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OIL SHALE – A LOCAL ASSET UNDER GLOBAL CONSTRAINT

K. BRENDOW*

World Energy Council, London, www.worldenergy.org
21, chemin de la Nonnette, CH 1292 Chambésy/Genève, Switzerland

This paper describes the world oil shale scene in mid 2009 and evaluates prospects to 2020. The volatility of conventional oil prices during 2007 and 2008 and assertions about a forthcoming depletion of competing fossil fuels have revived interest in oil shale. National expansion plans which recognize oil shale as a strategic local and huge resource are reviewed and contrasted with investor concerns about future prices and policies, rising cost, the emergence of new competitors and tightened protection of air, water and land use.

Introduction

Expectations in the 1970s that the vast resources of oil shale could raise world oil shale production to 150–200 Mt (million t) by 2000, have been grossly disappointed, primarily for lack of viability and – less – environmental concerns. Worse, world production of oil shale declined from its peak in 1981 at 47 Mt to 16 Mt in 2000, recovering thence to an estimated 21.4 Mt in 2007. Important locally (in Estonia, Brazil and China and less in Germany, Israel and Russia), the contribution of oil shale to meeting world energy demand remained close to nil.

The rising prices for conventional oil and gas on the world market between 2000 and mid 2008 revived interest in oil shale. Feasibility studies highlighted the potential strategic advantage of oil shale as a domestic fuel for securing energy supplies, alleviating the balance of payment and enhancing employment. New oil shale operations were said to be technically feasible, environmentally acceptable and viable, also in the long term. The prices of conventional oil and gas were projected to be driven upwards by the depletion of reserves, while those of oil shale remained immense. However, to date, this message did not “carry”: oil shale capacities extended notably in China and Brazil only.

* Corresponding author: e-mail *k.brendow@bluewin.ch*

Regarding the next three or four decades, conventional oil and gas reserves suffice to cover projected world demand, the more so if demand grows less than hitherto expected. Oil prices are projected to rise to 110 $/bbl (IEA) – 115 $/bbl (EIA) by 2020 and to 122 $/bbl (IEA) – 130 $/bbl (EIA) by 2030. Such price levels encourage the combustion of oil shale and the production of shale oil, whose future costs are estimated at between 20 $/bbl and 60 $/bbl. However, investors will have to bear in mind geological, technical and institutional uncertainties and, in particular, **additional charges** resulting from climate change mitigation policies. These policies would hit oil shale harder than its competitors and **may place even existing oil shale operations at risk.**

Such uncertainties could, though, be attenuated.

- <u>Governments should enhance policy predictability and planning security:</u> this implies inter alia determining climate change mitigation policies; defining the role of oil shale in energy policies; easing regulatory processes when a multitude of authorities are involved; stimulating early investors in carbon capture and storage (CCS) or pressurized fluidized bed combustion (PFB); supporting CO_2-related RD&D and international technology transfer as part of an international effort.
- <u>Industry should maintain entrepreneurship:</u> this implies inter alia controlling costs and risks; preparing for CCS and PFB; bringing in-situ extraction to maturity; designing new units "capture-ready"; assisting emerging oil shale countries (consulting, equity investments, CDM [clean development mechanisms] projects); enhancing the value of shale oil products; utilising waste.
- <u>Academia and developers should focus on CO_2-related R&D:</u> this implies inter alia adapting CCS technology to oil shale operations; appraising and reducing CO_2 emissions in in-situ and surface retorts and fluidized beds; testing CO_2 storage in shale deposits; cooperating internationally particularly on internationally comparable definitions and statistics of oil shale resources and reserves.

Given these conditions, world oil shale production might rise from 21.4 Mt in 2007 to a conservative 33–39 Mt in 2020, driven by expansion particularly in China and Jordan. Here and elsewhere, oil shale could serve as a bridge fuel towards a sustainable energy economy without, however, attaining the global significance which its vast resource base suggests.

