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Driving on wood. The Swedish transition to wood gas during World War Two

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ABSTRACT

This article is about the rapid transition to gasifiers in Sweden during World War Two, which made it possible to fuel cars with domestic wood instead of petrol, the imports of which seized during the war. The transition had been prepared in the interwar period and was executed very effectively in the beginning of the war. However, when the war was over and petrol became available again most gasifiers were quickly dismantled. In the concluding discussion, the concepts of *head wind* and *tail wind transitions* are introduced to analyze why gasifiers were introduced so rapidly in the beginning of the war, and why they were dismantled just as quickly after the war. It is argued, that the gasifiers were a clear example of a head wind transition, and the gasifier transition is briefly contrasted with two other energy transitions in Sweden that were tail wind transitions: the development of hydropower and of nuclear power.

KEYWORDS

Gasifiers; wood; charcoal; Sweden; World War Two; head wind transition; tail wind transition

Introduction

In Swedish movies and pictures from World War Two, you often see cars and trucks with a strange large device mounted at the back or the front of the vehicle. These devices were gasifiers (sometimes also called gas generators) and they made it possible to replace petrol with wood or charcoal for driving a car. During the war, the Swedish imports of oil products were drastically reduced, and as the country had no domestic oil resources this meant a major challenge for the automobile sector, which had grown very fast during the interwar year period. However, it also created huge incentives to introduce alternative car fuels.[1] Gasifiers turned out to be the most realistic alternative for a fast transition and by the end of 1942 almost 70,000 vehicles had been provided with such devices. This meant that most trucks, buses, taxis as well as some private cars could keep on rolling fueled by wood or charcoal throughout the war. Nevertheless, when the war was over and oil imports were gradually resumed, the gasifiers were quickly dismantled.

The introduction of gasifiers remains the fastest energy transition that has ever occurred in Sweden. How did it come about? Which actors were involved? Had there been preparations made for this transition before the war? What kinds of measures were

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introduced to make it happen? How did the wood gas-fueled cars work during the war? Could sufficient wood and charcoal be supplied? Did other problems arise and if so, how were they handled? Why were the gasifiers dismantled again when the war was over? These are the main issues that will be dealt with in this article.

In the concluding section, I will discuss the rise and fall of wood gas using a distinction between what I call *head wind transition* and *tail wind transition*.[2] Crises of different kinds like war, sudden price increases of basic energy resources or the realization of far-reaching environmental consequences of existing energy systems may spur the former. Such a crisis can induce influential actors to start developing new energy systems that seem necessary for coping with the new situation but do not seem very attractive from other points of view, rather a change 'under the gallows'. Major technical innovations or discoveries of new energy resources may spur the latter. If powerful actors perceive these new opportunities as possibilities for creating attractive new future energy systems, they may invest huge resources to overcome major economic, technical, political, and legal obstacles. I will analyze the gasifier transition in terms of a head wind transition and contrast it with two other Swedish energy transitions of a tail wind character – the respective development of hydropower and of nuclear power.

Experiences from World War One

In the last decades of the nineteenth century Sweden's imports of coal grew very fast, and in January 1900 a parliamentarian submitted a motion warning that:

> Our industry, our communications, our navy are thus/. . ./dependent on imported coal. In case of war, with a blockade of our harbors,/. . ./our defense and our industries would face the most utter difficulties due to lack of fuel./. . ./Our country's entire independence and economy thus has a Damocles sword constantly hanging over it.[3]

Despite this warning, coal imports kept growing fast as Sweden had very limited domestic resources of coal and other fossil fuels. By 1914, imported coal covered about half of the Swedish energy demand.[4]

When a major war broke out in August 1914, the metaphor of a Damocles sword did at first not seem very relevant. During the first two and half years of the war Swedish imports of coal actually increased. However, after Germany launched unrestricted submarine warfare in February 1917, imports were radically reduced. To cope with this difficult new situation, the Swedish government established a Fuel Commission charged with planning and managing the country's fuel supply. It focused primarily on increasing the domestic production of fuelwood and organized large-scale felling in state-owned forests. The Commission was in the end not able to meet the enormous demand for wood and as a result, a parallel black market evolved, featuring much higher prices. The Commission was also responsible for managing the small quantities of fossil fuel that could still be imported. It introduced a rationing system for coal, coke and kerosene to be able to meet the most urgent needs.[5]

The energy crisis during the war spurred interest in Sweden's energy vulnerability and ways to cope with it. In 1915, a government commission presented a report that was the first attempt to make an overall assessment of the country's energy supply, estimating the total domestic deposits of peat, coal, shale oil and other fuels and the total potential for

hydropower production. The report also discussed how domestic energy sources could be converted to different kinds of fuels and emphasized the need for research in this area. Two leading engineers, Axel F. Enström and Sven Lübeck, were the main authors of this report, and they would become key actors in developing a Swedish energy policy in the following decades. Both were educated at KTH Royal Institute of Technology, and as consulting engineers they had contributed to the building of hydropower plants before the war. Lübeck became Member of Parliament in 1915 for the Conservative Party, while Enström started working for the influential National Board of Trade in 1916 and became one of its leading officials.[6]

In 1916, Lübeck submitted a motion signed by his party leader and 60 other parliamentarians arguing for the establishment of a national research institute for 'power and fuel' similar to the German Kaiser-Wilhelm-Institut für Kohlenforschung. This motion got a positive response in Parliament and was sent to the National Board of Trade for further investigations and here Enström played a key role. He assembled leading engineers (professors at KTH, managers in industry and high-ranking government officials) for discussions about how to organize such a research institute. Because of these discussions, a new idea emerged for an Academy of Engineering Sciences devoted not only to energy research but also to technical research at large. Enström was able to mobilize broad support for this idea and in 1919 the Swedish Academy of Engineering Sciences, IVA, was formally established as the first of its kind in the world and with Enström as first CEO. The academy assembled leading engineers from academia, industry and government.[7]

