Project: Opening up Natural Resource-Based Industries for Innovation: Exploring New Pathways for Development in Latin America

CASE STUDY | Thickened Tailings Technology

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1. Introduction

This report corresponds to the findings of one of the four case studies conducted in Chile as part of the project "Opening up natural resource-based industries for innovation: Exploring new pathways for development in Latin America". One of the types of "alternative pathways" we are interested in are "path-repairing" alternatives, i.e. those that aim to correct specific problematic aspects of the dominant sociotechnical regime, but that do not propose a radically different way to organize the activity.

As we described in the sectoral report, there are some technologies that have been developed and adopted by mining companies because they help them reduce some of their productive constraints, and at the same time, have significantly better social and/or environmental outcomes. One of this is the thickened tailings technology. Tailings are a mixture of residual minerals, rocks and water. The more water that can be recovered from the tailings and recirculated to the process, the better for the company, because of the prices that water has reached in the desertic northern regions of Chile. But as we will explain, this technology has a number of important benefits, besides the first and obvious one that is reducing the demand for fresh water.

At the same time, is it important to mention that this case also have some aspects of "path-creation", as important efforts to adapt technologies are have been involved in the implementation of thickened tailings projects, resulting in the accumulation of important technological capabilities in local firms and engineers.

The report starts by describing the methodology, explaining what tailings are and the problems associated to them, and then what are thickened tailings and their history in Chile. After these introductory sections, we analyze the five main questions of our study:

1. *How widespread has the alternative become?*
2. *How distant is the alternative to the dominant trajectory?*
3. *To which extent is the alternative promising or delivering better outcomes?*
4. In which ways has the availability of internet and/or other ICT technologies contributed to the development of the alternative?
5. Which are the main barriers that block the diffusion of the alternative?

Finally, we present a summary of our findings for these questions.

2. Methodology

As for all the cases under study, we base our work on both secondary information and primary information obtained from interviews to key informants. While the secondary information was fundamental for the previous stage of the project, where we described the dominant trajectory and its problems, in this stage we base ourselves on the primary information and follow a case study methodology (Flyvbjerg, 2006). Still, there is a significant and fast-growing amount of secondary information that will be particularly useful for understanding the extension of this alternative and the expectations about it.

We focus the study on the issues discussed in the Consolidated Paper (Marin and Benavente, 2011) that summarizes our adaptation of the Transitions Framework to study the problems of sustainability and generation of diversity in Latin American economies, starting from natural resources.

We conducted interviews at engineering firms, to visiting international experts, and to high executives of a mining group that has been key in the development of this technology. Also to other experts that have seen the development of this technology from academia or government agencies.

We used the software QSR NVivo 8 to analyze the data collected. We coded different fragments into concepts, research questions, and actors. This allowed us to later produce queries that crossed, for example, research questions with different important concepts of interest, to easily analyze our data but to do it in a very thorough way.

3. Context: Tailings, water and pollution

Tailings are mixes of water, rocks, and minerals coming from the flotation process that are not useful for reprocessing or reuse. Tailings are deposited in secure basins, and water then evaporates from them. Until the 1960's however, these deposits were far from safe, as there was no regulation at all. Moreover, it the 1930's tailings were simply disposed of in the ocean or in the open. An accident in the 1960's resulted in the first regulation about their construction, and in the following decades there was more and more conscience about their importance. This resulted in technological improvements, including the use of thickeners to extract water from the tailings.

The standard way to dispose of tailings is to deposit them, in pulp form, in reservoirs sorrounded by large supporting walls. The concentration of solids in these tailings is between 25% and 68% approximately, meaning in the best of cases, there is more than a 30% of water in them, and in the worst cases, a 75%. As we described in some detail in the sectoral report

(Benavente and Goya, 2011), water shortage is one of the main constraints that new mining operations are facing. Around 9% of total water consumption in Chile is related to mining (World Bank, 2011), but in the northern Antofagasta Region it is as much as 70% (IAT-RedSur, 2012). And Antofagasta and its neighboring mining regions are desertic regions, where water scarcity is an increasingly worrying issue, both for agriculture and human consumption. In fact, 'water' was probably the most repeated problematic concept throughout our fieldwork, together with the "social license to operate".

From the perspective of mining companies, the simplest problem can be the price they could have to pay to secure water rights. But in some cases it is not a matter of price, there is simply no water available close the area of a potential mine. And when there is water available, it is not as easy as paying its high price. There is also the "social license to operate"; communities are becoming increasingly aware of their rights. And there have been some remarkable developments during the last year and a half in Chile both in terms of social movements and judicial actions affecting polluting industries and controversial investment projects.

As if conflicts related to water were not enough, tailings have more problems besides being a source of water wastage. First of all, they are huge, and demand immense areas with appropriate conditions to build deposits. Second, contaminated water can leak to underground water sources, and eolic erosion (i.e. wind blowing over the reservoir) can raise dust that affects communities that are close to the mine (as well as affecting its own operation). Finally, because of their water contents, they are unstable, and are affected by rain (not a big problem in northern Chile), or earthquakes (a risk that is present throughout the country). The more important risk is that of liquefaction: soil can be turned into a liquid-like state and cannot affect structures, which collapse and turn tailings into extremely dangerous landslides. Even after mines stop operating, tailings continue to be a threat: until very recently there was no regulation about mine closure, and many tailings were left to their own after mines stopped operating, presenting a threat to local water sources' cleanliness and inhabitant's lives.

4. Thickened tailings

"Thickened" tailings are tailings that go through a "thickening" process, i.e. a mechanical dewatering process that reduces significantly their water content. This is done using high rate thickeners and filter presses. How much tailings can be thickened depend on a series of highly technical conditions (such as viscosity and shear stress) and whether it is economic to use them also depends on technical conditions, such as the geography in the mine area. There are different degrees of thickening, and there are no clear cuts that define the conditions associated to each. One particular case of thickening are "paste tailings" where tailings are turned into a particular state ("paste") with very little water content, and that require different and expensive equipment to propel them, because of their rheological properties.

