

Challenges for developing a system for biogas as vehicle fuel – lessons from Linköping, Sweden

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Abstract: Biofuels are being employed in nearly all the EU member states to fulfill the targets set up by the European Directive 2003/30/EC to have a 5.75% share of renewable energy in their transport sector by 2010. In Sweden ethanol is the leading biofuel, while biogas mainly depend on local initiatives with the city of Linköping as a case in point.

Our purpose with this article is to analyze the development of biogas in Linköping within a framework of technological transition theory. To this we add a set of concepts from large technical systems-literature to address and re-analyze two earlier studies on the biogas development in Linköping to achieve a deeper understanding of this success story. We argue that the establishment of a development trajectory for biogas depended on the ability of the involved actors to establish and nurture their social network, to create learning processes and stimulate the articulation of expectations and visions. It was also important that these three factors were allowed to influence each other for the system to gain a momentum of its own.

Furthermore, the biogas development in Linköping is found to be interesting in that the triggers for the development came from a variety of levels and angles. Initially, the rising fuel prices after the oil crises in the 1970's resulted in an increased interest in renewable fuels in general. Second, an anticipated national pipeline for natural gas planned through Linköping was considered a huge potential for methane exports. A part from these external energy incentives, the local trigger was the bad urban air quality caused by the public transport authority's bus fleet. The breakthrough came when it was discovered that by-product biogas from the wastewater treatment facility could be used as a fuel for transport.

When the plans for the national pipeline were rejected, a fruitful co-operation between the municipally owned production facility and the public transport authority was set up to meet the constructed demand from public transport. This cooperative pair-arrangement was the starting point for the biogas niche trajectory as other actors subsequently were enrolled to increase the size and agency of the network.

Nowadays, biogas and other renewable fuels play a significant role in the supply of transport fuels for Linköping. In 2009, a total of 9.5% of all transport fuels used in Linköping were from renewable sources, i.e. biogas (4.6%), ethanol and biodiesel. This puts the city well ahead of the European target of 5.75% renewable fuels by 2010.

Keywords: *Technological transitions, niche management, biogas, renewable energy, biofuels for transportation*

1. Introduction

Our purpose with this conference paper is to analyze the process of biogas development in Linköping using technological transition theory. We argue that the success story was an example of the interplay between three technological niche processes; social networking, learning processes and the articulation of expectations. Our focus is mainly local, but since national initiatives and plans also affected the process, some of these are included in the description. We suggest a local Swedish "style" of technological niche development as a topic for further research.

2. Methodology

To create a deeper understanding of the development of biogas in Linköping, we assemble a new theoretical perspective to re-analyze two earlier studies on this topic. The theoretical perspective stem from two bodies of literature; the main framework come from technological transitions-theory [1], [2], to which we add key concepts from large technical systems theory developed by Thomas Hughes [3], as well as findings from Swedish scholars within this field

[4], [5]. No new empirical material has been collected and the analysis veers more towards theory building than generalizable conclusions.

3. Theory

The basic conception of the paper is that technical systems are embedded in a societal context; they are socio-technical, which means that technical systems and societal actors both affect and are affected by each other [2]. This reflexivity is particularly evident in the case of emerging socio-technical systems, whose meaning and performance are still under negotiation in the process to reach a concluded design solution [6].

If successfully spread, an emerging socio-technical system may be taken up and evolve into a socio-technical regime, consisting of prevailing institutions and rule-sets (formal laws and regulations), which provide stability [7]. In a regime, relationships are since long established between for example suppliers, user and producer groups, research networks, public authorities and societal groups [2]. Different kinds of socio-technical systems often share the same characteristics within the same country. A typical feature of the Swedish way of constructing socio-technical regimes is the "development pair"-configuration; a close, long-term relationship between an industrial company and a state customer regarding development projects on new technical systems. An example of this is the cooperation between the Swedish Powerboard (Vattenfall) and ASEA (later ABB) [5].