Fuel research in the interwar years

In the interwar period, IVA became the leading Swedish institution in the energy field responsible not only for R&D but also for investigations and information campaigns. It received government funding as well as financial support from industry. An overarching ambition was to decrease the dependency on imported fuels, and the research focused both on measures for increasing energy efficiency in industrial processes and domestic heating and on possibilities for increasing the use of domestic fuels instead of imported fuels.[8] In particular, there was a growing interest in liquid fuels. This had to do with the fast expansion of automobilism. Before World War One, trains and horse carriages were totally dominating modes of land transport in Sweden, and there were less than 5000 motor vehicles. After the war, the number of cars started growing quickly. In 1923, there were 50,000 vehicles and by 1939 the number had risen to almost 250,000, of which 63,000 trucks, 5,000 buses and 180,000 private cars.[9] The growing automobilism was dependent on imported liquid fuels, and five global oil companies – Standard Oil, Shell, Texaco, BP and Gulf – established subsidiaries in Sweden in the 1920s. They built no less than 12,000 petrol stations, supplying the Swedish car and bus fleet with 1.2 million tons of petrol and diesel in 1939.[10]

The increasing dependence on imported oil products worried IVA. In a speech in 1922, Enström cited a report from the US Geological Survey warning that the known global resources of oil would start to run short if the ongoing expansion in oil

consumption would continue, and he argued for fueling motor cars with domestic energy sources that were non-depletable, like wood and hydropower. In an IVA report in the late 1920s, it was emphasized:

> The most delicate fuel issue for Sweden at present is without doubt the liquid fuels. It hardly needs to be said that the car based transports are day by day becoming increasingly indispensable for all parts of society, and because of this it is unavoidable that even minor disturbances in the oil market will cause major disruptions.[11]

How then could this delicate fuel issue be tackled? One domestic alternative for petrol was sulphite ethanol based on wood. This was a proven technology at the time, and there were a number of small factories in Northern Sweden producing it. The challenges for sulphite ethanol were political and economic rather than technical. The temperance movement was strong in Sweden at the time and feared that sulphite ethanol would increase alcohol consumption. However, in 1923 the sulphite industry was able to present an effective denaturant, croton aldehyde, which when added to ethanol made it obnoxious to drink. Moreover, the cost for producing sulphite ethanol was much higher than the cost for imported petrol, and the pros and cons of subsidies and tax reductions were intensely discussed in Parliament.[12]

Another option that emerged in the 1920s was to produce fuels through hydrogenation. IVA supported research to investigate methods for producing oil products out of wood, and it established a Coaling Laboratory on its own premises in downtown Stockholm. In 1930, IVA was able to get government funding for building a pilot plant based on the German inventor Friedrich Bergius´ method of hydrogenation of wood, peat, charcoal and tar. Experiments in this plant showed that it was indeed possible to produce oil products out of these sources, but that it was very costly and complicated.[13]

During the 1920s, a third option gradually attained increasing interest, namely gasifiers, which could use either charcoal or wood for producing a gas consisting of 1/3 combustible gases (mainly carbon monoxide) and 2/3 non-combustible gases (mainly nitrogen). Such gasifiers had been developed in the late nineteenth century for fueling stationary engines. In the early 1920s small gasifiers adapted for vehicles were developed first in France, where the military and the car industry cooperated, and later also Germany and other European countries began to test this technology. The gas from a gasifier could – after cooling and cleaning – be inserted into a car engine built for kerosene. Because of the high content of non-combustible gases, this gas had a significantly lower power than kerosene.[14]

The engineer Axel Svedlund was a Swedish pioneer in the field. In 1913 at the age of 22, he started importing gasifiers and associated stationary engines. When the imports were interrupted during the war he started manufacturing gasifiers by himself, and in 1918, he started experimenting with gasifiers for vehicles using charcoal as fuel. His business grew gradually and in 1929, he established a company called AB Gasgenerator for producing his 'Svedlund gasifier'. In the mid-1920s, the engineers and brothers Klas and Henrik Widegren also started experimenting with gasifiers. They first imported and tested gasifiers made by the Hungarian engineer Julius Heller in 1924. Heller's gasifiers only worked with charcoal as fuel, but the Widegren brothers became convinced that it would be more economical to use wood as fuel because the total

efficiency was much higher. In 1927, they constructed a gasifier adjusted for wood as fuel, which became known as the 'Widegren gasifier'. However, they had technical problems with their gasifiers and decided to close down their business in the early 1930s.[15]

As in other countries, the Swedish military and in particular the army service corps showed interest in wood gas for vehicles. In 1925, they started testing gasifiers on trucks and buses. A few years later, the army and IVAs Coaling Laboratory started a joint research project on the potential of wood gas as car fuel. Together they conducted thorough tests with gasifiers of both foreign and domestic construction and using both charcoal and wood as fuel. They carefully measured acceleration, speed, fuel consumption and other parameters.[16]

A first attempt to introduce wood gas

The deep international economic crisis in the early 1930s had severe consequences for the Swedish forest industry. The export of Swedish forest products (pulp, paper and timber) decreased dramatically and unemployment in the forest industry increased correspondingly. Influential actors in the forest industry proposed the use of charcoal as a car fuel as a way to increase domestic demand for forest products and reduce unemployment. Through successful lobbying this led to a first attempt to introduce wood gas on a larger scale. Swedish Parliament made a decision in the spring of 1932 to set up a state loan fund of 200,000 SEK, from which car owners could borrow money at favorable terms to buy a gasifier. Furthermore, it also decided that cars with gasifiers would get a reduction in vehicle license duty.[17]

