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## PREDICTED ENVIRONMENTAL AND SOCIAL IMPACTS OF THE PROPOSED OIL SHALE INTEGRATED TRI-GENERATION SYSTEM (OSITGS)

J. O. JABER\*  
S. D. PROBERT

School of Mechanical Engineering,  
Cranfield University  
Bedford MK 43 0AL, UK

M. A. TAHAT

Department of Mechanical Engineering,  
Faculty of Engineering,  
Jordan University of Science and Technology  
Irbid, Jordan

*A preliminary analysis of the OSITGS was conducted to determine the nature and expected rates of various effluent streams emerging from such a processing facility. Mining and processing of oil shale will significantly disturb the environment (e.g. pollution by dust particles and ash derived from oil shale as well as various gaseous emissions will ensue in the neighbourhood of the development project). However, it is likely that solid-waste handling (including ultimate disposal) as well as land use impacts will be of greater concern than air emissions from the proposed oil shale operations. It is predicted that the proposed OSITGS will be an environmentally acceptable technique for producing synthetic fuels and electricity from oil shale.*

### Introduction

Oil shale deposits remain abundant compared with other fossil fuel reserves. On a world scale, the availability of crude oil and natural gas can be measured in decades (i.e.  $\sim 60 \pm 10$  years), whereas the readily-available identified oil shale reserves are sufficient to satisfy the world's energy needs for several hundred years.

There are major difficulties facing the development of the oil shale industry, such as the environmental impacts of the processes involved. For example, in Estonia, employing pulverised oil shale combustion systems, they incur serious operational difficulties. Among them low availability of boilers as a result of corrosion, fouling and slagging (which are enhanced in the presence of alkali metals, sulfates and chlorides in the raw shale) as well as water-, land- and air-pollution problems [1-6].

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\* E-mail: j.o.a.jaber@cranfield.ac.uk.

In this study, a broad-brush analysis is undertaken deliberately because uncertainties concerning the future performance and costs of technologies that will compose the proposed system. More importantly, the main aim of the present study is to draw attention to expected environmental impacts of the proposed OSITGS and appropriate mitigation measures that can be imagined at present.

### Description of the Integrated Tri-Generation System

The main objective of developing OSITGS is to foster the development of an economically competitive and environmentally acceptable oil shale industry, whose products can compete commercially without government subsidies. The proposed basic plant is a complete facility for mining, retorting, gasification and combustion of the oil shale as well as for disposing of the spent shale [7]. It consists of a circulating fluidised bed combustor (CFBC), gasifier and combined-cycle plant, and a retort - see Fig. 1. The proposed plant would be capable of processing oil shale into synthetic fuels and electricity, with a nominal capacity of ~8,000 barrels per day of shale oil and 400 MW<sub>e</sub> installed capacity for electric power generation [8].

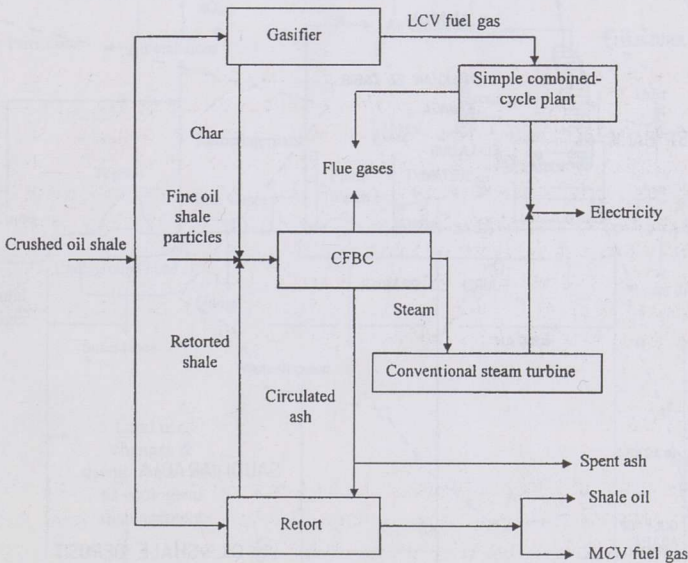


Fig. 1. The oil shale integrated tri-generation system

### Location and Climate

The proposed plant should be established near oil shale deposits (in the central part of Jordan) about 100-150 km south of Amman - see Fig. 2. The locality is flat to rolling with some hills: the average elevation is between 700 and 800 m above sea level. The climate there is very hot, dry and dusty in summer, and cold and dry in winter, with monthly

average temperatures of  $\sim 5^{\circ}\text{C}$  in winter and  $\sim 37^{\circ}\text{C}$  in summer. However, the maximum temperature during the summer usually exceeds  $40^{\circ}\text{C}$ . The annual rainfall is normally between 50 and 100 mm, but the amount may vary significantly from year-to-year. Rain-storms are localised and floods are comparatively few: hence it is considered to be a semi-desert area. But there are few small and low desert dams, which are filled during the rainy season but dry up towards the end of summer.

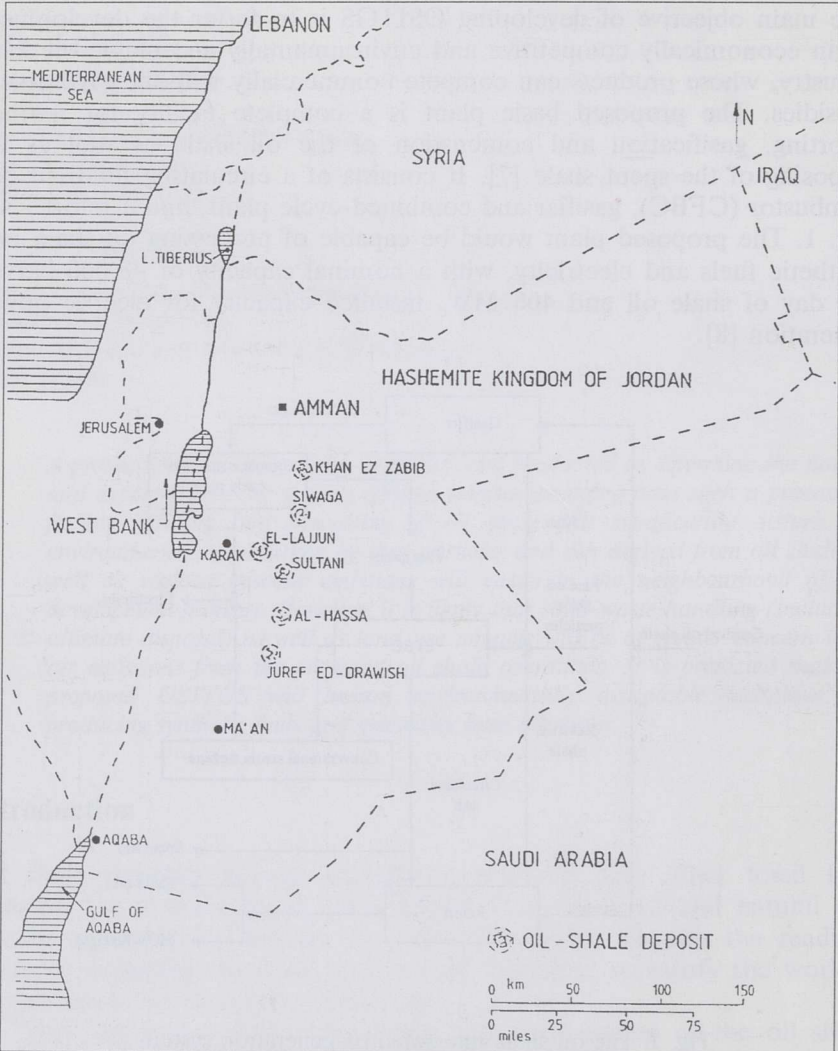


Fig. 2. Location of oil shale deposits

Wildlife resources near the oil shale deposits are similar to those of extensive stretches of land along the Desert Highway (that connects Amman and Aqaba *via* the western desert) and the nearby areas. There are no existing habitat protected areas in conflict with oil shale deposit locations. Much of Jordan's archaeological resources remain undis-

covered, and, if known, unexcavated in a scientifically reasonable way. The oil shale deposits occur in remote areas, which are not expected to include any significant archaeological sites. However, before the proposed oil shale project is to be built, then responsible authorities with expertise in the relevant areas should be consulted about any resources that might be in need of special protection.

