Time and Cost to Commercialize an Oil Shale Surface Retorting Technology

Richard Sherritt, Jim Schmidt and Jimmy Jia
PROCOM Consultants Pty Ltd
Unit 4, 38 Limestone Street, Darra QLD 4076 Australia

Abstract

An oil shale surface retorting technology is commercialized by building and operating a series of progressively larger plants. Capital and operating costs depend on the size of the plant. The rate that a plant achieves its annualized design capacity is assumed to depend on the relative size of a prior plant of the same technology and is based on the experience of mineral processing plants in general. Development strategies of a commercial project are compared using a simple real options model.

The economic analysis illustrates that for a particular project there is an optimum number of intermediate plants that maximizes the weighted net present value of the project. An unproven technology must also promise a significant advantage over a demonstrated technology to justify additional development time, costs and risk.

Introduction

Oil shale processing is deceptively simple; just add heat and oil is produced. This attractiveness lures many would-be hopefuls into thinking they can develop their own technology from scratch or simply adopt an existing sub-economic scale process. With no well-established commercial technologies which can meet current environmental and economic requirements on offer for new resources, oil shale processing has languished. The would-be investor has therefore many choices when selecting a technology, but all technologies will need some further development to be commercial. The development process will also contain a myriad of choices. This paper is designed to provide a tool to help in evaluating the different technologies and development decisions. The approach can also be applied to other process developments with the correct data.

In an attempt to reduce scale up risks, the development of a surface retorting technology to produce oil from oil shale is likely to proceed through a series of scale-up steps before a successful commercial-sized plant can be realized. The current stage of development and the number of scale-up steps planned will not only affect the time and cost of subsequent commercialization but also the chance of success or failure.

Beginning with laboratory data and a concept for a continuous process, the next step to developing an oil shale retorting technology would be to build and operate a pilot plant. One or more additional intermediate plants of increasing size may be required before the largest single module is achieved. A commercial plant may require multiples of the largest module.

At each development stage, decisions have to be taken as to the extent of the scale up of the technology. Every aspect of the technology bears risks, including mining, feed preparation, oil upgrading, product marketing and environmental compliance. Therefore, careful analysis is required as to the composition of each successive plant and the assumptions made to ensure the risks are minimised. There are many potential pitfalls, so each new plant is not always well behaved.

Development costs are often overlooked when evaluating the economics of a commercial shale oil project. The objective of this report is to present a methodology to evaluate development options. Estimates of costs and times to commercialize an oil shale retorting technology assume a project includes a mine with a thermal extraction process to produce oil. No particular retorting technology or location is specified. Rather, reasonable inputs and examples are used to illustrate the issues involved. Any specific development would need to be analysed in more detail with consideration to its unique situation.

Capital Costs

Curves for estimating the capital cost of a shale oil plant of a specified feed capacity are shown in Figure 1.

The curve for a single module is based on the capital cost of $250 million (AUD 2001) for Stage 1 of the Stuart Shale Oil Project which had a design feed capacity of 6,000 t/sd. This equates to about $42,000 per daily tonne oil shale feed. A capacity-ratio exponent of 0.6 is used to estimate the cost of single module plants with feed capacities from 100 t/sd (pilot plant) to 25,000 t/sd (commercial module).

If the capacity of a plant is increased by increasing the number of modules then the economy-of-scale is reduced. The capital cost of a plant with multiple duplicate modules is based on estimates for a commercial PetroSIX shale oil plant in Brazil (Bachmann et al. 1993). The capital cost of each module was reduced 10% by installing 2 modules, 25% by installing 5 modules and 33% for 10 modules. The cost per module was predicted to not decrease further for more than 10 modules.

Using these factors gives about $38000 per bbl/sd for a 10-module 100,000 bbl/d commercial plant that yields 0.42 bbl of oil per tonne of oil shale. As a comparison, the cost of an oil sand plant of similar size in Alberta is about CND$30000 per bbl/sd (Alberta Chamber of Resources, 2004).