I THE PAST

Expectations in the 1970s that the vast resources of oil shale could raise world oil shale production to 150–200 million t (Mt) by 2000 [1], have been grossly disappointed, primarily for lack of viability and – less – environmental concerns. Worse, world production of oil shale declined from its peak *in 1981 at 47 Mt to 16 Mt in 2000, recovering thence to 21.4 Mt in 2007. Important locally (in Estonia, China and Brazil, less in Germany, Israel and Russia), the contribution of oil shale to meeting world energy demand remained close to nil.*

A. Resources and reserves

World oil shale resources (excluding tar and oil sands) are huge, however rudimentary and incomparable related information may be. At the end of 2005, resources had been conservatively estimated at 2.8 trillion barrels or 409 billion t [2]. These are theoretically equivalent to 5 times the amount of conventional oil resources.

Oil shale resources are well distributed worldwide. Some 40 countries have registered about 300 deposits, with the USA accounting for 74% of world resources, Russia for 9%, Brazil, Italy and Congo (Dem. R.) for about 4%. Estonia, the leader in oil shale production and combustion, accounts for 0.6% of world resources (Fig. 1).

Of course, economically recoverable reserves are much lower, due to higher cost in comparison with conventional oil, thermal degradation, deepness and restrictions on land use. Presently worked reserves are estimated at 1.2 billion t [In the absence of statistics of world oil shale reserves, the author assumes viability of present production, at 20.6 Mt in 2007, for a remaining lifetime of the mined deposits of 60 years] (Fig. 2).

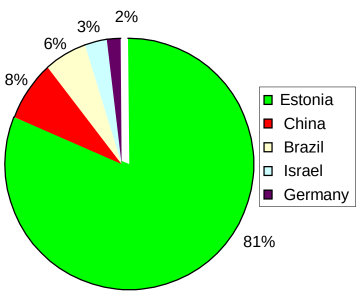

Fig. 1. World oil shale production, 2006 17.3 million tons.

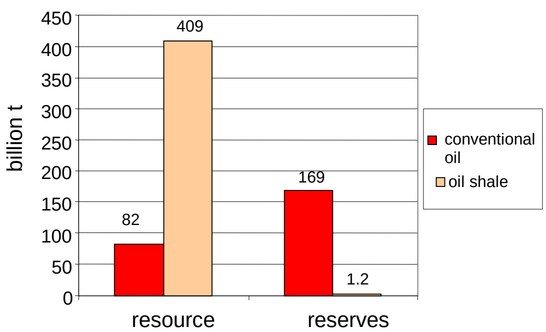

Fig. 2. Oil and oil shale resources and reserves.

B. Production and use

From a low annual 3 Mt production during 1880 to 1940 world oil shale production rose to a peak at 47 Mt in 1981, driven by developments in north-western part of the USSR, including Estonia. Thereafter, competition from cheap oil and (Russia) gas prompted a decline of production to 16 million t in 2000. Production rose in 2007 to 21.4 Mt, due to increased use in Estonia. Oil shale was also mined in China, Brazil, Israel, Germany and Russia. World oil shale production for 2020 is estimated at between 33 Mt and 39 Mt (Fig. 3 and Table).

While most of the attention for oil shale is directed at its use as a source for oil, in practice 66% of it is used for power generation, due to the dominant role of Estonia in world oil shale production and use. In Estonia about 80% of oil shale production is used for electricity generation and 20% for shale oil production (2007: 436,000 t) and as a feedstock for chemicals [3].

C. Price competition

Oil prices and not the much heralded oil shale resources play the determining role in the development of oil shale. The correlation between oil prices and oil shale production is quite strong (Fig. 3). The decline of oil prices as of 1980 prompted a decline of oil shale production in Estonia from 31 Mt in 1980 to 12 Mt in 2000. Production rose again in Estonia between 2000 and 2007 (+32% to 16.5 Mt), when prices for competing heavy fuel oil increased by 129%, of natural gas by 111% and of coal by 43%.

