

## Sustainability Assessment Methods for Development of Oil Shale Deposits

SERGEI SABANOV  
SRK Consulting, Cardiff, UK

The demand for oil shale depends on the oil market; as the reserves of the oil are being depleted, the oil shale becomes more and more important as a source of energy and as alternative source of liquid fuels and chemical raw materials. Oil shale mining processes impact on the environment, economy and people, whilst there may be positive contributions to the economy and social progress through mining there are also negative impacts to the environment. The aim of this study is to elaborate sustainability assessment methodologies suitable for the development of oil shale deposits. The method is based on analysis of general characteristics of oil shale and related rocks from over one hundred oil shale deposits around the world. The sustainability assessment methods provide a guide to decision making for the oil shale mining industry and can be used in the exploration, planning, exploitation and closure stages.

**Keywords:** sustainable mining, oil shale, in-situ retorting.

### 1. Introduction

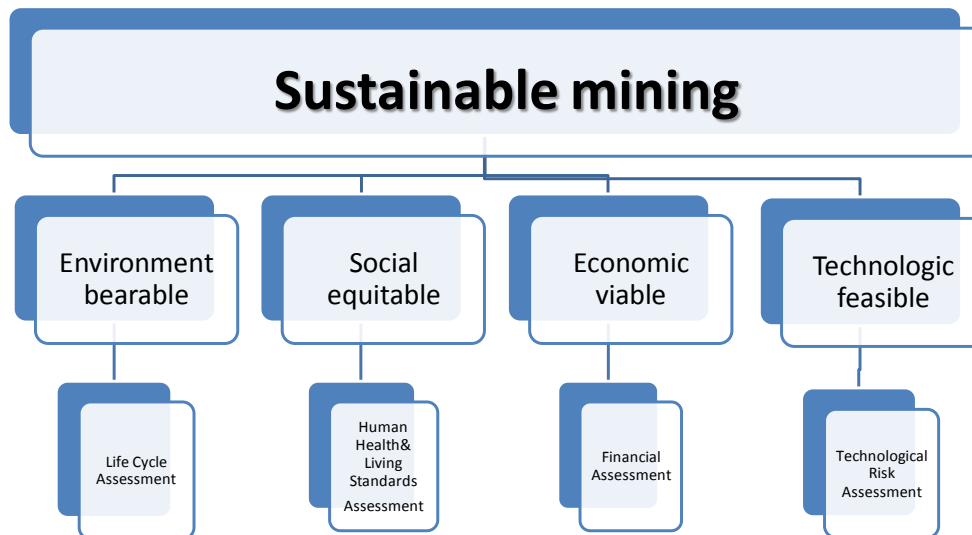
There are more than 550 oil shale deposits widely distributed between 50 countries around the world. The oil shale deposits are located at various depths below the surface and have different thicknesses of productive layers. Oil shale is defined as a sedimentary rock containing 10-75% of organic matter. The organic matter is characterised by its element composition. An important indicator of organic matter showing oil content is ratio of hydrogen (H) to carbon (C) - H/C. For kurkersite this ratio is H/C-1.51, for torbanite H/C-1.74, for tasmanite H/C-1.55. The oil yield does not depend of H/C ratio only but is also controlled by the initial material of the organic matter and the degree of decomposition. The mineral part of oil shale may consist of terrigenous material, carbonates, or both. The terrigenous material is mainly composed of clay, supplemented by quartz and feldspars. Carbonates are represented by calcium carbonate (calcite) and in some cases dolomite.

Oil shale is formed from organic material which may have several different origins. It is often categorized according to the origin of the organic material into three major categories: terrestrial, lacustrine, and marine. The marine (more often are used in industry; kukersite, tasmanite, marinite) oil shale deposits are the result of salt water algae, acritarchs, and dinoflagellates [9].

Oil shale can be developed either by open and underground mining or also by in-situ technologies. The oil shale quality is determined by the oil yield and calorific value. The prospects for development of a given deposit can be estimated taking into consideration geographical location, deposit type, depth, structural features, thickness and also seam orientation. The aim of this study is to elaborate sustainability assessment methodologies suitable for the development of the oil shale deposits.

