

# Tolerating the intolerable: Flash smelting of copper and the construction of technological constraints

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Janne M. Korhonen

Aalto University

[jmkorhonen@gmail.com](mailto:jmkorhonen@gmail.com)

## Introduction

Just before New Year's eve in 1944, Eero Mäkinen, the managing director of small Finnish copper producer Outokumpu sat down to pen a letter that instructed his staff to begin developing something the world had never seen before.<sup>1</sup> In the letter, Mäkinen warned that Outokumpu's single electric smelting furnace might not be able to serve the company for much longer due to lack of reliable electricity supply. He also noted cursorily that the obvious alternative, smelting Outokumpu's ore with heat generated from fossil fuels, would also be problematic since it would make the smelter dependent on imported coal. In conclusion, he devoted most of the letter detailing the staff to look into a novel alternative: smelting copper using heat liberated from burning the ore itself.

Only four years later, this line of inquiry resulted to Outokumpu being the first copper smelter in the world to adopt so-called "flash smelting" practice for commercial use. In this practice, the energy required came from burning sulfur, a component of common copper ores. In principle, the method did away with the need for extraneous energy, an improvement so radical that even today, variations of this process produce the majority of world's primary copper.<sup>2</sup> A narrative well entrenched in the history of metals and mining industry suggests that this innovation resulted from a constraint imposed by the electricity shortage in post-war Finland: Outokumpu simply had no other options and was therefore compelled

<sup>1</sup> Letter from Eero Mäkinen to John Ryselin, 30.12.1944. Folder Kirjeenvaihto 1944 A-U, K31 (OKA). Sources and explanations for abbreviations in parenthesis are found in the Bibliography.

<sup>2</sup> Moskalyk, R. & Alfantazi, A. Review of copper pyrometallurgical practice. Also author's interviews with successor company Outotec personnel.

to invent something radical — or to perish.<sup>3</sup> Seemingly, the intolerable constraint had radically shaped an entire industry for decades to come.

But how intolerable this constraint actually was, and how the constraint itself became a constraint? In this article, I extend the work of earlier historians by examining in more detail the birth of flash smelting and the question "what makes constraint a constraint?" I argue that as far as they influence technological change, even supposedly inflexible physical constraints, such as lack of coal seams in Finland, are to a large extent social constructions.

Evidence presented in this paper suggests that instead of being forced to make a breakthrough and then miraculously realizing it, Outokumpu in fact had at least three other credible alternatives at its disposal. Furthermore, any of these could have been argued to be prudent and possibly even *more* prudent choices for a company in Outokumpu's position. Finally, I present evidence that what was seen as a supposedly intolerable constraint in 1944-45 had been seen as an entirely tolerable necessity only some years earlier, and that this shift in opinion had more to do with changing perceptions of the feasibility of different technological alternatives than with actual changes in Outokumpu's operating environment. The evidence suggests that many, though certainly not all, of the constraints constraining our choice of technological systems contain a significant socially constructed component.

The presence of a socially constructed component within perceived constraints implies that constraints could be renegotiated, at least to an extent. In this case, even a supposedly unyielding constraint, lack of energy supplies in Finland, turned out to be a quite malleable concept in reality. Whenever the desired technology so required, this constraint was renegotiated, downplayed or entirely ignored, only to resurface as a somewhat *post hoc* rationalization for decisions already made. Likewise, when the needs must, even the intolerable may turn out to be surprisingly tolerable after all.

Studying constraints and how they are used in rhetoric about technology is an important topic for technology studies for at least two reasons. First, much of the history of technology tells us that physical constraints, such as availability and cost of components, raw materials or labor, have greatly shaped the evolution of technology. With the rise of social study of technology, we have learned that mental constraints, such as accepted frames of reference, matter as well. Concepts such as constraints have an important role in helping to explain questions such as the extent

<sup>3</sup> For examples, see the histories of Outokumpu and flash smelting such as Annala, V., *Outokummun historia 1910-1959*; Kuisma, M., *Outokumpu 1910-1985*; and Särkikoski, T., *A Flash of Knowledge*. For similar narrative from an outsider, see e.g. Habashi, F., *History of metallurgy in Finland: the Outokumpu story*, and Habashi, F., *The Origin of Flash Smelting*.

of technical variation, the emergence of dominant designs, the rate and direction of technological change, and occurrences of technological discontinuity. However, few if any studies so far have attempted to explore the nature of constraints themselves. As far as their effects on technological change and the evolution of technology have been studied, they have been largely treated as exogenous factors that affect technologists either as physical constraints (e.g. lack of specific resources) or as mental constraints (“thinking inside the box”).<sup>4</sup>

Second, examining the nature of constraints is meaningful not only for historians but for the world as a whole. We live in a time when both technological systems and constraints are abundant. From regulatory and sociopolitical limitations to diminishing raw material availability, rising energy prices and the growing awareness that some waste sinks such as the atmosphere are not unlimited after all, our choices for technological systems and their components are heavily influenced and constrained by factors other than engineering or economics.<sup>5</sup> Although one could argue that ultimately all the constraints can be reduced to economic ones, this reductionist approach loses much of interesting and relevant detail. For example, the mechanisms through which social and raw material constraints impact on technological systems and their development can be quite different.

The literature on the history of technological systems is rife with examples of constraints affecting technological development, from how gasoline shortages altered the design of automobiles to how raw material constraints pushed jet engine designers in Second World War Germany to come up with radical engine innovations.<sup>6</sup> Unpacking what these constraints actually mean and how they become constraints would advance our understanding of the constraints we increasingly face and truly need to overcome – and what constraints we might be able to renegotiate and reconstruct with social and rhetorical tools. These tools, in turn, are more powerful if we have analyzed and understood what makes a constraint, and how the constraints are constructed. In the end, my paper seeks to remind us that when technologists argue that their choices are constrained by

<sup>4</sup> For examples, see e.g. Gibbert, M., & Scranton, P., Constraints as sources of radical innovation? Insights from jet propulsion development; Hoegl, M., Gibbert, M., & Mazursky, D., Financial constraints in innovation projects: When is less more?; Weiss, M., Hoegl, M., & Gibbert, M., Perceptions of Material Resources in Innovation Projects: What Shapes Them and How Do They Matter?

<sup>5</sup> I use the term “technological system” in the sense of “open sociotechnical systems” in Hughes, T. P., *Networks of Power: Electrification in Western Society, 1880–1930*.

<sup>6</sup> For automobiles, see Hughes, T. P., *American Genesis*; for jet engines, Gibbert & Scranton, *Constraints as sources of radical innovation?*, Giffard, H. S., *Making Jet Engines in World War II*, and Constant, E. W., *The Origins of the Turbojet Revolution*.

certain factors, critics and historians should keep in mind that these constraints may in fact turn out to be significantly more malleable and ambiguous than the technologists themselves may acknowledge, even in confidential communications.

The story of Outokumpu's changing constraints and the development of flash smelting is also a dramatic and fascinating story in itself. It has not received much attention in the literature on the history of technology and is almost unknown in the English-speaking world. The case is also an example of rarely studied birth of a process innovation and provides a privileged view to a period of rapid change in otherwise relatively slow-moving industry. I therefore believe that the study can be useful to students of other settings and eras as well.

