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Autoproduction of Electricity: Cases from Danish Industry until 1960

In the Danish historiography of electricity supply systems, autoproduction or on-site generation of electricity has received remarkably little attention. There are at least three reasons for this. One is that most accounts of the history of electricity supply focus upon public supply ('public' in this sense relates to the supply area, not to ownership), that is, they aim to describe the industry which has electricity production and sale as its primary task. The object of description thus excludes autoproduction systems, where the producer and consumer of electricity are identical.[1] Another reason is that the industrial sector, hosting the bulk of autoproduction installations, did not play such an important role in the Danish electrification process (and thus received less attention) as in other Nordic countries.[2] But the neglect also seems related to a more systematic conception of the history of electrification, which builds upon a basic scheme of progressively succeeding technologies or technological systems. In this view, autoproduction of electricity is interesting only because it constitutes the oldest form of electricity supply. It emerged in the early 19th century with the development of electricity-producing machines (batteries, generators) and appliances (particularly lighting), and was introduced in Denmark in the late 1850s in the form of a demonstration of an arc light at the Christiansborg Palace riding ground. Furthermore, it gained significant application in the 1880s, particularly in indoor lighting of industrial establishments. Yet from the moment that public supply from a central station arrived in the early 1890s, autoproduction ceased to be a system of interest other than as a forerunner of this 'higher stage' in the electrification process.[3]

Such a bias, however, is only partially justified. For although the construction of a national public supply system certainly is the most important event in the history of electrification, its emergence does not imply that other systems became oblivious. This paper, then, aims to provide an initial exploration of autoproduction of electricity in Denmark in the period up to 1960, when a centralised public supply system had been firmly established. It will firstly be argued that the Danish autoproduction of electricity had a history worth investigating also after the introduction of public supply systems in the 1890s, even after the introduction of regional systems in the 1910s and the completion of a national, centralized system in the decade after the Second World War. It is furthermore argued that the feasibility of autoproduction systems cannot be treated in general terms, but depended upon their context of application. This is extensively illustrated for the two most important contexts of autoproduction of electricity in Denmark up to 1960, the paper and cement industries. Finally, the flour industry is studied as a contrasting case, where the purchase of electricity from public supply companies nearly completely replaced the autoproduction of electricity during the first half of our century.

The dynamics of the autoproduction system

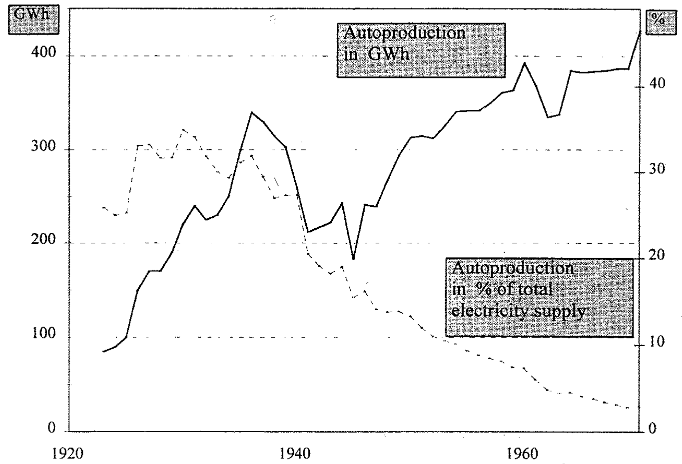
Illustrative of the conception of autoproduction of electricity as merely a forerunner of public supply is Valdemar Faaborg-Andersen's history of electricity supply in Denmark, which represented electrification in an 8 vols. work on Danish culture in the early 1940s. It describes the subsequent introduction of autoproduction from 1857 (the arc light demonstration at Christiansborg Palace), public supply of limited areas from central stations and with low voltage, direct current transmission from the early 1890s (in 1891 central stations were established in Køge and Odense, in 1892 in Copenhagen), public supply of larger areas with larger stations and high voltage, alternating current transmission from 1907 (when high voltage transmission was adopted by supply companies in Copenhagen and Skovshoved) and finally public supply from few, large power stations interconnected in a regional grid (which largely covered the Eastern Danish region in the 1920s, but evolved significantly slower in the Western Danish region). Autoproduction is only mentioned for the period until its successor arrived in the 1890s.[4] Yet Faaborg-Andersen was well aware that autoproduction still existed in his time. But he was confident that the completion of the national centralized public supply system would finally favour the more 'rational' alternative of public supply: Public supply was the 'natural choice' of electric supply system, constrained only by 'irrational' sentiments such as the reluctance of autoproducers to give up their independence.[5] His view comprised, to follow Pinch & Bijker, an implicit asymmetry: The success of the public supply system was attributed to its economic and technical superiority, while the continued existence of the older technology (presupposed to be technically and economically inferior) was attributed to 'social factors.'[6] Faaborg-Andersen's statement was typical and reflected a conception of electrification, which had predominated in electrotechnical engineering circles in Denmark at least since the 1910s, when the absolute superiority of a centralised public supply system (based upon the notion of economies of scale) over other public supply systems and autoproduction was formulated: The centralised public supply option combined the most advanced technology (large production units, high voltage transmission and a national grid) with unambiguous economic superiority, and it was only a matter of time before autoproduction would disappear.[7]

As a general presupposition, this opinion cannot stand close scrutiny. Instead, the technological and economic properties of the electricity supply systems involved depended upon the context of their application. An argument for the economic feasibility of autoproduction in specific contexts was for instance provided by Michael B. Mogensen, an electrotechnical engineer of the firm United Paper Factories, Ltd. (A/S De forenede Papirfabrikker) in the early 1940s. Mogensen did not disagree with the centralisation project of his electrotechnical colleagues; on the contrary, he considered the rationality of centralized public supply sufficiently proven. But contrary to Faaborg-Andersen, he propagated the economic feasibility of autoproduction of electricity in large industrial enterprises. Autoproduction was particularly attractive in factories, which required heat as well as power in the production process: These factories could often autoproduce combined heat and electric power, in case of which electric power would be almost for free, since heat had to be produced anyway. Furthermore, autoproduction might also be economically feasible in large factories without a significant heat consumption, as they often had a steady power consumption (and consequently a high load factor and low production costs for electricity), while public suppliers had to cope with the peaks and troughs of the household electricity market (and consequently had a lower load factor). This could make even large power plants for public supply comparatively expensive compared to industrial autoproduction in larger units. In addition, in a review of autoproduction technology Mogensen implicitly illustrated that autoproduction systems might well employ the latest supply technologies: Although historically the oldest electricity supply system, autoproduction was by no means confined to technologies from before the public supply era.[8] Autoproduction of electricity, in conclusion, was not an economically and technologically 'inferior' electric supply system in an absolute and ahistorical sense.

This observation corresponds to the actual dynamics of autoproduction of electricity as a supply system. The available statistics do not confirm the predicted decline of autoproduction following the expansion of public supply. This may be illustrated, firstly, by the sheer amount of autoproducing installations. As stated above, autoproduction systems were rapidly introduced in the 1880s particularly for lighting purposes. A survey in 1886, based upon installations installed by Danish electrotechnical firms, included 45 autoproduction installations for electric lighting installed since 1878, while another 4 were under construction.[9] These installations preceded public supply systems by half a decade or more. Yet by 1909, when the Danish Electricity Commission ("Elektricitetskommissionen", established with the 1907 Electric Supply Act) found its registration of Danish electricity producers more or less complete and counted approx. 200 public supply plants, the number of autoproduction installations had increased to approx. 800.[10] Also in the next two decades, when centralized public supply became available in large parts of the country, the number of autoproducers did not decrease, but

doubled instead to approx. 1600. Their number only topped around 1950 with some 2100 autoproducers, and then stabilized at approx. 2000 for the following decades.[11]

Secondly, a more precise indicator of the dynamics of autoproduction installations in Denmark is their annual amount of electricity produced. From 1923 onwards estimates of the amount of autoproduced electricity in Denmark were published annually (see graph 1). As smaller autoproduction installations (which constituted the vast majority) were excluded and the criterion for inclusion varied slightly over the years, the graph only illustrates the overall dynamics of the autoproduction supply system. Yet it suffices to illustrate that autoproduction not simply perished as public supply systems grew. On the contrary, if anything, it increased, and continues to do so today.[12]



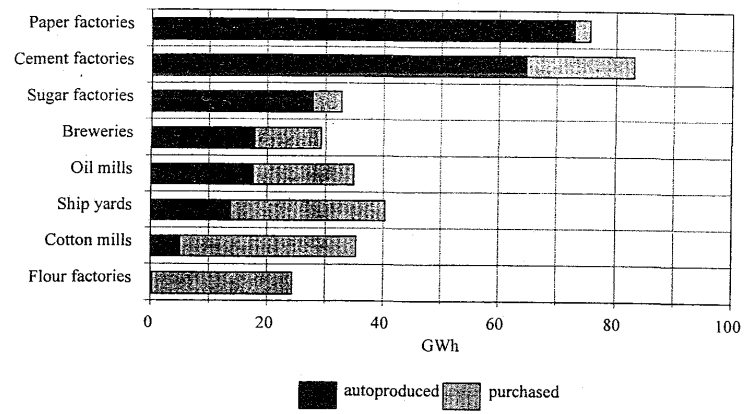
Graph 1: The annual autoproduction of electricity (incl. sales to public supply) in GWh in Denmark until 1970 and the relative share of autoproduction of the total electricity supply in Denmark (incl. imports).[13]

As the graph also illustrates, the continued existence of autoproduction as an electricity supply system did not contradict the success of public supply systems. Autoproduction and different forms of public supply systems can instead of succeeding systems be regarded as coexisting systems, in which particularly the centralised public supply system grew much faster than the other available systems from the 1930s (as the decreasing relative importance of autoproduction in the Danish electricity supply structure indicates). To eliminate autoproduction from the history of electricity supply systems, however, is to eliminate not only a system with a specific context-dependent dynamic, but also the vast majority of electricity producing installations and a considerable part of the Danish electricity market in GWh.

Which, then, were these autoproducers? In the 1886 survey breweries, distilleries, sugar factories and steam ships were well represented, but private villas and public offices were also included. These installations consisted most often of a steam engine which provided power to a 'lighting machine' (a dynamo or a generator), which supplied a system of arc lights or/and incandescent electric lights. More decisive for the continued dynamics of autoproduction of electricity in the twentieth century, however, was the autogeneration of electricity for power purposes. Electric motors gained significance in Denmark from the early 1890s, but their application first accelerated around 1910.[14] As a result, the autoproduction of electricity was nearly completely concentrated in the realm of industrial production. In 1933, 93% of the nearly 100 MW of (stationary) autoproduction installations were installed in factories, the rest in public undertakings (hospitals, sanatoria) and agriculture. By 1960, 99% of all registered autoproduction (nearly 400 GWh) came from industrial firms under the Factory Inspectorate (that is, firms with more than 5 workers excl. the building trade and dairies). Both figures, however, again exclude the overwhelming majority of small autoproduction units.[15]

Within the realm of industrial production, the autoproduction of electricity can be identified for individual branches of industry from 1939 to 1951, when detailed surveys over power consumption were published in the statistics of production. Graph 2 illustrates the importance of autoproduction in the electricity consumption of the eight most electricity-intensive branches of industry in Denmark in 1951 (surplus production sold to the grid is excluded). Industry, again, only includes firms under the Factory Inspectorate.

In 1951, Danish industry consumed 827 GWh electricity, one third of which was autoproduced. Obviously, the largest power consumers were also the largest autoproducers of electricity for own consumption: The top eight most power intensive industries included the top 6 of industrial autoproducers of electricity. Furthermore, it is remarkable that two industries, the paper and cement industries, were responsible for approximately half of all autoproduction of electricity in Denmark. Equally remarkable, other very power intensive industries such as flour factories and cotton mills largely relied on purchased electricity.



