2375 ppm	Non-Commercial Project	3	3.2	3	Priority 2 It has the second-best uranium grade with good geological potential.
3	Mika prospect, North-East Nigeria	Uranium mineralisation in rhyolite	52 t U	540 ppm	Non-Commercial Project	3	3.3	3	Priority 3 It has the third-best uranium grade and good geological potential.
4	Gabrunde prospect, North-West Nigeria	Uranium-bearing pyrochlore mineralization in peralkaline granite	60 t U	215 ppm	Exploration project	3	3	4	Priority 4 It has the least uranium grade and the least geological potential.

Conclusions

UNFC has been applied to provide a better understanding and quantifying of uranium resources in Nigeria. The resource classification system is being adapted as a tool for decision-making, economic management and government planning of Nigeria's uranium and other solid mineral resources. Application of UNFC, shown in Table 1, indicated that uranium in Nigeria so far can be classified as Non-Commercial and Exploration Projects. However, with the newly available high-resolution airborne radiometric data covering the entire country, it indicates that discoveries can be anticipated through ground radiometric surveys, geological mapping, mineral evaluation and complimentary geochemical analyses in the target areas that exhibit high radiometric anomalies.

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Considerations related to the application of UNFC to uranium projects and associated resources in Paraguay

Prepared by Clyde Yancey, Victor Fernández of Uranium Energy Corporation (UEC); Harikrishnan Tulsidas, United Nations Economic Commission for Europe (UNECE); and Luis López, National Atomic Energy Commission (CNEA) of Argentina.

Introduction

This case study provides considerations related to the application of the United Nations Framework Classification for Resources (UNFC), and in particular, the specific Guidelines for Application of the UNFC for uranium and thorium resources [1] to uranium projects carried out by the Uranium Energy Corporation (UEC) in Paraguay.

In Paraguay, all known uranium occurrences are found in the eastern part of the country, and most of them are situated in the sandstones in the western flank of the Parana Basin. The sandstone host of the uranium deposit is most often of clastic-detrital origin, is located in continental carbonaceous and/or pyrite-bearing fluvial environments or, less commonly, in mixed fluvial-marine environments. The age of most major sandstone uranium deposits ranges from Paleozoic to Mesozoic. Within south-eastern Paraguay, there is one uranium deposit close to the town of Yuty, and drilling indicates elongated, uranium-bearing roll fronts. At least one other area with good potential for becoming a new uranium district is presently under investigation to the east and north of the city of Coronel Oviedo (Figure 1). Additional uranium potential in eastern Paraguay is also likely to exist in Upper Permian sandstone near the town of Curuguaty and within Silurian sandstone sequences east of the village of Eusebio Ayala. To date, uranium mining has not been undertaken in Paraguay.

Figure 1. **Location of known uranium occurrences in Eastern Paraguay**

Table 1. **Uranium resources in Paraguay**
Effective dates: 24 August 2011 – Yuty and 15 October 2012 – Coronel Oviedo [2]

Deposit	*Type*	*Million Tonnes Ore*	*Grade % U_3O_8*	*Pounds* U_3O_8*
Yuty (Uranium Energy Corp) NI 43-101 Resources	Sandstone Hosted	*Measured*		
		2.054	0.062	2,801,000
		Indicated		
		5.783	0.048	6,113,000
		Inferred		
		2.139	0.047	2,226,000
Coronel Oviedo (Uranium Energy Corp) NI 43-101 Exploration Target	Sandstone Hosted	*Exploration Target Range*		
		26.3 to 48.9	0.040 to 0.052	23,100,000 to 56,000,000

* 1 tonne uranium (U) = 2,600 pounds U3O8

Table 2. **Uranium resources in Paraguay shown in UNFC and NEA/IAEA classification schemes**
Effective dates: 24 August 2011 – Yuty and 15 October 2012 – Coronel Oviedo [2]

Project	*UNFC Class*	*UNFC Sub-class*	*UNFC Category*	*Resources (tU)*	*NEA/IAEA Production Centre Status*	*NEA/IAEA Classification*	*Resources (tU)*	*Total (tU)*
Yuty	Potentially Commercial Project	Development Pending	E2 F2.1 G1	1,080	Prospective	RAR <$130/kgU	3,430	4,290
			E2 F2.1 G2	2,350				
			E2 F2.1 G3	860		IR <$130/kgU	860	
Coronel Oviedo	Exploration Project		E3.2 F3.1 G4	8,900 to 21,500	---	PR	8,900 to 21,500	8,900 to 21,500

RAR = Reasonably Assured Resources
IR = Inferred Resources
PR = Prognosticated Resources

Uranium exploration, development and production are managed under the Vice Ministry of Mining and Energy, which in turn falls under the Ministry of Public Works and Communications (MOPC). To date, neither of the two agencies has published any uranium resource numbers. About 4,290 tonnes of uranium (tU) of Canadian Securities Administrators (CSA) National Instrument 43-101 (NI 43-101) resources have been reported from the Yuty Project by the public mining company Uranium Energy Corporation (UEC) [2]. Yuty is categorized as a Potentially Commercial Project according to UNFC. UEC also reports an NI 43-101 Exploration Target at Coronel Oviedo ranging from 8,900 to 21,500 tU which can be categorized as Prognosticated Uranium Resources according to the Organization for Economic Co-operation and Development (OECD) Nuclear Energy

Agency (NEA)/International Atomic Energy Agency (IAEA) Uranium Classification, commonly known as the "Red Book". Coronel Oviedo is categorized as an Exploration Project, taking into consideration UNFC criteria. Resources/project classification is summarized in Table 1 (NI 43-101 Resources and NI 43-101 Exploration Target) and Table 2 (UNFC and NEA/IAEA). The Bridging Document between the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) Template and UNFC and the Bridging Document between the NEA/IAEA Uranium Classification and UNFC have been used in this case study [3].

No other uranium projects in Paraguay have identified resources.

Yuty Project

The Yuty Project covers 117,232 hectares and is located approximately 200 kilometres east and south-east of Asunción, the capital of Paraguay. Exploration for uranium in South-eastern Paraguay was started in 1976 by Anschutz, after the Concession Agreement between the Government of Paraguay and Anschutz in December 1975. This agreement allowed Anschutz to explore for "all minerals, excluding oil, gas, and construction materials." The initial uranium exploration carried out by Anschutz in 1976 covered an exclusive exploration concession of some 162,700 square kilometres, virtually the whole eastern half of Paraguay. This was followed by a programme of diamond drilling and rotary drilling over selected target areas. In total, some 75,000 metres of drilling was completed from 1976 to 1983. An additional 31,000 metres were completed by Cue Resources Ltd between 2007–2011 to define the current Yuty resource [2].

The Yuty Project area is situated within the western part of the Paraná Basin in south-eastern Paraguay, which also hosts the Figueira Uranium Deposit in Brazil (Figure 2). The area is underlain by upper Permian-Carboniferous (UPC) continental sedimentary rocks [4]. The continental sedimentary units of the San Miguel Formation (of the UPC) are known to have a high potential for uranium exploration in eastern Paraguay. The source of the uranium is thought to be the underlying Coronel Oviedo Formation, which is correlated with the Itataré Formation underlying the Rio Bonito Formation in Brazil.

Occasional diabase sills and dykes intrude the sedimentary rocks, such as at the Yuty Project. Outcrops are rare, mostly along with road cuts, and mapping is done by drilling. The rocks of the Yuty area are very gently east-dipping and un-deformed. Occasional north-west and north-east trending normal faults cut the sedimentary units. Exploration work to date suggests that the uranium mineralization within the San Miguel Formation is strata-bound and possibly syngenetic or diagenetic in origin. Recent interpretation of exploration data suggests that areas of limonite and hematite alteration within the grey-green, fine-grained sandstones of Yuty have characteristics similar to the alteration assemblages present at roll front-type uranium deposits of the Powder River Basin and South Texas Coastal Plaines in the United States (Figure 3).

The mineral resources of the Yuty Project are contained within a sub-horizontal layer of fine-grained sandstone of the massive sand unit of the San Miguel Formation. The resource estimate was based on the development of a three dimensional geologic and resource model. The geological model was based on a uranium radiometric drill hole value cut-off of 0.02% equivalent U_3O_8 at a minimum thickness of 0.1 metres. This further defined the extent of the mineralized zone. The resource estimation was completed utilizing standard geostatistical methods applied to a three-dimensional block model developed in commercial modelling software.

Figure 2. **Occurrence of uranium in the Parana Basin, Paraguay and Brazil**

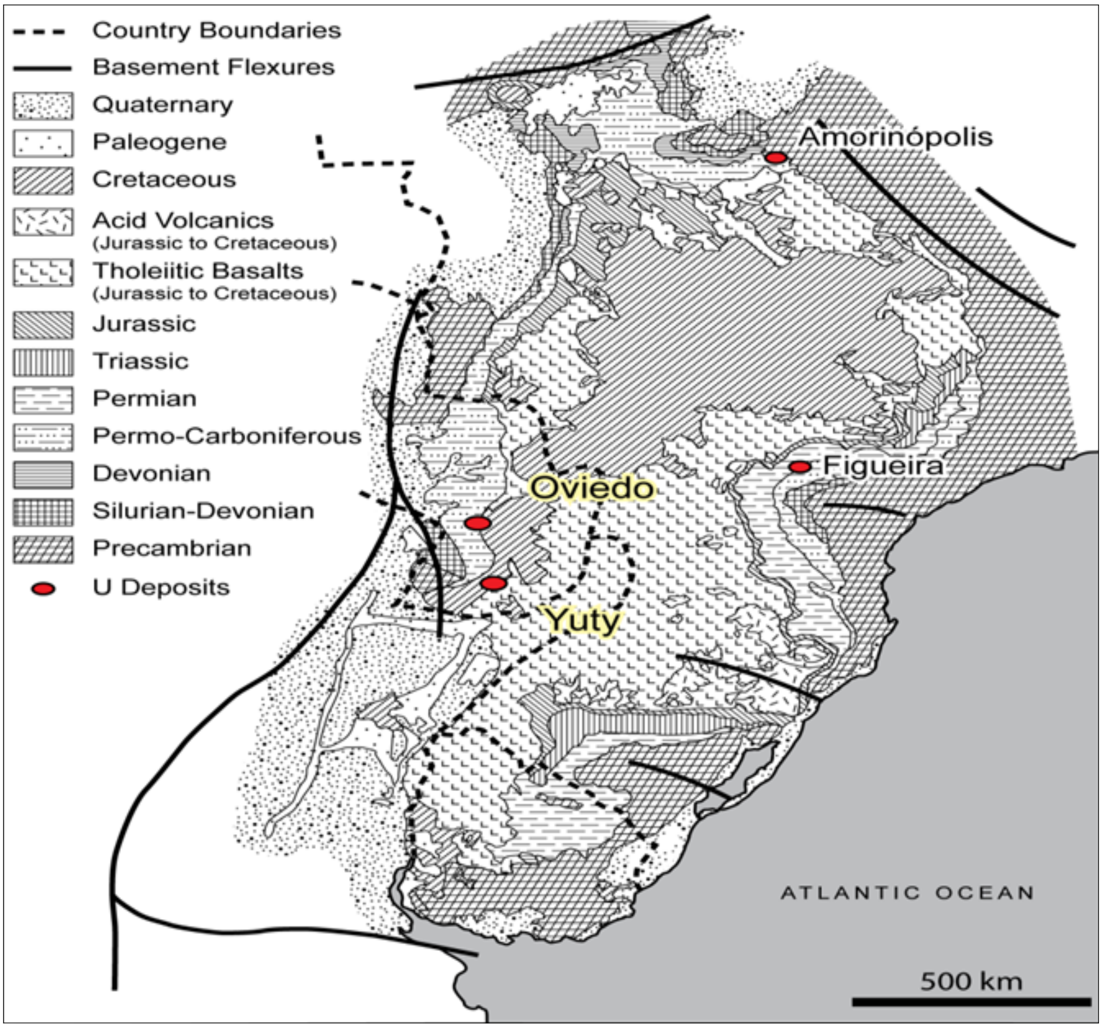

Figure 3. **Yuty Project**

(Photo UEC)

About 4,290 tU grading between 0.047 per cent and 0.062 per cent U_3O_8 of Canadian National Instrument 43-101 (NI 43-101) certified resources have been reported [2]. The quantities are classified as Reasonably Assured Resources (RAR) with cost category <US $130/kgU (3,430 tU) and Inferred Resources with cost category <US $130/kgU under the NEA/IAEA scheme (See Appendix 3 in the "Red Book") [5]. These resources are categorized as G1, G2 and G3 under UNFC (Table 2).

Coronel Oviedo Project

The Coronel Oviedo Project is located in South-eastern Paraguay, approximately 150 kilometres east of Asunción, the capital of Paraguay and 170 kilometres north of Yuty. The Coronel Oviedo Project consists of a large mineral concession covering a total area of approximately 188,000 hectares. The Coronel Oviedo Project located in central Paraguay was subject to reconnaissance uranium exploration between 1976 and 1983 by Anschutz Corporation of Denver, Colorado, United States of America, and by Crescent Resources of Vancouver, Canada, between 2006 and 2008. During 2012, UEC completed a 10,000-metre drilling programme. A total of 35 holes were drilled, averaging 290 metres in depth. The holes were drilled on the east to west lines across known geologic structures believed to be integral in controlling uranium occurrence. The holes were drilled on wide spacing, approximately 1 to 2.4 kilometres apart (Figure 4). A radon extraction survey was completed along the western basin margins, following up on historic airborne radiometric anomalies and outcrop sampling results that indicate a potential for shallow uranium mineralization.

Figure 4. **Coronel Oviedo Project**

(Photo UEC)

The most significant result of recent drilling at Coronel Oviedo was that it identified a redox boundary along some 21 kilometres and demonstrated that significant thicknesses (1.9 to 11.1 metres) of mineralization are present. Also, based on surface radiometric anomalies and limited drill data, the redox boundary may be projected an additional 40 kilometres. Based on this drilling, an NI 43-101 Exploration Target at Coronel Oviedo was calculated ranging from 23.1 to 56 million pounds U_3O_8 (8,900 to 21,500 tU), with 0.04 per cent to 0.052 per cent U_3O_8 grade [2]. These are designated as Prognosticated Resources under the NEA/IAEA scheme, as the quantities are expected to occur in deposits for which the evidence is mainly indirect and which are believed to exist in well-defined geological trends or areas of mineralization within the known deposit, i.e., the Yuty Project. The quantities of uranium in the Coronel Oviedo Project are classified as G4, according to UNFC (Table 2).

Project feasibility considerations

To demonstrate the feasibility of these sandstone uranium deposits to in-situ recovery (ISR) technology, aquifer pumping tests are typically performed. Aquifer testing at both Yuty and Coronel Oviedo has been performed. The testing indicates that the uranium-bearing unit has aquifer characteristics that would support operational rates for ISR mining and that the aquifer properties determined from the test fall within the range of values determined at other uranium ISR projects located in the ISR provinces in the United States of America. Limited core data from both project sites indicate that the uranium mineralization is in radiometric equilibrium. Limited agitated leaching studies at Yuty indicate that either alkaline or acid leach liberate the uranium. Based on the studies, the Yuty Project has been classified as F2.1, i.e. “Project activities are ongoing to justify development in the foreseeable future”. Based on the feasibility studies of the Coronel Oviedo Project, the quantities have been classified as F3.1, in accordance with UNFC Generic Specification R “Classification of quantities associated with Exploration Projects” (UNFC incorporating Specifications for its Application, ECE Energy Series No. 42, ECE/ENERGY/94, Part II, VI Generic Specifications), which is “where site-specific geological studies and exploration activities have identified the potential for an individual deposit with sufficient confidence to warrant drilling or testing that is designated to confirm the existence of that deposit in such form, quality and quantity that the feasibility of extraction can be evaluated.”

Socio-economic considerations

When the Ministry of Public Works and Communications grants a mineral concession to an operator, the project initially enters the Exploration Phase for a maximum of six years during which period a company must advance and demonstrate a viable project. The Exploration Phase is followed by the Exploitation Phase for a maximum of 20 years plus one ten-year extension, during which period the environmental licensing process may begin. This is a key milestone required before starting production, as well as allowing for reductions in land and various investment costs. The Exploitation Phase is followed by the Production Phase, which lasts for an indefinite period. The Yuty Project is in the first year of the Exploitation Phase, and the Coronel Oviedo Project is in the fourth year of the Exploration Phase.

The Paraguayan Mining Law requires that all applicable environmental laws be met for mining concessions and permits to be granted by the Government. For all uranium projects granted in the territory of the Republic of Paraguay, the projects must be compliant with all applicable regulations and plans, and the licenses approved by the Secretary of the Environment (SEAM) which is the national enforcement authority. In order for uranium production to proceed, a detailed plan for assessing environmental baseline conditions and environmental impacts must be submitted, approved, and implemented before the initiation of production.

During the prospection and exploration phases at both the Yuty and Coronel Oviedo Projects, the local population was directly involved in project work to support drilling and field development activities. These jobs have mainly been temporary involving fieldwork and field activity support. The field staff involved in the maintenance of the current facilities are local [2].

The economic benefits of the drilling activities carried out near Yuty were well perceived by the surrounding community, which has been positively affected by the development of residential and commercial infrastructure that was constructed largely for the San Antonio community directly adjacent to the Yuty Project. The town of Yuty has also experienced economic benefits from the development of the project.

No significant conflicts over activities related to uranium exploration projects under development by mining companies have been reported through the use of the voluntary processes of public hearings with affected communities [6]. The aim of the public hearing process was to generate a means of direct communication with more than 2,500 people around the country to adequately report on the scope of the aforementioned mining projects.

Based on the above considerations, the quantities of uranium in Yuty Project are classified as E2, i.e., “Extraction and sale is expected to become economically viable in the foreseeable future”. The uranium quantities in the Coronel Oviedo Project are classified as E3.2, i.e., “Economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase).”

Conclusions

Based on careful consideration of the E, F and G criteria of UNFC, the Yuty Project has been classified as a Potentially Commercial Project with E2, F2.1 and G1, G2 and G3 and 4,290 tU. The applicable Sub-class is designated as Development Pending.

The Coronel Oviedo Project is classified as an Exploration Project with E3.2, F3.1 and G4 and 8,900 to 21,500 tU.

The application of the Bridging Documents between the CRIRSCO Template and UNFC and the NEA/IAEA “Red Book” Classification and UNFC make the transfer of uranium quantities from one system to another accurate and consistent, thus making reporting done under different schemes comparable.

The case study demonstrates that the project maturity model of UNFC is particularly useful for companies such as UEC that are engaged in mineral exploration and development. UNFC can be helpful to reflect the accurate project maturity based on the current status of the project and will be useful in the company’s resource management functions. At a national level, the application of UNFC contributes to a better understanding of the availability of reliable resources in Paraguay and how these resources can contribute to the mining industry and the supply of nuclear fuel resources for the international market.

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Application of UNFC for reassessment of uranium resources of the Eko Remaja and Rabau Sectors, Kalan Area, West Kalimantan, Indonesia

Prepared by Frederikus Dian Indrastomo, Heri Syaeful and Mirna Berliana Garwan of the Center for Nuclear Minerals Technology (PTBGN), National Nuclear Energy Agency (BATAN), Indonesia.

Introduction

Uranium exploration in the Kalan Area, West Kalimantan started in 1973 and is still on-going. The Eko-Remaja and Rabau Sectors are important sectors in the Kalan Area. Metasiltstone and schistose metapellite are uranium favourable rocks in the Eko-Remaja sector, while metasiltstone is the favourable rock for the Rabau Sector. Uranium resources in the Eko-Remaja Sector are estimated at 1,243 tonnes U_3O_8 with 0.1% average grade. Uranium resources in the Rabau Sector are estimated at 294 tonnes U_3O_8, with average grade 0.09% U_3O_8. A pre-feasibility study was conducted in the Kalan Area for the Eko-Remaja Sector from 1991 to 1993 to calculate the economic value of uranium deposit in the area. Resource classification using the Indonesian National Standard (SNI-1998) resulted in the Measured Mineral Resources (A2) category for both sectors.

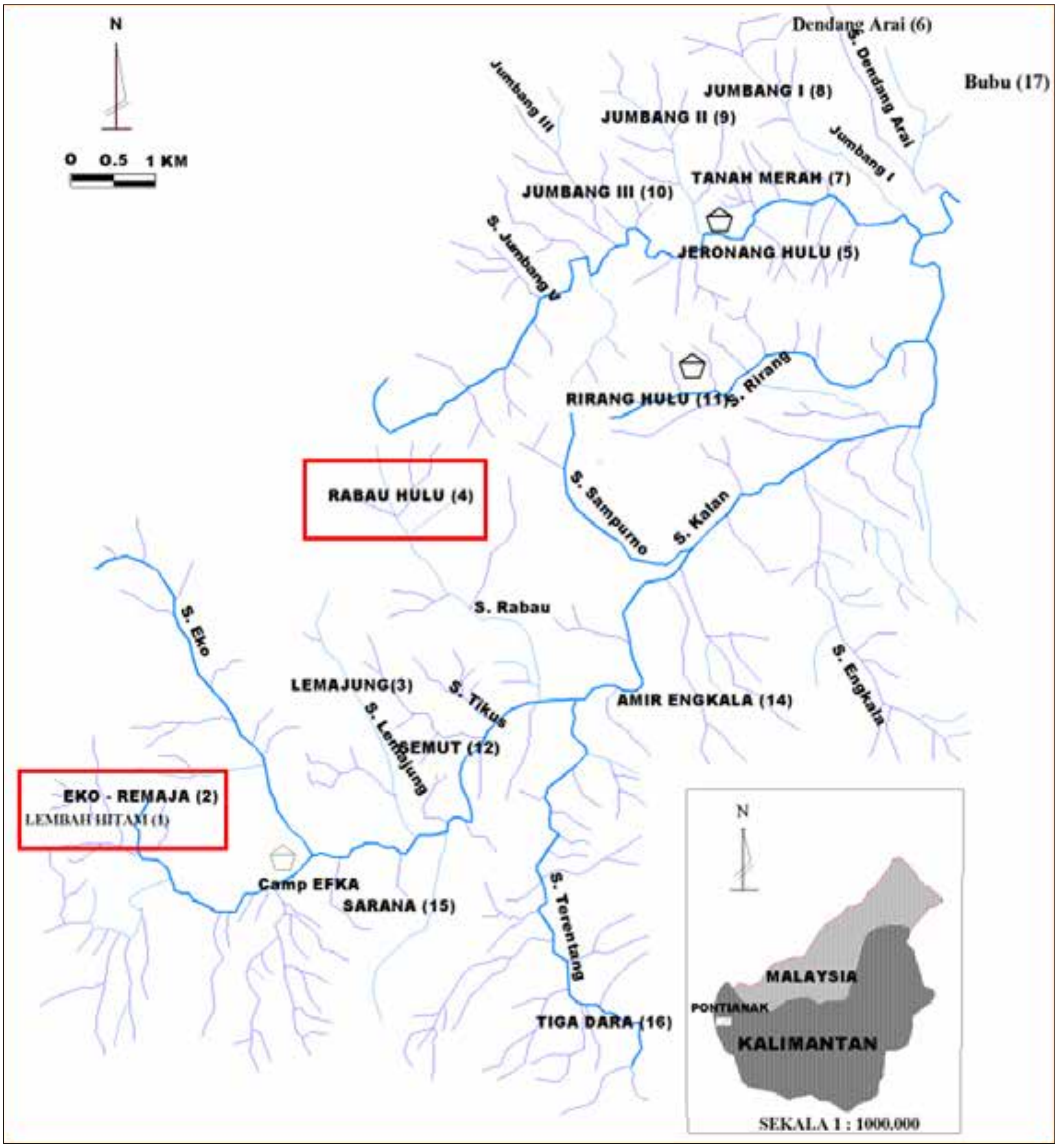
Meanwhile, resource classification according to UNFC resulted in E3.2; F2.2; G1 categories for the Eko-Remaja Sector, and E3.3; F2.3; G2 for the Rabau Sector. Both sectors are classified in the Non-Commercial Projects Class. With regard to Sub-celasss, the Eko-Remaja and Rabau Sectors are classified as Development Unclarified and Development Not Viable respectively.

