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TECHNOLOGY SELECTION FOR AN OIL SHALE DEPOSIT

Author: Jim Schmidt

Director: PROCOM Consultants P/L
Level 7, 371 Queen Street
Brisbane Qld 4000
Australia

Email: jim.schmidt@procom-consultants.com
Web: www.procom-consultants.com

ABSTRACT

With the growing dependence on imported oil which is at historically high cost, many companies are once again looking towards other resources. The world holds huge reserves of energy in the form of oil shale, which have not been successfully exploited except in some exceptional circumstances. ith the current price and potential reduction in supply of crude oils, it is again time to reassess oil shale reserves. However, the problems faced in bring oil to market from an oil shale deposit are not trivial, as history has shown. ach oil shale deposit has characteristics which make it unique from mining, processing, marketing, environmental and social perspectives.
Making oil from shale is misleadingly easy. Making oil in a profitable manner which is consistent with stringent environmental criteria presents an array of problems which are not normally encountered by other processes. Each oil shale deposit has its own characteristics which makes the processing of that shale unique. Taking on such a development is not for the feint hearted, but help is at hand from the experiences gained worldwide.
The problems in bring the oil to market faced by the resource owner is complicated by the fact that one process does not fit all. There are no commercially available technologies which can meet all the criteria outlined above. While there are many technologies available at laboratory or pilot plant scale, there are none which have been successfully scaled up to a commercial module or which has been established as a commercial plant comprised of a series of commercial modules. It is not possible to simply adopt an off the shelf technology and order a plant without undertaking developmental works.
Marketing the oil also presents challenges. The nature of the oil produced will depend on the deposit, the process and processing conditions used. The processing and upgrading of the oil will depend on the market demands and economics.

The nature of the raw oil together with market demands will determine processing requirements and uses for oil from shales. Specific processing and user issues will need to be uncovered and process development undertaken to reduce operational and marketing risks. he developer of a deposit is therefore faced with a series of challenges in selecting and developing a suitable technology. That technology will of necessity require staged development to arrive at a viable commercial installation

to minimise risk of failure. Staged development is costly in terms of time and money and must be undertaken from a basis of understanding of the shale, its processing and scale up issues. he authors have experience in the selection and development of oil shale technologies which can readily be applied to oil shale deposits to reduce costs and minimising the risk at each stage of project development to shorten the time required to reach commercial profitability

INTRODUCTION

The common material called oil shale is a hydrocarbon (kerogen) bearing sedimentary rock which releases oil only after heating to pyrolyses or destructively distil the kerogen. Kerogen is the fossilised remains of algae and spore from plants, which lived in and around the waters, marine or lacustrine, over millennia, many millions of years ago[1]. Variability of weather patterns and seasons during the deposition affect the kerogen content and make up, so each layer or facies may exhibit different properties. Shale deposits are unique as each has differences in origin, subsequent history, properties and so with no surprise process differently.

Making oil from shale is deceptively simple, just heat to 500 ^{o}C and hold for a few minutes. A full range oil and high calorific off gas equivalent, representing about 60% of the original hydrocarbon is readily achieved in a simple apparatus. Unvolatilised kerogen fragments remain on the shale matrix as coke. The difficultly is in selecting and developing a suitable commercial process which can adequately address all of the particular properties of the deposit safely, economically and in a sustainably manner environmentally. While there are many potential processes available at varying levels of development, there are no effective commercial processes available today which are readily transferable between deposits. This is despite the quantum and cheapness of reserves of oil shale around the world and the amount of development money which has been expended in attempts to initiate an oil shale industry. By comparison, the Oil Sands Industry of Alberta Canada is flourishing, albeit after a 30 year gestation period of perfecting a single process on a single resource with the cooperation between large corporations and government.

Entry barriers to establishing an oil shale industry facing each developer are substantial, without a proven process, all of the hard questions have to be answered for each development.