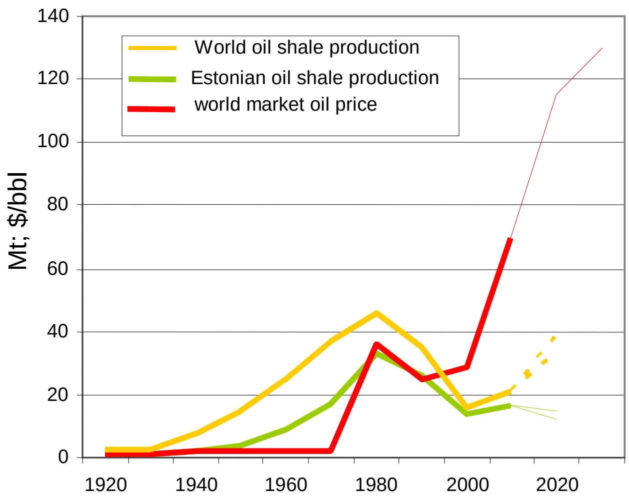

Fig. 3. World and Estonian oil shale production and world market price for oil.

Sources: for actual world oil shale production [2, p. 97], for actual oil price development [4], for oil price projections [5, p. 88].

D. Global significance

The present contribution of oil shale (about 5 Mtoe) to meeting world energy demand (2007: 11,099 Mtoe) is close to nil.

II THE PRESENT

Rising prices for conventional oil and gas on the world market between 200 and mid 2008 revived interest in oil shale. Feasibility studies highlighted the potential strategic advantage of oil shale as a domestic fuel for securing energy supplies, alleviating the balance of payment and enhancing employment. New oil shale operations were said to be technically feasible, environmentally acceptable and viable, also in the long term. Prices of conventional oil and gas were projected to be driven upwards by the depletion of reserves, while those of oil shale remained immense. However, to date, this message did not "carry": oil shale capacities extended notably in China and Brazil only.

A. Rising, and growingly volatile, world market energy prices

During 2000–2007, annual average spot prices for crude oil on the world market (WTI) rose 140% to 72.20 $/bbl, for heavy fuel oil CIF ARA by 250% to 70 $/bbl and for natural gas imports into the European Union by 270% to 8.93 $ per million BTU [4, p. 31]. Coal imports CIF ARA rose by 175% to 73.17 €/tce.

However, the tide turned after a peak in July 2008 (149 $/bbl). WTI prices for oil declined by 80% to 34.60 $/bbl till February 2009 and those for coal CIF ARA by half to 37.5 €/tce. This decline almost fully neutralized the rise of world market energy prices since 2000.

B. New interest in oil shale

The rise of oil prices up to mid 2008 revived interest in oil shale, primarily in shale oil. The exceptions were Turkey, where shale oil would be used to supplement fossil fuel in power generation [2, p. 116], and Jordan, where a 900 MW power station based on oil shale has been ordered [According to The Baltic Times, 8 May 2008, energy company Eesti Energia announced on April 30, 2008 that it has signed a contract with the Jordanian government and the state-owned power company to build Jordan's first oil shale fuelled power plant (900 MW); experience from Estonian power generation suggests that 900 MW require an approximate annual shale production of 4–5 Mt (Ilmar Petersen, The unique experience of oil shale utilization at AS Narva Elektrijaamad (Joint Stock Company Narva Power Plants), lecture given at the WEC Executive Assembly, Tallinn, September 2006)]. The drop of oil prices in 2008 did not seem to overly impress planners who insisted on the long-term advantages of oil shale in terms of resource, security of energy supply, balance of payment and employment opportunities.

Exploratory drilling and feasibility studies were launched in the United States [Following President Bush's Energy Bill of 2005, section 369, a Task Force on Strategic Unconventional Fuels produced a Report on Initial Findings and Recommendations in September 2006] [6], Jordan [7], Turkey [8], Indonesia [9], Morocco [10], Ukraine [11] and Mongolia [12]. Existing shale oil facilities were extended in China (Fushun, Heilongjiang, Longkow and Jilin) [12, 13] and Brazil, but mothballed in Australia [14]. Oil shale use for power generation ceased in Russia in 2005; small quantities continue to be mined for pharmaceuticals [2, country report on Russia]; in 2008, construction began for an oil shale-based cement factory [15]. In Israel, since 1988, oil shale is used for power generation (12 MW using 400,000 t of shale) [16].