In December 2015, the National Energy Council of Indonesia completed the national energy plan to 2050. This is reported to exclude major nuclear capacity or nuclear as the last option for electricity-generating in the country. Nevertheless, a roadmap of nuclear energy development was established which covers the steps for building a research power reactor and encourages international cooperation. However, uranium and thorium resources are still a very important tool to increase stakeholder confidence in the reliability of the use of nuclear power plants in Indonesia.

Uranium exploration by the National Nuclear Energy Agency of Indonesia (BATAN) started in the 1960s. Since 1996, exploration activities have been focused on Kalan, Kalimantan, in which the most significant indications of uranium mineralization have been found. Recent exploration activity in the Kalan Area was carried out at the Lemajung sector in 2013 involving 1,500 m of drilling. This was continued at the Lembah Hitam sector in 2014 with 375 m of total depth drilling.

Since Kalan is a remote area, planning for uranium mining development in Kalan should ideally consider all of the sectors as one unit. With estimated uranium resources, the Eko-Remaja and Rabau sectors are important sectors in the Kalan Area, this is in addition to Lembah Hitam, Lemajung, and others (Figure 1). Until now, a pre-feasibility study has only been conducted for the Eko-Remaja Sector to assess its reserves and mining feasibility. UNFC offers an important and beneficial tool to map the status of the sectors in the context of the strategic development plan of Kalan.

Figure 1. **Location of the Eko-Remaja and Rabau Sectors (red boxes) in the Kalan Basin**



The area of uranium mineralization in the Eko-Remaja Sector is in the Eko Hill, upper stream of the Kalan River. In the Rabau Sector, the area of uranium mineralization is along the upper stream of the Rabau River, which is a branch of the Kalan River.

Preliminary mapping of Indonesian National Standard (SNI-1998) Code to UNFC

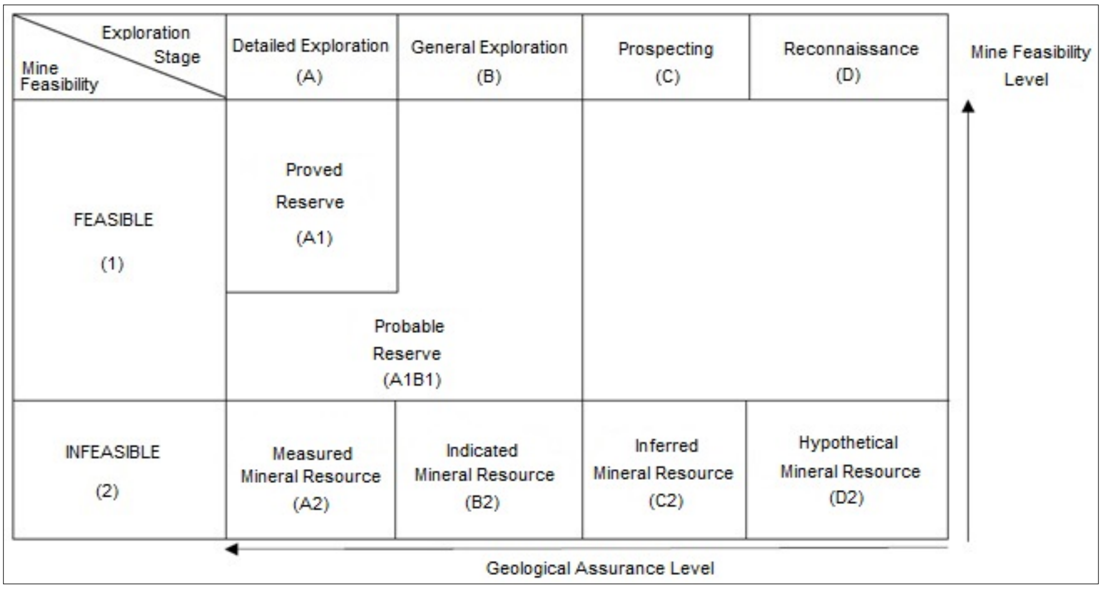
Mineral resource and reserve classification in Indonesia is reported using the Indonesian National Standard (SNI) code number 13-4726-1998 (Figure 2). This Code was adapted from the JORC Code, which has been used by most national and international mining companies in Indonesia. The SNI Code classification has two axes: Geological Assurance Level (X-axis) and Mine Feasibility Level (Y-axis). Resources and reserves classifications refer to the criteria of these axes [1].

According to the SNI Code, the level of geological assurance depends on four exploration stages: Detailed Exploration (A), General Exploration (B), Prospecting (C), and Reconnaissance (D); and two categories of mine feasibility: Feasible (1) and Infeasible (2). In the Prospecting and Reconnaissance stages, the mining level is Infeasible.

Mineral resources are classified into Hypothetical Mineral Resources (D2) and Inferred Mineral Resource (C2). The D2 category is defined from the Reconnaissance stage, while the C2 category is defined from the Prospecting stage. In the General Exploration and Detailed Exploration stages, the mineral resources are classified as either Indicated Mineral Resource (B2) or Measured Mineral Resource (A2) respectively.

In the mine feasibility category of Feasible (1) and during the General Exploration and Detailed Exploration stages, a mineral reserve is classified as Probable Reserve (A1B1) and Proved Reserve (A1). Mine feasibility assessments include economic, mining, marketing, environment, social, and legal factors. These assessments will determine the status of the resource and when it is upgraded to the status of a reserve.

Figure 2. **Mineral resource and reserve classification using the SNI code**



The X-axis describes the mine feasibility level, while the Y-axis describes the geological assurance level [1].

UNFC classifies the mineral resources of a project, including uranium resources, based on three basic criteria: Economic and social viability (E), Field Project status and feasibility (F), and Geological knowledge (G) [2]. The relation between UNFC and the SNI Code can be mapped, as shown in Table 1. The Exploration Projects, Non-Commercial Projects and Potentially Commercial Projects classes of UNFC are mapped to the Infeasible class in the SNI Code. The Commercial Projects of UNFC are equivalent to the Feasible Resources of the SNI Code.

The Commercial Projects of UNFC are mapped to the Proved and Probable Reserves of the SNI Code. The Potentially Commercial Projects in UNFC are mapped to the Measured, Indicated and Inferred Mineral Resources of the SNI Code. The Non-Commercial Projects of UNFC do not have an equivalent in the SNI Code. The Additional Quantities in Place in UNFC are also not defined in the SNI Code. The Exploration Projects of UNFC are mapped to the Hypothetical Mineral Resources of the SNI Code.

Table 1. **Proposed mapping of UNFC to the SNI Code**

<table>
<tr><th colspan="5">UNFC Classification</th><th colspan="2">SNI-1998 Classification</th></tr>
<tr><th colspan="2">UNFC Classes and Sub-classes</th><th colspan="3">UNFC Categories</th><th colspan="2">SNI Classes and Sub-classes</th></tr>
<tr><th>Class</th><th>Sub-Class</th><th>E</th><th>F</th><th>G</th><th>Class</th><th>Sub-Class</th></tr>
<tr><td rowspan="4">Commercial Projects</td><td>On Production</td><td>1</td><td>1.1</td><td rowspan="2">1</td><td rowspan="4">Feasible</td><td rowspan="2">Proved Reserve</td></tr>
<tr><td rowspan="2">Approved for Development</td><td rowspan="2">1</td><td rowspan="2">1.2</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Probable Reserve</td></tr>
<tr><td>Justified for Development</td><td>1</td><td>1.3</td></tr>
<tr><td rowspan="3">Potentially Commercial Projects</td><td>Development Pending</td><td>2</td><td>2.1</td><td>1</td><td rowspan="7">Infeasible</td><td>Measured Mineral Resource</td></tr>
<tr><td rowspan="2">Development On Hold</td><td rowspan="2">2</td><td rowspan="2">2.2</td><td>2</td><td>Indicated Mineral Resource</td></tr>
<tr><td>3</td><td>Inferred Mineral Resource</td></tr>
<tr><td rowspan="2">Non-commercial Projects</td><td>Development Unclarified</td><td>3.2</td><td>2.2</td><td>3</td><td rowspan="2">Not defined</td></tr>
<tr><td>Development Not Viable</td><td>3.3</td><td>2.3</td><td>1,2,3</td></tr>
<tr><td rowspan="2">Exploration Projects</td><td rowspan="2"></td><td>3.2</td><td>3.1</td><td>4</td><td rowspan="2">Hypothetical Mineral Resource</td></tr>
<tr><td>3.2</td><td>3.2, 3.3</td><td>4</td></tr>
</table>

Uranium exploration in the Kalan Area

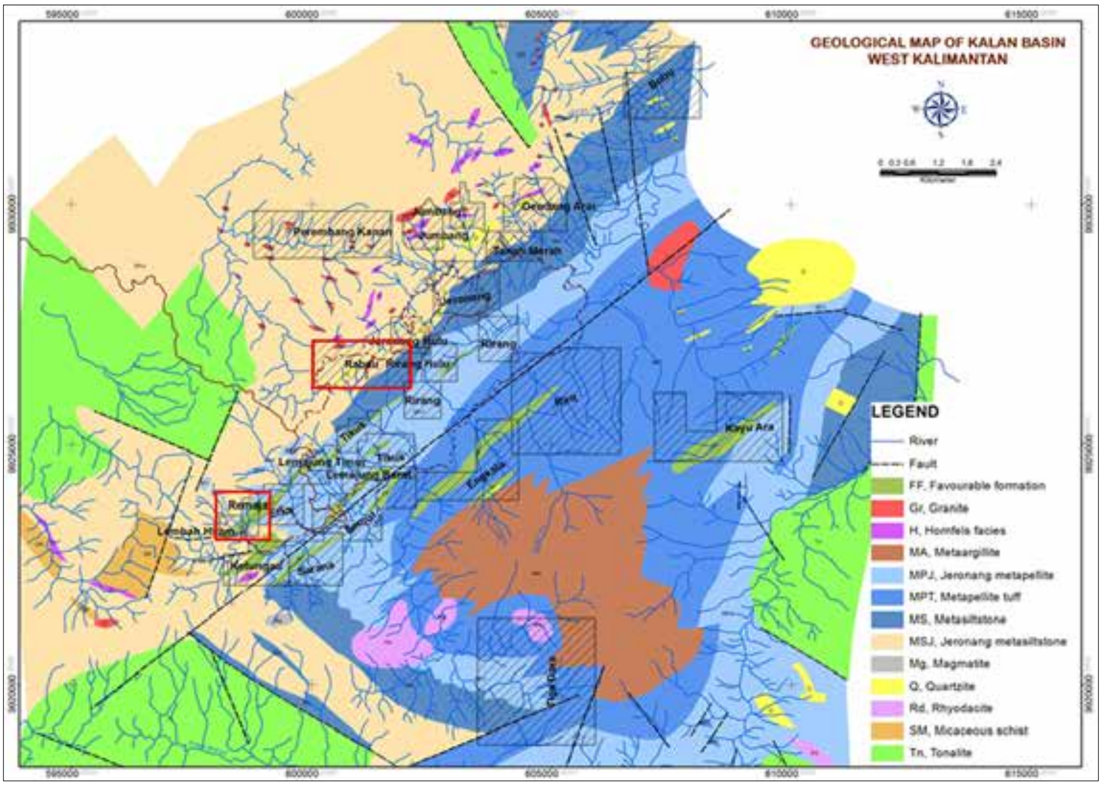
Uranium exploration projects in the Kalan Area, West Kalimantan, Indonesia started in 1973 to 1976, as part of a cooperation between the National Atomic Energy Agency (BATAN) and the Commissariat à l'Énergie Atomique (CEA). The Kalan Area includes the Kalan and Ella Ilir basins, which is composed of metamorphic rocks of the "Schwaner Group" (Figure 3) [3, 4] classified into lower, middle and upper rock series. The lower rock series includes metasiltstone-metapelites, fine-grained quartzite, amphibolic-facies leopard metasiltstone, volcanic rocks, and leucocratic granites. The middle rock series is composed of quartzite rocks and the upper rock series of metaargilic groups, metapelites, metasiltstone and greenschist facies metapelite andalusite. The basement of the Kalan Basin is mainly composed of granitoid (Figure 4) [5].

A sinistral strike-slip fault of N 50°E bearing is the main fault in Kalan Basin. This fault is accompanied by N 30° E and N 10° E trending strike-slip sinistral faults, and N 140° E dextral faults. Fold structures in this area include the N50° – 70° E trending Kalan Syncline Superstructure, and internal structures associated with the lower rocks series, which is related to magmatic processes. These tectonic structures and lithologies controlled the uranium mineralization which occurs in metasiltstone. This lithology is the uranium favourable zone in both the lower and upper rock series.

Uranium mineralization in the Kalan Basin is grouped into the Dendang Arai – Jumbang I, Tanah Merah, Jumbang II – III, Jeronang, Rirang, Rabau, Amir Engkala, Lemajung, and EFKA sectors [3, 4].

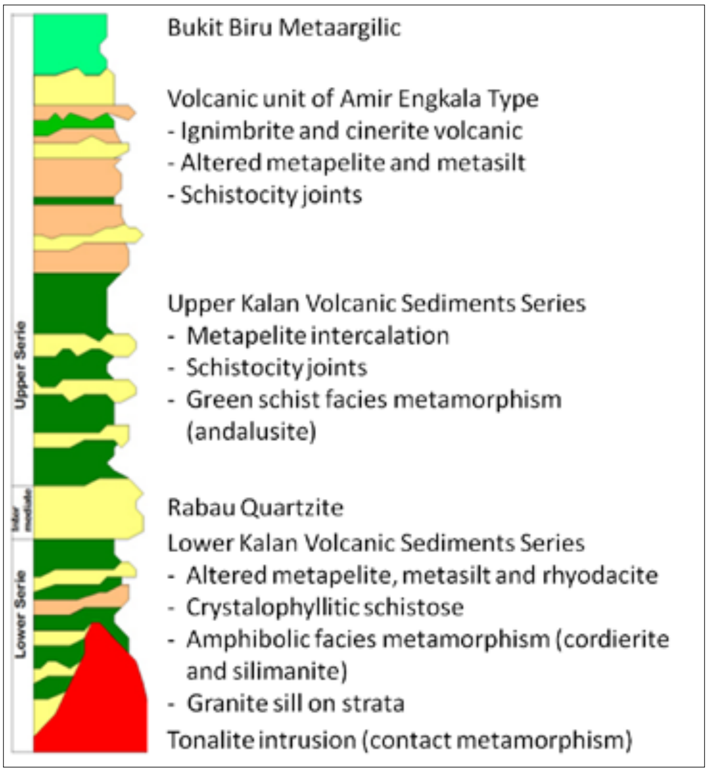
The geological map in Figure 3 shows the lithology variation of the Schwaner metamorphic rocks and the NE-SW and NW-SE trending faults (the main fault in the Kalan Basin), which control uranium mineralization in this area. Sectors of uranium deposit in the Kalan Basin are shaded and the case study area of the Remaja and Rabau sectors are highlighted with a red line [3].

Figure 3. **Geological map of the Kalan Basin**



The stratigraphy column of the Kalan Basin which is composed of metamorphic, metasediments, and intrusion rocks is shown in Figure 4 [5, 6].

Figure 4. **Stratigraphy column of the Kalan Basin**

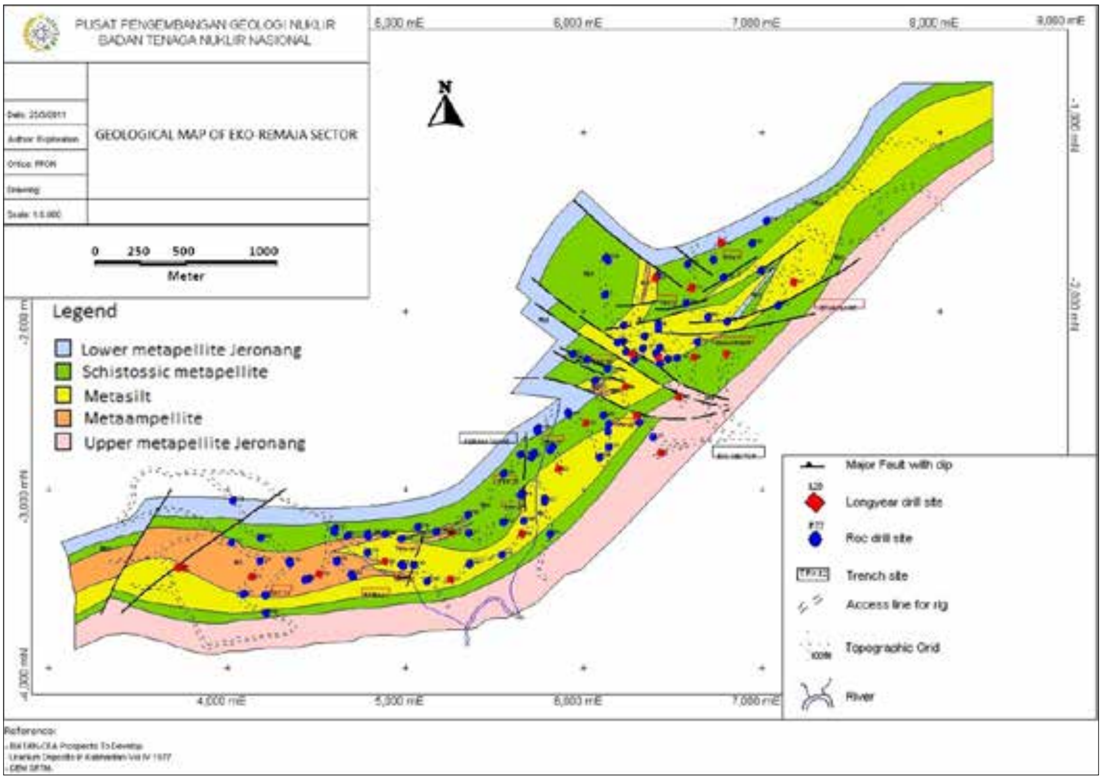


Uranium resources of the Eko-Remaja Sector

The Eko-Remaja sector is located in Eko Hill, the upper stream of the Kalan River (Figure 1). This area is composed of metapelite Jeronang, schistose metapelite, metasiltstone, and metapelites units (Figure 4) [3]. Schistossic metapelite and metasiltstone comprise the favourable uranium mineralization zone – they are located among sterile metapelite Jeronang. Geological data in this sector has been completed with 355 boreholes including tunnel boreholes, with a total depth of 25,203 m. During 1981 to 1982, a 618 m exploration tunnel striking N 50^{0} E (main tunnel) through Eko Hill on level 450 m was created. The tunnelling continued by creating crossing tunnels and an accessing tunnel with a total length of 905.8 m. Based on surface geological mapping, tunnel observation and boreholes assessment, the mineralization pattern strikes N 270^{0} – 300^{o}E, dips 60^{o} – 70^{0}, and is controlled by lithology and tectonic. The uranium favourable zone in the Eko-Remaja Sector strikes N 50^{o} E and dips 60^{o}, and the width of the distribution zone is 80 – 200 m. Uranium mineralization occurs on breccias-fault and veins parallel to the schistose plane. The mineralization planes are parallel to one another and are named the Mineralization Plane (BM). There are 17 Mineralization Planes identified in the area [4].

The geological map of the Eko-Remaja Sector showing metasiltstone and schistose metapelite as uranium favourable rocks among sterile metapelite Jeronang rocks is provided in Figure 5 [3].

Figure 5. **Geological map of the Eko-Remaja Sector**



A pre-feasibility study was conducted in the Kalan Area in 1991 to calculate the economic value of mining and processing the uranium ore in the area. The study focused on the Eko-Remaja Sector as the most advanced in the exploration stage (Figure 2). The uranium resource in this sector was estimated using the Inverse Distance Square (IDS) method. The data from 9 to 85 boreholes are used for each measured area. The grid and IDS radius were assigned 10 x 10 m and 25 m respectively. Uranium grades were obtained from gamma-ray diagram logs measured in boreholes. The uranium resource in the Eko-Remaja Sector was estimated as 1,243 tonnes U_3O_8 with an average grade of 0.1% and an average thickness of 0.89 m [4].

The mining method for the ores was determined by considering the mechanical condition of the rock. Geomechanics classification of the rock mass rating was used [7]. Based on the borehole-coring data, the strength of the rock was categorized as fair to moderate. These conditions require a systematic support system for mining, such as cut and fill and shrinkage. Cut and fill was deemed suitable for the Kalan mineralization [4].

From the metallurgy study of the ores, the average Grinding Work Index for the rod mill was 16.3 KWH/ton to produce 80% products at a size of -65 mesh. The processing capacity was 400 tonnes of ore per day, and the average grade of uranium ore was 1,000 ppm. The capacity was reduced to 250 t/day by using 1,600 ppm uranium grade. The uranium grades were sorted by using Radiometric Ore Sorting (ROS) which increased the uranium ore grades by up to 1.6 times and reduced its weight by 38% [4].

The pre-feasibility study calculated the economic cost of mining and processing. The total cost for mining, processing and all other services was USD 74.4/KgU. The total capital requirement for facilities, buildings and working capital was USD 18,465,974. Based on the study, the economic uranium price calculated was USD 21.5/KgU. The price was assumed for five years after the start of mining. If the production capacity reaches 400 tonnes of U per year, mining in the Eko-Remaja Sector is expected to operate for 11 years [4]. The local communities and local governments strongly support realization of the mine, noting that it will create jobs and provide income to the local government.

