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A model for technology development in oil sands tailings

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Abstract

Technology development is a key component of oil sands tailings management. As new needs arise from production demands, increasing environmental standards, heightened regulatory vigilance and cost saving imperatives, technology must be developed to meet those needs. The development of tailings technology has become a time- and resource-intensive process, with no guarantees that the investment will lead to a commercially viable product. The demand for a robust technology development process was recognised as key to the development of Tailings Development Roadmaps for the Alberta Innovates – Energy and Environment Solutions (AI-EES) project. One of the key components of the project was to deliver a tailings technology development model that would serve as a guideline for technology development within the oil sands tailings industry. In providing a framework for technology development, valuable resources are carefully integrated so as to enhance the prospects for success, while reducing risks and delays.

This paper describes an 18 step iterative technology development model, developed through a literature review of technology development within international mining and other industries and tailings sectors, consultation with oil sands tailings industry experts, and a specialist workshop. The 18 steps are integrated into four stages of development: Formulation and Mobilisation; Research; Development; Commercial Implementation. Each stage and each step is defined in terms of priorities, goals, pitfalls, roadblocks and remedies along the technology development path, with essential iterations and linkages to other steps. The ultimate goal of the model is to reduce the number of promising tailings technologies that fail, to identify potential fatal flaws as early as possible in the development cycle, and to focus the investment of time, funding and valuable resources on the most rewarding technologies.

In presenting this model, it is the authors' hope that other tailings sectors may benefit from the insights gained in the oil sands, to provide scrutiny of the model proposed, and offer additional learning which may add further value to tailings technology development worldwide, and particularly in the paste tailings community.

1 Preface

For new technologies to progress and reach commercial success, a well formulated research and development model should be followed. The tailings technology development model was designed to provide steps to progress new technology from an idea, to research, field trials and ultimately commercial implementation as well as to advance current technologies at varying stages of development. The model was developed through consultation with oil sands industry experts in technology development as well as through a literature survey of industries that are known for technology development such as the product development and energy industries. Close attention was paid to common pitfalls and roadblocks to technology development. These are presented for most of the steps in the model along with some possible remedies. The model was a foundation of Component 4 of the Tailings Development Roadmaps for the AI-EES project. Further information on the project can be found in the following references: Boswell et al. (2012); Longo et al. (2012); McKenna et al. (2012); Nelson and Fair (2012); Sawatsky and Cowan (2012); and Sobkowicz (2012).

2 Tailings technology development model

The model is made up of four equally important stages: Formulation and Mobilisation; Research; Development; and Commercial Implementation. The model presents 18 steps that capture specific developmental goals (Figure 1). The steps of the model are laid out on a continuous path, which represents the suggested progression of technology development, it is important to note that no shortcuts are shown. In addition to the main path there are also several arrows directed back to the Conceptualization and Pilot steps. This signifies that even well planned technology development will encounter problems, which can result in further testing being required or a complete reconceptualization of the technology. There are also several overarching goals that are encompassed at every step.