- The bulk of the literature to date focuses on the conceptual issues of oil shale retorting with the experience being limited to pilot plant studies [2, 3]. Problems experienced in larger scale plants which operate continuously, consuming large amounts of feed from a particular deposit add an additional layer of complexity. The obvious problems usually present themselves during pilot plant stages and are resolved during scale up or immediately a new plant is commissioned and are common to most plants.

- More complex problems relate to specific processing problems which are new to the experience of the designers and operators, are not identified or resolved at pilot plant scale or during scale up or become apparent only after longer operating periods on the particular feed materials. These longer term problems are unlikely to be adequately addressed in the design unless that or similar experience is available or learned through a slow and deliberate scale up history, with thorough testing of assumptions and appropriate tests engineered and performed to derive acceptable scale up criteria.

- Fundamental to the process of selecting a technology, are the scale up and operational issues in achieving a commercial design. These challenges can take many years to overcome, as was the experience of the Oil Sands Industry. Complications arise due to the variability of the shale feed properties and composition. Consider how to obtain a sample which is representative and exhibits all of the likely issues from a deposit of many millions of tonnes. The sample required for laboratory tests is a few grams or kilograms, running a pilot plant for a few weeks is only a few thousand tonnes.
- External factors are common to all projects, however the sensitivity of any one project to particular items requires early screening and regular monitoring to avoid delays and added costs.
- Commercialisation of a retorting technology will take a minimum of three to five years per development stage and potentially cost many millions of dollars to fully consider all aspects of developing an industry[4].

- A failure for the design to appropriately manage any key property or variation in properties may be enough to force a change in direction or scarp a technology.

Starting with the end in mind, the process chosen should complement the shale properties. The shale must continue to exhibit the key characteristics required in the process throughout the processing life of the deposit to enable scale up. The process may involve iterative stages of research and development.

Any application of a technology should be flexible but robust enough to allow key elements of the feed to vary within prescribed ranges. Defining acceptable design ranges for the shale properties requires a longer term approach to understanding the resource and the process to a suitable level of certainty. This is traditionally handled by progressing through a range of development stages which allow progressively longer runs with representative feed. There is however also a clear need to sustain longer term operations at small scale to continue the learning and development.

This paper attempts to shed some light on the operational issues to be addressed in an operating plant, such as designing for[5]:

- Establishing and proving Scale up data,
- Integration of mining, crushing, processing and ash disposal steps,
- Acceptable process control, operability and reliability,
- Acceptable feed quality variation and understanding its impacts on design and process stability,
- Satisfactory separation techniques of gas, oil, water, solids,
- An understanding of Raw and Product Oil quality and market acceptance,
- Understand emissions and upset conditions and their management,
- Improve design standards, and
- Understand environmental, social and economic issues.

TECHNOLOGY SELECTION FOR AN OIL SHALE DEPOSIT

Past experiences from two attempts at demonstration scale oil shale plants in Colorado and Australia clearly indicate the importance of technology selection and scale up stages.

When the oil shale does not exhibit the required properties to make the technology work effectively, the scale up stage faces enormous problems financially and operationally. These problems arise due to the flow on effects of revenue disruption, mounting costs, distractions caused by the annoyance of stakeholders starting with neighbours and progressing to governments.
For a project to succeed through all developmental stages, not only does the core technology have to be correctly selected, all of the other areas impacted by the project must be concomitantly developed to a point that robust relationships have been cemented when temporary issues have to be addressed.

Key elements of technology selection include a consideration of:

1. Project specific factors
2. External factors
3. Lessons from Experience
4. The resource
5. Available technologies
6. Matching product quality and market requirements
7. Technology selection

Project Specific Factors
Despite the fact that oil is so readily produced by heating shale, the continuous processing of shale in an acceptable manner has not been successfully developed which can be transported from one shale to another. The selection and development of a suitable technology can not be easy, or it would have been done before as there have been many attempts. The complexity of the task requires a rigorous application of staged learning to reduce risk progressively. Possible development stages include:

- Establish Project scope and guidelines
- Literature search,
- Shale sampling and analysis,
- Resource definition,
- Bench scale,
- Laboratory scale testing,
- Small pilot plant scale,
- Process Development Unit,
- Larger Pilot plant trials,
- Demonstration Plant scale up to a commercial module, and
- Replication of modules to develop a Commercial Plant.

