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Absorptive capacity, knowledge circulation and coal cleaning innovation: The Netherlands in the 1930s

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Before World War II, Dutch State Mines, the national, state owned coal corporation, was confronted with major challenges, specifically that foreign coal was sold at dumping prices in the home market. At the same time, coal cleaning needed to be improved in order to offer higher quality coal against lower coal processing costs. In this paper we illustrate how State Mines relied on its innovative capacity in order to overcome the economic, technological and market changes. The coal cleaning innovations at State Mines show how absorptive capacity was of prime importance for the firm's innovative capacity. External knowledge acquisition as well as internal knowledge building proved to be relevant, although the balance changed over time. While initially acquisition and assimilation of external knowledge (*potential absorptive capacity*) were essential to improve the existing coal cleaning processes, internal knowledge building was needed to come to real improvements in coal cleaning. The establishment of a licensing company was essential to exploit this knowledge. An important feature was that State Mines was always well aware of its lack of capabilities and knowledge and open to search for and learn from knowledge outside its firm boundaries. Moreover, expectations determined the search for external knowledge.

Keywords: innovation; knowledge; absorptive capacity; expectations; Dutch State Mines; coal cleaning; hydrocyclone; Tromp system; loess washing system; Barvoys system

In the 1930s, Dutch State Mines,[1] the national, state owned coal corporation, established in 1901, was confronted with major challenges. It had to sell coal for profit on a market on which foreign coal was sold at dumping prices. At the same time, coal cleaning needed to be improved in order to offer higher quality coal against lower coal processing cost. In these situations, firms have to rely on their innovative capacity in order to overcome the economic, technological and market changes. In order to understand and evaluate State Mines' possibilities and actions, we first provide a brief introduction to research tools for innovation at the micro level. We will then present our case study. Finally, we will evaluate Dutch innovations into coal washing from both the theoretical and the historical point of view.

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From the 1990s onwards research into innovative capabilities of firms was influenced by the resource-based view and its offshoot, the knowledge-based view. In Smith's study the firm is considered as 'a collection of resources and competences ... that is, as a store of (technological) knowledge applied to the resolution of a problem' (as cited in Oerlemans, 1996, pp. 32–33). This combination of resources and capabilities is considered essential for the firm's innovative capacities. Firms have an active role in the innovation process, in the words of Nonaka 'the potential to innovate of a business would depend on its capacity to create new knowledge, spread it through the organization, and incorporate it in new products, services, and processes' (Nonaka & Takeuchi, 1995, p. 3).

We have to realise, however, that the expression 'to create new knowledge' not only includes investments in in-house research, but all the knowledge seeking and acquiring activities. Innovation is considered, as formulated by Jorde and Teece (1990, p. 96), 'as an incremental and cumulative activity that involves building on what went before, whether it is inside the organization or outside the organization, and whether the knowledge is proprietary or in the public domain'. Innovative firms interact with other organizations in an institutional setting to gain, develop and exchange various kinds of knowledge and information and other resources. One of the most extended studies on the major success factors for innovations in the chemicals and scientific instruments sectors, the project SAPPHO of the 1970s pointed at the importance of internal relations within firms, external collaboration with users and with external sources of technical knowledge. Since then these main results have also been confirmed by studies in other industries.

Knowledge and information from external sources are, as is stressed in many studies, important for small companies that do not own research and development (R&D) facilities. Parsons and Rose (2004), for example, illustrated how personal networks contributed to the innovative capacity of small entrepreneurs in the British outdoor textiles trade. But external knowledge and information were just as important for large firms as well as for those who had their own R&D infrastructure. A recent study on the search strategy of UK manufacturing firms strongly suggests that 'the lack of openness of firms to their external environment may reflect an organisational myopia': managers overemphasise internal sources and underestimate the value of external sources (Laurensen & Salter, 2006, pp. 131–150).

Especially the balance and interplay between internal knowledge building on the one hand and external knowledge acquisition on the other forms a key factor in firms' capability development. A firm's knowledge sourcing activities are closely related to its internal knowledge building. Without an internal knowledge base it becomes even more difficult to scan the environment and evaluate the relevance of knowledge from external sources. An accurate valuation of knowledge sources becomes even more difficult when the state of technology is in flux. Nascent technologies still have to prove their technological attainability, economic viability and social acceptation.

This brings us to the concept of absorptive capacity, which is seen as a core capability for innovative performance. Cohen and Levinthal have defined the concept of *absorptive capacity* as the ability of a firm to recognise the value of new, external information, assimilate it, and apply it to commercial ends. It is a resource based capacity, dependent on skilled staff, artefacts, R&D facilities, organisational culture and opportunities for knowledge exchange and transfer. Cohen and Levinthal also argue that the development of absorptive capacity depends on a firm prior knowledge. Absorptive capacity, and, as a consequence, innovative performance, are path-dependent: 'once a firm ceases investing in its absorptive capacity in a quickly moving field, it may never assimilate and exploit new information in that field, regardless of the value of that information' (Cohen & Levinthal, 1990, p. 13).

The definition of Cohen and Levinthal (1990), however, is broad and contains different activities (see Lane, Koka, & Pathak, 2006).[2] Moreover, little is known about how these processes of investing in absorptive capacity and the assimilation and exploitation of new information exactly takes place. This justifies a further unravelling of the construct of absorptive capacity. In their review of absorptive capacity, Zahra and George (2002) define it as a set of organisational routines and processes by which firms acquire, assimilate, transform and exploit knowledge. They view the two first dimensions, acquisition and assimilation, as *potential absorptive capacity*, as it does not guarantee the exploitation of knowledge. The dimensions transformation and exploitation are named *realised absorptive capacity*, which reflects the firm's capacity to leverage the absorbed knowledge. This distinction is useful to explain why some firms are more successful than others with their absorptive capacity, as a firm's improved performance is based on realised absorptive capacity. This absorptive capacity is also related to non-R&D competencies, like production, distribution and manufacturing (Cohen & Levinthal, 1990).

The concept of absorptive capacity links internal knowledge building to external knowledge acquisition. There is not only a continuous interaction between internal knowledge building and external knowledge acquisition, however, the balance between the relevance of internal and external knowledge can change over time. Davids and Verbong (2007) illustrate how in the early 1950s Philips' limited research and production expertise made it necessary but also possible to use semiconductor knowledge from external sources to produce transistors. Increased R&D capabilities led to a lead in high frequency transistors, but also to diminishing receptivity for external knowledge sourcing, when ICs became important.

When focusing on knowledge building and acquisition it is important to realise that not all created knowledge is explicit. Most literature concerning knowledge pays attention to the distinction between explicit and tacit knowledge. While explicit knowledge is highly codified, tacit knowledge is, as pointed out by Polanyi in the 1950s, the knowledge which exceeds what can be expressed verbally. Most studies illustrate that the transferability of tacit knowledge is much more difficult than that of codified knowledge and demands considerable effort (Nonaka & Takeuchi, 1995; Polanyi, 1958). Also important is the distinction between more general and more specific knowledge, which is closely related to codified versus tacit knowledge. Often, but not always, general knowledge is codified in character and specific knowledge is incorporated in instruments, machines or people.