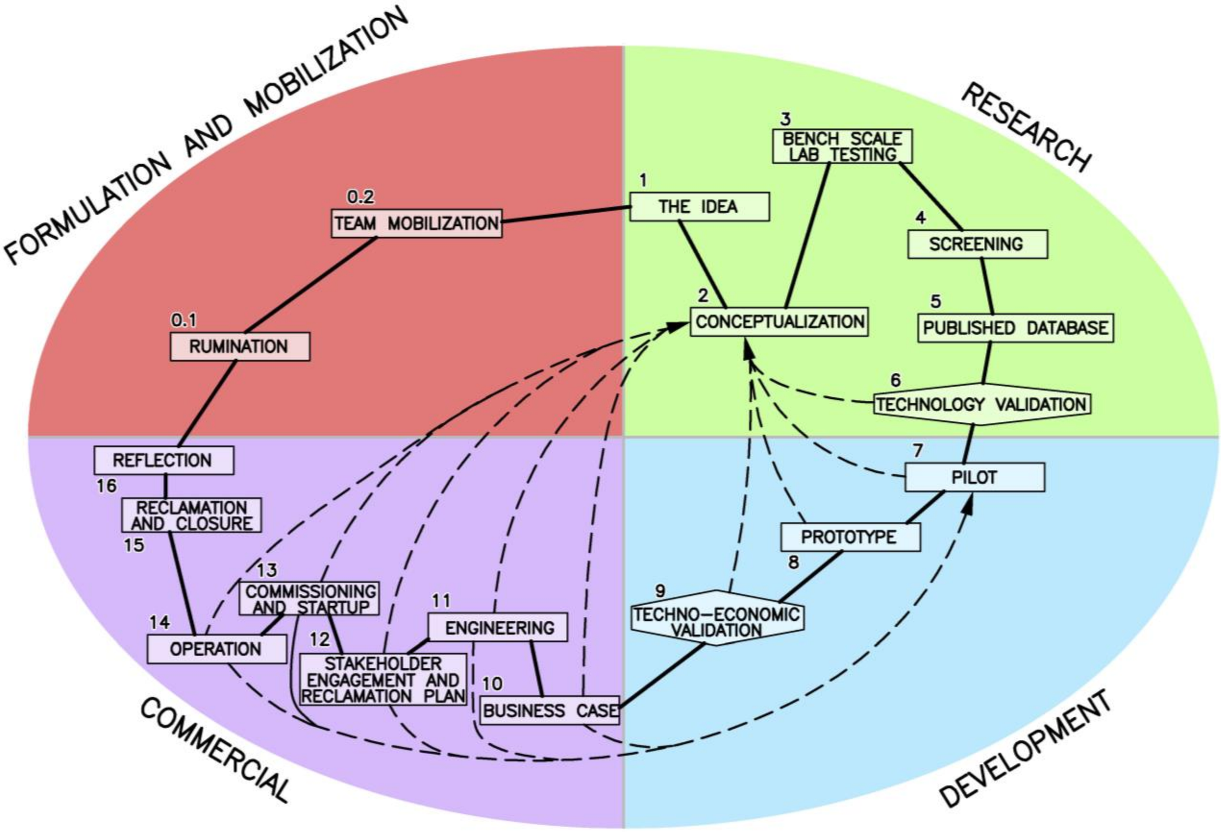

Figure 1 Schematic of the tailings technology development model

The first stage, prior to entering the technology development cycle, is Formulation and Mobilisation. The stage focuses on understanding the goals and constraints of the project, as well as laying the groundwork for overarching goals such as the business case and regulatory and reclamation requirements. The stage also focuses on establishing the lines of communication internally and externally to connect all of the pertinent stakeholders.

The initial stage of the technology development cycle is the Research stage. The goal is to propose an idea and research its underlying physics in the laboratory, and to establish if the technology can potentially meet the defined project objectives. If the technology withstands an internal and external critique, it can progress to the next stage.

Once in the Development stage, effort is first directed on the best operating process at a small field scale, with controlled inputs (referred to as a pilot test). Several such pilot tests can be conducted until an optimal process is found. The process is then scaled up to continuous operations in a small module of a commercial operation (referred to as the prototype stage), with the goal being to determine if the technology can be integrated with operations and has the potential to be scaled up to a commercial size.

The final technology development stage is commercial implementation. The next step is to establish if the technology is economically and environmentally capable, over its lifetime, of meeting regulatory and stakeholder requirements. This is followed by a comprehensive engineering design of the technology, construction, commissioning and start-up. Further modifications may be required after technology start-up to optimize its performance within the commercial setting.

Model pitfalls and possible remedies are represented by the following symbols:

Pitfall

Remedy

2.1 Gate zero – formulation and mobilisation

Prior to laboratory testing, large-scale field-testing and commissioning for commercial use, the framework for the development and adoption of the technology is established by defining the boundaries of the technology and the application. Communication channels between all stakeholders and decision-making groups are established. Thus the first stage of technology development consists of two steps: rumination and team mobilisation. These steps are fundamental and must be completed prior to successfully commencing research and development.