The percentage of solids in these tailings goes between 70% and 85% approximately, much higher than traditional tailings. There are even some technologies trying to go beyond this, but they are only in preliminary stages, and involve completely different techniques to move the residuals.

Figure 1 – Thickened (on top) versus traditional tailings (on the bottom). It is possible to appreciate how solid "thickened" ones are. The one on the right instead, has clearly a large content of water. (Source: Galaz, 2011; Minera Petaquilla, 2012)

Besides water recovery, thickened tailings present other benefits: geomechanical stability (no risk of liquefaction), less eolic erosion, and less risk of polluting underground water.

There are over 30 operations around the world using different forms of "high density" tailings, since the 1970's. There are many interesting examples in Australia, South Africa and Canada, with good results and reliable operations. In Chile, interest in the technology has been increasing since 2002, when a local environmental consultancy firm organized a congress to promote the technology. There is one important difference between Chile and the rest of the world: the scale of the mining operations. Those using thickening technologies in the rest of the world are mostly mines that would be considered medium scale in Chile. And in fact, most of the current examples in Chile (five out of seven) are medium scale mines, which have had good results with the technology. There is one important large scale mine that recently started operating and works with thickened tailings, but it has had important problems in achieving its design operation levels.

The technology was originally disregarded because of its high investment costs, but some companies appreciated its potential to minimize conflicts with communities. In fact, the first company that built a thickened tailings operation in Chile (Minera Las Cenizas[1], at its Cabildo operation) went for this technology to avoid problems with a local community, even when they already had the necessary approvals for a traditional tailings reservoir. They are recovering around 70% of the water, compared to the 40% that would be obtained with traditional tailings.

During the last decade, important capabilities have been developed, both in the operation of this technology and in everything related to laboratory testing and pilot plants. There have been also important levels of networking and knowledge sharing, both with foreign companies and between domestic ones.

One of the landmarks has been the thickened tailings operation at Minera Esperanza. Owned by the only Chilean-controlled mining group that operates large scale mines in Chile (Antofagasta Minerals[2]), Esperanza represented an important technological leap for the technology at the global level, designing a system that has almost three times the capacity of what was the previously largest operation in the world (95.000 tons per day, versus 36.000 tons per day at Pinjarra and Kwinana). This might be an important turning point, making the evaluation of this technological alternative a must for all future operations, including large scales one, that previously disregarded it. However, there are still some issues to be resolved in the operation of their thickened tailings operation.

[1] The mining group Las Cenizas was born in 1978, and currently controls three processing plants and several mining deposits with a total yearly production of 25,000 tonnes of fine copper. The company plans to invest US 130 millions between now and 2015, to increase their yearly production to 31,000 tonnes (Quepasamineria, 2012).

[2] Antofagasta Minerals is the mining branch of the Luksic group. The Luksic's are Chile's wealthiest family, controling leading companies in mining, industry, finances, food, and telecom, with a total worth of around USD 18 billion (Forbes, 2012). Antofagasta Minerals controls the mines Los Pelambres, El Tesoro, Michillla, and Esperanza in Chile, and is working on its internationalization. Its Chilean operations, with 640,000 tonnes of copper, represented around 12% of Chilean copper production in 2011 (Esperanza, 2012; COCHILCO, 2012).

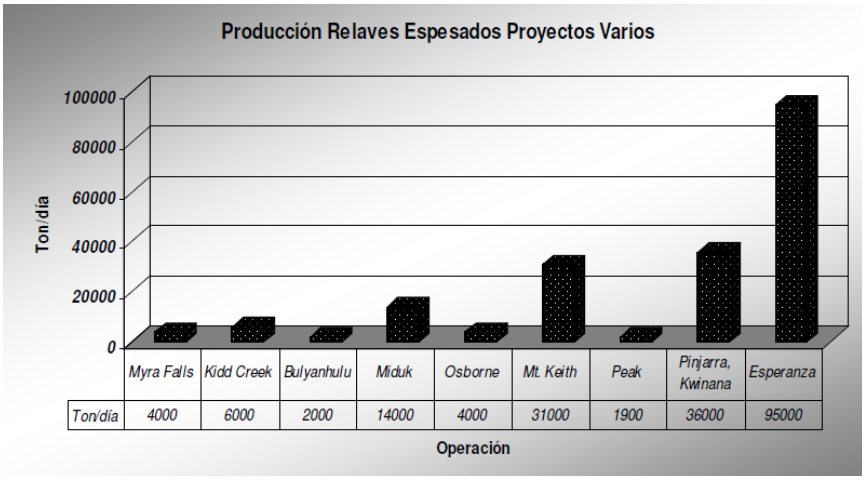

Figure 2 – Daily tonnage of tailings for Esperanza and other deposits around the world. (Source: Thiele and Parraguez, 2011)

5. Q1: How widespread has the alternative become?

Following our adaptation of the Transitions Framework, described in the Consolidated Paper (Marin and Benavente, 2011), we describe the diffusion of the alternative in terms of networks, expectations, learning processes and policy initiatives.

5.1 Networks

From among the cases studied in Chilean copper mining, this is by far that with the largest amount of organizations involved. Two processes have been important in network development: first, when mining companies design and build thickened tailings operations, they collaborate with different foreign and domestic experts and engineering firms. Second, there have been several industry encounters focused on this technology, where current experiences have been discussed in detail, providing an incredible source of information and learning for those that are operating the technology or considering its implementation.

There were some connections with the technology in the 1970's (at Codelco's Salvador Division), but not much happened before a seminar organized by a Chilean environmental consultancy firmed, that was contacted to do this by a renowned global consultancy firm. Environmental evaluation is an important part of the process necessary to obtain approval for mining operations, so these companies play an important role in the early phases of these projects. But besides environmental conditions, there are of course all technical details about implementation, for which foreign experts have been recruited, especially considering that there until recently there was no local experience with the technology.