Not only the kind of knowledge and transfer mechanism can differ, also various sources of knowledge. Universities and research institutes have always been important sources of scientific knowledge, although the importance can differ in time. Homburg illustrates in his inaugural lecture how before World War II especially through contacts with university professors the direction was from universities to industry, while this changed after the war. However, we are not only interested in these sources but pay special attention to knowledge transfer between companies, suppliers, clients, and (competing) firms in the same sector. When we talk about suppliers we should include material, components, instrument and machine suppliers.

This forms the background for our first set of questions. We want to know if State Mines was able to meet the market and technological challenges in the 1930s and how important its absorptive capacity was in this respect. Was there transfer of knowledge, from what sources and in what form? Did this change over time and if so why and in what direction?

An interesting aspect of the concept introduced by Cohen and Levinthal is the role of absorptive capacity in 'conditioning the updating of expectations'. No attention, however, was paid to the question how expectations of (parts of) the firm about technological and market opportunities attributed to the development of absorptive capacity.[3] But without prospects the intention to learn will be minimal. This is the aspect of receptivity or 'intent to learn' as Hamel (1991) calls it.

In technological studies the importance of expectations and visions in technological development are highlighted. A major contribution is made by Van Lente (1993) with his dissertation, *Promising Technology*. In his work on the role of expectations in technological development he addresses that there are three levels of expectations, which are interconnected. Expectations about (future) artefacts, processes and materials can be categorised at the micro level. These so-called search expectations contain specifications, are problem oriented and guide search processes. They add to the agenda of firms and research groups. Expectations about a technical-scientific field or industrial sectors function on another level. They are less specific, 'they state something about the general direction of the field, and about opportunities the field offers'. An example of these meso level expectations, that guide the actions of the field, are ideas about the future market dominance. Finally expectations about societal forces and trends and technology as a whole (macro level) are broad, diffuse and general. The shared vision in the 1950s that semiconductors would change the world of electronics can be labelled as a macro level expectation (Van Lente, 1993, pp. 182–187).[4] Van Lente illustrates how expectations are used as legitimation for decisions, actions, etc., to mobilise funds and attention of others and to reduce uncertainty. In this paper we will see how this influenced State Mines' decisions to invest in research and development capabilities in the field of coal cleaning. Without expectations exploring untrodden paths is hampered. We therefore assume that expectations, investments in knowledge building and knowledge acquiring capabilities are mutually dependent, and that the aspect of receptivity plays an important role in this dependency.

This brings us to the next set of research questions: how receptive was State Mines to learning from external knowledge sources? Did this change over time? And how important were expectations about technological and market possibilities in this respect?

Diversity of knowledge flows for coal cleaning innovation at Dutch State Mines (1930s)

When Dutch State Mines (*Staatsmijnen*) was looking for better coal cleaning systems, a wide variety of knowledge flows was used. Sources included foreign companies, nearby companies, in-house experiments, pilot plants, literature search, and licences to build and get experience with newly developed coal cleaning systems. This variety of sources was vital in building up the knowledge absorption capability.

State Mines originated in 1901, when the Dutch minister Lely sent a proposal to the parliament to establish a national, state owned coal mining company. The parliament accepted, as they agreed that the exploitation of the coal mines in the south of the Netherlands had too much strategic importance to leave it to privately owned companies only. State Mines was a latecomer in the field, which was illustrated by the fact that almost all anthracite containing concessions were already in the possession of coal mines with private ownership. As a result, State Mines had to exploit concessions with fat coal, a grade which contained a high percentage of volatiles. Therefore, fat coal was unsuitable for home heating, the most profitable line of business.

State Mines started exploitation of its collieries, named after Dutch royalty, in 1907 (Wilhelmina), 1914 (Emma), 1918 (Hendrik) and 1926 (Maurits). The scale of its operations was large: around 1930 State Mines employed about 22,000 persons.

Even though State Mines was owned by the state, Lely's bill specified that it should be run for profit. In addition to the economic and strategic objectives, the bill also included a plan for a model mine, which should use the best and newest technology available and which would not have to be profitable in the short term (Schot & de la Bruhèze, 2003, p. 269).

From early on, State Mines welcomed any method to minimise waste and increase coal recovery. The Dutch coal was buried in deep and thin layers which led to high production costs, whereas many collieries abroad had much lower pit-head costs, because coal was more easily accessible there. For example, in 1947, the Dutch pit-head costs were about $13 a ton, whereas in the eastern part of the United States, these costs were about $3 a ton (Driessen, 1947).

In the 1920s, coal from the United States, Great Britain, Germany and Poland was sold on the Dutch market at bottom prices, so that market pressure increased even more. At the same time, increasing oil production decreased the demand for coal. State Mines managed to survive these difficult times by implementing pro-active and innovative strategies, which were initiated by its managing directors. One of these was Frits Van Iterson, who was originally a professor in mechanical engineering at the Technical University in Delft. In 1913 he was appointed as State Mines director for the works above ground. Van Iterson initiated the modernisation of State Mines by introducing long term planning, debottlenecking, large scale production, research and development, and diversification into coking and chemicals production.

Then, the advantage of being a late entrant in the field also became apparent. As State Mines started from scratch when building its collieries and processing facilities, the company could design its colliery operation on a large scale with an optimal lay-out, whereas collieries abroad with long histories carried the burden of existing installations which were either technically obsolete, or too small and inefficient in lay-out.

To decide on how to design and run the installations, Van Iterson, his colleagues and his staff, informed themselves thoroughly. They regularly travelled abroad to visit collieries, research and development facilities, and suppliers. External knowledge acquisition was combined with internal knowledge building: knowledge from external sources was collected in order to evaluate and test it, transform it if necessary and then use it. Director C.T. Groothoff used a variation of a bible quotation to summarise this strategy as 'Put all things to the test, keep what is good' (RHCL, 17.26/03A-313, 7/4/1936).[5] Until 1929, tests and experiments were carried out by plant engineers and scientists who were located in plant facilities, plant laboratories and workshops. Then, Van Iterson established the Central Experiment

Station (*Centraal Proefstation*), to perform mining and mechanical engineering research and development. After that, an R&D strategy was further prepared and set up by a commission that conducted several study tours in the early 1930s. The result was that, in parallel to the Experiment Station, a Central Laboratory would replace all plant laboratories in 1940 (Van Rooij, 2007). This laboratory would include new facilities such as a library, a patent department, and its staff would have ample opportunity for communication with external researchers and students.

From 1929 to 1948, the Central Experiment Station was headed by chief engineer Max Driessen. He was a mechanical engineer with a degree from the well-known Swiss Federal Institute of Technology Zürich, *ETH*, and had working experience in Switzerland and the United States.