The general expectation was that, given enhanced exploration and testing, new shale oil operations were technically feasible, environmentally acceptable and commercially viable. Various cost estimates were ventured (also Fig. 4):

- for Estonia (2005): 30 $/bbl, Enno Reinsalu // Oil Shale. 2005. Vol. 22, No. 3;
- for US (2005): 30 $/bbl, Harold Vinegar, Shell in-situ conversion process // 26th Oil Shale Symposium, Golden, Colorado, 16 and 17 October 2006;
- for Israel (2006): less than 20 $/bbl (catalytic cracking with bitumen from conventional oil refining) // Business Week, 6 July 2006;
- for US (2006): 70-95 $/bbl, falling to 30-40 $/bbl, Wikipedia // Oil Shale Economics, Rand Corporation;
- for US (2008): 60 $/bbl (Raytheon-Schlumberger radio frequency in-situ extraction), JTP Online (The Society of Petroleum Engineers), 1 February 2008;
- for US (2009): 38 $/bbl for true in-situ, 47 $/bbl for surface mining, 57 $/bbl for underground mining and 62 $/bbl for modified in-situ, all with a 15% rate of return, Carolus Marshall // Oil & Gas Journal. 2009. Vol. 2, No. 2;
- for Jordan (2009): 50 $/bbl, Bsieso, M. S. Jordan's commercial oil shale exploitation strategy, 2009, unpublished.

Shale oil at 40–60 $/bbl cannot compete with conventional oil at 35 $/bbl (end 2008), but well at 115 $/bbl, the higher estimate of the US Energy Information Administration for 2020 [5, p. 88] (Fig. 4).

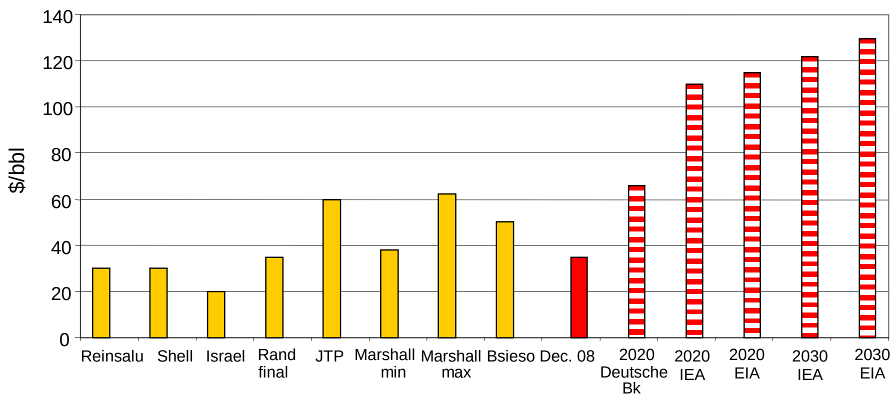

Fig. 4. Estimated cost of shale oil (yellow) versus actual (red) and projected price of oil (lined red).

III THE FUTURE

Regarding the next three or four decades, conventional oil and gas reserves suffice to cover projected world demand, the more so if demand grows less than hitherto expected. Oil prices are projected to rise to 112 $/bbl (International Energy Agency – IEA) – 115 $/bbl (USDOE Energy Information Administration – EIA) by 2020, and to 122 $/bbl – 130 $/bbl, respectively, by 2030. Such price levels encourage the combustion of oil shale and the production of shale oil, whose future costs are estimated at between 20 $/bbl and 60 $/bbl (Fig. 4). However, investors will have to bear in mind geological, technical and institutional uncertainties. In particular, ***additional charges*** *resulting from climate change mitigation policies would hit oil shale harder than its competitors and* ***may place even existing oil shale operations at risk.***

A. No medium-term depletion of oil reserves

The assumed depletion of conventional oil and gas reserves will certainly happen one day. But would it do so during the next thirty-forty years – the time horizon for major oil shale infrastructure projects?