### Sources of Major Pollutants

The building and operation of OSITGS will utilise resources, such as land and water - see Fig. 3, and the plant will produce gaseous, liquid and solid pollutants that must be treated and disposed of in acceptable ways. Table 1 summarises these principal sources of pollutants arising when the raw oil shale is converted to useful products, by-products or wastes *via* different processing units.

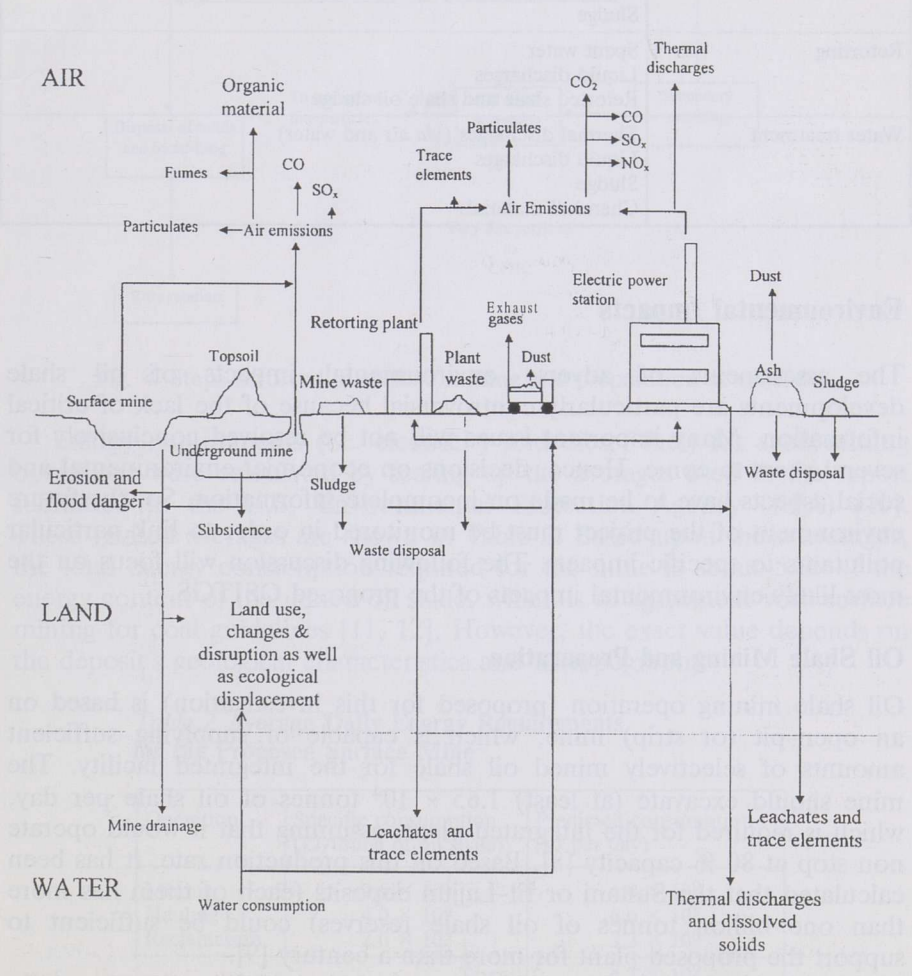


Fig. 3. Environmental impacts of oil shale activities

Table 1. Major Sources of Pollution from the Integrated Tri-Generation System

Activity	Pollutant
Mining operations	Fine particulates (dust) and fly rock Leachates Noise and vibration Fumes and diesel machinery emissions
Oil shale preparation	Fine particulates (fugitive dust emissions) Leachates Solid waste
Operating the CFBC	Air emissions (SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub> , particulates and trace elements) Spent ash (solid waste) Wastewater from the blow-down system and maintenance
Running the gasifier and combined-cycle plant	Fine particulates Air emissions (SO <sub>2</sub> , NO <sub>x</sub> , CO <sub>2</sub> , particulates and trace elements) Residual char Sludge
Retorting	Spent water Liquid discharges Retorted shale and shale oil sludge
Water treatment	Thermal discharges ( <i>via</i> air and water) Liquid discharges Sludge Chemical materials

## Environmental Impacts

The assessments of adverse environmental impacts of oil shale developments are particularly controversial because of the lack of critical information. Many important issues will not be resolved conclusively for several years to come. Hence, decisions on economic, environmental and social aspects have to be made on incomplete information. So, the future environment of the project must be monitored in order to link particular pollutants to specific impacts. The following discussion will focus on the most likely environmental impacts of the proposed OSITGS.

### Oil Shale Mining and Preparation

Oil shale mining operation (proposed for this investigation) is based on an open-pit (or strip) mine, which is capable of supplying sufficient amounts of selectively mined oil shale for the integrated facility. The mine should excavate (at least)  $1.65 \times 10^4$  tonnes of oil shale per day, which is required for the integrated plant, assuming that it would operate non stop at 80 % capacity [8]. Based on this production rate, it has been calculated that the Sultani or El-Lajjun deposits (each of them has more than one billion tonnes of oil shale reserves) could be sufficient to support the proposed plant for more than a century [9].

Given the shale's density, on average, of about 1.8 tonne per m<sup>3</sup> (in place) and a 95 % oil shale recovery rate, it is calculated that 0.112 and 0.108 km<sup>2</sup> of land per year, for El-Lajjun and Sultani sites, respectively, would be disturbed for mining operations. Again, if it is assumed that

overburden has the same density as the shale and its volume expands by about 35 (±5) % upon removal, when it is piled to a height of 10 m, the area required for overburden disposal is estimated to be ~0.41 and 1.1 km<sup>2</sup> per year in the case of El-Lajjun and Sultani deposits, respectively.

The steps involved in oil shale mining include topsoil removal and storage; overburden drilling, blasting and removal; oil shale drilling, blasting, extraction and primary crushing as well as land reclamation - see Fig. 4. It is important to note that on-site, secure explosive storage should be provided for the bulk blasting agents, and access to the blasting areas must be controlled prior to the blasting.

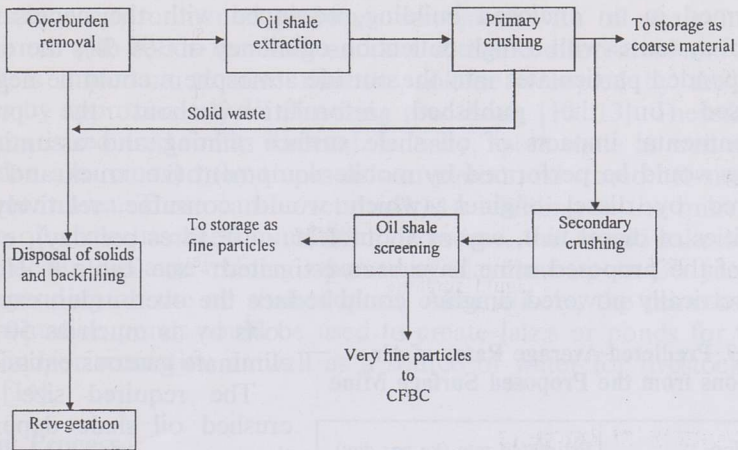


Fig. 4. Steps involved in surface mining and preparation of oil shale

Energy requirements (i.e. electricity and diesel fuel) for such mining operations were calculated by scaling up the averages used in the report submitted to the U.S. Environmental Protection Agency (EPA) [10]. These revised averages are shown in Table 2. Based upon these averages, the total energy consumption required for the mine is about 5 % of the energy content of the mined oil shale, which is in agreement with surface mining for coal guidelines [11, 12]. However, the exact value depends on the deposit’s geological characteristics and its topography.