In its first years, Driessen and his staff were very much involved in coal cleaning improvement. Coal needs to be cleaned, because in its natural condition it is usually mixed with rock and other impurities. Originally, this cleaning was carried out in the shafts, but in the nineteenth century the first dedicated coal cleaning installations were built above ground in Belgium. After that, the German collieries followed, so that in 1850 there were dozens of coal cleaning installations in the Ruhr area. In the Netherlands, the first coal washery was built by the Domaniale Mine at the very end of the nineteenth century (Gales, 2004, pp. 36–40). The first coal washing machines, like the jig wash and the Baum machine, were simple and processed the coal in batches. First, coal and rock particles were submerged in a water basin. The machines then used fluid or air flows to separate the coal, as coal is lighter than rock and will float to the surface. As most coal also contained middlings, a mixture of coal and rock, these washing machines were very inefficient. Nevertheless, in the early twentieth century most coal washeries applied this cleaning method.

In the 1930s, State Mines needed new coal cleaning installations. The existing ones needed replacement due to age and insufficient capacity, because of the increase of the mines' production. In addition, there was a need for better, larger scale and automated coal cleaning in order to decrease production costs. In order to satisfy customers, the coal cleaning process also had to result in pure, good quality coal both for home use and for iron and steel production.

State Mines had already successfully solved coal processing problems when its Emma mine washery was commissioned in 1913. It was processing coking coal, and because this coal was very fragile the amount of coal fines was so excessive that State Mines needed a coal fines separator to prevent too much coal waste. Chief mining engineer C.T. Groothoff knew of a separation process from the ore industry which might be useful. It was named froth flotation and was based on a suspension of coal and rock fines that was foamed by the addition of frothers and agitating the liquid. The fines would then float to the surface and could be removed. To adapt this process for the Emma mine, mechanical engineer J.W. Kleinbentink developed a foaming machine, which was patented and named after him (Van Iterson, 1937). Another example is the centrifuges which were used to dewater the fines suspension. These were first bought from American manufacturer Elmore, around 1924. State Mines optimised the construction, found out that Elmore's patents did not apply for the Netherlands and then approached Dutch manufacturers to copy the equipment. Eventually, manufacturer Reineveld was selected, who later added this centrifuge to its product line.

In the 1930s, the best available method was the American Chance flotation process, in which the coal and rock mixture was led through a sand-water suspension

(Figure 1). Because of the difference in density, rock particles settle down, whereas coal particles float to the surface. The first Chance coal washery was built in the United States in 1921. The method's main disadvantage was that the sand-water suspension needed continuous stirring in order to prevent sand from settling down at the bottom of the separation basin. This needed to be prevented to keep the density of the sand-water suspension sufficiently high for the separation process. To overcome this advantage, several mining companies, engineering contractors and manufacturers were developing variations of the Chance float-and-sink-process, by using different suspension materials and by changing the installation.

State Mines management and staff started scouting for the best methods available, which they evaluated by literature research and visits to coal cleaning installations (RHCL, 17.26/03A-33). Late in 1933, Van Iterson and two chief engineers visited a Chance washery in England. They were positive about the system's efficiency (RHCL, 17.26/03A-33, R.R. no. 82A). When Driessen visited the same installation to assess its construction, he was critical about it. He expected operational problems because of blockage, wear of spray nozzles, and he was concerned about the engineering and the way the slides were driven (RHCL, 17.26/03A-33, R.R. no. 82).

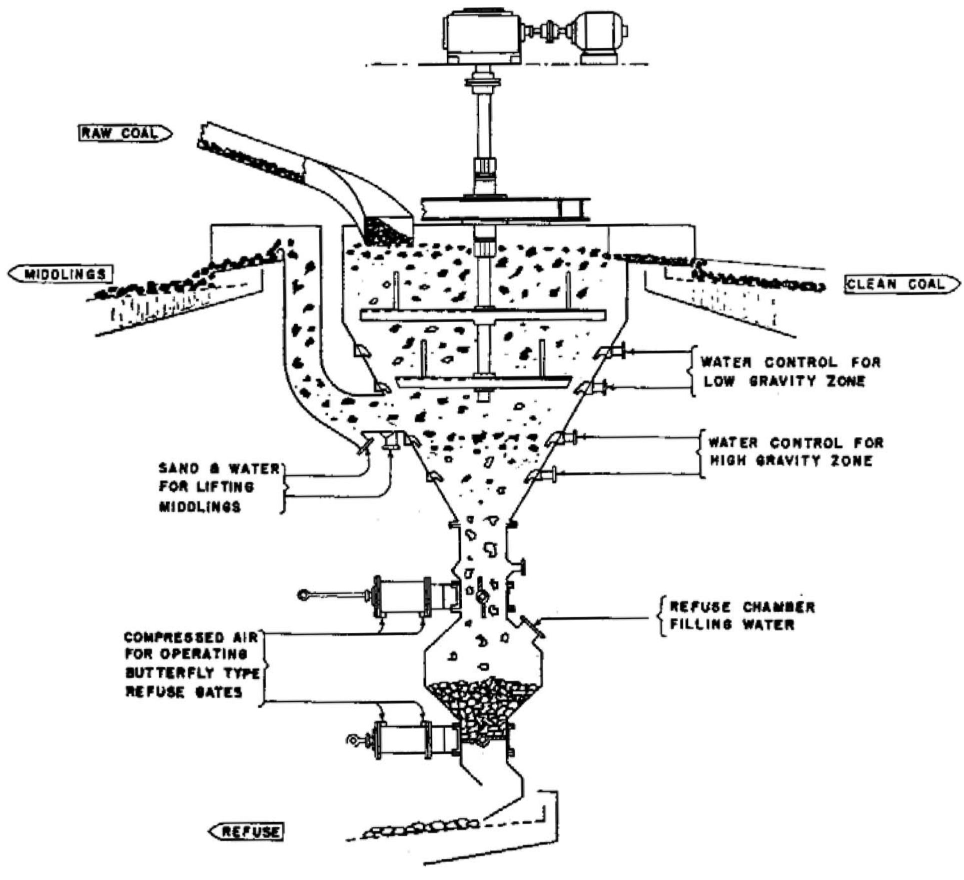

Figure 1. Chance washing cone.
Source: Mitchell, 1950, p. 482. Reproduction by permission of AIME.

In the meantime, an alternative to the Chance system was available, at the Sophia-Jacoba mine which was located near State Mines, just over the border with Germany.[6] The mine had Dutch owners, and among them was the industrial magnate Frits Fentener van Vlissingen. The mine's technical director was Gerard Jan de Vooys, the son of the mine's director. He was a mining engineer who started working at the Sophia-Jacoba mine after obtaining his university degree at the Technical University of Delft in 1925.