The cost saving of installing a larger plant at an existing site can be estimated from the experience of the PetroSIX shale oil plant (Bachmann et al. 1993). The cost saving for the commercial module was about 50% of the capital cost of the smaller demonstration plant.

Many other factors will affect the capital cost such as location, type of mine, existing infrastructure, type of retorting technology, extent of oil upgrading and by-product treatment.

Operating Costs

Like capital costs, the operating costs per unit of capacity decreases as the plant capacity increases. Figure 2 shows an estimate of the relationship between operating costs and plant capacity. The operating costs consist of a fixed and variable component. One of the primary operating costs of a small plant is the administration and operating labour while mining cost becomes a more significant component in a commercial plant.

Again, numerous other factors affect the operating costs such as location and cost of utilities and labour. If the oil shale feed is a by-product of a large existing

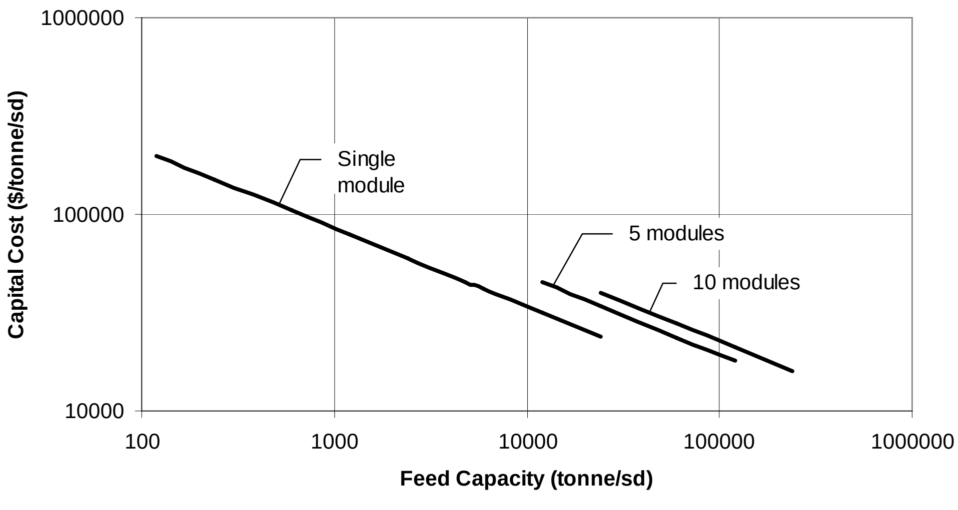

Figure 1: Relationship between installed capital cost and feed capacity of a new plant

coal mine then mining costs will be reduced.

Rate of Achieving Design Capacity in Mineral Processing Plants

All new plants require time to achieve their design capacity. There can be many unanticipated pitfalls during initial operation (Schmidt, 2006; Merrow et al., 1981). The extent to which aspects such as the plant size, feed properties and technology depart from that of prior plants will increase the time the new plant will take to reach design capacity.

Figure 3 shows curves for the rate of achieving design capacity from a study of the mineral processing industry (McNulty, 1998). The performances of 41 mineral processing plants were separated into four categories according to their rate of achieving the annualized design capacity. Plants in a particular category showed similarities in design readiness and departure from prior plants. For the purposes of this paper, the curves in the figure have been labelled according to a category's typical extent of departure from prior plants. The McNulty study noted that plants that fell into the 'Unproven technology' category were often abandoned after four years of operation.

Rate of Achieving Design Capacity in Shale Oil Plants

Table 1 summarizes the experience of achieving annualized design capacity at a few demonstration-scale shale oil plants. The small data set mirrors observations of the mineral processing industry in general. The PetroSIX plant in Brazil with a scale-up factor of 4:1 achieved the 'Scale-up' curve in Figure 3 while the Unocal plant at Parachute Creek and the ATP plant at Stuart had much larger scale up factors and approximated the 'Unproven technology' curve.

Interestingly, the three plants also experienced the same final outcome observed for mineral processing plants in general. The Parachute Creek and Stuart plants were shut down after 4 to 6 years of operation, while the PetroSIX plant continues to operate at design capacity 15 years after the start of operation.