As a result of these measures AB Gasgenerator got 250 orders for gasifiers in the summer of 1932, and Parliament decided to increase the loan fund with an additional 500,000 SEK. However, the boost for gasifiers was of short duration. Many buyers of gasifiers were disappointed, complaining about lower motor power, lack of operational reliability, difficulties in buying appropriate charcoal; and about how troublesome, filthy and tedious wood gas was as compared with petrol. The number of loan applications sank from 225 in 1933 to only four in 1934, and many car owners that had bought gasifiers dismantled them from their cars. Gasifiers had ended up in disrepute, and the end of the economic recession meant that the forest industry could export again and did not need them as a market any longer.[18]

However, the proponents of wood gas did not give up. Some of its strongest supporters were Axel F. Enström, the CEO of IVA, and the researchers at IVA's Coaling Laboratory. Other enthusiasts for this technology were officers in the army service corps and some engineers in the forest industry and in the nascent Swedish car manufacturing industry, consisting of the companies Scania-Vabis and Volvo, both mainly producing trucks and buses. Jointly these actors were able to convince the Minister of Defense that gasifiers could play a crucial role in case of a future war, and in January 1937, the Minister appointed a government commission with the task of presenting suggestions for how the use of gasifiers could be promoted in peacetime to increase preparedness for wartime. Enström was appointed chair of the commission, which had two more members, both from industry. A lieutenant from the army service corps served as secretary.[19]

After two and a half years of work, the commission presented its final report to the government on 8 July 1939.[20] Enström summarized the commission's proposals in an article in a motorist journal emphasizing that:

> Should misfortune come over us rapidly, all that can be marshalled of petrol and fuel oil will have to be reserved for the fighting forces. For civilian use there is no other alternative than driving on charcoal.[21]

Large-scale transition to wood gas in World War Two

Less than two months later 'misfortune' did indeed occur, when the German attack on Poland on September 1 triggered what would become World War Two. On September 6 the Swedish government appointed a Wood Gas Board with the task of planning and organizing a fast introduction of gasifiers. The obvious choice of chair for the Board was Enström, and he immediately put into practice the proposals that his previous commission had suggested even though Swedish oil imports would continue during the first half year of the war. It was only after the German occupation of Denmark and Norway in April 1940 that imports ceased almost completely. The little that could still be imported went to the fighting forces, as Enström had predicted.

The Wood Gas Board implemented a whole array of measures. It devoted much effort to *education and training* of drivers and fitters, not least because previous experience had demonstrated the risk of fires and poisoning if gasifiers were not handled properly. It arranged the first course already in September 1939 in cooperation with the Army and a car manufacturing company. No less than 15,000 drivers and fitters participated in such courses during the first years of the war. The Board also introduced a special wood gas certificate, certifying that the holder had passed a wood gas driver test.[22]

The Board moreover proposed to the government to introduce more generous *economic subsidies* to car owners than previously, and this led the government to increase the state loan fund with 2 million SEK. However, car owners were not so tempted to take these loans because they were tied to high demands on security. Only 350 loans were taken in the first year of the war. In October 1940, the rules for borrowing were softened and now the lending increased. The fund approved almost 9,000 loans the following year.[23]

Early on, the Wood Gas Board wanted to *control the quality* of the various gasifiers and it introduced a type of testing in September 1939. During the testing procedure, the testing team also gave the manufacturers advice for how to improve their constructions. The testing was not compulsory, but a test certificate from the Wood Gas Board made it easier to sell gasifiers. Moreover, those who wanted a loan from the state wood gas fund had to buy a certified gasifier.[24]

At the outbreak of the war, there were only two domestic manufacturers of gasifiers; besides AB Gasgenerator, a company called AB Graham-Lundqvist, which had entered the field in the late 1930s selling their 'Gragas gasifier'. The Board discussed whether the market for gasifiers should be strictly controlled by the state or left free. It chose the latter policy with the hope that competition among many manufacturers would lead to lower prices. Soon, a whole range of manufacturers emerged. Two of these developed new types of gasifiers, the 'Källe gasifier' and the 'Mako gasifier'. In addition, many small firms started manufacturing their

own versions of these four main gasifier types. In the first years of the war, AB Gasgenerator had a clear lead with a market share of about 50 percent.[25] By the end of the war, 150 companies manufactured no less than 500 different types of gasifiers.

The supply of charcoal and wood was another issue that the Board took on. On its initiative, the state-owned Wood Gas Company was established in June 1940 with the task of buying, producing and selling fuel for gasifiers on a large scale and making sure that the prices were reasonable. Within a year, this company had created a national supply system fueling about half of all the wood and charcoal used for cars, and it sold this fuel at 750 stations around the country.[26] Compared to the 12,000 petrol stations operating before the war this was not so much, but it still meant that most owners of gasifier cars had a fuel station within a reasonable distance. Moreover, car owners could easily store wood or charcoal at home.

In the beginning of the war charcoal was the dominant fuel as charcoal gasifiers were easier to handle and quicker to start. However, the share of gasifiers using wood grew in the early years of the war. The main reason for this was economical; with the same initial amount of wood a car could be driven a 2.5 times longer distances if the wood was used directly in a gasifier than if the wood was first converted to charcoal and then used in a gasifier.[27] This is illustrated in Figure 1. In particular, owners of trucks and buses used for long hours mainly chose wood gasifiers, while most private car owners used charcoal gasifiers. This is illustrated in Figure 2.