The exploration stage in the Eko-Remaja Sector was at the level of Detailed Exploration. Significant volumes of surficial geological and geophysical data were collected in this area. The subsurface data was obtained from coring and non-coring boreholes, systematically spaced at 50 x 50 m for drilling in the ground's surface, and very closely spaced for fan-shaped drilling in the tunnel. This was considered to bring a high level of confidence, and consequently the uranium resources of the Eko-Remaja Sector were classified as Measured Mineral Resources (**A2**) according to the SNI Code.

After careful evaluation of the data, the current study considers the resources to correspond to G1 in UNFC, i.e., quantities estimated with a high level of confidence. Based on the fact that all project activities in the area are on hold, the resources are assessed to correspond to F2.2. The economic viability of extraction cannot be determined due to insufficient information. Therefore E3.2 has been assigned to the project. Based on this assessment, uranium resources of the Rabau Sector are assigned the Non-Commercial Projects Class and Development Unclarified Sub-Class, or **E3.2; F2.2; G1** categories.

Even though the resources were classified as Measured Mineral Resource (A2) according to the SNI Code in 1990-1991, which should have equated to a Potentially Commercial Project in UNFC, the current assessment is that the resources correspond to a Non-Commercial Project.

Uranium resources of the Rabau Sector

The Rabau Sector is located in the upper stream of the Rabau River, a branch of the Kalan River (Figure 1). Geologically, this area is located between the Upper Series and Lower Series rocks of the Kalan Basin. This area is often called the intermediary line. The lithology is composed of silt-pelitic grained rock; the thickness is up to 800 m [3]. The sector is dominated by lithology of micro-muscovite quartzite (>75%), and muscovite quartzite, micro-biotite muscovite quartzite, leopard quartzite, and biotite hornfels (Figure 3). The area contains granite intrusions, the position of which was likely controlled by tectonic structures. Micro-muscovite quartzite has silt to medium-sand grain size, a milky white (weathered) or greyish white (fresh) colour and is composed of quartz, feldspar, sericite, and (or) muscovite. Muscovite quartzite has coarse sand grain size, is milky white (weathered) or greyish white (fresh) in colour, and is composed of quartz, feldspar, sericite, and or muscovite. Micro-biotite muscovite has silt to intermediate-sand grain size, is white reddish-brown (weathered) or blackish white, brown, or greenish (fresh) in colour and is composed of quartz, feldspar, and biotite. Leopard quartzite has clay to coarse-sand grain size, is white with black-reddish dotted (weathered) or white with black, brown, or greenish dotted (fresh) in colour, and is composed of quartz, feldspar, biotite, and (or) andalusite. Biotite hornfels has a silt grain size, is white reddish-brown (weathered) or greyish black (fresh) in colour, and is composed of quartz, feldspar, biotite (Figure 3).

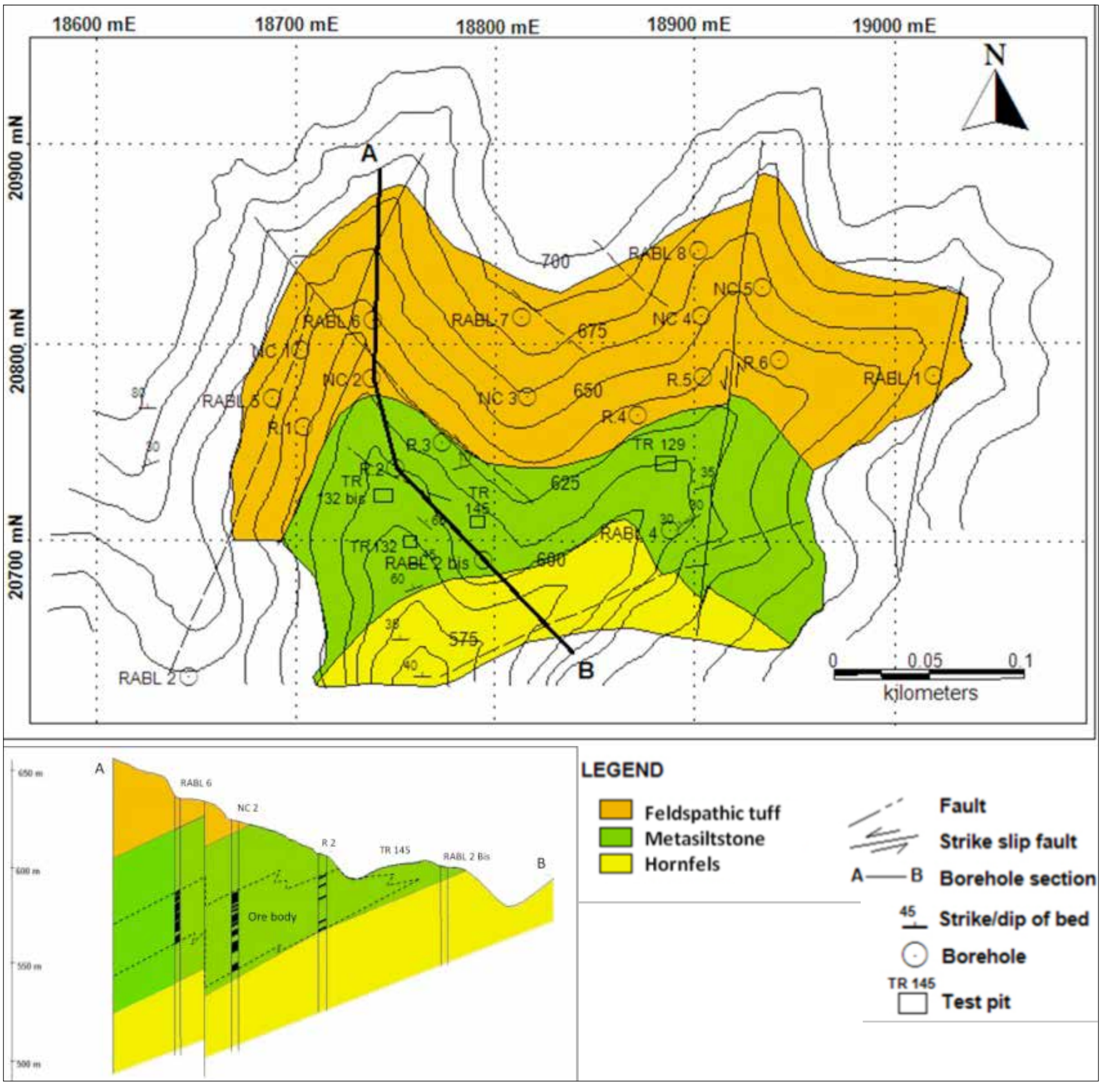
CEA began uranium exploration in the Rabau Sector in 1974. From 1985 to 1991, exploration was continued by BATAN, beginning with a geophysical survey in 1985 using the induced polarization (IP) method. Detailed on-the-ground exploration was undertaken in 1985, and exploration drilling in 1986. The drilling programme resulted in 14 coring boreholes (with a total length of 2,574 m) and 6 cutting boreholes (with a total depth of 413 m). In 1990, uranium resources were estimated using the existing boreholes data, along with additional data from 9 new coring boreholes (with a total depth of 1,002 m). In 1991, the uranium resources were recalculated using four additional coring boreholes (with a total depth of 726 m) [8].

The detailed geological mapping for this sector that was conducted in 1986, classifies the stratigraphy into hornfels, feldspathic tuff, and metasiltstone units (Figure 6) [6]. Metasiltstone is the favourable zone for uranium mineralization. The mineralization occurs in a zone of the vein and brecciation orebodies with a direction of 250^{o} -260^{o} E and dipping 20^{o} – 40^{o} to the north. Mineralization also occurs as a result of magmatic fluid that fills the pore space as discontinued nodules. The thickness of the ore body is between 0.1 m to 5.9 m, with an average thickness of 1.10 m [6, 9, 10]. In the northern area, the mineralization plane has a thickness of up to 5.9 m, but the area is narrower and the uranium grades are lower in the zone with a depth of up to 200 m. Meanwhile, in the south the mineralization planes are close to the surface, and the grades are higher [10]. Uraninite, the primary uranium ore mineral, is associated with magnetite, ilmenite, molybdenite, pyrrhotite, pyrite, chalcopyrite, bornite, sphalerite, and brockite [6, 12]. In addition to the primary mineral, secondary minerals include gummite and autunite were found. Based on the associated minerals, uranium mineralization was formed during the hydrothermal process at temperatures between 200^{o} – 500^{o}C generated by granite intrusion [13]. Geological structures in this area are strike-slip sinistral faults that trend N 50^{o} – 70^{o} E. Strike-slip faults trending N 5^{o} – 10^{o} E and N 140^{o} – 160^{o} E formed after the uranium mineralization [11].

An estimate of the uranium resources within the Rabau Sector was undertaken in 1990-1991 using data from 33 boreholes. The boreholes were spaced 50 x 50 m to obtain detailed geological data. The calculated resources in this area are 294 tonnes U_3O_8. The average grade is 0.034 – 0.143 % U_3O_8, with an average grade of 0.09% U_3O_8 and the average thickness varies between 0.02 to 1.4 m [6].

The exploration stage in the Rabau Sector was at the level of Detailed Exploration. A significant volume of surficial geological and geophysical data was collected in this area. The subsurface data was obtained from coring and non-coring boreholes, systematically spaced at 50 x 50 m spacing. This was considered to give a high level of confidence, and consequently, the uranium resources of the Rabau Sector were classified as Measured Mineral Resource (**A2**) according to the SNI Code.

Figure 6. **Geological map of the Rabau Sector [6]**



The current study, after careful consideration of the data, considers the resources to correspond to G2 in UNFC, i.e., quantities estimated with a moderate level of confidence. Based on the fact that there are no current plans to develop or acquire additional data, the resources are assessed to correspond to F2.3. Based on realistic assumptions of future market conditions, it is currently considered that there are no reasonable prospects for economic extraction and sale. Therefore E3.3 has been assigned to the project. Based on this assessment, the uranium resources of the Rabau Sector are considered to in the Non-Commercial Projects Class and the Development Not Viable Sub-Class, or **E3.3; F2.3; G2** Categories.

Even though the resources classified in 1990-1991 as Measured Mineral Resources (A2) according to the SNI Code should have equated to a Potentially Commercial Project in UNFC, the current assessment is that the resources correspond to Non-Commercial Projects.

Conclusions

This case study attempts to revisit the uranium resources that were discovered and actively worked on in Indonesia in the past. As the uranium resources were estimated and classified according to the SNI Code, a preliminary mapping to the international standard, UNFC, was carried out. This has helped to reassess the project maturity of these projects and to classify them according to UNFC.

Uranium exploration conducted by the Indonesian Government to date is classified as Non-Commercial Projects. Uranium resources in the Eko-Remaja and Rabau Sectors were classified initially according to the SNI Code and estimated as 1,243 and 294 tU3O8 respectively. In this scheme, the resources are classified as Measured Mineral Resources (A2). The current case study classifies these uranium resources according to UNFC as a Non-Commercial Project. The Eko-Remaja Sector is classified as the Sub-class "Development Unclarified", with categories E3.2; F2.2; G1. Meanwhile, the Rabau Sector is classified into the Sub-class "Development Not Viable", with categories E3.3; F2.3; G2 (Table 2).

Table 2. **The EFG criteria for the Projects of the Eko-Remaja and Rabau Sectors**

Sector	*UNFC*					*Resource (tU308)*
	E	*F*	*G*	*Class*	*Sub-Class*	
Eko Remaja	3.2	2.2	1	Non-Commercial Projects	Development Unclarified	1,243
Rabau	3.3	2.3	2		Development Not Viable	294

There are no private or state companies currently involved in these projects. However, in the future, by considering the domestic requirement for uranium for nuclear power these projects could be revisited, and additional data could be generated. In that case, there is a possibility that additional resources could be added and that the project maturity of the projects could be improved.

This case study demonstrates the usefulness of UNFC for reassessing the project maturity of the uranium resources in Indonesia. Using UNFC, the historical resources data on uranium in Indonesia reported according to the SNI Code have been reassessed and re-classified. The study has helped to clarify the current project maturity of resources in two projects and also helped to identify the requirements for further work that could help advance these projects to supply uranium for domestic use.

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A case study on the application of UNFC to uranium, thorium and niobium resources of Venezuela

Prepared by John Manrique, Universidad Particular de Loja, Ecuador

In Venezuela, there are favourable geological environments for the formation of mineral deposits of uranium. Currently, the only identified uranium deposit of significance in Venezuela is the uraniferous phosphatic rocks of the Navay deposit, Táchira State, which is considered an unconventional source of uranium. According to estimates made in the 1970s based on exploratory drilling in place, the Navay deposit contains a total of 42,000 metric tons of uranium. This information was published in the IAEA "Red Book" of 1986. According to the United Nations Framework Classification for Resources (UNFC), this deposit would be in the class E3 F3 G4, i.e., an Exploration Project.

Similarly, there are favourable environments for thorium deposits in the country in the Guiana Shield. In the 1970s, the Cerro Impacto deposit was discovered, which is a thick laterite thought to be the product of intense alteration of a carbonatite intrusion. The laterite contains anomalies of thorium (Th), barium (Ba), rare earth elements (REE), zinc (Zn), lead (Pb) and niobium (Nb). Exploratory drilling and resource calculations estimated 324,000 tons of Th and 583,200 tons of Nb in the laterite deposit. This ranks Venezuela as seventh in the world for thorium resources. According to UNFC, the Th and Nb quantities in the Cerro Impacto deposit can be classified as a Non-Commercial Project, with Sub-class Development Unclarified (E3.2, F2.2, G3).

This case study proposes the use of the UNFC classification for these two deposits. Venezuela has occurrences of uranium (U) and Th associated with several geological environments; however, they do not have known commercial deposits of U and Th. The classification according to UNFC could be updated in future if the mining of these commodities, as well as other co-occurring minerals with high value and demand, are sought, such as P_2O_5, REEs, and Nb.

Introduction

Favourable geological environments for the formation of mineral deposits of uranium are revealed by detection of radiometric and geochemical anomalies in potential host rocks, anomalies of U-Cu (copper) mineralization in rocks, U anomalies in waters and sediments, or geological-geochemical environments favourable for the deposition of uranium [1]. Currently, the only uranium deposit discovered in Venezuela is in the uranium-containing phosphatic rocks at Navay, Táchira State (Figure 1), which is considered to be an unconventional uranium resource. According to calculations made in the 1970s, from exploratory drilling in place 42,000 tons of U were estimated. This estimate was published in the IAEA "Red Book" editions of 1986 and 1988 (and reproduced in the 2016 edition) [2].

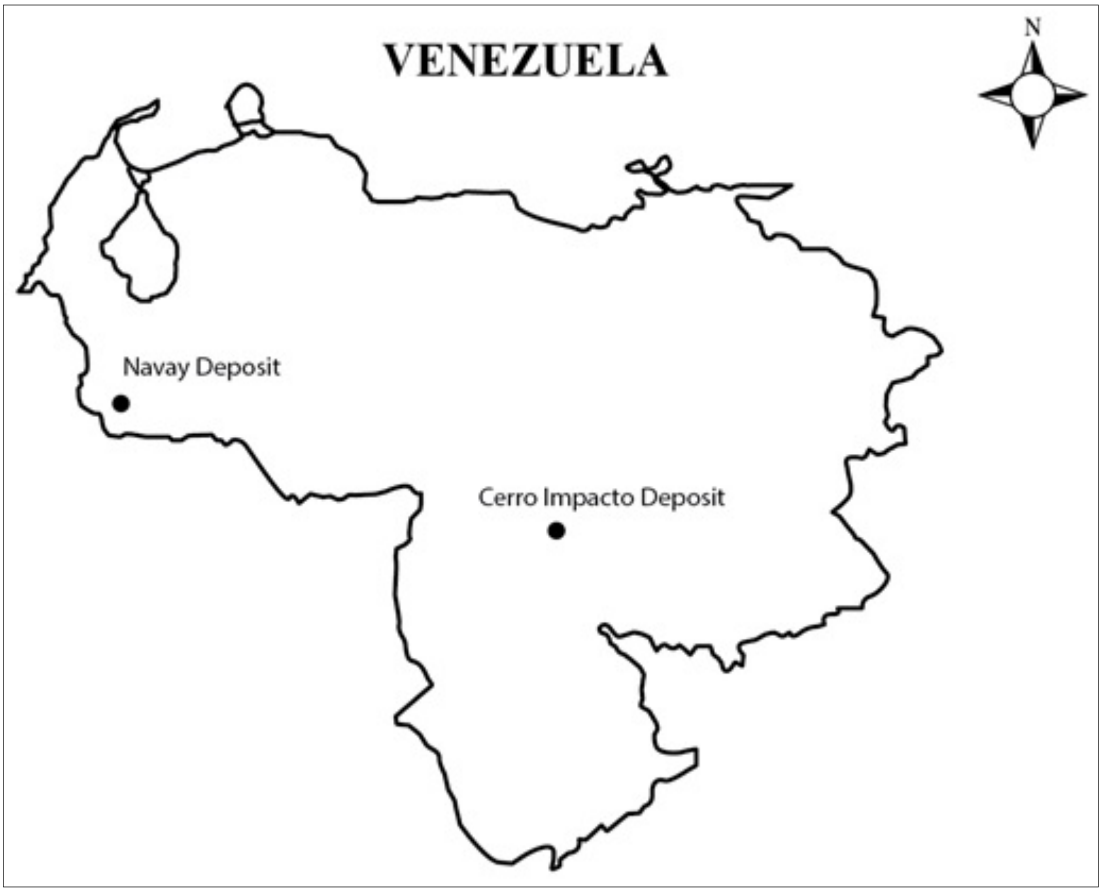
Similarly, there are favourable environments for deposits of Th in the country, represented by radiometric anomalies in igneous rocks and sediments as well as geochemical anomalies in stream sediment samples in the Guiana Shield region [3]. In the 1970s, the Cerro Impacto deposit was discovered (Figure 1), which is thick laterite, thought to be the product of intense alteration of underlying carbonatitic rock. This deposit contains anomalous Th, Ba, REE, Zn, Pb and Nb. From exploratory drilling, resource calculations estimated there to be 24,000 metric tons of Th, which as previously noted ranks Venezuela as the seventh country in terms of Th resources in the world [2].

Geology of the Navay deposit

Cretaceous sedimentary rocks exposed in the south-east of Táchira State belong to the sedimentary basin of Apure-Barinas. In this basin, the Cretaceous rocks can be divided into two intervals (Lower-Middle and Upper). The Barremian-Turonian sequences (Lower-Middle Cretaceous) include the Río Negro-Aguardiente-Escandalosa Formations, and the upper Coniacian-Maastrichtian sequences are represented by the Navay-Burgüita Formations [4].

The Navay Formation consists of siliceous shales, cherts, fine-grained sandstones and phosphatic layers with remains of organisms. This formation consists of lithological facies deposited in shallow waters, cutting timelines, but with a local age of Campanian-Maastrichtian. The thickness varies between 100 and 320 m. Marked lateral variations are due to the high position of the basement, the water depth, and the relative position of the mouth of river sediment transporters. The upper unit is the Quevedo Member, consisting of phosphatic sandstone in the south-east towards the Guiana shield, which becomes predominantly sandy and contains hydrocarbons in the Silvan and Silvestre fields in Barinas. Finally, the upper unit correlates with the Chert Member of the Táchira of the La Luna Formation, with the upper part of the formation exposed in Trujillo and the Guavinita Member of the El Tigre Formation in the subsurface of Guárico [5].

Figure 1. **Sketch map showing the location of uranium and thorium deposits in Venezuela**



Radiometric survey of the Navay deposit

The radiometric anomalies caused by enrichment of uranium in the phosphatic mineral (0.01-0.04% U), bounded (mountainous row or slip) on the Las Tapas - El Toro, are associated with the top of the Navay Formation, equivalent to the base of the Burgüita Formation. Pasquali (1980) [6] made the first public reference to the discovery of these phosphate rocks.

The radiometric anomalies are surface bands whose width is a function of a dip of phosphatic horizons (phosphatic siltstones, and thin sandstone phosphatic layers with traces of organisms). The phosphate layers are highly porous sands. They are permeable, permitting leaching that mobilized and enriched P_2O_5 lower horizons and/or in fracture zones [7]. Tests on samples of phosphate rock of the Quevedo Member near Las Tapas are listed in Table 1.

Table 1. **Analysis of phosphate rock of Quevedo Member**

Rock	*U (ppm)*	*P205 (%)*	*Si02 (%)*	*F (%)*
Phosphatic aluminic sandstone	100-400	11	73	0.85
Phosphatic limonite	50-200	12	61	0.30
Layers of remains of fish and shellfish	50-160	13	51	0.70

An anomalous radiometric belt located between the Las Tapas farm and the villages of El Mono and Fila El Toro, was first discovered in early 1978. The deposit was evaluated in August 1978, through seven "AUGER"-type holes, which totalled 50 m. Subsequently, more boreholes were drilled to a lithological correlation and contents of U and P_2O_5 in the deposit, for a total of 22 boreholes in the area, totalling 955 m of drilling.

Geochemistry of the Navay deposit

According to these studies, in the Las Tapas-La Lucha-Las Adjuntas there are surface enrichments with an average of 16% P_2O_5 and 106 ppm U for a thickness of 5 m and extending for about 200 Ha. The U resource would be 3,226 metric tons based on an average concentration of 0.01% U in the rock, and P_2O_5 content would be 4,839,000 tons based on an average concentration of 15% P_2O_5 in the rock [4].