## 2. Sustainability Assessment Methods

Sustainability assessment is a comprehensive, integrated and far-sighted approach to decision making. A key feature is that all significant undertakings must make a positive contribution to sustainability. The mining industries worldwide are changing their mining practices by developing and implementing a variety of technologies and mining methods compatible with the principles of sustainable development. Adoption of the principles of sustainable development by the oil shale mining industry comes at a cost and requires major changes to current mining practices. Relating the different approaches to sustainability assessment across disciplines and against the background of the conceptual framework allows us to appraise their relative potentials and limitations [1,2,3,4,5]. The Sustainability Assessment can be broken into four constituent parts: Environment bearable, Social equitable, Economic viable, Technologic feasible.



**Figure1-Sustainability assessment methods**

### 2.1 Environment bearable

The environmental impacts associated with oil shale preparation and productions vary substantially depending on the mining methods applied, i.e. open pit, underground and in-situ retorting. When assessing Environment quality as part of a Sustainability Assessment the objective is to include all activities that usually take place around a mine site. The Life Cycle Assessment (LCA) tool is a suitable tool to use to analyze and assess the environmental impact of oil shale mining [10,11].

Good environmental practices prevent undesired surface subsidence and hazards related to them and emissions to sensitive receptors. Sustainable mining in densely populated regions means rehabilitation of mined areas to accommodate leisure, agricultural or industrial facilities.

## **2.2 Social equitable**

This part addresses the risk of accidents and harm resulting from mining and the associated emissions on community. Social-economic well-being procedures describes the relationship between appropriate technology of mining activities and its social impact and incorporates Standard of Living, Basic Human Needs, Education, Community and Equal Opportunity assessments [2,4,5].

## **2.3 Economical viability**

The Financial assessment examines viability of oil market and the economic value of land use. It incorporates Economic Growth, Research and Development, Codes of Conduct, Compliance, Corporate Governance, Risk and Crisis Management techniques [2,3,6].

Financial sustainability is a reflexion of stable predomination of incomes over expenses provides broad manipulation of financial assets of companies by their effective and smooth process of oil shale development and oil products realisation.

## **2.4 Technologic Feasible**

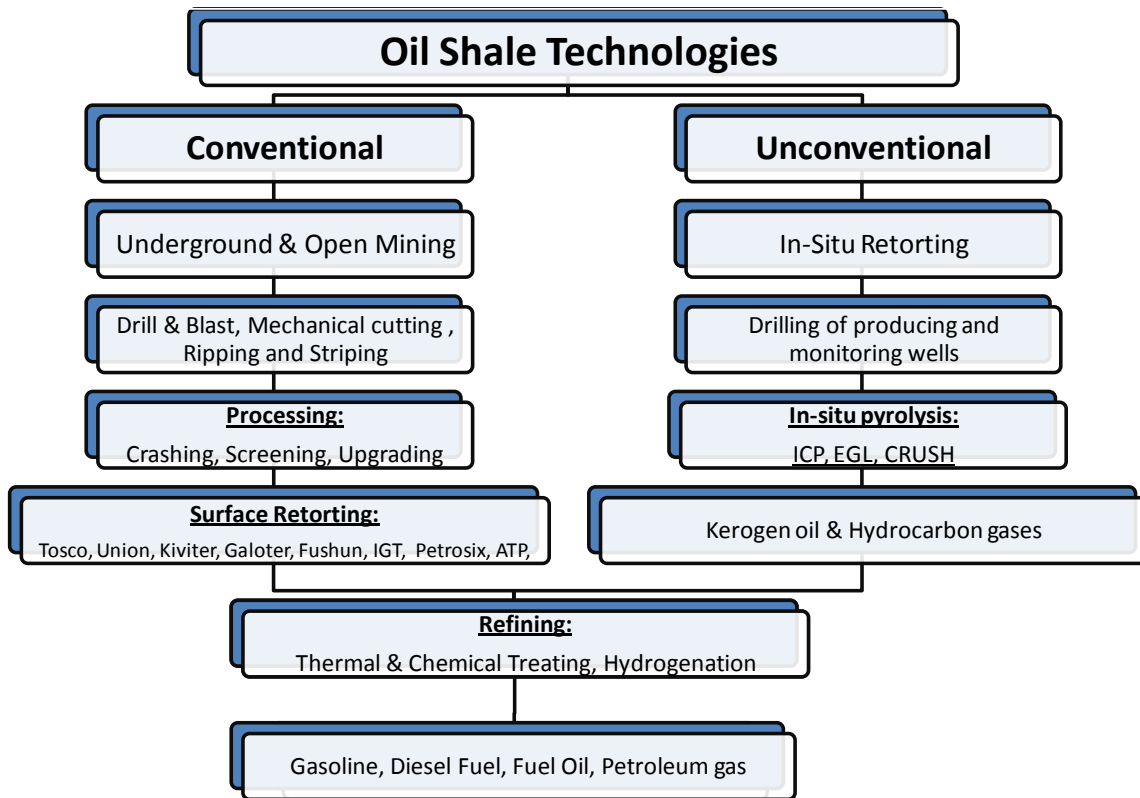
Technologic Feasibility is carried out to determine whether the oil shale deposits have the capability to be developed by the best available technologies. The powerful tool to determine the technologic feasibility of a project is Technological Risk Assessment.