The Wood Gas Board was not the only organization promoting the introduction of gasifiers. The Royal Automobile Club, which was the country's oldest and most influential motorist organization, wrote much about gasifiers in its journal, *Svensk motortidning*. Moreover, it arranged two big races for wood gas fueled cars, the first in September 1940 and the second in winter conditions in February 1941. In both instances, about 130

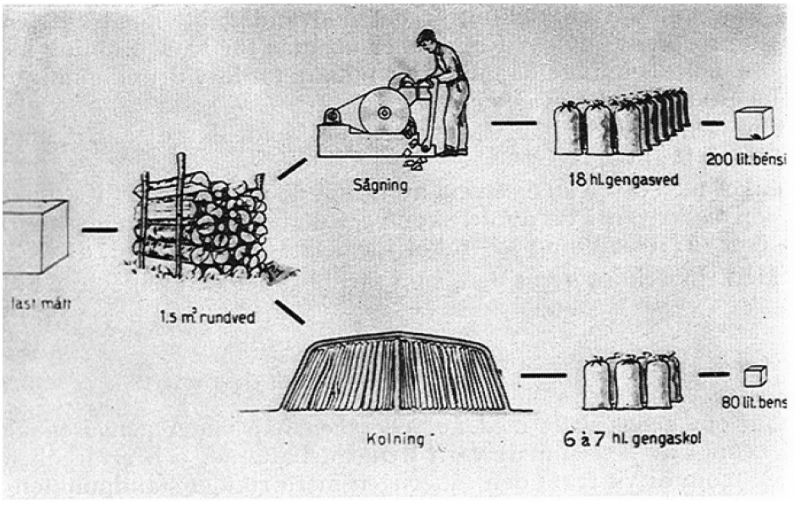

Figure 1. The scheme illustrates that the same amount of wood replaces 200 litres of petrol if used directly in a gasifier, and replaces 80 litres if the wood is transformed into charcoal. Original source: Ingeniörsvetenskapsakademien, *Gengas*, 86. Reproduced with permission of the Royal Academy of Engineering Sciences.

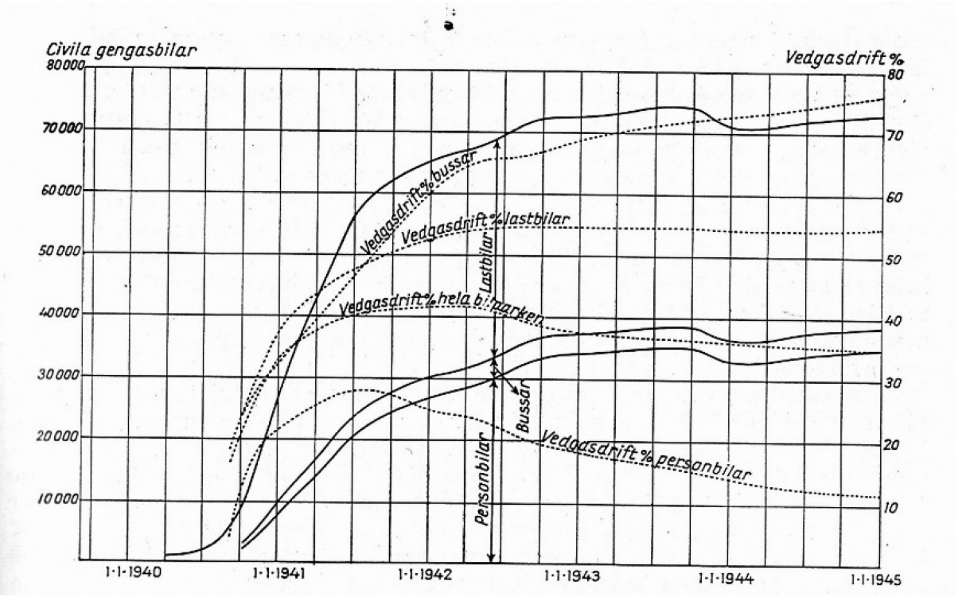

Figure 2. Number of cars with gasifiers in Sweden, fueled by wood (ved) or charcoal (träkol). The solid lines depict the total number of vehicles (axis at the left). 'Lastbilar' means trucks, 'bussar' means buses, 'personbilar' means private car. The dashed line depicts the percentage of vehicles in each category using wood gasifiers (axis at the right). 'Vedgasdrift' means vehicles using wood gasifiers. The rest used charcoal gasifiers. Original source: Ingeniörsvetenskapsakademien, *Gengas*, 9. Reproduced with permission of the Royal Academy of Engineering Sciences.

vehicles – including both private cars and trucks – participated, and the races attracted much public attention. *Svensk motortidning* wrote a long article about the race and on its cover page there was a photo of cars driving through a snow-covered forest and the text: 'White Swedish winter woods provided fuel as well as worthy framing for the Winter race'.[28]

All the efforts of the Wood Gas Board and other actors led to a very fast increase of gasifiers as illustrated in Figure 2. In the autumn of 1940, a 'take-off' occurred and within a year the number of gasifiers had increased tenfold from 5000 to 50,000. The number of gasifiers stabilized a year later at little more than 70,000 units, sufficient to power almost all commercial traffic by trucks, buses and taxis as well as the private cars of the well to do. It is to this day the fastest increase of a new energy technology that has ever occurred in Sweden.

Driving on wood gas

Car owners that bought a gasifier soon realized that driving on wood gas was very different from driving on petrol or diesel. Starting the car was much more complicated and time consuming; the gasifier had to be carefully loaded with wood or charcoal and it took at least 15 minutes after lighting the fire before there was sufficient gas to start driving. After about two hours of driving, the gasifier had to be reloaded. Moreover, the gasifier and the engine had to be cleaned regularly, which was both a time consuming and

filthy job. In addition, the driving was different; the driver had to shift gears frequently to maintain a stable engine rpm and had to keep a constant eye on the air-gas mixture to avoid engine stops.[29] The engine was significantly weaker than before, almost 50 percent weaker as compared to driving on petrol and 20 percent compared to diesel.[30] This meant slower acceleration and a lower top speed, all of which led to new driving habits. Many drivers were tempted to keep an even speed through curves and crossings, and they accelerated before an uphill. This in turn led to higher accident rates in car traffic.[31]