Graph 2: Electricity consumption in the 8 most electricity-intensive industries in Denmark in 1951 in order of consumption of autoproduced electricity.[16]

In the following, the background for the choice of electricity supply system is explored for the contexts of the paper, cement and flour industries. In each case ample attention is given to the branch-specific technological context, which actors in the electrification process (factory entrepreneurs or technicians as well as agitators for electrification) anticipated when addressing the questions of electrification and of which electricity supply technology to apply. Thus the possible technical and economical feasibility of the autoproduction system will be illustrated; however, it will also be argued that other aspects than the strictly technical and economical properties of supply systems (addressed by Mogensen and Faaborg-Andersen) decisively influenced the success or failure of the autoproduction system.

Case 1: The paper industry and the rationality of autoproduction systems

Technical/economic background[17]

Two innovations are commonly emphasized as crucial for the paper industry, which existed at the eve of electrification in the late 19th century: The continuous paper making machine provided an alternative to the individual production of each arc of paper, and wood pulp (mechanically pulped or chemically, i.e. cellulose) was a cheap and widely available alternative raw material to rags. The former was invented just before the 19th century and first introduced in Denmark in the late 1820s; the latter had been developed from the 1840s and was widely adopted in the Danish paper industry in the 1870s. By then, four large well-established Danish paper factories and five newly erected ones competed fiercely for the home market (as exports were limited), a competition which was temporarily reduced by a cartel agreement in 1882 and permanently solved in 1889 with the establishment of the firm United Paper Factories Ltd., taking over 9 out of Denmark's 10 paper factories (previously owned by 6 different firms). The remaining factory was owned by a publisher and produced chiefly for own consumption. United Paper Factories largely controlled the Danish paper industry in the entire period under consideration, using its near monopoly to rationalize the Danish paper industry by closing down some factories and specializing others in the production of specific types of paper or cardboard. Competition arrived primarily from abroad and from few Danish factories, some of which were owned by and produced for publishers and others were quite small. Altogether, however, the number of paper factories in Denmark remained remarkably constant (between 10 and 14 factories) in the period up to 1960.

With regard to physical situation and design, paper factories were situated outside urban areas near streams and rivers providing the necessary water for the production process, and comprised besides the factory building(s) several storage buildings, offices and a water works, thus occupying a comparatively large area. The actual production process contained three basic stages: (1) Preparing the raw material, a pulp of fibres and water; (2) intermeshing the fibres into a paper sheet; and (3) preparing the final product. In the preparation department, first a semi-prepared pulp would be produced from the raw material. If the raw material were rags, a group of workers would sort and clean them before they were mixed with a large portion of water in the chopping machines (tubs containing revolving cylinder with knives) and cooked in a boiler. Alternatively, waste paper would be ground on a special roller stand, while semi-prepared wood pulp normally could be purchased from specialized factories. Secondly, the final pulp would be prepared in a differently adjusted set of chopping machines, where different semi-prepared pulps (rags pulp, wood pulp) might be mixed and chemicals added (for bleaching, colouring and making the paper ink-prove and untransparent). The result was a pulp containing approx. 99 parts of water to one part of fibres.

In the paper making department one would find the paper making machine(s), in which the fibres were intermeshed and water extracted. The basic characteristics of the paper making machine had been well defined by 1880 and remained basically unchanged until the 1950s. The machine, perhaps 50 metres long, was divided in three parts. At the so-called 'wet end', the diluted pulp would be projected upon an endless travelling belt consisting of a wire mesh, on which the fibres would intermesh and part of the water be drained (more water was removed

while the 'wire' passed over suction boxes). In the so-called 'press part' of the machine, the mass was projected upon an endless travelling felt and led between a set of pressure rollers, consolidating the web and pressing more water out. When entering the last section of the machine, the 'drying end', the paper sheet (still containing 66% water) was likewise led between a number of heated metal rollers, which caused the water to vaporize. The outcoming sheet (containing 3-6% water) was finally wound in a reel. Hereafter the paper sheet was cut and received additional treatment according to paper type and desired quality in the finishing department. Fine paper qualities, for instance, passed through special roller stands for extra smoothing.

The factory, then, demanded plenty of rotary action for the choppers in the preparation department, the paper machines (basically consisting of revolving rollers either carrying transport belts or pressing the pulp) and the final roller stands. In addition, there were transport machines and water pumps. Turbines often produced part of the power, but additional steam engines (and later diesel an crude oil engines) were indispensable. From here, the power was (before the introduction of electric power transmission) distributed to the machines by means of shafts and belts. Finally, the boiler(s) played a decisive role in the energy scheme of the factory, providing not only steam to the steam engines, but also to the drying end of the paper making machine.

Electrification of the paper industry

According to the registers of the Electricity Commission, all larger Danish paper factories (that is, all United Paper Factories plants and the main publisher plant) were equipped with means for autoproduction of electricity by 1910.[18] What made electricity attractive in the paper industry, and why was autoproduction chosen? Obviously, electric lighting preceded electric power; already the 1886 list of factories with electric lighting installations mentions the erection of such an installation at the Ørholm paper factory, which provided electricity to a hundred 'Edison lamps'. Electricity was produced by a small dynamo connected to the central steam engine of the factory, and a battery could take over when the steam engine was shut down.[19] However, according to the 1910 register the auto-production installations of paper factories were with very few exceptions far larger than lighting required, which typically was up to 10-20 kW. Instead they contained installations from 100 kW to more than 450 kW, which placed them amongst the largest autoproducers of their time and electric power stations of middle sized towns.

Electric drive, then, had been massively adopted. The possibility of electric drive in paper factories had already been conceived in the 1890s, when electric transmission of waterpower received worldwide attention. Being situated near rivers and streams and having experience with turbines, paper factories seemed particularly well suited to adopt this technology, as paper factories in for instance Austria, Sweden and Niagara Falls in the United States illustrated.[20] The argument for electric drive in these cases was, of course, to make cheap but distant water power resources available.

In Denmark, however, water power resources were modest, and other advantages of electric drive were more important. According to the electrotechnical magazine *Elektroteknisk Tidsskrift*, which actively propagated the introduction of electric drive in Danish industry during the first decades of our century, several arguments made electrification particularly attractive in the paper industry:[21] Firstly, since the paper factory buildings normally occupied a comparative large area, a mechanical power transmission system would be comparatively large and cause comparatively large power losses relative to electrical power transmission (in small systems, by contrast, losses of an electrical transmission system might be relatively higher due to the double energy conversion losses in both generator and motor). Secondly and more important, electric drive would improve the quality and quantity of paper making due to the superior steadiness as well as regulability of electric motors. Contrary to turbines in particular, electric motors of certain types could yield a steady power supply to the paper making machine under changing loads; and although it was possible to regulate the drive speed in mechanical transmission systems, this involved fragile (in reliability and durability) gearing and shafting compared to press-button control of electric motors. The increased steadiness and regulability of electric drive, then, improved the paper quality by producing paper of a more constant weight and thereby increased homogeneity. Besides a quality criterion this was an important economic factor as well, because irregularities in the paper would have to be cut out subsequently and hence cause paper losses. Ultimately, such irregularities might cause the paper sheet to crack, and the entire machine would have to be turned down. Finally, the reduced risks of irregularities and cracks in electric driven paper machines allowed considerably higher production speed and thereby increased the productivity of the factory.

Thirdly, like the paper making machine, the rollers in the finishing department benefitted from optimal power regulation, which electric motors could provide. The traditional belt driven roller stands normally had two speeds only, a low starting speed and a higher operating speed. The change from one speed to the other involved a significant risk of breaking the paper, which made regulable electric motors indispensable.

Fourthly, while the chopping machines of the preparation department did not require similar power regulation, they would often be idle. Here the 'general' economic advantage of individual electric drive, where each machine had its own motor, applied: An individual idle machine could simply be shut off. In mechanical or electric line drive (one motor powering all machines) or group drive (one motor for each group of machines), by contrast, the belt providing power to a machine

could at best by shifted to an idling pulley, but still cause idling losses in the transmission system. Finally, electric drive could power a wide variety of transport machines, such as electric cranes attached to the ceiling carrying the wood pulp to the preparation department.[22]

While the propagators of electric drive emphasised the advantages of all-electric drive, Danish paper factories often only applied partial electric drive at least until the 1910s. An example was the newly established Ravnholm paper factory north of Copenhagen (1907). The factory was established on the initiative of Adolph Bock, exploiting the successful Klippan paper factory in Sweden, in an attempt to break the near monopoly of United Paper Factories. The attempt failed, and already the following year United Paper Factories bought the factory and transferred its machinery to a leading UPF factory. Still the Ravnholm factory was remarkable because it presented state of the art technology, and was described by a leading German paper magazine as one of the most modern paper factories in the world.[23] Power was exclusively produced by a large, 800 hp. steam engine, and was transmitted mechanically from the engine house to the preparation building. Yet the paper making department and the finishing department were supplied by means of electric power transmission: Electricity from a 259 kW generator in the engine house was transmitted at 440 volts to the two electric motors of the paper making machine as well as the electric motors of the roller stands and cutting machines.[24]

By the late 1920s, electric drive of the paper making machine and the finishing department was regarded as the standard in Danish paper factories. The tendency now was towards unit drive; the paper making machine was divided in an increasing number of sections with different power requirements. At first, as in the case of the Ravnholm factory, the machine was divided into two sections with different speed requirements. Later, the amount of electric motors was increased until each roller in the machine had its own motor. The optimal speed of the paper could now be optimized, that is, the tension of the paper sheet at each section of the machine could be regulated between narrowly specified boundaries. In addition, automatic regulation could correct even minor speed changes in particular sections. Illustrative is the combined paper and cardboard making machine in UPF's new factory in Copenhagen in the early 1930s, which contained no less than 14 electric motors, varying in size from 6 hp to 88 hp. As a consequence of the application of electric drive in each section of the paper making machine, its power efficiency might be improved with a factor two, and the production speed could be further increased without cracking the paper sheet.[25]

The success of autoproduction in the paper industry

Autoproduction of electricity, then, had been introduced in the paper industry for lighting purposes prior to the public supply era, and was maintained for lighting purposes and partial electric drive until the 1910s. According to the Electricity

Commission registers, paper factories also maintained autoproduction during the process of adopting all-electric drive. The success of autoproduction of electricity in the paper industry is illustrated by table 1.

Table 1: Some choices of electrification in Danish paper factories 1940-1952 (Source: Statistics of Production[26]).

	1940	1946	1951/52
Electric engine power in % of total engine power installed	85%	88%	93%
Consumed autoproduction in % of total electricity consumption	98%	97%	97%
AC generating power in % of total generating power	46%	46%	62%

Firstly, the table illustrates that by 1940 electric motors had clearly taken over the power supply of the paper industry, constituting 85% of the motor power installed (excl. prime movers used exclusively for electricity production). The figure even underestimates the importance of electric drive, as prime mover horsepowers applied both for driving machinery and generating electricity are included as non-electric machine drive. Secondly, autoproduction of electricity remained almost the sole mode of acquiring electricity in the paper industry even in the early 1950s, when a modern electricity supply structure had largely been established in Denmark. And thirdly, these autoproduction systems contained partly direct current, partly alternating current generators.

What made autoproduction so particularly attractive in the paper industry even after public supply had become available? In part, paper factories required power on a scale, which early public supply stations would not be able to provide. But by the 1940s and 1950s, public supply was available from very large public power stations. Instead the main argument for autoproduction in the paper industry, according to UPF engineer Michael Mogensen, was the necessity to produce large amounts of heating steam for the drying part of the paper making machine, and hence the possibility of combined production of heat and power: It was possible "in an economical fashion to combine heat production with the production of power consumed in the enterprise, which currently is solely distributed with the aid of electricity."[27] As a result, paper factories maintained their autoproduction of electricity even though the Danish public supply structure was rationalized, only exceptionally opting for public supply.

UPF's newly erected factory Ny Maglemølle near Næstved in the late 1930s is exemplary.[28] The area was covered by the public supply company Sydøstsjællands Elektricitets Aktieselskab (SEAS), one of the first regional public supply systems on Zealand and early included in the East-Danish power grid, thereby gaining access to cheap electricity from the large Copenhagen public power plant H. C.