2.1.1 Step 0.1 – rumination

The first step, which is often missed or glossed over, is rumination, or a period of deep thought during which goals are defined and thought is applied to addressing where the potential technology development fits into the big picture. The rumination period should be used to frame the drivers for a potential technology, understand how it interacts with plant processes and lay out the path forward and ultimate objectives of the technology.

When answering these questions, it is important to be sufficiently and objectively critical, since the answers will shape the development of the technology and will be used to evaluate progress and direction. This is also the time to start developing the business case, and understanding how the implementation of the technology will impact other plant processes and reclamation goals. These concepts will continue on throughout the technology development cycle with other aspects such as examining for fatal flaws and regulatory compliance.

Hesitating between steps results in a loss of momentum and an increase in cost.

Develop criteria for when to proceed to the following steps as well as budgeting for the increase in costs that comes with moving to the next step, and planning and mobilising resources.

2.1.2 Step 0.2 – team mobilisation

Failures of many promising innovations have been linked, not to the technology itself but, to the absence or lack of communication within the team charged with developing the technology. Having an industry class team is a step, but without a proper structure and communication strategy even the best teams can fail.

The project champion should be selected from a pool of experts and be intimately involved in the day-to-day development of the technology. The champion's role is to understand all of the challenges and hoops the technology faces and be able to address these obstacles while remaining objective (McKenna et al., 2011; Edmondson et al., 2001). The champion should be detail-oriented while maintaining an understanding of where the technology fits into the overall process. They should also be integral in facilitating team communication and fostering a positive, collaborative environment.

As important as the champion is the project challenger: a dedicated reviewer who is informed, and able to perform an objective but critical assessment of the technology's promise, and to mount a robust challenge to the technology based on real physics and understanding of the fundamentals. The challenger must have the support of the decision makers (management, technology, operations, environmental, etc.) and may involve representatives of different components of the overall operation. If there are multiple challengers they must work to stay on the same page. A degree of independence of the challenger is an advantage (McKenna et al., 2011).

Finally, it is imperative that communication be maintained within the development group as well as between the various company stakeholders. The team needs to have well defined roles and understand that while not all concepts will merit further consideration and may not make it past the early stages of development that it is a reflection on the technology, not on the group working with the technology. Criticism should be constructive and centre on the fundamentals and real physics to help differentiate success of the technology from success of the team. Lines of communication should be kept open and care should be taken to deliver one project voice to prevent confusion amongst team members and other stakeholders.

Creating confusion about project teams roles and responsibilities.

An honest viewpoint of the technology is not freely shared and the project team acts defensively in technology meetings.

Management/decision makers need to be clear that the success of the team is not tied to the commercial success of the technology but to the quality of the investigation. The roles of champion and challenger are recognised within the project team and each remains objective throughout the development of the technology.

2.2 Stage 1 research

The initial stage of technology development is the research stage. This stage is typically performed at the lab scale, with the primary purpose of generating understanding about the technology. The primary evaluation tool should not be cost, because costs estimated at this stage are rarely indicative of the costs of full scale implementation. The work performed at this stage should be focussed on understanding the fundamentals, developing the technology, recording the results, and compiling a database of reliable information (Cooper, 2007).

It is vital to recognise the difference between reactive and anticipative research and the importance of balancing efforts between the two. Reactive research occurs when research chases solutions to immediate problems, which may solve the immediate problem, but often results in suboptimal solutions in the long term. Anticipative research, on the other hand, involves more discussion and identification of the cause of the problem, which allows a program to be carried out to develop solutions before they are required. A complete problem-solving program should have funding and resources allotted to both branches of research and ideas. The research stage can range from months to years, depending on the initial state of the technology. By the end of the research stage the question "Can it be done?" should be answered.

2.2.1 Step 1 – the idea

To formulate the idea a big picture look is taken to identify the root issues being faced. Ideas should be looked at optimistically with a focus on fundamental drivers.