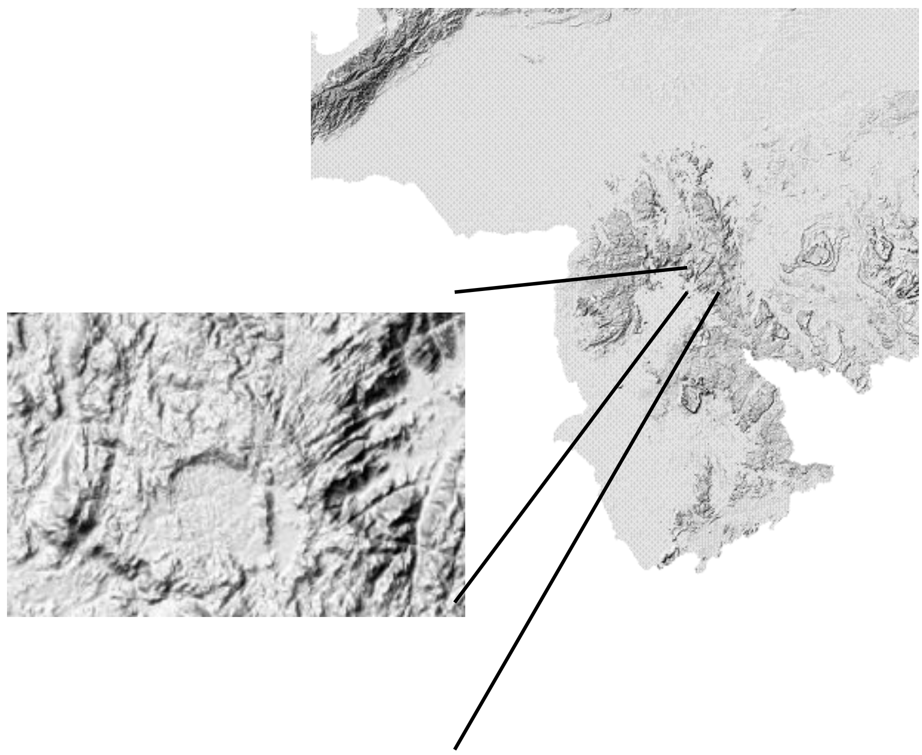
A geochemical study was recently conducted on several samples of the Navay deposit [8], using different analytical techniques: portable X-ray fluorescence (pXRF), total reflection X-ray fluorescence (TRXRF) and inductively coupled plasma atomic emission spectroscopy (ICP-AES). The background concentration of U is 102 ppm, reaching a maximum value of 160 ppm in a calcareous phosphatic sandstones. According to the chemical composition of the samples, most correspond to phosphatic rocks (median 17.25% and maximum 24.81% P_2O_5), quartz sandstones (median 25.60% and maximum 88.70% of SiO_2) and phosphatic limestones (median 27.88% and maximum 70.40% of CaO) [8].

In this case study, sub-anomalous and anomalous values of other metals with economical interest were found in the Navay deposit: Cu (261 ppm), Zn (268 ppm), and zirconium (Zr) (510 ppm), as well as anomalous values of chromium (Cr) (1653 ppm) [8].

Geology of the Cerro Impacto deposit

In Venezuela, there is a lateritic deposit containing an estimated 300,000 t of Th, called Cerro Impacto, that also hosts two important elemental associations: Th-Nb-Ti (titanium)-Zn and Ba-Ce (cerium)-REE [9]. The Cerro Impacto is located south of the Cedeño District of Bolivar State, almost on the boundary line with the Amazonas State and approximately at the intersection of the 6th parallel north latitude with the meridian 65° 10' west longitude (Figure 2).

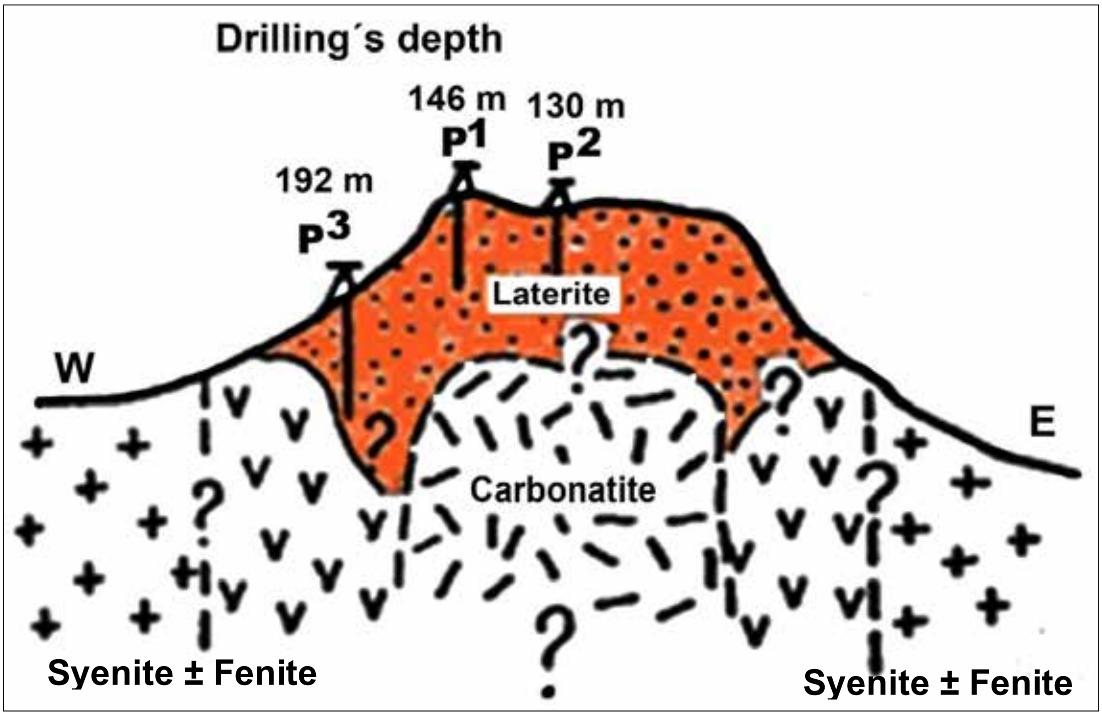
Figure 2. **Location of the Cerro Impacto**



It is elongated from north to south hill, nearly 10 km long and 2 km wide, bounded on the north and south by two smaller hills, called Cerro Norte and Cerro Sur, respectively. They are bordered by two rivers (north and south), which are in turn collected by the principal river called Sabueso, part of the headwaters of the river Cuchivero. All three hills are surrounded by an almost circular valley, approximately 18 km in diameter [9].

The Cerro Impacto has a complex geological constitution. The central, prominent part of the hill is covered with a thick lateritic mantle whose thickness is not yet known but should not be less than 250 m according to information obtained from the surveys. This laterite is a mostly goethite ferruginous type with smaller and variables quantities of manganese and aluminium in lower abundance [9]. In the area of Cerro Impacto, outcrops are entirely altered rocks and enriched in secondary phosphate, barium (Ba), aluminium and rare earth elements. The only occurrences of unaltered mineral, which is apparently in the primary rock on the hill, are fragments of barite ($BaSO_4$) mass medium to coarse-grained and with white to very dark colours [10].

Figure 3. **A cross-section of Cerro Impacto showing drillings**



Altered rock that forms a band or halo surrounding the central part of Cerro Impacto is possibly syenite. This rock can be a finite, which can occur in complex carbonatite derived by the alkaline metasomatic alteration of surrounding quartz-feldspathic rocks, such as granites and gneisses. This can be corroborated by the granitic rocks in the zone, both in the surrounding valley and in the immediate vicinity, which follows the band or halo of apparent fenitization. The rock that forms the core of Impacto, from which the laterite seems to derive, is not yet known because it is completely covered by a thick lateritic mantle. However, according to the associations of elements, it has been concluded to be a carbonatite intrusion [9] (Figure 5).

Geochemistry of the Cerro Impacto deposit

According to chemical analyzes of samples of laterite, the major elements present are: Fe, manganese (Mn), Al, Ba (not always present), Ce and Ti. Minor elements are: Ba, Ti, Ce, lanthanum (La), niobium (Nb), Pb, Zn, Th, Si, and sometimes strontium (Sr) and vanadium (V). Trace elements are mostly: Sr, V, praseodymium (Pr), neodymium (Nd), samarium (Sm), gadolinium (Gd), (Y), Zr and Cu and sometimes scandium (Sc), sulphur (S), beryllium (Be), Ni, Co, bismuth (Bi), tin (Sn), molybdenum (Mo), gold (Au) and silver (Ag). U was not detected (corroborated by analysis of gamma spectrometry) or radium (Ra).

The laterites consist essentially of hydrated oxides of Fe, Mn and Al. Two geochemical associations were established regarding elements which are minority:(1) Nb, Th, Ti and Zn, with erratic Pb enrichments, and (2) Ba, Ce and other rare earth elements (La, Nd, Sm, Y) [9]. Aarden et al. (1973) [10] indicate that the association of rare earth elements (REE) in the Impact is primarily Ce, which indicates that the most abundant elements in the deposit are the light REE (Ce, La, Pr, Nd, Sm and Eu), which indicates the presence of monazite.

The concentration values of some reported by several authors, in samples of the central part of Cerro Impacto elements are shown in Table 2.

Table 2. **Concentration of certain elements in the laterite samples from the central part of Cerro Impacto**

Element	*Concentration (%)*	*Content x 1,000 metric tons*
Ti	1.8	1,944
Mn	0.38	410
Fe	50	54,000
Zn	0.583	636
Nb	0.45	583
REE	0.7012	757
Nd	0.0141	20.3
Pb	0.233	251
Th	0.3	324

Geophysical Description of the Cerro Impacto Deposit

Magnetometry and gamma-ray spectrometry techniques were used for the study of the whole Cerro Impacto and North Hill. Using magnetometric analysis, it was determined that there is a lithological variation between the two areas because there is a change in the magnetic susceptibility of the rocks [10].

Furthermore, the study of gamma-ray spectrometry discriminated between K (potassium), equivalent Th (eTh) and equivalent U (eU). The survey obtained satisfactory parallelism between measurements of anomalous eTh in the area compared to those observed by chemical analysis of X-ray fluorescence values of rock samples [10]. The presence of eTh and absence of eU was confirmed by chemical analysis data. These abnormalities of Th were also detected by radioactivity measurements using thermoluminescence dosimetry [11]; the radioactivity measurements were similar to the Th concentrations obtained via X-Ray Fluorescence.

Mineralogy of the Cerro Impacto deposit

Rutile, anatase and brookite were identified, accounting for the Ti concentrations in laterites. X-ray diffraction did not identify minerals that contain Nb, Th, Zn or Pb. Sifontes (1975) [9] indicates that these metals appear to be absorbed and distributed evenly in the mineral components in laterites (hydrous oxides of Fe, Mn and Al), or occur as crystallized form or amorphous compounds at too low concentrations too low to be detected by diffraction X-ray [10]. However, other minerals identified in many samples correspond to monazite, and barite and laterite samples obtained from drill holes contained bastnasite (Ce, La, rare earths)(CO_3F).

In samples with significant concentrations of Ba and Ce, barite and monazite were not identified, but instead a member of the gorceixite-goyacite series $BaAl_3(PO_4)(PO_3OH)(OH)_6$ - $SrAl_3(PO_4)(PO_3OH)(OH)_6$ was found. These secondary phosphates are very variable in composition, allowing replacement of almost free cations and may contain rare earths, Pb, Zn and Th as the elements located in the middle [10].

Recent studies of mineralogy of samples from Cerro Impacto [12], using various techniques such as optical microscopy, X-ray diffraction and electron microprobe, identified these mineral phases: Goethite FeO(OH) and hematite Fe_2O_3 as major minerals , and as minor phases, Ilmenorutile $(Ti,Nb,Fe)O_2$, columbite $FeNb_2O_6$, rutile TiO_2, monazite $(Ce,La,Nd,Th)PO_4$, leucoxene $FeTiO_3$, allanite $(Ce, Ca, Y)_2(Al,Fe)_3(SiO_4)_3(OH)$ and quartz SiO_2.

Based on the evidence obtained by geochemical, geophysical and geological analysis, it suggests that the Impacto laterites are derived from a series of rocks belonging to a carbonatite complex with a great similarity with the deposit of Mrima Hill in Kenya and Araxá in Brazil. These deposits are similarly topographic prominences covered by ferruginous laterites and residual soils containing Nb, Th and rare earth elements in which minerals of the goyacite-gorceixite series is a common constituent of the soils. From the economic standpoint, the most important elements are Th, Nb (Table 3), rare earth elements, Zn and Pb.

Table 3. **Resources and average tenor of Th and Nb in Cerro Impacto laterites [10]**

Element	*Metric tones*	*Tenor average (%)*
Th	324,000	0.30
Nb	583,200	0.45

In this case study, the Cerro Impacto deposit can be considered a multi-element deposit for which a study could include the calculation of resources for several items that currently are valuable such as Nb, REE, Zn and Pb. If the economic feasibility study is positive, thorium could be extracted as a by-product of the other metals. Metallurgical tests must be made on samples from around the deposit to evaluate possible industrial extraction processes.

Uranium resources

Venezuela reported in the NEA/IAEA "Red Book" of 1986 and 1988 [2] a total of 163,000 metric tons of uranium as undiscovered resources, based on exploration plans undertaken in the country in the 1970s in several areas, such as the Guiana Shield, the Andes, Eastern basin and other areas with anomalies. The only uranium deposit that was determined is the Navay phosphatic deposit. Table 4 [2] lists the uranium resources in Venezuela, assigned as Reported Undiscovered Resources, in the category of Speculative Resources in the range Costs Not Assigned, according to the Red Book classification.

For this case study, the United Nations Framework Classification for Resources (UNFC) was applied. UNFC is a system for classification and presentation of information on energy and mineral resources that is accepted universally and applied internationally. It is a generic system based on principles on which the amounts are classified according to the three fundamental criteria of economic and social viability (E), status and viability of projects in the field (F), and geological knowledge (G) by a numerical coding [13]. Combinations of these criteria result in a three-dimensional system

In the case of unconventional uranium resources in Venezuela, in the "Red Book" of 1986 and 1988, the resources associated with phosphate rock (42,000 metric tons U in Table 5), are calculated approximately based on the exploration studies of the Navay deposit. According to UNFC, this deposit would be in the Category E3, F3, G4. This means that the Navay deposit is considered as an Exploration Project. The E3 Category has been assigned to the uranium quantities in this deposit, as it an unconventional uranium resource in phosphate rock, has low tenor, and the recovery of uranium as the primary commodity will not be economically viable in the foreseeable future. Uranium production could be possible as a by-product of phosphate mining and phosphoric acid production. Hence the phosphate mining and phosphoric acid production by a potential fertilizer industry must be investigated for its socio-economic viability before the recovery of uranium as a by-product could be considered.

The Category E3 is assigned because the extraction and sale of uranium is not expected to become economically viable in the foreseeable future. There is an internal demand for phosphates to produce fertilizers, but the evaluation is at too early a stage to determine the economic viability. Hence, production of uranium is not expected in the foreseeable future. This could change if progress is made in investigating the socio-economic viability of the phosphate and phosphoric acid production. If such a study is undertaken in the future, the classification of the uranium project could be reassessed and assigned to a higher E Category.

The F3 Category defines that the feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data. Mineral enrichment studies have not yet been done for phosphate, silica or the secondary recovery of uranium from phosphates for this project, although there are similar deposits worldwide, where recovery of uranium from phosphoric acid has been demonstrated [14].

The G4 Category has been assigned as the estimated quantities of uranium associated with a potential deposit are based primarily on indirect evidence. Some drilling has been carried out to date, but more is required to calculate resources with greater confidence. The quantities could be assigned to G3 if more exploration is carried out. Based on the recent geochemical evidence, there are anomalous uranium values in layers of phosphate sandstones of the Navay deposit which could be further drilled and investigated.

In conclusion, the Navay project is considered as an Exploration Project. This site could be developed to produce raw material for the fertilizer industry, and subsequent recovery of uranium also could be possible. However, more detailed geological and geochemical exploration are needed to calculate the resources of P_2O_5, SiO_2, U and other metals of economic interest. Likewise, technical feasibility studies must be done, including ore mineral beneficiation tests and consideration of the aspects of NORM (Natural Occurrence Radioactive Materials) [15]. This project could be considered as a project that promotes food sovereignty with an environmentally-friendly manufacturing process because if uranium is not separated from phosphate it can be used for fertilizers, soil and food.

Table 4. **Reported undiscovered resources (in 1,000 tU as at 1 January 2013) [2]**

Country	Prognosticated resources			Speculative resources			Total SR
	Cost ranges			Cost ranges			
	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU	<USD 130/kgU	<USD 260/kgU	Cost range unassigned	
Venezuela	NA	NA	NA	0.0	0.0	163.0	163.0

NA = Data not available.

Table 5. **Unconventional uranium resources (1,000 tU reported in 1965-2003 [2])**

Country	Phosphate rocks	Non-ferrous ores	Carbonatite	Black schist/shales, lignite
Venezuela	42	NA	NA	NA

NA = Data not available.

Thorium and Niobium resources

In the case of Thorium (Th) resources in Venezuela, the Cerro Impacto deposit contains an estimated total of 324,000 metric tons of Th, and 583,200 metric tons of niobium(Nb), calculated approximately from analysis of samples obtained from several holes drilled into the thick laterite. Because Th nuclear fuel is not globally used at this time, this Th does not have a market; thus, the classification of the Th resources for this case study has only one category, resources identified. Accordingly, Venezuela has 324,000 tons of identified Th resources in place.

The E3 Category refers to evaluation is at a stage too early to determine economic viability. The Th and Nb resources could be assigned to the Sub-Category E3.2, as the economic viability of extraction cannot yet be determined due to insufficient information.

The estimated quantities of Th and Nb are based on only a few boreholes. Hence the Category G3 is assigned for the project.

The F3 Category has been assigned to Th and Nb, as the feasibility of extraction by a defined mining operation cannot be evaluated due to limited technical data. The estimated quantities could be assigned to the Sub- Category F3.2 as the project activities are on hold and/or the justification as a commercial development may be subject to significant delay.

Applying UNFC to the thorium and niobium resources of the Cerro Impact deposit they are both assigned to the category E3.2, F3.2, G3. Hence the project is assigned as a Non-Commercial Project with the Sub-class Development Unclarified.

A more detailed geochemical exploration study is needed to evaluate the resources of Th and other metals that have commercial value at present in the deposits, such as REE, Nb, Fe, Ti. Additional metallurgical tests are also needed to evaluate the feasibility of extraction of these metals.

The Th (324,000 tons) and Nb (583,200 tons) and other possible co-occurring minerals such as REE in this deposit could have the potential to advance project to Potentially Commercial Project. Above all, the amounts and concentrations of Nb and REE need to be highlighted both of which have growing markets today; the demand for these metals has increased in recent years hence the extraction of Th could be considered as a by-product of the above elements.

The existing mineral resources (Th, REE, Nb, Fe, and Ti among others) will not be extracted by any mining project in the short term. Other factors to consider are the inaccessibility to the site (it is in the middle of the jungle), environmental aspects and its distance to towns, as well as possible social problems associated with indigenous populations.

Conclusions

The Navay deposit with 42,000 metric tons of U is considered as an Exploration Project with UNFC categories E3 F3 G4 assigned to it (Table 6). This deposit could be developed to produce raw material for the fertilizer industry, and simultaneous recovery of uranium could be envisaged. However, a more detailed geological and geochemical exploration study is needed in order to calculate the resources of P_2O_5, SiO_2, U and other metals of economic interest. Likewise, mining feasibility studies must be done, including ore mineral benefit tests and consideration of aspects of NORM.

Table 6. **UNFC classification of U, Th and Nb resources of the Navay and Cerro Impacto projects**

Deposit/Project	*Estimated quantities*	*E*	*F*	*G*	*UNFC Class/Sub-class*
Navay (Phosphate U)	42,000 tU	3	3	4	Exploration Project
Cerro Impacto (Th)	324,000 tTh	3.2	2.2	3	Non-Commercial Project/Development Unclarified
Cerro Impacto (Nb)	583,200 tNb	3.2	2.2	3	Non-Commercial Project/Development Unclarified

In the case of the Th and Nb resources in Venezuela, the Cerro Impacto deposit contains an estimated total of 324,000 metric tons of Th and 583,200 tons of Nb, calculated from analysis of samples obtained from several holes drilled into the thick laterite. Th-based nuclear fuel is not used globally at this time, so in contrast to uranium, thorium does not have a significant market today but could be used as nuclear fuel in the future. Thus, the country needs to know its potentially available resources of Th and its development potential as a sub-product of tradable metals such as Nb and REE. By applying UNFC to the thorium and niobium resources of the Cerro Impact deposit, the deposit is assigned the category E3, F3.2, G3, which is a Non-Commercial Project with Sub-class Development Unclarified (Table 6).

Venezuela has occurrences of U and Th associated with several geological environments; however, there are no commercial deposits of U and Th. The Navay and Cerro Impacto deposits could be assigned to higher categories in UNFC based on future investigations that contemplate the mining of these commodities and others that currently have high value and demand such as P_2O_5, REE and Nb.

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Application of UNFC to Bioenergy Resources

Example: Quantifying bioenergy resources, Brazil

BP has played a central role in creating a new way for reserves and resources of renewable energy to be assessed on a like-for-like basis with fossil fuels.[15]

BP worked with the United Nations, industry, academia and other organizations to extend the United Nations Framework Classification for Resources (UNFC) used to assess petroleum and minerals to include renewables.

This will enable companies to make plans in which renewable and fossil fuel resources are considered on a similar measure – barrels of oil equivalent (boe). This also helps investors assess organizations and for governments and other agencies to develop an overall view of a country or region's energy resources.

The framework takes account of the technical and commercial maturity, as well as the social and environmental impact of renewables projects and their expected recoverability, in a comparable way to fossil fuel resources. This is possible because – although renewables are potentially infinite – the energy obtained from renewable projects is governed by a similar range of technical and economic factors as for conventional resources.

BP led the development of the resource classification for bioenergy and is one of the first companies to test it for a real-world project which it has done for its Brazilian biofuels business. Using this classification, BP has estimated that the commercial[16] bioenergy resources for its three Brazilian sugarcane ethanol plants[17] are 187.0 mmboe[18,19] of cumulative ethanol and power production that goes to the market over the expected asset lifetimes.[20]

There is the potential to see some further upside through additional projects and further efficiency improvements. For example, it is estimated that volumes could be increased by over 25% if sugar and non-sales volume of power were converted into saleable bioenergy products.

The assessment demonstrates the potential that renewable energy has in contributing to the energy resource base, as well as providing useful insights for opportunities to further extend the commercial resource base.

The work done by BP in testing the framework for bioenergy resources in Brazil marks an important milestone in attaining sustainable energy production and consumption, as called for in the Sustainable Development Goals.

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15 Source: https://www.bp.com/en/global/corporate/sustainability/climate-change/case-studies/quantifying-renewable-resources.html

16 UNFC classification: E1, F1, G1 + G2, where E1 refers to the highest classification under the socio-economic viability axis; F1 refers to the highest classification under the project feasibility axis, and G1 + G2 refers to best estimates of quantities recovered or produced.

17 BP's three Brazilian sugarcane ethanol plants, Tropical, Ituiutaba, and Itumbiara.

18 Million barrels of oil equivalent. Conversion of hydrous ethanol to boe: 1 bbl ethanol = 0.564 boe based on relative ethanol and crude lower heating values, assuming hydrous ethanol water content of 5%v/v. Conversion of power to boe: 1 GWhe = 1,666 boe based on thermal generation efficiency equivalence considering a modern power station operating at 38% efficiency.

