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NEW DIRECTIONS FOR SHALE OIL: PATH TO A SECURE NEW OIL SUPPLY WELL INTO THIS CENTURY
[ON THE EXAMPLE OF AUSTRALIA]

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Abstract

Australia has enjoyed near self-sufficiency in crude oil production since the late 1960s but has declined to 80–90 % in recent years. This is expected to drop to below 50 % of demand by 2019–2020. *Southern Pacific Petroleum NL* is pioneering the development of breakthrough technology to unlock oil from Australia's largest oil resource, with 17.3 billion barrels of oil shale held in ten deposits along the coast of Central Queensland, Australia. These deposits could support production of more than one million barrels of oil per day, helping to secure oil self-sufficiency for Australia and meet part of a growing oil demand in Asia.

The company spent more than A$150 million on research and development before embarking on a demonstration plant to produce oil commercially. It is the depth of this research and its application that has provided a sound basis for the development of a new industry that can help fuel the growing demand for oil in the transportation sector in a way that is environmentally responsible. The company's initial operations at the Stuart deposit, located 15 km north of Gladstone, Central Queensland, is the start of a multi-stage risk-managed approach to developing a shale oil industry using the first-of-a-kind Alberta Taciuk Processor (ATP) technology.

Stage 1, a 4,500-bpsd (barrels per stream day) demonstration-scale plant, is a 75 : 1 scale-up of a successful laboratory pilot plant developed to process oil sands in Canada. The Stage 1 plant was constructed in 1997–1999 and has produced over 500,000 barrels of oil to date. A great deal of operating data has been captured and the plant has been able to run in excess of 52 days continuously at peak rates up to 84 % of capacity. A current capital

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program will push both throughput and availability to design rates over the next year.

The **Stage 2** plant, with a capacity of approximately 15,000 pbsd, will share services and infrastructure with the Stage 1 plant.

This is projected to lead into a commercial plant ultimately producing up to 200,000 bpsd of light sweet crude equivalent, based on multiple commercial ATP units. At this rate, Stuart could offset current oil imports to Australia and meet one quarter of the current Australian demand for crude oil. The full commercial plant would be supplied by oil shale from the Stuart Resource for more than 30 years.

The raw oil produced in the Stage 1 ATP from the Stuart deposit has an API gravity of 42º. As the raw oil is a product of pyrolysis, it requires on site treatment to stabilize it and to reduce nitrogen and sulphur levels to best meet refiners' needs.

In Stage 1, the naphtha/kerosene fractions are hydrotreated to produce an ultra low-sulphur 'water-white' product, which can be readily used to make gasoline and jet fuel. Shale oil has been certified as a feedstock for jet fuel production by the world's leading accreditation agencies. A long-term contract has been signed for the sale of naphtha to *Mobil Oil Australia*. The second product, light fuel oil, is sold into the Singapore fuel oil market as a blending stock.

The successful performance of the ATP at the Stuart Stage 1 plant under sustained operations has now demonstrated its technical viability, economic potential and environmental sustainability. Oil from shale is Australia's emerging new clean-energy industry.

Introduction

Australia is no stranger to oil shale development. Production from oil shale deposits in the states of Tasmania and New South Wales dates back to the 1860s. Unfortunately, the last producing mines closed in the early 1950s when cheaper crude oil again became plentiful. Between 1865 and 1952, about 4 million tonnes of oil shale were processed.

From the late 1960s (after discovery of the Bass Strait fields) up until the early 1990s, Australia has been principally self-sufficient in crude oil. Bass Strait and other indigenous crudes are predominantly light and sweet and well suited to meeting Australia's high transportation fuel usage without extensive processing. The early 1990s net imports have increased to 10–20 % of supply.

With production from existing fields reducing and a relatively poor prospective outlook for discovering major new fields, the Government forecasts put the dependency on imported crudes rising to 52 % by 2020 [1]. This will potentially have a marked influence on Australia's balance of payments unless alternates sources of crude oil are found.

Australian refiners [2] are also facing change, with new clean fuels regulations coming into force. With the preferred clean indigenous crudes depleting, refinery processes will need to be upgraded to accommodate the increasingly sour nature of imported feedstocks.