There were two other risks associated with gasifiers that turned out to be even more serious. The first was poisoning, as the gas from gasifiers consists of 20–30 percent carbon monoxide; a gas that is invisible and odorless. If inhaled carbon monoxide blocks the blood cells' absorption of oxygen and this causes suffocation. As about 100,000 people were engaged in driving and serving gasifier cars many were affected, and the term 'wood gas illness' ('gengassjuka' in Swedish) was coined during the war to refer to this kind of poisoning. Such poisoning was mostly due to leakage of gas while starting or cleaning a gasifier inside a garage with insufficient ventilation. Several of the winters during the war were extremely cold and intoxications in garages occurred mainly in wintertime. At times carbon monoxide also leaked from a gasifier into the interior of a vehicle during travel, intoxicating the driver and/or passengers.[32]

A significant number of people were acutely poisoned by wood gas; in 1940 there were 60 known cases, seven of which resulted in death, in 1941 there were 901 cases (17 deaths) and in 1942, a total of 1,135 cases were recorded (11 deaths). In addition, many people were affected by chronic poisoning from lower levels of carbon monoxide. This led to diffuse symptoms like fatigue, headache, vertigo, apathy and heart trouble, which were at first not recognized as consequences of gasifiers, but towards the end of the war circa 1,600 people were officially recognized as cases of chronic carbon monoxide poisoning. Moreover, a number of seemingly strange car accidents started occurring when experienced drivers would suddenly lose control of their cars and drive into the ditch or into oncoming cars. It turned out that these accidents were caused by the intoxication of drivers.[33]

The second risk associated with gasifiers was fires. During the war, nearly 3,000 gasifier-related fires occurred, often destroying not only a car but also the garage in which it was stationed. Incorrectly constructed or mounted gasifiers and careless maintenance caused many of the fires. These fires mainly led to material losses and not so often injuries or fatalities. The total economic cost of the fires was 15 million Swedish crowns, of which 5 million was due to ruined cars and load, and 10 million to ruined garages.[34]

The Wood Gas Board was aware of these potential risks from the very beginning of the war and this was why it started courses for drivers and fitters, and why it introduced type testing of gasifiers. However, when the extent of the two risks became obvious it devoted much effort to assemble information about intoxications and fires and promulgated new instructions regarding the construction, mounting and maintenance of gasifiers. The Board also initiated ambitious information campaigns about the risks related to the gasifiers and these efforts led to fewer fires and intoxications towards the end of the war but did not prevent them.[35]

The dismantling of gasifiers

On 2 November 1944 the main Swedish daily *Dagens Nyheter* had an article with the headline (using parlance we can assume was deliberately chosen): "'The Moor has done his duty, the Moor can go", says wood gas man'.[36] The article was based on an interview with the CEO of the state-owned Wood Gas Company, Gunnar Magnusson. He said that the Company was preparing to wind up its business in the coming year as the war was coming to an end: 'Swedes´ inherent aversion against the awkward and filthy handling of gasifiers will probably be decisive, and a general return to petrol can certainly be expected. I believe that people will be willing to pay rather much more for petrol than before the war to get rid of gasifiers'. The only future use of gasifiers that he foresaw was for stationary engines in remote places of the country.

These expectations turned out to be correct. When the war was over, the five oil giants with Swedish subsidiaries could soon resume oil imports.[37] When petrol was available again at Swedish petrol stations, most gasifier owners quickly dismantled these devices from their cars to enjoy the simplicity and cleanliness of using petrol as well as the higher power it offered. By the end of 1945 the number of cars with gasifiers was 58,000, by the end of 1946 it was 7,000 and by the end of 1949 only 500 cars still had a gasifier.[38] The Wood Gas Company closed down by the end of 1946. 'The Moor' had indeed gone and, as Magnusson had predicted, no one seemed to miss him.

Some of the main actors that had been involved in the transition to wood gas during the war decided to compile the experiences and the lessons learnt. This work was organized under the auspices of the Swedish Academy of Engineering Sciences, IVA, and in 1950, it published a 350-page book with the title *Gengas. Svenska erfarenheter från åren 1939–1945* (Wood gas. Swedish experiences from the years 1939–1945). The explicit aim of this book was to summarize and preserve this experience for the future. In 13 chapters, the scientific, technical, economical and managerial experiences are thoroughly analyzed. Moreover, the government Board for Economic Defence (Överstyrelsen för ekonomisk beredskap), which was responsible for preparedness planning for future war, was careful to keep the knowledge and experience about how to construct and use gasifiers alive. In fact, gasifiers were part of Swedish preparedness planning until the early 1990s.[39]

In the 1950s and 1960s, the number of cars increased tremendously in Sweden, reaching almost two million in 1970. Swedish planners, architects and politicians strived to rebuild urban areas and create a car society with the US as a model, and they did so more consistently than any other European country.[40] This contributed to a very fast increase of Swedish oil imports, and in the early 1970s, oil supplied about 75 percent of Sweden's total energy demand. The dependency on oil imports became very tangible with the oil crisis in 1973 and the subsequent rise of prices on petrol and diesel. A few years later a very ambitious energy R&D program was launched by the Swedish government, including research on alternative fuels for motor vehicles, such as ethanol and methanol. Research on gasifiers was, however, not part of this program and there have not been any serious attempts to introduce gasifiers in Sweden since that point, either.

However, in the late 1970s and early 1980s when oil prices were very high, there was a renewed interest in gasifiers for use in developing countries. The Swedish International Development Agency, SIDA, funded efforts to develop gasifiers for rural power generation in Sub-Sahara Africa. A number of such plants were built in the early 1980s, but when oil prices fell a few years later, most of these were closed.[41] Another sign of the renewed interest in gasifier technology at this time is that the Solar Energy Research Institute in Colorado, in the US, translated and re-published the above-mentioned book first published by IVA in 1950.[42]

Concluding discussion

Why were gasifiers introduced so rapidly?

The Swedish transport sector faced an extraordinary situation in the beginning of the war. The almost complete cessation of oil imports from April 1940 and onwards threatened to bring the whole fleet of automobiles to a stop. The incentives for developing an alternative energy system for fueling cars were immense.