Around 1930, the washery of the Sophia-Jacoba mine was no longer able to adequately clean its coal. As a result, the anthracite mine had to sell its coal at a discount. Something had to be done, and De Vooys took up the challenge. Knowing the Chance system, De Vooys developed a new washing installation, named Barvoys, for which he used a suspension based on a baryte-clay mix that was almost identical to the fluid he knew from boring mining shafts (Figure 2).

The Barvoys system included a special washing basin which had a scraper to remove the cleaned coal from the fluid surface (Figure 3). The main advantage was that the suspension was very stable, so that no additional stirring of the suspension was needed to prevent settling of baryte. However, after coal cleaning, the diluted suspension needed to be thickened and the stability of the suspension made thickening in the large thickener basins a slow process. The new Barvoys system was published in Glückauf, a German mining journal, in 1934 (Gröppel, 1934).

De Vooys developed a number of techniques for boring mine shafts and processing and cleaning coal. These patents were licensed via his own company Barywa. Licenses for Germany and Russia had to be arranged via the Sophia-Jacoba company. Through his licensing experiences De Vooys learnt what kind of services to give to his customers. This was different from the attention and care that could be given to the pilot installation of Sophia-Jacoba, where De Vooys himself was always available. Therefore customers' installations should operate with less risk taking: 'companies, which are not subjected to intensive supervision and where the desire to have a trouble free installation does not result in continuous alertness, should not use suspension which is not sufficiently stable' (RHCL, 17.26/30-10, 31/12/1946).

State Mines staff visited the Barvoys washery in August 1933 (RHCL 17.26/03A-310).[7] De Vooys admitted the delegation after they signed a statement that they would not copy his system (RHCL, 17.26/03A-313). After the visit, State Mines decided to buy a licence (RHCL, 17.26/33-199). A Barvoys washery at State Mines

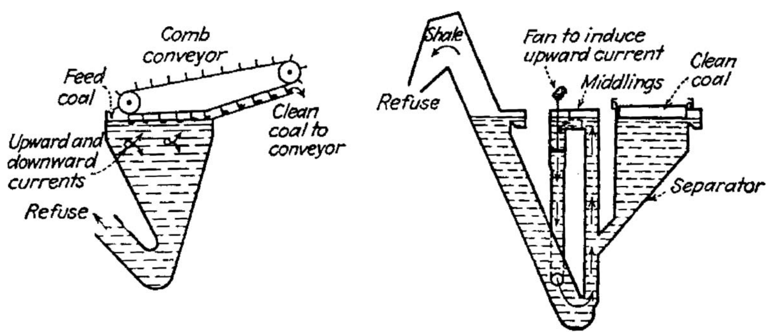

Figure 2. Barvoys process separators.
Source: Mott, 1936 (as cited in Mitchell, 1950, p. 496). Reproduced by permission of AIME.

Figure 3. Sink and float box at Sophia-Jacobs colliery.
Source: Montanhistorisches Dokumentationszentrum/Bergbau-Archiv Bochum, Bestand 175, Sophia-Jacoba GmbH, Hückelhoven (Rheinland).

would facilitate their learning process. Chief engineer Van Vloten explained that: 'for us the value of cooperating with De Vooys was to buy their experiences in order to avoid teething troubles'. De Vooys asked a licensing fee of 0.25% of the value of processed coal. State Mines thought this was too expensive and started negotiating with De Vooys. Because it was important for De Vooys to have a good Dutch reference for his cleaning system, he gave in and in 1936 he accepted the State Mines' offer of a 0.125% fee to build a Barvoys coal washery for the Wilhelmina Mine (RHCL, 17.26/30-10, 27/05/1936).[8]

Not by coincidence, a second alternative system was available near State Mines as well, at Domaniale Mine.[9] In 1932, this mine had a washing problem because of the abundance of flat stones in the anthracite coal, which were hard to remove with their existing washing system. In the same year, the new washery engineer was employed, Klaas Frederik Tromp, who was to oversee and optimise the existing washery and the briquette plant. Before he was employed by Domaniale Mine, Tromp worked for several institutes and companies, like Philips and a gas plant (RHCL, 17.04/2162). Tromp graduated from the Technical University in Delft in 1922, probably in chemical engineering.

When the Domaniale Mine heard of the new Barvoys system, they were immediately interested and a delegation, which included Tromp, visited De Vooys early in 1933.[10] They liked the Barvoys system and asked De Vooys whether he would allow them to build a pilot installation (RHCL, 17.04/2162).[11] De Vooys did not mind, but he asked a licensing fee of 2% of the value of the washed coal, which was very high. Additionally, he asked his visitors to sign a statement that they would not in any way copy what they had seen at the Sophia-Jacoba mine. J.F. Fock, Domaniale's director declined the offer. He also refused to sign the statement, because De Vooys had sent his request after the visit. Then, Fock asked his own engineer Tromp to develop a coal washing system which would be different from the Barvoys. For that purpose a design office and workshop was available. Tromp succeeded, and in September 1933 a patent was requested for the Tromp washing method based on a magnetite or pyrite suspension (Figure 4). Its disadvantage was that, just like Chance's sand-suspension, Tromp's suspension was not stable, so that continuous stirring of the suspension was needed. The first Tromp washer was

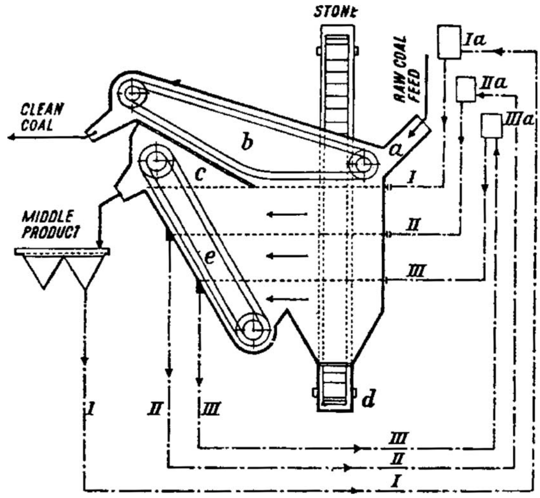

Figure 4. Tromp washer.
Source: Mitchell, 1950, p. 498. Reproduced by permission of AIME.

commissioned in 1937 and built in cooperation with the German manufacturer Humboldt Deutz Motoren AG Köln (De Quartel, 1940, p. 114). The Tromp system was very successful and several installations were licensed (Farrenkopf & Przigoda, 1997, p. 123).[12] Unfortunately, it also became the source of severe disagreement between Tromp and his directors, because they had never clearly agreed who was to be the owner of the patents.

Tromp also defined a method in which calculations for washing results were standardised, so that they could be compared on a curve (Tromp, 1937). This method became a standard tool to determine the maximum possible washing efficiency.[13] It was published in German and English journals.

State Mines was interested in the system and after visiting the Tromp washery it was decided to buy a licence for the Maurits Mine. The licensing agreement for a Tromp washery at the Maurits Mine was signed in November 1938 (RHCL, 17.04/2679).