Southern Pacific Petroleum NL has a vision to supply some or all of this potential shortfall, through the commercialization of the ATP technology taking feed from the 17 billion barrels of resource they control in Central Queensland, Australia. *SPP* is currently operating a demonstration plant as a part of a staged development of the ATP technology and the Stuart Resource. This paper overviews the company, the resources, the development plans for the Stuart deposit, and commissioning experience for the demonstration plant.

Southern Pacific Petroleum, the Company, and Its Oil Shale Resources

With the threat of oil price shocks, a new chapter in the history of oil shale development in Australian began. The two companies were established in 1968, with identical boards and management, *Southern Pacific Petroleum NL, SPP* (to pursue petroleum interests), and *Central Pacific Minerals NL, CPM* (to pursue mineral interests). In 1973 the far-sighted founder, Sir Ian McFarlane, decided to prospect for oil shale.

Armed with the knowledge of the problems that the initial Australian fledging oil shale industry had suffered and the experience in Colorado, an exploration program was undertaken by *SPP*/*CPM* in the 1970s and early 1980s. The objective was to find high-quality oil shale deposits amenable to open-pit mining operations in areas near infrastructure and deepwater ports. This process was successful in defining ten silica-based oil shale deposits of commercial significance along the coast of eastern Queensland.

SPP/*CPM* became known as the 'Rundle Twins' after the discovery of the 2.6 billion barrel Rundle deposit. They took up interests on this and subsequent deposits on a 50/50 basis as any development would embrace both mining and oil technology.

These deposits are elongated basins that developed as lakes and subsequently filled with fresh water sediments containing the fossilized remains of algae, which were so abundant during the Tertiary period. Individual oil shale seams range in thickness from 1 to 30 m and extend to 20 km in length. *In-situ* shale oil in the Queensland deposits held by *SPP*/*CPM* and its co-venturers is estimated at over 20 billion bbl.

The Stuart resource is the candidate deposit chosen for initial development based on a combination of factors including:

- Silica-based shale with low metal impurities
- Highest grade seam uppermost in the deposit covered by 14-m overburden

- Thick seams suitable for open-cast mining
- Conventional truck and shovel mining operation without need for blasting
- High average oil grade – 93 LT0M (litres per tonne at zero moisture); demonstration plant feed 172 LT0M
- Within 4 km from all necessary utilities (electricity, water, natural gas)
- Close to infrastructure (industrial city, roads, wharf)
- Resource preservation status (State Government)

Deposit	Oil shale resource*	SPP net interest, %
Condor	4.8	100
Yaamba Group	4.0	100
Duaringa	2.5	100
Stuart	2.6	100**
Rundle	2.6	50
Nagoorin	2.4	50
Nagoorin South	0.4	100
Lowmead	0.7	50
TOTAL	20.2 billion bbls	17.3 billion bbls

* Based on a cutoff grade of 50 L/t at zero % moisture. Excludes 9.8 billion barrels (gross and net) of other oil shale in-situ at depths below 500 meters and at high waste-to-ore ratios.
** Suncor Energy entitled to 5% royalty on production on Stage 1 only.

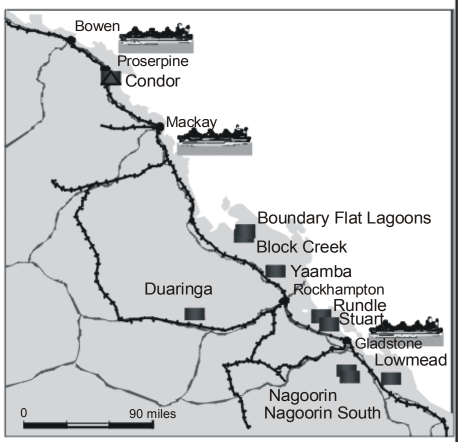


Fig. 1. SPP scale resource

Both Stuart and the adjacent Rundle oil shale deposits in Central Queensland represent an immense potential source of high-quality hydrocarbons. The combined resource is about 40 km long and 5 km wide and contain sediments up to 1,000 m thick.