Table 2. Average Daily Energy Requirements for the Proposed Surface Mine

Operation	Specific consumption (kJ/tonne of oil shale)	Predicted consumption (kJ per day)
Mining	$2.5 \times 10^5$	$4.0 \times 10^9$
Hauling	$4.0 \times 10^4$	$6.6 \times 10^8$
Reclamation	$2.0 \times 10^3$	$3.3 \times 10^6$
Total		$4.7 \times 10^9$

Air emission sources associated with mining operations include: wind erosion; topsoil removal and storage losses; drilling of overburden and oil shale; blasting; excavation; loading and unloading (which are the largest sources of particulates in the extraction operation, its emission factor being ~0.2 kg per tonne according to the EPA); road dust from transporting the overburden and oil shale; combustion emissions from diesel-powered equipment (which would emit significant quantities of pollutants); as well as oil shale primary and secondary crushing. Again, according to the EPA, the suspended solids emission factor from primary crushing is about 0.05 kg per tonne of oil shale, and about 0.280 kg per tonne for secondary crushing. However, if secondary crushing is performed in an enclosed building, equipped with the necessary dust control systems (with a high collection efficiency of >99 %), the emission of suspended particulates into the outside atmosphere could be negligible.

Based on the published information about the predicted environmental impacts of oil shale surface mining and assuming that mining would be performed by mobile equipment (i.e. truck and shovel) powered by diesel engines (which would consume relatively large quantities of diesel fuel, e.g. of about  $1.25 \times 10^5$  litres per day), emission rates of the proposed mine have been estimated - see Table 3. However, an electrically powered dragline could reduce the overburden excavation costs by as much as 50 % and eliminate gaseous emissions.

**Table 3. Predicted Average Rates of Air Emissions from the Proposed Surface Mine**

Emission	Estimated rate (kg per day)
Particulates	1,500
Sulfur oxides*	1,000
Nitrogen oxides	2,500
Hydrocarbons	300
Carbon monoxide	1,500
Solid waste**	16,500,000

\* Average sulfur content of diesel fuel is presumed to be 1 % by weight.

\*\* This represents overburden only and does not include spent shale.

The required size of the crushed oil shale depends on the specific operating conditions of the process being employed. In the proposed OSITGS, the required size is  $\geq 6$  mm. In order to reduce operating costs (i.e. the cost of transporting raw shale), the primary crushers are located close to mining operations - see Fig. 4, whereas secondary

crushers are located at the processing site (i.e. outside the mine). During the conveying of oil shale, dust emission problems arise: these can be reduced (by between 60 and 80 %) by providing enclosures around the conveyer and transfer points. After secondary crushing, the shale is conveyed to storage hoppers, which feed different processes within the plant. Fine oil shale particles (i.e. of <6 mm maximum dimension, which may be produced at a rate in the range of 2500 and 3500 tonnes per day) are separated from the shale by screening and fed to the CFBC. If such fine particles need to be disposed of, these would represent a huge source of solid waste as well as particulate emissions. The crushing and sizing facilities are a potential source of fugitive dust emissions: it is estimated (based on an emission factor of  $1.25 (\pm 0.25)$  kg per tonne) that for the size of the proposed plant, about 20 tonnes of dust per day could be generated. Water spraying and/or shale wetting could be used (which may reduce up to 80 % of the dust that would otherwise be dispersed) as well

as particulate control systems (such as bag filters, wet scrubbers and mechanical collectors, which have a collection efficiency exceeding 95 %), in order to reduce these dust emissions.

In order to avoid a shutdown of the processing units, a sufficient quantity of the coarse ore should be maintained as a strategic storage to allow uninterrupted operation of the downstream processing facilities for at least one month. This may be achieved by diverting the excess quantity of oil shale excavated during periods when the coarse ore production exceeds the feed requirements of the plant. It is recommended that sufficient stored fine oil shale be always available to feed the plant for at least one operating shift (i.e. ~8 hours).

The major environmental problems associated with oil shale mining are incurred with solids handling and the ultimate disposal of the spent shale. It is important to note that the volume occupied by the shale increases by approximately 12 % during processing [10, 13]. Therefore, a larger area is required for its disposal. Initially, spent shale as well as the overburden are removed (by trucks or conveyors) and stored off-site in a containment area. These can be returned as backfilling to the mine only after the oil shale has been mined out. However, this would take a long time to occur, because mining operations may last up to 30 years or more depending on the oil shale deposit. Alternatively, the mine as well as sedimentation ponds could be used to create lakes or ponds for water storage and/or recreation as well as a source of water for livestock and wildlife [14].

### **Retorting Process**

The indirectly heated retort module comprises the retorting and shale oil upgrading as well as support facilities, with a nominal production capacity of 8,000 barrels of shale oil per day. Major processing steps for a commercial-scale oil shale retorting plant are pyrolysis or retorting, oil and gas recovery, sulfur recovery, hydrogen generation, oil hydrotreating, ammonia separation and, finally, retorted shale cooling and disposal. However, in the proposed integrated plant, the retorted shale will be circulated to the CFBC in order to recover its energy potential - see Fig. 5.

In addition, the hot spent ash from the CFBC would be used as the heat carrier for the pyrolysis process to achieve the required retorting temperature of about 490 ( $\pm 20$ ) °C. Thus, the necessity for extra fuel for such a purpose (i.e. raw shale heating) will be avoided, consequently, pollutants (in particular air emissions) from the retorting process would be far less.

Main pollution emission sources from this module are spent ash and retorted shale handling, sulfur recovery and the storage facilities for hydrocarbon products. Particulate emissions would be low, due to the fact that no combustion occurred within the retort compared with similar retorting units. Consequently, particulate control systems will most likely not be required (especially if conveying and handling systems are designed to be completely closed and well sealed). However, there would be a need for a few small ash-wetting units in order to control the dust emissions.



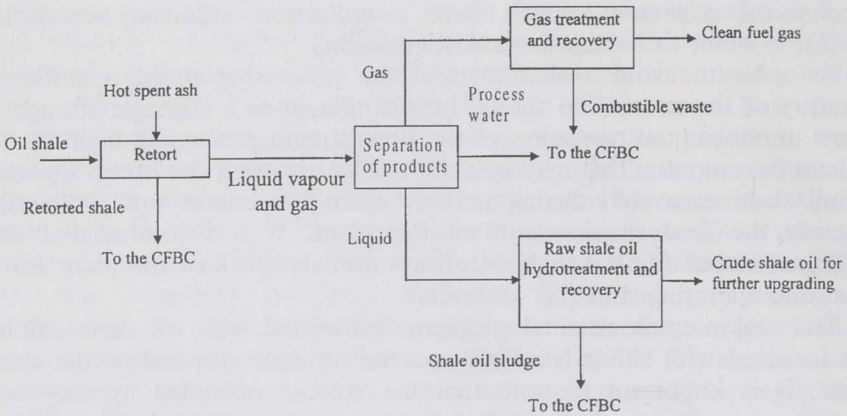


Fig. 5. The indirectly-heated retorting module

In the retorting process, most of the sulfur content of the processed oil shale will be trapped in the retorted shale and a small percentage (~10 %) released with the oil and gas products [15]. Sulfur dioxide is the only emission from the sulfur recovery unit. However, sulfur compounds are removed from the fuel gas stream and converted (in a Claus plant) to elemental sulfur. Based on the published information about sulfur recovery facilities, it is found that the elemental sulfur recovery efficiency would exceed 99 %: thus, only a small percentage would be released to the atmosphere. The cleaned fuel gas may then be compressed and sent to a conveyance (e.g. pipeline) system. Sulfur (recovered from the fuel gas cleaning) stock piles are a potential source of air pollution, due to dust emissions as a result of wind blow. This can be reduced significantly by pouring the sulfur into huge blocks for storage or forming small pellets or chunks of sulfur and allowing them to harden. It is estimated that such simple techniques can reduce expected emissions by > 70 %.

The final hydrocarbon products (i.e. shale oil and fuel gas) would be held in storage tanks to wait shipment *via* pipeline, train or road tankers, for further processing or directly to end users. These operations are associated with hydrocarbon (volatile organic compounds) emissions from storage facilities, loading and unloading activities. Such emissions are similar to those emitted during the storage of crude oil, when floating roof tanks are employed. The equivalent emission factor for storing shale oil would be approximately  $3.5 \times 10^{-3}$  kg per day per  $\text{m}^3$  of the tank volume. This low emission rate is due to the use of the floating-roof technique, which can provide great reduction of the tank breathing losses compared with similar size fixed-roof tanks. In addition, if vapour-recovery systems were employed, the hydrocarbon emissions would be reduced further.