There had been evaluations for large scale thickened tailings by some companies in Chile, but Esperanza's was the first one that was considered viable and developed. Its design and construction required largest R&D effort because of the need to scale technology up, they learnt from operations in Australia, including a mine operated by BHP, and were supported by international consultancy firms. Domestic engineering firms sent proposals to participate in the project, but the company decided in favor of foreign firms. In the end, this might not have been the best decision, as problems with engineering companies (as well as with equipment suppliers and others) might be part of the explanation of the problems that this operation has been experiencing during its first year (it began operations in April 2011). Another example is Minera Las Cenizas' Cabildo operation. A domestic engineering firm (later acquired by an international one) worked on its design together with an international expert, and after some adjustments, has been operating without major problems. But in no case this can be compared to Esperanza's, as Cenizas' deposit is comparable in size to other deposits that had been operating for a long time in other countries, so there is much previous experience about their design and operation.

Something that must be stressed is that, as in other complex large scale projects, there are many disciplines involved in the design and operation of tailings deposits, including hydraulics, geotechnics, geology, hydrogeology, environment, processes, etc. Several disciplines have to be integrated, the predominance of one over the others is an issue that should be taken care of, and the exchange of experiences among different professionals is an important factor to improve outcomes. Sometimes firms may need to complement each others' strengths in particular areas of engineering when participating in these projects.

Some of the events that have brought together people involved in thickened tailings projects include a workshop organized by an international and a national engineering firms in 2010, and the "RELPAS" seminar, that will have its fourth version in November 2012. The 2010 workshop brought together large mining companies and international referents in the industry and included theoretical and applied activities. The RELPAS seminar, organized by an environmental consultancy firm and an editorial firm, that publishes a leading mining journal in Chile, has been effective in bringing together the experiences from engineering firms and mining companies with both medium and large scale tailings. Apparently, a conference during 2002, sponsored by a leading global consultancy firm in environmental issues, gave the kick start to the interest and development of thickened tailings in Chile.

Mining companies, suppliers, engineering firms, and foreign expert consultants have all been important in the adaptation and development of the technology. The actor that has had a relatively limited role is the State. It will be discussed in more detail in the section about policy initiatives, but as a general idea, there is some disagreement about whether more governmental involvement would be relevant or not for the development of the technology.

There are currently seven thickened tailings operations working or in pilot phase (five at medium scale and two at large scale) and others under study. In fact, all companies are now evaluating the alternative of thickened tailings when they need to design a new tailings deposit, although in many cases it is not the chosen alternative, as will be discussed below. However, the technology and the network of people and firms working on it has been improving and growing steadily during the last couple of years, what together with water scarcity, will most certainly mean that more and more projects will use this technology. There are some critic voices however, who complain that those working on the topic form a mostly "closed club"[3].

5.2 Expectations

There is relative consensus about the future for this technology. If the current operations have good results, it will become more and more widespread. All new projects are contemplating the technology in their prospective phases. There is *"a feeling of solution when talking about this technology"*, however, as some interviewees stated, *"there are still questions to be solved"*, and the mining industry *"has not solved the problem of tailings"*.

Any technology that reduces water consumption is good both for communities and mining companies. This particular technology also has other social and environmental benefits, and in some cases, its capital costs could be lower than for traditional tailings. The caveat is that thickened tailings are not possible everywhere, at least with current technologies. There are at least two important factors: the rheological characteristics of the tailings (such as viscosity), and the geographic conditions where the tailings can be deposited, as well as its distance to the thickening plant. Water availability might be the single most relevant factor when deciding the type of tailing to be used, but other factors are still important, and that is why actors do not expect the technology to be adapted everywhere. For example in some cases it might not be feasible to obtain very high percentages on solids, and in others building a thickened tailings operation could be much more expensive than a traditional one both in terms of capital costs and operation. There are also conditions where thickened tailings are not currently the solution (e.g. rainy regions) or would not be economically convenient for firms (e.g. water is easily available). But learning and experience should play an important role in increasing the cases where this technology can be used.

A positive future prospect is that there are some technologies aiming at even higher degrees of thickening, but these still need development, including efficiently solving issues such as transport, that change significantly in their requirements as tailings change their characteristics. Figure 3 shows an example of one of these technologies being applied in Chile.

[3] This affirmation refers mostly to international consultants.

Figure 3 – Dry stacking at La Coipa, Chile (Source: Tailings.info, 2012)

5.3 Learning processes

This technology has had a period of initial learning and dissemination during the last decade in Chile. One of the reasons why catch-up has been slow relative to other mining countries is the scale of mining operations in Chile, which meant that someone needed to be the first to try with large scale thickened tailings, when there were serious doubts about its feasibility. While this pioneering large-scale operation has had problems, it is just starting its second year of operation, and results have been improving. As someone explained, when being innovative, it is easy to be tempted to go too fast, but it is important to be careful and avoid mistakes. Currently the consultants that worked on the design are working on improving the operation, in something that has been described by some people as mostly *"improvisation"*, but recognizing that *"they have made progress"*. Most of the engineering challenges that are present are well known, but it is still necessary to find the best answers for each of them.

And even if this mine took an important first step, for future projects it is not as easy as to look at this experience and copy it, it is not only "free-riding". The second one *"will have to have its own learning"*, but it will probably be shorter and less costly[4].

[4] Esperanza invested over 10 million dollars in total research, although some of those costs are shared with other objectives.