In-situ oil shale at Stuart totals 6.5 billion tonnes at a cut-off grade of 50 LT0M and down to 350-m depth. With an average moisture content of 19 wt% and grade of 93 LT0M (with some zones more than 200 LT0M), the contained shale oil is estimated at 2.6 billion bbl, according to the JORC Convention.

Using new low-cost production technology, the low-sulphur oil products produced from these oil shale deposits could significantly enhance Australia's options in meeting future demand for cleaner transport fuels to improve air quality and in reducing dependence on oil imports. As such, the Stuart Oil Shale Project at Gladstone in Queensland is one of the most significant new developments in the Australasian oil and gas industry.

The Stuart Project was initially formed as a joint venture between Australian companies *SPP* and *CPM* and *Suncor Inc. of Canada* and commenced in June 1997. *Suncor* left the project in April 2001 during the commissioning of the demonstration plant to concentrate its efforts on the Millennium expansion of its oil sands operations in Alberta. *SPP*/*CPM* assumed 100 % owner and operator status, and has made substantial progress towards commercialization of the technology.

In February 2002, in order to remove the complex cross share holding between the companies, a corporate restructuring was undertaken. The result was one publicly listed company, *SPP*, which became a holding company for the group's interests. *CPM* was delisted from the exchange.

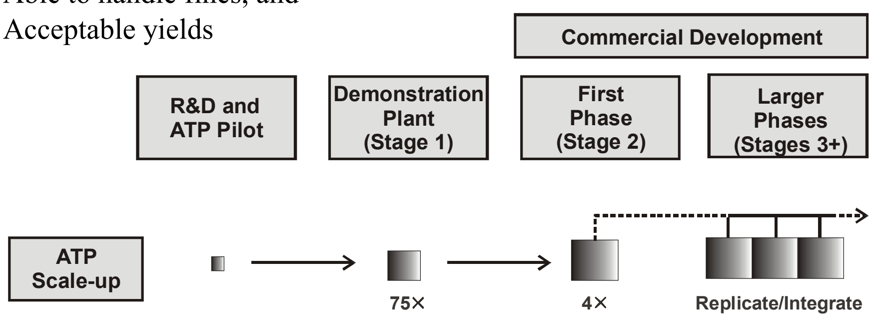
Stuart Development Plan

Staged Approach

With the discovery of the Queensland oil shale deposits from 1973 to late 1980s, *SPP* and its co-venturers embarked on an extensive two-pronged program in the 1980s to evaluate possible oil recovery technologies. The first prong involved an extensive evaluation of ten licensed retorting technologies including pilot plant testing of seven of these. The second prong involved a basic research program carried out in conjunction with many institutions and agencies worldwide, in addition to the Commonwealth Scientific Industrial Research Organization (CSIRO) in Australia. In total, these encompassed 16 major technical groups and expenditures in excess of A$150 Million.

This program identified the ATP technology as the best candidate for further evaluation. The positive attributes of the ATP were seen to be:

- Simple, robust design
- Energy self-sufficient process
- Processed shale is dry and easily handled
- Mechanical transfer of solids through the machine with no moving parts
- Solid-to-solid heat transfer
- Able to handle fines, and
- Acceptable yields



Oil shale (tpsd)	80	6,000	23,500	up to 380,000
*Oil products (bpsd)**	*75*	4,500	15,500	up to 200,000
Timing	1980s	1999	2006	Phased 2010-2013

** Reflects varying oil content in oil shale feed in various stages.*

Fig. 2. Stuart staged development strategy

Early in the life of the Stuart Project it was recognized that any development of the oil shale deposits had to incorporate the ideas of sustainability. In order to achieve a considered and widely accepted progression for such an enormous task the vision was to embark on a staged development. Each of the stages would be aimed at minimizing the risk of successive steps such that, as the main aim, the commercial plant can be built with minimum technical risk. Risk is defined as involving the triple bottom line-social, commercial and environmental aspects.

The development plan being pursued at Stuart began with detailed programs undertaken in bench- and lab-scale test units and progressed to a pilot plant. Special rigs to investigate scale-up potential also provided a sound basis for the continued development of the ATP. The result of this work culminated in the Stage 1 Demonstration plant.