### Gasifier and Combined-Cycle Plant

Crushed oil shale is fed to the gasifier, where it is pyrolysed in order to produce the desired LCV fuel gas. This raw fuel gas contains principally carbon monoxide, hydrogen, carbon dioxide, nitrogen as well as small amounts of methane, hydrogen sulfide and carbonyl sulfide. Because the gasifier would operate at elevated temperatures in a reducing atmosphere, there will be neither oxides of sulfur nor nitrogen in the product gas. The raw fuel gas undergoes an initial stage of cleaning in a cyclone or high-temperature filter to remove particulates - see Fig. 6.

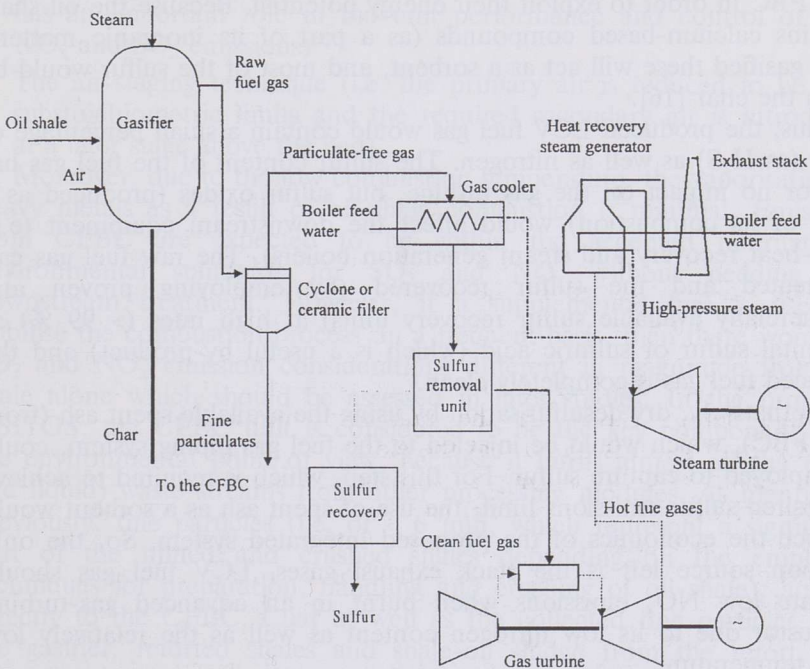


Fig. 6. Gasifier and combined-cycle system

Then it is cooled (*via* a heat exchanger which is the preferred mode for power generation or petrochemical applications, where the heat is used to raise more steam for feeding the steam cycle) down to between 400 and 600 °C in order to reduce its content of alkali salts (i.e. potassium and sodium compounds) to meet the requirements of various combined-cycle systems. Wet scrubbing (which would result in the complete removal of alkali salts as well as fine particulates) may be used, but it will require large amounts of fresh water, which is not easily available in Jordan. Finally, the fuel gas passes through a sulfur recovery unit in order to remove sulfur, so when this synthetic gas is burnt in a turbine or boiler, flue gas desulfurisation is unnecessary. In the case of the OSITGS, the clean LCV fuel gas is burnt in a gas-turbine combustor, and waste-heat from the high-temperature (i.e. > 500 °C) exhaust gases at the exit of the gas turbine is recovered by a waste-heat boiler. The latter will produce high-pressure steam that can be used to drive a steam

turbine generating more electric power. Residual char (and the associated ash which contains a major portion of the trace elements present in the oil shale feedstock) together with the fine particles collected from the fuel gas stream are circulated to the CFBC, where they are burnt to release heat for high-pressure steam generation.

Potential sources of air pollutant emission for this module are: residual carbon from the gasifier, sulfur recovery, and stack flue gases. However, there are no particulates emitted from this processing unit due to the fact that the fuel gas is cleaned and treated prior to its combustion, and the collected fine particles would be burnt together with the residual char in the CFBC in order to exploit their energy potential. Because the oil shale contains calcium-based compounds (as a part of its inorganic matter), when gasified these will act as a sorbent, and most of the sulfur would be left in the char [16].

Thus, the produced LCV fuel gas would contain a small percentage of sulfur (as  $H_2S$ ) as well as nitrogen. The sulfur content of the fuel gas has little or no impact on the gas turbine, but sulfur oxides (produced as a result of its combustion) would affect the downstream equipment (e.g. waste-heat recovery and steam generation boilers). The raw fuel gas can be treated and the sulfur recovered (by employing proven and commercially available sulfur recovery units) at high rates ( $> 99\%$ ) as elemental sulfur or sulfuric acid (which is a useful by-product) and the produced fuel gas is completely clean.

Alternatively, dry desulfurisation by using the available spent ash (from the CFBC), which would be injected to the fuel gas piping system, could be employed to capture sulfur. For this step, which is required to achieve the desired sulfur emissions limit, the use of spent ash as a sorbent would enhance the economics of the proposed integrated system. So, the only pollution source left is the stack exhaust gases. LCV fuel gas should generate low  $NO_x$  emissions when burnt in an advanced gas-turbine combustor due to its low nitrogen content as well as the relatively low flame temperature.

This is completely in agreement with the results of commercial-scale (integrated coal and/or biomass) gasification combined-cycle projects and technical studies, which have shown that the greenhouse gas (e.g.  $CO_2$ ) and particulate emissions per unit of output from gasification combined-cycle systems are drastically lower than recommended limits in the environmental protection standards, such as the clean air act and new source performance standard in the USA [17-19].

### **Circulating Fluidised-Bed Boiler and Conventional Steam Cycle**

In this module, oil shale is burnt in a bed of solids fluidised by high-velocity primary air: here the shale would be combusted under oxygen deficiency, while the calcium carbonate in the oil shale would be calcined to lime which reacts with sulfur dioxide to form calcium sulfate. Secondary air would be introduced at higher levels to provide the additional air required for combustion. The off-gases and the entrained solid particles are separated in cyclones and recirculated to the boiler. Heat is extracted from the combustor as well as from the flue gases

before being cleaned up and released to the atmosphere *via* the stack, and used to produce high-pressure steam, which drives a conventional steam turbine to generate electricity. Based on the published information about the experience gained from the only two semi-commercial scale CFBC units fuelled by oil shale worldwide, it is found that the sulfur retention in the bed (i.e. during combustion) is >95 %, which is equivalent to a concentration of SO<sub>2</sub> of < 30 ppm (or <260 mg) in the flue gases per MJ produced [20-22]. Also, NO<sub>x</sub> emission rates are low due to:

- The combustion temperature being relatively low (i.e. ~800 °C, which has an important role in the unit performance and control of both NO<sub>x</sub> and SO<sub>2</sub> emissions)
- The air-staging technique (i.e. the primary air is reduced to be near substoichiometric limits and the required secondary air is introduced at a later stage above the bed)

Moreover, due to the low combustion temperature, the vaporisation of heavy metals as a result of oil shale combustion is minimal. Emissions from CFBC are expected to be within the accepted international environmental standards for SO<sub>2</sub> and NO<sub>x</sub> without needing any downstream treatment. However, if a supplemental fuel is used to stabilise the combustion process on a frequent basis, then there would be SO<sub>2</sub> and NO<sub>x</sub> emission considerations different in magnitude from the shale alone which should be assessed in later studies. In the proposed OSITGS, the CFBC unit is considered to be the key component from the environmental point of view, because it burns almost all the (solid and liquid) waste streams from other processing modules. As mentioned previously, fine particles (i.e. of < 6 mm, which represent a significant part of the mined and crushed shales depending on the employed techniques for preparation, handling and crushing of oil shale), are fed directly to the CFBC. Char as well as the collected fine particles from the gasifier, retorted shales and shale-oil sludge from the retort, and other waste streams are fed to and burnt in the CFBC. This will increase the resource usage as well as the plant efficiency. Equally important is the great reduction in the rate of pollutants generation, so adverse environmental impacts of the proposed integrated system are reduced.