State Mines did not limit itself to buying licences. It also acquired external knowledge by literature research and study tours and visits. In addition, State Mines conducted a number of experiments in order to gain a better understanding of coal cleaning, so that they could improve on it. Most of these experiments were conducted in the Experiment Station. For example, in May 1934 Driessen experimented with a pilot Chance washery. Instead of a sand suspension, he tried to use a suspension made of middlings.[14]

The knowledge for processing and handling coal is, even nowadays, to a large extent tacit knowledge which has to be gained by doing, trying and having a feel for the matter. Although at first sight solids flow seems very comparable to fluids flow, hardly any formulas for design and prediction are available. Even though the solids can be quite well characterised by density and size, in practice it is problematic, as particle size is dependent on wear, and the latter is difficult to fully predict. As a result, the field of solids handling is very much a field where hands-on experience is required and where troubleshooters are needed to start up installations. Therefore, the need for pilot plants and experiments were associated with the kind of knowledge that had to be acquired and generated. It also required staff with a talent for tinkering and troubleshooting (Figure 5). External knowledge acquisition and internal knowledge building went hand in hand.

As is demonstrated above, these pilot plants also had a second purpose, associated with the experimental status of solids handling knowledge. The only way to convincingly show that a new coal cleaning system worked was to demonstrate this, and this is how De Vooys, Tromp and later State Mines used it as well. So, after tinkering and troubleshooting, the pilot plant staff also needed the skills to demonstrate, in order to transfer knowledge to internal and external customers.

The engineers from State Mines had a preference for the stability of the Barvoys suspension, but they did not like to spend money on buying baryte. Therefore, they looked for a cheaper and easily obtainable alternative. Loess, which was the earth on which the Dutch collieries were situated, seemed a natural choice. The first economic estimate was that loess would be 40 times cheaper than baryte. Driessen did some theoretical modelling of particle properties for suspensions, and decided that loess suited the necessary ratio between the volume of the solid particles and the volume of the suspension (ADSM, Archief Driessen, 08/03/1938). The loess suspension was rather stable so it would not need continuous stirring, but it was sufficiently unstable to allow it to settle faster than baryte during thickening of the suspension (ADSM, Archief Driessen, 08/03/1938; Driessen, 1939b, p. 333).

As the proof was in demonstrating the principle, the engineers first tried the loess suspension in an existing pilot washery (RHCL, 17.26/03A-40).[15] The experiment was successful, so the Experiment Station built a loess pilot installation with a capacity of 40 tonnes per hour in the Emma washery (Figure 6). It was commissioned in May 1937 and from the start it was also used for commercial

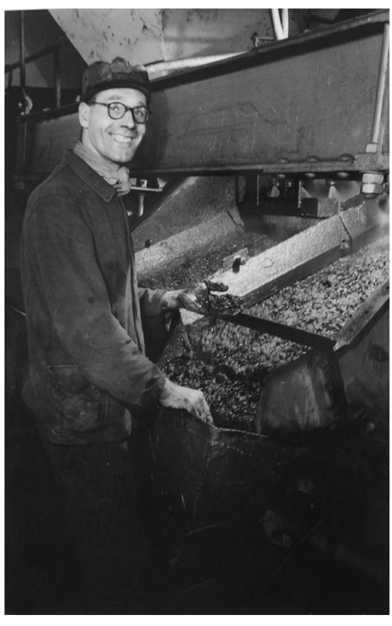

Figure 5. Leeman’s smile indicates that the experiments are going well.
Source: DSM archive.

coal cleaning. A patent was filed for in May 1937 in all coal processing countries, even though the hardware of the installation was very similar to the Barvoys system. That was a problem that State Mines had to tackle after De Vooys complained. First, a special loess washing basin was developed. It had no steep walls like Barvoys and Tromp but was a shallow trough with vertical walls so that it suited the properties of the loess suspension (Figure 7). Then, the problem of suspension thickening needed a solution. For that project, State Mines consulted Dorr, who was the manufacturer of large, electro-mechanically driven thickener basins. In 1938, several samples of the suspensions were sent to Dorr to determine the required basin diameter. In the end, Dorr's advice was much more conservative than State Mines'. Dorr advised a diameter of 10 metres, whereas State Mines concluded that a 7-metre diameter would suffice (RHCL, 17.26/03A-39). In parallel, the Experiment Station also tested improvements on the design of the Dorr thickeners. In the same month, October 1938, Driessen had a brainwave and tried to use a small cyclone as a suspension thickener. A cyclone is a cylindrical vessel with a radial side inlet, a top outlet, and a conical bottom outlet (Figure 8). At that time, it was known as a device

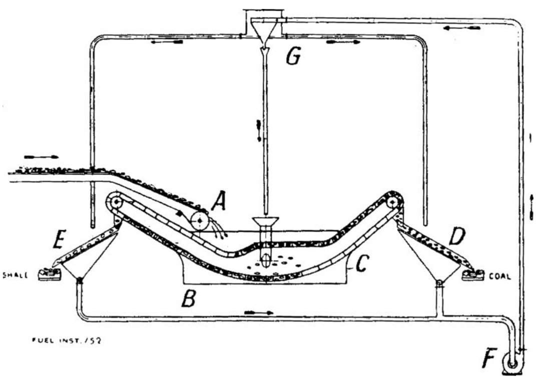

Figure 6. Loess washery.
Source: Driessen, 1939b, p. 334. Reproduced with the kind permission of the Energy Institute.

Figure 7. Trough type washer at State Mine Maurits.
Source: DSM archive.

to purify gases. Due to the geometry, the incoming flow would be centrifuged, so that particles like sawdust and other solids would be removed through the bottom outlet and the clean gas would leave via the top.[16] The advantages were the small size, the lack of electromechanical drive, and the continuous processing (Figure 9).

Cyclones had only been used with gases, but Driessen speculated that a cyclone could also separate particles from liquids.[17] The experiment proved to be right, as it

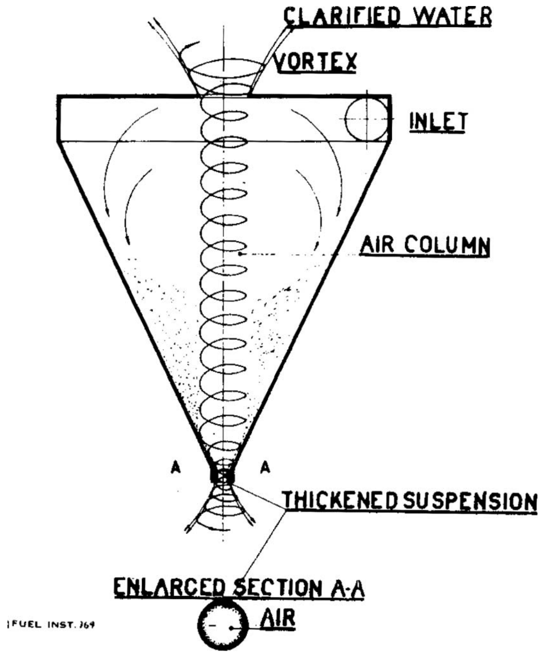

Figure 8. Cyclone thickener.
Source: Driessen, 1939b, p. 336. Reproduced with the kind permission of the Energy Institute.