The plant was built on a green field site adjacent to the mine and has a nameplate capacity of 4,500 bpsd using 6,000 tonnes per day of shale on average 172 LT0M as feed to the unit. The ATP is 8.5 m in diameter and 62 m long and represents a 75 : 1 scale-up from the original pilot plant.

Two products are produced, an extra low-sulphur naphtha and a light low-sulphur fuel oil which are marketed in Australia and in Singapore, respectively.

The objectives of the demonstration plant are to:

- Demonstrate that the principal technology works and can be scaled up
- Integrate all major processing steps: mining, crushing, processing, hydrotreating
- Understand and document process controls/operability/reliability issues
- Understand and document the resource: mining/variability/process impacts
- Understand and document suitable feed-preparation steps to ensure a stable process
- Demonstrate satisfactory separation systems for gas, oil vapor and solid
- Demonstrate product quality and market acceptance
- Specify fit for purpose equipment for scale-up, considering operability and reliability
- Understand emissions and design control systems to accommodate
- Specify design standards for a robust design, and
- Understand environmental and social issues and accommodate them in the development

To date, these objectives have been largely proved or determined as applicable in the Stage 1 plant. *SPP* considers that technology is ready to be developed to the next stage, that of building a commercial module.

Plans for the Stage 2 project envisage it will be constructed adjacent to and sharing infrastructure and utilities with the Stage 1 plant. The design basis is a 4 : 1 scale-up in feed rate to about 25,000 t/d of shale feed to produce 15,500 bpsd of shale oil products. The Stage 2 ATP is a commercialsized module with a diameter of about 11.5 m and 60 m long. The design will incorporate lessons learned and efficiencies from Stage 1, in addition to developmental features trialled at pilot stage to improve throughput. Capital costs are projected to be $US300–330 million (2002$) with operating costs of US$7–9 per bbl (2002$).