### **Solid Waste Disposal and Land Reclamation**

Since almost all the waste (e.g. retorted shale, char, shale oil sludge and fine particles) streams are fed to the CFBC, it is estimated that, at peak operation, the plant would generate approximately 550 tonnes of spent shale per hour (i.e. ~10,600 (±5 %) tonnes per day, when about 16,500 tonnes of raw shale are processed) for disposal. The spent shale geometry would be approximately the same size as the charged shale (i.e. ≤ 6 mm with a bulk density of ~1.25 tonne per m<sup>3</sup>), but some of the spent shale may be crushed as a result of moving through the plant facilities. The spent shale is wetted by spraying water: its moisture content should be in the range of 10-20 % by weight in order to control dust and to bring it up to the optimal levels for compacting and final disposal [11, 13, 23]. So, the amount of spent ash that would be sent for final disposal is in the

range of 600–700 tonnes per hour, and if it is piled to an average height of about 10 m, approximately 0.53–0.62 km<sup>2</sup> of land would be covered annually. Wastewater (which might contain compounds such as phenols, amines and organic acids) collected from different processes would be used for this purpose, but it may raise a local odour problem in the neighbourhood.

The chemical and physical characteristics of spent shale are dependent on the specifications of the raw oil shale and the employed processing technology. However, in the case of the proposed OSITGS and due to the relatively high temperatures in the CFBC, burnt shale similar to Portland cement in appearance and properties would be produced. It would be highly alkaline and may be used in agriculture to lower the acidity of the soil [24], grey to black in colour and occupy a volume of 12–20 % greater than raw oil shale. Burnt shale contains low concentrations of residual organics and some magnesium and calcium oxides derived from the decomposition of the corresponding carbonates.

Raw oil shale contains trace elements in its inorganic part. These elements may become a part of the emissions released to the environment during either oil shale processing and combustion or spent shale disposal [25]. Various organic species are formed when kerogen is decomposed. These organics can be emitted during different stages of processing or with the disposed spent shale. There is little information available concerning trace emissions of elements or organics from oil shale processing facilities. However, some of the factors influencing trace emissions from oil shale processing are their original concentrations in the raw shale, composition of the kerogen and the processing technology being employed.

For example, oil shale fed to the CFBC will encounter an oxidising atmosphere, but at retorting (or gasification), it is subjected to a reducing atmosphere, which may contain localised spots with excess oxygen. In the case of Jordanian oil shale, besides the organic matter, it contains metals (e.g. uranium, molybdenum, vanadium, chromium, cobalt and nickel) in low concentrations, as well as aluminium and iron in higher concentrations [9]. After the shale has been passed *via* the different processes, the trace elements become concentrated and enriched on the surface of small ash particles [26, 27]. This may be considered an advantage, because it would make the recovery of some of these valuable metals easier.

In addition, the eventually produced ash can be used as a raw material for the building and road construction industries, as well as a raw material for the cement industry [28]. Such an approach will further enhance the economic feasibility of oil shale harnessing projects and, equally important, reduce effluent emissions. However, there is still a great potential for leaching soluble trace elements from the spent ash, with a higher tendency of fly ash to leach trace elements in addition to fugitive particulate emissions which threaten human health. This happens because of smaller particle size and trace elements which are completely separated from organic matrix due to the fact that fly ash particles undergo extreme heating in the free-board section of the CFBC.

Therefore, ash disposal from the proposed facility appears to pose some risk of ground water contamination, especially when the mining development reaches the water table (i.e. ~70-100 m deep in the proposed areas near oil shale deposits) and if the ash is placed in the bottom of the mine it could be the subject to leaching by ground water [24]. A possible mitigation measure would be to place overburden and/or bottom ash in the bottom, while placing fly ash closer to the surface (under the top-soil layer). Water trenches should also be dug on the surface around the mining area and solid wastes site to prevent indigenous surface and ground water from contamination with rainwater run-off from the disturbed areas and to prevent water from these sources entering the disturbed areas. Run-off water can be collected and used later for wetting the haul roads and spent ash.

Liquid and solid wastes produced by oil shale processing plants must be completely stabilised prior to disposal. If not, the generated wastes can cause contamination of underground water and translocation of waste components by the plants growing in the area as well as by the animals and birds that live on those plants [29]. It has been proved that the root and epigeal parts of the plants absorb heavy metals (such as titanium, copper, strontium, lead, barium and nickel) from the soil mixed with spent shale [30-33]. Ash alone is an inhospitable medium for growing plants, due to its small particle size (which encourages erosion and compaction as well as cementation), high alkalinity and content of dissolved salts. This will cause poor root penetration: in addition it may be toxic to plant growth. Thus, a reasonable layer (i.e. 10-30 cm) of original top-soil should be added on the surface in order to allow a quick growth of vegetation cover. The reclaimed area should be fenced, maintained and monitored during its early years to ensure its stability.

### **Environmental Advantages of the OSITGS**

Because the proposed plant employs innovative technologies and there is no similar commercial-scale facility existing, there have been no opportunities to verify the predictions for either the technical or financial performances or generation of emissions arising from such a project. However, OSITGS would possess advantages compared with employing either the direct combustion or retorting technologies of oil shale. The most important point is that the proposed system is expected to be highly-efficient, so the associated adverse environmental impacts (related to mining and solid waste disposal) would be proportionately less - see Fig. 7, which summarises the impacts of the proposed integrated plant.

Based on the Jordanian oil shale characteristics and the size of the proposed plant (which is equivalent to  $\sim 1.5 \times 10^8$  MJ per day, taking into account the efficiency of electricity generation), about 850 ( $\pm 20$ ) tonnes of raw shale per hour must be processed [8]. A commercial-scale retorting plant, with a production capacity of 50,000 barrels (i.e.  $3.4 \times 10^8$  MJ) of shale oil per day, requires mining of about 75,000 ( $\pm 10\%$ ) tonnes of oil shale per day [34]. Table 4 summarises the predicted performance of the proposed OSITGS regarding the required rates of raw oil shale in comparison with conventional utilisation methods: these

**Table 4. Raw Oil Shale Consumption for Various Processing Technologies**

Method	Proposed capacity (MJ per day)	Estimated required oil shale (tonne per day)
Retorting	$3.4 \times 10^8$	75000 ( $\pm 10\%$ )
Direct combustion	$9.8 \times 10^7$	21000 ( $\pm 5\%$ )
OSITGS	$1.5 \times 10^8$	20500 ( $\pm 5\%$ )

figures should be regarded as illustrative because they were derived from estimates by companies proposing to set up oil shale plants.

Approximately 0.14 kg of raw shale is required per MJ of the final products when using the OSITGS in comparison with about 0.21 and 0.22 kg per MJ in the case of direct combustion for generating electricity or the conventional retorting process producing shale oil only, respectively. Such a big difference (~60 %) of raw oil shale consumption per unit of energy produced is mainly due to (i) the integration of