Figure 9. Cyclone thickener – State Mines thickener in album Driessen.
Source: DSM archive.

turned out to be a great success.[18] Next, the hydrocyclone was installed as a suspension thickener in the loess pilot washery and a dedicated team, consisting of staff from the Experiment Station, the Central Laboratory, the washery and the engineering contractor, optimised the installation (RHCL, 17.26/03A-43) (Figure 10). Furthermore, patents were requested in several countries.

After the success of the loess system demonstration, State Mines decided to build a loess washery at the Maurits Mine (Figure 11). Because it was the first industrial size loess washery, the Experiment Station supported its initial troubleshooting. Jan Leeman, a mechanical engineer who had a polytechnic college degree, was therefore sent to the Maurits washery.

On 4 April 1941, there was a blockage in the washing installation: its filter inlets were blocked by coal fines. Leeman easily found the cause, but he also realised that something very interesting had happened. As a result of the upset, the hydrocyclone had not thickened the loess suspension as it should, but it had carried out another function, one that filled an important need of State Mines. The hydrocyclone had separated coal fines from the suspension, and had therefore functioned like a cyclone coal washer. So, instead of separating all solid particles from water as usual, the hydrocyclone had only separated the finest kind of solid particles: the coal fines (ADSM, Archive Driessen, 17/09/1942).

On 21 July 1942 a patent was requested for the cyclone washer, with Driessen and his staff members Krijgsman and Leeman as the inventors (ADSM, Archive Driessen, 04/01/1943). The patent procedure took a long time, because it was difficult to convince the patent researcher. The main issue was whether the cyclone washer was really different from other separation equipment that used forces which were centrifugally directed. State Mines wrote many letters to the Patent Board

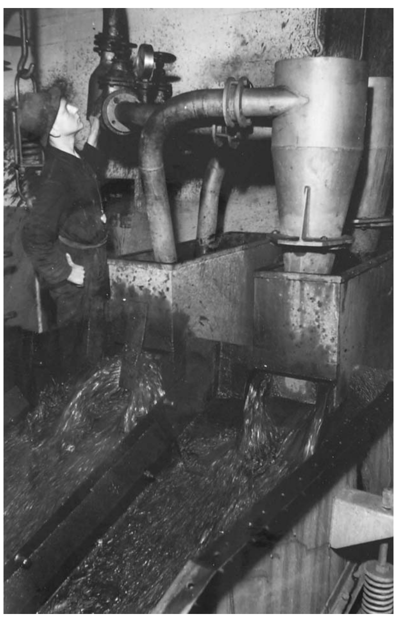

Figure 10. Heynen is reading the inlet pressure of the cyclones.
Source: DSM archive.

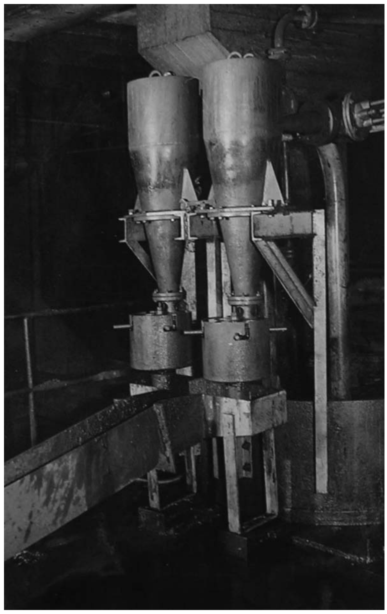

Figure 11. Two thickener cyclones from the trough-type washing installation at the State Mine Maurits.
Source: DSM archive.

(*Octrooiraad*), and agreed that the step from cyclone thickener to cyclone washer was indeed counterintuitive, as it was first used to separate liquids and solids and then to separate two different types of solids in a liquid. Finally, on 19 May 1944, the Patent Board approved the patent.

The discovery of the coal washing effect was truly coincidental, because Leeman had not intended this washing effect all. Nevertheless, it can be argued that because of his coal cleaning development experience and knowledge Leeman was able to notice the washing effect.

In June 1938, after the loess system demonstrations had been successful, State Mines contacted Coppee, its Belgian engineering contractor and supplier, which also had offices in London, Paris and the USA. Coppee's coal cleaning experience dated from the early 1900s, and it had already sold several coal cleaning installations to State Mines. Under strict confidentiality, Coppee was asked whether it was interested in a licence for State Mines' loess system. It was and the result was that in January 1939 a licensing agreement was signed for Belgium, France, England and possibly the Netherlands. Coppee's enthusiastic reaction made State Mines realise 'what the meaning of their own (loess) process was. It is to be expected that our process will fulfil a leading role in the future. Considering the increasing needs of mine companies to better separate their products, it will be possible to make a lot of money and to collect many valuable experiences for our own companies' said Dr Gé Berkhoff, director of the Central Laboratory[19] since 1940 (ADSM, Archive M.G. Driessen, 19/06/1942).

Immediately after the agreement was signed, Coppee requested that prospective customers from Poland and England could visit the loess washery, so that customers could see for themselves how it worked. Therefore, it was a high priority for the State Mines loess team to demonstrate a working loess washery, although they were still very busy troubleshooting the installation, solving excessive wear and plugging problems, optimising dimensions of the equipment, material selection and process control.

Coppee's first priority was publicity, because its loess system licence could only become profitable when customers were aware of the process. Therefore, Coppee arranged with State Mines that Driessen would give a presentation at the Institute of Fuel in London in May 1939. Additionally, the paper about the loess-suspension washing process and the hydrocyclone was published in the Institute's Journal and *The Colliery Guardian*. The presentation was well received and resulted in excited reactions (Driessen, 1939a,b). Especially the miraculously small size and powerful capacity of the hydrocyclone thickener made people curious and enthusiastic (RHCL, 17.26/03A-43).

In his paper, Driessen mentioned that he was surprised by the concentration of regional coal cleaning innovations: 'It is somewhat remarkable that within 15 miles of one another, three different washing processes using suspensions have been developed by Netherland engineers' (Driessen, 1939b, p. 327). However, considering the knowledge flows this regional synergy was not a coincidence. On the contrary, it was the location that explained and caused the result of easy knowledge flow, because Tromp and Driessen followed their neighbour-pioneer De Vooys.

It could be argued that the invention of the hydrocyclone was a coincidence, as it was not a planned development. However, State Mines built up R&D capabilities with the expectation that the company would acquire, transform and generate knowledge, so it was a desired result, although it had never been planned for.