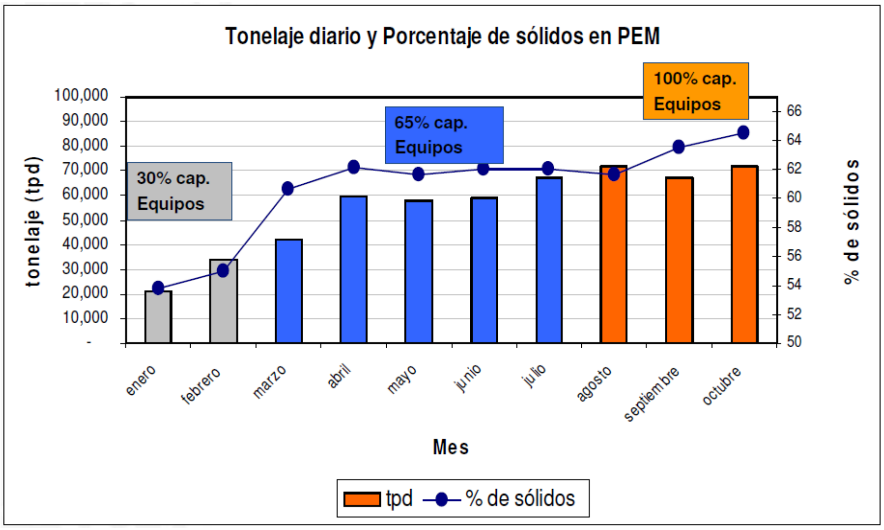

Figure 4 – Evolution of daily tonnage and percentage of solids in Esperanza's tailings. (Source: Thiele and Parraguez, 2011)

In these initial experiences of learning and adaptation, it has been important to observe foreign experiences, but now it is also important to keep learning and to disseminate the learning that mining and engineering firms have had across the industry: their experiences, problems, and solutions will be fundamental in the implementation and success of future projects. One of the main objectives of the workshops and seminars (some with over 150 participants) has been to *"disseminate the developments obtained during the application of the thickened tailings technology"*. Exchanging ideas and opinions among people with different experiences is fundamental, especially for *"a topic that is still under development"*, where *"everyone can contribute with something"*. Engineering firms, national and international experts, as well as mining companies with medium and large scale thickened tailings operations have participated, sharing rich technical information about their experiences and problems. In other words, there has been a real and useful exchange of knowledge and learning between the participants. The meetings also have an important "preaching" effect on the rest of the industry and government agencies.

Besides these meetings, engineering firms tend to play a role in diffusing learning, as the same engineering firms work with several different mining companies, transferring and improving everyone's knowledge as they do it.

And even if these opportunities to share experiences are highly valuable, there is still little relatively little experience in the country in this area, especially in large scale operations, so there is much to be learnt and improved. In general, tailing deposits are described as being always *"spectacular in paper"*, but having a very complicated operation in practice

5.4 Policy initiatives

There are two broad areas where policy is relevant for this technology: research and development, and regulation.

Regarding the first, there was a CORFO-financed[5] project oriented at generating information about the characteristics of tailings in different mining operations, and evaluate potential water savings by increasing the tailings' concentration. Mining companies send their samples to the laboratories at the Santiago-based engineering firm JRI, where they are analyzed to define feasible thickening levels for each one, as well as the ideal operating parameters. Close to 95% of current tailings were studied and characterized, and much heterogeneity was found in their thickening potential.

Public financing for this project was useful in promoting the technology, bringing different actors together to participate, coordinating them, and likely reducing the costs of the study by having scale economies. At the same time, it has induced the development of domestic capabilities in terms of laboratory research and engineering associated to this technology, which could have important social returns.

With respect to regulations, there have been three relevant ones. The first regulation on tailings was the result of a dramatic incident produced after an earthquake in 1965, with hundreds of deaths. A new decree on tailings deposits was dictated in 2007, and in 2011 a law that regulates the closure of mining projects.

At least two things have been criticized about the 2007 normative, even if it is an improvement over what existed before. One is that as it defines different types of deposits, *"it leaves little flexibility for the creation of new configurations and technological change"*. Another problem is that in some cases it was based on foreign experiences, and it should be updated and adapted to the domestic knowledge that has since then been generated.

Besides the topics discussed above, there is some disagreement on whether the public sector has a role or not. Some people indicate that thickened tailings are "better" than traditional ones, so regulation has not much to do here, and that the industry will keep adopting this technology as it shows results. Other state that it would be important for governmental officials to get acquainted with the technology and understand it, and this could help its diffusion and development. There are countries where it is environmental authorities driving the process towards thickened tailings. On the other extreme, some are worried about the regulator's being much more cautious and won't easily approve future large scale projects that use this technology if current operations have problems.

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[5] CORFO is the national development agency that provides different types of subsidies to promote innovative activities.

In sum, there is a significant network around this technology, where knowledge exchange and collective learning has played a relevant role. Future prospects for the technology are relatively good, and could have significant impacts in reducing negative aspects associated to the dominant regime, but there is consensus in saying that this is not "the definitive solution" for the problem of tailings. The functioning of the technology at large scale operations is also something that needs improvement. Regarding the public sector, there is some disagreement on whether more public involvement would be relevant or not for this technology. But at least up to now, the government has not complicated the development of the technology, and co-funded a project that could be important for the future expansion of this alternative.

6. Q2: How distant is the alternative to the dominant trajectory?

6.1 Guiding principles

To state it in a few words, *"you go to paste as the cost-benefit relationship in water is beneficial"*. Again, the guiding force behind *most* decisions is purely productivity. Mining companies evaluate carefully the costs and benefit of different possibilities for tailings deposits, evaluating both installation and operation costs. Sometimes paste or other types of thickened tailings will be clearly preferable, but sometimes traditional ones will be chosen.

When do other factors come in? Thickened tailings reduce dust pollution, do not pose the risk of liquefaction, and reduce the mine's water consumption. All of these issues improve the companies' relationship with communities, but many times these are simply positive byproducts of a purely cost-benefit driven decision based on water costs.