19 The assessment is based on ethanol and power price assumptions consistent with BP's long-term crude planning assumptions, expected processing rates, availabilities and conversion efficiencies, and the best estimate of sugarcane ethanol plant lifetimes consistent with planned maintenance/sustain capex spend and the expected asset economic lifetime as achieved generally the sector.

20 This classification corresponds to the Society of Petroleum Engineers proved plus probable category (2P) commonly referred to as the best estimate of the petroleum resources. This is included for the purposes of comparison only.

Hypothetical cases studies

Five hypothetical case studies are provided below to demonstrate the potential use of the Specifications for application of UNFC to Bioenergy Resources to different types of bioenergy projects. All data and information are fictitious, and the examples are provided to illustrate how UNFC could be used.

Bioenergy case study 1: Cyclone Corn Ethanol

The specific objectives of this hypothetical case study are to demonstrate the treatment of an energy source (biomass in the form of corn) sourced via a system of purchase agreements, the accounting for potentially commercial projects, and policy/ regulatory support uncertainty. Please note that the case study has been abbreviated for clarity. Accordingly, it does not include the full range of documentary evidence to support the classification and underlying assumptions.

Project Location: Des Moines, Iowa, U.S.A.

Data date: 2014, Historical Data to 2005

Date of evaluation: 1 January 2015

Quantification method: Simulation-based on the business operating plan, technical data, historical feedstock and product pricing, and future forecast from a government agency.

Estimate type (deterministic/probabilistic): Deterministic (scenario).

Project Summary and Background

Cyclone Ethanol (Cyclone) has a corn-ethanol production facility in the State of Iowa that entered commercial service 1 January 2015. The operator has retained a third party to classify Renewable Energy Resources.

The Project includes a new ethanol production facility (the “Facility”) as the renewable energy extraction process, with which the operator Cyclone intends to produce 55 million gallons per year (“MGPY”) of denatured ethanol. The operator of the Project has executed contracts for the part of the supply of feedstock corn, offtake of the ethanol produced, and has obtained the necessary permits to construct and operate the Facility.

The Facility utilizes a design from an established technology provider that is employed at approximately 100 other corn ethanol production facilities. The conversion (extraction) process at the Facility produces; anhydrous ethanol, wet or dry distillers grains with solubles (WDGS or DDGS respectively), and inedible corn oil from yellow dent number 2 corn. Corn is supplied via conveyor from a grain elevator located adjacent to the facility. Cyclone permitted the Facility as a minor source of air emissions, allowing the operator to produce ethanol at a maximum production rate of 60 MGPY.

Renewable Energy Source biomass is available as yellow dent number 2 corn, the majority of which is grown by farmers within a 50-mile radius of the new facility. Corn is traditionally sold in bushels, with 1 bushel equal to 56 pounds of corn. Corn can be stored for long periods in grain bins, allowing year-round delivery of feedstock.

The principal Energy Product is denatured anhydrous ethanol meeting the specifications within the American Society of Testing and Materials (ASTM) standard specification *D4806 – 14 Standard Specification for Denatured Fuel Ethanol for Blending with Gasoline for Use* *as Automotive Spark-Ignition Engine Fuel*. The cyclone has sanctioned the installation of a biodiesel production system to produce biodiesel from the co-product corn oil, and it is currently in construction. Upon its completion on 1 January 2016, the Facility will be capable of producing biodiesel compliant with ASTM D6751 *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels* which is eligible for a biodiesel production tax credit of $1 per gallon produced. The biodiesel production tax credit is scheduled to expire on 31 December 2018, unless renewed by the U.S. Congress, and biodiesel production is uneconomic without the aforementioned tax credit. Cyclone is also examining the potential to produce cellulosic ethanol from the corn fibre. This cellulosic ethanol utilizes ASTM D4806 for the product quality specification but is eligible for certain tax credits, and another policy supports via the U.S. Renewable Fuel Standard (RFS) due to the greenhouse gas reductions compared to fossil-derived fuels. The cellulosic fuel production process is at the pilot testing phase; installation at the Facility would be the first commercial installation.

Project Definition

Bioenergy Source(s)

- U.S. Yellow Dent Number 2 Corn per U.S. Department of Agriculture (USDA) Federal Grain Inspection Service, *Grain Inspection Handbook*

The Yellow Dent Number 2 Corn is considered to be a Bioenergy Source within the definition set out in the Bioenergy Specification on the biogenic basis, and via the agricultural cropping, harvesting and re-cropping of the corn the rate of extraction does not exceed the rate of replenishment and the replenishment is via biomass of the same type.

Bioenergy Product(s) & Reference Point(s)

Table 1. **Bioenergy Product(s) & Reference Point(s)**

Energy Product	*Reference Point*	*Specification*	*Reporting Units*	*Supplemental Information*
Anhydrous Ethanol	Rail Car Loading Meter	ASTM D4806	Mill Gals	RFS “Renewable Fuel” Category D6
Biodiesel	Truck Loading Meter	ASTM D6751	Mill Gals	RFS “Biomass Based Diesel” Category D4
Anhydrous Cellulosic Ethanol	Rail Car Loading Meter	ASTM D4806	Mill Gals	RFS “Cellulosic Biofuel” Category D3

Non-Energy Product(s)

- DDGS
- Inedible Corn Oil

Authorisation and Commitment

The facility was constructed by Cyclone, and its performance testing was completed before commercial handover from the Engineering, Procurement, and Construction contractor to Cyclone on 31 December 2014. The facility has all the environmental permits and licenses necessary for commercial operation.

Product Approvals: Cyclone has registered the facility under the U.S. Environmental Protection Agency as a renewable fuel producer of D6 Renewable Fuel and is filing the documentation to register as a producer of D4 Biomass-Based Diesel.

Quantification

Operating Plan/Performance: The multi-year operating plan is based on the nameplate capacity of the Facility, 55 MGPY, which is considered to be the best estimate of future production levels. The highest confidence estimate was considered to be the EPC Contractor guaranteed production rate of 50 MGPY (91 per cent of the nameplate capacity). The low confidence production level has been assessed at 60 MGPY based on test runs and the maximum throughput under the existing permitting.

Grind margins are stable and have historically been positive. As a proxy for future economics, the operator collected local pricing information from January 2005 to December 2014 to calculate the operating margin per gallon of ethanol that the Facility would have enjoyed had it been in operation at that time.

Table 2. **Grind Margin**

Ethanol Margin Based on Historical Pricing (January 2005 to December 2014)	*Ethanol Price ($/gal)*	*DDGS ($/ton)*	*Corn ($/ton)*	*Natural Gas ($/MMBTU)*	*Margin ($/gal)*
Current (December 2014)	$2.02	$138	$3.77	$6.97	$0.60
Average	$2.06	$149	$4.37	$7.11	$0.46
Median	$2.11	$129	$3.82	$6.97	$0.36
Standard Deviation	$0.42	$60.20	$1.82	$2.06	$0.40
Maximum	$3.15	$299	$8.15	$12.42	$2.17
Minimum	$1.06	$68	$1.48	$3.30	$(0.06)
The probability that Grind Margin is Positive					96.7%
50% Exceedance Grind Margin					$0.36
90% Exceedance Grind Margin					$0.07
Number of Months Evaluated					120
Number of Months where Margin is greater than $0.00					116
Number of Months where Margin was equal to or less than $0.00					4

Project Lifetime: The Facility was designed for a 20-year service life and Cyclone has prepared a long term operating plan that includes both (1) major maintenance to renew or replace those capital equipment items that have a service life shorter than that of the Facility and (2) preventative and corrective maintenance spend to repair or replace equipment as necessary to support continued operation of the Facility. Provided that the Facility is operated and maintained consistent with generally accepted engineering practices and all required renewals and replacements are made on a timely basis, the high confidence level confidence estimate of the Facility technical lifetime is 20 years, moderate confidence level estimate is 25 years and a low confidence level estimate is 30 years. There is at this stage no proposal to re-invest in the Facility to significantly extend its operating life beyond 30 years.

Feedstock Access and Entitlement: The operator has executed a feedstock supply contract with a large privately-held commodity trader in which the trader guaranteed to supply 50% of the feedstock corn required to operate the plant, with liquidated damages equal to the cost to acquire alternative feedstock or lost revenues in the event of the trader's non-performance. The Term of the agreement is for ten years following the commercial operation date of 1 January 2015. Corn sourced under this agreement is assumed to be of the highest confidence.

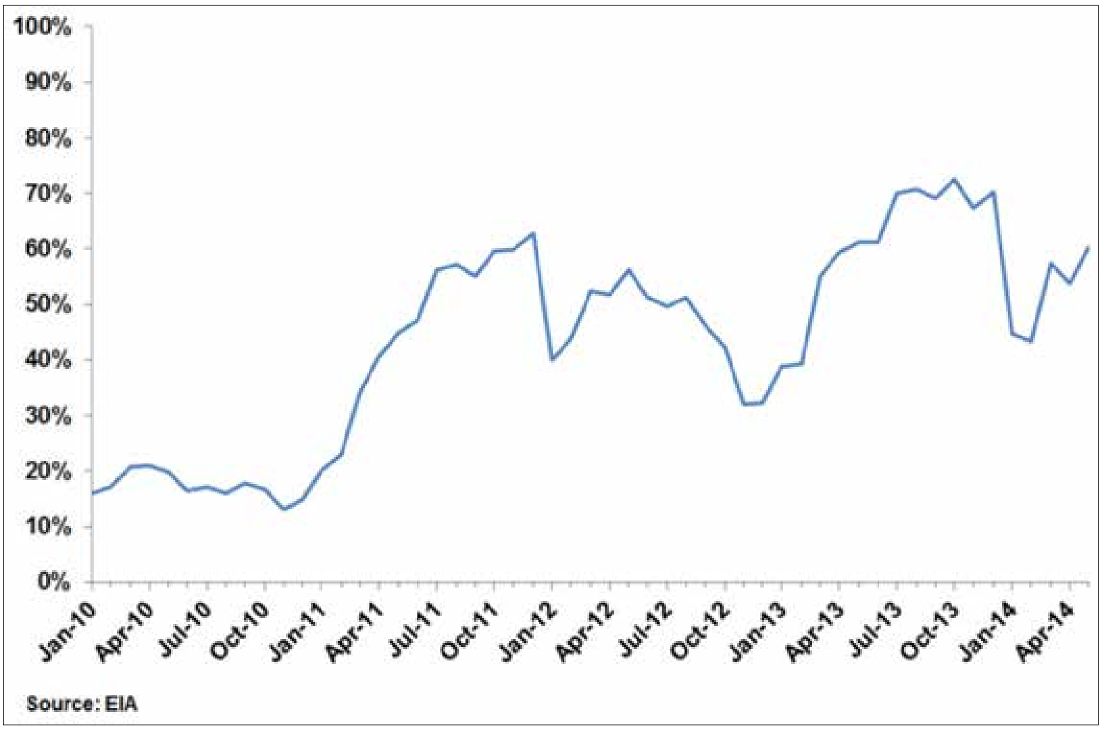
The remaining 50% of the feedstock corn is to be supplied by the local farmers on a spot basis at the grain elevator adjacent to the Facility. The cyclone has retained experienced grain origination personnel to schedule grain deliveries with local farmers as well as determine the daily grain pricing. The grain origination manager's prior employment was at an operating ethanol facility in Ames, Iowa, United States of America, approximately 20 miles north of the Cyclone facility. Given the historical performance of the grain origination personnel in the local market, the aggregate quantities from contract and spot are assumed to be the best estimate.

The cyclone has obtained the 10-year feedstock pricing forecast from the United States Department of Agriculture (USDA), and feedstock yields and pricing are both anticipated to be stable with minimal increases due to inflation and productivity gains.

Facility Access and Entitlement: Cyclone has 100% equity ownership of the Facility and intends to continue as the owner/operator of the Facility for the foreseeable future.

Monetization of Energy Products: The operator has entered into an ethanol marketing agreement for offtake of 100% of the ethanol produced at the Facility. The Term of the agreement is to be for ten years, with automatic one-year renewal periods. Offtake of biodiesel is to be to the same marketer based on the terms within the ethanol marketing agreement.

Figure 1. **Monthly U.S. Biodiesel Production Capacity Utilization Rate, January 2010 – May 2014**



In addition to revenues from the sale of biodiesel, the US Treasury provides a $1 per gallon biodiesel production credit. Cyclone is reliant on this credit for their biodiesel production to be economically viable. This credit comes in the form of a direct payment to Cyclone from the US Government. While the biodiesel production credit has been extended annually since 2005, the tax credit is scheduled to lapse 31 December 2018, unless extended by future legislation. Prior lapses in the tax credit have had a significant impact on utilization in the biodiesel industry, with reductions in utilization in January before the credit's retroactive extension as indicated in the following chart from the United States Energy Information Administration (EIA).

Policy Framework: The US Renewable Fuel Standard (RFS) establishes a blending mandate for the inclusion of renewable fuels within the US fuel pool. Ethanol produced at the Facility qualifies as Renewable Fuel under the RFS with a 20% greenhouse gas reduction, and biodiesel qualifies as Biomass Based Diesel with a 50% greenhouse gas reduction. The RFS blending requirements are set to increase through the end of 2022, after which the blend levels are to be adjusted annually by the EPA. The RFS is not subject to a sunset provision at this time. The $1 per gallon biodiesel production tax credit is independent of the RFS, and it was currently scheduled to sunset on 31 December 2018. The biodiesel tax credit has been extended several times in the past. However, its extension is not guaranteed.

While the RFS provides an incentive to blend ethanol, sales of ethanol are not wholly dependent on the RFS as ethanol producers discount their product as necessary to incentivize retail gasoline outlets to blend ethanol. If the RFS was abandoned, the resulting corn glut would likely reduce the cost to produce ethanol to the level required to incentivize the retailers to blend. In the event the price of corn drops below the cost of production; the USDA has a number of subsidy programmes that would enable the farmers to continue to produce corn.

Current Expansion: Cyclone has sanctioned and is constructing a biodiesel production unit to convert the inedible corn oil co-product into biodiesel.

Biodiesel production is economic at current commodity pricing levels with the $1 per gallon biodiesel production credit. Annual production for biodiesel production unit is anticipated to be 1 million gallons of biodiesel and is adjusted according to the Facility's ethanol throughput rate. Accordingly, the high confidence level production is 900,000 gallons per year, the moderate confidence production level is 1,000,000 gallons per year, and low confidence production level is 1,100,000 gallons per year.

Cyclone intends to use the inedible corn oil co-product to produce biodiesel, no other source of feedstock has been identified in the event ethanol production is halted.

Future Expansion: The operator is evaluating a cellulosic ethanol technology for inclusion within the Facility. The technology is a bolt-on cellulosic ethanol production unit which uses enzymes to break down corn fibre which is then fermented into ethanol.

Cellulosic ethanol is forecast to cost $5 per gallon of ethanol to produce. However, prices are falling such that production is expected to be economically feasible in 2 years. Approximately 35 per cent of the DDGS co-product is corn kernel fibre in the form of glucan or xylan which can be converted to sugars and fermented. The cellulosic ethanol technology provider guarantees a yield of 70 gallons of cellulosic ethanol per ton of corn kernel fibre-fed, while tests at Facility indicated that the yield of cellulosic ethanol is expected to be 80 gallons per tonne of corn kernel fibre-fed. The theoretical maximum conversion of the corn kernel fibre is 168 gallons per tonne. Based on these yields, the guaranteed capacity is expected to be (high confidence level) 3,900,000 gallons per year, the best estimate of yield based on testing (moderate confidence level) 4,500,000 gallons per year, and the theoretical conversion (low confidence level) 9,500,000 gallons per year.

UNFC Classification and Quantification

Table 3. **UNFC Classification and Quantification**

Class	*Sub-Class*	*Classification*	*Energy Products*	*Quantity*	*Units*
Commercial Project	On Production	E1 F1.1 G1	Ethanol	250	Mil gals
		E1 F1.1 G1+G2	Ethanol	1,375	
		E1 F1.1 G1+G2+G3	Ethanol	1,800	
	Approved for Development	E1.2 F1.2 G1	Biodiesel	1.8	
		E1.2 F1.2 G1 + G2	Biodiesel	24	
		E1.2 F1.2 G1 + G2 + G3	Biodiesel	31.9	
Potentially Commercial Project		E2 F2 G1	Cellulosic Ethanol	31.2	
		E2 F2 G1 + G2	Cellulosic Ethanol	103.5	
		E2 F2 G1 + G2 + G3	Cellulosic Ethanol	292.6	

E Category Classification and Sub-classification

Table 4. **E Category Classification and Sub-classification**

Project	*Category*	*UNFC Definition*	*Reasoning for classification*
On Production Ethanol Plant	E1	Extraction and sale has been confirmed to be economically viable	The plant is an operating viable concern, with all necessary approvals, authorisations and commercial contracts in place to produce ethanol.
	Sub-category	*UNFC Definition*	
Corn Oil Biodiesel Expansion	E1.2	Extraction and sale is not economic on the basis of current market conditions and realistic assumptions of future market conditions, but is made viable through government subsidies and/or other considerations.	Economic viability of biodiesel is dependent on regulatory support, specifically the $1 production tax credit. The uncertainty on future evolution (post-2018) of this legislation is considered in the G Axis categorisation.
	Category	*UNFC Definition*	*Reasoning for classification*
Cellulosic Ethanol from DDGS	E2	Extraction and sale is expected to become economically viable in the foreseeable future.	Cellulosic ethanol is anticipated to be economic within 2 years

F Category Classification and Sub classification

Table 5. **F Category Classification and Sub-classification**

Project	*Category*	*UNFC Definition*	*Reasoning for classification*
On Production Ethanol Plant	F1	Feasibility of extraction by a defined development project or mining operation has been confirmed	A current operational unit.
	Sub-category	*UNFC Definition*	
	F1.1	Extraction is currently taking place	

Table 5. **F Category Classification and Sub-classification (continued)**

Project	*Sub-category*	*UNFC Definition*	*Reasoning for classification*
Corn Oil Biodiesel Expansion	F1.2	Capital Funds have been committed, and implementation of the development project is underway.	Biodiesel unit is in construction.
	Category	*UNFC Definition*	*Reasoning for classification*
Cellulosic Ethanol from DDGS	F2	Feasibility of extraction by a defined development Project or mining operation is subject to further evaluation.	The project has access to Bioenergy Source, further development work at pilot scale is required prior to final sanction.

G Category Classification and Sub-classification

Table 6. **G Category Classification and Sub-classification**

	Reasoning for classification		
UNFC Definition	*G1*	*G1 + G2*	*G1 + G2 + G3*
	Quantities associated with a known deposit that can be estimated to a high level of confidence.	Quantities associated with a known deposit that can be estimated to a moderate level of confidence.	Quantities associated with a known deposit that can be estimated to a low level of confidence.
Project			
On Production Ethanol Plant	Annual ethanol production at 25 MGPY (high confidence level estimate of performance) for a period of 10 years. The period of 10 years is the aggregate high confidence level estimate based on 50 per cent of the biomass under contract for ten years. The high confidence level estimates the technical life of the asset (20 years) is not a constraining factor.	Annual production at 100% of the operating plan (moderate confidence level estimate) for a period of 25 years for ethanol based on the moderate confidence level technical life of the Facility.	Annual production at 110% of the operating plan (high confidence level estimate) for 30 years.
Corn Oil Biodiesel Expansion	Annual biodiesel production of 900,000 gallons for two years, the current expiry of the biodiesel tax credit.	Biodiesel annual production at 1,000,000 gallons per year for 24 years (is not to enter service until the beginning of the second year). Assumes spot contracts are available to the Project for the technical life of the Facility.	Biodiesel annual production at 110% of the operating plan (1,100,000 gallons per year) for 29 years (is not to enter service until the beginning of the second year). Assumes spot contracts are available to the Project for the technical life of the Facility.
Cellulosic Ethanol from DDGS	Annual cellulosic ethanol production of 3,900,000 gallons for eight years, assuming the g the start-up of the unit in 2 years following the date of the assessment and before the expiration of the long-term feedstock contracts.	Annual cellulosic ethanol production of 4,500,000 gallons for 23 years, assuming start-up of the unit in 2 years following the date of the assessment and the Facility operating at the best estimate production rate for the moderate confidence level technical life of the Facility.	Annual cellulosic ethanol production at 10,450,000 gallons per year for 28 years, assuming start-up of the unit in 2 years following the date of the assessment based on the low confidence level technical life of the Facility. The production rate is based on the theoretical conversion rate of 9,500,000 gallons per year increased by 110% to allow for the increased DDGS fibre supply due to the increased operating rate of the corn ethanol operations.

Glossary (Units)

Volume	
MGPY	Million Gallons (US) Per Year
Mill Gals	Million Gallons (US)

Bioenergy case study 2: Miscanthus cellulosic ethanol

This is a hypothetical case study/example to demonstrate a potential application of the Potential Resource category.

Project Location: North Tennessee, United States of America

Data date: 2015

Date of evaluation: 1 January 2016

Quantification method: Simulation-based on Miscanthus yield modelling and indicative performance data for a cellulosic ethanol process from a technology licensor.

Estimate type (deterministic/probabilistic): Deterministic (scenario).

Project Summary and Background

Company ACME is carrying out an initial screening/desktop study on for the location of a possible 50 mill gal cellulosic ethanol plant using Miscanthus as a feedstock. ACME has identified a potential location in North Tennessee, US. Miscanthus yield estimates are based on modelling, using University of Illinois work on yield mapping of Miscanthus and Switchgrass yields. Estimates for cellulosic plant performance based on indicative data proved by a cellulosic ethanol technology licensor.

Project Definition

Bioenergy Source(s)

Miscanthus Giganteus. Miscanthus is a fast-growing energy grass. It is a perennial crop that regrows after harvesting from rhizomes (rootstalk) over harvest cycles for up to 20 years, after which replanting can occur.

The Miscanthus accessed by the project has been assessed to be a Bioenergy Source within the definition set out in the Bioenergy Specification on the basis that:

(a) It is biogenic.

(b) The intended rate of extraction will not exceed the rate of replenishment. The project includes the agricultural activities necessary for the on-going cultivation and harvesting of the crop.

(c) The harvested Miscanthus will be replaced by Miscanthus either from regrowth or replanting or replanting with a similar species of energy grass.