Certainly not. Since the 1970s, the reserve-to-production ratio for oil and gas has consistently remained around 40 years for oil and 50–60 years for gas [In 1970, the r/p ratio for oil was 39.5 years and for gas 53 years] [17, 4]. Proven oil reserves even increased during 1987–2007 by 17% and proven gas reserves by 38% [4, pages 6 and 22]. New "big" fields (Brazil offshore, at 60–90 $/bbl) and enhanced recovery would further delay the projected decline of world oil and gas production (and smoothen a related increase of prices). So would the slow-down of world demand due to recession.

B. An almost comfortable oil price projection for 2020 and 2030

While oil and gas will not "run out" physically for decades to come, the question for the oil shale industry is how particularly oil would be priced on the international market. As indicated in Fig. 4, estimates for 2020 range from 66 $/bbl (Deutsche Bank) to 110 $/bbl (IEA) and 115 $/bbl (EIA). For 2030, the latter project 122 $/bbl and 130 $/bbl, respectively. This may comfort a number of investors although uncertain climate mitigation policies and oil price volatility may affect their willingness to commit funds under conditions of growing uncertainty and risk.

C. New, unfamiliar competitors

At 115 $/bbl or so for conventional oil, not only oil shale but also other sources of energy would see their competitiveness enhanced: coal-to-gas and liquids, gas-to-liquids, nuclear or renewables. Also investments into efficiency would be more attractive. Already to date, oil shale is said to have fallen behind other alternative fuels [18]. Many of these alternatives to oil shale are lower in price and ecological footprint [19]. For sure, oil shale prospects must not only be evaluated against the price of oil, but against non-oil competitors.

There are no studies which assess the place of oil shale in a future global energy mix. The closest approximation would be coal, whose share in world primary energy consumption is estimated to rise from 25% in 2005 to 28% in 2030 in the IEA reference scenario, or to fall to 23% in the IEA alternative policy scenario [20, pages 592 and 594]. These changes are not dramatic, perhaps suggesting that also oil shale developments need much time, either way.

Contrary to the global scene, a modelling effort has been undertaken for Estonia, which specifically includes oil shale as part of total energy scenarios. The study concludes that oil shale would remain the main power station fuel till 2030. However, driven by environmental constraints, its use for power generation would decline in favour of natural gas (prices and supply security permitting), coal (depending on the stringency of CO_2 emission limits), renewables and possibly nuclear fuel. Whether pressurized fluidized bed power generation units as of 2015 would be a significant option for oil shale [21, 22] is not a generally shared view.

D. Reduction of costs unlikely

The limited competitiveness of oil shale during the last decades has prompted initiatives to better the situation through improved or innovative technologies and management practices, in

- **mining**: selective mining and backfilling [23];
- **retorting**: in-situ processing, radio-frequency critical-fluid in-situ extraction, near-zero CO_2 emission surface retorting, Electrofrac ™ in-situ conversion;
- **combustion**: pressurized fluidized bed combustion, co-liquefaction of oil shale and wood, co-combustion with coal;
- **product enhancement**: by-products from shale oil and waste, hydro treatment of products;
- **environment protection**: desulphurization, denoxification, reclamation of mined lands, safe disposal of spent shale, protection of water resources, CO_2 trapping in shale ash or spent retort zones, mineral adsorption of CO_2;
- **management**: information technology, risk assessment, international consulting;
- **scientific cooperation:** exchanges of views and research results.

The bad news is that the much heralded cost cutting technologies from in-situ conversion or retorting (Fig. 4) did not “take off” so far. There is still a way to go from field tests to demonstration plants and industrial application, including the solution of regulatory problems in multi jurisdictional states, such as the United States. Worse: the potential of cost reduction may be absorbed by rising costs for steel, concrete, energy and equipment, or proven insufficient to compete with prices of conventional oil.

The good news is that the cost of oil shale production in Estonia remained stable and is expected to remain so till 2020 [21, p. 213]. Shale oil production rose from over 200,000 t in 1992 to 436,000 t in 2007. The adaptation of circulating fluidized bed combustion from coal combustion proved a breakthrough in terms of efficiency and depollution, involving only slightly higher electricity costs [24].