2.2.2 Step 2 – conceptualisation

The goal of conceptualisation is to assemble the best possible view of the technology through investigation of the fundamentals, understanding why the idea is unique or different and unearthing previous results of the technology in the same or other industries. This stage should be geared to proving that the technological principles and primary assumptions are valid. The purpose of the conceptualisation step is to unearth as much of this information as possible, and can lead to the early identification of fatal flaws.

Conceptualisation may be quite extensive in terms of level of effort, and may need to be revisited, even frequently, as pitfalls and roadblocks are encountered along the way. It may even become a complete re-conceptualisation. This may be apparent when considering the number of paths leading back to Step 2, in Figure 1.

2.2.3 Step 3 – bench scale laboratory testing

This step represents the first major investment in time, resources and money towards an idea. The focus of the initial testing is to generate an understanding of the fundamental physics and principles of the technology, what barriers exist to limit the technology and what the optimal result could be. Testing should validate the claims made about the technology and work towards establishing the robustness of the process and sensitivity to input conditions. A key output would be a set of operating parameters that the technology will work within.

Not relying on, or not uncovering the science behind the technology, resulting in a lack of knowledge of why things are happening when they go wrong – simply papering over the flaws.

Keep researching the fundamentals. They are an important component of the scale up issue: through understanding the fundamentals it becomes easier to understand why results deviate from expectations during larger scale development.

Remain open to scientific critique. Make provision for, and welcome informed interrogation of the technology, approach to testing and bench parameters.

2.2.4 Step 4 – screening

The screening process entails a more severe critique of the technology and its fundamental behaviour. The process should take into account other aspects of the technology such as environmental or safety concerns, the human element, role of vendors, intellectual property rights and an understanding of where the technology fits in the big picture.

The future of a vendor's company may rest on the continued use of their technology.

Vendors making claims about overall cost savings that are not realised after the development of the technology.

Research and attack the underlying physics and fundamentals. Make sure that they make sense and stand up to intense scrutiny. Understand that meaningful costs cannot be quantified until after the prototype stage.

2.2.5 Step 5 – published database

Throughout the research phase, information is gathered and generated about a technology. Too often this information is lost or becomes buried. The results need to be published for scrutiny in a database so that successes, limitations, benefits and discoveries can be effectively updated and communicated to the decision makers as well as to other interested parties. It is important that the database is well organised and easily accessible such that if the barriers to the technology are removed in the future the technology can be revisited (National Society of Professional Engineers, 1990). The goal of the database is that every technology sees the light of day and is fairly evaluated. It can also be used to discover synergies between technologies. The database should be maintained throughout the life cycle of the technology and the findings of the research should be clearly presented in publications or presentations to attract valuable observations and criticisms.

Not sharing information (positive or negative) for fear of resistance, legal or intellectual property challenge, attacks on personal status, pride, ego, etc.

Develop a policy of knowledge sharing and transfer; continually update stakeholders and promote buy-in.

Allowing the overall view of the worthiness of a technology to be shaped by perceptions and preconceived ideas.

Review scientific critique of the technology by weighing it against the fundamentals and the underlying physics; dismiss invalid criticism with researched facts.

2.2.6 Step 6 – technology validation

This step marks the first decision point for a technology. While a technology can develop a fatal flaw at any step, this represents the first major evaluation of the technology. At the end of the research stage it is nearly impossible to accurately or even reasonably estimate costs (Cooper, 2007). While maintaining an optimistic viewpoint, the technology is evaluated to determine if the science is well understood, the technology fits into the project's goals and if the technology possesses a reasonable probability of success.

Not dealing with fatal flaws in a timely manner.

Ask if there are fatal flaws at every one of the 18 steps. Remember that flaws do not have to be entirely technical; other factors such as environmental, social, economic and operational impacts can also be fatal flaws. Place strong reliance on the evaluation of the technologies by technical experts.