## Background: Outokumpu and technonationalism in pre-war Finland

Finland, a country straddling the Arctic Circle and in the 1930s a home to some 3.6 million people, is not often noted in the annals of mining and metallurgy. Despite a history of small-scale mining dating to early 1500s and governmental efforts between about 1830 and 1850 to promote domestic metal sources, by the turn of the 20th century practically all mines in Finland had ceased to operate. Finland's limited and diminishing deposits could only support small-scale metallurgical industries, which were out-competed by newer methods favoring mass production. Against this background, in a country where four out of five people were employed in agriculture or forestry<sup>7</sup> a fortuitous 1910 discovery of a rich copper ore deposit under Outokumpu ("strange hill") in eastern Finland did not self-evidently lead to the eventual development of a major process innovation.<sup>8</sup>

Since the ore body had been found by employees of the government's Geological Survey, its legal ownership was initially shared between the government and the landowner. The Hackman trade house, which had purchased out other landowners in the area, did express interest in gaining total control of the deposit, but the government, realizing the importance of the discovery, adamantly refused to relinquish control to private interests before the full value of the deposit was firmly established and appropriate royalties could be determined. The question that would

<sup>7</sup> For Finnish economic history, see Hjerppe, *Suomen talous 1860-1985*, particularly p. 59.

<sup>8</sup> The overall history of Outokumpu is drawn primarily from Kuisma, M., *Outokumpu 1910-1985*, and Annala, V., *Outokummun historia 1910-1959*. For Finnish mining history, see e.g. Poutanen, P. *Suomalaisen kuparin ja sinkin juurilla: Orijärven kaivos 1757-1957* (the history of Orijärvi copper mine); ; Nordström, W. E., *Svartå Bruks Historia* (the history of Svartå ironworks); histories and statistics of Finnish mining industry published by Geological Survey of Finland, particularly statistic "Finland's mines 1530-2002".

continue to shadow many subsequent discussions and decisions about Outokumpu for the next two decades was how the enterprise should be organized, and who should take charge. Fundamentally, the issue could be boiled down to a relatively simple question: would the wealth under Outokumpu be best exploited with the aid of foreign investors and technological expertise they could bring, or should the Finnish government seek to develop necessary expertise nearly from scratch while building up the investments required?

While the original plan had been to contract only copper recovery expertise from abroad, continuing problems with the selected recovery method and the unwieldy ownership structure led to a brief 1917-1920 interlude where Outokumpu was rented to the Norwegian developer of the method. The collapse of this venture in the aftermath of post-war slump in metal prices, Outokumpu's continuing financial difficulties and the government's desire to shut out foreign "speculators" eventually led to the mine's nationalization in 1924, with Eero Mäkinen (1886-1953) as the managing director. Mäkinen was a geology PhD with mining engineer's training and had proven his loyalty to the new Finnish state as a volunteer White Guard officer during Finland's brief but bloody civil war in 1918. He had originally been selected as state-appointed "controller" or overseer of Outokumpu in 1918, and named managing director in February 1921. After 1932, the unwieldy ownership structure was finally clarified as Finnish state-owned companies were reorganized into joint stock companies. These were to be operated outside direct political control and "according to commercial principles", even though the government retained practically all of the shares.<sup>9</sup>

Outokumpu's status as nationalized company came to play an important role in the development of flash smelting, and therefore a brief digression is in order. The clash between proponents and opponents of nationalization illustrates the different perceptions about technology, industry and the state, and the sometimes competing tensions inherent within Outokumpu and state enterprises in general. During the period, the amalgamation of interactions between engineering and nationalism had engendered a form of "techno-nationalism" <sup>10</sup> whose proponents competed with (generally) more conservative proponents of small state and more *laissez-faire*

<sup>9</sup> For the history of Finnish state-owned companies, see Kuisma, M. *Valtion yhtiöt: nousu ja tuho* (State enterprises: their rise and fall).

<sup>10</sup> E.g. Fridlund, M., & Maier, H., *The Second Battle of the Currents: A Comparative Study of Engineering Nationalism in German and Swedish Electric Power, 1921- 1961*; Waqar, S., & Zaidi, H., *The Janus-face of Techno-nationalism: Barnes Wallis and the "Strength of England"*, and Hecht, G., *The Radiance of France*. For a discussion of the mentality and values of period's Finnish engineers in particular, see Michelsen, K.-E., *Viides sääty. Insinöörit suomalaisessa yhteiskunnassa*; see also discussion of state-owned companies and their role in Kuisma, M., *Valtion yhtiöt: nousu ja tuho*.

economic policies. Meanwhile, techno-nationalism allowed even staunch political conservatives such as Eero Mäkinen to find allies from the political Left, as the latter usually supported nationalization of important industries as a matter of principle. As Fridlund and Maier have noted in their work on techno-nationalism, the term “nationalism” refers here to the word’s anthropological meaning of “conscious or unconscious beliefs concerning membership of a larger nation,” not just the narrow political-ideological meaning.

In the end, the nationalization can be interpreted as a victory for techno-nationalistic elements within Outokumpu and Finnish government, personified in Outokumpu's managing director Eero Mäkinen, and as a defeat for *laissez-faire* economic policy and for those who doubted whether Finland held resources and expertise needed to run a successful mining business. Alongside many other Nordic engineers, Mäkinen undoubtedly shared the then-common notion of technological progress as a nation-building tool, particularly valuable in the still mostly agrarian and relatively poor Finland. Therefore, while economic efficiency might have suggested the mine to be rented out to foreign experts, nationalistic considerations and visions of the future required another approach.

Mäkinen's view, which he justified by his experiences during the "Norwegian period" (1917-1920), was that foreign ownership would lead to the mine being emptied rapidly and ineffectively and the ore transported elsewhere for smelting and refining. In contrast, nationalization would ensure that copper and sulfur in Outokumpu's ores would help build Finnish industry while maximizing the overall benefits to society. Furthermore, Outokumpu's ore was seen to hold strategic importance: in case of another European war, copper would be needed for cartridge cases and sulfur for paper mills, fertilizer, and the manufacture of explosives.<sup>11</sup>

Meanwhile, stability brought by nationalization and improving financial situation had allowed Outokumpu to proceed with its expansion plans. In 1929, the mine, whose output had been as little as 5 200 tons of copper sulfide ore in 1921, exceeded 100 000 tons of annual ore production, and in 1931, 156 000 tons were mined, yielding about 6400 tons of copper. This sufficed to put Finland on a map as an important European copper-producing country, even though Outokumpu's share

<sup>11</sup> For Mäkinen's views, see e.g. memorandum of AB Outokumpu Oy's operations at Outokumpu, E. Mäkinen 12.12.1919, folder O18 A4 1918-1925. EDA; Copy of letter draft from Eero Mäkinen to cabinet minister K. Järvinen, undated (likely April 1928), folder EM-lausunnot O26 A4 1928. EDA. Mäkinen's long-held techno-nationalism features very prevalently in e.g. his obituary by his long-time friend, professor Eskola, *Eero Mäkinen: Memorial Address*. For broader aspects of nationalization, see Kuisma's history of Outokumpu.

of European production in 1931 was just short of 4 percent.<sup>12</sup> In the late 1920s and early 1930s, Outokumpu collected almost all of its revenue from exports of ore concentrate. However, Mäkinen worked hard to persuade Finnish pulp and paper mills to replace their sulfur imports with sulfur dioxide produced by treating Outokumpu's ore. Between 1932 and 1935, most Finnish pulp mills did indeed take up the offer, buttressing Outokumpu's national significance as a supplier of vital ingredient to wood and paper industries, the nationally acknowledged backbones of Finnish industrialization.<sup>13</sup> These interdependencies, combined with Outokumpu's financial success in the 1930s and Mäkinen's forceful promotion of growing Finnish mining and metals industry, secured Outokumpu an important position within Finnish economic life.<sup>14</sup>

However, turbulence due to Great Depression and the crash of copper prices put Mäkinen's grand plans temporarily on hold. From early 1920s, Mäkinen had lobbied vigorously for a domestic copper smelter and refinery. In modern terms, he wished to maximize the value added to Outokumpu's ores in Finland, as a part of his conviction that this "national treasure" should benefit Finland as much as possible. The old, inefficient copper refinery had been closed down in 1929, and planning for a new smelter, to be completed by 1933, commenced immediately. Building, however, would require funding from the owner – the government. Even though the Economic Defense Council, the government body responsible for the oversight of strategic industries and materials, strongly supported the project and wanted it to proceed as rapidly as possible, the economic downturn had drained the state's coffers. Since private Finnish investors were not forthcoming, and because Mäkinen perceived the smelter to be too important to be left to foreign investors, government's refusal in 1931 left Outokumpu and Mäkinen with little choice but to shelve the project for the time being. It should be emphasized that the decision to exclude foreign investors was Mäkinen's to make. In 1932, Finnish government even suggested that the smelter should be financed with foreign loans, and a consortium of French investors offered precisely such a loan, only to be rebuffed by Mäkinen.<sup>15</sup>

<sup>12</sup> Production figures from Outokumpu's annual reports in PKA. International statistics from Julihn, C. E., & Meyer, H. M. (1933). Copper. In O. E. Klessling (Ed.), *Minerals Yearbook 1932-33* (pp. 27–52). All figures in metric tons.