Technological Risk Assessment techniques defined in its broadest sense, deals with the probability of any adverse event. Various types of risk considered in the mining activity include the engineering risk, human health risk and ecological risk. Technological Risk Assessment is the process of deciding whether the existing risks are tolerable and risk control measures are adequate. It incorporates the phases of risk analysis and risk evaluation [10,11].

## **3. Oil shale development technologies**

The conventional oil shale mining technologies involve surface retorting to convert the organic matter into the kerogen oil. The surface retorting process requires a feed of lumpy oil shale. For surface and underground mining the drill-and-blast and mechanical cutting methods are used. After blasting, the rock is crushed, screened and upgraded in a dense media separation plant. Further processing incorporates transportation of the processed oil shale to the retort facility, retorting the kerogen oil followed by refining the kerogen oil to fuels and chemicals.

The technological processes for conversion oil shale to fuels are presented in Figure 2.



**Figure 2. Technological processes for conversion oil shale to fuels**

Unconventional technologies involve in-situ retorting processes where the kerogen is heated underground in the natural geological formation. The kerogen oil and hydrocarbon gases are pumped to the surface and refined into fuels and chemical products. After the recovery of oil, the retorted area can be flushed by water and steam to remove any remaining hydrocarbons and minerals and also to recover heat from this area to generate additional energy. In-situ processing has the potential to reduce the surface footprint, waste disposal problems, runoff and other problems associated with mining such as spent shale disposal and surface reclamation [8].

#### 4. The Sustainability Assessment Techniques

The sustainability assessment techniques can be summarised as follows:

- Assessment of oil shale resource characteristics in terms of product quality and profitability:
  - Mineralogical, chemical and oil yield studies of oil shale;
  - Introduction of numerical indicators of quality corresponds to manner of the oil shale utilization (for example, minimum oil content 4% or calorific value 1000-1500 kcal/kg and sulphur over 8%. Oil shale with oil yield less than 3% could be classified as marginal resources);
  - Scheduling of oil shale production in a plan that applies appropriate capital and operating costs to determine economic viability.

- Design of systems and technology for surface mining, underground mining, modified in-situ retorting, true in-situ retorting) and determining the requirements for infrastructure
- In-situ process thermal and chemical reaction modeling, kerogen oil recovery modeling, geomechanics reservoir simulation
- Investigation of bedrock hydrological and mineral-related elements, soil formation, sediment transport and deposition is aid in understanding the structure and function of natural ecosystems
- Definition of in-situ stress regime through geotechnical monitoring
- Geotechnical assessments of open pits (cuts), underground mines and the stability of in-situ retorted areas
- Identification of the opportunities to economic mine waste management
- Integration of life-cycle models of oil shale and energy commodities to describe global geologic occurrences, genetic processes, present and future uses, recycling potential, possible substitutions, disposal strategies and associated environmental effects:
  - Identification of local flora and fauna to ecosystem loss or damage;
  - Long-term environmental monitoring of leaching process (“spent” shale-co-product of in-situ retorting) and it influence on water quality;
  - Land use and reclamation.