2.2.7 Research stage shortcut

An alternative method to researching a new technology is to buy a commercial technology that is in commercial use in the same or in a slightly different industry. Choosing to shortcut a technology involves a slightly different planning stage. Strategic fit to five and ten year plans are reviewed; benefits and end result are evaluated against the long range plan. If positive, then the decision on a new technology is made to proceed. If not positive, the evaluation is simply recorded and the search for a solution moves on. The danger of shortcutting a technology is that it can be based on a lack of understanding of the fundamentals, which can lead to wasted effort down the road if a technology behaves unexpectedly because the fundamentals of the technology were not well understood in the first place.

2.3 Stage 2 – development

The second stage is the development stage proper, in which a technology progresses from an idea or a successful laboratory test to a commercial readiness level before introduction into day-to-day operations. Within the development stage, the technology has progressed to a scale where costs can begin to be quantified for implementation of the technology: costs and fatal flaws can now be more fully evaluated and considered.

The development phase may also be an iterative process, and can take several years to complete, depending on the complexity of the technology and the number of issues that need to be addressed. The focus of this stage is to determine if the technology works, with the goal being to validate, assess fatal flaws, introduce, scale up, check the reliability and optimise under field conditions. As a technology progresses through the following steps, the associated costs of investigation (and level of effort) escalate substantially, so it is essential that technologies are robustly evaluated before advancing further.

2.3.1 Step 7 – pilot

A pilot is a miniature representation of the full process with the intent to validate the critical assumptions, seek out fatal flaws and reinforce the fundamental research and the physics involved. Pilot programs can be conducted off-site but should still involve the technical and subject experts from the research stage. The focus should be on establishing that the process works, then shifting to addressing all of the key weaknesses identified. While it may be tempting, it makes no sense to paint a rosy picture of benefits if a potential fatal flaw to the technology has not been dismissed.

Performance of the pilot should be constantly monitored and evaluated against predictions based on the fundamentals discovered in the research stage. Constant evaluation is a requirement and the pilot program may be made up of several stages to ensure that it is possible to isolate and characterise cause and effect. The urge to progress to the prototype stage must be resisted until all fatal flaws, risk and weaknesses are addressed. The overall aim of the pilot is to create a model that is robust and has weathered robust critique.

Constantly changing the input parameters for and design of a pilot during the study, because the product does not show the same promise as in the laboratory.

Pilot studies should take a systematic approach to technology validation. Objectives for the pilot study should be clearly mapped out in advance. Changes in the parameters should be well thought out and the testing program should be robust enough to investigate possible flaws in the design. If the technology cannot reproduce results of a similar value to the laboratory step it needs to be investigated whether the underlying assumptions were sufficiently grounded in sound science, geotechnical and related engineering.

Proving out easy, well understood aspects of the technology while ignoring fatal flaws.

Pilot testing should entail a prioritised attack on the unknowns. Limitations of the technology should be sought out and pushed to their limits.

Not analysing the data during and after the pilot trial resulting in a lack of understanding of the results and the process.

Build time into the pilot schedule and allocate resources to analyse the data. These resources should be supported by the technical experts.

2.3.2 Step 8 – prototype

After evaluating the results of the pilot program and determining that the technology is worthy of further investigation, the technology can progress to the prototype step. The main difference between a pilot and a prototype is that a pilot is an investigation at small scale into the fatal flaws of the technology as well as optimum process conditions. Pilots may be multiple iterations to find the optimal design for the technology, while once at the prototype stage the parameters for the technology are set and it becomes an integrated investigation into a whole system.

The costs associated with prototypes are much larger than in the pilot stage. All of the fundamentals should have already been investigated and the most promising design should be settled on before progressing to the prototype stage. It is important to resist the notion that something needs to get built or deposited for show. Designs and programs must be well thought out and involve all key stakeholders.

Design of the prototype requires significant input of the operational staff and technical experts. The prototype should focus on one promising design and eliminate all unanswered questions, gain confidence in full-scale operations and identify the costs associated with the technology. Another key issue is that of scale up, this is addressed by Boswell et al. (2012), who enumerate some the challenges of scale up in the tailings industry.

Moving to large-scale trials too early in the development stage before addressing fatal flaws or operational sensitivity.

Design and stick to a robust pilot trial that is centred on uncovering any fatal flaws, establishing ideal operating conditions and understanding the fundamentals of the technology. Costs are much larger at the prototype stage than the pilot stage and only one or two designs should be pursued.