<sup>13</sup> According to Hjerppe's economic history of Finland (p. 143), forest industry products comprised up to 85 percent of Finland's exports during the 1920s and 1930s.

<sup>14</sup> See e.g. Hjerppe, and also Kuisma's treatise on Finnish state-owned companies.

<sup>15</sup> Annala, pp. 275-276.

## Interlude: the technology of copper

In hindsight, the delay may have been a boon to Outokumpu. In 1929, there were two fundamentally different technologies for wresting copper from the ore. In the relatively novel hydrometallurgical method, copper could be leached from the ore using sulfuric acid and then electrolytically separated from the solution. This method had been used at Outokumpu's old refinery, but scaling and modifying it to meet the demands of increased production and the desire to separate more valuable metals from the ore presented significant challenges. For a company in a hurry, whose financial position was precarious, and which lacked technical expertise to develop novel methods, the risks of going so far beyond "entirely mature standard operating procedures" were unacceptable. As it turned out, even today hydrometallurgical methods remain problematic for copper sulfide ores of the type found at Outokumpu.<sup>16</sup>

The "standard procedures" Mäkinen had in mind involved smelting, that is, separating valuable metals by heating the ore. In 1929, the general consensus visible from contemporary discussions was that all these pyrometallurgical methods required plentiful external energy sources, such as fossil fuels or electricity. Of numerous different pyrometallurgical methods, Mäkinen considered seriously only the most mature one, coal-fired reverberatory smelting. To this end, he commissioned a German smelter builder Krupp-Grusonwerk for a preliminary design for a plant. However, as Finland lacked domestic fossil resources, reverberatory smelting would have been dependent on imported coal. This was a clear drawback in Mäkinen's plans, and in various memoranda he tried to soften the issue by arguing that if "war emergency" prevented coal imports, proposed copper furnaces could nevertheless be run with domestic firewood.<sup>17</sup> Foreign experts who reviewed the plans reinforced Mäkinen's case: under the circumstances, reverberatory smelting was "undoubtedly the correct method".<sup>18</sup>

<sup>16</sup> A thorough discussion of pros and cons of the various alternatives, and Mäkinen's reasons for rejecting hydrometallurgy, can be found from a memorandum "Uusi kuparitehdas, P.M. 16.12.1929" ("New copper factory"), folder EM-lausunnot O26 A4. EDA. See also a book written by Mäkinen, *Vuoriteollisuus ja metallien valmistus* ("Mining industry and manufacture of metals"); and other contemporary copper metallurgy manuals.

<sup>17</sup> Aside from aforementioned 1929 memorandum, this argument is made again in two separate memoranda addressed to government's Economic Defense Council, dated 5.2.1930 and 21.3.1930. Folder EM-lausunnot O26 A4. EDA.

<sup>18</sup> The quote and details of Krupp-Grusonwerk's plans are from two external reviews by consulting engineers Palén and Münker. In folder Uusi kuparitehdas 1929-1933. EDA.



Interestingly, just some years before Mäkinen had argued the exact opposite. In a memorandum from 1925, he had flatly stated that the dependence on coal meant that "the use of reverberatory furnace cannot be contemplated [in Finland]."<sup>19</sup> The principal reason for this flip-flopping was a change in the expectations of technological feasibility, brought about largely by nationalistic considerations. The 1925 plans stipulated a small operation where limited quantities of copper would be extracted with previously used hydrometallurgical methods without resorting to smelting at all. In contrast, the 1929 plans sought to expand production with a significantly larger plant that could also recover other metals, particularly strategically important iron, as byproducts. This would not be possible with hydrometallurgy.

However, there were no purely commercial reasons that necessitated a smelter of any kind. Outokumpu could well have operated a small-scale copper extraction business for meeting a part of domestic consumption while exporting most of its copper ore concentrate, or even concentrate on very profitable ore exports only, but in 1929, these no longer fit Mäkinen's vision of Outokumpu as a linchpin of Finnish metals and chemicals industry. If the Great Depression hadn't intervened, it seems very likely that Mäkinen would have obtained the funding and proceeded with reverberatory smelting. As it happened, the delay allowed Mäkinen some time to think about the alternatives.

Surviving records and extant histories do not tell precisely when Mäkinen began to question the commitment to reverberatory smelting, but soon after government's negative funding decision he asked Finnish engineer K.E. Ahola, who was pursuing his PhD studies in Germany with a stipend from Outokumpu, to study the possibility for smelting Outokumpu's ore with electricity.<sup>20</sup> Electric smelting had been practiced since late 1800s in some rare locales endowed with plentiful hydropower reserves.<sup>21</sup> As Mäkinen and Ahola saw it, the method offered certain benefits over reverberatory smelting, including better control over metallurgy and pollution and possibly more economical operation, provided that electricity could be obtained cheaply enough. Since 1921, a potential source of such power had been under construction at Imatra, near the Soviet border and close to the preferred location for the smelter. Its first three turbines were completed in 1929, but even though the

<sup>19</sup> Memorandum by Mäkinen, "Muistio Outokummusta 13.2.1925." See also memorandum "Outokummun kehityksestä ja sen tuotannon lisäämisestä," dated 25.10.1923 (Of Outokumpu's development and increasing its production). Folder O18 A4 1918-1925. EDA.

<sup>20</sup> Letter from Mäkinen, dated 8.10.1931, and Ahola's response. Correspondence between Mäkinen and K.E. Ahola, 5.1. – 21.12.1931. Folder Kirjeenvaihto 1931 A-Ki, K31. OKA.

<sup>21</sup> Lyon, D. and Keeney, R. The Smelting of Copper Ores in the Electric Furnace.

timeline would have fitted Outokumpu's preferred schedule, there is no evidence of electric smelting being even considered for Outokumpu before 1931.<sup>22</sup>

Nonetheless, further investigations resulted to a switch in preferred furnace technology. Electric smelting could be cheaper, and it eliminated the main drawback of the previous plan, its dependence on coal imports. In May 1933, Outokumpu unveiled a plan to build an electric smelter if state-owned utility Imatran Voima would sell its electricity cheaply enough. Otherwise, the earlier plan calling for coal-fired reverberatory furnaces would stand.<sup>23</sup> Negotiations concluded successfully in January 1934, however, and what was at the time the world's largest electric copper smelter was finally inaugurated in February 1936. Once the planned copper refinery and copper mill were completed in 1941, Finland was self-sufficient in copper products and gained a strategic resource that was particularly valuable during the barter and *quid pro quo* trade of the war years. The exact value of Outokumpu's products during the war years is hard to ascertain due to the nature of the trade, but it is clear that they were of considerable importance.<sup>24</sup>

## The war years and after: the birth of flash smelting

The outbreak of the Second World War seemed to vindicate the misgivings about coal as a fuel. Availability of fossil fuels in Finland diminished considerably due to supply disruptions, and by 1945 total fossil fuel use had fallen to approximately one quarter of pre-war levels.<sup>25</sup> On the other hand, mobilization greatly reduced demand from civilian economy, and a 25 percent increase in firewood fellings was able to compensate the lack of fossil fuels to some extent. Still, Eero Mäkinen and the Economic Defense Council must have been relieved that Outokumpu's ore was being smelted without imported fuels and could contribute to Finland's all-out mobilization. While hard evidence remains scant, it seems reasonable to believe that wartime experiences - including the death of his son in action in 1942 - only served to strengthen Mäkinen's already well-developed techno-nationalist leanings.