Ørstedsværket as well as Swedish water power resources (in 1939, SEAS took all electricity from these two sources). Yet the paper factory chose to erect its own power station, which started regular operation in 1938. Although this 6 MW power station had the size of the municipal public supply station of a middle sized Danish town, it was significantly smaller than regional power systems at the time (20-40 MW) and of course the Copenhagen power plant (160 MW).[29] Likewise, another leading UPF factory, the Dalum paper factory near Odense, erected a new 4 MW power station in the late 1940s despite the proximity of the municipal 27 MW plant in Odense (which in turn was interconnected with the 86 MW regional system plant in Southern Jutland).[30]

Technically, the co-production of heat and power in both these new power stations involved advanced power technology.[31] Steam for heating purposes was not taken directly from the boilers, but could first perform labour in a Brown Bovery two-cylindered steam turbine (which was connected directly to the electricity generator). The turbogenerator contained several steam outlets: Steam for the main heating purpose of paper drying (other applications were glue boiling and factory heating) was taken from an outlet between the two cylinders, and thus performed labour in the high pressure cylinder before it was led through an underground channel to the paper making department of the factory. The amount of drying steam as well as its temperature could be regulated precisely (the latter was achieved by blowing condensation into the steam). The rest of the steam continued to perform labour in the low pressure cylinder and was led to the condenser, which - characteristically for the large steam outlet - was designed only for a half resp. two-thirds of the power generating capacity of the turbine.

Besides the use of modern steam turbines, the high voltage, alternating current distribution of electricity through the factory and the interconnecting links to the public power grid illustrated that these factory power plants might incorporate advanced technological options. Hence, both factories had 10 kV main feeders for internal electricity distribution, and both had interconnecting links with the public supply undertakings of their region and contracts specifying the terms of cooperation: On one hand, the public supply system was used as a back-up system, and electricity could be purchased on Sundays and holidays, when the factory machinery was turned off. On the other hand, on weekdays surplus electricity could be sold to the public supply company. Such cooperation was maintained while the public supply systems grew: In the case of the Dalum factory, for instance, cooperation with the public supply system started as early as 1917 to support the local public power station Dalum-Hjallese through wartime supply shortages. Through this station, the factory later cooperated with the large Odense municipal supply company, and when the centralisation of electric supply was completed in 1953 with the establishment of a new central public power station for entire Funen, cooperation was continued with the administrating company (I/S

Fynsværket).[32]

This, however, is not to say that autoproducers of electricity only used the technology that was most 'advanced' in standard electrification terminology (that is, AC distribution and connection to the public power grid). For instance, in this context of factory supply economic performance of the power station was important, but secondary to simplicity and low maintenance demands. This reflected that paper production rather than power production was the main concern of the factory, and was e.g. explicitly mentioned as the reason for choosing a more simple boiler preheating construction than technically possible (which large public supply plants might have preferred).[33] Likewise, DC distribution was maintained in parts of the factory, as direct current motors with their superior regulability were preferred at the paper making machines. In UPFs new Copenhagen factory in the early 1930s, for instance, most motors were directly fed by AC from the main feeder; yet the electricity was converted to direct current in the paper making department, and was subsequently fed into a common backbone for all 14 section motors of the paper making machine. Automatic regulators secured the steady output of the converter regardless of variations in voltage or frequency in the feeding AC system, as well as steady power supply under variable load.[34] The case of the paper industry, then, illustrates how autoproduction of electricity could remain economically feasible, and that autoproducers might draw upon the entire spectre of available electricity supply technologies to shape a supply system corresponding to the particular factory requirements.

Case 2: Autoproduction vs. public supply in the cement industry

Technical/economic background[35]

The production of hard-burnt so-called Portland cement, applied as an hydraulic mortar (i.e. hardening in air as well as in water) or mixed with small stones as concrete, was developed in the first half of the 19th century, and introduced in Denmark from the late 1860s. Yet the first Danish cement factories, situated on Zealand, were comparatively small, and did not last beyond the 1880s. Instead the Danish cement industry emerged around two areas at the Limfjorden and Mariager fjords in Northern Jutland, residing over huge chalk deposits for raw material and providing access for deep-draught vessels for transport of the large amounts of hardcoal used and the comparatively heavy and voluminous product, cement. The factories involved were large and few: Denmark had 5 factories by the turn of the century, 3 more were established before the outbreak of the First World War, the number again decreased to 4 in the 40s and 50s and was at 5 by 1960. Also from the beginning of the century, competition was reduced by the establishment of a cartel dominated by Aalborg Portland Cement Factory, Ltd., which operated the largest Danish cement factory at Rørdal near Aalborg. The cartel gradually evolved to include all but one factory in 1920, and like in the paper industry the co-operation was used to reorganize the industry in times of recession (in the 1930s and in the 1970s); in 1937, the participating firms were formally amalgamated into A/S Aalborg Portland. Competition came only from a cement factory established under the cooperative movement (Dansk Andels Cementfabrik), established in 1913 as a direct response to the cartelisation of the industry, and having a market share of a fifth to a fourth for the period under consideration. Since the 1930s, this meant primarily the home market, and although the exports of Danish cement factories had been considerable until then, they would decrease to insignificance by the 1950s.

How was a modern Danish cement factory from the early 20th century designed physically?[36] Basically, in the production process (1) the raw materials chalk and clay were mixed to obtain optimal chemical properties, (2) burned to clinker and (3) finally ground to powder. But all functions from gathering the raw materials by surface mining techniques to the distribution of cement by trucks and ships fell under the domain of the factory. The factory premises were considerably larger than even the paper factory premises, including for instance chalk and clay quarries, large basins for mixing and grinding the raw materials, various factory buildings and storage silos, extensive intra-factory transport systems and harbour facilities.

In the chalk and clay quarries, the raw materials were dug up largely by hand power and transported to the preparation section of the factory by means of dumping waggons on tracks, normally pulled by horses. In various sections of the preparation department, the raw materials were mixed and ground. This was increasingly achieved by the so-called wet process (which dominated in Denmark for the entire period under consideration): The raw materials were diluted in large basins, and the resulting slurry pumped into tube grinders (hollow, fast revolving cylinders containing flint stones, which ground the slurry). Finally they were mixed in the correct proportions in mixing basins.

In the kiln department, rotary kilns rapidly replaced continuous shaft kilns (which only few decades before had been introduced as an alternative to periodic kilns, which were still in use at some factories) after their first introduction in Aalborg Portland's Rørdal factory in 1899. Rotary kilns were long (well over a hundred metres in the 1930s), nearly horizontal, slowly rotating hollow cylinders, where the raw material entered continuously at the higher end and an incoming jet of air and powdered hardcoal burned at the lower end. From the beginning, Danish rotary kilns were adapted to the wet process: The slurry was pumped from the preparation basin directly into the higher end of the kiln, and on its way down was first dried, then gradually heated (and calcined) and finally sintered at the lower end at temperatures of 1400-1500 degrees Celsius. The resulting clinker (with the size of a walnut) then passed through a likewise slowly revolving and sloping cooling-cylinder, where it was cooled by an air jet. The clinker was then stored for several days (for improving quality and grindability) and then ground to powder in the cement mill department, which consisted of a set of ball and tube grinders. The product was now available for packing. In addition to these departments, this heat intensive factory would contain a hardcoal grinding department; after storage and drying, hardcoal was ground to powder in ball grinders and injected at the lower end of the kiln together with the preheated air jet from the cooling cylinder.

The cement factory, then, required plenty of power for rotary action. Figure 1a illustrates the main machinery and the mechanical power transmission system based upon power supply from a single central steam engine. The steam engine (K) provided power to respectively the raw material grinders (B), the stirring mechanisms in the slurry bassin (C), the hardcoal grinders (E), the kiln rotators (F) and the cement grinders (H). In addition, it powered ventilators, transport machines and pumps. Together, these machines had a very large power consumption and placed cement factories among the most power intensive factories in Danish industry, as their average power consumption even surpassed that of ship yards, cotton mills and paper factories.[37]

During the period up to the 1960s under consideration here, the basic layout of the production process remained fairly constant, although the machinery was constantly improved; in case of Aalborg Portland's factories, technological development from the very beginning occurred in close cooperation with the Danish cement machine manufacturer F. L. Smidth & Co (which had direct interests in Aalborg Portland) and included for instance larger and more efficient grinders and kilns.[38]

Electrification of the cement industry

The 1886 survey of electricity supply systems in Denmark included the Cimbria cement factory, the oldest cement factory on Jutland, which illustrates the role of electric lighting in the cement factory: Electricity was produced on a 6 kW dynamo, which was powered by the main steam engine of the factory and supplied some forty incandescent lamps for indoor lighting as well as the outside of the engine house and the kilns. Furthemore, it supplied three bright arc lights at the slurry bassin, the harbour and the chalk quarry. This enabled the factory to operate during the night; bright electric lighting of the chalk quarry, for instance, enabled the workers to continue in shifts throughout the night and supply the large chalk demand of the factory. The lesser nightly demand of clay, by contrast, was stocked during the day.[39]

Yet, like in the paper industry, it was the application of electric power that made the cement industry particularly electricity intensive during the first decades of the 20th century. What, then, were the advantages of electric drive in such a factory?

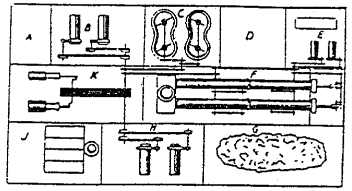


Figure 1a: Mechanical drive. A= Initial crushing; B= Tube grinders; C= Stirring mechanisms for the slurry; D= Hardcoal storage; E= Hardcoal grinders; F= Rotary kilns; G= Clinker hall; H= Cement grinders; J= Steam boiler; K= Central steam engine.

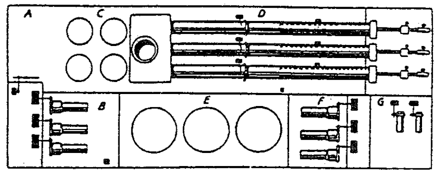


Figure 1b: Individual electric drive (excl. power station). A= Initial crushing; B= Tube grinders; C= Slurry storage; D= Rotary kilns; E= Clinker silos; F= Cement grinders; G= Hardcoal grinders; ■= Electromotor.

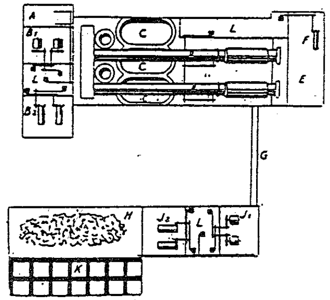


Figure 1c: Group electric drive (excl. power station). A= Initial crushing; B= Tube grinders; C= Slurry basin; D= Rotary kilns; E= Hardcoal storage; F= Hardcoal grinders clinker silos; F= Cement grinders; G= Clinker transport; H= Clinker hall; J= Cement grinders; K= Cement silos; L= Motor rooms; ■= Electromotor.

Figures 1a, b and c: Basic scheme of a cement factory (wet process) with mechanical drive, with individual electric drive and with group electric drive. Source: "Elektriciteten i Cementfabrikkerne", Elektroteknisk Tidsskrift (1913/14), Vol. 18: pp. 93-94.

Again, these advantages were exclaimed in electrotechnical magazines in the early 1910s. Information was to a large extent provided by electrotechnical firms as Siemens-Schuckert and AEG, which had electrified several large cement factories in Germany and recognized the cement industry as a large potential customer, as examples of e.g. electrified German cement factories could illustrate.[40]

Electric drive was, of course, recommended for all machinery.[41] Like in the case of the paper industry, a key argument was that the particular large mechanical transmission systems in these spacious factories caused very large power losses. In small and middle sized factories (up to 300.000 barrels of cement produced annually), the energy losses of mechanical and electric transmission might equal out. But for larger factories electric power transmission would be preferable, as losses in shafts and belts increased faster than electricity losses. The problem could of course be solved by placing different steam engines in the various sections of the factory, but this solution had decisive drawbacks compared to electric drive: On one hand, if the engines were supplied with steam from a common boiler, large heat losses would occur in the pipeline installations. Decentral boilers, on the other hand, would complicate the operation and increase investment costs substantially.