E. A tightened protection of air, water and land use

In Estonia, the full application of the EU Directive on Large Combustion Plants, as of 2008, will reduce pollution further. Implementation will lead to the closure of existing oil shale pulverized combustion units by 2015, in part (only) replaced by circulating fluidized bed units. The share of oil shale in power generation is expected to decline from 56% in 2006 to 33% in 2020. This decline is expected to be balanced by increased use of biomass and wind and some natural gas [22]. This structural change is not driven by obligations under the Kyoto Protocol, as under no scenario Estonian CO_2 emissions would exceed Kyoto and post-Kyoto levels till 2030 [21, p. 219].

In the United States, policies with regard to producing oil shale are being re-assessed. On 25. February 2009 the US Interior Department blocked a Bush administration plan “to open parts of the Mountain West for oil shale development, announcing that it would first study the water, power and land-use issues that complicate one of the nation's most abundant but controversial untapped sources of energy” [25]. If economic extraction could be demonstrated and potential water resource, infrastructure and environmental problems overcome, oil shale production could be significant. As to the “take off” and its yield, views differ: Killen [26] suggests that production could begin within 5–10 years after the clarification of the issues mentioned, while the Energy Information Administration does not foresee a take-off before 2023. As to the yield, Marshall [27] expects between 1.5 Mbd and 2.4 Mbd for 2035 (see box), whereas the Energy Information Administration expects oil shale production to reach only 0.15 Mbd by 2030 [5, p. 80].

The effect of incentives on US shale oil production under a 40 to 60 $/bbl oil price scenario

- b-a-u: 0.5 mbd by 2020, rising to 2035
- with tax incentives: 1.5 Mbd by 2035
- with RD&D incentives: 2.4 Mbd by 2035
- cumulative savings on oil imports: $325 bill.

Source: Marshall [27]

F. Reducing CO_2 emissions: a deadly or a manageable challenge for oil shale?

a. The *post-Kyoto* process: Concerns about global climate change, resulting inter alia from fossil fuel combustion, are presently being translated into policies, both at the European Union and global levels (*post-Kyoto* negotiations). The stringency and world-wide application of the latter process is presently subject to negotiations which are intended to be concluded by 2012. If the agreement were to limit the rise of mean global temperatures to 2.8 °C, the use of coal (the closest approximation for oil shale) would have to decline by 12% in 2030 compared with 2005 [20, tables 5.4 and 5.5 (450 ppm Stabilisation Case)] and much more later.
b. Related EU policy: The European Council agreed in 2008 to reduce CO_2 emissions by 20% by 2020 from 1990 levels and, under conditions, by 30% by 2030 as part of the *post-Kyoto* global climate change negotiations. For 2050, much higher reduction targets are envisaged (~50%). The solution for polluters consists of quitting [According to The Baltic Course, 30.3.2009, Estonia's largest oil shale processing company Viru Keemia Grupp decided to interrupt preparations for establishing a cement plant due to the difficult economic situation and having not been granted CO_2 emission allowance] or delocalizing their business, buying pollution rights (European Emissions Trading Scheme), raising combustion efficiency or deploying carbon capture and storage systems (CCS). This latter technology is expected to be commercially available around 2020, but raises investments in power generation by 30–100% and electricity costs by 10–20%. By 2030, costs might fall, though, from the present 50–100 \$/t CO_2 to 25–50 \$/t CO_2 [19, 28]. The European Council made 300 million € available for first-of-a-kind CCS demonstration projects and other innovative renewable energy sources.

Ten questions to oil shale operators on CO_2 preparedness

1. Is CO_2 mitigation "mission critical" for oil shale's future? Or rather water, oil price, energy security?
2. Are oil shale operators, equipment manufacturers and researchers prepared to prioritize the CO_2 issue?
3. Would efficiency gains in power generation and retorting suffice to meet new CO_2 emission reduction targets?
4. In particular, would circulating fluidized bed combustion suffice? If not: would pressurized fluidized bed combustion?
5. Is carbon capture and storage the ultimate solution? If so, can capture technologies be adapted to oil shale? If not, what are the alternatives?
6. Pending CCS maturity, should new units be designed as "capture ready"? Would "early player" incentives help?
7. What is the potential to reduce CO_2 emissions from in-situ conversion and surface retorting?
8. Is storage and adsorption of CO_2 in shale deposits feasible, viable and sustainable in the long term?
9. Do operators conceive CDM (Clean Development Mechanism) as an option?
10. In the longer term: would CO_2 mitigation erode your business?