While the fuel choice had been undoubtedly correct from wartime perspective, in retrospect the Soviet border had not been the best location for an important national asset. The smelter nevertheless continued to operate until summer 1944, when a Soviet offensive forced it to evacuate to Harjavalta, at western coast of

<sup>22</sup> Heikinheimo, M. (Ed.) *Sähkö ja sen käyttö*. (Electricity and its uses.)

<sup>23</sup> "Estimates of Costs of Construction and Production for Outokumpu Copper Smelter", memorandum dated May 29th 1933. Folder Imatran kuparitehdas 1933-1938. MÄK.

<sup>24</sup> See e.g. Vuorisjärvi, E. *Petsamon nikkeli kansainvälisessä politiikassa 1939-1944*; Perkins, J. *Coins for Conflict: Nickel and the Axis, 1933-1945*.

<sup>25</sup> Statistics Finland. *The use and sources of energy 1917-2007*.

Finland. The smelter was disassembled and moved to a new site, resulting to six-month halt in production. Even worse, armistice in September resulted to the Soviet Union annexing large tracts of Finnish land, including two major hydropower plants. At a stroke, a third of Finland's pre-war electricity generation capacity was lost. For Outokumpu, the shortage was compounded by location: compared to Imatra, where another state-owned company produced vast amounts of cheap hydropower, at Harjavalta the electricity had to be obtained from sometimes recalcitrant private companies. In western Finland, the electricity grid was built and operated largely by private pulp and paper producers, and their requirements could be at odds with the newcomers' demands.<sup>26</sup>

This move from a state-centered technological regime, to use Hecht's concept of technological regimes, to a privately operated regime combined to drive up the price of electricity for Outokumpu.<sup>27</sup> The average (inflation corrected) price more than doubled from 1944 to 1945 and continued to rise, reaching a peak at nearly eight times the 1944 prices in 1948. As a share of total costs per ton of copper, the cost of electricity went from less than ten percent to 40 percent in 1948.<sup>28</sup>

<sup>26</sup> Tensions are illustrated in e.g. correspondence between Mäkinen and local electricity utility chief G.M. Nordensvan. Folder Kirjeenvaihto 1945 H-Ö, K31. PKA. I thank an anonymous reviewer for pointing out the tensions Outokumpu's move to a privately owned electricity grid may have engendered.

<sup>27</sup> Hecht, *Radiance of France*. For a study of technological regimes in Finland, albeit in different context, see Särkikoski, *Rauhan atomi, sodan koodi*. I'm again indebted to anonymous reviewer for pointing out the connection.

<sup>28</sup> Electricity prices and costs from Outokumpu annual reports. Folder Vuosikertomuksia, E1. PKA. Copper prices from Kelly, T. D. and Matos, G. R., *Historical Statistics for Mineral and Material Commodities in the United States*.

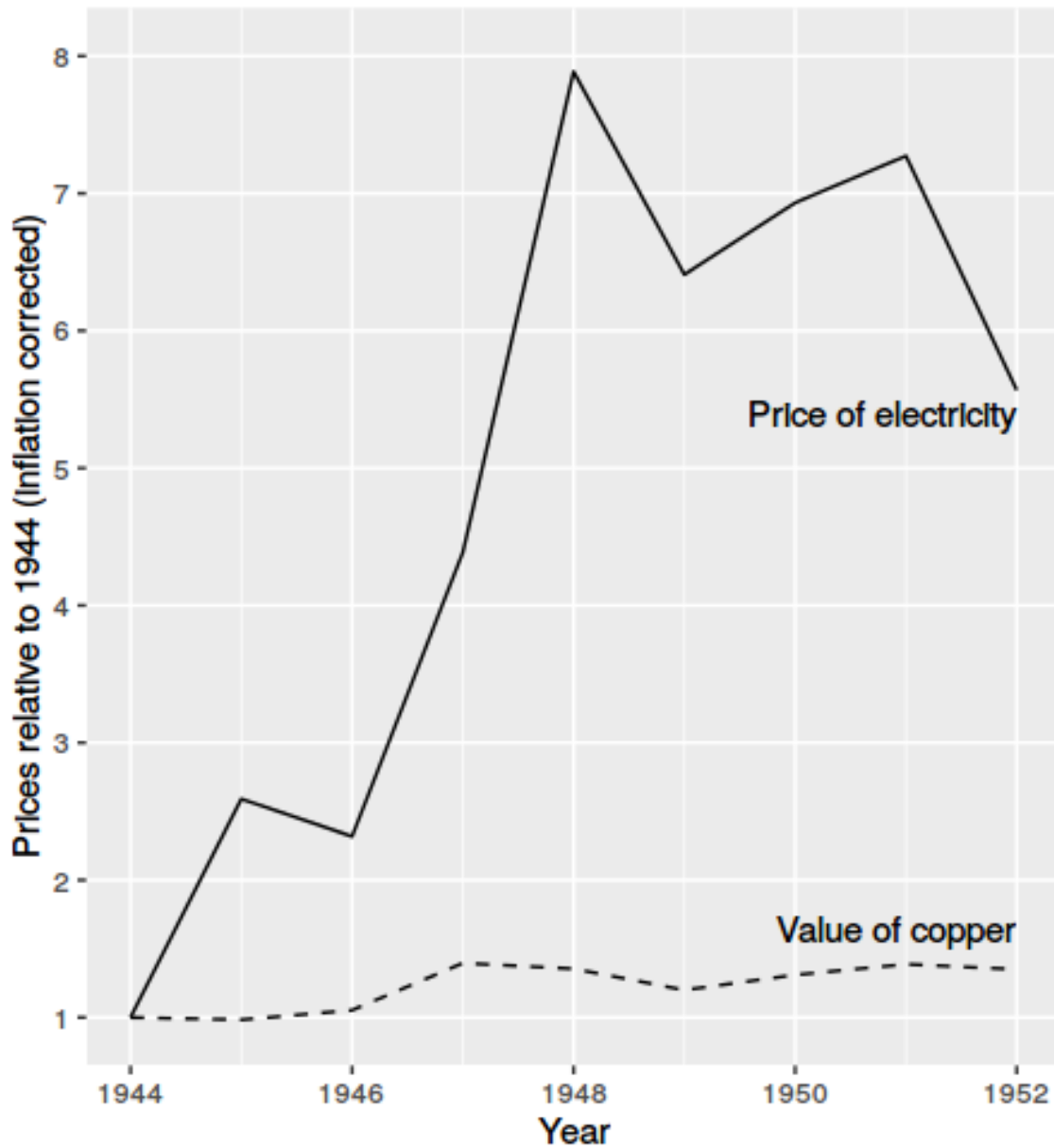


FIGURE 1: Inflation-adjusted relative price of electricity, and relative price of copper in the U.S. (in constant 1998 dollars, to illustrate the approximate value of Outokumpu's production.) It should be emphasized that war reparation quotas and export license system meant that the value of Outokumpu's production and its importance to post-war Finnish economy cannot be reliably assessed by average market price alone.<sup>29</sup>

<sup>29</sup> Electricity prices and costs from Outokumpu annual reports. Folder Vuosikertomuksia, E1. PKA. Copper prices from Kelly, T. D. and Matos, G. R., Historical Statistics for Mineral and Material Commodities in the United States.