Lack of buy-in and understanding from operations.

Involve operations staff during the planning and development of the prototype because they will be tasked with subsequent implementation at the commercial scale. Operations, management and process engineers should work together in increasing measure to ensure integration and engagement.

2.3.3 Step 9 – techno-economic validation

The techno-economic validation step represents the second major decision point for a technology. While a technology may have shown much promise it now needs to be evaluated to ensure that it still addresses the goals for the project. Costs must be known on a unit basis before any final decisions can be made. Before a technology passes through the gate between development and commercial stages, it must be evaluated to assess its readiness for commercial implementation and determine if it meets all internal and external stakeholder and regulatory requirements. It must be established that its performance merits a commercial investment and that decision must be made without considering what has already been invested in the technology.

2.4 Stage 3 – commercial

The commercial stage represents the final stage for a technology and traverses the whole lifecycle of the technology in full-scale operation. A commercial scale technology is intended to operate for as long as there is a need and the costs for a commercial unit are therefore substantial. Each of the following steps involves considerable amounts of time and effort and must be completed efficiently and thoroughly for the technology to be a success. Even if the following steps are executed thoroughly there are no guarantees that a technology will fulfil the promise showed in the research and development stages, and alternative avenues should therefore continue to be explored.

2.4.1 *Step 10 – business case*

The first step in the commercial stage is the finalisation of a comprehensive business case, where an assessment is made of the ability of the technology to meet internal and external stakeholder requirements as well as prove economically and environmentally viable. The business case must be robust and be approved by all relevant company and project stakeholders. It should consider the risks, management of risks, costs and support available over the life cycle of the technology. The business case should be thought of in both short and long-term costs.

Underestimating the capital and lifecycle costs and implications of commercial implementation of the technology.

Design the prototype trials with full-scale operations in mind to generate representative costing numbers for full scale implementation.

Continuing the development of a flawed technology due to the current level of corporate commitment and expenditure in the technology.

Decisions on technology development need to be made on merit. Technologies should only be able to progress to the next development step when they have nothing left to prove at the current development step. It needs to be accepted at the corporate level that many technologies will fail to reach their commercial potential, and that the net should therefore be cast sufficiently wide to capture potential technologies and solutions.

2.4.2 *Step 11 – engineering*

After the development and approval of the business case, a technology can proceed to the engineering step. The business case involves quantifying all costs, benefits and risks associated with a project. The engineering step involves designing a process, within a budget, to realise the benefits, while managing the risks. During engineering it is important to maintain the input of the technical staff that have been party to the technology through the research and development stage, as well as involving (and actively seeking input from) the operations staff who will have to manage the technology during its operation. The design should be for the life of the technology and consider shut down, reclamation and closure procedures.

Lack of communication and understanding between operations, management and engineering teams which results in undisclosed changes being made to the final design.

Engage company stakeholders directly throughout the development process. The decision-making groups should understand what is trying to be accomplished and be able to give constructive input on the design.

2.4.3 *Step 12 – stakeholder engagement and reclamation plan*

The ultimate success for a technology involves more than just the operational results of the process. It also involves more than just the operating company; it may involve the whole industry as well as the public and the government. If the outputs and final results of a process are unacceptable to the public or the regulators it reflects negatively on the entire industry and can make an otherwise deserving process fail. It is important to effectively engage the public and the regulators to develop a plan together for an acceptable landform.

Not properly accounting for the true environmental cost in monetary and environmental terms.

Investigate reclamation during the prototype phase and include instrumentation to monitor the environmental effects. The aim of the study should be to publicly present the data and to quantify costs of reclamation.

2.4.4 *Step 13 – commissioning and start-up*

Very seldom will a technology be brought from the development stage to the commercial stage and be an instant success. To realise its full potential, the technology requires support from the development team and needs to be embraced by all stakeholders. The commissioning phase may take several years depending on the amount of optimisation and whether or not the technology is implemented in stages or not. A decision may be required to send the technology back to the development stage, as anything beyond minor optimisation can prove to be very expensive in time and money. If the technology satisfies all of the defined goals, it can be considered for incorporation into the day-to-day operations.