Economic Analysis

Using the above information and a simple real options model (Copeland and Keenan, 1998; Corlazar et al., 2001), strategies for developing an oil shale retorting technology are compared in the following examples.

Example 1: Number of scale-up steps?

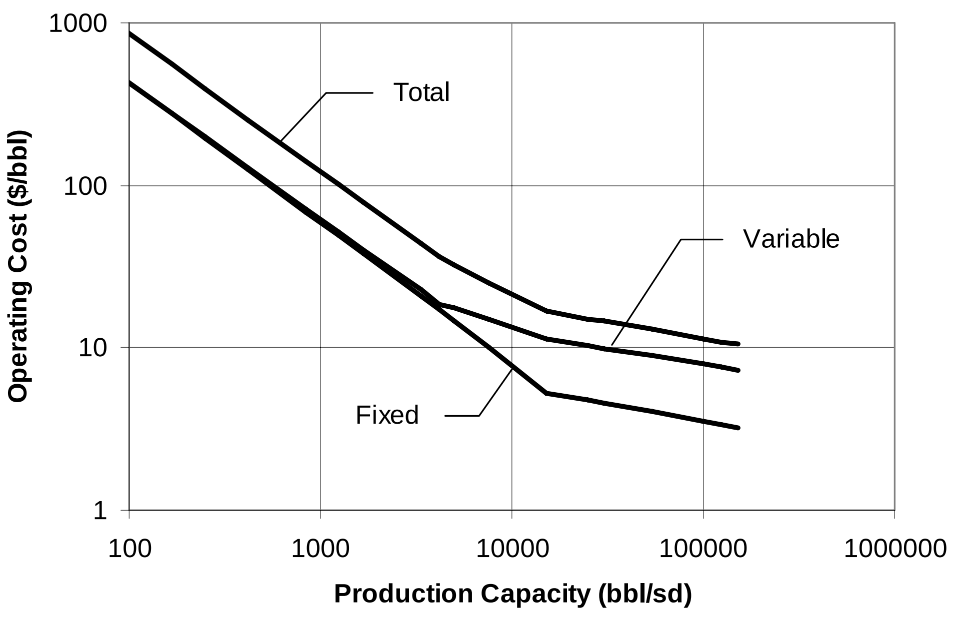

Figure 2 Relationship of production capacity on production costs

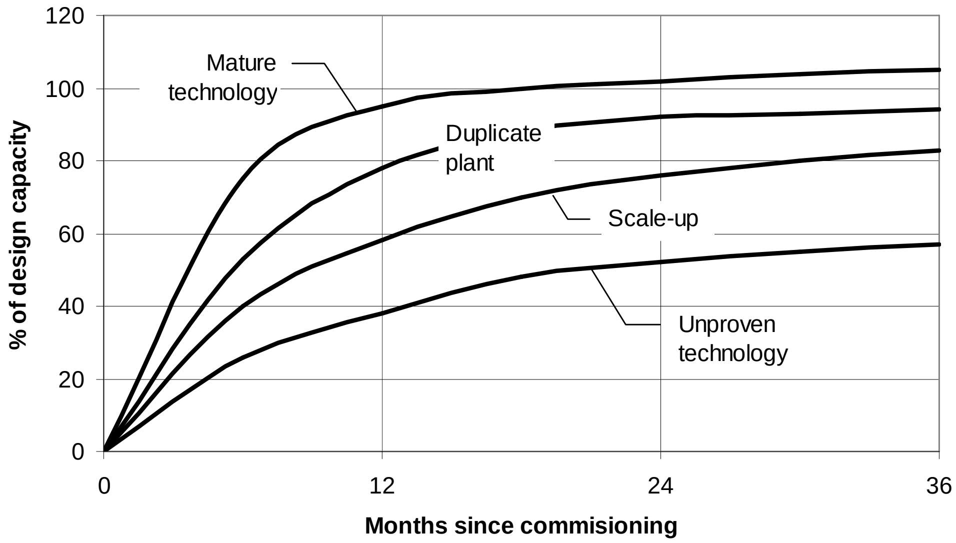

Figure 3 Time for a mineral processing plant to achieve annualized design capacity (McNulty, 1998).