As the year 1944 was drawing to close and even before the electric smelter was operational at Harjavalta, Eero Mäkinen therefore penned the letter mentioned in the introduction, calling for his engineers to develop an alternative to electric smelting. In the letter, he briefly noted that while industry standard reverberatory furnace might seem to be the straightforward choice, its coal would have to be imported. Therefore, his engineers would have to come up with a furnace that wouldn't need either fuels nor electricity to smelt copper concentrates. Mäkinen had more or less made up his mind, and in all surviving communications, other possibilities merited only two very brief mentions.<sup>30,31</sup>

On the face of it, Mäkinen's dismissal of reverberatory smelting and his call to go beyond state of the art is puzzling. The times were bad for experimentation, as Outokumpu's products were now needed more than ever. In addition to rebuilding the war-ravaged country and earning invaluable foreign currency, copper products featured heavily in the onerous war reparations the Soviet Union demanded as a price of not occupying the country. Signed two weeks before Mäkinen's letter, on 17th December 1944, the war reparations agreement called for a delivery of 300 million pre-war dollars' worth of specific industrial goods (e.g. cables, locomotives, ships, electric and industrial machinery) in six years. Relative to size of economy, the reparations exceeded those demanded from Germany in 1919.

The brunt of the demands was placed on products of metals industries. Outokumpu's copper was a critical ingredient in many products, and full 90 percent of its planned 1945 output was allocated for the war reparations products. deliveries. These deliveries consumed the majority of smelter's output until 1948. As one contemporary observer put it, the demands were "frightfully large".<sup>32</sup> Furthermore, Outokumpu's byproducts (sulfur and iron) were in demand in other sectors of Finnish economy.<sup>33</sup> By the time he wrote his letter, the broad lines of the

<sup>30</sup> "Electricity demand of Harjavalta copper smelter," letter to engineering consultancy Ekono, charged with implementing energy rationing measures, 23.12.1944.

<sup>31</sup> Letter from Mäkinen to local electricity utility chief G.M. Nordensvan, 6.10.1945. Folder Kirjeenvaihto 1945 H-Ö, K31. PKA.

<sup>32</sup> Heikkinen, S. *Sotakorvaukset ja Suomen kansantalous* (War reparations and the Finnish economy), p. 100. Also Michelsen, K-E. *Sotakorvaukset: Suuren teollisen projektin anatomia* (War reparations: the anatomy of a grand industrial project), quote from p. 209. Both in Rautkallio, H. (ed.), *Suomen sotakorvaukset* (Finnish war reparations). For Outokumpu's role, see Kuisma, M., *Outokumpu 1910-1985*, p. 235 onwards.

<sup>33</sup> See e.g. Rautkallio, H. (ed.), *Suomen sotakorvaukset* (Finnish war reparations).

war reparations demands must have been known to Mäkinen, who was active in politics as well. In fact, he was so well-connected that he would be elected into Finnish parliament as a member of conservative Coalition party in April 1945 and before his unexpected death in October 1953 he served briefly as a cabinet minister of public works.

An unstated but prevalent fear among many Finns at the time was that any delays in reparations deliveries could and would be used by the Soviet Union as a pretext for Communist takeover or even Soviet occupation and annexation. Furthermore, copper was scarce in Europe: if Outokumpu did not deliver, copper might have been impossible to obtain at any price. In this light, Outokumpu would have been perfectly justified to continue using its proven electric furnace or to switch to another proven process instead of employing its valuable engineering staff and spending its reserves of spare parts on what could well have been a wild goose chase. In particular, fireproof furnace bricks were in a very limited supply: A December 1944 letter in Outokumpu's archives despairs that furnace bricks simply cannot be found in Finland or imported from war-torn Europe.<sup>34</sup>

Against this background, the demands these more conservative options placed on Finnish energy resources would almost certainly have been manageable. First, while electricity shortage was real, Finnish industries managed to cope. When the crisis reached its peak after a dry spell had drained hydropower reservoirs in 1947 and electricity was finally rationed, nationally important industries were at the top of the list of consumers still receiving electricity.<sup>35</sup> Although supply situation did cause some headaches for Finland's two electric smelters – the another being Vuoksenniska steel works, also built to exploit Imatra's hydropower but not evacuated during the war – there are no indications of deliveries being endangered because of insufficient supply. A thorough examination of Vuoksenniska's archives surviving at Central Archives for Finnish Business Records (ELKA), while uncovering plenty of correspondence about rationing, failed to unearth any evidence of significant disruptions. Furthermore, Vuoksenniska even increased its electricity use during the period.

In fact, even Outokumpu coped with the worst electricity shortage in Finnish history: flash smelting became operational only in 1949, after electricity rationing was already over, and even as late as in 1953 electric smelting accounted for nearly

<sup>34</sup> Letter from Kymi Ltd., 20.12.1944. Folder Kirjeenvaihto 1944 A-U, K31. OKA. See also Särkikoski, T. Flash of Knowledge.

<sup>35</sup> Principles of rationing were established in circular N:o 23848 from Kansanhuoltoministeriö (Ministry of Supply) to grid-connected electric plants, received at Outokumpu on 3.10.1947. Folder Kirjeenvaihto 1947 A-Ke, K31. PKA.

a third of total production.<sup>36</sup> Outokumpu did consider a partnership with a local paper mill in order to build a new hydropower station as an alternative to flash smelting, but the success of the latter made this plan ultimately redundant.<sup>37</sup>

Second, even if Outokumpu had switched to coal-fired reverberatory smelting, the increase in coal demand would hardly have been overwhelming. In a letter written exactly one week before aforementioned 1944 letter to his engineers, Mäkinen informed Ekono, a consulting organization responsible for energy rationing measures, that Outokumpu was prepared to convert to coal-fired reverberatory smelting should electricity supply be in jeopardy.<sup>38</sup> At this time, the coal situation in Finland was as dire as it would get during these years. In late September, coal and coke reserves totaled 345 000 metric tons, a far cry from estimated annual demand of 850 000 tons.<sup>39</sup> However, Mäkinen's letter to Ekono stated that if Outokumpu were to fully replace electric smelting, it would need only 18 000 tons of coal per year; less, if some electricity could be obtained as well. As a bonus, waste heat from the furnace would be used to generate electricity, easing demands elsewhere. It is worth noting that Mäkinen's letter contained no indications that Outokumpu *had* to abandon electric smelting. Furthermore, coal supply situation began to improve fairly soon during 1945, well before Outokumpu made a firm decision to build a flash furnace.

Third, there is no evidence whatsoever that Mäkinen and Outokumpu even seriously considered using firewood to replace or supplement electricity or other fuels. In early 1930s, Mäkinen himself had justified the reverberatory plans by arguing that firewood would be used as an alternative fuel if coal supplies were in jeopardy. Firewood had been used extensively to supplement fuel imports in wartime Finland, and consumption peaked at 25 million cubic meters in 1945.<sup>40</sup> According to figures presented in a 1925 study about relative merits of coal and firewood in Finland, the 18 000 tons of coal could have been replaced completely with 90 000 to 120 000 cubic meters of firewood, depending on its quality.<sup>41</sup> If some coal or some electricity

<sup>36</sup> Kuisma, M. *Outokumpu 1910-1985*, p. 126.

<sup>37</sup> Kuisma, *Outokumpu 1910-1985*, p. 166.

<sup>38</sup> "Electricity demand of Harjavalta copper smelter," letter to engineering consultancy Ekono, charged with implementing energy rationing measures, 23.12.1944.

<sup>39</sup> Seppinen, J. *Vaaran vuodet? Suomen selviytymisstrategia 1944-1950*, particularly p. 155 onwards.

<sup>40</sup> Statistics Finland. *The use and sources of energy 1917–2007*.

<sup>41</sup> In *Voima- ja polttoainetaloudellinen yhdistys Ekono*, publication N:o 10: *Kivihiili höyrykattilan polttoaineena* (Coal as a fuel for steam boiler).

could have been obtained, the demand would have been correspondingly lower. This would have represented a sizable but hardly impossible increase in firewood demand, particularly as the demobilization of the army freed thousands of able-bodied men to seek employment in the forestry sector.