The cost and time period to arrive at a successful commercial plant can be counted in the order of billions of dollars and ten to twenty years of largely ground breaking work. The reality may be daunting for many companies; therefore, it is critical that in

taking on a potentially costly, long term project, that the expectations are more progress related and without restrictive imposed time and cost deadlines. A mentor with a passion will help.
The temptation to shortcut a thorough development program is high, but may increase project risk. Small oversights can result in failure to achieve desired outcomes in a staged development program. Similarly, adopting existing pilot plants may lead to false expectations as they tend to be the first stage of development for the particular shale/Technology duo. Design parameters may not be suitable to accommodate the properties of new shale. Operation of existing test rigs may require modifications or rebuilds to better suit the shale in question.
The appetite for risk of the Proponents will be a key consideration as to the number of development stages. Experience has shown that deviations from a rigorous development stages has resulted in fundamental problems being exposed. The Estonian experience[6] has shown that very small scale up factors from one stage to an other are important in overcoming known problems or exposing new problems.
With the volatility in the market place, it is clear that throughout its life time any long term project will potentially suffer funding reductions, be exposed to difficult times and adverse decisions. A project requires insulation from this volatility. In order to establish and sustain the project, management guidelines should be in place with specific goal of shepherding the project through the developmental stages. The following elements should be considered in establishing the Project:

1. Broad vision and mission of the project team, to set a full array of goals both short and long term,
2. Overall project development strategy,
3. Project team make up and roles defined,
4. Milestones, the decisions required, the group who should make the decisions to move to the subsequent stage
5. Project Execution plan to achieve each successive milestone
6. Design criteria for the project – environmental, social, economical
7. Scope of work for each stage
8. Success standards
9. Success measures
10. Stakeholder Communication Strategy
11. Review processes and documentation

In developing this overview or roadmap, literature reviews can assist in establishing specific project criteria such as:

- Quality expectations: Setting and maintaining high standards from the outset, for the entire project work will reduce inconsistency in the interpretation of results and allow comparison of data from different campaigns. These standards should be enduring and will preferably commence with the analysis of literature, through resource survey work, process technology testing on to full scale operations.
- The development strategy: Discrete project phases will undoubtedly require a series of small campaigns to conserve funds. As the certainty of the project increases, the data gathered through each phase must continue to be appraised for relevancy and tested by third party experts in the field. This will improve the reliability of decisions made and minimise repeat testing.

- Risk Reduction: Knowing when enough work has been done to reduce risks requires detailed and focussed study of the variables which may affect each aspect of the development process. Appropriate tools should be employed to contain risk.
- Measures of success:

External Factors

With the sensitivity of the development of any new technology, the impacts of external factors should be assessed early in the process to better understand key sensitivities, watch points and design parameters for the project.
Oil produced from shale produces more net carbon dioxide per barrel than conventional oils when they are consumed. This raises their profile in today's Greenhouse Gas sensitive world, and will create a significant challenge for technology development. Strategies are required to define and manage the likely issues.
An analysis of the interests of likely stakeholders who will participate in and/or scrutinise the development will aim to highlight their support areas and concerns. Strategy development can follow.

- Technology suppliers
  - What are key shale properties for the Technology,
  - Status of the technology, its application and current development areas,
  - Status and operability of the Test facilities
  - Process for assessing relevance for new shales and to establish suitable test data
  - Time periods and likely costs required to undertake development work
- Resource holders
  - Are access agreements in place
  - Alignment of goals and objectives of each of the parties into the future
  - Are agreements in place
- Research institutions
  - What fundamental research on the shale deposit and processing can be undertaken
  - Issues investigation potential and time frame
  - What is the correct balance between external research providers and in house expertise
  - Establish and monitor project standards
- Analytical Laboratories
  - Test procedures for oil shale derivatives
  - Solids handling and analysis

  Shale oil analyses can present challenges to conventional crude oil laboratories. Concentrations of nitrogen and trace metals are likely to be higher than normally encountered. Results from typical empirical crude oil derived tests may give misleading results if not interpreted correctly.
- Regulatory Agencies
  - Familiarity of the agencies with the project and the need for the project,

  - Applicability of the regulations to new developments,
  - Processes to be followed to achieve the desired approvals, and
  - Information required and the level of scientific proof necessary.