There were other arguments in favour of electric drive, too: For instance, electric power transmission would substantially decrease repair and maintainance costs, which could be rather high for these large mechanical transmission systems. Another important advantage included the labour saving effect of electrification, as electric transport machines could make the factory more automatic. Finally, electric power transmission increased the flexibility of factory design, that is, power requirements would no longer dictate where the machines had to be situated. Up till then, cement factories had been designed according to the power flow and not the production flow: The most power intensive machines, the slurry grinders and the cement grinders (which together consumed no less than two-thirds of the total power requirement of the factory[42]) would be located as close to the central steam engine as possible, as illustrated in figure 1a (very large factories, however, would often install small separate steam engines to provide power to more remote sections of the factory). Electric power transmission, by contrast, made possible individual and group drive and thus a factory design that followed the rationality of the production flow. Some design possibilities are illustrated in the figures 1b and 1c, illustrating cement factory designs with individual drive and group drive respectively. Indivdual drive had the advantage of optimal control of the individual machines and reduced mechanical transmission to a minimum; yet, it had the disadvantage to group drive that it was not always possible to install the motors in dust-isolated rooms, which made casing of the motors necessary, as cement dust was omnipresent in early 20th century cement factories.

Danish cement factories introduced electric drive immediately after the turn of

the century, and although it was introduced in stages, electric drive dominated already by 1910. Illustrative is the electrification of the 'Danmark' cement factory. Electric drive was first introduced in 1903, extended substantially two years later (when Aalborg Portland bought itself into the enterprise and thereby added a substantial amount of capital), and completed in 1909-10 with the erection of a new electric power station following the conversion to rotary kilns (this was the last cement factory in Denmark to adopt the new kiln technology). This final step "secured a strongly improved power economy in the new factory building."[43] Yet, it was not necessarily the application of electric drive in the factory buildings that triggered the introduction of electric power: In the beginning of a large extension and modernization process between 1907 and 1909, Aalborg Portland's Rørdal factory first introduced electric power supply to modernize the raw material transport between the chalk and clay quarries and the factory. Whereas the dumping waggons previously had been pulled by horses, now electric locomotives (electric locomotives had the advantage over other locomotives that they could be driven by uneducated labourers) took over raw material transport on these 1 resp. 2,5 km. tracks. In the following year, electric drive was also introduced in the actual production process, and a new power plant was erected to supply electric power to new kilns, a new wet-process preparation department, a new hardcoal milling department and of course to the electric traction.[44]

By 1910, all Danish cement industries had electric supply systems, and all but one had introduced electric drive on a massive scale; indeed, the three largest cement factories had an electric power supply that could match the supply systems of larger province towns (the largest factory, Aalborg Portland's Rørdal factory, had a power plant that was larger than the newly erected municipal power plant supplying Aalborg city).[45] However, like in the paper industry, individual drive would become standard only in the following decades. Illustrative is the cooperative cement factory, which had been equipped with electric drive from its establishment in 1913 with a 430 kVA system, and had been expanded since in several stages. Yet only in the first half of the 1920s mechanical power transmission by shafts and belts was dismissed altogether, and individual drive installed throughout the factory. The wiring, which connected the turbogenerators with the motors, stretched 29 km. in total.[46]

Autoproduction and public supply in the cement industry

Although most foreign cement factories produced their own electricity, the editors of *Elektroteknisk Tidsskrift* were pleased to present a German cement factory supplied by a public supply company in the early 1910s. This particular factory was in operation round the clock and had an annual electricity consumption of approx. 10 GWh, which allowed for 'more beneficial conditions' in case of public supply.[47] This option, however, was not chosen by the Danish cement industry.

According to the registers of the Electricity Commission, all eight existing Danish cement factories at the eve of the First World War had autoproduction installations, and maintained them until the early 1930s.[48] Table 2 suggests that this situation had hardly changed by the 1940s and the early 1950s; while electric motors dominated the factory power supply completely, four-fifths or more of the electricity consumption was autoproduced, while an increasing yet minor share of this consumption was purchased from public supply companies. The overall consumption of autoproduced electricity increased at least until 1960, when it reached 83 GWh annually, whereafter it decreased.[49]

Table 2: Some choices of electrification in Danish cement factories 1940-1952 (Source: Statistics of Production[50]).

	1940	1946	1951/52
Electric engine power in % of total engine power installed	95%	96%	95%
Consumed autoproduction in % of total electricity consumption	91%	89%	78%
AC generating power in % of total generating power	85%	96%	98%

What made autoproduction attractive in this particular case? Firstly, the issue of co-production of heat and power, which was emphasized as a decisive factor in favour of autoproduction in the paper industry, is worth investigating. In the early 1920s the Technology Commission under the Ministry for Domestic Affairs classified the cement industry as a 'non-combined heat and power producer', and thereby as an industry likely to benefit from public electric power supply.[51] This indicates that the consumption of steam from the boilers for heating purposes was limited. On the other hand, the Commission obviously overlooked the possibility of applying waste heat in the exhaust gasses from the kilns to generate power. Waste heat boiler technology had been (unsuccessfully) pioneered already before the turn of the century, and received 'almost universal attention of cement manufacturers' by 1915, at least in the United States.[52] In Denmark, F.L. Smidth & Co started research on this technology and installed such waste heat boiler systems at several Danish cement factories (among which the large Rørdal factory) shortly after the First World War. In the early 1930s, waste heat boiler technology was still referred to with optimism.[53] By the late 1930s, however, this technology received less attention. It was observed that considerable fuel savings had been obtained, but the waste heat boiler system also had disadvantages: It proved complicated to operate, and the dependence of the boiler on the kilns constrained the steady operation of the power station.[54] In retrospect, other methods of energy conservation had become more important, particularly more power efficient grinder designs and more heat economic kiln designs. Notably, the exhaust gas

temperature in F. L. Smidth kilns had been reduced from approximately 550 degrees Celsius in the late 1910s to 200 degrees in the late 1930s and to the near minimum of 130 degrees (just before condensation effects) in the late 1940s, which obviously decreased the feasibility of waste heat boilers. Waste heat, then, was primarily employed for other applications such as factory heating and drying in the hardcoal department rather than for electricity production.[55]

There were other physical characteristics of cement factories, however, that made autoproduction of electricity attractive. In case of the cooperative cement factory, the factory power plant size and its load factor were identified as crucial factors in favour of autoproduction.[56] Firstly, this factory had a power station significantly larger than the local public supply company, that is, the municipal supply company of Nørresundby (like the cooperative factory situated at the north bank of the Limfjorden): While the latter had an engine power of 0.7 MW in 1925, the cement factory had recently erected a new power station with two 3 MVA turbogenerators (one of which was for back-up). It turned out, however, that the turbogenerators could supply the factory with half load, and sale of the surplus electricity was an attractive option. Secondly, then, the production of surplus electricity turned out so cheap, that the municipality preferred to purchase its electricity from the cement factory and use the municipal plant as a back-up station only. From 1925 the factory supplied the Nørresundby municipality and its surroundings, and by a renewed contract in 1934 the municipality increased its purchases and commenced supply to other towns and their surroundings, which found it beneficial to purchase about half or more of their electricity supply from Nørresundby and hence the cement factory. The steady load of the factory was emphasized as the decisive economic variable: The municipal power plants were judged to exploit in average 15 to 20 % of their engine power, while the cement factory plant supplying both the factory and the public might exploit 40% of its engine power. This was due to the lighting peaks of the public load, which e.g. forced the public power stations to start back-up engines, while the cement factory simply could turn off some of its power intensive grinders and thereby maintain a steady load for the turbogenerators. Thanks to its size and load factor, the cooperative factory then became a major autoproducer of electricity and also an important public supplyer. In the 1920s and 1930s the cement factory sold about a fourth to a third of its electricity production; in 1935, sales were 7.3 GWh, while total production was at 18 GWh. This production was not only much larger than the combined production of public power stations in the Vendsyssel supply region (that is, Northern Jutland above the Limfjorden, see Fig. 2); it was also larger than the nearly 15 GWh production of the Aalborg municipal power station at the southern bank of the Limfjorden, that is, the public power station of one of the largest province towns in Denmark, which supplied the Northern Jutland supply region south of the Limfjorden.

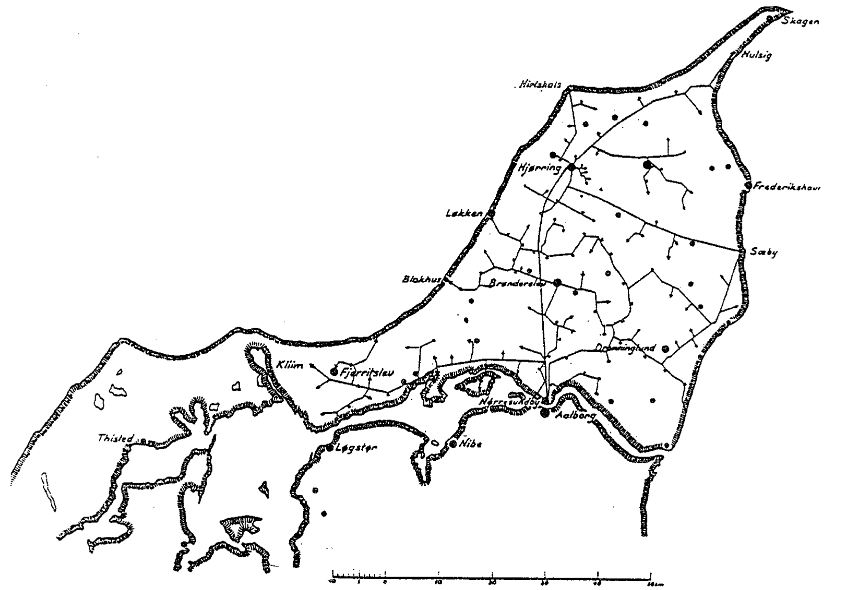


Figure 2: The Vendsyssel electricity supply region (roughly Northern Jutland above the Limfjorden) was largely supplied by surplus electricity from the cooperative cement factory in Nørresundby at the north bank of the Limfjorden. Notably, Aalborg Portland's Rørdal cement factory was situated few kilometres East of Aalborg at the South bank of the Limfjorden, and thus belonged to the Aalborg municipal supply region (which roughly supplied the Northern Jutland region below the Limfjorden). Source: Marius Holst, Dansk Andels Cementfabrik 1911-1931 (Copenhagen, 1932): p. 81.