My answer to the question of why gasifiers were introduced so rapidly is that this process was a clear-cut example of a head wind transition. It was spurred by an acute crisis caused by the cessation of oil imports, and this crisis challenged actors to develop an alternative energy system to cope with the new situation. Leading actors had foreseen the crisis and made preparations that could be implemented at short notice. This paved the way for a fast introduction of gasifiers and the parallel development of a national supply system for wood and charcoal.

In the introduction to IVA's above-mentioned book published in 1950, the editors claim:

> In summary it must be said now afterwards that the transition to wood gas/. . ./was an outstanding achievement, possible only through excellent cooperation between all parties concerned. Through the years better or entirely new solutions to many problems emerged and valuable results were attained, both in terms of experiences of construction and operation and in terms of organizational and sanitary issues.[43]

This quote can of course be dismissed as self-praise of the actors involved, but as an observer looking back I tend to agree that it indeed was an 'outstanding achievement' made possible by close cooperation between many actors striving to pursue a head wind transition.

The transition to gasifiers had been well prepared in the interwar years by a small number of men with Axel F. Enström as its primus motor. In the beginning of the 1920s Enström created what can be called a 'gasifier network', consisting of small group of engineering colleagues in the forest and car manufacturing industries and officers in the army service corps. This network initiated testing of gasifiers in the late 1920s. During the economic crisis in the early 1930s, the network lobbied parliamentarians, which led to the creation of a state loan fund for gasifiers and reduced taxes for cars using wood gas. Even if this effort to introduce gasifiers failed when the crisis ended, it still gave valuable experience. Moreover, the gasifier network was able to convince the Minister of Defense to set up a commission chaired by Enström to investigate how gasifiers could be implemented in case of war.

As soon as war broke out, the Swedish government appointed a Wood Gas Board, chaired by Enström and with other colleagues from the gasifier network as members. The Wood Gas Board was given considerable powers to implement the policy that the previous commission had presented. What characterizes this policy is its broad scope. It addressed all the major actor categories that had to be enrolled in the effort: It organized training of drivers and fitters, it gave sufficiently attractive subsidies to car owners, it encouraged gasifier manufacturers to test and further develop their products, and it set up a state-owned company that was responsible for the supply of wood and charcoal. Thus, the small gasifier network of some dozen men were able to launch a gasifier program that in total addressed more than hundred thousand people. The most crucial actors were the vehicle owners. After April 1940, they had the choice to either buy a gasifier and use wood or charcoal as fuel or to unregister their vehicle. The large majority of all vehicle owners chose the latter alternative mainly because they could not afford a gasifier; around 180,000 out of 250,000 cars were unregistered and thus idle during the war years. However, a large majority of the owners of the economically most important vehicles – trucks, buses and taxis – chose to buy a gasifier to be able to continue their business.

As motor vehicles were costly, most owners of the vehicles were relatively rich, but the drivers and mechanics that were actually handling the gasifiers were mainly working-class men. However, the gasifier was not solely a male technology. At the outbreak of the war, many young men were enrolled in the Armed Forces, and to compensate for them the leading women organizations in the country established a Women's

Figure 3. Three members of Sweden´s Female Car Corps Organization cleaning a gasifier in Gothenburg, March 1944. Source: TT Nyhetsbyrå. Reproduced with permission.

Preparedness Committee that among other activities also started training women in driving and maintaining vehicles. In 1942, a special organization, Sweden's Female Car Corps Organization (Sveriges Kvinnliga Bilkårers Riksförbund) was established. Thus, a few thousand women did actually drive and maintain gasifier vehicles during the war (See Figure 3).[44]

Even if the wood gas policy launched by the gasifier network was successful, it was not optimal in all respects. After the war, one of its main architects, Gunnar Lindmark, was self-critical about one crucial aspect of the policy. Lindmark was vice-chair of the Wood Gas Board during the war and had been CEO of the Swedish truck manufacturing company Scania Vabis in the interwar period. In the IVA book from 1950, he regretted that the Board had encouraged a free market for gasifiers:

> The disadvantage of the free market showed itself in a variegated flora of different types, not always so well worked through, whereby many buyers have made palpable losses not only in terms of less usable gasifiers but also in terms of destroyed motors. The number of different, not type-tested gasifiers, so called handicraft constructions, was quite big. Undeniably much material and work would have been saved, if the development from the very beginning would have been focused on a limited number of gasifier types that would have allowed a far-reaching standardization.[45]

This seems to be a correct assessment. It is probable that a policy focusing on a few manufacturers and gasifier types would indeed have led to better and safer, and also cheaper gasifiers, as they could have been produced in longer series. However, this would hardly have changed the overall pattern of the gasifier transition; most private car owners would still not have been able to afford a gasifier.

Why were gasifiers dismantled after the war?

If the wood gas transition was indeed such an 'outstanding achievement', why then did this transition not remain a lasting one? Why were almost all gasifiers quickly dismantled from Swedish cars after the war? Why did not the gasifier network try to preserve the new system?

There were clearly a number of drawbacks and weaknesses of the gasifiers: the lower power output of vehicle engines, the time consuming and filthy maintenance work before and after driving, the danger of poisoning and of fires to mention the most important ones. New technologies often have drawbacks in an early stage, but in many cases, these are overcome through hard work of the promotors of the technology. Some of the above mentioned weaknesses were also partly overcome during the war. After the war, these improvements could have continued. Why did this not happen?

My answer to this question is the same as to the previous one: because it was a head wind transition. Or to put it more precisely, because the main actors in the gasifier network perceived it as a head wind transition, a necessary adaptation to the special wartime conditions, but did not regard it as a tail wind transition with long-term benefits also under normal peacetime conditions. There were certainly some actors, not least manufacturers of gasifiers that saw it as a tail wind transition and hoped that the technology would survive the war. The domestic market for gasifiers had diminished

after the initial expansion in 1941 and 1942, and there was hardly any export of gasifiers. The gasifier manufacturers were thus small companies and did not have much political influence.