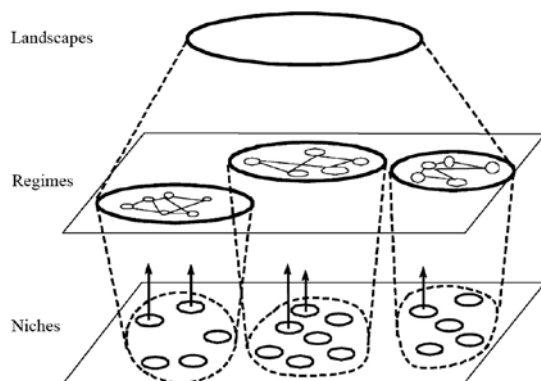


Fig 1. Multiple levels as a nested hierarchy[1]

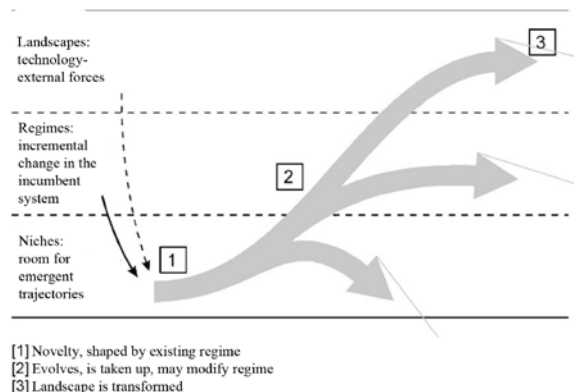


fig 2. Describing the niche trajectory[1]

Regimes are located at the meso-level in a heuristic model for socio-technical systems developed by Frank Geels, fig 1. Most changes in socio-technical regimes are of an incremental nature, so for major regime changes to occur, external pressure from outside of the regime level is needed [7]. An example of external pressure is when the oil crises during the 1970's increased the transportation regime's interest in renewable fuels.

The oil crises are examples of events in the socio-technical landscape. The landscape is located on a macro level in the model and is even more sturdy and hard to change than regimes. It contains technology-external factors such as financial fluctuations, diplomatic relations and international conflicts [2]. So while both the landscape and regime levels stabilize the incumbent practices of different socio-technical systems, they also create disincentives and barriers for disruptive technologies to develop [7].

The heuristic spaces for disruptive and/or emerging technical systems are the technological niches, found at the bottom of the socio-technical hierarchy. Here, change can still be radical, as uncertainties caused by socio-technical "child diseases" must be overcome. It is important

to find an organizational form and agreements between the involved actors, for example through the formation of joint ventures. The technology must furthermore be trustworthy, the operational risks low, and subcontractors with the right components must exist on the market. [4]. Uncertainties at the niche level can be overcome by constructing a first and large enough secure market outlet to lower the economic risks involved in doing research on a yet immature technology. This is important as 'incubation room' where the nurturing can proceed without the pressures from mainstream market selection. The focus of this paper will be at the level of technological niches for which three crucial processes have been identified [2]:

1. The building of social networks with meaningful relational connections between involved actors. Such networks are the arena for users, decision-makers and other interest groups to give feedback about the technical system to firms, engineers and researchers, and vice versa.
2. The creation of learning processes is important, not only for technical aspects such as design and user preferences, but also from a societal point of view to understand for example regulation and infrastructure requirements.
3. Finally, the articulation of expectations and visions around a socio-technological system is important both to attract attention and resources from the social network, as well as to provide space for learning processes.

Achieving a successful interplay between the three processes is necessary to develop a development trajectory for a new radical socio-technical system [2]. If this is successful, the system can start to expand and require other systems and organizations to adapt. This is what Thomas Hughes calls 'momentum', a dynamic inertia that strives to enlarge the action space for and increase the number of activities in the socio-technical system. Momentum thrives on overcoming reverse salients, i.e. anomalies and/or uneven development that constrain the system from expanding. Reverse salients stimulate inventive activity and are thereby also important drivers for learning processes [3].

All socio-technical regimes have started out as niche trajectories. Regimes are the formalized results of social network activities, learning processes and achievements surrounding a technical system, which have gained enough momentum to overcome reverse salients and develop into a socio-technical regime in its own right, fig 2.

4. The biogas development in Linköping

4.1. Empirical data

The following description is in large parts collected from two reports. The first is a published paper by biogas researcher Magdalena Falde [8], and the second is an unpublished report on the Linköping biogas development written by Undén [9], the former CEO of Svensk Biogas. We have taken into account that Undén have all the reasons to write a success story and have tried to stay away from bias in our description. The intention has been to re-frame these written accounts from a technological niche development perspective.

4.2. Context: biofuels in Sweden

Biofuels achieved attention on a national Swedish level after the oil crises of the 1970's. A large-scale methanol initiative characterized the first years of development without achieving much of a break-through. While methanol always remained a strictly top-bottom initiative, ethanol could to a larger extent be endorsed and played out locally [10]. The same was also

true for biogas; which still can be seen in the fact that most of Sweden's biogas facilities and the achieved competences most often remain within municipally owned companies [11].