The time and cost of development can be reduced by limiting the number of scale-up steps but the likelihood of achieving design capacity decreases as the size of the steps increase. What is the optimum scale-up factor that best balances the time and cost of development with the risk of failure?

For this example, suppose a technology has been successfully tested at pilot scale (10 bbl/sd). An oil shale resource contains 1 billion accessible barrels of oil; enough for a commercial plant to produce 125,000 bbl/sd for 30 years. Three strategies are considered. In the first, only one intermediate plant with a design production capacity of 1,250 bbl/sd is built. The scale-up factors from the pilot to the intermediate plant and from the intermediate plant to the commercial plant are 125 and 100, respectively. In the second strategy, two intermediate plants are built. The design production capacities are 250 and 5,000 bbl/sd. The scale up factor for each follow-on plant is 25 or 20. In the third strategy, 5 intermediate plants are built with capacities of 50, 250, 1,250, 5,000, and 25,000 bbl/sd. The scale up factor for each follow-on plant is 4 or 5.

In this example, the geology of the mine allows the early plants to be fed with a higher grade feed. Plants with production up to 5,000 bbl/sd can be fed a higher grade oil shale that yields 0.7 bbl of oil per tonne of feed. For larger plants, the feed grade decreases to 0.42 bbl/tonne.

Table 1 Rate of achieving annualized design capacity for demonstration-scale shale oil plants

Project	Unocal Parachute Crk	PetroSIX MUI	ATP-Stuart
Reference	Reeg et al., 1990	Bachmann et al., 1993	SPP, 2000-2003
Start of operations	1987	1992	1999
Scale-up factor	100:1	4:1	75:1
Year of operation	% of annualized design capacity		
1	17	64	16
2	32	73	23
3	32	na	45
4	40	na	na

na – not available

All plants are assumed to experience either the 'scale-up' or 'unproven technology' curves in Figure 3 for achieving annualized design capacity. The probability of achieving the 'scale up' curve depends on the scale up factor and is assumed to be 33% for a factor of 100:1 to 125:1, 67% for a factor of 20:1 to 25:1 and 90% for a factor of 4:1 or 5:1. If a plant does not achieve the 'scale-up' curve, then it is assumed that there are no follow-on plants after 4 years of operation.

The time for designing and constructing a plant is assumed to be 2 years for a 50 and 250 bbl/sd plants, 3 years for a 1,250 and 5,000 bbl/sd plants and 4 years for a 25,000 and 125,000 bbl/sd plants. All intermediate plants are run for 4 years before either the design and construction of the follow-on plant begins or the project is abandoned. None of the intermediate plants continue to operate after 4 years.

Each plant is built on a new site so there is no capital cost saving from using infrastructure from a previous plant. Other assumptions are given in Table 2.

The decision tree for the first strategy illustrated in Figure 4 has 3 possible outcomes.

1) The 1,250 bbl/sd intermediate plant does not achieve adequate production after 4 years of operation and the project is abandoned,
2) The intermediate plant achieves adequate production to justify building the commercial plant. However the commercial plant does not achieve adequate production and the project is not continued.
3) Both the intermediate plant and the commercial plant are successful and the commercial plant continues to operate for the remainder of its 30 year design life.

Table 2 Assumed inputs

Discount factor	8%
Plant life –intermediate	4 years
- commercial	30 years
Oil price	$50/bbl
Design availability	90%
Salvage value	$0

The project cash flow and the net present value are determined for each outcome using estimates for capital costs, operating costs and revenues. The probability of each outcome is determined from the scale up factor. Outcome 1 has a net present value (NPV) of negative $134 million and probability of 67%. Outcome 2 has a NPV of negative $166 million and a probability of 22%. Outcome 3 has a NPV of positive $6,363 million but only a probability of 11%. By weighting the individ-