All in all, given the importance of Outokumpu's copper and byproducts, it is hard to believe that forceful Eero Mäkinen wouldn't have been able to browbeat the government into allocating electricity, coal import quotas, firewood or some combination of the above to Outokumpu, even if that had meant more stringent rationing among the populace. In other, arguably less pressing issues ranging from spare parts to miners' rations, Mäkinen and Outokumpu's management had not hesitated to leverage Outokumpu's importance to war reparations and to national economy when demanding preferential treatment.<sup>42</sup> Copper must flow for Finland's sake, Outokumpu's management argued when demanding new conveyor belts or more tobacco for the miners. But in the critical furnace issue, Mäkinen apparently did not even attempt to exert his considerable influence. Why?

We need to seek the reason for his behavior from another change in the perceptions of what was technologically feasible and desirable. In 1944, Outokumpu was a different company to what it had been in 1929 or even in 1939. Rather than being a newcomer to metallurgy in a country with scant traditions in metals industry, during the last decade it had built and operated advanced, large-scale metallurgical plants, building a considerable experience base. Perhaps most importantly, Mäkinen's long-standing efforts to buy, license, or steal necessary foreign technologies and expertise in order to nurture domestic engineering expertise had borne fruit. In the international copper industry, much of the information and knowledge were shared relatively freely even among potential competitors; for example, in 1949 the chief developer of a competing method was given a tour of Harjavalta smelter.<sup>43</sup> However, oral tradition holds that Outokumpu was not above resorting to industrial espionage when necessary, and some of the passages in abovementioned early 1930s correspondence between Mäkinen and K.E. Ahola are certainly suggestive.

In any case, Outokumpu's plants were using state of the art technologies, and they were finally staffed with capable home-grown engineers. Outokumpu did not have a research and development department *per se*, and before 1949, its small laboratory focused almost exclusively on quality control. However, solving problems inherent

<sup>42</sup> See e.g. the correspondence between Outokumpu and Suomen Gummitehdas Ltd. regarding spare parts (April 1945, in folder Kirjeenvaihto 1945 C-G. PKA) and 1947 efforts to attract more miners with extra rations (letter to Minister of Supply Murto, 22.7.1947. Folder Kirjeenvaihto 1947 A-Ke, K31. PKA).

<sup>43</sup> Letter from Paul Queneau (Inco), 10.8.1949. Folder Liekkisulatus – tiedusteluja. TJA.



in running metallurgical processes and coping with wartime exigencies had honed its engineers' skills and confidence in developing and scaling up novel solutions to unexpected problems.<sup>44</sup> The company's rising star and later managing director Petri Bryk (1913-1977) in particular had played an important role in these exploits, including developing a domestic method for extracting valuable nickel from Finnish ores (an invention that resulted to Outokumpu's first in-house patent in 1942), and as he would later explain, after these successes and the considerable experience with "elegant" electric smelting "it felt uncomfortable to take a step backwards in smelting technology."<sup>45</sup> In this way as well, confidence made flash smelting more attractive than "backwards" alternatives. Bryk's words and the overall attitude of Outokumpu's engineers are a reminder of how technical criteria alone can only rarely explain technologists' support for new technologies.<sup>46</sup> Nevertheless, this case illustrates how enthusiasm needs to be backed by confidence in the new technology.

### The problem that had "very much vexed the minds of professional men:" the development of flash smelting<sup>47</sup>

This confidence enabled Mäkinen and Outokumpu to pursue solutions that had been far from maturity in early 1930s. In itself, the idea of smelting copper ore using only energy from the ore itself (so-called "autogenous" smelting) was not a novel one for any competent copper metallurgist in the world in 1944. Sulfur could burn and release energy, and in a different form, the idea had been utilized in the industry between approximately 1890 and 1935. Finnish metallurgists were perfectly aware of this "pyritic" method and its variations, as evidenced by a detailed discussion in a textbook of mining and metallurgy written by Eero Mäkinen himself in 1933.<sup>48</sup> However, this early method was a dead end because it required a rare type of ore.<sup>49</sup> Once suitable deposits were exhausted, the method fell into disuse. Nevertheless,

<sup>44</sup> See the history of Outokumpu's metallurgical research, Mäntymäki, H. "Fugit Irraparabile Tempus".

<sup>45</sup> See e.g. Mäntymäki, H. "Fugit Irraparabile Tempus"; Särkikoski, Petri Bryk. Quote from Petri Bryk's presentation on flash smelting at Harjavalta, 27.3.1949. Folder Autogen etc. TJA.

<sup>46</sup> Schatzberg, E. *Ideology and Technical Choice: The Decline of the Wooden Airplane in the United States, 1920-1945*; Schatzberg, E. *Wings of Wood, Wings of Metal: Culture and Technical Choice in American Airplane Materials, 1914-1945*.

<sup>47</sup> Quoted from Bryk's 27.3.1949 presentation.

<sup>48</sup> Mäkinen, E., *Vuoriteollisuus ja metallien valmistus*, pp. 452-454 in particular.

<sup>49</sup> Sticht, R., *Pyritic Smelting - Its History, Principles, Scope, Apparatus, And Practical Results*.

the idea continued to attract metallurgists who were always on a lookout for cost savings, as the fuel savings and general simplification of the smelting process could theoretically halve the smelting costs.<sup>50</sup>

Meanwhile, ore concentration technology had developed as a response to falling copper ore grades, and in the 1890s, prototypes of these concentrators began to produce extremely fine, almost powder-like copper sulfite concentrate. In this form, sulfur was in theory much easier to ignite than it had been in earlier, gravel-like concentrates, and the first known patent for a furnace burning pulverized concentrate dates from 1897.<sup>51</sup> The essential components of Outokumpu's eventual furnace design were already included in a 1915 patent, and other inventors continued to tinker with the design up until the war.<sup>52</sup> In the 1930s, active research and development efforts were conducted in the United States, Canada, France, Yugoslavia, and Soviet Union.<sup>53</sup> Despite some promising initial results, these experiments did not lead to operational furnaces. In particular, the slump in raw material prices caused by the Great Depression had made copper producers reluctant to invest in new, uncertain technologies.

Nevertheless, contemporary observers clearly believed that the autogenous method held promise. As two of them noted in a treatise on copper metallurgy published in 1942, by then the necessary components and know-how seemed to be available and the only remaining obstacle was the construction of a suitable furnace.<sup>54</sup> Development resumed after the war, and Canadian mining giant Inco actually beat Outokumpu by a few months with its own pilot furnace using the same idea but quite different principles. Inco's furnaces maintained critical heat balance by

<sup>50</sup> Sticht, R. Pyritic Smelting.

<sup>51</sup> Bridgman, H. L., U.S. Patent 578,912: Process of Reducing Ores.

<sup>52</sup> Klepinger, J. H., Krejci, M. W., & Kuzell, C. R., U.S. Patent 1,164,653: Process of Smelting Ores. Of examples of later inventors, see e.g. Freeman, H., U.S. Patent 1,888,164: Process of Smelting Finely Divided Sulphide Ores; Zeisberg, F. C., U.S. Patent 2,086,201: Ore Roasting; Haglund, T. R., U.S. Patent 2,209,331: Roasting Process.

<sup>53</sup> Cooper, J. P., & Laist, F., An experimental combination of shaft roasting and reverberatory smelting. Norman, T. E., Autogenous Smelting of Copper Concentrates with Oxygen-enriched Air. Bouthrou, J., "Saint-Jacques-ugnens användning för behandling av floterade kopparsalssconcentrat." (The use of Saint-Jacques furnace for copper flotation concentrates.) 17.7.1937. Folder Liekkisulatus 1945-54. BRY. See also Bryk et al., Flash Smelting Copper Concentrates; and an undated note listing Russian language articles in Outokumpu's library about autogenous smelting from 1934 to 1945, in folder Kuparirik. sulatuksesta Venäjällä, TJA.