It is also necessary to continually monitor the technology to determine whether or not it is producing the desired results. A comprehensive instrumentation and monitoring program should be set up to collect the data and time should be allocated to properly analyse the data. A monitoring plan should be set up prior to the commencement of commissioning and should be tailored from experiences during the development stage. Monitoring is useful in assessing the reliability and productivity, and in providing information to fully assess the economics of the technology. The monitoring information from all steps needs to be added to the database and should be published as discussed in Step 5.

2.4.5 *Step 14 – operations*

Not all technologies will reach the full-scale operations step. Failure to reach this step can occur for a large variety of reasons. However, by the time a technology reaches this step there should be a high degree of confidence that the technology will work as planned and envisioned. It is still necessary to involve the technical team to critique ongoing monitoring data and continue to report the findings. It is useful because the team can help diagnose and prevent output problems.

Not maintaining the continued involvement of the technical subject matter experts resulting in a lack of understanding and buy-in.

Continue to involve technical experts, champion and challenger throughout the life of the technology to pass on understanding of the technology to new groups.

2.4.6 *Step 15 – reclamation and closure*

After the technology has run its course and the final product is on the ground, it is time to reclaim and close the landforms. The reclamation and closure program should already be well developed from trials performed during the development stage as well as through communication with stakeholders and with the regulators. The main difficulties here are in dealing with tailings product that does not meet the criteria for reclamation; however, plans should have already been developed during previous steps for handling of off-spec material. The final closure landscape should already have been developed in concept with the appropriate stakeholders to produce an agreed upon result, in Step 12. If it is only occurring for the first time in Step 15, this may well be too late to avoid high costs of implementation or change.

2.4.7 Step 16 – reflection

The final step in technology development is reflection. This is consistent with any quality improvement process. This time serves to empower the necessary feedback mechanisms which will give effect to the continuous improvement cycle for the next generation of technologies.

3 Conclusions

The oil sands industry is investing billions of dollars in technologies to develop tailings treatment programs. These programs have to be designed to handle large operations, with 1.4 million barrels of crude being produced per day, and legacy holdings (Alberta Energy, nd). A large number of technologies are being investigated as part of this process. The goal of the model is to provide a ‘what next’ guide to aid the progression of technology from its current state to a commercially viable form. The model presents technology development in four stages. While each stage contains a varied number of steps, they are each assigned an equal portion of Figure 1. This signifies that there is an equal amount of importance for each of the stages. It is common for technology development to focus in on the technical steps in the model. Ideas are taken to the lab, built on a larger scale as a pilot or prototype, and then rushed to engineering design and into full-scale operation. While technologies have been successfully developed in this manner, there is much risk involved and costs in time and money can be exorbitant. An emphasis needs to be placed on perceived softer components of technology development that start even before any technologies or ideas have been identified. Establishing the lines of communications between groups within the company and externally with stakeholders is critical to success. Organisational hesitation can account for 50% of the total time expended in developing a technology.

This model represents a guideline for technology development within the tailings industry. At each step the technology must be examined for fatal flaws or roadblocks to further development, either through a lack of promise of the technology or its limitations. Decisions can then be made to shelve the technology or to send it back to previous steps for further evaluation and development. This iterative process is presented by the arrows on Figure 1. The model was developed with the recognition that technologies will be received in varying stages of development. Technology development and implementation represents a significant portion of capital and operational expenditure within the oil sands industry. Currently, a large number of technologies are being investigated and developed and many more are awaiting their turn. It is the authors’ hope that this model will help create a more efficient system for developing, accepting and rejecting technology in a timely and cost effective manner.

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This entire model was formed in concert between a series of interviews and information garnered during a literature search. To view the list of references directly and indirectly used during formulation of the model please see the Component 4 report of the AI-EES Tailings Roadmap and Action Plan which can be found at http://ai-ees.ca/reports.aspx.

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