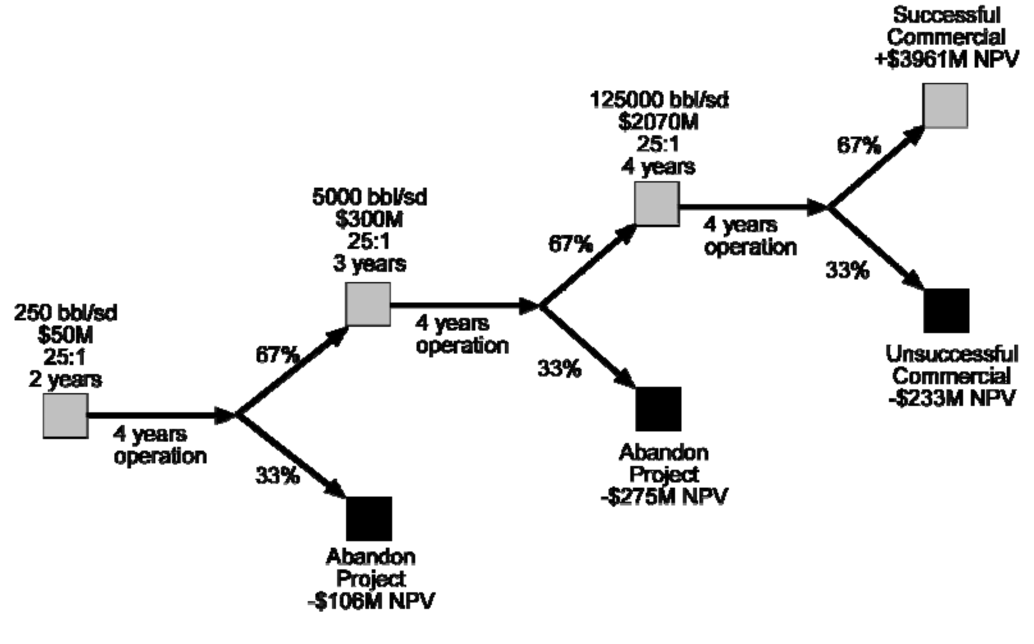

Figure 4 Decision tree for 2 intermediate plants

ual outcome NPVs by the corresponding probabilities, the weighted NPV of the first strategy is calculated to be positive $552 million.

For the second strategy, shown in Figure 5, there are 4 possible outcomes. Three of the outcomes have negative NPV. The outcome of a successful commercial plant has a NPV of $3,861 million and a probability of 22%. The weighted NPV for this strategy is determined to be $978 million.

For the third strategy, shown in Figure 6, there are seven possible outcomes. With the exception of the successful commercial plant, all outcomes have a negative NPV. The NPV of the outcome with the successful commercial plant is $530 million and the probability is 53%. The weighted NPV for the third strategy is only $188 million.

Results for Example 1 are summarized in Table 3. The weighted NPV for the three strategies illustrates how too few intermediate plants reduces the probability of success while too many intermediate plants devalues the project by increasing costs but also by delaying successful commercialization.

The example shows that there is optimum number of intermediate plants that maximizes the weighted NPV.

Example 2: New or demonstrated technology

Suppose that a technology has been

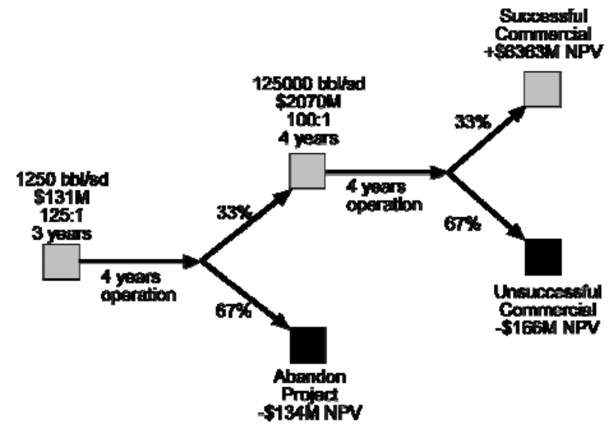

Figure 5: Decision tree for 1 intermediate plant

demonstrated at 5000 bbl/sd and that the demonstration indicates that 80% availability will be achieved in future plants. A second technology is predicted to have the same capital and operating costs as the first technology but promises a better availability of 95%. However, the second technology has only been successfully piloted at 250 bbl/sd.