Bioenergy Product(s) & Reference Point(s)

Table 7. **Bioenergy Product(s) & Reference Point(s)**

Energy Product	*Reference Point*	*Specification*	*Reporting Units*	*Supplemental Information*
Cellulosic Ethanol	Road/Rail Car Gantry Meter	Specification ASTM D 4806 (water 1.0%vol max)	US gals	

Non-Energy Product(s)

Nil

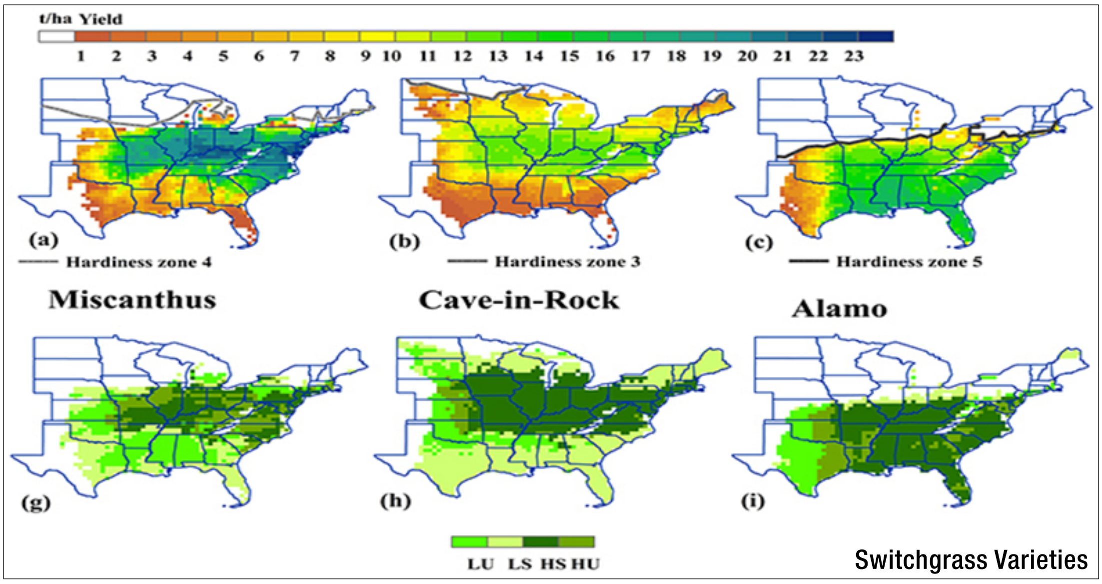
Authorisation and Commitment

The basis of this evaluation is ACME's initial screening (appraise) study. No regulatory approval has been sought or is required at this stage of project evaluation. No commercial contracts, e.g. land options, have yet been entered into.

Quantification

Miscanthus Yield Data: Based on the Miscanthus and Switchgrass yield modelling work carried out by the University of Illinois Estimates of Biomass Yield for Perennial Bioenergy Grasses in the USA, Yang Song, Atul K. Jain, William Landuyt, Haroon S. Kheshgi, Madhu Khanna 2014 (available at: http://rd.springer.com/article/10.1007%2Fs12155-014-9546-1).

Figure 2. **Miscanthus Yield Data**



Conversion Performance: Based on indicative data (no performance guarantees, not project-specific) provided by the cellulosic ethanol technology licensor, the evaluation is assuming an ethanol conversion of 80 gals ethanol/oven dry tonne of Miscanthus. The plant is energy (steam & power) sufficient due to the firing of the stillage and a proportion of the Miscanthus feedstock. There are no power exports for sales.

Since both the estimates for Miscanthus yields and conversion plant performance are based on indirect evidence, they are classified as G4 estimates, that is estimates based primarily on indirect evidence.

Project Lifetime: The best estimate assumption of 30 years based on guidance from the potential technology licensor.

Feedstock Supply Access and Entitlement: ACME has carried out a preliminary review of the potential land availability in a potential supply envelope around the plant's proposed location. The review has considered the feasibility of leasing sufficient land for various landowners/farmers in an approximately 50 km radius of the location to supply the plant with sufficient feedstock (approximately 625 Kodte pa) to support production of 50 mill gal. The review has also considered the possibility of alternative feedstocks such as corn stover, to provide a supplemental supply. The review indicates that the best estimate is that sufficient feedstock can be secured for 20 years that is for two crop planting cycles.

No land optioning has occurred yet.

Conversion Plant Access and Entitlement: ACME is assumed to have 100% equity of the plant.

Monetisation of Energy Products: ACME's preliminary discussions with the United States Environmental Protection Agency and the California Air Resources Board (CARB) indicate that the cellulosic ethanol will respectively qualify as a cellulosic biofuel under the Federal Renewable Fuels Standard cellulosic Renewable Volume Obligation (RVO), and will additionally qualify for a carbon intensity of approximately 20 g CO_2eq/MJ under the California Low Carbon Fuels Standard. Moreover, the data from the technology provider indicates that advances in the cellulosic biotechnology package will enable cellulosic ethanol's production cost to become competitive with gasoline in the next ten years. ACME preliminary discussions with several US fuel suppliers demonstrate that there would be interest in overtake agreements for the plant's production for durations of up to 10 years. Based on the above ACME has determined that there is sufficient evidence that the plant's production of cellulosic ethanol can be economically monetised.

UNFC Classification and Quantification

Table 8. **UNFC Classification and Quantification**

<table>
<tr><th>Class</th><th>Class</th><th>Classification</th><th>Energy Products</th><th>Quantity</th><th>Units</th></tr>
<tr><td rowspan="2">Potential Resource</td><td>Exploratory Project</td><td>E3.2 F3 G4.1+4.2</td><td>Ethanol</td><td>1,000</td><td rowspan="2">Million US Gals</td></tr>
<tr><td>Additional quantities in place associate with a potential resource</td><td>E3.3 F4 G4.1+4.2</td><td>Ethanol</td><td>3,179.4</td></tr>
</table>

E Category Classification and Sub-classification

Table 9. **E Category Classification and Sub-classification**

Category	*UNFC Definition*	*Reasoning for classification*
E3	Extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability.	Project is at its early initial screening/appraise stage.
Sub-category	*UNFC Definition*	
E3.2	Economic viability of extraction cannot yet be determine due to insufficient information (e.g. during the exploration phase).	
Sub-category	*UNFC Definition*	
E3.3	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.	Considers the difference of the total energy supplied to the plant as defined by the cumulative lower heating value of Miscanthus vs. the cumulative energy (lower heating value) of the cellulosic ethanol extracted assuming an ethanol conversion of 80 gal ethanol / oven dry te of Miscanthus. Potential for improvements in conversion efficiency not considered at this stage.

F Category Classification and Sub-classification

Table 10. **F Category Classification and Sub-classification**

Category	*UNFC Definition*	*Reasoning for classification*
F3	Feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data.	Assessment based on Miscanthus yield modelling data and indicative cellulosic ethanol performance data.
F4	No development project or mining operation has been identified.	No feasible technical option assumed to be available to increase either Miscanthus yields and subsequent conversion beyond 80 gals ethanol/oven dry te of Miscanthus.

G Category Classification and Sub-classification

Table 11. **G Category Classification and Sub-classification**

	Reasoning for classification	
UNFC Definition	*G4*	*G4.1 + G4.2*
	Estimated quantities associated with a potential resource based on indirect evidence	Best estimate of the quantities
Project		
Exploratory Project	Assessment based on indirect evidence in the form of Miscanthus yield modelling (c.f. crop trials at the proposed location) and indicative cellulosic ethanol process performance (c.f. pilot plant data and/or process guarantees).	Assessment based on the following best estimates assessments: Miscanthus yield: 20 dry te/ha/yr Land required: 31.3 K ha Total Miscanthus supplied: 25 Kodte/yr Ethanol Conversion: 80 gal / odte /yr Plant Lifetime & Feedstock Supply: 20 years
Additional quantities in place associated with a potential resource		Assessment based on the un-extracted energy in the Miscanthus represented by the difference of its lower heating value (17.95 GJ/dry te) and the energy of the ethanol recovered (Lower Heating Value 21.28 GJ/m3).

Glossary (Units)

Volume	
Mill gal	Million US gallons
Mass	
Kodte pa	Thousand oven dry metric tonnes per annum

Bioenergy case study 3: Biopower

This is a hypothetical case-study/example produced with the purposes of demonstrating the application of the UNFC Bioenergy Specifications. The specific objectives are to provide a biopower case study that demonstrates the treatment of an energy source (biomass in the form of wood pellets) sourced via a long-term contract. Please note that the case study has been abbreviated for clarity. Accordingly, it does not include the full range of documentary evidence to support the classification and underlying assumptions.

Project Location: Sault Ste. Marie, Ontario, Canada

Data date: 016, Historical Data to 2000

Date of evaluation: 1 July 2017

Quantification method: Simulation-based on the business operating plan, technical data, forecast feedstock pricing, and fixed product pricing based on government contract

Estimate type (deterministic/probabilistic): Deterministic (scenario)

Project Summary and Background

Soo Power (Soo) is currently constructing a biomass power generation facility in the Canadian Province of Ontario that is scheduled to enter service on 1 January 2018. The operator has retained a 3rd party to classify Renewable Energy Resources.

The Project includes a new biomass power facility (the Facility) of 60 megawatts (MW) capacity for the renewable energy extraction process, with which Soo intends to produce 417,000 megawatt-hours (MWh) per year of renewable power. The operator of the Project has executed contracts for the long-term supply of wood pellets, has secured a 20-year Feed-In-Tariff contract for power offtake with the Independent Electricity System Operator (IESO) of Ontario, and has obtained the necessary permits to construct and operate the Facility.

The Facility utilizes a bubbling-fluidized-bed (BFB) boiler and steam-turbine-generator (STG) from established technology providers that are commercially established in the power generation market. The conversion (extraction) process at the Facility produces renewable power and a co-product ash stream which is sold for de minimis value as a fertilizer. Wood pellets are supplied via barge from a third-party pellet production facility located on the west side of Lake Superior in Thunder Bay, Ontario. Soo permitted the Facility with the Ontario Ministry of the Environment and Climate Change (MOE), allowing the operator to produce power at a 60 MW nominal capacity.

Renewable Energy Source biomass is available from Lakehead Pellet Company (Lakehead) in a commodity grade produced for sale to Canadian and European clients. Lakehead's renewable biomass pellet production plant is a 500,000 metric tonnes per year (tpy) plant using yellow pine as its principal feedstock. Pellets can be stored for long periods in bins, allowing year-round delivery of feedstock.

The principal Energy Product is renewable electrical power; the Facility is directly connected to the IESO grid using a 115 kilovolt (kV) substation according to the requirements of the Interconnection Agreement (IA) with IESO.

Project Definition

Bioenergy Source(s)

- Lakehead "Standard" grade pellet - pellet specification: a minimum net caloric value of 16.5 megajoules per kilogram, total moisture between 5 and 10 per cent, a maximum ash content of 1.5 per cent, and a tamped bulk density of 650 to 750 kilograms per cubic metre (kg/m^3).

The wood pellets are considered to be a Bioenergy Source within the definition set out in the Bioenergy Specification on the basis that they are biogenic, and via the forestry operations of harvesting and re-cropping that the rate of extraction does not exceed the rate of replenishment and the replenishment is via biomass of the same type.

Bioenergy Product(s) & Reference Point(s)

Table 12. **Bioenergy Product(s) and Reference Point(s)**

Energy Product	*Reference Point*	*Specification*	*Reporting Units*	*Supplemental Information*
Renewable Electricity	IESO Utility Meter at Substation	N/a	kWh	Renewable Biomass required to comply with FIT 2.0 Exhibit A

Non-Energy Product(s)

- Ash

Authorisation and Commitment

The Facility is currently in construction and is scheduled to reach commercial operation on 1 January 2018 (the COD). The facility has all the environmental permits and licenses necessary for commercial operation.

Product Approvals: Soo is to file paperwork with the IESO indicating that the biomass is from a renewable source and that Soo has complied with the various provisions of the IA, metering plan, and has achieved COD.

Quantification

Operating Plan/Performance: The multi-year operating plan is based on an availability factor of 89 per cent, an annual net capacity of 53.5 MW, yielding 417,000 MWh/year based on a net heat rate of 12,400 British Thermal Units per kWh (Btu/kWh). The highest confidence estimate was estimated to be at a reduced availability case of 84 per cent, yielding 394,000 MWh/yr and the low confidence level case has been estimated with an availability factor of 94 per cent, yielding 440,000 MWh/yr. The high and low availability cases are Soo's estimates based on operations at their other biomass power operations.

The Facility does have the potential to increase the efficiency of the conversion from wood pellets (reduce the heat rate); although the costs to do so are not expected to be economically viable within the foreseeable future nor the methodology by which it could be done been identified. The design efficiency of the Facility is 27.5 per cent (3,412/12,400), as an early estimate, Soo considers the high confidence level case to be a 5 per cent reduction in the heat rate to 11,780 Btu/kWh (29.0 per cent efficiency), the moderate confidence level case to be a 10 per cent reduction in the heat rate to 11,160 Btu/kWh (30.5 per cent efficiency), and the low confidence level case to be the theoretical heat rate of 7,260 Btu/kWh (efficiency of 47 per cent).

Project Lifetime: The Facility was designed for a 20-year service life, and provided that the Facility is operated and maintained consistent with generally accepted engineering practices and all required renewals and replacements are made on a timely basis, the high confidence level confidence estimate of the Facility technical lifetime is 20 years, moderate confidence level case estimate is 25 years and a low confidence level estimate is 30 years. There is at this stage no proposal to re-invest in the Facility to significantly extend its operating life beyond 30 years. The FIT contract term is for 20 years from COD; this term cannot be extended under the existing FIT programme. Biomass power would not be economic selling into the wholesale electricity markets at this time.

Feedstock Access and Entitlement: Soo has executed a 10-year pellet supply contract with Lakehead, the pellet supply contract includes successive one-year renewal terms unless one of the parties terminates the agreement via written notice six months before the end of the term or a renewal term. Lakehead has signalled their intent to supply pellets for the full 20-year term as Soo's FIT contract allows them to pay higher prices for pellets than Lakehead can obtain via other outlets (the European spot market). Lakehead has assigned any rights they might have to classify reserves to Soo as a condition of the pellet supply contract.

Facility Access and Entitlement: Soo has 100% equity ownership of the Facility and intends to continue as the owner/operator of the Facility for the foreseeable future.

Monetization of Energy Products: Soo is to receive CAD$0.156 per kWh of electricity under the FIT 2.0 pricing Schedule in effect at the time of execution of the FIT contract. Soo is an IESO Market Participant so direct payments are made from the IESO to Soo every month based on the kWh reading at the IESO controlled meter in the 115 kV substation that services the Facility. Transmission losses from the substation to the high voltage lines are borne by IESO. Soo's FIT contract is for a term of 20 years following COD; the FIT term cannot be extended.

Policy Framework: The Ontario Feed-In-Tariff was developed as a result of the Ontario Green Energy Act (GEA) to promote the greater use of renewable energy resources by establishing a standard method to contract for renewable energy generation, offering stable prices and long term contracts. Funds to pay the FIT electricity rates are generated via the Global Adjustment, a cost added to the market price of electricity within Ontario.

Future Expansion: The FIT contract does not permit an increase in the contract capacity, so Soo does not have any plans for expansion at this time.

UNFC Classification and Quantification

Table 13. **UNFC Classification and Quantification**

Class	Sub Class	Classification	Energy Products	Quantity	Units
Commercial Project	Approved for Development	E1.2 F1.2 G1	Electricity	7,880	thousand MWh
		E1.2 F1.2 G1 + G2	Electricity	8,340	
		E1.2 F1.2 G1 + G2 + G3	Electricity	8,800	
Non-sales Production		E3.1 F1.2 G1	Electricity	957	thousand MWh
		E3.1 F1.2 G1 + G2	Electricity	1,014	
		E3.1 F1.2 G1 + G2 + G3	Electricity	1,070	
Additional Quantities in Place		E3.3 F4 G1	Electricity	23,296	thousand MWh
		E3.3 F4 G1 + G2	Electricity	24,659	
		E3.3 F4 G1 + G2 + G3	Electricity	26,022	

E Category Classification and Sub-classification

Table 14. **E Category Classification and Sub-classification**

Category	UNFC Definition	Reasoning for classification
E1	Extraction and sale has been confirmed to be economically viable	Power plant investment sanctioned and construction underway. Investment case demonstrates economic viability under the project economic and commercial assumptions, including the provision of a 20 Feed-in- Tariff (FIT).
Sub-category	***UNFC Definition***	
E1.2	Extraction and sale is not economic on the basis of current market conditions and realistic assumptions of future market conditions, but is made viable through government subsidies and/ or other considerations.	Economic viability of renewable biomass power production in Ontario is made possible via the subsidized FIT rate due to the GEA for a period of 20 years.
E3.1	Quantities that are forecast to be extracted, but which will not be available for sale	The parasitic loss between the gross power output of 60MW and the net power output of 53.5MW, at a capacity factors of 84%, 89%, and 94% for G1, G1+G2, and G1+G2+G3 respectively.
E3.3	On the basis of realistic assumptions of future market conditions it is currently considered that there are not reasonable prospects for economic extraction and sale in the Foreseeable Future	Efficiency improvements have not been identified nor are there prospects for the improvements to be economically viable in the foreseeable future. Additional quantities in place estimated based on design efficiency.

F Category Classification and Sub-classification

Table 15. **F Category Classification and Sub-classification**

Category	UNFC Definition	Reasoning for classification
Sub-category	***UNFC Definition***	
F1.2	Capital Funds have been committed and implementation of the development project is underway.	Facility is in construction, but is not anticipated to enter service until 6 months following the date of the classification.
F4	In situ quantities that will not be extracted by a currently defined development project	Improvements necessary to increase the efficiency have not been identified.

G Category Classification and Sub-classification

Table 16. **G Category Classification and Sub-classification**

	Reasoning for classification[1]		
UNFC-Definition	***G1***	***G1 + G2***	***G1 + G2 + G3***
	Quantities associated with a known deposit that can be estimated to a high level of confidence.	Quantities associated with a known deposit that can be estimated to a moderate level of confidence.	Quantities associated with a known deposit that can be estimated to a low level of confidence.
Project			
Commercial Project	Annual electrical production at 84 percent availability (high confidence level estimate of performance) for a period of 20 years. The period of 20 years is based on the term of the FIT contract (from COD). Biomass supply contract is for 10 years, and renewable for successive years under common commercial terms. The high confidence level estimates the technical life of the asset (20 years) is not a constraining factor.	Annual production at 100% of operating plan (moderate confidence level estimate) with production at 89 percent availability for a period of 20 years. The period of 20 years is based on the term of the FIT contract (from COD). Biomass supply contract is for 10 years, and renewable for successive years under common commercial terms. The moderate confidence level estimates the technical life of the asset (25 years) is not a constraining factor.	Annual electrical production at 94 percent availability (low confidence level estimate of performance) for a period of 20 years. The period of 20 years is based on the term of the FIT contract (from COD). Biomass supply contract is for 10 years, and renewable for successive years under common commercial terms. The low confidence level estimates the technical life of the asset (30 years) is not a constraining factor.
Non-Sales Production	The parasitic loss of 6.5 MW under the respective G1, G1+G2, and G1+G2+G3 operating conditions as follows:-		
	84% availability for a period of 20 years.	89% availability for a period of 20 years.	94 % availability for a period of 20 years.
Additional Quantities in Place	An estimate of the energy (expressed in MWh) not recovered from the wood chip after net power output (sales) and parasitic load, for the G1, G1+G2, and G1+G2+G3 case respectively. Calculated as (Net Power Output+ Parasitic Load)/ (1/efficiency -1), where efficiency is taken as the design efficiency of 27.5%.		
1) It is noted that all cases assume a Project Lifetime of 20 years determined by the length of the FIT contract, and that a second Project based on an extension and or new FIT contract may be possible provided that additional investments are planned to extend the physical lifetime of the Facility.			

Glossary (Units)

Power / Energy	
BTU	British Thermal Units
MW	Megawatts
MWh	Megawatt Hours
KWh	Kilowatt Hours

Bioenergy case study 4: Sugarcane ethanol

This is a hypothetical case-study/example produced with the purposes of demonstrating the application of the Bioenergy Specifications. The specific objectives are to provide an exemplar treatment of project maturity, project life uncertainty within G axis, additional quantities in place, non-energy product and non-sales quantities, access and entitlement. Given the breath of the case study and the number of projects involved it by necessity is abbreviated and does not present the full range of supporting information that would be required in a full classification, and to support the underlying assumptions. In particular, it does not present the documentary evidence that would be required to support E1, F1 classifications.

Project Location: San Paulo State, Brazil

Data date: 015

Date of evaluation: 1 January 2016

Quantification method: Simulation based on businesses operating plan and supporting commercial and technical data.

Estimate type (deterministic/probabilistic): Deterministic (scenario)

Project Summary and Background

Usina BioSucro is Brazilian sugarcane ethanol plant based in San Paulo state (near Ribeirao Preto). It has an existing capacity of 5 million tonnes pa of cane crushing, with an ethanol equivalent capacity of 102 mill gal. It produces two grades of ethanol, hydrous and anhydrous and two grades of sugar VHP (international raw sugar grade for the export market) and Crystal (semi refined sugar for the domestic market). It has the ability to flex 60:40 either way between ethanol and sugar and can produce anhydrous ethanol to a max 30:70 anhydrous and hydrous ethanol split.

It has cogen consisting of high pressure (60 bar) boilers fired using bagasse, and 2x 20 MW turbo alternators. It currently produces all its internal steam and power requirements but does not have sufficient cogen capacity to export power to the grid. However, a cogen expansion project is under construction. Currently, the surplus bagasse is being sold as a low-value component into animal feed rations.

The mill accesses its cane from a portfolio of land leases (65%), long-term cane supply contracts (35%) and very small (balancing) volume of spot (annual) cane contracts. The cane is a semi-perennial crop grown on 4 - 6-year ratoons (planting cycles). Mechanical harvesting is used for all its cane.

Project Definition

Bioenergy Source(s)

Sugarcane (*Saccharum*) – multiple varieties.

The sugarcane accessed by Usina BioSucro is assessed to be a Bioenergy Source within the definition set out in the Bioenergy Specification on the following basis:

(a) It is biogenic.

(b) The rate of extraction does not exceed the rate of replenishment.

(c) The cane that is harvested for processing is replaced with re-growth and replanting of cane.

Specifically, with regards to points 2, and 3, the mill has a clearly defined agricultural planting plan that ensures the continued supply of cane for the mill, and by optimising ratoon (planting) cycle optimises the cane yield and sugar content of the cane. Also, the cultivation plan also optimises the cane yield and sugar content both on an in-year and multi-year perspective through the optimisation of the various agricultural inputs (e.g. fertilizer, vinasse (nutrient-rich wastewater recycled from the mill), supplemental irrigation, soil conditioning inputs and herbicide and pesticide inputs. The replacement of the cane occurs both within the ratoon (planting) cycle via re-growth of the cane, and via the re-planting of the cane on a field by field (harvest area basis) at the end of each ratoon as defined in the planting plan.