But this is not necessarily always the case. In the case of Las Cenizas' Cabildo mine, they already had authorization and everything ready for a traditional tailings deposit, but to avoid conflicts with communities, they explored new technologies and ended up building the first thickened tailings operation in Chile. The pressure from local communities and the *"social license to operate"* are becoming increasingly central issues in the design and evaluation of new mining projects. Previously, spending resources on waste management was seen as a waste itself, especially when there was water available. But as mining companies factor in the "social license" in their calculations, conflicts with communities might represent so high costs that reducing conflicts, even if it is costly, may well pay off, especially in the long term. Whether this counts as a different *guiding principle* or not is something else, but the cost associated to social conflicts (as well as possibly more strict environmental regulations) are increasingly pushing companies into environmentally and socially more responsible technologies. Previously, spending resources on waste management was seen as a waste itself, especially when there was water available.

6.2 Products

The final product here is still copper (mostly in concentrate form). But we could consider two other *products* here: knowledge and capability generation, and the tailings themselves.

If we look at this case as *path-creating*, we see that domestic companies and professionals are acquiring capabilities in this technology, and most important, Chile is *"certainly pushing the boundaries"* in this technology, and could in the future sell this knowledge to other mining countries.

If we look at the residuals as "products", of course they have differences with traditional tailings. These ones are still not known as much, but they do have some defining characteristics: more stability, less impact from the wind, and less risks of polluting underground water, to name the more important ones. Another important difference is the ease and speed for closing the operation, compared to traditional tailings. This is also something valuable for local communities.

6.3 Technology

The core of this case is a technological improvement that reduces problems associated to the dominant regime. Starting from foreign experiences, the technology has been used in several medium scale mines, and a large scale project pushed the global knowledge frontier in adapting the technology for much larger-scale operations that previously existing deposits.

There are many differences in terms of the technology used in these and in traditional tailings, but we will not go into technical details. Some remarkable aspects are the role played by the sorrounding walls: in traditional deposits they are supporting the tailings. In thickened ones, they are only containing it (as the more solid tailings are self-supporting, as shown in Figure 6), and are not even always needed. Pumping technology also changes, especially with paste tailings, which require "positive displacement" pumps. There are also differences in the thickening process and in the way the tailings are distributed in the deposit. Definitive closure is also different; it can take years with traditional tailings, while it can in theory be immediate with thickened ones.

Figure 5 – Thickeners at Minera Esperanza. (Esperanza, 2012)

Figure 6 – Top figure: diagram comparing conventional (on the left) and thickened (on the right) tailings. Bottom figure: deposit of thickened tailings in Vaudreuille, Canada. (Sources: Galaz, 2011; Valdebenito, 2007)

In some aspects, the technological problems that thickened tailings are facing are very similar to the engineering problems faced by traditional tailings, but for the latter the problems had already been solved. There is still the need for more experience to learn about the technologies and in general about how to work with materials that behave in sometimes fundamentally different ways than traditional tailings.

6.4 Industrial structure

The actors and experiences associated to this alternative are distributed through the same network and industrial structure that is the dominant regime's one. But in terms of knowledge sharing, learning and collaboration, there appear to be differences in the way it works across different technologies. For example in biotechnology-related issues, there appears to be some more secrecy and closed working groups. In thickened tailings, there are no collaboration agreements between companies (tailings' characteristics are highly deposit-specific), but there is significant knowledge sharing and collective learning. The difference might have different explanations. Some are related to characteristics of the technology and its development, others to its role in the productive process and the ubiquity of the problem across the industry, and yet others to the existence or not of actors that bring the industry together.

As with other technologies, the developments are done by mining groups together with engineering firms, but there is also the participation of international experts. Being experts, each new technology means that the appropriate individuals must be contacted.

Another aspect that is noteworthy, although is not directly a difference between the dominant regime and the alternative, is the fact that several important domestic engineering firms – particularly some with experience in this technology– have been acquired by large international firms during the last couple of years. This might or might not have an impact in terms of the generation of diffusion of knowledge. Companies are bought with their teams and client lists, but there might be different orientations when ownership changes.

6.5 Knowledge

Knowledge-related aspects have been described in the previous points. Although the problems are similar, new knowledge is needed to operate this kind of tailings. And the generation of this knowledge, particularly when it is knowledge that is not available in the rest of the world (in what we could see as the "global" dominant regime), might be important when looking at the *path-creating* aspect of this alternative. The structure of the network where this knowledge is generated is contained in the dominant regime, but the particular network associated to this technology seems to be highly collaborative, vis-à-vis other technologies.

6.6 Culture and Values

As discussed before, social pressure, stemming both from environmental issues and other problems that affect local communities, is an increasingly important issue, mentioned constantly during the fieldwork. As its importance continues to growth, even if companies are driven by profit-maximization, the wellbeing of all stakeholders will become an increasingly central issue for mining companies. This could result in a cultural change as evaluating environmentally- and socially-responsible technological alternatives becomes the first thing that decision makers think of when designing new projects.

A new long-term relationship between societies as a whole, local affected communities, and large mining companies might be necessary for the new expansion phase of mining in Chile. Technologies that have been developed mainly driven by productive factors might prove key in establishing this new relationship, where mining companies keep giving taxes and jobs, but stop producing negative externalities.

Another important cultural aspect is that, at least in what concerns this technology, the industry has had a very collaborative approach.

7. Q3: To which extent is the alternative promising or delivering better outcomes?

Following the classification used in the Chilean sectoral report, we will describe alternatives that improve productive, economic, environmental or social outcomes. Firm-level *productive* improvements are considered because some of the main problems of the dominant regime are associated to productive restrictions, and these are fostering the development of alternative pathways. A clear case of this is the development of thickened tailings: the main improvement is the reduced water consumption (positive for both firms and society), but also has important environmental and safety benefits, which are not appropriable by the firms. In other words, they produce less negative externalities than the usual in the sector.