An economic analysis of a commercial plant only for each technology will give a larger NPV for the newer technology due to 15% improvement in annual oil production. However the comparison does not include the remaining development time and cost of either option or the additional risk of the less developed technology. How would the two technologies compare if the remaining development of each technology was included in the comparison?

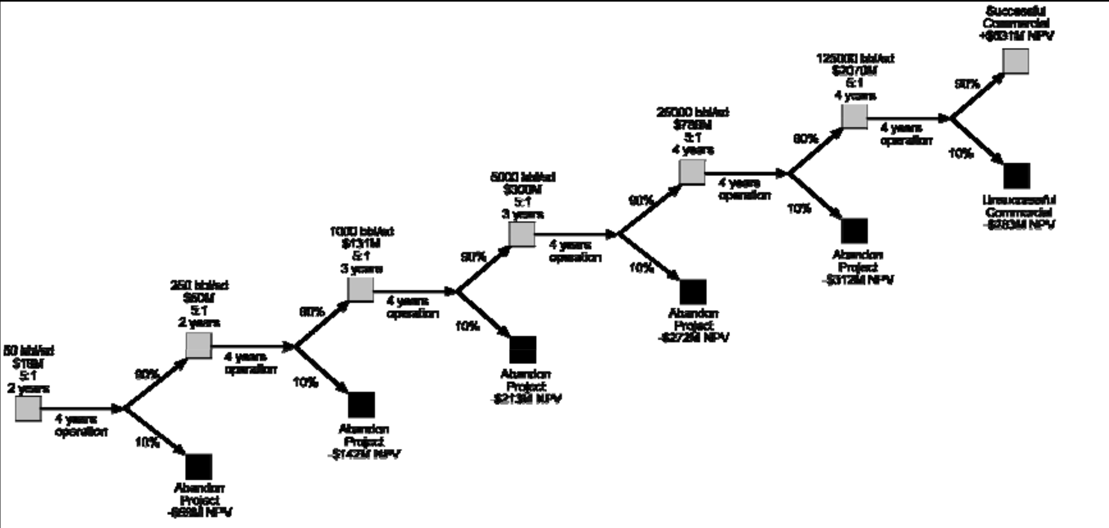

Figure 6 Decision tree for 5 intermediate plants

Figure 7 illustrates a development strategy to commercialize the older technology. One intermediate plant of 25,000 bbl/sd is a 5:1 scale-up of the previous plant and will require another 5:1 scale-up to the commercial plant. As in Example 1, the cash flow and NPV are determined for each of the three possible outcomes. A weighted NPV is calculated from individual outcome NPVs and probabilities.

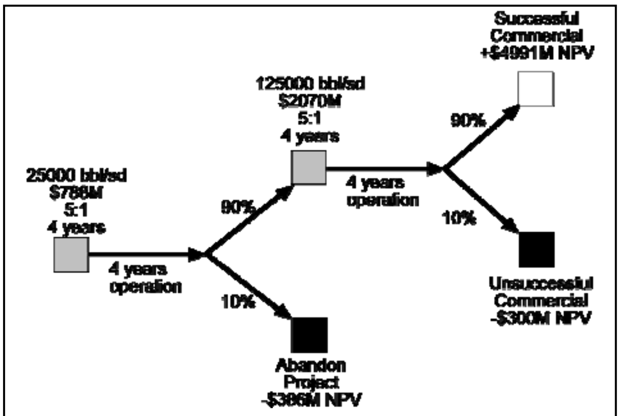

Figure 7 Decision tree for older technology

Figure 8 illustrates the strategy for the newer technology. Two intermediate plants of 5,000 and 25,000 bbl/sd give a scale up of 20:1 for first intermediate plant, 5:1 for the second intermediate plant and 5:1 for the commercial plant. There are four possible outcomes.

Results for Example 2 are summarized in Table 4. The weighted NPV of the new improved technology is significantly lower. Not only is the probability of achieving the best outcome lower but the NPV of the best outcome is lower as well. This reduction in NPV is partly due to the costs of the additional intermediate plant but is primarily due to the delay of commercialization.