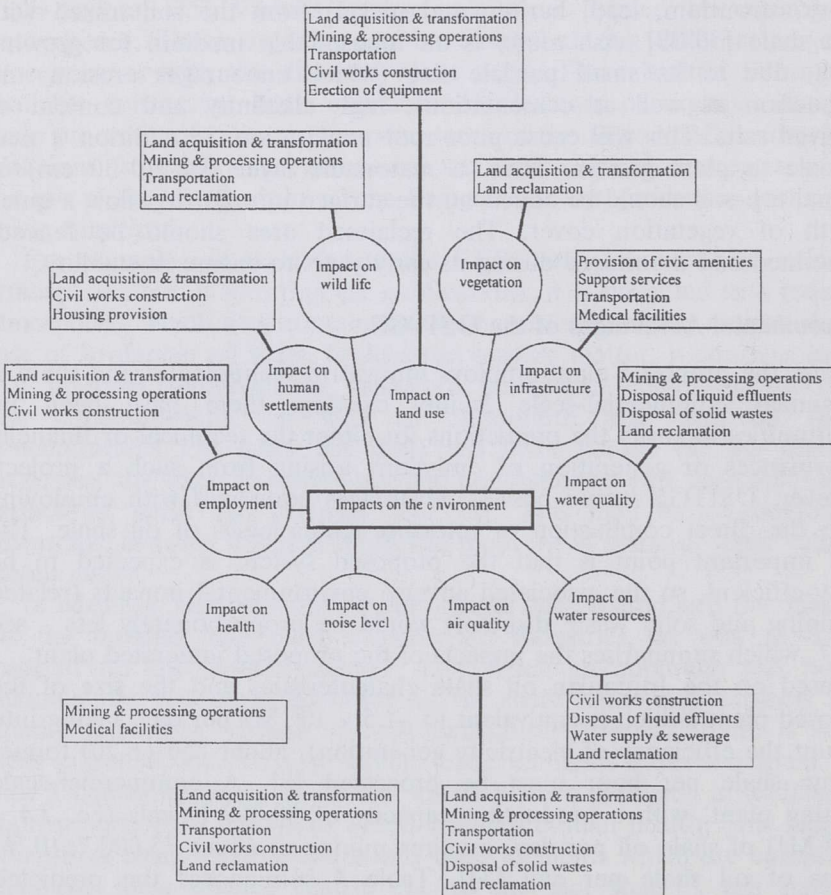


Fig. 7. Environmental impacts of the activities associated with OSITGS

different processes (gasification and combined cycle, retort and CFBC), leading to greater thermodynamic efficiencies and (ii) the relatively high efficiency (i.e. ~50 %) of the simple combined cycle. Improving the efficiency of the proposed system reduces not only the feed-rate of the oil shale, but also the quantities of pollutants (such as solid waste and gaseous emissions) which are emitted. Consequently, adverse environmental impacts along the whole oil shale supply sequence (i.e. extraction and preparation, storage and transportation), as well as processing operations would be reduced.

Major gas emissions from oil shale processing plants are particulates, nitrogen oxides, sulfur oxides and carbon dioxide, the relative amounts emitted increase as the thermal efficiency decreases. Much concern has been expressed recently over the "excessive greenhouse effect", where the increased concentrations of CO<sub>2</sub> in the atmosphere from the burning of fossil fuels are leading to global increases in the air temperature and long-term climatic changes.

It is argued that burning hydrocarbon fuels with the highest hydrogen/carbon ratio (i.e. natural gas) would reduce CO<sub>2</sub> emissions per unit of heat (or energy) produced. However, this is not the case with synthetic fuels, where the total amount of CO<sub>2</sub> generated must include that portion released during their manufacture. In Table 5, there are the estimates of the amount of CO<sub>2</sub> produced per unit of synthetic fuel calorific value in the manufacture of the product from carbon, and in its combustion [35].

**Table 5. Comparison of CO<sub>2</sub> Produced in Synthetic Fuel Manufacturing Processes and the Burning of the Fuel (mol CO<sub>2</sub> per MJ of product)**

Fuel	Manufacture	Combustion	Total
C	-	2.54	2.54
CH <sub>2</sub>	1.36	1.61	2.97
CH <sub>4</sub>	2.17	1.25	3.42
CH <sub>3</sub> OH	1.92	1.57	3.49

In shale oil production or oil shale direct combustion, there is an additional release of CO<sub>2</sub> due to the decomposition of the carbonates present in the raw shale. Thermal decomposition occurs at high rates at  $\geq 500$  °C: therefore, it is not expected to be a great factor in the indirectly heated retorting process. Although CO<sub>2</sub> is potentially a pollutant of global concern, its emission is not controlled by the present air quality and pollution standards that are imposed on air emissions in most countries.

As for the oil shale combustion process, a relatively high temperature (i.e. on average ~800 (±50) °C in the case of fluidised-bed combustors and about 1200-1400 °C for pulverised oil shale combustion) is necessary in order to ensure complete oxidation of the carbon monoxide (CO) and various hydrocarbon (HC) species. Consequently, decomposition of carbonates occurs, but only a small percentage (i.e.  $\leq 10$  % of their total



content) of this decomposition is desirable for the capture of sulfur oxides (i.e. mainly  $\text{SO}_2$ ).

In the case of the integrated tri-generation system, carbonate decomposition could be easily limited to the desired level (i.e. to about  $700^\circ\text{C}$ ) by cooling the upper part of the combustor in order to reduce the  $\text{CO}_2$  emissions. This can be achieved by injecting wastewater (containing ammonia) from the retorting process into the upper zone of the CFBC. This would help in controlling the temperature, as well as in reducing the  $\text{CO}_2$  and  $\text{NO}_x$  emissions dramatically. As a result, the need for wastewater facilities to treat the discharged process water streams would be eliminated. But it is important to note that other factors such as the  $\text{CO}_2$  partial pressure and the short residence time in the high-temperature region may also limit the excessive decomposition of carbonates.

It is hard to estimate the quantities of  $\text{CO}_2$  that would be produced by the proposed oil shale project. However, it is predicted that, if only one quarter of the carbonate content of the raw shale is decomposed, this would be responsible for emitting approximately 20–25 % more  $\text{CO}_2$  than from the combustion process alone. Such an endothermic decomposition reaction would consume approximately 5–8 % of the total heat released during the combustion process in the CFBC [36]. This is unfavourable from the flue-gas emission point-of-view, but simultaneously the decomposed carbonates will produce a pozzolanic ash, which is desirable for improving the characteristics of the spent shale in order for it to be used later as a raw material in the construction and cement industries or for safe disposal.

Visually, the proposed OSITGS is in many respects similar to that employed in conventional oil shale mining and processing plants, which rarely please the eye during the day and will be visible for quite a long distance. In addition, oil shale and waste piles surrounding the plant are unsightly and would produce high amounts of dust. This will contribute significantly to reducing the visibility and alter the natural coloration of the sky. Transportation of products by rail or road may also be considered unsightly and will produce noise, dust and gaseous emissions which may become serious annoyances. High-voltage electricity overhead transmission lines are unsightly as well, but the proper tower design and siting could reduce the possible adverse impacts.

### Monitoring and Control

The availability of pollution control, better combustion techniques and new mining methods coupled with enforcement of a wide range of environmental protection requirements should reduce or prevent, to a large extent, much of the environmental degradation that accompanied oil shale development. The environmental effects of oil shale utilisation may differ from region to region, not only because of oil shale extraction and combustion activities, but also because of differences in geologic, demographic, topographic, and climatic factors.

The proper choice of a control method (or combination of methods) to be applied for any specific source depends on factors other than the

characteristics of the source itself. For example, a certain level of control may be acceptable for a single source, but a much higher degree may be required for the same source when its emissions combine with those of other sources. The following discussion highlights general issues related to control systems for major pollutants that would be generated from the OSITGS.

### *Carbon Monoxide and Hydrocarbon Emissions*

These emissions can be controlled most effectively through good operating practice, such as proper fuel system adjustment and tuning. Operations should be within the design limits at all times and according to the recommendations of the manufacturer as well as maintenance being undertaken at appropriate intervals. However, automatic control of the fuel-air ratio at combustion should be used in order to lower the CO and HC emissions and increase the plant efficiency as well as reduce the operating cost.

Hydrocarbon emissions from non-combustion sources (e.g. storage and loading operations) can be controlled by employing tanks with floating roofs (or internal floating covers for fixed-roof tanks) and vapour recovery units. The use of the floating roof technique can provide up to 80 % reduction of the breathing losses. However, vapour recovery systems would reduce the emissions further to around 95 %. HC emissions (and odour problems) from wastewater separators and treatment facilities may be reduced by sealing the oil/water mixture from the atmosphere (e.g. providing floating covers over the separators) and the collected vapour would be sent to a recovery unit.

Also, hydrocarbon losses from safety-relief and venting systems should be collected from the discharging points and piped to recovery units or disposed of *via* flares, whichever is the more feasible environmentally and economically. Regular inspection and maintenance programmes for piping, flanges, valves and tanks would help in reducing HC and other emissions from the processing plant.

### *Particulate Emissions*

Primary control for particulate and fugitive dust emissions is influenced by water spraying (with or without chemical agents) or shale wetting, which could reduce by up to 80 % of the emission load depending on the watering frequency and the extent of the surface used. This is considered to be the best method for controlling fugitive dust emissions.