In addition to size and load factor, there were other factors favouring autoproduction in the cement industry. The maintainance of the autoproduction plant at Aalborg Portland's Rørdal factory on the south bank of the Limfjorden, for instance, was until recently motivated partly by the fact that the power machinery had been written of in the balance sheet, and partly by the co-production of heat and power from the boilers, which had gained in significance, primarily due to the necessary preheating of the low-quality crude oil which was increasingly used for fuel.[57]

Like in the case of the paper industry, then, autoproduction of electricity could remain economically feasible in the period under consideration and beyond with reference to technical advantages such as exploiting the large and steady factory power demand and the co-production of heat and power, first by waste heat utilization and later by more conventional co-production of heat and power. A

further examination of the cases of the cooperative factory and the Rørdal factory after 1960, however, suggests the more complex character of the choice of electricity supply system. During the 1950s the Aalborg municipal supply company had erected and thereafter expanded a new power station, which by 1960 had an engine power of 118 MW and had been integrated in the West Danish power grid. In response, the public supply companies of the Vendsyssel supply region gathered in NEFO (Nordjysk Elektricitets FOrsyning) in order to purchase electric power from the large Aalborg plant (until NEFO established its own central power plant in the late 1960s). Relative to this plant, the cement factory power plant had now become a comparatively small power station and rapidly lost importance as a supplier of the public: While it had supplied most of the Vendsyssel region in the late 1940s, in 1960 only the public supply companies of Nørresundby and surroundings purchased approx. half of their electricity from the factory (the other half was purchased from NEFO and hence mainly the Aalborg plant). Under these circumstances, the cooperative factory reevaluated the feasibility of its autoproduction plant in the early 1960s: The relatively high operation and maintenance costs were problematised, and the fact that power production only was a secondary task to cement production was emphasised. Yet the feasibility of the autoproduction plant decisively depended upon the electricity price set by the public supply company; after 'fierce negotiation', NEFO could offer 'favourable conditions' for purchase of electricity by the factory. This tipped the scales in favour of public supply: In 1962 the cooperative factory closed down its power plant and started purchasing its electricity from NEFO.[58]

By contrast, the expansion of the Aalborg municipal power plant did not motivate the Rørdal factory to close down its power plant: The autoproduction plant continued to produce electricity cheaper than electricity purchased from the Aalborg municipal supply company. However, the economic advantage of autoproduction was no longer as self-evident as it had been previously, and did no longer provide incitements for new investment in this 'secondary' activity to cement production. Therefore, the factory maintained its existing autoproduction installation, but also extended its cooperation with the Aalborg municipal supply company to buy an increasing amount of additional electricity to meet the increasing electricity demand of the factory. Also here the public pricing system was a decisive factor, and also here this was clearly revealed when the Rørdal factory finally shut down its power plant in 1992: A new and more beneficial pricing agreement with the Aalborg municipal supply company was mentioned as the immediate cause, which made the maintenance costs of the old power machinery a decisive drawback of the old system and thus tipped the scales to the favour of exclusively public electricity supply of the factory.[59]

This suggests, then, that by 1960 neither autoproduction nor public supply was unambiguously the economically superior technology in the context of the cement industry. Instead, supposedly peripheral factors proved decisive, such as the pricing strategies of the public supply companies involved. This theme will be further addressed in the case of the flour industry.

Case 3: The flour industry and the success of public electricity supply

Technical/economic background[60]

The mass production of flour in so-called automatic corn mills had been developed in the United States in the late 18th century, but was first introduced in Denmark in the Copenhagen area in the 1830s, and spread to most province towns during the 1850s and 1860s. By the 1870s, Danish flour factories flourished and constituted a leading industry in technology and exports; yet they were forced to reorganize in the flour crisis of the 1880s and 1890s, when the most important importers of Danish flour (Germany and Sweden) took to protectionist measures to favour their own flour industries. Production was concentrated in approx. forty large factories, and focus shifted from export to urban home markets. This situation remained basically unchanged in the period under consideration here, as the number of flour factories in Denmark remained fairly constant between 35 and 50 factories before 1960.[61] This number also shows that the flour industry was not nearly as concentrated as the paper and cement industries. In absense of firms with virtual or real monopolies, an important factor regulating the industry were the branch interest organisations, although different production conditions limited cooperation to specific fields for many years.[62]

Dependent on transport facilities for raw material and fuel on one hand and large urban markets on the other, flour factories were normally situated in the harbours of larger towns, where they occupied considerably less space than the paper and cement factories did. Physically, flour factories were often multi-stored buildings (5-stored buildings were not uncommon) flanked by similarly high storage buildings or silos. In a modern flour factory of the turn of the century, at least four departments with a typical set of machines could be distinguished. Firstly, the silos for grain storage contained automatic scales of balance weighing the incoming grain as well as cleaning machines for initial cleaning, for instance ventilators removing dust and sand by suction (and later shaking grates removing larger stones etc.). Secondly, the actual cleaning department, often at the top floor of the factory building, contained machines for removing dust (ventilators and brushing machines), seeds and some small stones ('trieurs'), metal pieces (magnets) and a wet cleaning machine removing sponged grains and remaining stones. Thirdly, in the grinding department the roller grinder system had been massively introduced during the reorganisation process caused by the flour crisis. In a single roller stand,

the grain was grinded between to revolving cylinders; The department, then, was made up by a system of differently adjusted roller stands (with decreasing distance between the rollers and different grooving) and bolters alternately, so that the grain was grinded gradually: Flour was extracted after each grinding step, and the remaining particles grinded further. In this way, a high grinding efficiency could be obtained. In the final department, flour mixing machines and packing machines prepared the final product.

In addition to these machines, the entire process of mass-producing flour had from the very beginning depended greatly upon transport machines like elevators and Archimedean screws, which transported the grain and flour from machine to machine and from department to department. This enabled a continuous flow, in which human interference was eliminated as far as possible. Consequently, like the paper and cement industries the flour industry was extremely capital intensive, and also flour factories were in operation continuously day and night (generally with the exception of Sundays and holidays).

Finally, rotary action to all these machines, of which the grinders were most power demanding (consuming approx. three-fifths of the factory power demand[63]) was normally provided by a large, central steam engine of approx. 100 hp. around the turn of the century. From the steam engine in the basement or the engine house, power was transmitted to the different floors of the factory by means of the a vertical main shaft. At each floor, power was taken and by shafts and belts provided to groups of machines with similar power requirements. The factory therefor had a cleaning floor, a sieving floor and a grinding floor. Parallel to the main shaft, finally, belts might transmit power between the floors, for instance from the steam engine to some fast revolving cleaning machines.

Slow electrification of the flour industry

Like in the previous cases of the cement and paper industries, electric lighting was introduced in the flour industry in the 1880s, and its economy, steadiness and fire safety quickly made electric lighting attractive for the modern flour factory.[64] An early example is the new electric lighting installation of the Langebro Steam Mill, a leading flour factory in Copenhagen which was modernized in 1888. The installation, which was praised for its safety and its economy compared to the previous gas lighting system, consisted of a small dynamo attached to main shaft of the factory thus utilizing surplus power from the central steam engine (it consumed merely 6 of the 220 indicated steam engine horsepowers) and some 50 steady lamps in the factory itself, some 20 lamps in offices and for outdoor lighting and sockets where transportable lamps could be plugged in. A back-up system consisting of a small steam engine and a directly connected dynamo was used when the factory machinery was idle.[65]

While electric lighting was no less popular in the 1900s than in the other industries reviewed, electric drive remained notably absent. Arguments for partial electric drive had already been forwarded by electrotechnical propagators around the turn of the century: At that time, mechanical power transmission was generally considered optimal to supply most machines, but electric power transmission might provide power to particularly transport machines like elevators and conveyor belts, which were often idle and thus could be shut of in case of individual (electric) drive.[66] Yet, the 1906 industrial census noted no electric motors in the flour industry at all and the 1914 census only a few. In addition, the registered autoproduction installations (some of which the censuses might have missed) in 1910 remained typically very small with very few exceptions. Of these, the largest electricity producer (Munke Mølle in Odense) only reported that electricity was used for lighting, while two others (factories in Vejle and Esbjerg) did use electric drive on a very limited scale only: Although electricity was produced by a dynamo powered by the central steam engine of the factory, electric drive was not used in the factory itself but exclusively in the storage buildings.[67]

By the 1910s, the slow introduction of electric drive was reflected by the increasing dissatisfaction in electrotechnical engineering circles with the pace of electrification of the flour industry. Although transport machines and machines outside the main building were occasionally driven electrically, the flour industry was far behind other industries in Denmark to invest in electric drive. For instance, it was complained that "only in exceptional cases electricity has been applied in the flour industry of our country" and that this industry was "perhaps the only occupation, where electricity has not gained wider application." Examples of electrification of some of Germany's, England's and Sweden's leading flour factories were used to illustrate this Danish 'backwardness.'[68]

Furthermore, flour factory entrepreneurs and technicians were blamed for holding on to the idea that electric drive was too expensive in their industry, a view which according to the propagators of electrification was based upon short sightedness. For flour factory entrepreneurs were in the habit of assessing power supply options plainly as the power costs per installed horsepower per hour. The propagators of electrification, however, argued that *indirect* savings made all-electric drive feasibile, even though the total amount of motor horsepowers would increase.[69] These indirect advantages not only included the possibility of individual drive to turn off idle horsepowers. Firstly, factory entrepreneurs should be reminded of the fact that the very design of the production process followed the necessities of power distribution rather than of the production flow, while individual electric drive enabled to place machines, where they fit best according to the production process. Secondly, electric motors produced more steady power than other engine types, which for flour factories was particular important in the aspirators (ventilation machines) in the cleaning department, where the speed of the air stream separating dust from grain was crucial. Thirdly, this steady drive would

facilitate more steady grinding and sieving and therefore a higher productivity as well as a better product. Finally, electric drive enabled the measuring of power losses; often, roller stands would be in need for re-grooving and cause major power losses without being identified. In an electric power transmission system, however, an installed ammeter would immediately indicate the increased power consumption of such a roller stand and facilitate immediate action.

Few years after, all-electric drive was indeed introduced in the Danish flour industry. Among the first electrified Danish flour factories in the mid 1910s were the 'Olympia' factory in Randers and a new factory in Svinninge.[70] The preference of group drive over individual drive at this time is illustrated by the electric power installation of the Svinninge factory: In the silo, a 10 hp. electric motor powered the transport machines and an aspirator. In the cleaning department at the third and top floor of the main building, a 15 hp. motor powered another aspirator, a trieur, an electromagnet, a brushing belt and a roller stand for initial crushing. At the grinding department, a 40 hp. motor powered the midget grinders (multiple grinding and sieving machines), a smooth roller stand and another aspirator. Finally, the packing department used a 5 hp. engine for the flour mixing machine.

But although all-electric drive thus was introduced in the Danish flour industry, the transition from mechanical to electric drive was by no means completed by the 1920s. Many flour factories continued for decades to apply electricity for lighting only and incidentally for partial electric drive, while the main machinery remained powered by the central steam or diesel engine. Extreme examples are the flour factories in Nykøbing Falster and in Horsens, which both had electric lighting by 1910, but did not introduce all-electric drive until after the Second World War.[71]

This comparatively slow transformation process, then, reflected serious drawbacks of all-electric drive from the point of view of factory entrepreneurs. They were not only annoyed by the propagating attitudes of electrotechnical engineers, but particularly rejected the advantages of group or individual drive. Different from most industries, they regarded the full-automatic flour factory as one large machine. This implied, firstly, that nearly all machines were in operation continuously, which rendered the acclaimed economic profits of group or individual drive minimal. And secondly, this implied that a breakdown anywhere in the factory might necessitate a complete factory stop. As continuous operation was the main economic factor in the flour factory, there was no point in introducing a large number of new potential breakdown sources in the form of electric motors all around the factory, where they would often be surrounded by dust and hard to get to for maintenance and repairs. In this line of thought, central line drive minimised the breakdown risk, and for central line drive the advantages of electric motors over steam and diesel engines were minimal.[72]

All-electric drive and the transition from autoproduction to purchase of electricity

According to the registers of the Electricity Commission, in the early 1910s autoproduction of electricity in the flour industry did not dominate as it did in the paper and cement industries: More than half of the flour factories either purchased electricity or did not use electricity at all. On the other hand, the autoproduction system still was an important supply system, and many flour factories of even larger province towns and Copenhagen preferred autoproduction of electricity to public supply.[73] Between 1915 and the beginning of the Second World War, however, most of these autoproducing flour factories replaced their autoproduction installations with public supply. The remaining autoproducers opted largely for public supply after the war or in the early 1950s. The choices of electrification in the Danish flour industry by the 1940s are illustrated in table 3.

Table 3: Some choices of electrification in Danish flour factories 1940-1952 (Source: Statistics of Production[74])

	1940	1946	1951/52
Electric engine power in % of total engine power installed	70%	75%	88%
Consumed autoproduction in % of total electricity consumption	7%	6%	1%
AC generating power in % of total generating power	8%	37%	43%

By 1940, then, electric motors already were the most important power source for machine drive (but they did not yet dominate as in the paper and cement industries), and their share of the total machine drive increased in the following decade. Simultaneously, the importance of autoproduction relative to public supply decreased rapidly, and in the early 1950s no less than 99% of the consumed electricity in the Danish flour industry was purchased. Finally, the increasing relative importance of AC generators in autoproduction is due to the fact that the most technically advanced flour factories were the last to give up autoproduction.