The *economic* problems we studied are related to the long term dependence of the Chilean economy on copper exports, and the need for developing technological capabilities. In terms of better economic outcomes, this alternative can be looked at from the prism of path-creation. It has helped develop local knowledge and engineering capabilities, something that is fundamental if we consider natural resources as a source of knowledge demand that could help diversify the Latin-American economies.

7.1 Productive

As has been reinforced throughout this report, water saving is *the* most important issue. And from the narrowest perspective of the firm, it represents a reduction in water costs (water rights and especially pumping costs), as more water is recovered from the tailings and recirculated back into the productive process. Tailings are one of the obvious places to look at when thinking about water efficiency, because of the massive scale of the process.

But there are other important benefits from the point of view of the firm and its results. When flat surfaces are available (not the norm in the Andes area, where most mines are), these deposits can have a significant reduction in capital costs, as there is no need to build the large and strong supporting walls needed for traditional deposits. And not only the cost of the structures is reduced, also the area needed for disposal is usually reduced. In some cases these can also result in longer lifetimes for the deposits. The closure of these deposits is also cheaper and easier.

One interesting development is the construction of thickened tailings deposits *on top* of previous, traditional tailings. However, there is much uncertainty sorrounding the stability of these deposits, especially in a seismic country like Chile. These cases are mostly motivated by cost reduction by the firms.

Another improvement in this direction, which has been operating in Chilean “El Toqui”[6] mine, is backfilling. They have been putting paste tailings *back into the underground mine* since late 2010. The most important benefit of this is being able to recover zones of the mine that were not considered in previous plans, through the use of mineralized pillars. This possibility, however, is only present for underground mines, and feasibility depends on the conditions of the site.

Figure 7 – Example of underground mine backfilling with tailings, at Cleveland Potash, Boulby Mine, UK. (Source: Tailings.info, 2012)

7.2 Economic

In terms of national economic competitiveness, and the development of technological capabilities to support sustainable and long term growth, thickened tailings might be one of the areas where the country can develop expertise. As one of the experts interviewed pointed out, the sector is fragmented in terms of its frontier technologies, and there are particular niches where there is potential to develop technologies that go beyond copper mining. Because of the experience that is being developed, both in medium scale and adapting the technology to larger scales, domestic expertise in the area could get to be recognized and exported to other mining countries and industries. The fact that large foreign firms are acquiring relatively small domestic engineering firms is a good sign. There are already domestic capabilities to conduct pilot and laboratory tests, and in general the human resources needed to supply *“a complete and effective solution to dispose paste tailings”*. But even if there are capabilities, there is still not enough experience, that needs more time to build up.

There are also potential markets, for instance Peru, where there are deposits of similar characteristics and not as much domestic experience developed. The technology and capabilities developed can also be transferred to other mining industries, where the Chilean experience scaling the technology up could be relevant.

[6] This mine extracts mainly zinc, lead, gold and silver. But we include it here because it is a very interesting case in terms of its tailings.

7.3 Environmental

The environmental benefits of this technology are strong. First of all, significant water recovery, meaning less fresh water is consumed by the mining operations, something critical in desertic regions. As the material is more compacted and there is less free water (see Figure 8), the potential for leaking polluting substances into underground water sources is greatly reduced. This is a serious danger in many tailings deposits.

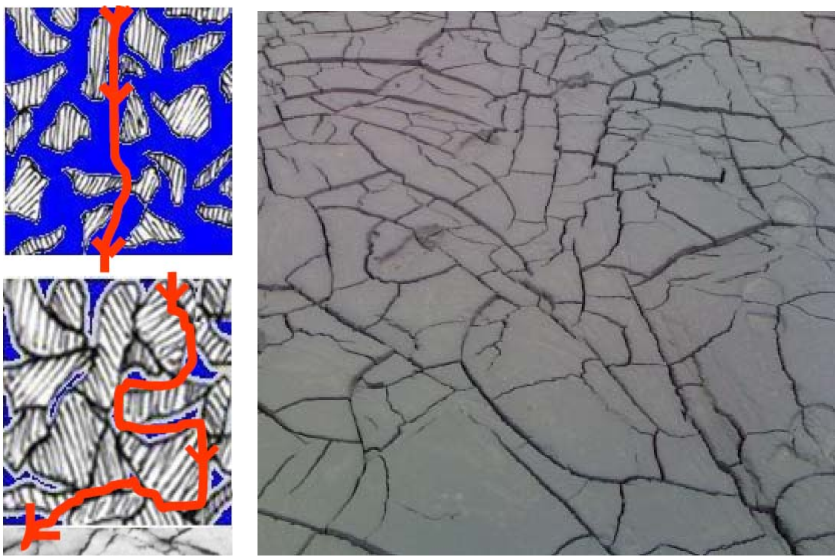

Figure 8 – The diagram on the left shows how thickened tailings (bottom) have less free water and make it more difficult for water to leak through the ground. On the right, the cracks show that water leaves through the top, through evaporation, and not leaking underground. (Sources: Valdebenito, 2007; Galaz, 2011))

Due to their higher density, thickened tailings also require less surface to operate (or the same one for a longer operation time). This can be an important environmental benefit in some cases. Under some conditions tailings can even go back underground, further improving on this respect. Dust pollution is also substantially reduced, because thickened tailings are more agglomerated than traditional ones.

Regarding closure, it can take between 10 and 20 years for traditional deposits, while it can be immediate with paste tailings (unless nutrients are planted in the upper layers). However, there is no experience in the closure of large scale operations, and if the operation is not conducted carefully, the surface area can end up being larger than with traditional tailings.

Looking at the interaction between this case and the use of seawater in the production process, there is a virtuous relationship between the two: the substances in the salty water produce an agglomerating effect, hardening the tailings and further reducing dust pollution.