Bioenergy Product(s) & Reference Point(s)

Table 17. **Bioenergy Product(s) & Reference Point(s)**

Energy Product	*Reference Point*	*Specification*	*Reporting Units*	*Supplemental Information*
Hydrous Ethanol	Road Gantry Meter	ANP No. 7 AEHC (water 4.9%vol max)	KM3	
Anhydrous Ethanol	Road Gantry Meter	ANP No. 7 AEAC (water 0.4%vol max)	KM3	
Cellulosic Ethanol	Road Gantry Meter	ASTM D 4806 (water 1.0%vol max)	KM3	
Electricity	Export Meter	230kV	GWhe	

Non-Energy Product(s)

Table 18. **Non-Energy Product(s)**

Product	*Reference Point*	*Specification*	*Reporting Units*	*Supplemental Information*
VHP Sugar (very high polarization)	Mill Weighbridge	ICUMSA 1200	Kte	Export grade
Crystal Sugar	Mill Weighbridge	ICUMSA 150	Kte	Domestic grade
Bagasse	Mill Weighbridge	NA	Kte	Local animal feed rations

Authorisation and Commitment

The mill is a currently operating asset and assessed by its auditors in its last statement of annual accounts as a viable going concern. It has all the necessary licences and permits to operate from the Brazil Federal San Paulo State authorities. This includes water extraction, and waste water discharge permits both for the agricultural and industrial activities.

In addition, there are several projects, detailed below, at various stages of development/ sanction.

Table 19. **Status of development/sanction**

Project	*Status*	*Description*
Cogen Expansion	In Construction	Expansion of existing boiler capacity with an additional 20MW TA to enable the incremental firing of bagasse and export power sales.
Debottleneck (0.25 mtpa crush)	Developed, Awaiting Sanction	Debottleneck of existing capacity 0.25 mpta additional crush capacity developed and awaiting sanction. Additional cane already secured to a high level of confidence estimate of 5 years.
Expansion (1.25 mpta crush)	Under Development	The expansion project of an additional 1.25 mpta crush project being developed. 60:40 Ethanol:Sugar. Economic life estimates: High level of confidence 30 years, Moderate level of confidence 35 years Low level of confidence 45 years. Land origination underway. Moderate level of confidence in securing cane for 35 years.
Cellulosic Ethanol Project	On Hold	A project to convert the additional bagasse produced from the two expansion projects, combined with additional trash/cane straw recovery from the existing cane to cellulosic ethanol. Production capacity is 20 mill gal pa.
100% Ethanol Production	Conceptual/ Early Stage Development	A conceptual project considering the installation of additional fermentation capacity to produce 100% ethanol.

Quantification

Operating Plan/Performance: Usina BioSucro's Financial team prepares and maintains a long-term operating plan. This plan covers the existing asset and potential upgrades/ expansions that are in the development pipeline. The plan assumes a 50:50 ethanol: sugar production ratio, and a 70:30 hydrous: anhydrous split. The Operating Plan production profile is Usina BioSucro's "Best Estimate" (G1 + G2) of its future productive capacity. The high confidence level (G1) of is future production is considered to be 90% of its current Operating Plan volumes.

Table 20. **Operating plan volumes**

Performance Summary				
		High Confidence	*Best Estimate (Operating Plan)*	*Low Confidence*
Annual Cane Crush	Ktpa	4,500	5,000	5,000
% of Operating Plan	%	90%	100%	100%NB
Ethanol: Sugar Ratio		50:50	50:50	50:50
Aggregate Recoverable Sugar (TRS)	Kg/te cane	130	135	140
Ethanol Hydrous	KM3 pa	131.3	151.4	157.1
Ethanol Anhydrous	KM3 pa	54.4	62.7	65.1
Sugar (VHP + Crystal)	Ktpa	278	321	333

NB: For simplicity, in this case study, harvest/seasonal constraints assumed to limit mill annual cane crush rates to operating plan rates from a multi-year planning perspective.

Project Lifetime: The high confidence level estimate of the mill's current economic life is 25 years (G1), based on a technical assessment of the mill's engineering team, and in consideration of the projected sustain capex spend contained in the mill's operating plan. The engineering team's best estimate of the mill's economic life is 35 years (G1 + G2). Based on typical mill lifetimes elsewhere in the Brazilian cane sector there is a high confidence level (G1 + G2 + G3) that the mill will achieve an economic lifetime of 45 years.

Feedstock Supply Access and Entitlement: The cane supply consists of a mix of land leases (65%), long-term cane supply contracts (approximately 35%), and a very small (balancing) volume of spot (annual) cane contracts. The typical duration of the land leases is five years, with the option (at the mill's discretion) to extend by one year. The cane supply contracts are for four years. In aggregate the mill (including the one-year extension provisions) has in place legal contracts that secure cane for the next five years.

Under the land leases the mill is responsible for the entirety of the agricultural operations, consisting of the initial cane planting, cultivation, harvesting, and subsequent transport to the mill. The land leases price on a formula that is linked to the Consecana cane formula price (which in turn is linked to ethanol and sugar prices) and a defined base sugar content. The mill is therefore exposed to the costs of the agricultural operations, the Consecana price, and the actual recovered yield of cane from the fields and the differential in actual cane sugar content and the base sugar content.

Under the cane supply contracts, the grower is generally responsible for all the agricultural operations. However, in some instances, the mill carries out some or all of the agricultural operations with the costs charged back to the grower. The cane prices on a per tonne basis, linked to the Consecana price, based on an assumed cane sugar content, but the mill has the right to all the cane from the stipulated area of land. Therefore, the mill is primarily exposed to the Consecana price, and the differential in actual cane sugar content and the assumed sugar content.

Conversion Plant Access and Entitlement: Usina Biosucro is the 100% equity owner and operator of the mill and associated agricultural operations.

Monetisation of Energy Products

Hydrous/Anhydrous Ethanol: Sold through a combination of spot and annual term contracts priced off the ELSAQ quotation. A proportion of the Anhydrous grade is sold in tank in Port Santos and subsequently exported typically to California, United States. There is a reasonable expectation that the mill can continue to monetise its ethanol production in this manner for the foreseeable future.

Power (sales): Approximately 90% of power sales from the cogen facility that is under construction have been contracted under a Capacity Tender Auction for 10 years at price of 140 R$ (Brazilian Real)/MWh. The remaining 10% will be sold in the spot power market. There is a reasonable expectation that at the end of the 10-year contract that the mill will either be able to re-tender for another power supply contract or receive equivalent remuneration via the spot market.

Sugar Sales: The sugar production is sold via an annual term supply arrangement at a price indexed to the New York No.11 Sugar contract. There is a reasonable expectation that the sugar production can be monetised in this manner for the foreseeable future.

Cellulosic Ethanol: The intention would be to sell volumes via annual or longer term contracts to fuel supplier in tank in Port Santos for export into the United States or the European Union.

UNFC Classification and Quantification

Table 21. **UNFC Classification and Quantification**

<table>
<tr><th rowspan="2">Class</th><th rowspan="2">Project Name</th><th rowspan="2">Sub-Class</th><th rowspan="2">E & F Classification</th><th rowspan="2">Energy Products</th><th colspan="3">G Axis Categorisation / Quantity</th><th rowspan="2">Units</th></tr>
<tr><th>G1</th><th>G1 + G2</th><th>G1 + G2 + G3</th></tr>
<tr><td rowspan="6">Commercial Projects</td><td rowspan="2">Current Project</td><td rowspan="2">On Production</td><td rowspan="2">E1.1 F1.1</td><td>Hydrous Ethanol</td><td>657</td><td>5,299</td><td>7,070</td><td>KM3</td></tr>
<tr><td>Anhydrous Ethanol</td><td>272</td><td>2,195</td><td>2,930</td><td>KM3</td></tr>
<tr><td>Cogen Expansion</td><td>Approved for Development</td><td>E1.1 F1.2</td><td>Power</td><td>889</td><td>6,664</td><td>8,150</td><td>GWhe</td></tr>
<tr><td rowspan="3">Debottleneck Project</td><td rowspan="3">Justified for Development</td><td rowspan="3">E1.1 F1.3</td><td>Hydrous Ethanol</td><td>33</td><td>265</td><td>353</td><td>KM3</td></tr>
<tr><td>Anhydrous Ethanol</td><td>14</td><td>110</td><td>146</td><td>KM3</td></tr>
<tr><td>Power</td><td>45</td><td>333</td><td>407</td><td>GWhe</td></tr>
<tr><td rowspan="5">Potentially Commercial Projects</td><td rowspan="3">New 1.25 mtpa Crush Train</td><td rowspan="3">Development Pending</td><td rowspan="3">E2 F2.1</td><td>Hydrous Ethanol</td><td>164</td><td>1,325</td><td>1,767</td><td>KM3</td></tr>
<tr><td>Anhydrous Ethanol</td><td>68</td><td>549</td><td>732</td><td>KM3</td></tr>
<tr><td>Power</td><td>225</td><td>1,666</td><td>2,037</td><td>GWhe</td></tr>
<tr><td rowspan="2">Cellulosic Ethanol from Bagasse</td><td rowspan="2">Development on Hold</td><td rowspan="2">E2 F2.2</td><td>Anhydrous Ethanol</td><td>340</td><td>2,646</td><td>3,402</td><td>KM3</td></tr>
<tr><td>Power</td><td>-380</td><td>-2,955</td><td>-3,800</td><td>GWhe</td></tr>
<tr><td rowspan="4">Non-Commercial Projects</td><td rowspan="3">100% Ethanol Production</td><td rowspan="3">Development Unclarified</td><td rowspan="3">E3.2 F2.2</td><td>Hydrous Ethanol</td><td>853</td><td>6,894</td><td>9,183</td><td>KM3</td></tr>
<tr><td>Anhydrous Ethanol</td><td>499</td><td>4,041</td><td>5,375</td><td>KM3</td></tr>
<tr><td>Power</td><td>122</td><td>986</td><td>1,313</td><td>GWhe</td></tr>
<tr><td></td><td>Development not Viable</td><td>E3.3 F2.3</td><td colspan="5"></td></tr>
<tr><td colspan="3">Additional Quantities in Place Associated with Resource</td><td>E3.3 F4</td><td>Total Energy</td><td>122</td><td>935</td><td>1183</td><td>PJ</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td rowspan="4">Non-Sales Production</td><td rowspan="2">From current Production</td><td rowspan="2"></td><td rowspan="2">E3.1 F1</td><td>Power</td><td>1,607</td><td>12,495</td><td>16,065</td><td>GWhe</td></tr>
<tr><td>Steam</td><td>6,690</td><td>52,052</td><td>66,924</td><td>GWhs</td></tr>
<tr><td rowspan="2">From New Projects (excl. Cellulosic Ethanol Project) Projects</td><td rowspan="2"></td><td rowspan="2">E3.1 F2</td><td>Power</td><td>482</td><td>3,749</td><td>4,820</td><td>GWhe</td></tr>
<tr><td>Steam</td><td>2,007</td><td>15,616</td><td>20,077</td><td>GWhs</td></tr>
<tr><td></td><td>From Cellulosic Ethanol Plant Project</td><td></td><td>E3.1 F2</td><td>Power</td><td>380</td><td>2,955</td><td>3,800</td><td>GWhe</td></tr>
</table>

E Category Classification and Sub Classification

Table 22. **E Category Classification and Sub Classification**

<table>
<tr><th>Projects</th><th>Category</th><th>UNFC Definition</th><th>Reasoning for classification</th></tr>
<tr><td rowspan="3">Current Project

/ Cogen Expansion

/ Debottle-neck Project</td><td>E1</td><td>Extraction and sale have been confirmed to be economically viable</td><td>Access and Entitlement: The mill has a demonstrated portfolio of land leases and long-term supply contracts that demonstrate that it has the right and entitlement to access the necessary supplies of cane to supply the mill at its rated capacity. The additional cane required for the debottleneck project will be supplied in part by already delivered productivity/yield improvements, with the mill currently selling out the surplus cane rather than reducing its lease/contract portfolio. The supply sources for the additional cane requirements have been identified by the land origination team with options taken out. These options will be exercised on sanction of the debottleneck project.

The operating entity is the sole owner of the mill.

Market and Sales Connectivity: The mill has in place the necessary physical logistical infrastructure required to transport/ transfer the ethanol, power and associated non-energy products to their respective markets. The capacity is sufficient either sufficient to handle the increased volumes arising from the additional projects, or the inclusion of additional required capacity is included within the associated project itself.

As per 3.5 the mill has all the necessary commercial contracts in place to monetise both the energy and non-energy production and there are reasonable expectations for this to continue for the foreseeable future.

Authorization: The existing sugarcane mill and associated agricultural operations have all the necessary approvals, permits authorisations in place. These regulatory approvals extend to the Cogen Expansion and Debottleneck Project.

For the US ethanol exports the mill has successful registered with both CARB and the EPA, and hence the mill’s ethanol production is approved and recognised both under the US Federal Renewable Energy Directive, and the Californian Low Carbon Fuels Standard. The mill is also certified under the Bonsucro sugarcane sustainability standard covering its ethanol and sugar production. As Bonsucro is a recognised and approved standard under the EU Renewable Energy Directive, this enable the mill’s ethanol to qualify as a recognised biofuel under the biofuel regulations/targets of any of the EU28 member states.

Economic Case Validation: The mill and the associated agricultural operations is a viable operating concern and the 10-year operating plan demonstrates economic operations under the operational and market assumptions.

Social and Environmental Considerations: There are no known social or environmental contingences that would impact the operation of the Project, or impact/prevent the Cogen Expansion or Debottleneck Projects. In addition to all necessary authorisations being in place, the mill has an active social engagement plan with the local community and is regarded as a responsible and valued business, source of employment and wealth generation within the local community.</td></tr>
<tr><td>Sub-category</td><td>UNFC Definition</td><td rowspan="2">The ethanol and power (for sales) production is economic without the need for regulatory support currently and the forward assumption on the price environment. Brazil does not have any ethanol targets or mandates and hydrous competes at the pump against gasoline on an un-subsided basis.

The proportion of ethanol that is exported to California does receive regulatory support under the Californian Low Carbon Fuels Standard (LCFS) and the US Federal Renewable Fuels Standard (RFS). However it is accretive in value terms and not fundamental to either the project as a whole or to the production of the volumes concerned.</td></tr>
<tr><td>E1.1</td><td>Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions.</td></tr>
</table>

Table 22. **E Category Classification and Sub Classification (continued)**

Projects	*Category*	*UNFC Definition*	*Reasoning for classification*
New 1.25 mtpa Crush Train ***/ Cellulosic Ethanol from Bagasse***	*E2*	Extraction and sale has not yet been confirmed to be economic, but on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic extraction and sale in the Foreseeable Future.	**Access and Entitlement:** Additional Cane Requirement – the land origination required to access the additional cane required to support the new 1.25 mpta crush train is way under way, with some land options already taken out. The site selection of the existing mill and the subsequent land access strategy was determined with such a possible expansion in mind. The existing land leases and cane supply contracts have been executed in a manner to "protect" the mill's cane supply envelope and hence facilitating future expansion. Therefore there are reasonable expectations that the mill will be able to access the sufficient additional supplies of cane. Additional bagasse/trash requirement- the additional bagasse/trash requirement to support the proposed lignocellulosic ethanol project will be accessed by additional trash collection from the fields as part of the cane harvesting operations through the adjustment of the harvester "blower settings". The project team has determined the appropriate levels of trash collection consistent with maintaining soil condition, moisture content etc. The mill would remain the sole operating entity of both the new crush train and the cellulosic ethanol plant. **Market and Sales Connectivity:** As per the E1 classification the mill has in place all the necessary physical infrastructure necessary to transport/transfer the additional production to market. The additional ethanol and sugar production will be sold via the existing commercial frameworks. The mill has reasonable expectations that it will be able to monetise the additional power production via a long-term power supply contract at a similar price to the contract recently agreed. The cellulosic ethanol production will be sold via long-term supply contract for export to a US fuel supplier. The mill has had initial conversations with potential US off-takers that confirm their interest in accessing such volumes and indicative price levels. **Authorization:** The mill has reasonable expectations that the existing regulatory and permitting framework can be expanded to cover the new crush train. This includes the additional water extraction permits required for the additional supplemental irrigation requirements. The cellulosic ethanol project will require an addition regulatory approval necessary to enable the use of and disposal of genetically modified yeasts, and the use of certain pre-treatment chemicals. Conversations are already underway with the appropriate regulatory authorities and there is currently no indication that approval will not be granted. In addition in order for the cellulosic ethanol to receive US regulatory support under the Federal Renewable Fuels Standard and the California Low Carbon Fuels standard the cellulosic ethanol plant must be registered together with support information with both the EPA and CARB. This has yet to occur, but based on similar third party projects the mill has reasonable expectations that approval will be granted in this case. **Economic Case Validation:** New 1.25 mtpa Crush Train – based on the existing market assumptions this project is economic with a demonstrated payback and internal rate of return that meets the mills internal hurdle requirements. Cellulosic Ethanol - under current assumptions this project is economic, but only marginally so. Given the plant's additional power requirements and the subsequent reduction in power sales, there are questions on the project's sensitivity to future power prices.

Table 22. **E Category Classification and Sub Classification (continued)**

Projects	*Category*	*UNFC Definition*	*Reasoning for classification*
New 1.25 mtpa Crush Train / Cellulosic Ethanol from Bagasse	*E2*	Extraction and sale has not yet been confirmed to be economic, but on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic extraction and sale in the Foreseeable Future.	**Social and Environmental Considerations:** For the new 1.25 mtpa Crush Train project there are some local concerns on the increased number of truck traffic and the suitability of some of the local road infrastructure, in particular some weak bridges. The project is working with the local community to allay these concerns in terms of demonstrating truck traffic management, a program of road water spraying on key road to minimise dust, and a programme to strengthen certain bridges. At this time, the mill has reasonable expectations that these concerns can be effectively addressed and they will not impede the execution of the project. Given its smaller size there are no known issues that would impact the execution of the cellulosic ethanol project.
Projects	*Category*	*UNFC Definition*	*Reasoning for classification*
100% Ethanol Production	*E3*	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.	**Access and Entitlement:** This project would utilise the existing cane supply base required to support the existing mill, the debottleneck project and the new 1.25 mtpa expansion. **Market and Sales Connectivity:** The project would use the existing logistical infrastructure, but would require additional onsite ethanol tankage and road loading gantry capacity in order handle the increased volumes. **Authorization:** No additional permitting or regulatory approvals required. **Economic Case Validation:** Under the current existing market and future assumptions investing in additional ethanol production at the expense of current sugar production/capacity would not be economic. In addition the loss of loss of optionality to swing between ethanol and sugar production would potentially be significant and a major change to the mill's business model. However, there may be future ethanol, sugar demand & supply scenarios where this would be economic. **Social and Environmental Considerations:** No additional social or environmental contingencies identified.
	Sub-category	*UNFC Definition*	Project would only be economic under certain ethanol, sugar demand & supply scenarios. The likelihood of these scenarios is still being investigated.
	E3.2	Economic viability of extraction cannot yet be determined due to insufficient information (e.g., during the exploration phase).	
Non-Sales Production	*E3.1*	Quantities that are forecast to be extracted, but which will not be available for sale.	Steam and power produced from the mill's cogen facility fuelled by bagasse (cane residue) for internal consumption by the mill.
Additional Quantities in Place Associated with Resource	*E3.3*	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.	Non-extractable energy in the cane.

F Category Classification and Sub-classification

Table 23. **F Category Classification and Sub-classification**

Projects	*Category*	*UNFC Definition*	*Reasoning for classification*
	F1	Feasibility of extraction by a defined development Project or mining operation has been confirmed.	
	Sub-category	*UNFC Definition*	The existing mill and associated agricultural operations are already underway.
Current Project	*F1.1*	Extraction is currently taking place.	
Cogen Expansion	*F1.2*	Capital funds have been committed and implementation of the development Project or mining operation is underway.	The cogen expansion project has been sanctioned and construction is underway
Debottle-neck Project	*F1.3*	Sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development Project or mining operation.	All the engineering, agricultural development, land origination and economics and commercial evaluation has been carried out. A financial memorandum requesting sanction for the project has been prepared and is awaiting sanction.
Projects	*Category*	*UNFC Definition*	*Reasoning for classification*
	F2	Feasibility of extraction by a defined development Project or mining operation is subject to further evaluation.	
	Sub-category	*UNFC Definition*	
New 1.25 mtpa Crush Train	*F 2.1*	Project activities are ongoing to justify development in the Foreseeable Future.	Work is actively underway to develop the project and prepare a case for financial sanction.
Cellulosic Ethanol from Bagasse	*F 2.2*	Project activities are on hold and/or where justification as a commercial development may be subject to significant delay.	Initial development work has been carried out, but given the marginal economics, the capital requirements, the uncertainties on impact of the project economics on future power prices, the exposure to the project on US regulatory support for advanced biofuels and some associated uncertainties, the mills management as decided to put the project on hold and devote business development resources to more attractive opportunities.
100% Ethanol Production	*F 2.2*	Project activities are on hold and/or where justification as a commercial development may be subject to significant delay.	The project is not deemed to be economically viable under current or future market conditions, but may be economic under some ethanol and sugar supply & demand scenarios, but these are currently assessed to be unlikely to occur within the foreseeable future.
Additional Quantities in Place Associated with Resource	*F4*	In situ (in-place) quantities that will not be extracted by any currently defined development project or mining operation.	Non-extractable energy in the cane.

G Category Classification and Sub-classification

Table 24. **G Category Classification and Sub-classification**

	Reasoning for classification		
UNFC Definition	***G1***	***G1 + G2***	***G1 + G2 + G3***
	Quantities associated with a known deposit that can be estimated to a high level of confidence.	Quantities associated with a known deposit that can be estimated to a moderate level of confidence.	Quantities associated with a known deposit that can be estimated to a low level of confidence.
Project			
Current Project	The production profile is based on the high confidence level estimates set out in the performance summary table in section 3, for a period of 5 years. The period of 5 years is the aggregate high confidence level estimate of the confidence in securing cane supply based on the aggregate length of land lease and cane supply contracts (including the 1-year extension provisions) that are currently in place. N.B. the high confidence level estimate of the technical life of the asset (30 years) is not constraining.	The production profile is based on the best estimate (Operating Plan) set out in the performance summary table in section 3 for a period of 35 years. The period of 35 years is based on the mill's cane origination's team reasonable expectations to maintain cane supplies to the mill for a period of at least 35 years. In aggregate this would comprise 7 further ratoons, cane growing cycles. This view is supported by the selection of cane fields to protect the mill's cane supply envelop to minimise competitive from other mills, the strategic relationships developed with the landowners and cane growers and their limited alterative options, coupled with demonstrated practice elsewhere in Brazil. In addition, the agricultural team has demonstrated agricultural improvement plan with the objective of increasing cane productivity, both yield and total recoverable sugar content, maintaining soil condition, and protecting against pest and pathogens. The plan targets a 1% pa yield improvement which is consistent with historical performance both by the mill and within the entire sector. The increased cane yield will support in part the debottleneck and expansion projects, but will also progressively reduce the land area requirement to support the mill's processing capacity. The moderate level of confidence estimate for the technical life of the asset (35 years) also constraints the production profile to a limit of 35 years.	The production profile is based on the low level confidence level estimate set out in the performance summary table in section 3 for a period of 45 years The period of 45 years is based on the low level of confidence estimate of the technical life of the asset and a low level of confidence estimate of the extension of the cane supply also to 45 years. Note: upside views on increased cane yields resulting from the agricultural improvement plan assumed to result in lower land utilisation rather than increased production.