c. Projected impact: Generally, new generation methods like fluidized beds could reduce CO_2 emissions from oil shale-based power plants from an average of 1600 kg CO_2/MWh to about 1000 kg CO_2/MWh and even 140 kg CO_2/MWh, if CCS was applied. In retorting, and depending on the calorific value and mineral composition of the oil shale, about 2.4 mol CO_2/MJ are emitted, compared with 2–2.25 mol CO_2/MJ for coal [29]. Low CO_2 emission shale oil processes are investigated, in particular in-situ conversion.

In Estonia CO_2 emissions per capita are twice as high as in the European Union. However, Estonia's CO_2 emissions are presently well below the Kyoto targets and will remain so till 2030 under any scenario. This could theoretically allow a rise of oil shale production from 16.5 Mt in 2007 by about 6 Mt to 22 Mt in 2020 [30]. But the "National Development Plan for the Use of Oil Shale 2008–2015" [31] stipulates that oil shale mining shall not exceed 15 Mt by 2015. A target of a 20% share of renewables in electricity generation and CHP by 2020 would lead to a decrease from 16.5 Mt in 2007 to about 12 Mt in 2020 [21, Fig. 6; 22].

The energy strategy of Estonia limits oil shale mining to 15 Mt by 2015

The technical feasibility of CO_2 storage in the Baltic States and the potential of sequestration in alkaline ash have been studied as part of an EU research effort [32].

In the United States, polices with regard to reducing CO_2 emissions have still to be determined and will have to be consistent with a possible international *post-Kyoto* agreement. Storage options are already examined [33]. Field tests suggest that in-situ conversion produces less CO_2 emissions than surface retorting [34, 35].

The newly industrializing countries ought to reduce their CO_2 emissions under business-as-usual conditions by 15 to 30%, according to the EU. This means that traditional surface retorting and combustion would have to become less polluting and more efficient. The question is whether efficiency gains would suffice to comply with climate mitigation obligations or whether international technology transfer and funding would become necessary. McKinsey estimates that technology transfer to reduce greenhouse gases in developing countries would require $100 billion/year with additional $30–50 billion devoted to adaptation of infrastructures [36].

Whatever the additional costs of mitigating climate change: they would be higher for oil shale than for coal, oil or natural gas, due to its higher carbon content.

IV AN ENABLING AGENDA AND ITS PROJECTED IMPACT

Such handicap could be attenuated, though, by a concerted action of all stakeholders: Governments, Industry and Academia. Given this action, oil *shale use would rise. It could serve as a bridge fuel towards a more sustainable energy economy in a number of countries. However, it would not attain the global significance which its resource base suggests.*

Boom or bust? As the above analysis has suggested, there can be no certainty either way. But the uncertainty can be reduced by a determined and concerted action of all stakeholders.

A. Governments

The lead role in this respect has to be assumed by governments, as at present the main doubt about oil shale's future results from the implications of a possible global climate change mitigation policy and from a tightening of "classical" environmental protection policies. In determining their policy, Governments should:

- be mindful of the geopolitical leverage offered by the vast oil shale resources;
- provide more eco-planning security for the oil shale industry, in particular with regard to:
    - the targets of reducing CO_2 and other hazards on water, air and land use;
    - related reference years;
    - the "grandfathering" (recognition) of reductions already accumulated during the Kyoto process;
- ease the regulatory process, particularly when a multitude of jurisdictions are involved;
- determine the role of oil shale in national energy policy, thereby taking into account benefits in terms of security-of-energy-supply, balances-of-payment and employment;
- stimulate other stakeholders to play their role in implementing this policy
    - offer tax incentives;
    - support oil shale-related RD&D;
    - support early investors in CCS power plants, capture-ready units and PFB [The Government of the Federal Republic of Germany issued on 26.2.2009 amended conditions for "Ungebundene Finanzkreditgarantien", which reduce the investor's commercial risk in foreign investments in raw materials and energy (see BMWi Pressemitteilungen of 26.2.2009; www.agaportal.de)];
    - reduce the financial risk of oil shale investments (tax exemptions, revenue guaranties);
- monitor, if necessary limit, the effects of oil shale mining and use on human health, air, water and land use;
- support technology transfer to emerging nations as part of an international effort.