7.4 Social

The issue of water recovery from tailings is not as evident as, for instance, the difference made by the use of seawater or renewable energies. For this reason, the increased water recovery does not always have a strong impact on the population, it is not as important for helping obtain the “social license to operate”. But the most evident social benefit associated to thickened tailings is not water saving, but safety. The 1965 accident that resulted in the first regulation for tailings reportedly killed over two hundred people, most of whom were never found, and the company received no legal punishment. As seen in Figure 9, some deposits are located in extremely dangerous positions in relation to local communities. The top panel in Figure 10 shows an accident that occurred close to Santiago in 2003. There is also the case of deposits that were abandoned by companies, as until 2011 there was no law regulating mine closure. After the 2010 earthquake four people were killed by one of these abandoned deposits (Ramos, 2010). Agriculture can also be seriously affected by tailings, there was an incident in 2002 (bottom panel of Figure 10) that polluted the water sources that supply an important agricultural valley (Cooperativa, 2002).

Figure 9 – “Las Tórtolas”, a tailings deposit in northern Santiago, poses a risk for a nearby settlement and agricultural activities. (Source: Calabrán, 2009)

Figure 10 – On top, an accident at “Cerro Negro”, near Santiago, on October 2003 (the white circle shows three individuals, to have a scale reference). On the bottom, another one at the Cobrex mine in 2002, that threatened the waters of the Elqui river. (Source: Tailings.info, 2012)

Now there is a mine closure code, as well as better regulation about tailings. But the risk of liquefaction still exists. After an earthquake, sand is compacted and water can rise from the tailings, producing a liquefied soil that cannot support anything. Most people claim that the risk of liquefaction is *“nonexistent”*, however, some careful voices warn that we still do not have the experience of a large earthquake in a thickened tailings deposit, and there is still at least the risk of some collapse and gliding of material. But this would not have the *“catastrophic potential”* of liquefaction.

Last but not least, the reduced water use and reduced risks of water and dust pollution are environmental benefits that have clear social impacts. The dust problem is in fact forcing several mining companies to conduct important research efforts to reduce it.

As an expert in the sector stated, *“these advances are not only important from the environmental and productive optics, and they go beyond the management or rationalization of operating costs. These advances also allow us to keep reducing socio-environmental uncertainties, something that is strategic to facilitate the social license for mining operations.”*. The case of Las Cenizas’ Cabildo operation is emblematic, as after having all necessary permits to construct a traditional deposit, decided to study other alternatives because of social pressure, and eventually installed a thickened tailings operation (including deposits on surface and underground backfilling).

Figure 11 – The surface deposit of thickened tailings at Las Ceniza's Cabildo operation (Source: Straub, 2011)

8. Q4: In which ways has the availability of internet and/or other ICT technologies contributed to the development of the alternative?

The internet is as important as in any other sector for easing coordination and communication between actors, but the rich knowledge sharing situations in this case have been face-to-face meetings.

Moreover, software and computational power to assist in the different planning and design phases is of course important, but not something characteristic of this alternative pathway. In fact, the challenge that has been found when scaling the technology up is that things do not work in practice as was planned in paper (or screen). What is necessary here is a lot of practice, applied work on site, to improve operating conditions and bring the operation close to its design parameters. It's engineering in its most traditional sense.

When asked about the importance of these technologies specifically for technologies like thickened tailings, one mining executive clarified that ICTs are *"habilitators"*, and not *"an end* *in themselves"*. What could be particularly important for the future of mining, and could play a role in the operation of thickened tailings deposits, is process automation and control. In thickened tailings for instance, there could be continuous monitoring of operating conditions, to improve operation.

9. Q5: Which are the main barriers that block the diffusion of the alternative?

In this section we discuss some factors that have affected the diffusion of the alternative in the past, are doing it now, and also some that could be promoting the initiative but are not doing it.

9.1 Capabilities

The most relevant barrier to the diffusion of this technology might be technological capabilities. Or more precisely, the lack of experience and appropriate technologies to efficiently deal with all types of tailings existing in Chile. The characteristics of the tailings that are relevant for thickening have a large variability across deposits, spanning ranges that cover over two orders of magnitude. Experience and learning can be enough to have thickened tailings in some cases, but in others, it goes beyond mere capabilities and will require the development of new methods and technologies.

In the particular case of Esperanza, that is a world-level example of technological innovation, in betting for thickened tailings at large scale, it has been difficult to operate under design conditions, and particularly, to achieve this conditions in a stable way. Selection of consultants and suppliers appear to have played a role in at least some of their problems. Most of the problems are relatively understood, but the appropriate solutions and operating conditions have not been found yet.

9.2 Economics

Although increased water efficiency is always a desired outcome in the desert, it is not always economically efficient for companies to choose thickened tailings. In some cases capital or operational costs may be too high, too much to be compensated by water savings (and the pecuniary costs of water clearly dominate over the costs related to social problems, in terms of the relative importance they receive).

Looking at this alternative from its *path-creating* perspective, something that could represent a threat is the acquisition of domestic engineering companies. But this might or might not turn out to be a problem, it could even be an incentive for other domestic firms and a positive development in terms of knowledge transfer. But it could also "take knowledge away" from domestic professionals and reduce domestic learning.

9.3 Vested interests

Vested interests do not appear to be a problem. For mining companies, there is no problem in switching technologies when a new one is better, *especially* if someone has already shown that the technology works, and this has already happened in Chile for medium scale, and is beginning to happen for large scale operations. On the other hands, there are engineering firms that have spent years developing capabilities in designing and building traditional tailings deposits, but they are only suppliers and there is a market with competition, so under no circumstances could engineering firms block technological changes to benefit from their sunken learning efforts.

However, it must be made clear that companies will not “choose” to adopt this technology at any point in time: new mining projects are designed together with their tailings deposits, and this last for several years. So the decision for tailings technology is taken at the beginning of the project, or eventually when a deposit gets full, and it is necessary to design and build a new one. But when a tailings deposit is already approved, built, and has space to keep receiving tailings, the sunken costs are too high and there won’t be changes in this respect.