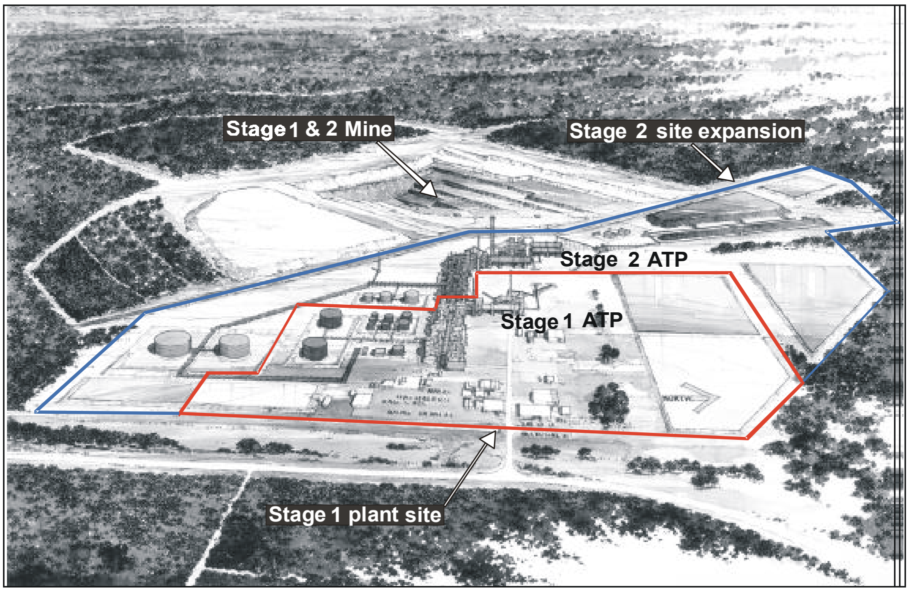


*Fig. 3.*Stuart first commercial stage

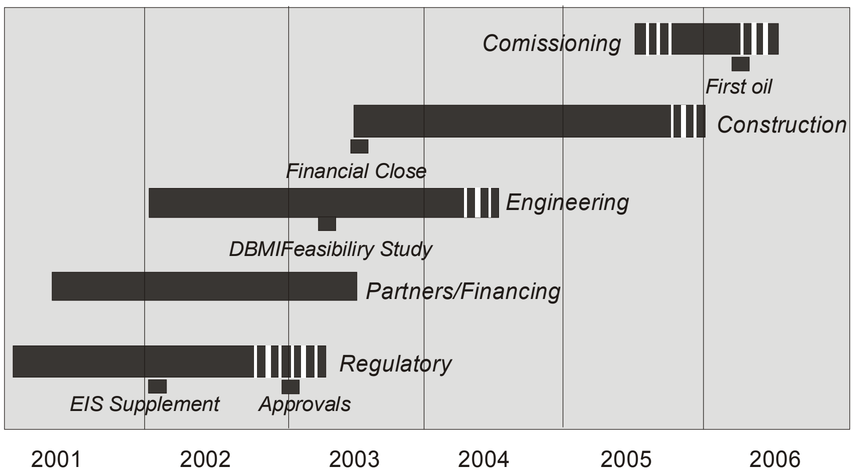


Fig. 4. Stage 2 schedule

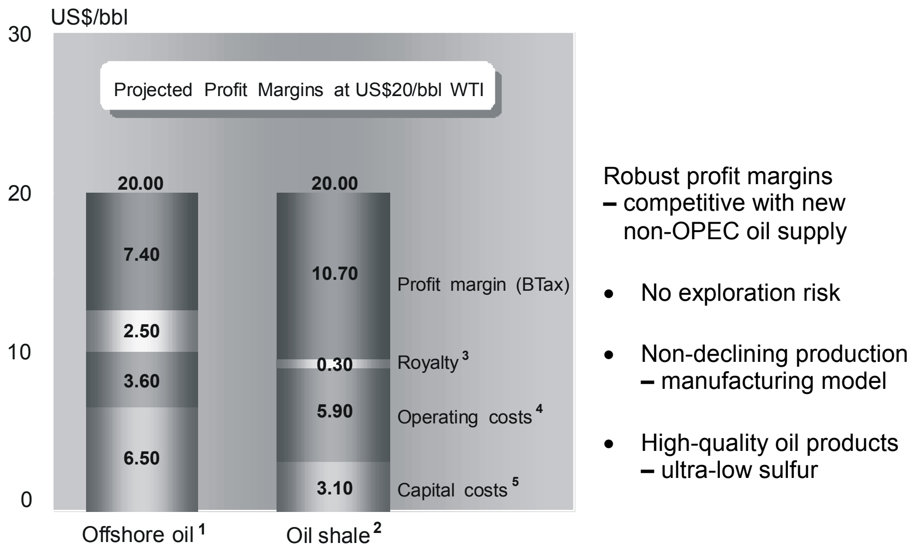
SPP is close to achieving regulatory approvals on Stage 2 and is currently actively pursuing partners and financing for the project. A basic Design Basis Memorandum was developed in March 1999. This is the platform for continuing design studies, which aim to incorporate Stage 1 learning. Construction is expected to take 27 months with first oil in 2006. The product slate is similar to that of Stage 1. New features of the plant will include hydrogen recovery produced gas to supply the hydrotreaters and reduce the need to reform natural gas.

Following on from Stage 2, further commercial stages are expected to follow incorporating a replication of ATP modules at the size prototyped in Stage 2. The Stuart deposit can support a total production from such a commercial plant in excess of 200,000 bpsd for over 30 years.

The product slate for a commercial module may vary from raw oils through to highly refined products, dependent on the demand and the markets at the time. Project economics have been based on a single highly refined synthetic crude product, boasting very low sulphur and nitrogen concentrations.

Proposed Commercial Product Slate

Indices	Stuart synthetic oil
Gravity, API	48
Sulphur, ppm wt	<100
C4, wt%	7
C5 – 177 °C, wt%	34
177–343 °C, wt%	41
343–500 °C, wt%	18
Diesel cetane number	60+



Notes: 1. Actual cost structure of GOM, W. Africa, N. Sea, Brazil, CERA Report, July, 1999.
2. Projected oil shale costs for 157,000 bpsd commercial development (Internal estimates October 2002), including in-plant greenhouse gas mitigation steps (energy efficiency; bio-ethanol co-production). Exchange rate US$/A$ = 0.55.
3. Oil shale 1.5% (Queensland State); conventional 12.5% (assumed average).
4. Oil shale: representative year.
5. Oil shale: initial capital (amortized over 30 year projected life) and sustaining capital (representative year). Offshore oil: finding and development costs.