<sup>54</sup> Newton, J., & Wilson, C. L., *Metallurgy of Copper*. Pp. 160-161.

enriching air with oxygen (and therefore avoided heat loss from heating nonreactive nitrogen in normal air), while Outokumpu recycled waste heat with heat exchangers. When these proved unmaintainable, Outokumpu compensated with fuel oil burners. Problems with oxygen generators caused Inco's commercial scale furnace to be delayed until 1952. Nevertheless, the Inco furnace was even more efficient than Outokumpu's, so much so that Inco, unlike Outokumpu, refused to license its design to potential competitors. There are no indications, however, that Inco's post-war work had any direct influence for Outokumpu's research and development.<sup>55</sup>

Under Mäkinen, Outokumpu had assiduously cultivated its knowledge base and international contacts. As a result, Outokumpu's experts were certainly aware of developments in the field, as insider reports from Yugoslavian experiments in its archives can confirm.<sup>56</sup> In fact, Krupp-Grusonwerk, Outokumpu's original choice of furnace supplier, had suggested a very similar autogenous furnace for Outokumpu already in the early 1930s, but "the deal fell through because the furnace was then much too experimental."<sup>57</sup>

But in 1944, Mäkinen was confident enough of two things: first, flash smelting was in a technical sense a feasible proposition; and second, that his staff could and should make it work. As noted above, the components were known to exist, Outokumpu's staff was competent enough, and now the question was simply how to put the pieces together. Whether the furnace would prove to be economical was another matter entirely. No evidence survives of detailed cost calculations from that period. However, assessing the overall desirability of flash furnace in 1944 would in any case have been extremely difficult, because rationed supply and war reparations demands meant that normal economic calculations did not necessarily apply. In 1951, after the worst was already over, the costs of electric and flash smelting were determined to be almost exactly the same when ongoing R&D costs – in 1947, representing 12 percent of Outokumpu's annual revenues – were included.<sup>58</sup> Nonetheless, in Outokumpu's techno-nationalistic atmosphere, the flash furnace was an attractive proposition simply because it could help Finland in her energy crisis.

<sup>55</sup> For a comparative study of the two, see Korhonen, J. M., & Välikangas, L., *Constraints and Ingenuity: The Case of Outokumpu and the Development of Flash Smelting in the Copper Industry*.

<sup>56</sup> Bouthrou, Saint-Jacques...

<sup>57</sup> Mäkinen's letter on 30.12.1944.

<sup>58</sup> Memorandum on production costs of copper, 12.1.1952. Folder Liekkisulatus 1945-54. BRY. See also Memorandum "Flash smelting - electric smelting." 27.9.1954. Folder Liekkisulatus 1945-54. BRY. Kuisma, Outokumpu 1910-1985, p. 126.

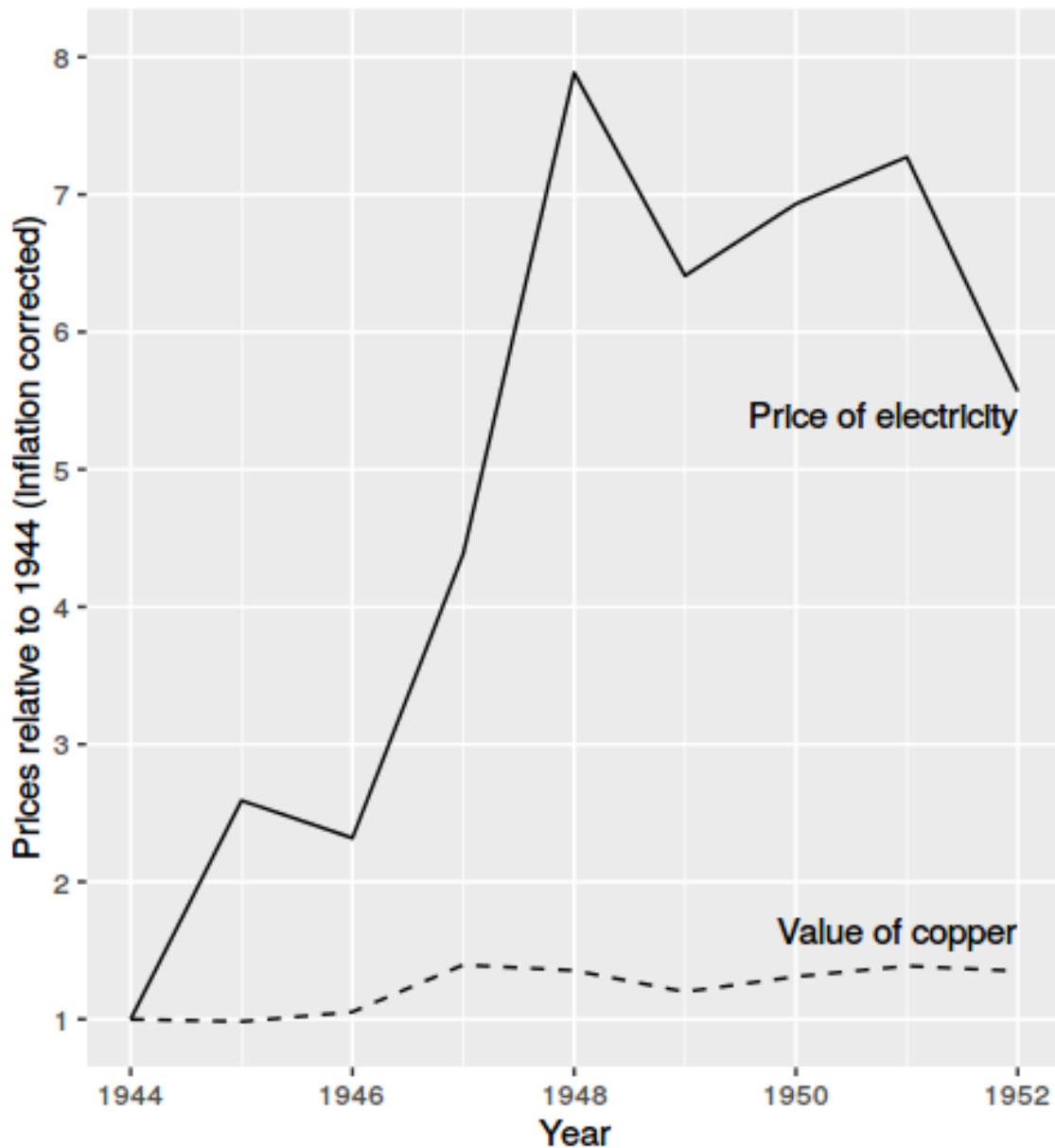


FIGURE 2: Total cost per ton of copper in 1958 as a function of electricity price with flash, electric, and fuel-oil fired reverberatory furnaces. R&D costs are not included. By that time, cheap and easily handled fuel oil (even scarcer than coal in 1944) had replaced coal in many copper smelters, and the calculation does not fully represent the situation in 1944.<sup>59</sup>

<sup>59</sup> "Comparison of Smelting Costs for Different Smelting Methods". 26.3.1958. Folder Liekkisulatuslaskelmia. TJA.

Mäkinen's belief in the technical feasibility and desirability of a furnace independent from external fuel sources, and his nationalistic motivations, influenced how Outokumpu's staff again perceived the coal constraint. As in 1925, so in 1945: “[T]he use of reverberatory furnace cannot be contemplated here, as we do not have cheap oil or coal that this method absolutely requires,” Mäkinen had written in 1925.<sup>60</sup> “[R]everberatory smelting was intolerable because the whole copper production would have become dependent on fuel imports from abroad,” wrote Bryk in an English introduction to flash smelting in late 1951.<sup>61</sup> Bryk, who was being groomed to succeed ailing Mäkinen, had internalized the techno-nationalist frame that made coal imports such an “intolerable” problem – fittingly enough for a man who would become the managing director of state-owned Outokumpu after Mäkinen's death in 1953 and remain at the post until 1972.