  Not all regulatory agencies are prepared for technology development. Regulations are generally set up around established industries which can be clearly defined by referring to similar plants. Shale oil plants are generally first of a kind, with commissioning and operational problems.

- Government Departments
  - Access to resource from other developments,
  - Support for the development of a process to produce oil,
  - Clear requirements for the project,
  - Support for infrastructure development, and
  - Financial incentives to reduce the costs of developmental stages.

- Financial Institutions
  - Development support,
  - Communications to potential investors,
  - Flow of funds as required.
- Environmental groups
  - Sensitivity of the natural features surrounding the Deposit and processing plant
  - Agreement on the needs for development of the resource
  - Terms for moving forward
- Community interests
  - Alignment of community and company plans
  - Involvement of the local community
  - Health and safety issues

Background information and questions from stakeholders can be incorporated into the design stages to streamline development.

Experience

While no two oil shale deposits are the same, some basic experience is transferable. The bulk of relevant characteristics of the shale, resource and the available technologies are common.
A review of the collective published experience will provide fundamental resource and technology requirements and interrelationships. This will facilitate a matching process to link possible processes with the resources in question. A risk profile may be established which will list the investigative work required to understand the particular resource or allow selection between resources for development. The processes to develop interrelationships are iterative, and for new entrants to the field, this can be frustrating and lead to flawed decision making if under typical project constraints of time and cost.
The Literature research period should be ongoing throughout the project to minimise the potential for previously exposed issues to be overlooked.
Many retorting processes have been developed to conceptual and pilot stage over the last 100 years to 1990, with little activity until recently. Much of the research into

these technologies may not be well documented or may not be available to new entrants. Pilot studies may therefore be longer and more capital and labour intensive than planned.

Associations with Institutions can nurture continued research into the industry and provide support to overcome problems. As shale oils and solids are not well researched without strong government or industrial support, it may take years to develop a core of expertise in understanding the problems of the industry. In Australia many of the people who dedicated years into the study of shale processing during the period around the second oil shock of the early 1980s, have retired and institutions have turned their attention to different projects as funding dried up during the years of cheap oil through the 1990s.

The Resource

Processing any natural resource brings many surprises for the unprepared. The process chosen must suit or be adaptable to the unique features of the deposit.

Most high yield continuous processes demand a consistent feed material, with variations of specified parameters within a specified range. The difficulty facing a developer is to know and understand the parameters which have greatest impact at each of the desired scale up sizes. A pilot plant operation alone may not highlight the potential problems for larger sized units.

The grade of the oil shale is traditionally determined in a Fisher Assay unit. This simple process for preparation of oil from a prepared shale sample, combines a separate drying stage with a retorting process which ramps the temperature of about 80grams of finely crushed representative shale, by 10C per minute until 500C is achieved and then held for a set time. The Modified Fisher Assay method, therefore allows different shales to be rated for oil, gas and retort water yields in a standard procedure.

Oil Yield units vary widely and can lead to confusion. Adoption of a standard will reduce confusion for any project. Conversion factors from other units are required to support analysis and benchmarking.

Mining and blending to achieve consistency of a range of properties is possible, however added costs may not make this an attractive option for oil shale. Blending of suitable mixtures will be a part of the day to day mine plans to provide feed within an acceptable range. Some processes will accept more feed property variation than others. The feed properties which must be held consistent will vary between processes, so matching the particular properties of the shale to a technology is a key element of the selection process.