Fig. 5. Projection for total development

A commercial plant producing in excess of 150,000 bpsd would appear very similar to the current developments in the oil sands industry in Alberta. At this scale, the costs for producing oil from shale are very competitive even as compared with conventional offshore developments in Australia and other parts of the world.

While operating costs are higher for oil shale, there are few exploration costs and, once established, the plants have a regular feed for upwards of 30 years hence amortized capital costs are relatively lower.

Project Development

The Stuart Project Stage 1 definition and design work was based on the 1987 pilot plant test results, with mining and process/engineering studies updated in 1989 and further product marketing research undertaken in 1995–1996. Hydrotreating studies were undertaken through 1989–1991 with a major technology supplier using oils that were produced in pilot plant trials in 1987. Conventional technology and readily available catalysts were used as a basis.

In 1990, two major international engineering groups independently undertook work to verify the design, operability and cost estimates of the proposed Stage 1 of the Stuart Project. Both companies endorsed the project as a demonstration of the technology and the feasibility of the scale-up. *SPP* armed with the favorable engineering results, moved ahead to obtain excise and environmental approvals.

– During 1991, discussions with the Australian Federal Government resulted in providing exemption to product excise taxes on up to 600,000 barrels of gasoline derived from oil shale naphtha until the end of 2005 (maximum A$36 million per year).
– In 1993, an Environmental Impact Study for Stage 1 was completed, resulting in the approval of the Environmental Management Strategy and granting a 30-year Stage 1 Mining lease by August 1996.
– A joint venture agreement was struck between *SPP*/*CPM* and *Suncor* in 1995 to move into a demonstration phase. Project financial close was achieved in June 1997 after an EPC contract was signed to construct Stage 1 plant in April of that year. Construction was started in August 1997 and completed by April 1999. Commissioning, equipment enhancements and production testing has continued up to the present time.

The Design Basis

The Stuart Project is a fully integrated mining, oil recovery and partial upgrading project. The mined shale (truck and shovel) is crushed. The process is simple and includes crushing shale from run-of-mine size to minus 6 mm before drying to 8 wt% moisture which is fed to the ATP. Here shale is preheated against the processed shale leaving the machine. The processed shale is moistened before returning to the mine for burial. Leachate tests from the processed shale class it as a benign solid suitable for disposal in domestic waste sites.

Feed shale is retorted at 500 °C by mixing hot (750 °C) combusted shale with preheated and dry feed shale. Kerogen is pyrolysed into a hydrocarbon vapor that leaves the ATP *via* cyclones to remove solids. Fine dust is removed in a hydrocarbon vapor scrubber and shale solids and a small stream of heavy oil are returned to the retort.

Product vapor is distilled to provide a light fuel oil (LFO) product. The column overheads are compressed and the naphtha fraction is removed from progressive stages of compression and cooling. A sponge circuit is used to improve recovery of $C4^+$ from non-condensable off gas.

The raw naphtha is quite unstable. It is hydrotreated over commercial catalyst to improve stability and remove nitrogen (0.7 wt%), sulphur (0.35 wt%) and oxygen (1.1 wt%) impurities to <1 ppm wt levels. The products are run down to on-site storage then piped to a shipping jetty 2 km from the plant.