Because of the political developments, De Vooys had to leave Germany in September 1939, when the Germans took over control of the Sophia-Jacoba mine. In 1937, De Vooys confronted Domaniale Mine with its infringement of his patents (RHCL, 17.04/2679 Documents 1938–1941). As Domaniale Mine refused to settle, De Vooys began proceedings against Domaniale's patents. Finally, both parties agreed to stop the lawsuits. Despite the earlier disagreements, De Vooys approached Domaniale Mine again in July 1941. He discussed whether they could cooperate, as their licensees Wedag and Humboldt had already drafted an initial agreement. In the end, it was not feasible to merge their licensing activities. De Vooys' licensing fees were three times higher than the licensing fees for Tromp's system, which made it unattractive and too complicated to renegotiate with the existing licensees. Therefore, De Vooys became more interested in cooperating with State Mines. He also thought State Mines' excellent R&D facilities would support licensing activities well, and he had to act fast, because his main patents would not last very many years, just until about 1947 (RHCL, 17.26/51-38, 29/10/1946).[20]

In the same period, in June 1942, one month before the washing cyclone patent request was sent to the Patent Board, State Mines organised a meeting to discuss its coal washing plans. This meeting was the kick-off for State Mines' own 'company for the exploitation of patents', which became licensing company Stamicarbon (RHCL, 17.26/21B-116).[21] It was thought that Stamicarbon would have a better market position if it could sell licences of all three Dutch float-and-sink processes. This would stop them from competing with each other via their engineering contractors and it would also protect the Dutch interests. As a consequence, Kleinbentink, one of State Mines' chief engineers, approached the Domaniale Mine and De Vooys. Domaniale Mine was not interested, probably because the dispute with Tromp had flared up again. Therefore, De Vooys was the only candidate left.

However, Driessen advised against cooperating with De Vooys, because he thought that De Vooys' position as a coal cleaning pioneer was past and he might even hamper State Mines research (ADSM, Archive Driessen, 05/07/1942). But Driessen was not able to convince his directors, which made him feel that his coal cleaning inventions were unrecognised. As he also had trouble with State Mines' internal politics and rigid hierarchy, he eventually left State Mines and emigrated to the United States in 1948, where he licensed and developed hydrocyclones as an independent consultant.

State Mines continued negotiating with De Vooys and the final agreement was signed in August 1946 (RHCL, 17.26/30-10, 29/5/1947). He had already drafted a working scheme to coordinate and organise licences to engineering contractors in various countries. For his company Barywa the German Wedag was the house engineering contractor, for State Mines it was Coppee. However, the new Stamicarbon should preferably have one licensee per country. Therefore, several meetings with the contractors were organised, in order to reorganise the licences. Finally, Stamicarbon was established in July 1947 (Excerpt Chamber of Commerce, 1947).

Stamicarbon still exists and celebrated its sixtieth anniversary in 2007 (Smith, 2007). It is now only licensing technologies related to chemical plants and processes. Since its establishment, it has licensed 185 float and sink coal washeries and 685 cyclone washers; 450 of the 685 cyclones were used in the coal industry, 232 were for ore washing plants and 3 for recycling plants. Stamicarbon kept its focus on research, development, and worldwide start-up assistance, whereas sales and engineering activities were carried out by engineering contractors.

When in the 1960s State Mines abandoned coal mining and transitioned to become a bulk chemicals manufacturer, coal cleaning research was also stopped. The result was that solids separation and processing licensing activities decreased. Coal and solids handling activities were stopped in 1989, when the last coal cleaning start-up engineers retired.

Recapitulation and concluding remarks

The coal cleaning innovations at State Mines illustrate how absorptive capacity was of prime importance for its innovative capacity. External knowledge acquisition as well as internal knowledge building proved to be relevant, although the balance changed over time. The case even shows how during the first phase of the process acquisition and assimilation of external knowledge (*potential absorptive capacity*) were essential to improve the existing coal cleaning processes. These innovations can be labelled as more incremental in nature. While for real improvements in coal cleaning the transformation of knowledge at State Mines was essential and by developing a licensing company State Mines proved to be able to exploit this knowledge.

State Mines had, to use the words of Zahra and George (2002), not only *potential absorptive capacity* but also *realised absorptive capacity*. In this respect it was important that State Mines was always well aware of its lack of capabilities and knowledge and was open to searching for and learning from knowledge/experience outside its firm boundaries.

Initially mainly the transfer of knowledge from outside the company boundaries contributed to adjustment of the knowledge and expertise base. During these years most attention was paid to trouble shooting and problem solving to improve existing production processes. State Mines' management and staff tapped into a wide variety of knowledge sources to improve coal cleaning systems. Externally, foreign and national knowledge was used. Internally, experiments were conducted and production size facilities were built on a licence. Experiment Station staff were involved in study visits and troubleshooting, so that they transferred knowledge within the organisation. The two licences for coal cleaning systems of Dutch coal mines nearby were most critical for State Mines' developments (Figure 12).

After State Mines' staff had assimilated this knowledge, they enhanced their knowledge base and were able to develop their own variation of a suspension coal cleaning system: the loess washing system (1938). This development took place in the Experiment Station, which had been established in 1929 in order to increase State Mines' R&D capabilities. The Experiment Station was a location where knowledgeable and experienced staff were available and developed. This facility was important because a significant part of coal cleaning knowledge is of a tacit nature, and in it both formal development experiments and creative exploratory experiments were conducted. The former resulted in the loess washing system, the latter resulted in the hydrocyclone thickener (1938). Later it was discovered by accident that the hydrocyclone, a small apparatus in comparison to the large cleaning basins, could perform as a washing device (1941).

The coal cleaning innovation results made State Mines realise that this knowledge could be marketed to many mining companies. In order to facilitate these knowledge flows, licensing capabilities were developed. For marketing and strategic reasons, it initially tried to include the two competing Dutch systems. In the end, only De Vooys joined Stamicarbon. State Mines was well aware of its limitations in licensing. The company kept to coal cleaning innovation and operation and troubleshooting knowledge. For engineering and manufacturing capabilities it worked with engineering contractors who would conduct all engineering and marketing activities, and who maintained relations with manufacturers and suppliers.

The case also illustrates that the knowledge source and kind of acquired knowledge were closely related, with regard to its level of specificity, tacitness as well as the content (technical or market related). For example, next to licensees' support from the licensor, tacit knowledge of existing coal cleaning systems was necessary. Moreover, the importance of the various knowledge sources and the acquired knowledge was also not the same for the various phases of the innovation process. This is illustrated by the early acquisition of licences, whereas later the Experiment Station was the vehicle for knowledge generation. After that, engineering contractors were needed to be able to license to other mines. Codified knowledge – mostly via licence contracts – from competitors was essential for State Mines to achieve product development. While personal contacts and flows of knowledge were also used by State Mines, it was State Mines' R&D capabilities that resulted in internal developments and knowledge generation which led to its own licensing company. Finally, we have to realise, however, that a sharp demarcation between sources that offer general as well as more specific information cannot be made. De Vooys offered both general codified and specific tacit knowledge on the basis of a licensing agreement.