It is assumed that the roads (while haulage occurs) and the mine area can be kept in a wetted condition through an annual deposition of water equal to the net annual evaporation rate (any rainfall would be taken as an additional safety factor, because how much is absorbed and how much runs-off are variables). So, water consumption for dust control is the product of the area to be wetted down and the likely evaporation rate.

Advanced particulate control systems (such as bag-filters, wet scrubbers and mechanical collectors) have high collection efficiencies. Table 6 compares the alternative control methods in terms of the degree of control achievable and secondary pollution resulting from the control unit.

Table 6. Emission Control for Particulates

Method	Collection efficiency (%)	Secondary pollution*	Installation cost
Water spraying	60-80	(1)	Very low
Water spraying with chemical agents	90	(1)	Low
Mechanical collectors	75-95	(2) and (3)	Medium
Wet scrubber	≥ 95	(1)	High
Electrostatic precipitators	≥ 99	(2) and (3)	High
Fabric filter	≥ 99	(2) and (3)	High

\* (1) water/solid slurry, (2) recovered dust, (3) disposal problem.

Flue gases emerging from a CFBC do require the use of proven particulate capturing (or cleaning) equipment such as bag-house or electrostatic precipitators with typical control efficiencies of > 99 %, as in other combustion systems in order to achieve a low (i.e. < 10 %) stack-opacity. The collected fine particulates could be conveyed to the bed in order to exploit their energy or mixed with ash for disposal [37]. Particulates (and gaseous) emissions, as a result of combustion from diesel-powered equipment, can only be reduced by the proper fuel system adjustment, regular maintenance, use of the specified type of fuel and well-planned operations. Emission of particulates from conveying and handling systems of raw oil shale and spent ash can be reduced dramatically if designed to be completely closed and well sealed (i.e. providing metal-enclosures around the transference points with rubber curtains to hold dust emissions). The next step is to remove the particulate-laden air from the enclosures and pass it through to a control device.

#### *Sulfur Oxide Control Systems*

The main SO<sub>2</sub> source that can be controlled by commercially available methods, is the fuel gas clean-up and sulfur-recovery unit. Emissions from other processes and activities are relatively small and some of these emissions may come from multiple and diverse sources like diesel exhausts (as a result of the combustion of fuel which contains a small amount of sulfur) from the mining equipment. Some degree of SO<sub>2</sub> control from these sources can be accomplished by either substituting a lower-sulfur fuel or switching to electrical power where feasible.

Usually a sulfur-recovery unit is designed to convert sulfur compounds (e.g. H<sub>2</sub>S and COS) removed from the process streams into elemental sulfur or sulfuric acid, with an average removal efficiency of ≥ 90 %. The unconverted gases that pass through the unit are usually incinerated to SO<sub>2</sub> because it is a less hazardous compound. It is predicted that the proposed plant would generate less SO<sub>x</sub> emissions compared with existing conventional electric power stations (in Jordan) fuelled by heavy fuel oil with high sulfur content of about 3.8 percent by weight.

### *Control of Nitrogen Oxides*

$\text{NO}_x$  formation as a result of the combustion of LCV fuel gas in a gas-turbine combustor is most likely to be relatively low due to the lower flame temperatures as well as the low nitrogen content of the fuel gas [38]. Wet scrubbing, directly after the gasifier, can remove ammonia completely from the fuel gas, but there is a thermodynamic penalty as well as the requirements for additional quantities of freshwater and wastewater treatment. Also catalytic oxidation (e.g. the selective catalytic reduction) of  $\text{NH}_3$  at elevated temperatures could be used for the same purpose, but it is relatively expensive [39].  $\text{NO}_x$  emissions from the CFBC can be controlled by injecting ammonia at the furnace exit [40].

However, in the case of the proposed integrated plant, wastewater (containing ammonia) from the retorting process may be injected into the upper zone of the CFBC. This would control the temperature and simultaneously reduce the rate of  $\text{NO}_x$  emissions, so avoiding the need for wastewater facilities to treat the process wastewater streams. Nitrogen oxides from diesel-powered equipment can be controlled by applying good operation modes (e.g. fuel system adjustment, engine tuning and maintenance programmes according to the manufacturer's guidelines) and/or using electrical equipment.

$\text{N}_2\text{O}$  emissions have received considerable attention recently, due to their high contribution to the excess greenhouse effect as well as the destruction of the ozone layer in the stratosphere [41]. Reduction in the  $\text{N}_2\text{O}$  emissions can be achieved by raising the temperatures and decreasing the percentage of excess air. A high temperature leads to the thermal decomposition of  $\text{N}_2\text{O}$ , but this will increase  $\text{NO}_x$  formation. Thus, the same factors that promote low  $\text{NO}_x$  emissions promote high  $\text{N}_2\text{O}$  emissions, so there should be a trade-off between these two pollutants. However, air staging, which is used in the CFBC, can reduce the rate of  $\text{N}_2\text{O}$  emissions without increasing the rates of emission of other pollutants [42].

### *Water Effluents*

The integrated tri-generation plant is assumed to operate on zero wastewater discharges. This can be achieved only by routing all streams (with high dissolved solids and organics including run-off and process water) to a lined evaporation pond. However, water should be saved by recirculating wastewater (after being treated through neutralisation and filtration) and using it for wetting the spent ash (or dust disbursement) and reclamation activities. Moreover, wastewater that contains ammonia, when injected into the high-temperature region of the CFBC, would control both the temperature as well as the emissions of nitrogen oxides generated as a result of direct combustion of oil shale. Thus, for such an integrated plant, it is deemed that there is no need for a wastewater treatment facility. However, the potential pollution of underground water resources by acids and heavy metals then exists. In the long term, preventing the contamination is the most cost-effective approach to groundwater protection [43].

Generally, environmental protection costs are difficult to assess at this stage, because they would involve not only the cost of control,

monitoring and recording systems as well as calibration units, but also the manpower required for data processing and the additional hardware. It could be said that actual costs will depend on the availability of the facilities and man-power (which may be different from one site to another, depending on fuel characteristics, plant design and applicable regulatory standards). Recognising these difficulties, it may be possible to highlight the relative importance of control costs. For example, Table 7 shows the average costs of air pollution controls in new base-load coal-fired power plants [44]. It is predicted that in the case of OSITGS, the cost of environmental monitoring and controls will add about 4-6 % to the average cost of electricity generated *via* this new system. These increases are not negligible (i.e. have small impact on the price of electricity and/or other products to consumers), but they are reasonable. This is mainly due to the fact that a significant ratio of the generated electricity would be *via* the CCGT as well as there is no need for a flue gas desulfurisation unit, which is very costly to install and operate.

**Table 7. The Indicative Air Pollution Control Costs in a New Coal Power Plant (US\$ 1985)**

Control method	Capital cost (US\$/kW)	Annual total cost (% of cost of electricity generated)	Operation and maintenance cost (% of annual cost)
Particulate control			25-55
• ESP	15-40	1-3	
• Bag-filter	25-50	2-4	
Sulfur oxide control			35-70
• FGD	70-200	9-16	
Nitrogen oxide control			50-80
• Combustion modifications	1-15	1-2	
• Flue gas denitrification	35-85	3-5	

## Socio-Economic Impacts, Safety and Occupational Health

In addition to local environmental problems, which are associated with the oil shale development project, several problems would develop in the region such as social, occupational safety and health issues. Greater impacts are expected from oil shale facilities, simply because they are built on a larger scale than other energy conversion plants [45]. However, on the other hand, such a project would bring to local communities the advantages of economic growth and employment [46].

In this study, only social, occupational safety and health issues related to surface mining (which is deemed the most appropriate method to be employed for oil shale extraction in Jordan) and oil shale processing will be discussed briefly.

### Socio-Economic Impacts

A commercial-scale oil shale processing project would reshape the social, economic and political life of the communities in which it occurs. The

scope and intensity of such impacts differ from one region to another, depending on the local conditions such as the nature of the pre-development economy and socio-political structure.