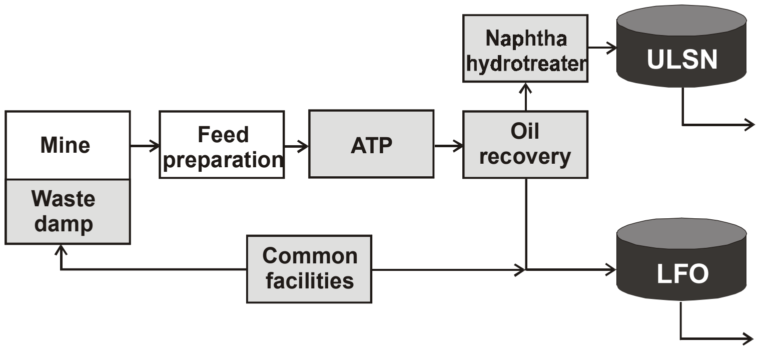


Fig. 6. Process flow diagram

Stuart Stage 1 Product Quality

Indices	Crude shale oil	LFO	Ultra low-sulphur naphtha (ULSN)
API gravity	42º	24º	57º
Sulphur, wt%	0.35	0.4	< 1 ppm
Nitrogen, wt%	0.8	1.1%	< 1 ppm
Viscosity, cS, at 40 ºC	2.7	7.0	–

Commissioning Experience

The commissioning of this first-of-a-kind plant, although somewhat protracted, was in line with industry [3] experience when dealing with a naturally occurring mineral and a number of complex processing stages involving solids, liquids and gases.

The commissioning progressed in stages. Initial operations (July 1999 to May 2000) were highlighted by a series of campaign runs which provided the opportunity to test equipment on process fluids, to establish control relationships, and highlight areas requiring improvement such as odor, noise and dust concerns. While these runs only averaged 13 hours each, sufficient design data was developed to progressively overcome the problems. A data archiving system facilitated data capture and retrieval for analysis.

Major capital works followed in second half of 2000. Modification to the process control loops, the hydrocarbon vapor scrubber, which separates dust from product oils, and the flue gas scrubbing circuits were undertaken. The plant was at this stage capable of up to 5 days continuous operations.

Operating and reliability issues then became the focus from December 2000 to September 2001. Typical modifications included a revamping of the interlock logic to make it compatible with continuous operation, improvements in burner reliability for the fuel gas produced from the process and the automation of systems which had manual field controls. The emphasis was to free up operators to better support the plant.

With longer runs, operational issues also began to arise. Small amounts of polymers were formed in the retort off gas compression stages and in the sponge oil circuit. This fouled flow meters and heat exchanges a few days into each run. Chemical and water mist injection provided relief for the compressor and the method of on-line cleaning of the flowmeters (annubars) was developed. The sponge fluid and the operation of the sponge circuit were changed to avoid continually thermally working the light gas oil fractions, which promoted formation of polymers. This proved very successful.

Flue gas systems from the dryer and ATP are cleaned by cyclones followed by venturi scrubbers before moving to the stack. The scrubbing circuits are passed through a settler to remove entrained solids, which are added to the dry processed shale to provide adequate moistening to contain dust and returned to the mine. Dissolved salts from the mineral matter in the shale soon resulted in calcium sulphate/sulphite scale formation. This has been overcome with the addition of chemicals and improvements to the pH control of the circuits.

The final phase of commissioning is concentrating on extending operating stream factor and increasing plant capacity. The plant throughput continues to be below design due to limitations in the direct-fired, concurrent rotary dryer. Its capacity is restricted to meet odor guidelines. A new fluid-bed dryer will be installed to remove this limitation over the coming year.

Plant availability has increased to about 50 % with the longest continuous run period of 52 days. While this is creditable, the target is to achieve 80–85 % available by implementing a number of reliability improvements.

The plant has produced oil to specification since the initial commissioning. Shale oil production totaling over 550,000 barrels of LFO and ULSN up to September 2002 has been achieved. The ULSN is sold under contract to *Mobil Oil Australia* and the light fuel oil is readily sold into the fuel oil blending market as a cutter stock in Singapore.

With this experience, the information is now available to design a fit for purpose commercially scaled plant with required reliability. Stage 1 as a demonstration plant has proven the technology works and provided design detail for all unit operations for a commercial plant. It does, however, require more capital to achieve its design throughput.

Developing a Sustainable New Industry

SPP is committed to a sustainable development path that contributes to a healthy environment, a strong economy and social wellbeing. A number of leading edge measures are being implemented to meet the environmental goals embodied in this commitment.

The air emissions abatement program underway at Stuart, focused on particulate and odors, is an important element of the project's sustainable development initiative. All releases to atmosphere from the plant are below regulatory limits.