Finally, the case of State Mines illustrates that expectations determined – directly as well as indirectly – the search for external knowledge. To optimise coal cleaning,

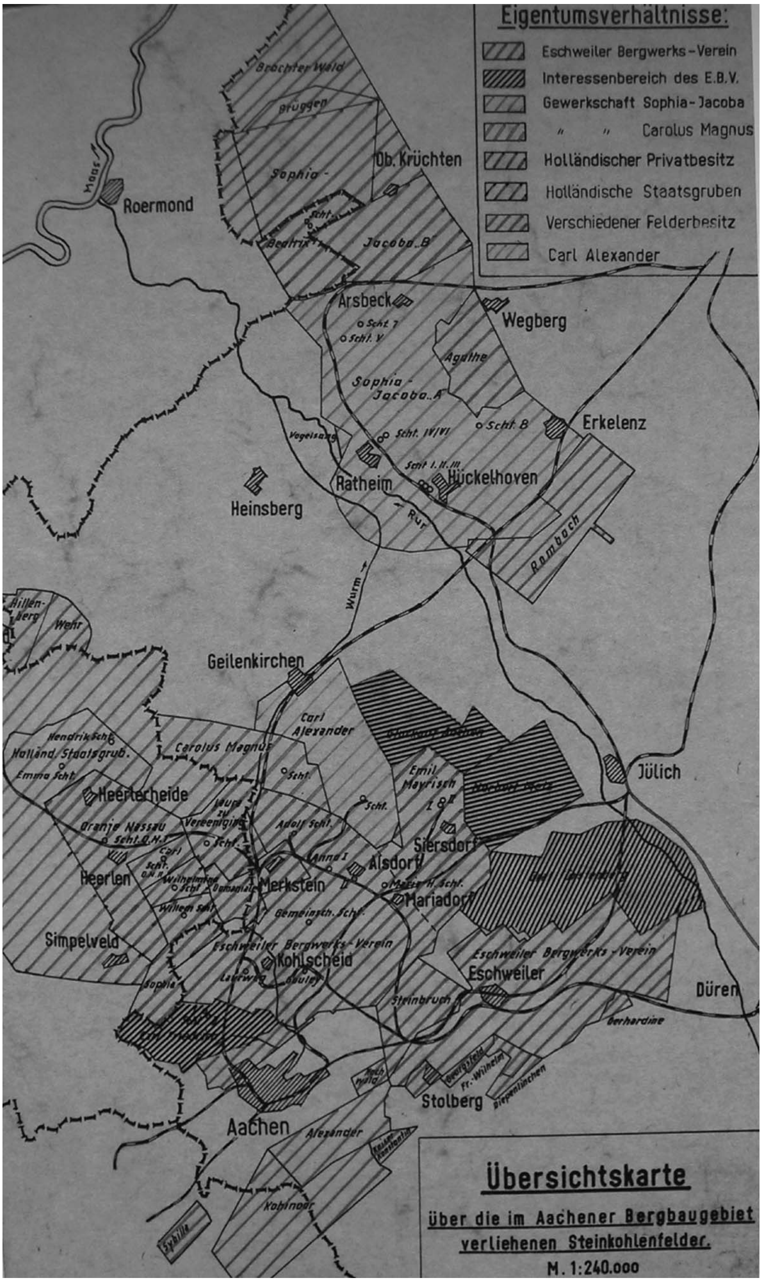

Figure 12. The region of the three mines: State Mines (Emma, Hendrik), north of Heerlerheide, the Sophia-Jacoba mine at Huckelhoven, and the Domaniale Mine east of Heerlen.
Source: Farrenkopf & Przigoda, 1997, p. 11.

management and staff scouted for the best methods available by doing broad searches and acquired necessary licences. The support from engineering contractors was essential to expand its activities and develop a licensing company. State Mines' licensing company Stamicarbon was very successful and it still exists. Today Dutch State Mines is no longer a coal mining company, but a chemicals and biotechnology company named DSM. Its history provides us with an important example of how capabilities are not technology dependent but transferable at a micro-economic level.

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Notes

1. The literal translation of *Staatsmijnen* is State Mines and will be used in this article. *Staatsmijnen* named itself *Dutch State Mines* in English. When the transition to the chemical industry was made, it was renamed DSM, as it is still known today.
2. According to Lane, Koka and Pathak (2006), who analysed almost 200 articles in this field, a major shortcoming of the literature on absorptive capacity is the limited attempts to revise and expand Cohen and Levinthal's (1990) original definition.
3. One of the shortcomings of the studies on absorptive capacity as signalled by Lane et al. (2006) is the lack of attention paid to the process by which absorptive capacity is developed. They find this very surprising because they stress that Cohen and Levinthal's (1999) view of the construct clearly encompasses the need to understand the dynamics within the organisation that could lead to the ability to recognise, assimilate and utilise useful external knowledge (Lane et al., 2006).
4. Van Lente (1993) calls these levels specifications, functions and scenarios.
5. This is a quote from 1 Thessalonians 5:20–22, 'Put all things to the test, keep what is good and avoid every kind of evil.' However, apostle Paul is not asking Christians for evolutionary innovation, but to test their beliefs in order to only keep the good.
6. The exploitation of the Sophia-Jacoba mine started in 1912. For the history of the Sophia-Jacoba mine and some background on coal cleaning development, see Farrenkopf and Przigoda (1997).
7. A number of follow-up visits were conducted, for example on 20 January 1934, 2 August 1935.
8. This washery had to process anthracite.
9. Coal exploitation in the area of Domaniale Mine started around 1115. In 1715 it produced 150,000 tonnes coal per year with 800 miners.
10. The visit was conducted before 14 March 1933. RHCL, 17.04/2162, Opmerkingen betreffende conclusie van ir. Tromp dd. 30.12.1949, 19.1.1950.
11. Reference is made to a letter which Domaniale Mine sent to Gewerkshaft Sophia-Jacoba, 14 March 1933 (RHCL, 17.04/2162).
12. The Tromp system was so successful that in the 1980s Sophia-Jacoba's new washery used a Tromp magnetite suspension instead of the De Vooys baryte-clay suspension.
13. For example, State Mines used it to evaluate the performance of its washeries.
14. This was later developed into another State Mines washing system.
15. This pilot installation was actually a Chance sand-suspension washing installation. This test was communicated by State Mines with De Vooys during a visit.
16. Probably State Mines also used cyclones for gas cleaning. But references are unclear or not dated.
17. Before Driessen, the paper industry had already experimented with cyclones and liquids, as patents show (1937).
18. In hindsight Driessen was lucky that he first tried the cyclone with a loess suspension. When the cyclone was tried with a baryte-clay suspension, it appeared that the baryte particles were too small to be separated (Driessen, 1939a, p. 931).

19. The Central Laboratory included the Research Department since 1940.
20. Argued by De Vooys to the Commissarissen of Barywa.
21. In October 1942 a contract was drafted to make it possible for State Mines to exploit coal cleaning licences.

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