The newly established companies for exploiting oil shale will provide the employees (and their families) with adequate facilities (e.g. housing) and general services (e.g. education and medical care) as fringe benefits. Workers at the proposed plant will not build only mining, processing and transportation systems, but also a whole town (or villages) complete with housing and commercial services, cultural activities as well as social and political systems. Such new settlements would offer better living standards as well as profitable and long-lasting business and employment opportunities for local residents.

In addition, the property cost is expected to be about ten times more than prevailing rates for the surrounding areas because of the underlying oil shale. Oil shale developments may lead to marginal farmland becoming valuable for future housing or mining sites. This will provide its owners with the opportunity to sell at great profits, but those who do not sell (e.g. farmers), may not be able to replace their workers who switch to higher-paying jobs. Local and central governments would also benefit through taxes, which may be levied on oil shale property, wages, sales, companies income and on the final products. It is expected that such an industry would create at least between  $10^3$  and  $1.5 \times 10^3$  jobs (including mining operations) on a permanent basis and a few more temporarily. This simply means that the national economy would grow. Thus, such a proposed industry would help the whole country to prosper.

### **Safety and Occupational Health**

Mines and processing plants are unhealthy places to work due to the presence of risks such as dust, noise, fumes and machinery. However, the concern for workers' health and safety should be expressed by labour unions, company officials as well as the local and central government authorities.

Occupational illness (which may result from normal operation and/or accidents) may require a long time (i.e. two to three decades) to become manifest, so it affects (most likely) older or retired workers. The main health risks (such as dust, trace elements, noise and vibration as well as harmful fumes and gases) are associated with almost all of the oil shale processing operations and activities. The majority of outdoor workers (e.g. miners, heavy-equipment operators, truck drivers, supply workers, welders and mechanics) are exposed to health hazards (e.g. fine dust, which lead to lung disease) and job stress (e.g. compulsory shift work).

The general public living near the oil shale processing plant would also be affected by deaths and disabilities from respiratory diseases or water and/or food contamination with trace elements and organic matter. Experience gained from coal mining and processing has shown that preventative measures, in addition to the enforcement of related health and safety standards, in the work place are the most effective approaches for controlling occupational disease.

Studies of occupational diseases among oil shale miners are non-existent because few people have worked in such operations for few years. However, the experience gained in Estonia suggests that workers should be monitored for the evidence of pulmonary fibrosis [47, 48]. Although conditions there are not the same as those in Jordan, the incidence of respiratory diseases in other industries (e.g. phosphate mining) indicates that exposure to the shale dusts and ashes could be hazardous. Therefore, workers should use respirators and most importantly, every effort should be made to suppress dust as well as monitor the workers' health.

Hence, there is a great possibility that oil shale derived products can cause serious diseases such as a cancer or tumours among the workers. Epidemiological studies have confirmed such a conclusion. A survey carried out in Estonia showed that a high ratio of the workers as well as the local population in the oil shale regions (e.g. Kohtla-Järve and Kiviõli sites) suffered from bronchial, stomach or intestines cancers [49, 50]. However, this is only true in the case of high-temperature retorting (i.e. directly-heated, which produce more carcinogenic final products) and pulverised oil shale combustion.

Safety can be measured in different ways, but the most obvious is the actual number of recorded fatalities and injuries. This number depends on the total number of workers and the accident frequency rates, which can be expressed as per million hours of worker exposure or per tonnes of oil shale processed. Although during the last few decades working conditions have been improved (due to the introduction of new machines, safer technologies and new labour regulations, and safety and environment standards), many still consider mining operations and the maintenance of such industries a dangerous job. It has been found that establishing better working relations, well-planned processes, better job design, and more effective training will have a positive influence on the productivity and safety records. Consequently, total operating cost of the plant will be reduced.

In general, it is hard to estimate the future number of fatalities or injuries and the involved costs of oil shale operations. It is predicted to be similar to those (i.e. between 0.1 and 1.0 immediate deaths per GW generated annually and almost the same rate for subsequent deaths due to this cause) that have occurred in heavy industry, for example, in phosphate mining and coal-fired electric power plants, including risks associated with coal mining and waste disposal, which are almost exclusively occupational accidents and generally do not fall into the category of severe accidents [51, 52].

It can be concluded that oil shale mining and processing would lead to an occupational risk of approximately 1-2 deaths per GW generated annually. However, these figures should be treated with extreme caution due to the associated uncertainties (e.g. they do not take into account fatalities during the construction phase of the proposed plant, which would increase the total number of accidents).

		RANK			ATMOSPHERIC					AQUATIC			TERRESTRIAL						
		GLOBAL	REGIONAL	LOCAL	SO <sub>2</sub>	NO <sub>x</sub>	PARTICULATES	RADIOACTIVE	HEAVY METALS	CO <sub>2</sub>	HYDROCARBONS	PARTICULATES	RADIOACTIVE	ACIDIFICATION	(1) DISTURBANCE	(2) SUBSIDENCE	DESTRUCTION		
FOSSIL FUELS	OIL SHALE	MINING	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○	(3)	
		TRANSPORT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	(3)
		CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	(3)
	COAL	MINING	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
		TRANSPORT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
		CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
	OIL	DRILLING	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
		TRANSPORT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
		CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
	NATURAL GAS	DRILLING	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
		TRANSPORT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
		CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	
NUCLEAR ENERGY	MINING	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	TRANSPORT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	DECOMMISSIONING	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
BIOMASS	HARVESTING	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	TRANSPORT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	DECOMMISSIONING	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
HYDROPOWER	CONSTRUCTION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	FLOW CHANNELS	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	(4)	
PHOTO-VOLTAIC	CONSTRUCTION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	DECOMMISSIONING	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
WINDPOWER	CONSTRUCTION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
SOLAR-THERMAL	CONSTRUCTION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
GEOTHERMAL	DRILLING	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	CONSTRUCTION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	(5)	
WASTE INCINERATION	COLLECTION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	TRANSPORT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		
	CONVERSION	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○		

- (1) MAINLY IN THE FORM OF MINING OR ANALOGOUS ACTIVITY AND RESULTING SOLID WASTE DISPOSAL
- (2) MAINLY THE RESULT OF MINING OR ANALOGOUS ACTIVITY AND/OR MASSIVE RESULTING CONTAMINATION
- (3) PRELIMINARY PREDICTION
- (4) EUTROPHICATION OFTEN OCCURS
- (5) THERMAL POLLUTION AND SOME HEAVY-METAL CONTAMINATION

Fig. 8. Comparative ranking of the environmental impacts of different power generation technologies



Moreover, operation of the proposed OSITGS may lead to additional risks because of huge quantities of raw oil shale required per unit of output compared with coal plants.

To summarise, quantification of environmental risks is extremely difficult when the impacts are unlikely to lead to any easily identifiable effects on human health, as there is no obvious scale against which to quantify them. The proposed integrated plant is predicted to be cleaner and would generate less (gaseous, solid and aqueous) pollutants than traditional methods - see Fig. 8, which is based on data provided by a report concerning environmental and health effects of various conventional and renewable systems for electricity generation [51]. Such a new system for exploiting oil shale is promising: it is envisaged that, in the long run, the integrated system would achieve much better environmental, technical and economic performances compared with conventional methods (i.e. oil shale direct combustion or retorting processes, when employed on an individual basis).

In addition, the environmental impacts of plant construction are expected to be normal for the type and size of the proposed facility. However, a higher capital investment would be involved at the beginning.

## Conclusions

The serious environmental constraints associated with OSITGS appear, under present circumstances, insufficient to prevent the development of an integrated oil shale plant. However, based on the preliminary analysis, such a system is predicted to be highly efficient and clean compared with known oil shale processing systems. The most likely environmental impacts are those associated with oil shale mining and spent ash disposal as well as wastewater streams, which would occur also with conventional utilisation methods for the oil shale.

The future beneficial use of the extensive oil shale deposits depends not only on the development of suitable process economics but also on the development of suitable environmental controls. Thus, oil shale future will be a mixture of promise and risk. However, oil shale can be considered Jordan's most extensive domestic fossil fuel source well throughout the 21st century and beyond. It will also have major socio-economic and cultural impacts on local communities.

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Presented V. Yefimov

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