## 5. Results of study and discussion

The elaborated methods is based on analysis of oil shale characteristics and related rocks over hundred oil shale deposits located in 27 countries. For characterisation of oil shale properties the conditional organic mass, ash, moisture, kerogen oil, pyrolitic water, gases and semi-coke yield, CO<sub>2</sub> of carbonates and chemical composition of oil shale mineral part (SiO<sub>2</sub>; Al<sub>2</sub>O<sub>3</sub>; Fe<sub>2</sub>O<sub>3</sub>; TiO<sub>2</sub>; CaO; MgO; SO<sub>3</sub>; K<sub>2</sub>O; Na<sub>2</sub>O; P<sub>2</sub>O<sub>5</sub>), elemental composition of kerogen (H; C; S; N; O; H/C) were used [12].

The oil shale deposits can by estimated by three basic grades: high, moderate and low. The results of the oil shale grades assessment are presented in Table 1.

**Table 1-Oil shale grade assessment**

Grade	Genetic Type	Quality	Group of Minerals
High	Sapropelic	Oil>30% Ash-6% S <sub>TOTAL</sub> -2%	Carbonate (CaO+MgO- 20%) Alimosilicate-Carbonate (CaO+MgO- 10-20%)
Moderate	Sapropelic- Humus	Oil -10-12% Ash-61-70% S <sub>TOTAL</sub> -2-4%	Alimosilicate-Carbonate (CaO+MgO >10%)
Low	Humus- Sapropelic	Oil<10% Ash>70% S <sub>TOTAL</sub> >4%	Silicate (SiO <sub>2</sub> + Al <sub>2</sub> O <sub>3</sub> >70%)

Estonian oil shale (kukersite) has a terrigenous and carbonaceous composition. The mineral part usually decreases calorific value. Modified in-situ retorting method was tested on

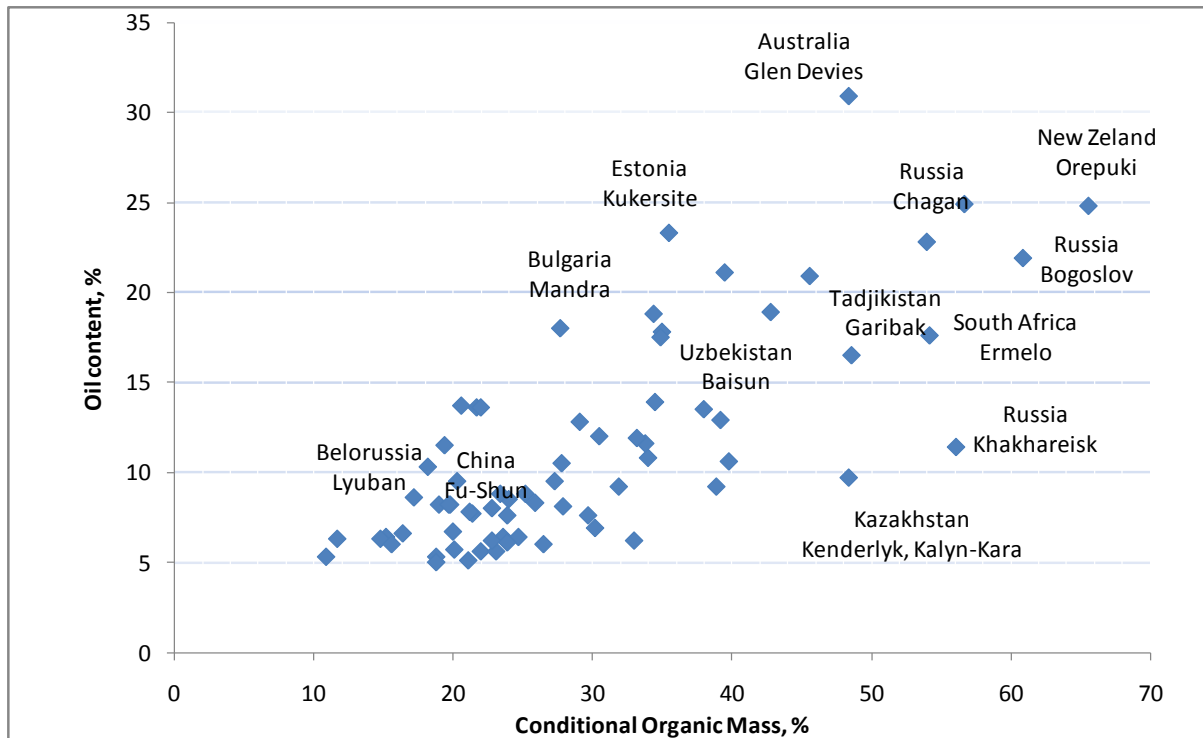
experimental mining block in Kivioli mine between 1950-1955. In this test, the rubilized oil shale was retorted over an area of about 3500 m<sup>2</sup> by electrical heat sources with an energy consumption of 50-200 kwhr/t of oil shale and used 10-15 m distance between producing wells. Kerogen oil received from modified in-situ retorting in comparison with process surface retorting had lower density and softer fractional composition. The efficiency of oil recovery using this technology was 50% [7]. It should be noted that true in-situ retorting is not applicable for Estonian oil shale on account of rich ground water horizons, small depth, tectonic faults and the presence of cracks.