Information of the deposit which will assist in technology selection includes:

1. Knowledge of the deposit
    a. Established sampling and analytical techniques
    b. Variability of the shale properties with facies, or depth
    c. Irregularities in shale properties and their impacts on the supply of a suitable feed material
    d. Impacts of variation of properties on the processing operation

The range of shales from around the world vary in their history (Marine vs Lake), their hydrogen to carbon ratios (governed by the organic matter which formed the deposit), the extent of impurities contained in the deposit, mineralogy of the base rock.

2. Ability to undertake a suitable mining operation
   a. Able to produce acceptable feed consistently in most weather conditions
   b. Supply correct particle size distribution to the Feed Preparation Plant
   c. Able to mine selectively to required parameters
   d. Achieve reasonable costs for mining and disposal of waste materials including processed shale.

   If the process can not accept broad swings in moisture content of the feed shale, precautions are required to avoid problems during rain events.

   Mine stockpiles will be required for blending and as a buffer to supply outages.

3. A detailed understand the implications of the shale characteristics on the technology will provide feed back to the mining operation. Lessons will be learned at each stage of the project which can be fed back to the designers for larger plants.

Parameter Impact on processing

a. Grade Potential yield structure, project economics
b. Variability of grade Assess blending requirements of feed to suit technology
c. Moisture content Stages in the processing is a dryer required or not
d. Variability of moisture content
   How this might affect the control of the technology
e. Friability of the shale in processing
   May affect the heat transfer process, and best technology
f. Sulphur content and distribution
   Sulphur balance for the technology will impact costs
g. Mining constraints Strip ratios, out of pit dumps, mine to plant haul distances
h. Mining costs are a high proportion of total processing costs.
i. Feed Preparation of shale to minimise waste and improve efficiency.

Mining costs are always a substantial proportion of the costs of producing oil from shale. Costs are higher for semi-commercial plants if design stream factors are not achieved. Problems in commissioning will therefore quickly add to costs as mining equipment will stand idle.

The exchange of information between process and mine is important in learning how to run a plant efficiently and to provide new design data for subsequent plants or modifications to existing.

4. Have adequate feed preparation facilities to produce an acceptable feed material consistently suitable to the process
   a. Sufficient stockpile areas to buffer production and usage demands
   b. Minimise re-handling of mined shale to reduce costs
   c. Minimise variability due to weather and shale blend etc
   d. Trouble free crushing in all weather situations

Clay based shales may present different problems to marine shales. A tendency to stick in feed chutes or to crushing surfaces can quickly affect throughput.

Shales may be subject to auto retorting if conditions are favourable. Retorting temperatures can be achieved if high concentrations of pyrite are present in damp well aerated stockpiles.

5. Manage solid wastes without major environmental issues
   a. Mine overburden, interburden
   b. Processed shale

   Leachate from waste materials may affect groundwater or surface waters if waste material placement is not managed. A thorough knowledge of the materials is required with strict adherence to a management plan.

The detailed information required in the technology selection process, may not always be readily available until the mining and processing operations have been undertaken for many months or years at a smaller scale. While selective information may be available from past studies, new technology selection studies must begin with a clean slate and will demand a systematic study of the shale and resource in association with the identified variables for each process of interest.

Resource definition will require significant drilling programs, core cutting for samples, and ultimately trial mines. Sampling of ore from a large resource to determine indicators of process ability introduces areas for close attention, including:

1. Variability of the resource
   While the deposits tend to be large and quite uniform within each layer or facie, variability between facies can be substantial, and requires detailed study. Samples are required of each core through each of the facies, rather than by set intervals.
2. External impacts on the Resource
   Many resources are impacted by faulting and thermal excursions. The impact can concentrate impurities which may affect the process ability.

The difference in the level of information available from a resource based on sampling for small scale trials and that from extensive mining for continuous operation of a processing facility is substantial. Until a resource is mined, much of the resource can only be inferred in terms of quality and minability. Achieving an insight into this knowledge without undertaking the mining is a specialist field of study and will need to be progressed with each development stage.