What caused this gradual but nearly complete transition from autoproduction of electricity to purchase of electricity from public supply companies? The table suggests that the introduction of all-electric drive in the flour industry and the decreasing importance of autoproduction of electricity might be correlated. Specific cases confirm this assumption. For instance, already the first Danish flour factories to adopt all-electric drive in the mid 1910s were supplied by public supply companies. The Svinninge factory thus obtained electricity from Nord-vestsjællands Højspændings Elektricitetsværk, an early regional supply company supplying North-Western Zealand and whose power plant was situated nearby. Likewise, the 'Olympia' factory in Randers (Jutland) obtained power from the

municipal supply company.[75] A typical later example is the flour factory at Slagelse, which had installed a 2 kW autoproduction system for electric lighting in 1903. In the 1930s electric lighting still was the only application of electricity in the factory, although it had been connected to the municipal power station, probably for back-up in case the main steam engine was shut off. But when electric drive was installed in 1940, the autoproduction installation was disposed of, and replaced by a 300 kVA transformator station in order to take electric power from the municipal supply system.[76]

In fact, this connection between the introduction of all-electric drive and the transition from autoproduction to purchase of electricity had already been stated in the early agitation for all-electric drive in the flour industry. In electrotechnical engineering circles, electrification of the flour industry was seen as a possibility to combine the diffusion of electric drive in the industrial sector with the growth of the public electricity supply system. On one hand, flour factories were particularly attractive customers for the rapidly expanding electricity supply companies; they had an extremely steady power consumption day and night, 6 or 7 days a week, which might greatly improve the load factor of the supply company. On the other hand, exactly because flour factories were a desired customer, in theory utilities might offer electricity at particularly low tariffs to attract this particular group as customers. These low tariffs, in turn, should make all-electric drive economically feasible for the flour factory. Therefore, already in 1910 the attitude of electrotechnicians was that "the question of electric drive in flour factories is relevant, only if electricity is purchased from a public supply plant." Under such circumstances, even the largest flour factories might be electrified with purchased power, as the examples of foreign flour factories illustrated.[77] It is also in the light of this double concern for the diffusion of electricity in society, that the irritation of the electrotechnicians about the slow electrification of the flour industry must be understood.

Supply from a public supply company, however, might pose some new problems for flour factories willing to electrify. For instance, in the 1910s there was a very realistic concern for blackouts in public supply systems using high voltage transmission, which per definition were beyond the control of the factory and for which public supply companies were unwilling to accept responsibility. Reliance upon such power suppliers, then, was incidentally depicted as "an evil, which is accepted as a matter of course in our modern times of centralisation."[78] Furthermore, in theory flour factories could autoproduce electricity at comparatively low cost: Their steady power consumption and hence high load factor did not only make them ideal public supply customers, but also ideal autoproducers. Finally, although the application of steam for heating cannot be compared with that of paper factories, flour factories did require some heating for drying the grain, for the conditioner (a new machine for exactly regulating the moisture content of the raw material) and factory heating. The importance of heating steam is illustrated by the flour factory in Nykøbing Falster, which maintained its steam boiler for heating purposes even after the steam engine had been replaced by a transformer station.[79]

Pricing policies and the success of the public supply system

Even this case of a nearly complete transition to public supply, then, is not necessarily best understood in terms of the unambiguous technical-economical superiority of public supply systems. Rather, the economic feasibility of purchased relative to autoproduced electricity depended upon a number of factors, which made the pricing policies of public supply companies decisive. Pricing as a general strategy to lure potential autoproducers into the public supply system was already identified and practised by leading regional supply companies in the early 1910s, arguing for differentiated tariff systems to favour large customers or - better - for individual negotiation with the specific consumer involved: The optimal electricity price should take into account the particular factory features as well as the supply system features, and be determined so as to benefit both parties.[80] Indeed, the first all-electric flour factories at Svinninge and Randers took the benefit from such pricing policies of the public supply companies concerned: The former had a special arrangement with The North-West Zealand regional supply company, which delivered electricity "on terms extremely favourable for the factory." The latter benefitted from a differentiated pricing system favouring large consumers.[81]

The importance of pricing policies and thereby the constructed character of the success of public supply in the flour industry was perhaps most clearly revealed in and immediately after the Second World War. In this period of increased electricity rates, representatives of the flour industry problematised the pricing methods of particularly municipal supply companies. Whereas progressive public supply companies long ago had recognized the need to attract large electricity consumers by means of individual pricing, municipal supply companies often continued one-sidedly to determine electric power prices at the general level of the supply company budget. Even worse in the view of the industry, the profit margin on electricity sales was unreasonably large, as often electricity supply was used to balance the municipal budget. The industry fiercely criticised this 'exploitation' of the municipal supply 'monopoly' (which often existed in practice), which was depicted as indirect taxation of the industrial sector.

Obviously, the problem was particularly pressing for the flour industry, for which electricity purchases constituted a major expense (in 1945 electricity purchase might constitute up to 20% of production expenses). As a consequence, while 30 years earlier electrotechnical engineers had pointed at the attraction of flour factories as customers of public supply companies, now flour factory representatives themselves pointed out this attraction in the language of electrical engineers - emphasizing their high load factor, extremely large operation time (possibly 5600 hours annually) and high power factor (0.9). Furthermore, they threatened that these characteristics did not only make flour factories attractive customers for public supply companies, but also the kind of consumers, which "would not hesitate to erect autoproduction installations, in case public supply companies cannot or do not want to recognize the value of flour factory customers by offering favourable electricity prices."[82]

An example of a factory which took this consequence was Munke Mølle in Odense, one of the very largest flour factories in Denmark. This factory had erected an autoproduction installation for lighting on its new premises in 1905, but had preferred to buy its electricity from the Odense municipal supply company by the early 1930s. During the Second World War, however, the factory problematised the relatively high electric power prices of the Odense municipal supply company, which was clearly exposed in a comparison of electricity rates across the country published by the Society for Danish Trademills. It showed that Munke Mølle was one of the most electricity intensive flour factories with an annual electricity consumption of 1.5 GWh, but still paid a significantly higher kWh price than much smaller factories elsewhere in the country.[83] The factory now urged a "more fair pricing policy" from the Odense municipal supply company, but although the supply company was willing to negotiate, it did at the time not meet the demand set by the flour factory: The electricity price should not exceed the costs for which the factory could autoproduce its electricity.[84] From 1946, therefore, the factory operated a new autoproduction installation, and the link to the public supply system became a back-up only. With reference to the pricing policy of the public supply company, then, a relatively small 0.3 MW autoproduction plant was judged more economical than supply from the nearly 30 MW Odense public power plant.[85]

In 1949, however, the public supply situation changed with the establishment of a supply company for the entire Funen region, the I/S Fynsværket, in which among others the Odense municipal supply company participated. This company would soon erect a new 82 MW power station, and could probably offer more advantageous electricity rates to the flour factory: In 1950 the Munke Mølle factory shut down its power plant and expressed the intention only to purchase electricity in the future.[86]

Conclusion

The cases of the paper, cement and flour industries have been used to place an often heard asymmetrical conception of the history of electricity supply systems in perspective. This conception presupposes an ahistorical economic and technological superiority of public supply systems relative to autoproduction systems. However, it has been shown that actors attributed a technical-economical rationality to the autoproduction system in the paper and cement industries for largely the entire period up to 1960, even though the public supply system by then had expanded for some seven decades and had been centralized. Conversely, it has been demonstrated that despite the apparent technical-economical rationality of public supply in the flour industry (and later in the cement industry), even here the success of public supply was not a matter of course, but involved the decisive social innovation of pricing policy, which opposed the conventional public supply company practice of determining electric power prices at an overall level based upon the overall production costs. The point of these observations is not, of course, to question the rationality of a centralized public supply system. It is to assert, firstly, that it is fruitful to study the history of electricity supply systems (like other authors have illustrated for other technologies) not as a rational series of subsequent, better technologies, but in a spectre of co-existing technologies. And secondly, that the success and failure of either system was not determined in a narrow technical-economical framework, but involved negotiation and agreement between social actors in a specific social and technological context. In this interpretation, autoproduction of electricity proved to be a dynamic sociotechnical supply system also in the age of public electricity supply.

Notes

[1] For the history of public electricity supply in Denmark see primarily Birgitte Wistoft et.al., *Elektricitetens Aarhundrede. Dansk Elforsynings Historie Vols. I and II* (Copenhagen: D.E.F., 1991-1992).

[2] The patterns of electrification of the Nordic countries are compared in Arne Kaijser, "Controlling the Grid. The Development of High-Tension Power Lines in the Nordic Countries" in Arne Kaijser & Marika Hedkin (eds.), *Nordic Energy Systems. Historical Perspectives and Current Issues* (Canton, MA: Science History Publications, 1995): pp. 31-54. For a comparative survey of the electrification of industry in the Nordic countries, which briefly touches upon the issue of autoproduction, see Timo Myllyntaus, "Kilowatts at Work. Electricity and Industrial Transformation in the Nordic Countries", *Ibid.* pp. 101-128.

[3] The importance of this view in the historiography of Danish electricity supply is postulated in Erik van der Vleuten, *Betragtninger over den danske elforsynings udvikling. Ph. D. Progress Report* (Århus: History of Science Dep., 1995).

[4] V. Faaborg-Andersen, "Elektrificeringen", in Svend Dahl (ed.), *Danmarks Kultur ved Aar 1940. Vol.4* (Copenhagen: Det danske Forlag, 1942): pp. 38-58. To my knowledge, the only account describing both autoproduction and public supply over a longer period of time is Steen Böcher's social-geographical account of the electrification of Denmark (after the example of Philip Hjulström in Sweden). Yet, also here an element of teleology is added. Steen R. Böcher, "Danmarks Elektrificering", *Geografisk Tidsskrift* (1945-46), Vol. 47: p. 1-42.

[5] V. Faaborg-Andersen, "Industriens Kraftforsyning gennem Tiderne" in Eugen Wolfson (ed.), *Danmarks industrielle Udvikling* (Copenhagen: Jul. Gjellerups Forlag, 1943): pp. 23-51 on p. 51.

[6] Wiebe E. Bijker, *Of Bicycles, Bakelites, and Bulbs. Toward a Theory of Sociotechnical Change* (Cambridge, MA.: The MIT Press, 1995): pp. 14-15 and 270.

[7] Already in 1911 Helge Holst predicted the disappearance of autoproduction of electricity due to the introduction of high voltage transmission. Helge Holst, *Elektriciteten. De elektriske Kræfters Frembringelse og Anvendelse i Menneskets Tjeneste. Vol. II* (Copenhagen: Gyldendalske Boghandel/Nordisk Forlag, 1911): p. 43.

[8] M.B. Mogensen, "De private elektricitetsværker og rationaliseringen", *Ingeniøren* Vol. 51 (1942): p. A113-116. A survey of technological options for autoproducing systems is M.B. Mogensen, "Nogle retningslinier for udførselen af elektriske stærkstrømsanlæg i store industrielle virksomheder", *Ingeniøren* Vol. 51 (1942): pp. E4-E11.

[9] N.C. Hansen, "Elektriske Lysanlæg udførte her i Landet", *Industriforeningens Tidsskrift* (1886), Vol. 2: pp. 322-35 and 355-360. To this must be added electric lighting systems installed by foreign companies, such as the system installed at Burmeister & Wain by Société Générale d'Electricité in 1879. Jørgen Rode (ed.), *Københavns Elektricitetsværker 1892-1942* (Copenhagen: 1942): p. 19.

[10] *Elektricitetskommissionen-Elektricitetsrådet 1907-1957* (Copenhagen: 1957): p. 38.

[11] Danmarks Statistik, "Elektricitetsværker i Danmark 1931/32", *Statistiske Meddelelser (S.M.)* 4, 93, 5: p.76; "Elektricitetsværkerne 1950/51", *S.M.* 4, 149, 2: p. 17; *Dansk Elværks-statistik 1960/61*: p. 48; *Dansk Elværksstatistik 1965/66*: p. 49. From 1923 to 1930 the smallest autoproducers were not included in the survey.