In contrast to Estonia, the Boltyshevskoe oil shale deposit in Ukraine has more suitable conditions for true in-situ retorting method. The Boltyshevskoe „bowl“ has an enclosed isometric configuration. Depth of productive oil shale layers is 100-500 m and occurrences of clay seams beneath and above are suitable to recover kerogen oil in-situ. Five oil shale horizons with different properties contain kerogen oil in the range 6-28% (Figure 3). The kerogen oil in some horizons contains 5-8% of paraffin.

Kenderlyk oil shale deposit in Kazakhstan consists of Kalyn-Kara and Luchshiy seams which carry the kerogen oil 9.4% and 18.2 % respectively (Figure 3). The kerogen oil has yield of gasoline fraction-25 %, diesel – 36% and ligroin-10%.

Baysunskoe oil shale deposit in Uzbekistan has one productive layer 0.4-0.9 m thick with dip 9-35 °. The kerogen oil content achieves 13.5 % (Figure 3). The oil shale ash can contain 0.1-1.0% of molybdenum.

Volzhskiy oil shale basin is most perspective in the western part of Russia. Kashpirskoe oil shale deposit has two horizontal oil shale productive layers with thickness about 0.5-1.5m. Sulphur total is higher than 3% and organic content reaches 20-30% (Figure 3). Also the oil shale contains a small quantity of Ni, Co, Cr, Mo, Zr, V [13].



**Figure 3. Conditional organic mass and oil content in different oil shale deposits of the world**

The analysis of oil shale deposits with different quality and composition gives possibility to elaborate suitable technology for development with high potential of oil recovery and minimum environmental disturbance. Conditional organic mass and oil yield for different world deposits are in the Figure 3. Using data from figure 3 with help of table 1 it is possible to assess main characteristics of oil shale. Ash and sulphur content are key parameters for choosing of oil refining technology. On the bases of elemental composition of kerogen, the empirical calculation of potential oil yield for each deposit can be used. The products of oil shale retorting process can help analyse applicability for suitable technology of oil recovery. Most oil shale deposits (Kazakhstan, Tadjhikistan, Uzbekistan, Kyrgyzstan, Ukraine, Belorussia, Russia etc.) have a potential to be developed by unconventional mining methods and need to be re-evaluated by modern methodologies.

## 6. Conclusion

The results of this study uses analysis of one hundred oil shale deposits of different quality and composition give possibility for choosing suitable technology for development of different type's deposits with high potential of oil recovery and minimum environmental and social disturbance. The empirical calculations of potential oil yield on the basis of elemental composition of kerogen can be applied to oil shale taking into account specific characteristics of each deposit. The products of oil shale retorting process can be recommended for analyse applicability of suitable technology for oil recovery. The sustainability assessment methods give opportunity to find better way for development of oil shale deposits in accordance with technological, economical, environmental and social sustainability.

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