Table 24. **G Category Classification and Sub-classification (continued)**

	Reasoning for classification		
UNFC Definition	***G1***	***G1 + G2***	***G1 + G2 + G3***
	Quantities associated with a known deposit that can be estimated to a high level of confidence.	Quantities associated with a known deposit that can be estimated to a moderate level of confidence.	Quantities associated with a known deposit that can be estimated to a low level of confidence.
Project			
Cogen Expansion	An annual power export of 100 GWhe consistent with the high confidence level production profile as per section 3, for a period of 5 years, again consistent with the cane supply assessment for the high confidence level estimate for the current project.	An annual power export of 190 GWhe consistent with the best estimate production profile as per section 3, for a period of 35 years, again consistent with the cane supply assessment for the moderate confidence level estimate for the current project.	An annual power export of 181 GWhe consistent with the high confidence level production profile as per section 3, for a period of 45 years, again consistent with the cane supply assessment for the high confidence level estimate for the current project. N.B, the reduced power export from the G1+G2 estimate is due to the higher cane sugar content/ hence higher ethanol production and hence higher mill energy requirements.
Debottle-neck Project	An additional 0.25 mpta of annual cane crush capacity operating to the same performance as per the high confidence level production profile in section 3 (e.g. 90% of operating plan) for a period of 5 years, consistent with the cane supply assessment for the high confidence level estimate for the current project.	An additional 0.25 mpta of annual cane crush capacity operating to the same performance as per the best estimate level production profile in section 3 (e.g. operating plan) for a period of 35 years, consistent with the cane supply assessment for the moderate confidence level estimate for the current project.	An additional 0.25 mpta of annual cane crush capacity operating to the same performance as per the high confidence level production profile in section 3 for a period of 45 years, consistent with the cane supply assessment for the high confidence level estimate for the current project.
New 1.25 mtpa Crush Train	An additional 1.25 mpta of annual cane crush capacity operating to the same performance as per the high confidence level production profile in section 3 (e.g. 90% of operating plan) for a period of 5 years, consistent with the cane supply assessment for the high confidence level estimate for the current project.	An additional 1.25 mpta of annual cane crush capacity operating to the same performance as per the best estimate level production profile in section 3 (e.g. operating plan) for a period of 35 years, consistent with the cane supply assessment for the moderate confidence level estimate for the current project.	An additional 1.25 mpta of annual cane crush capacity operating to the same performance as per the high confidence level production profile in section 3 for a period of 45 years, consistent with the cane supply assessment for the high confidence level estimate for the current project.
Cellulosic Ethanol from Bagasse	Cellulosic ethanol production from a 20 mil gal (76 km3) annual capacity unit operating at 90% capacity for a period of 5 years consistent with the high level confidence case assumptions.	Cellulosic ethanol production from a 20 mil gal (76 km3) annual capacity unit operating at 100% of capacity for a period of 35 years consistent with the best estimate case assumptions.	Cellulosic ethanol production from a 20 mil gal (76 km3) annual capacity unit operating at 100% of capacity for a period of 45 years consistent with the low confidence case assumptions.
	In each case the operating assumptions of the cellulosic ethanol plant are linked to the confidence case of the current project due to the interdependences of the plant on the bagasse/trash supply from the cane, and energy integration. The cellulosic ethanol plant is a net energy (power) importer and so reduces the power available for sales.		

Table 24. **G Category Classification and Sub-classification (continued)**

	Reasoning for classification		
UNFC Definition	***G1***	***G1 + G2***	***G1 + G2 + G3***
	Quantities associated with a known deposit that can be estimated to a high level of confidence.	Quantities associated with a known deposit that can be estimated to a moderate level of confidence.	Quantities associated with a known deposit that can be estimated to a low level of confidence.
Project			
100% Ethanol Production	The additional ethanol production represented by the swing from a 50:50 ethanol: sugar ratio to 100% ethanol enabled by investment in additional fermentation capacity from the total cane crush capacity including the current, debottleneck and expansion projects (6.5 mtpa).		
	100% ethanol production operating as per the high confidence level production profile in section 3 (e.g. 90% of operating plan) for a period of 5 years, consistent with the high confidence level cane supply assumptions	100% ethanol production operating as per the best estimate level production profile in section 3 (e.g. operating plan) for a period of 35 years, consistent with the best estimate cane supply assumptions	100% ethanol production operating as per the Low confidence level production profile in section 3 for a period of 45 years with the low confidence level cane supply assumptions
Non Sales Production	Mill Steam and Power consumption consistent with the high confidence level production profile in section 3 (e.g. 90% of operating plan) for a period of 5 years, consistent with the high confidence level cane supply assumptions.	Mill Steam and Power consumption consistent with the best estimate level production profile in section 3 (e.g. operating plan) for a period of 35 years, consistent with the moderate confidence level cane supply assumptions.	Mill Steam and Power consumption consistent with the low confidence level production profile in section 3 for a period of 45 years, consistent with the low confidence level cane supply assumptions.
Additional Quantities in Place Associated with the Resource	The un-extracted energy in the cane represented the difference of its lower heating value (15 GJ/ dry te) and the sum of the energy extracted in the form of ethanol, power (sales and non-sales), steam from all the projects consistent with the respective G1, G1 +G2, G1+G2+G3 assumptions as below:-		
	5850 mtpa cane crush consistent with the high confidence level production profile in section 3 (e.g. 90% of operating plan) for a period of 5 years, consistent with the high confidence level cane supply assumptions.	6500 mtpa cane crush consistent with the best estimate level production profile in section 3 (e.g. operating plan) for a period of 35 years, consistent with the moderate confidence level cane supply assumptions.	6500 mtpa cane crush consistent with the high level production profile in section 3 for a period of 45 years, consistent with the high level cane supply assumptions.

Glossary (Units)

Volume	
KM^3	Thousand cubic metres
Mill gal	Million US gallons
Mass	
Kte	Thousand metric tonnes
Ktpa	Thousand metric tonnes per annum
Mtpa	Million metric tonnes per annum
Energy	
GWhe	Gigawatt hours of electricity
GWhs	Gigawatt hours of steam
PJ	Peta Joules, 1015 Joules

Bioenergy case study 5: Biodiesel

This is a hypothetical case study/example produced with the purposes of demonstrating the application of the Bioenergy Specification. The specific objectives are to provide a biodiesel case study that demonstrates the treatment of multiple feedstock / bioenergy sources, the treatment of energy sources sourced via a system of purchase agreements, the accounting for a non-biogenic feedstock, policy/regulatory support uncertainty, and regulatory sustainability requirements. This is an abbreviated case study and does not present the full range of supporting information that would be required in a full classification and to support the underlying assumptions.

Note, this case study was first developed before the release of the European Commission's proposal for the European Union (EU) biofuel targets post-2020, and therefore does not consider the implications of the draft proposal for further restrictions on food-based biofuels post-2020. In a real-world situation, the release of such a legislative proposal that may have material implications on the project's economic viability would be a potential trigger point for a revaluation of the classification.

Project Location: Rotterdam, the Netherlands

Data date: 2015

Date of evaluation: 1 January 2016

Quantification method: Simulation based on businesses operating plan and supporting commercial and technical data.

Estimate type (deterministic/probabilistic): Deterministic (scenario)

Project Summary and Background

XYZ Renewable Diesel is an existing 100 ktpa hydrogenation plant located at Rotterdam, NL that has been operating for 3 years (start-up 2013). It processes fatty acid oils (palm oil and animal tallow) into renewable diesel (a biodiesel that is essentially chemically indistinguishable to diesel derived from fossil sources), via a hydrogenation process (technology licensed by XYZ).

The plant sources its non-renewable hydrogen from a neighbouring oil refinery (approximately 2%wt of the feedstock). Overall conversion is 90% (the remaining 10% is water), of which 5% is (bio)propane, 5% Bio Naphtha and 80% Renewable Diesel. The Renewable Diesel is supplied into the Dutch and German markets. The plant purchases process steam across the fence from the neighbouring refinery, and power from the grid. It also purchases natural gas ex grid to fire its process heater. The propane is sold to the refinery via a connecting pipeline.

Given that the Renewable Diesel's production cost is higher than conventional diesel under most price environments, the plant's economic viability is highly dependent on regulatory support. The relevant legislation is the EU Renewable Energy Directive which sets out biofuel targets out to 2020. This has been promulgated into EU member state legislation, including the Dutch, and German markets that the plant supplies, that have in each introduced biofuel mandates/targets out to 2020. However, policy post-2020 is currently unclear and yet to be determined both at an EU and a member state level. In addition, the EU has recently introduced a 7% (energy) cap on biofuels produced from food crops. The plant's production from palm oil falls into this category and would be limited by this cap. The production from the tallow is excluded.

A requirement of the Renewable Energy Directive is that qualifying biofuels meet certain sustainability criteria and are certified under the EU recognized sustainability scheme. XYZ Renewable Diesel corresponding sources RSPO certified Palm Oil and ISCC certified animal tallow to comply with these requirements.

Project Definition

Bioenergy Source(s)

Palm Oil - 50% of feedstock requirements.

Animal Tallow (category 1) – 50% of feedstock requirements.

Both the palm oil and animal tallow are considered to be Bioenergy Sources within the definition set out in the Bioenergy Specification on the basis that both are biogenic, and in both cases their rate of extraction does not exceed the rate of replenishment, and both are replenished by biomass of a substantially similar form. In the case of palm oil, this occurs via agricultural cropping and subsequent processing of palm fruit. In the case of animal tallow this is sourced as a waste as from the meat processing sector whose economic activity is considered to continue for at least as long as the lifetime of the project.

There are significant concerns relating to the sustainability of palm oil both as a biofuel feedstock and for other applications. This aspect is considered under the regulatory treatment of palm oil as a biofuel feedstock within European legislation, specifically the need to comply with sustainability standards and the cap on food-based biofuel targets.

The project also sources hydrogen derived from non-bioenergy from a neighbouring refinery for use in the hydrogenation process. A proportion of the hydrogen is chemically combined with the energy products. Since the hydrogen is a not a bioenergy source, its proportion is factored out of the reported energy products volumes.

Bioenergy Product(s) & Reference Point(s)

Table 25. **Bioenergy Product(s) & Reference Point(s)**

<table>
<tr><th>Energy Product</th><th>Reference Point</th><th>Specification</th><th>Reporting Units</th><th>Supplemental Information</th></tr>
<tr><td>Renewable Diesel</td><td>Road/Rail Car Gantry Meter</td><td>EN590
(EU Diesel Specification)</td><td>Kte</td><td rowspan="3">The proportion of non- renewable hydrogen factored out of the reported volumes.</td></tr>
<tr><td>Bio Naphtha</td><td>Road/Rail Car Gantry Meter</td><td>Bio Naphtha x.x 1.01.2013
(XYZ Renewable Diesel Manufacturing Specification)</td><td>Kte</td></tr>
<tr><td>Bio Propane</td><td>Pipeline meter</td><td>Propane x.x 1.01.2013
(XYZ Renewable Diesel Manufacturing Specification)</td><td>Kte</td></tr>
</table>

Non-Energy Product(s)

Nil

Authorisation and Commitment

The plant is a currently operating asset and assessed by its auditors in its last statement of annual accounts as a viable going concern.

The plant has all necessary permits and operating licences from the Dutch Government and Rotterdam Port Authority to allow operations. This includes water extraction and waste water discharge permits.

Product approvals: The plant and its renewable diesel and bio naphtha production is registered and approved as qualifying biofuels under the relevant Dutch, German, French, and UK legislation. As part of this approval, the Palm Oil sourced by the plant is certified under the Roundtable of Sustainable Palm Oil (RSPO) scheme, and the Animal Tallow under the International Sustainability and Carbon Certification Scheme. Both schemes are recognised and approved schemes by the European Commission as meeting the requirements of the EU Renewable Energy Directive.

Quantification

Operating Plan/Performance: The multi- year operating plan is based on a 50:50 mix of palm oil and tallow. This is taken to be the best estimate of future production levels. The price volatility on XYZ Renewable Diesel's feedstock is a significant exposure and the European Biodiesel Sector over the last 10 years has experienced periods of low or negative operating margins leading to run cuts. In view of this exposure, XYZ Renewable Diesel's high confidence production level has been assessed at 85% of its operating plan levels. The low confidence production level has been assessed as at 110% of operating plan based on test run results at optimal performance.

The non-renewable hydrogen element has been factored out of the reported estimated cumulative quantities of the energy products

Project Lifetime: Based on a technical assessment there is a high confidence level that under the current maintenance schedule (sustaining capex spend) the plant has a technical lifetime of 20 years, a moderate confidence level of 25 years and a low confidence level estimate of 30 years. There is at this stage no proposal to re-invest in the plant to significantly extend its operating life beyond 30 years.

Feedstock Supply Access and Entitlement:

Palm Oil: XYZ Renewable Diesel sources 50% of its Palm Oil requirements from a major Palm Oil Trader via a five-year supply deal that has a further two years to run. At this stage it is there is a high confidence level that this contract will be renewed for a further five years, and a moderate confidence level that further renewals thereafter will be possible.

The remaining 50% of the Palm Oil supplies are sourced by a mix of annual supply deals and spot arrangements. This approach (in combination with the LT supply deal) has ensured that the plant has been supplied with sufficient product for the last 3 years. Therefore, there is a high confidence level that this can be assured for a further 3 years. Thereafter, ongoing supply from this tranche of volume is to a moderate confidence level.

Animal Tallow: 100 per cent of XYZ Renewable Diesel's tallow requirement is sourced via 4 year supply deal from a single supplier that has a further 1 year to run. Negotiations are on-going to renew this supply deal, but the recent imposition of the 7% food base biofuel cap has significantly increased the competition for this feedstock, and currently there is only a low confidence level that this will be renewed at a price that is acceptable. XYZ Renewable

Diesel is currently exploring alternative options. However, the current alternatives are either to take a category 2 tallow from the same supplier (however this category of tallow is not acceptable in the German market, XYZ Ren Diesel's key market), or to source additional palm oil supplies. However, in this case XYZ Ren Diesel would exceed the 7% food-based cap and not be able to place the product in the European market. Exports to the US may be possible, but the viability is highly dependent on the soya oil / palm oil spread. In summary, the current conclusion is that there is only a low confidence level that this tranche of supply will be successfully / economically extended beyond the remaining 1 year.

Conversion Plant Access and Entitlement: XYZ Renewable Diesel has 100 per cent equity of the plant and is the owner operator.

Monetisation of Energy Products:

Renewable Diesel: XYZ Renewable Diesel has a mix of annual supply contracts with fuel suppliers in the German and Dutch markets. These supply contracts price at the monthly average Platts FAME (biodiesel) quotation for the delivery month + a premium that varies by supplier.

Bio Naphtha: Plant has contracted its entire volumes to a French gasoline blender in an annual supply contract. The French gasoline blender blends the bio naphtha into its gasoline pool to taking advantage of surplus octane and the high incentives for biofuel/ biogasoline blending in France. The pricing formula is the monthly Platts gasoline quotation plus a premium.

Bio propane: Plant has contracted its entire volumes via an annual supply deal to a neighbouring refinery in the Rotterdam area and supplies the product via a short pipeline. The refinery pays the Platts C3 monthly quotation. As the propane goes into the refiners C3 pool XYZ Renewable Diesel receives no premium for the propane bio credentials (despite attempts).

UNFC Classification and Quantification

Table 26. **UNFC Classification and Quantification**

<table>
<tr><th>Class</th><th>Sub-Class</th><th>Classification</th><th>Energy Products</th><th>Quantity</th><th>Units</th></tr>
<tr><td rowspan="12">Commercial Project</td><td rowspan="12">On Production</td><td rowspan="4">E1.2 F1.1 G1</td><td>Renewable Diesel</td><td>200</td><td rowspan="15">Kte</td></tr>
<tr><td>Bio Naphtha</td><td>12</td></tr>
<tr><td>Bio propane</td><td>12</td></tr>
<tr><td>Total</td><td>225</td></tr>
<tr><td rowspan="4">E1.2 F 1.1 G1 + G2</td><td>Renewable Diesel</td><td>784</td></tr>
<tr><td>Bio Naphtha</td><td>49</td></tr>
<tr><td>Bio propane</td><td>49</td></tr>
<tr><td>Total</td><td>882</td></tr>
<tr><td rowspan="4">E1.2 F 1.1 G1 + G2 + G3</td><td>Renewable Diesel</td><td>2,587</td></tr>
<tr><td>Bio Naphtha</td><td>162</td></tr>
<tr><td>Bio propane</td><td>162</td></tr>
<tr><td>Total</td><td>2,911</td></tr>
<tr><td colspan="2" rowspan="3">Additional Quantities in Place Associated with Resource</td><td>E3.3 F4 G1</td><td rowspan="3">Total Energy Products</td><td>25</td></tr>
<tr><td>E3.3 F4 G1 + G2</td><td>98</td></tr>
<tr><td>E3.3 F4 G1 + G2 + G3</td><td>323</td></tr>
</table>

E Category Classification and Sub-classification

Table 27. **E Category Classification and Sub-classification**

Category	*UNFC Definition*	*Reasoning for classification*
E1	Extraction and sale have been confirmed to be economically viable	The plant is an operating viable concern, with all necessary approvals, authorisations and commercial contracts in place. Economic viability is dependent on regulatory support, specifically German, Dutch and French biofuel targets/ mandates. The uncertainty on future evolution (post 2020) of this legislation is considered in the G Axis categorisation.
Sub-category	*UNFC Definition*	
E1.2	Extraction and sale is not economic on the basis of current market conditions and realistic assumptions of future market conditions, but made viable through government subsidies and/ or other considerations.	
Category	*UNFC Definition*	*Reasoning for classification*
E3	Extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability.	Considers the difference of the total energy supplied to the plant as defined by the cumulative lower heating value of the palm oil and animal tallow supplied and the cumulative energy (lower heating value) of the energy products extracted / produced. At this stage there is no realistic prospect of increasing the conversion of the palm oil/animal tallow supplied into final energy products.
Sub-category	*UNFC Definition*	
E3.3	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.	

Table 28. **F Category Classification and Sub-classification**

Category	*UNFC Definition*	*Reasoning for classification*
F1	Feasibility of extraction by a defined development project or mining operation has been confirmed	A current operational unit.
Sub-category	*UNFC Definition*	
F1.1	Extraction is currently taking place	
F4	No development project or mining operation has been identified	No feasible technical option to increase unit conversion beyond 90%, due to fundamental stoichiometric constraints.

G Category Classification and Sub-classification

Table 29. **G Category Classification and Sub-classification**

	Reasoning for classification		
UNFC Definition	***G1***	***G1 + G2***	***G1 + G2 + G3***
	Quantities associated with a known deposit that can be estimated to a high level of confidence.	Quantities associated with a known deposit that can be estimated to a moderate level of confidence.	Quantities associated with a known deposit that can be estimated to a low level of confidence.
Project			
On Production	Annual production at 85% of operating plan projections (high confidence level estimate of performance) for a period of 3 years. The period of 3 years is the aggregate high confidence level estimate of the confidence in securing supply based on the assessment of the supply contracts. The high confidence level estimates for the period of regulatory support (5 yrs to 2020), and the technical life of the asset (20 yrs) are not constraining factors.	Annual production at 100% of operating plan (moderate confidence level estimate) for a period of 10 years (to 2025). The period of 10 years is the moderate confidence level estimate of the future longevity of sufficient biofuel regulatory in XYZ Renewable Biodiesel key markets required for economic viability. The moderate confidence level estimates for the aggregate longevity of supply contracts, 13 years, and the technical life of the plant 25 years are not constraining factors.	Annual production at 110% of operating plan (low confidence level estimate) for 30 years. The period of 30 years is the low confidence level estimate of the technical lifetime of the plant. The low confidence level estimates of the longevity of the supply contracts (35 years) and regulatory support (35 years) are not constraining factors.
Additional Quantities in Place Associated with Resource	The un-extracted energy in the vegetable oil feedstock represented the difference of its lower heating value (36.5 GJ/te) and the sum of the energy extracted in the form of Renewable Diesel, Bio naphtha and Bio propane (as assessed by their lower heating values) consistent with the respective G1, G1 +G2, G1+G2+G3 assumptions as below: -		
	Annual production at 85% of operating plan rates for a period of 3 years.	Annual production at operating plan rates for a period of 10 years.	Annual production at 110% operating plan rates for a period of 30 years.

Glossary (Units)

Volume	
KM^3	Thousand cubic metres
Mass	
Kte	Thousand metric tonnes
Ktpa	Thousand metric tonnes per annum

Application of the United Nations Framework Classification for Resources
Case studies

The United Nations Framework Classification for Resources (UNFC) is a global classification and management system applicable to all energy, mineral and raw material resource projects including renewable energy, anthropogenic resource projects as well as injection projects for geological storage. Since the adoption of the Sustainable Development Goals (SDGs), managing energy and raw material resources in a sustainable manner has become paramount to all stakeholders such as governments, industry, investors and communities.

The sustainability focus of resource management aligns well with the goals of the Paris Climate Accord, which seeks low-carbon pathways in all appropriate developmental strategies. Successful resource management in the modern world requires relevant information on the resource base, understanding of the factors that are responsible for progressing the resources in the ground to production, adequate framework conditions set by the regulators and society, the enterprising capacity of the industry and the allocation of capital. A series of case studies on various resource projects from different countries are presented in this report to demonstrate how UNFC could be applied to assure sustainable resource management.

Information Service
United Nations Economic Commission for Europe

Palais des Nations
CH - 1211 Geneva 10, Switzerland
Telephone: +41(0)22 917 12 34
E-mail: unece_info@un.org
Website: http://www.unece.org

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