[12] The autoproduction of electricity accellerated in the late 1980s and early 1990s. In 1993, industrial autoproducers produced 548 GWh, while autoproduction installations based upon renewable energy sources (with primary production for own consumption) produced another

60 GWh. *Elforsyningen. Ti-års statistik. Status og Tendenser 1984-1993* (Danske Elværkers Forening, 1994): table 14A.

[13] Sources: **(1)** 1924/25-1938/39: Electric power plant statistics in resp. *Statistiske Meddelelser* 4, 72,5; *S.M.* 4, 74, 5; *S.M.* 4, 76, 4; *S.M.* 4, 79, 6; *S.M.* 4, 81, 3; *S.M.* 4, 85, 1; *S.M.* 4, 88, 1; *S.M.* 4, 90, 4; *S.M.* 4, 93, 5; *S.M.* 4, 95, 3; *S.M.* 4, 97, 5; *S.M.* 4, 98, 4; *S.M.* 4, 104, 2; *S.M.* 4, 107, 2; *S.M.* 4, 109, 2; *S.M.* 4, 112, 2. **(2)** 1939/40-1955/56: *Dansk Elværks-statistik 1955/56*: p. 50. **(3)** 1956/57-1960/61: *Dansk Elværksstatistik 1975/76*: p. 29.
In the 1920s and part of the 1930s, the selection criterion for inclusion in the statistics was an engine power larger than 100 kW. Later, the criterion was supervision by the Factory Inspectorate or an engine power larger than 50 kW. An indication of the representivity of these larger installations for the autoproduction of electricity in Denmark is that in 1960 only 176 of the approx. 2000 autoproducers were larger than 50 kW, but these accounted for 83% of the autoproducers' engine power. *Dansk Elværksstatistik 1960/1961*: p. 48.

[14] Per Boje, "Thomas B. Thriges økonomiske virksomhed 1894-1938" in Tage Kaarsted & Per Boje, *Thomas B. Thrige. Primus motor. Fra el-industriens barndom* (Odense: 1983): pp. 53-56 and 67.

[15] In 1933 the installed autoproduction capacity was 98 MW, excl. installations smaller than 30 kW. In 1960, autoproducers produced 393 GWh, excl. autoproducers not under the Factory Inspectorate and smaller than 50 kW. "Elektricitetsværker i Danmark 1933/34", *S.M.* 4, 97, 5: pp.80-81 and *Dansk Elværksstatistik 1960/1961*: pp. 50-51.

[16] "Industriel Produktionsstatistik 1951", *S.M.* 4, 152, 1: Table VI.

[17] See primarily Keld Dalsgaard Larsen, *Dansk papirindustri 1829-1994. Overblik og indblik* (Silkeborg: Silkeborg Museum, 1994). See also Hans Chr. Johansen, *Industriens vækst og vilkår 1870-1973. Dansk industri efter 1870 Vol.1* (Odense: Odense Universitetsforlag, 1988): pp. 72-75, 114-115, 168-170, 235-236 and 300-301; Andreas Jørgensen, "Dansk papirindustri 1870-1914. En oversigt", *Erhvervshistorisk Årbog* (1964), Vol. 15: pp. 46-72; *Den danske Papirindustri. De forenede Papirfabrikkers 25 aars Jubileum* (Copenhagen: Nielsen & Lydiche, 1914). Good descriptions of machinery are Eric Haylock, "Paper" in Trevor I. Williams, *A History Of Technology. Vol. VI. The Twentieth Century. Part 1* (Oxford: Clarendon Press, 1978): pp. 607-621 and Helge Holst, *Opfindelsernes Bog. Vol.III* (Copenhagen: Gyldendalske Boghandel/Nordisk Forlag, 1925), pp. 388-402.

[18] "Registre over anmeldelser 1908-33", *Rigsarkivet* [National Archives], Elektricitetsrådet (archive nr. 1404): B 149, 150 and 151 (covering the periods 1907-1915, 1916-1922 and 1923-1933 respectively).

[19] Hansen, "Elektriske Lysanlæg udførte her i Landet...", p. 359.

[20] E.g. "Udnyttelse af Vandkraft til elektrisk Drivkraft", *Nordisk Papir-Tidende* (1895), Vol. 1: p. 35; *Nordisk Papir Tidende* (1898), Vol. 4: p. 42.

[21] "Elektrisk Drift i Papirfabrikker", *Elektroteknisk Tidsskrift* (1911/12), Vol. 16: pp. 12-13 and 23-25.

[22] Other advantages of individual electric drive included substantially improved lighting conditions and worker safety (partly because the potentially dangerous belts were disposed off, partly because the machine could be turned off instantly by pressing a button placed anywhere in the factory in case of accidents). C. Stau Andersen, "Elektrisk Drift af Træmasse- og Papirfabrikker", *Elektroteknisk Tidsskrift* (1928), Vol. 24: pp. 71-72 and 75-76. For a general comparison of line, group and individual drive see Warren D. Devine, "From Shafts to Wires: Historical Perspective on Electrification", *Journal of Economic History* (1983), Vol. 43: pp. 347-372.

[23] "'Der Papierfabrikant' om Ravnholm Papirfabrik", *Dansk Papir Tidende* (1907/1908), Vol. 3: nr. 5.

[24] In other paper factories with partial electric drive, the factory workshop might use electric power while the paper making department still used mechanical power transmission. E.g. "Elektrisk Drift i Papirfabrikker..", p. 12.

[25] O. Røs-Petersen, "Elektrisk Drift i Papirmaskiner", *Ingeniøren* (1934), Vol. 43: pp.II 29-31.

[26] Remarks: (1) For 1940 and 1951/52, the sample included 12 and 13 paper factories respectively; (2) In the calculation of the relative importance of electric power, primary power used exclusively for electricity generation is excluded, while primary power used both for direct machine drive and for electricity generation is included as non-electric machine power. Therefore, the importance of electric drive is underestimated. Sources: "Produktionsstatistik 1940", *S.M.* 4, 114, 3: Tables III, IV and V; "Industriel produktionsstatistik 1951", *S.M.* 4, 152, 1: Table VI; and "Industriel produktionsstatistik 1952", *S.M.* 4, 155, 3: Tables VII and VIII.

[27] According to M.B. Mogensen, "Ny Maglemølle Kraftcentral", *Ingeniøren* (1939), Vol. 48: pp. E41-42 on p. E41.

[28] *Ibid.*

[29] "Elektricitetsværkerne 1939/40", *Statistiske Meddelelser* 4, 114, 1: Table I.

[30] "Kraftcentralen Dalum Papirfabrik", *Tidsskrift for Maskinvæsen* (1951), Vol. 61: nr. 1 and "Elektricitetsværkerne 1950/51", *S.M.* 4, 149, 2: Table 1 and appendix I. See also Jacob Hansen & Knud Mortensen, *Dalum sogns historie, Vol. II, part 2* (Dalum: 1968): pp. 308-309. In spite of ever more efficient public supply systems, paper factories remain major autoproducers today, although a substantial share of purchased electricity may be added. For instance, the largest Danish paper factory, Dalum paper factory, autoproduced 55% of its electricity consumption of 80 GWh in the late 1980s. The maglemølle factory autoproduced 'a minor share' of its electricity consumption. *Dansk papir i 100 år. De forenede Papirfabrikker A/S 1889-1989* (Copenhagen: 1989): pp. 135 and 139.

[31]For the following see "Kraftcentralen Dalum Papirfabrik.." and Mogensen, "Ny Maglemølle Kraftcentral.."

[32] *Dansk Elværksstatistik 1965/66* (Copenhagen: 1967): p. 31 [Description of public supply companies].

[33] Mogensen, "Ny Maglemølle Kraftcentral..", p. E41.

[34] Røs-Petersen, "Elektrisk Drift...", pp. 29-31.

[35] See primarily Carl-Axel Nilsson & Hans Kryger Larsen, *Forbrug og produktion af industrivarer. Dansk industri efter 1870 Vol 2* (Odense: Odense Universitetsforlag, 1989): pp. 167-188. For histories of the technologies involved see also S.B. Hamilton, "Building Materials and Techniques" in Charles Singer et.al. (ed.), *A History of Technology Vol. V. The Late nineteenth Century c. 1850 to c. 1900* (Oxford: The Clarendon Press, 1958): pp. 466-498 on pp. 483-487 and Helge Holst, *Opfindelsernes Bog Vol.IV* (Copenhagen: Gyldendalske Boghandel/Nordisk Forlag, 1926), pp. 50-58.

[36] For the factory structure see f.eks. "Cementindustrien Før og Nu", *Cementindustrien* (1917), Vol. 9: pp. 54-57. For a detailed technical layout of the leading Danish cement factory see Povl Drachmann, *Aktieselskabet Aalborg Portland-Cement-Fabrik 1889-1914. Et Festskrift* (Copenhagen: 1915): p. 22 ff. and p. 93 ff.

[37] Danish cement factories employed in average 732 hp. in 1906 and 1414 hp. in 1914. Shipyards employed 633 resp. 733 hp. in average, cotton mills 417 resp. 708 hp. and paper factories 318 resp. 654 hp. Finally, ice factories employed 764 hp. in average in 1914.

Statistisk Tabelværk 5, A, 12: Table 29.
[38] Important FLS machinery from the first half of the century included Unidan grinders, which combined ball and tube grinders in one design, and Unax rotary kilns, which combined kiln and cooling cylinders (among other improvements which greatly increased the thermal efficiency of rotary kilns). For a survey in English of technological development in FLS cement machinery during the first half of the 20th century, see Max Jensen, *F.L. Smidth & Co 1882-1957* (Copenhagen: 1957).
[39] Hansen, "Elektriske Lysanlæg udførte her i Landet..", pp. 324-325 and "Elektrisk Belysning paa Cementfabrikken Cimbria ved Hobro", *Den Tekniske Forenings Tidsskrift* (1886-7), Vol. 10: pp. 149-150. Other examples are Povl Drachmann, *Aktieselskabet Portland Cement-fabrikken >>Norden<< 1898-1923. Et 25-Aars Tilbageblik* (Copenhagen: 1923): p. 41 and Drachmann, *Aktieselskabet Aalborg Portland...*, pp. 27 (ill.) and 93-95.
[40] E.g. "Elektrisk Drift i en Portlandcementfabrik", *Elektroteknisk Tidsskrift* (1909), Vol. 13: p. 93 and "Elektriciteten i en Cementfabrik", *Elektroteknisk Tidsskrift* (1912/13), Vol. 17: p. 45.
[41] For the following see primarily "Elektriciteten i Cementfabrikkerne", *Elektroteknisk Tidsskrift* (1913/14), Vol. 18: pp. 93-95.
[42] *Ibid.* This situation had not changed in the 1960s, see J. C. Witt, *Portland Cement Technology* (New York: Chemical Publishing Company 1966): p. 101.
[43] Povl Drachmann, *Portland-Cementfabrikken Danmark 1899-1924. Et Historisk Tilbageblik* (Copenhagen): pp. 35-47.
[44] "Elektrisk Materialetransport i Cementfabrikker og Teglværker", *Elektroteknisk Tidsskrift* (1911/12), Vol. 16: pp. 27-28 and 42 on p. 27 and Drachmann, *Aktieselskabet Aalborg Portland...*, pp. 80-81.
[45] The Rørdal factory had 1130 kW engine power installed, the factory 'Danmark' 850 kVA and the factory 'Norden' 562 kW. "Registre over anmeldelser 1908-33..", B 149.
[46] Marius Holst, *Dansk Andels Cementfabrik 1911-1931* (Copenhagen: 1932): pp. 47-50 resp. *Dansk Andels Cementfabrik 1911-1931-1936* (Copenhagen: 1936): p. 36.
[47] "Elektriciteten i en cementfabrik...", p. 45.
[48] "Registre over anmeldelser 1908-33..", B 149, B150 and B151.
[49] After 1951, the statistics of production only reveal figures per group of industry; however, it may be assumed that the cement industry was the only electricity producing industry in the glas, clay and stone industry group (it was so in 1951). "Industriel produktionsstatistik 1960", *S.M.* 1962:5: Table 5.
[50] Remarks: (1) The sample included 5 cement factories in 1940 and 4 factories in resp. 1946 and 1952; (2) Sources: n.26.
[51] "Statistik over Industriens Kraftforbrug", *Elektroteknikeren* (1922), Vol. 18: pp. 111-117 (see also pp. 157-158).
[52] Cit. from R. K. Meade, *Portland Cement* (Easton, Pa.: Chemical Publishing Co. 1930), cited in Witt, *Portland Cement Technology..*, pp. 107-109.
[53] Povl Drachmann, *F.L. Smidth & Co 1922-1932* (Copenhagen: 1932): pp. 36-39.
[54] Einar Rønne, "Moderne Cementfabrikanlæg", *Ingeniøren* (1938), Vol. 47: pp. M33-36 and M41-44 on p. M41.
[55] *Ibid.* and B. R. Jacobsen, "Nogle træk af den nyere udvikling i cementindustrien", *Ingeniøren* (1949), Vol. 58: pp. 27-33.
[56] For the following see primarily Holst, *Dansk Andels Cementfabrik 1911-1931-1936...*, pp. 36-47. For the load factor argument see p. 37.