The main participants of the gasifier network were, however, not interested in maintaining gasifiers. The car manufacturing industry, with companies such as Volvo and Scania-Vabis, was a nascent enterprise with ambitions to become a major export industry.[46] They wanted to produce cars that were competitive on an international market and regarded petrol and diesel as the car fuels for the future. The Swedish forest industry had supported gasifiers in the economic crisis in the 1930s and during World War Two when exports of timber and pulp and paper had decreased dramatically. During the war years when wood became the country's main fuel, the annual felling of trees had been up to 20 percent higher than before the war.[47] After the war, the forest industry wanted to export as much as possible of their traditional products, and they saw gasifiers as a competitor for wood. For the military and in particular the army service corps the most important issue was to keep gasifiers as a part of Swedish preparedness planning, but this did not necessitate that gasifiers be maintained on cars. The most influential actors in the gasifier network were thus not interested in preserving the gasifiers. Moreover, the oil industry and its Swedish subsidiaries wanted not only to re-establish themselves on the market again but also to expand their business.

From the point of view of vehicle owners, the choice between keeping their gasifiers or dismounting them and going back to petrol or diesel was very simple once oil imports were back to normal. Owners wanted to avoid all the drawbacks of wood gas as soon as it was possible to do so. For the car owners that had unregistered their cars at the outbreak of the war, it was a self-evident choice to use petrol again when it became available.

What about politicians? Sweden had after all experienced two wars during which interruptions of energy imports had caused major problems and highlighted the vulnerability of Swedish energy supply, the danger of living under 'the Damocles sword'. Were there no politicians who wanted to maintain gasifiers based on wood and charcoal as a domestic and reliable energy system? No, there were hardly any politicians arguing for maintaining gasifiers for these reasons. Almost all politicians shared the prevailing view of gasifiers as a head wind transition that had been necessary during the war but without long-term potential in peacetime. Instead, a fierce political conflict developed after the war about how best to safeguard oil imports. In 1947, Gunnar Myrdal, the Minister of Trade in the Social Democratic government proposed a nationalization of the Swedish subsidiaries of the international oil companies as a way of increasing control over oil imports. However, the US government put pressure on Sweden to refrain from this and in the end, the Swedish government did not dare challenge the US and decided to refrain from nationalization, and Gunnar Myrdal resigned as Minister of Trade.[48]

In addition, many politicians favored the further expansion of hydropower as well as the development of nuclear power as future strategies for diminishing Sweden's dependency on imported energy.[49] These two options were viewed very differently than gasifiers.

Contrasting the gasifier head wind transition with two tail wind transitions

To clarify the head wind character of the gasifier transition I will briefly contrast it with two other Swedish energy transitions that took place in Sweden in the twentieth century: the development of hydropower and of nuclear power. These transitions were viewed by most actors as tail wind transitions.

The first of these transitions had started around the turn of the century 1900. The invention of alternating current (AC) technology in the early 1890s made it possible to transmit electric power over longer distances, and thus waterfalls located at a distance from urban areas and industrial plants could potentially be taken into use for power generation. However, the obstacles for exploiting this energy resource were considerable: huge investments were needed; new technology had to be developed; new water legislation enabling the building of large dams was required; and the resistance from political parties representing farmer interests had to be overcome.

Sweden had many energy-intensive industries, the owners of which became the major proponents of hydropower as they were convinced that it would generate power much cheaper than in coal-fired plants. Jointly with municipalities, they established regional power companies in the early 1900s. In addition, Swedish Parliament decided to establish a State Power Board in 1909. As a result, 70 percent of all electricity in Sweden was generated in hydropower stations by 1914, and 90 percent of all electric power was used for industrial purposes.[50] Gradually, power companies, manufacturers of electric equipment and energy-intensive industries formed a strong 'development block', to use a concept coined by the Swedish economist Erik Dahmén.[51] They shared a vision of hydropower as a tail wind transition that would bring large economic benefits not only to their own organizations but also to the country at large. Moreover, the Swedish governments also embraced the vision of hydropower as a tail wind transition and supported the development block.[52]

In the interwar years, most of the rivers in the Southern half of Sweden were exploited. The remaining unexploited rivers were located in the North, far from the big industrial centres in the South. The distances were too long to enable transmission. However, a close collaboration began between the country's major electrical equipment manufacturer, ASEA, and the State Power Board to develop high-tension power lines, and in 1952, they jointly built the world's first 400-kV transmission line from Lappland to Southern Sweden. In the 1950s and 1960s hydropower generation tripled in Sweden, providing industry with cheap electricity. Moreover, ASEA became a world leader in high-voltage technology.[53] Thus, hydropower fulfilled the expectations of its proponents.

However, in the early 1950s it became clear that if the growth in electricity consumption continued as before, the available hydropower would be exploited within three decades. Government, industry and power companies explored possible pathways for the future energy supply and soon a consensus emerged that nuclear energy was the most promising. In 1956, the Swedish Parliament adopted a very ambitious long-term policy to develop an entirely domestic nuclear fuel cycle based on Swedish uranium resources. Ten years earlier, it had been discovered that Sweden had Europe's largest uranium deposit. This domestic uranium was to be used in heavy-water reactors (HWR) without prior enrichment, which was a technology too expensive for Sweden. Moreover, the policy included the building of reprocessing plants as a means to extract plutonium for use in

future fast breeder reactors or for nuclear weapons production.[54] This autarkic policy had an obvious military dimension and the dual national goals of energy self-sufficiency and nuclear weapons explain why the government invested so much in this research. Through the 1950s and 1960s, nuclear technology was the largest recipient of state R&D support in Sweden.[55]