B. Oil shale operators

should:

- exploit potential for cost reduction (efficiency, economies of scale, information technology, risk assessment);
- deploy CCS and pressurized fluidized bed combustion, once mature
- design new combustion units as capture-ready;
- upgrade in-situ extraction test facilities into demonstration and commercial plants;
- view CCS as a business opportunity (enhanced oil and gas recovery);
- reduce emission penalties via CDM (clean development mechanism) projects;
- enhance consulting, invest in emerging oil shale countries;
- upgrade shale oil products and waste, develop niche applications.

C. Academia and developers

should:

- concentrate research efforts on reducing CO_2 emissions from oil shale operations;
- study the feasibility and viability of capture-to-storage oil shale systems;
- adapt carbon capture technologies (pre-, post- or oxyfuel combustion) to oil shale combustion;
- test CO_2 sequestration (CaO sorbents; chemical looping, CCS) [37–39] from surface retorting;
- analyze CO_2 emissions from in-situ extraction and their reduction potential;
- test mineral absorption and other means of CO_2 storage such as in ash, settling bonds [40] and shale deposits;
- study co-liquefaction of oil shale and wood, co-combustion with coal, biomass;
- continue ongoing international scientific cooperation, including on internationally comparable definitions and statistics on world oil shale resources and reserves.

D. Projected impact till 2020

Present documented expansion plans suggest that world oil shale production could rise between 2007 and 2020 by 55 to 80% to 33–39 Mt (Table).

Increases in Jordan and China – the new world leader in oil shale production and processing – more than outweigh the projected decline in Estonia. The global increase will be entirely for shale oil production, whose share in oil shale use would rise from 33% in 2007 to 44–48% in 2020. These projections are approximate and conservative: they do not anticipate a possible oil shale production in the US, Russia, Ukraine, Turkey, Morocco, Mongolia and others by 2020.

Table. **Actual 2007 and projected 2020 world oil shale production**

Area	2007	2020 low	2020 high	References
Brazil	2.2	2.2	2.2	Information from W. P. Martignoni: no expansion due to off-shore oil discovery.
China	1.4	13.4	15	Wikipedia: Oil Shale in China (Fushun, Heilongjiang, Longkow and Jilin); Shuyuan Li, Chinese oil shale business is going on // International Oil Shale Symposium, Tallinn, June 2009.
Estonia	16.5	12	15	Low: in case of a share of 20 % of renewables; high: limited national policy.
Germany	0.3	0.55	0.55	Information from Holcim Süddeutschland.
Israel	0.4	0.4	0.4	Jaakov Mimran [16].
Jordan	0	4.5	4.5	Eesti Energia to build a 900 MW plant.
Russia	0.6 0	+ +	+ +	WEC Survey of Energy Resources 2007: pharmaceuticals; J. Purga: a cement factory in Slantsy.
US	0	0	0	EIA Annual Energy Report 2009, p. 80: production begins 2023, reaches 0.15 Mbd by 2030; other estimates: Marshal, Killen.
Ukraine	0	+	+	Viru Keemia Grupp: planned Bolyshk processing plant (>5 Mt/a).
others	+	+	0.3	
World	21.4	33.1	38.5	

However helpful these developments are for the countries concerned, at the global level oil shale would not attain the importance that its huge resource base suggests.

Conclusions

World oil shale production, while expected to rise by a conservative 55 to 80% by 2020, remains a local asset. Proactive measures include affirmative national policies to attenuate investor uncertainties, the application of carbon capture and storage to reduce CO_2 emissions, and the intensification of international cooperation (equity investments; technology transfer; joint R&D; internationally comparable statistics of oil shale resources, production and use; application of Clean Development Mechanisms).

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