[57] For information about the power supply of the Rørdal factory, I am indebted to Henning Jensen (A/S Aalborg Portland).
[58] *Dansk Elværksstatistik 1960/61*: pp. 30-31 and *Dansk Elværksstatistik 1965/66*: p. 17-18 [Descriptions of public supply companies]. For arguments for the shift from autoproduction to public supply of the cooperative factory, I am indepted to dir. Jørgen Østerheden and former dir. Ib Fock (DAC).
[59] Contrary to the old system, the new pricing system distinguished between morning, afternoon and evening prices. By the way, although its electricity production ceased, the factory maintained the production of steam (as well as its recently reintroduced waste heat technology) for heating pruposes (preheating the oil, factory heating and district heating). For this information I am indepted to Henning Jensen (A/S Aalborg Portland).
[60] For the flour industry in the 19th century see Erik van der Vleuten, "Mel og damp. Om mølleriets modernisering i 1800-tallet", *Erhvervshistorisk Årbog* (1994), Vol.44: pp. 146-194. For the first half of the 20th century, see primarily A. Ranløv, "Danmarks Mølleindustri under skiftende Kaar" and H.H. Paulli, "Moderne Mølleriteknik" in A. Ranløv (ed.), *Korn. Vol. II* (Copenhagen: Alfred Jørgensens Forlag 1943): pp. 84-110 and 111-150 respectively.
[61] Of the industry and business censuses in 1906, 1914, 1925, 1935, 1948 and 1958, only the 1925 business census recorded more flour factories (64). Danmarks Statistik, *Statistisk Tabelværk* 5, A, 7: Table III.A; *Statistisk Tabelværk* 5, A, 12: Table V; *Statistisk Tabelværk* 5, A, 18: Table IV; *Statistisk Tabelværk* 5, A, 21: Table III.B; *Statistisk Tabelværk* 5, A, 24: Table II.B; *Statistisk Tabelværk* 1963: 7: Table 5. Flour factories are defined as flour producers with more than five workers.
[62] Until their fusion in 1929, Danish flour factories were organized for a number of years in two different societies: The *Society of larger Trademills in Denmark* (1915) and the *Society of Danish Trademills* (1922) (which fundamentally disagreed on the issue if Danish flour factories ought to import and sell foreign flour, but cooperated on a number of other issues). Besides, a number of flour factories remained unorganized. *Den Danske Møller. Tidsskrift for Dansk Mølleindustri* (1928), Vol. 1: nr. 1 and *Den Danske Møller* (1929), Vol. 2: nr. 7.
[63] At least in the early 1890s. See J. Baumann, "Forsög over Kraftforbruget i avtomatiske Valsemöller", *Tidsskrift for Skandinavisk Mölleindustri* (1892/3), Vol. 7: pp. 99, 107-109, 114-115, 122-123 and 131.
[64] F. V. Schiödt, "Elektriciteten i Mölleriets Tjeneste", *Tidsskrift for Skandinavisk Mölle-industri* (1887/88): pp. 18-19, 28-29 and 37-39. Schiödt represented the firm A/S Elektriker. See also W. Haase, "Anvendelse af Elektricitet i Möller", *Tidsskrift for Skandinavisk Mölleindustri* (1890/91): pp.170-171 and (1891/92): p. 171.
[65] "Det elektriske Belysningsanlæg på Dampmöllen ved Langebro", *Tidsskrift for Skandi-navisk Mölleindustri* (1987/88): pp. 121-123.
[66] "Elektricitetens Anvendelse i Mølleriet I.", *Elektroteknisk Tidsskrift* (1899), Vol. 3: pp. 51-52.
[67] "Registre over Anmeldelser 1908-1933": B149. For the Vejle, Esbjerg and Odense factories see resp. *Illustreret Tidende* (1915-16), Vol. 57: nr. 39; *Rigsarkivet*, Elektricitetsrådet, Journalsager nr. 333/40 (A/S Valsemøllen Esbjerg): "Anmeldelsesskema for et Jævnstrøms-anlæg" (1909) and "Anmeldelsesskema for et Jævnstrømsanlæg" (1910); and nr. 629/50 (A/S Munke Mølle, Odense): "Anmeldelsesskema for et Jævnstrømsanlæg" (1909).
[68] Cit. from "Elektricitet og Mølledrift", *Elektroteknisk Tidsskrift* (1911/12), Vol. 16: pp. 127-130 and 138-139 on p. 127. Other examples of electrified flour factories abroad were "To elektrisk drevne møller", *Elektroteknisk Tidsskrift* (1910), Vol. 14: pp.177-179 and 191-192 and "Elektrisk installation i en mølle", *Elektroteknisk Tidsskrift* (1916), Vol. 20: pp. 176-177 and (1917), Vol. 21: pp. 17-18.

69 "Elektrisk drift i møller", *Elektroteknisk Tidsskrift* (1915), Vol. 19: pp. 108-110.
70 "Den elektriske Valsemølle i Svinninge", *Elektroteknisk Tidsskrift* (1916), Vol. 29: pp. 192-193 and *Møllen. Tidsskrift for Skandinavisk Mølleindustri* (1917), Vol. 32: p. 116.
71 Liselotte Mygh, "Dampmøllen i Nykøbing på Falster", *Fabrik og Bolig* (1995): nr. 2, pp. 3-36 on p. 31 and *Rigsarkivet*, Elektricitetsrådet, Journalsager nr. 627/49 (Horsens Dampmølle): Letter from Horsens Dampmølle to Elektricitetsrådet on October 10, 1949.
72 Poul I. Jensen, "Elektrisk Kraft i Møller", *Møllen. Tidsskrift for Skandinavisk Mølleindustri* (1923), Vol. 38: pp. 58-59. In addition, an often heard disadvantage of DC motors was (contrary to electric lighting) the danger of fire caused by the sparks from the commutators. "Brandfaren ved Elektricitet. En Demonstration i Koblingstaarnet ved Aastrup Bro", *Møllen. Tidsskrift for Skandinavisk Mølleindustri* (1924), Vol. 38: pp. 193-194.
73 Such urban flour factories with autoproduction systems existed in for instance Ålborg, Horsens, Vejle, Esbjerg, Odense, Svendborg, Slagelse, Nykøbing F., Maribo and Copenhagen. "Registre over Anmeldelser..": B149.
74 Remarks: (1) The samples included 75, 77 and 59 flourfactories for 1940, 1946 and 1952 respectively, incl. approx. 30 larger bakery-mills; (2) Sources: n. 26.
75 "Den elektriske valsemølle i Svinninge...", pp. 192-93 and *Møllen. Tidsskrift for Skandinavisk Mølleindustri*(1917), Vol. 32: p. 116.
76 *Rigsarkivet*, Elektricitetsrådet, Journalsager nr. 1292/40 (Slagelse Dampmølle): "Anmeldelsesskema for et Jævnstrømsanlæg" (1909), "Rapport over et af Ing. Stellfeld Hansen den 6. Januar 1933 foretaget eftersyn af A/S Slagelse Dampmølle Elektricitetsværk" and "Teknisk Anmeldelse af en Transformatorstation" (1940).
77 Cit. from "To elektrisk drevne Møller...", p. 177. See also "Elektricitet og Mølledrift..", p. 127 and "Elektrisk Drift i Møller...", p. 108.
78 Cit. from Jensen, "Elektrisk Kraft i Møller...", p. 58.
79 Mygh, "Dampmøllen i Nykøbing på Falster..", p. 31.
80 See e.g. A. R. Angelo, ""Elektrisk Drift af Fabrikker fra Centrale Kraftanlæg", *Elektroteknikeren* (1913), Vol. 9: pp. 68-77.
81 "Den elektriske valsemølle i Svinninge...", p. 192 and *Møllen. Tidsskrift for Skandinavisk Mølleindustri*(1917), Vol. 32: p. 116.
82 Cit. from "Elektricitetspriserne", *Den Danske Møller* (1946), Vol. 19: nr. 7. See also "Elektricitetspriserne", *Den Danske Møller* (1943), Vol. 16: nr. 4 and "Elektricitetspriserne", *Ibid.* nr. 10.
83 "Elektricitetspriser og -Tariffer bør reguleres",*Den Danske Møller* (1945), Vol. 18: nr. 7.
84 "Odense Elektricitetsværk ændrer sin Prispolitik", *Fyns Venstreblad* (Feb. 28, 1946).
85 *Rigsarkivet*, Elektricitetsrådet, Journalsager nr. 629/50 (A/S Munke Mølle, Odense): "Teknisk Anmeldelse af en elektrisk Central, Understation eller Lign." (1946).
86 *Ibid*, 'Letter from Munke Mølle to Elektricitetsrådet on November 10, 1950'.

BJØRN IVAR BERG

Vannmyten om fyrsettingen — en kildekritisk studie

"After being heated, the rock was suddenly cooled by water, which caused it to crack open."
Webster's New Twentieth Century Dictionary: "Fire setting" (1978)

Folk som forbinder noe med gruvehistorie, «vet» iallfall én ting: Malmen ble brutt ved å varme opp fjellet med store bål *og så pøse på vann*, hvoretter fjellet sprakk opp og løsnet. Forestillingen blir stadig bekreftet, nylig også i den svenske *Nationalencyklopedin* (med undertittel *Ett uppslagsverk på vetenskaplig grund)* der leseren under *gruvteknik* finner følgende (bd. 8, 1992):

"Tillmakning innebär att berget hettas upp av eld och spricker sönder efter vattenbegjutning."

Encyklopedin gjengir Agricolas klassiske tresnitt, og gir det følgende tekst:

"Tillmakning under jord: berget hettades upp med eldbrasor, varefter vatten hälldes på, och berget sprack sönder."

Svenske - og engelske - oppslagsverk er dessverre ikke alene om å nøre opp under myten om påkasting av vann som en del av fyrsettingen ("tillmakning" synes å være et særsvensk uttrykk). Påstanden påtreffes til stadighet, også i faglitteratur, og også i norske arbeider. Likevel finnes det unntak, og for å holde oss i den leksikalske verden, f.eks. i *Aschehoug og Gyldendals Store norske leksikon* (1987):

"På grunn av varmeforskjellen nær fyrsetningen ble fjellet sprøtt og kunne lett brytes ut."

Likledes utelates vann i det eldre *Salmonsens Leksikon* (1920, bd. X, s. 297):

"Fyrsætningen, som bestod i, at man antændte et Baal saadan, at Flammen slog imod Fjældvæggen, hvorved Stenen ophedes, udvides og løsnes"

- og i *Brockhaus* leksikon (1882, bd. 2, s. 803 f):

"Die Wirkung des Feuers zerstört bei dieser Methode den Zusammenhang des Gesteins und zerreisst es infolge der Elasticität, welche das Wasser und andere flüchtige Substanzen, die in seinen Spalten enthalten sind, durch die Temperaturzunahme erlangen, und die durch das Feuer abgetrennten Gebirgsteile lassen sich, durch das Feuer mürbe gemacht, nachher ziemlich leicht zerkleinern."

Polhem 14(1996),155-194