Thus, government, industry and power companies also regarded the transition to nuclear power as a tailwind transition, a transition requiring huge investments and new technology but based on reliable domestic energy sources and promising low energy prices in the future. However, in the mid-1960s, power companies and ASEA began to question the economics of HWR reactors and of domestic uranium production (the Swedish uranium deposits are low-grade). This eventually led to a major change of policy, and Sweden instead built light water reactors (LWR) developed by ASEA but fueled by imported enriched uranium. Thus, the autarkic character of the nuclear energy program was abandoned. From 1965 to 1985, 12 such reactors were built in Sweden producing an amount of electricity equal to that of all hydropower stations.[56]

By contrasting the transition to gasifiers with the transitions to hydropower and nuclear power, I want to highlight its character as a head wind transition. During the war years, many influential parties saw gasifiers as the best way to cope with the lack of petrol and diesel, and a fast and very effective headwind transition took place. However, when the war ended there were not sufficiently influential actors that saw gasifiers as a long-term attractive energy system and that were prepared to invest resources to try to make this happen. Instead, many powerful actors regarded the further expansion of hydropower and later on the development of nuclear power as attractive tail wind transitions, and mobilized huge resources to enable this to happen.

However, these tail wind transitions have later been reinterpreted. A growing environmental movement in the 1950s and 1960s opposed a further expansion of hydropower, and in 1972, the Swedish Parliament decided to save remaining rivers from exploitation, and no further expansion occurred. Likewise, environmentalists started actively questioning nuclear power in the 1970s. This led to a referendum on the future of nuclear power in 1980. After the referendum, Parliament decided to continue expansion of nuclear power in the short term but to phase out all nuclear plants by 2010. Parliament later postponed this date, and at present six of the originally 12 nuclear power plants are still operating. However, the Swedish power industry does not regard nuclear power in its present large-scale form as a long-term option anymore. Its tail wind thus seems to have subsided.

Notes

1. On the history of ethanol biofuels in the US, see Jeffrey Manuel and Frank Uekötter in this issue.
2. Astrid Kander and I introduced this distinction in Kaijser and Kander, *Framtida energiomställningar*.
3. Motions in the First Chamber 1900, No. 13.
4. Kaijser and Högselius, 'Under the Damocles Sword'; Kander, *Economic growth, 50*.
5. SOU 1922:14; Schön, *Statliga styrmedel*.
6. Sundin, *Ingenjörsvetenskapens tidevarv, 56*.
7. Ibid.; Kaijser and Nilsson, *Teknik i samhällets tjänst*.

8. On the history of heating systems in Switzerland and Iceland, see Irene Pallua and Odinn Melsted in this issue.
9. Blomkvist, *Den goda vägens vänner.*
10. Stolpe, *Olja i samköp.*
11. Cited in Egan Sjölander et al., *Motorspriten kommer*, 48.
12. Ibid., 27–42.
13. Ibid., 54–58.
14. Nilsson, "Gengas före 1939."
15. Ibid.
16. Ingeniörsvetenskapsakademien, *Gengas, 3.*
17. Ekerholm, "Cultural Meanings of Wood Gas", 17 f.
18. Ibid.
19. Gasgeneratorkommittén, *Betänkande.*
20. Ibid.
21. Cited in Egan Sjölander et al, *Motorspriten kommer*, 68.
22. Ingeniörsvetenskapsakademien, *Gengas*, 5.
23. Ibid., 7.
24. Ibid., 6.
25. See note 14, above.
26. SOU 1952:50, 755 f.
27. If the coaling was done in a modern kiln, byproducts like tar and turpentine could partly compensate for the lower efficiency, see Ingeniörsvetenskapsakademien, *Gengas*, 86.
28. *Svensk motortidning* Nr 9, 1941.
29. Ekerholm, "Cultural Meanings of Wood Gas," 227.
30. SOU 1952:50, 849.
31. Ingeniörsvetenskapsakademien, *Gengas*, 332.
32. Ibid, 332.
33. Ibid., 315ff; Ekerholm, "Gengas och ohälsa."
34. Ingeniörsvetenskapsakademien, *Gengas*, 328ff.
35. Ekerholm, 'Cultural Meanings of Wood Gas.'
36. This citation derives originally from the 1783 play, *Fiesco´s conspiracy at Genoa*, by German writer Friedrich Schiller. It is a rejoinder by the character Hassan, acting as a spy for count Fiesco, when he is dismissed after having given intercepted letters to Fiesco.
37. Many oil fields were located in regions outside Europe that had not been battle grounds. In contrast it took much longer before coal imports could be resumed as the main coal fields were located in European countries heavily affected by the war.
38. SOU 1952:50, 845.
39. Björn Kjellström, personal communication. Kjellström is professor emeritus of Energy Technology, Luleå Technical University and a leading specialist in biomass gasifiers. He was project leader for SIDA's gasifier program in Africa in the 1980s.
40. Lundin, *Bilsamhället.*
41. Kjellström, personal communication.
42. Ingeniörsvetenskapsakademien, *Generator Gas.*
43. Ingeniörsvetenskapsakademien, *Gengas*, IV.
44. Egan Sjölander, *Motorspriten Kommer,* 72.
45. Ingeniörsvetenskapsakademien, *Gengas*, 6 f.
46. Schön, *En modern svensk ekonomisk historia*, 356.
47. SOU 1952:50, 749.
48. Jonter, *Socialiseringen som kom av sig*; Kaijser and Högselius, 'Under the Damocles Sword.'
49. Kaijser and Högselius, 'Under the Damocles Sword.'
50. Högselius and Kaijser, *När folkhemselen blev internationell*, 18.
51. Dahmén, 'Development Blocks in Industrial Economics.'
52. Högselius and Kaijser, *När folkhemselen blev internationell*, 35–39.
53. Fridlund. *Den gemensamma utvecklingen.*

54. Fjaestad, "Fast Breeder Reactors in Sweden."
55. Lindström, *Hela nationens tacksamhet.*
56. Kaijser. *Redirecting Power.*

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