## Conclusions

The history of Outokumpu's development of flash smelting should serve as a reminder that perceptions of technological constraints and even shortages of important inputs or raw materials may be just that – perceptions. There is no denying that wartime supply problems and post-war electricity shortage did motivate Outokumpu to seek alternatives to electric smelting. Absent the post-war shortage of electricity in Finland, it seems unlikely that *Outokumpu* would have developed flash smelting. (Interestingly, in neighboring Sweden, an important Boliden copper works concluded in late 1940s that wartime supply shortages were reason enough to convert its smelter from coal-fired reverberatory to *electric* furnaces to prevent future disruptions.<sup>62</sup>) However, the electricity shortage in itself did not determine how Outokumpu responded to it. As I've tried to illustrate, Outokumpu had a menu of at least three other options at its disposal, and given the politico-economic situation, could hardly have been faulted had it resorted to any of these instead. History could well have turned out differently, and if Outokumpu's engineers hadn't managed to make flash smelting work, Outokumpu and Eero Mäkinen might be remembered not as bold innovators but as gamblers who could not resist squandering resources on a fool's errand even when the independence of Finland might have been at stake. After all, the development of flash furnace was not without difficulties: as late as in 1954 Harjavalta's employees were concerned enough about their jobs that they delivered a widely signed petition listing eleven

<sup>60</sup> “E. Mäkinen. Muistio Outokummusta 13.2.1925.” Folder O18 A4 1918–1925. EDA.

<sup>61</sup> “Autogenous flash smelting at the Harjavalta Copper Smelter of Outokumpu Oy. P.B. 28.12.1951.” Folder Autogen etc. TJA.

<sup>62</sup> Herneryd, O., Sundström, O. A., & Norra, A. Copper Smelting in Boliden's Rönnskär Works Described.

serious concerns they had about the technical and economic viability of flash smelting.<sup>63</sup>

However, evidence suggests that Outokumpu's management and most importantly Eero Mäkinen strongly believed they could and should make flash smelting work. Their belief in the feasibility of flash smelting was grounded on their knowledge about the experiments and theoretical assessments from the previous five decades, and on Outokumpu's demonstrated ingenuity during the war. Nevertheless, investing in flash smelting's development must have been a risky venture for Outokumpu. As a result, Mäkinen's techno-nationalistic beliefs played a crucial role: Outokumpu would take the risk because it was a right thing to do. In brief, the reason why Outokumpu abstained from resorting to other alternatives can be best explained by Outokumpu's perceptions of feasibility and desirability of an alternative that did not require either electricity or coal. If Mäkinen and his key aides hadn't believed that flash smelting was both feasible and desirable, it seems more than likely that Outokumpu would have done what other Finnish industries at the time did – and pressured the government for coal or electricity.

This line of reasoning and evidence suggests that the coal and electricity constraints Outokumpu's management lamented and subsequent histories have implicitly accepted as immutable external forces were, to a large extent, intermingled with socially constructed obstacles. Constraints arise from perceptions of feasibility and desirability, and are as much a reflection of what was believed possible as what was thought to be impossible. An understanding of constraints was shared among Outokumpu's technologists, constituting a shared technological frame that guided decision-making and was perpetuated by the decisions made.<sup>64</sup> Once electric smelting was chosen, for example, attempts to change the technology would have to contend with the perception (true or false) that coal constraint had caused the selection of electric smelting, and therefore alternatives should also avoid using coal if at all possible.

This is not to say that constraints were imaginary. Lack of coal seams in Finland, for instance, *was* something that affected the decisions made by Finnish industries, and fundamental physical realities determine how much energy is at minimum required to break copper ore to its constituent elements. However, constraints can be subject to significant redefinitions when perceptions of technological feasibility or desirability demand it. Outokumpu's relationship with coal illustrates such reversals

<sup>63</sup> Memorandum "Harjavallan kuparitehtaan sulatusuunin toiminta," in folder Liekkisulatus 1945-54. BRY.

<sup>64</sup> See the literature on technological frames, e.g. Bijker et al., *The Social Construction of Technological Systems*, and Bijker, W. E., *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change*. See also Orlikowski and Gash, *Technological Frames*.

nicely. Dependence on coal made reverberatory smelting completely unacceptable to Eero Mäkinen in 1925. Only four years later, no other technology could be even considered and coal supplies were no problem at all, as Mäkinen's perception of the scale of copper industry desirable for Outokumpu and Finland had changed. Finally, after the decision to build the electric smelter in 1933, dependence from coal was again a reason, among others, to reject any thoughts of reverberatory furnaces.

The case study presented here shows how research can benefit from problematizing the concept of constraints instead of taking them as exogenous factors beyond the influence of technologists. Technologists and their beliefs about what is "good" have significant influence on what they believe to be feasible or infeasible. This finding echoes Schatzberg's now classic analysis of how ideology of metal as a symbol of progress is required to explain aviation community's enthusiasm towards metal instead of wood construction during the interwar period.<sup>65</sup> As an addition to Schatzberg's findings, I might suggest that perceptions of feasibility (or infeasibility) have a significant influence as well.

My study also casts further doubt on the more deterministic readings of technological change: even when confidential, presumably frank communications from technologists describe something as a constraint, it is possible that relatively small changes in the perceptions of technological feasibility or desirability can greatly alter the technologists' opinions of constraints. Researchers should therefore pay careful attention to the assumptions behind any statements that declare a particular path as impossible. As Mäkinen's flip-flopping between 1925 and 1929 illustrates, when one assumption – in this case, plant size – is altered, the seemingly intolerable constraint may suddenly become perfectly tolerable. Such reversals serve to underscore the importance of questioning and criticizing past and present narratives that suggest lack of alternatives for a decided course of (technological) action. Alternatives may, in fact, be even more straightforward than the ultimately decided course of action, but as this brief history shows, they are often forgotten afterwards. Historical research that can access contemporary deliberations should therefore serve as an useful antidote against excessive determinism.

## Acknowledgments and author bio

Janne M. Korhonen is a PhD candidate at Aalto University School of Business in Helsinki, where he is specializing on how perceived constraints influence technological change and technological change influences perceived constraints. He wishes to express his gratitude to Markku Kuisma and Tuomo Särkikoski, whose prior research on Outokumpu helped greatly in locating many key documents mentioned in this paper. Furthermore, he would like to thank the editor, the

<sup>65</sup> Schatzberg, E. Ideology and Technical Choice: The Decline of the Wooden Airplane in the United States, 1920-1945; Schatzberg, E. *Wings of Wood, Wings of Metal: Culture and Technical Choice in American Airplane Materials, 1914-1945*.

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The key sources for this paper have been the archives of Outokumpu Ltd. and its predecessors at the Central Archives for Finnish Business Records (ELKA) Mikkeli, Finland. These have been supplemented by 58 books on copper mining and metallurgy from 1848 to 1976, the contemporary trade and scientific press, and official histories of Outokumpu and flash smelting mentioned in the text. A full list of books consulted is available upon request.

The abbreviations in parenthesis refer to specific collections of Outokumpu archives as follows:

- , (PKA): *Pääkonttori* (Main Office) papers
- , (OKA): *Outokummun kaivos* (Outokumpu mine) papers
- , (MÄK): *Eero Mäkisen arkisto* (Eero Mäkinen's archive)
- , (BRY): *Petri Brykin arkisto* (Petri Bryk's archive)
- , (TJA): *Toimitusjohtajan huonearkisto* (Managing Director's personal archive)
- , (EDA): *Edeltäjien arkistot* (Archives of Outokumpu Oy's predecessors)

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