The retorting process is energy self-sufficient, as coke from pyrolysis is burned in the ATP. In a commercial plant design, there are many avenues for energy recovery and unit integration to reduce net carbon dioxide contribution.

In response to the threat of global climate change, the Stuart Project has targeted a carbon dioxide emission intensity for the planned **Stage 3** commercial plant (on a full fuel cycle basis) that is comparable less than that achieved in the production of conventional crude oil products. This presents a significant challenge given the higher energy intensity of the shale oil production process.

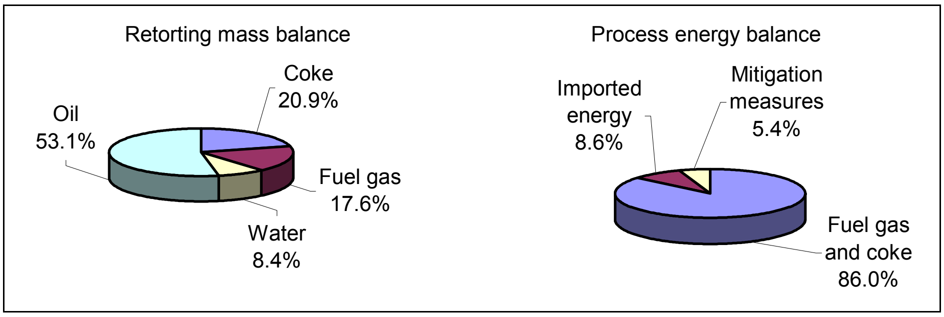


Fig. 7. Energy balance from retorting (65,000 bpsd case)

To achieve this goal, *SPP* has developed a cost-effective GHG strategy based on:

- Improving the production process to minimize the amount of energy used to produce each barrel of oil from shale
- Co-developing renewable bio-ethanol production from woody biomass, one of the cleanest and most greenhouse-friendly transport fuels available
- Developing tree plantations to sequester carbon as well as to enhance biodiversity and mitigate salinity

An ambitious and innovative program to develop an effective reforestation carbon dioxide sink was launched by the *Stuart Joint Venture* in 1998. To date, more than 250,000 trees have been planted on deforested lands in Central Queensland utilizing over 50 varieties of fast-growing native species. This research program is collecting important data on carbon dioxide sequestration rates in both the trees and surrounding soils as a basis for future expansions to this program. In September 2000, *SPP*/*CPM* also announced the first carbon trade in Queensland, in conjunction with the Queensland Government, based on an extension of these reforestation trials.

Work began over ten years ago to develop land rehabilitation practices for mined areas. Trials carried out in a large excavation site adjacent to the current Stuart Project were successful in achieving total revegetation with native species. This knowledge is being incorporated into the Stuart Project land rehabilitation program.

The Stuart Project is located near the Queensland coast adjacent to the industrial port of Gladstone. As a preventative measure to avoid contamination of the coastal waters, all water produced in the process and the rainfall on the plant and mine sites are collected, treated and reused on site. In addition, industry leading measures are being put in place to prevent discharges of untreated water from the rehabilitated mine area. An extensive groundwater monitoring program has been in place for ten years to understand the seasonal variation of water quality and level.

Conclusions

Success at Stuart has the potential to create a new production development paradigm for oil shale. This could lead to the creation of a new energy industry in Australia and other countries rich in oil shale resources, with attendant benefits in creating jobs, economic growth and a sustainable source of clean energy. The Stuart deposit alone, representing just one tenth of the known silica-based *in-situ* oil shale in Queensland, could support a production rate of 200,000 b/d for 30 years.

The Alberta Taciuk Processor is seen as the best technology to develop the Queensland oil shales. The staged development of the ATP on the Stuart deposit has progressed from pilot to a successful demonstration-scale unit. With this experience and expertise in development, design, and operations, *SPP* is poised to move to a commercial module of the ATP technology work targeted start-up in 2006. Further expansions owned develop a world-scale operation producing in excess of 200,000 bpsd.

Given the immense size of Queensland's and the world's oil shale resource, a breakthrough in production technology and associated supply costs is expected to have significant impact on world oil supply this century.

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