9.4 Infrastructure and equipment

Something that has been a constraint at some points, although it is not evident if it is now, is the availability of appropriate equipment to deal with the different tailings, especially in very large scales. It would not have been possible to build some of these operations a couple of years ago, just as new equipment might make it feasible to expand current tailings beyond what is possible today.

9.5 Institutions

Given that this is a relatively new technology in the country, some people point to the importance of regulating agencies having more contact with it. There are also some critics about rigidity and foreign experience-based details in current regulation, but this does not seem to be a fundamental limiting factor for most of the actors. However, other actors do recognize that sometimes ignorance about technologies in the public sector can become a problem. Someone also mentioned that authorities could be reluctant to authorize new projects if the technology does not prove completely that it can operate as planned.

What could be, more than a blocking factor, a *not-encouraging* factor, is the role of environmental and other regulations. In some countries, the adoption of this technology has been driven by environmental authorities. In Chile, is has currently been motivated mostly by economic considerations. Considering that –at least at current copper prices– mining companies obtain significant rents, regulations related to the social and environmental safety of deposits could be stricter and force some mining operations to go for this technology, even when it is not the most cost-effective one. There are important risks and negative externalities that could be reduced in this way, including of course the serious issue of water availability.

9.6 Natural

Probably the single most limiting factors are natural conditions (mineral deposits, geography[7], etc.) that determine whether it is economically efficient to use this technology or not in different situations. Whether this will change or not depends on future technological developments or on more stringent regulations that might force companies into this technology even when it is not their preferred solution.

10. Summary

In this report, we covered our main research questions for the case study of the “thickened tailings” technology. We looked at this technology mostly in its *path-repairing* dimension, i.e. an alternative that does not have the potential to produce radical changes in the dominant sociotechnical regime, but that nevertheless produces relevant improvements on environmental and social outcomes, reducing some of the many important problems associated to copper mining. The core of the case was the diffusion of an existing technology and its scaling-up, a diffusion associated to water scarcity, that can be an important cost or even constraint for new projects, and which is also associated to increasing social pressure from communities.

This alternative has had an interesting diffusion during the last decade. From no operation in existence, there are currently seven operating or in pilot phases, and more under evaluation. There have been several instances of discussion where professionals have shared experiences with the technology, something very important for everyone’s learning, especially in a new subject. Knowledge diffusion can also occur through experts and engineering firms that work with different mining companies and thus can have a more varied experience. The experience of Minera Esperanza, implementing thickened tailings at a scale never before seen, has been one of the most important developments, which could help Chile become a relevant actor in the world scene in this technology. It can also have important demonstration effects on the rest of the firms operating in Chile. The future for the technology looks good, but it’s not the panacea, as it is not ideal for all situations and there is much variability in tailings across the country. The government co-funded a project that produced important information about limits and conditions for thickening most of the tailings in Chile, and has also enacted several different regulations that are important for this technology. With respect to the expansion of the alternative, some people think the government is not relevant, others think that it could present barriers, and yet others think it could potentially play an important role in promoting this technology.

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With respect to the distance between this alternative and the dominant trajectory, there are some interesting aspects. The ultimate guiding principle in firms' decisions is still minimizing costs, but pressure from society has been growing at a very fast pace during the last few years, and having conflicts with communities is increasingly a cost that firms cannot overlook, especially when thinking on the long term. In terms of "products" this alternative is producing an important accumulation of capability, and when looking at the tailings themselves as a product, these are different to traditional ways in a number of important ways. The technology used also has important differences between traditional and thickened tailings, some of this technology and knowledge were first imported, but they are also being produced locally. However, there is still much space for learning and need for more experience with the technology, while traditional tailings' technology had been already mastered by engineering firms and mining companies. The alternative is located inside the structure of the established sociotechnical regime, but has two noteworthy aspects in this respect: only for some technologies these levels of collaboration seem to be observed, and it has happened in the last couple of years that several Chilean engineering firms with knowledge on this area were bought by foreign companies. Finally, it is hard to tell if there is a real cultural change behind, but social pressure is clearly moving several topics (such as safety and water efficiency) way up in the list of worries that mining companies have when thinking about new operations.

In terms of better outcomes, this alternative has many noteworthy aspects. From the perspective of the firms, there are cases where building and operating a plant of thickened tailings can be cheaper than one of traditional tailings. Water saving is also a key improvement. From the perspective of national technological capabilities, there is still much to be learnt, but there has also been an important accumulation of experience that could eventually be exported. The future development of other large scale thickened tailings deposits could make the country a leader in this area. Environmental benefits are many and important: less surface is required, there is less eolic erosion, less risk of pollutants leaking into underground water sources, and of course, an important increase in water recovery. The reduction in social risks is also very important: besides the increase in water availability and the reduction in pollution that was just mentioned, tailings deposits can collapse and pollute water sources, and even worse, there have been accidents resulting in hundreds of deaths. The last fatal collapse of a deposit was after the 2010 earthquake, and killed four people. Although not yet subject to the experience of a strong earthquake, thickened tailings should not produce accidents like these.

Internet and ICT's do not play a key role in this alternative, beyond the use of software to support the design of the deposits and the standard communication tools used to coordinate work in any industry. The final details to improve the operation of these deposits are seen on site, and require practical engineering work to adapt theoretical designs to actual operating conditions. Something that could be important for the future of the sector, and particularly could be used in thickened tailings, are methods for continuous monitoring.

In terms of the barriers, the main limitations for the diffusion of the alternative are the combination of natural characteristics (of the minerals and geography) and existing technologies. Thickened tailings are not the best alternative in all situations, at least not with current technologies and capabilities, and it is not clear when this will change, if it will at all. On the other hand, the public sector could impose more strict regulations in terms of safety, water usage, and pollution that could force mining companies to use thickened tailings even in situations where they would not consider them to be economically efficient (of course this should consider potential impacts on production levels).

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