The example shows how a new technology must promise a significant advantage over a technology that has been proven at a larger scale to justify the additional development time, costs and uncertainty.

Discussion

Another situation in the development of a technology for oil shale is where a technology has been developed to an intermediate stage but on a different feed. Because the physical and chemical properties of oil shale and oil shale products can vary greatly throughout the world and a new location may have different environmental, social and regulatory requirements, additional uncertainty and development costs are introduced.

A range of options are available to the investor in formulating a development strategy that addresses the risks. A development program may begin with construction and operation of a new pilot plant or testing the new feed in an existing intermediate size plant. Evaluation of the various strategies can be treated in the same manner using a similar methodology with the appropriate inputs.

Conclusions

A methodology of evaluating options for the commercialization of an oil shale retorting technology has been presented. Capital and operating costs for a plant are dependent on the plant size and the uncertainty that the plant will achieve acceptable performance is related to the scale-up factor from a prior plant of the same technology. Quantification of the uncertainty is based on a study of innovation in the minerals processing indus-

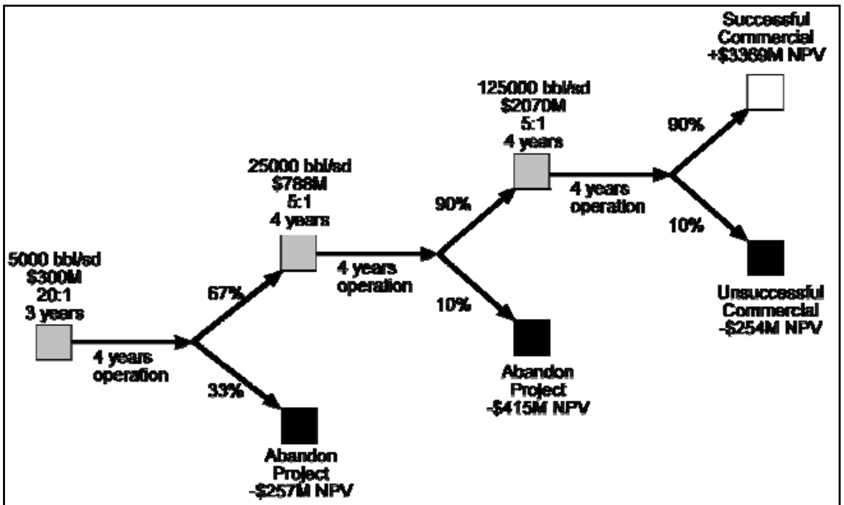

Figure 8 Decision tree for new technology

Table 3 Results of Example 2

Demonstrated capacity bbl/sd	Availability %	Number of intermediate plants	Best outcome NPV $ million	Best outcome Probability %	Weighted NPV $ million
5,000	80	1	4,991	81	3,977
250	95	2	3,369	53	1,671

try.

Two examples were used to illustrate the importance of development strategy and development time and costs in the valuation of a commercial project. The first example showed that there is an optimum number of intermediate plants that balances the time and cost of development with the uncertainty of successful commercialization. The second example indicated that a new technology must promise a significant advantage over a technology that has been proven at a larger scale to justify the additional development time, costs and uncertainty of the new technology.

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About the Authors

Richard Sherritt has over 20 years experience developing various oil shale retorting technologies at both the pilot and demonstration scale in Canada, Australia and USA. He has a PhD in Chemical Engineering from University of Calgary. rick.sherritt@procom-consultants.com

Jim Schmidt has over 35 years experience in process development, commissioning of first of kind plants in coal to oil, oil shale and chemicals, project management and operations. Jim founded PROCOM Consultants P/L after the closure of the Stuart Oil Shale plant in Gladstone Australia in 2004. Jim had been General Manager Development for SPP. jim.schmidt@procom-consultants.com

Jimmy Jia has 10 years experience in oil refinery process commissioning and operations in China. Jimmy has a PHD in Chemical Engineering from University of Queensland. jimmy.jia@procom-consultants.com

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