Feedback from the processing plant will be available when it encounters new problems. Typical occurrences will be due to either feed compositional changes or the accumulative impact of trace quantities of impurity after they obviously begin accumulating within equipment or otherwise begin affecting operations.

Data from small scale trials may not give a true picture for a continuous plant. Pilot plant feeds tend to be well blended if transported from the mine to the test facility as they will have been handled many times during preparation in mining, crushing and drying stages. If the same level of blending is not available in the feed to a plant designed from the pilot trials, differences may appear.

The flexibility of a vertical retort process to variation in feed composition may lull a project team into a false sense of security thinking that flexibility is transportable between technologies.

AVAILABLE TECHNOLOGYIES

Processing shale is deceptively simple, just heat to 500 ^{o}C and hold for a few minutes to produce a full range oil and high calorific off gas, with unconverted hydrocarbon remaining on the shale matrix as coke. The difficult lies in the heating of the feed oil shale and the heat recovery mechanism employed in the process to increase the net gain of available energy.

Technology types can be categorised a number of ways,

- In situ vs. Mined and processed above ground,
- Fines (feed less than 12 – 20 mm) vs. Lump (sizes above 12 –20 mm to 70 –100 mm top size) Retorts,
- Solid to solid heat transfer vs. gas to solids transfer in the retorting process.

The technology should meet expectations derived from a range of economic and strategic goals with considerations of:

1. Meeting the requirements of a long term vision of what is to be achieved based on realistic goals and time frame. The development strategy which flows from this must consider possible project life, intellectual property development and retention, data management, shale and resource characteristics, capacity of units and total plant, market requirements, transportation, infrastructure, economics and social implications. The statement is a living document which becomes more closely defined after suitable levels of research and development.
2. Being based on a realistic assessment of design conditions relating to the variability of the required feed shales.
3. Making the desired oil quality at acceptable liquid yields from all size ranges and oil shale faces (varying grades and physical properties) of the shale mined and crushed economically from the deposit of interest.

   The products vary with oil shale type and process. The oils can be quite unstable due to the thermal origins. Different process produce different quality oils from the same feedstock[8]. Where the oil vapours are produced and held at high temperatures (above 500 ^{o}C) in contact with fine shale solids for longer periods or can come in contact with even hotter solids above coking temperatures (about 750 ^{o}C), the oil tends to be lighter, more unsaturated with the off gas containing a higher percentage of hydrogen.

   Oil yields vary with technology and relate to the efficiency of the process in recovering heat, the uniformity of the retorting process, and the efficiency of separation of shale fines, off gas and oil vapours. Very efficient processes[7] can achieve yields above 100% of Modified Fisher Assay yields. Oil quality as measured by density tends to increase with increase in liquid yield as fewer hydrocarbons are converted to gas.

   Oils from process with higher liquid yields tend to be more aromatic and of higher density. The direct use of raw shale oils tends to be limited as low quality fuel oils, or feed stocks for chemical harvesting. If final products are typical transportation fuels, then upgrading steps are required. An analysis of the market and barriers to wide oil markets may tip the balance to a different shale processing technology.

All shale oils will have concentrations of nitrogen and sulphur together with some metals such arsenic, vanadium that put them out of the range of normal crude. Considerations of acceptability of the oils to a refinery therefore may require pretreating to increase marketability.

4. Being stable under a full range of design conditions, continuous and controllable automatically with economically presented run of mine feed with few process excursions or abnormal situations resulting in environmentally relevant releases
5. Demonstrating a high level of thermal efficiency, with the retorting process in energy balance, with the desired level of combustion of carbon from the ash achievable and surplus heat energy converted to useful or saleable forms
6. Producing an ash product which is safe and easy to handle and dispose of in an economical manner. Leachate should be acceptable under all possible disposable conditions.
7. Being operator and maintainer friendly: safe, quick and easy to start up and shutdown without the need for regular forced shutdowns due to unanticipated equipment failures. An ability to have a hot hold state is an advantage to allow small repairs without the need to shutdown fully.

   Reprocessing of oil shale derived liquids can present some challenges in relation to heat exchanger fouling, thermal stability and polymer formation in certain circumstances.
8. Being economical commercially with acceptable costs per barrel of oil produced at each stage of the development: as demonstrated by an ability to be scaled up to a commercial size for the deposit with acceptable efficiencies of throughput and yield for an acceptable capital cost.
9. Exhibiting operating and maintenance costs within industry norms:
   a. Waste streams should be treated to acceptable levels or contained, and emissions not adversely impact the community or the environment. By products should be saleable.
   b. The process should not be a heavy user of imported resources such as water, natural gas.
   c. The process should generate its own utility streams such high quality fuel gas, inert materials for warming up equipment during start up.
10. Health and safety risks to staff and community should be known, recognised and designed out to achieve acceptable risks without the need for excessive Personnel Protection.

Matching Product Quality and Market requirements

Marketing a new oil poses a set of problems for both producer and the purchaser.

Refineries are primarily driven by margins with emphasis on feed costs, yield structure, reliability and catalyst life. Each refinery is generally limited as to the type and range of crudes it may accept. Marketing shale oil into a refinery therefore may require hefty discounts to accommodate the modifications required or to compensate for the reduction in performance expected in treating the shale oil.

With a new product coming on line, the issues of process ability are key to a refiner. Stability of raw shale oils is lower than for most crudes, refineries may not be set up to handle such feedstocks. Hence naphtha may have to be treated at the oil shale plant. Shale fuel oil requires nitrogen blanket for transportation to reduce the likelihood of solids formation.

The fallout from changes in fuel specifications to lower sulphur content, affecting diesel engine performance, will ensure each refinery will be cautious of taking on any new feedstock in case it has latent impacts. The onus will be on the oil shale producer to understand the market sensitivities and the implications for the use of the product closely.

Production from a small pilot or demonstration plant can presents considerable challenges in developing a marketing strategy to accommodate project demands to lower capital and operating costs while maximising revenue. Tank sizes tend to be a compromise: large tanks to store production from a small plant can reduce shipping costs, however cash flow may be strained.

Establishing a foothold in the crude oil market will take time as users overcome fears of quality and supply reliability. It is only when an oil shale producer is accepted widely (with substantial production of on specification products) or a purpose built refinery is constructed can the best revenue be expected for the products. The initial selling price may be lower than desirable until the product becomes known and accepted. Upgrading requirements demanded by the market will increase site costs and complexity. This may impose further financial costs on production from small scale plants. This highlights the need for government assistance in the development stages. A heavy reliance on revenue from the oil produced from small development plants may subtly change the emphasis from data gathering to maximising production.The original project scope should define the expectations from the different stages.

CONCLUSIONS ON TECHNOLGOY SELECTION

No two oil shale deposits are identical. Each deposit has potential for variations which may affect the process ability of the shale in any selected technology.

Technology selection and development and resource definition are interrelated. The impacts of the resource on the technology should no be underestimated. Spend time to know your resource.

There are no technologies which can be readily applied to a new oil shale deposit. Selecting a technology is only the beginning, the development phase to adapt the process to the range of shale characteristics will continue for the life of the plant or mine.

Technology selection is governed by a complex set of interrelationships connecting shale type, environmental and market considerations around the particular resource in question. There is no substitute for continuous operation of the smallest sustainable plant in gaining knowledge to support subsequent designs. History is not kind on those who take short cuts or make mistakes in the development path. Once a technology is chosen, scale up issues and production support will be required for a long time to ensure that the final commercial technology is acceptable to the full gambit of stakeholders.

The support of a wide range of stakeholders, is required for the development of a technology suitable for a deposit. Early development of the relationships is desirable to support the project through hard times.

Development of a new oil shale resource will take many years to select and develop a technology to commercial status and potentially cost many hundreds of millions of dollars. The process should be thorough and not constrained by time to the detriment of quality.

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