4.3. Initial incentives

It was in many respects lucky circumstances that made biogas the option as the fuel for sustainable transportation in Linköping. Following the oil crisis (a critical event in the socio-technical landscape), the Swedish socio-technical regime discussions on environmental issues intensified on a national as well as local level. In Linköping, the discussion focused around the city center and especially the central bus stop square which was characterized by the smell of diesel exhaust and soot particles. Since the inner city was banned for other transportation vehicles than buses, the environmental problems could only be referred to them. This led to a joint will among the local politicians to improve the local transportation regime and the environment of the inner city in an economically feasible way. The local bus authority at the time, LITA, had problems convincing the citizens to continue using their buses, which had been regarded as the most sustainable transportation system in the city. The question became even more delicate for LITA since it coincided with both the expiration of the local authority monopoly for bus transportation and the widespread implementation of new catalytic exhaust technique in petrol driven private cars. On a deregulated market and with this technical alternative at hand, why would people choose their buses for transportation? LITA had only one choice, to change fuel in their buses [8]. All of these events in the local socio-technical transportation regime were influential in the biogas development process.

Parallel to these local triggers, there were plans to build a national natural gas pipeline through the county where Linköping is situated; a great possibility for both import and export of methane. This national project in the socio-technical energy regime, was part of Linköping's provider of regional services', Tekniska Verken AB (TVAB), search for alternative burning fuels. At the time TVAB had permission problems with their waste incineration plant, which the local authority threatened to close down. When the plans for the natural gas pipeline were rejected due to economical reasons, the idea of gas driven vehicles had stuck in the minds of the managers at LITA. Gas to them appeared as a new and unproven fuel but also attractive and with existing techniques for operation [8]. This interplay between national and local changes in different kinds of socio-technical regimes provided the ground for further initiatives for biogas on the local scale.

4.4. Early signs of a niche trajectory

When the bio-methane by-product in TVAB's wastewater treatment plant turned into a possibility, fuel for transportation was not at all their business idea. This was instead triggered by the fact that LITA was searching for new fuel for their buses. Replacing the missing natural gas with this existing source of bio-methane seemed obvious, even though bio-methane was mostly produced for reserve electricity purposes in Sweden at the time [8].

The two municipality-owned companies got the permission to perform a pilot study on refining the bio-methane from the wastewater treatment plant. The idea was to convert five diesel buses into bio-methane ones and put them in operation within regular traffic. This pilot study established the social network around the development project and added more concrete ways of practice. Part of the money invested in the project was a grant from the Swedish state; the rest came from the municipality of Linköping, the county, the regional bus authority, LITA and TVAB. Setting up this network of actors around a created offset market of bio-methane buses, proved successful as the first five rolled out in regular traffic in 1992. The work conducted in the pilot study was characterized by a steep learning curve. Several

technical issues concerning upgrading and distribution of bio-methane were solved and overcome during the scope of two years. The learning-by-doing process was considered fruitful to such an extent that the possibility of a full-scale operational project, from five to 20 buses, was discussed during the later part of the pilot study [9].

The wastewater treatment plant could not alone provide enough bio-methane for such an expansion, and had thus to be complemented by production from other substrates. Studies were carried out on different raw materials suitable for digestion at the same time as two other Swedish projects with bio-methane as fuel for transportation were about to start. This created a greater focus on the achievements done in Linköping and according to the CEO; a general wish of being pioneers was spread among both the personnel and politicians [9].

The calculations for the full-scale project of 20 buses showed that a switch to bio-methane would cost more than continued traffic with diesel buses. Nevertheless, the politicians made the decision to go ahead not only with 20 but the entire bus fleet of 65 buses, since economies of scale made the larger project less costly per driven kilometer. On the other hand, the capital risked in investments would also be bigger and with the implemented technology in the whole bus fleet of the inner city, a failure would be critical [9].

4.5. *Technological momentum catching on*

Around the same time, a new main supplier of raw material to the biogas digestion appeared in the form of the locally situated slaughterhouse Farmek. They had problems getting rid of their organic waste and biogas could be a way to secure their offset. Furthermore, the digested by-product from bio-methane production is a highly valuable fertilizer for farmland, so to secure the offset even further; LRF (the farmers association) was enrolled as an actor to take part in the social network surrounding the project as well. With this set-up, the bio-methane production system generated income at three times during the process: from receiving/treating the waste and the production of approved bio-fertilizer and bio-methane. Getting these actors to work together proved crucial, not the least since it at the same time confirmed the local authorities belief in the project. Successful enrollment of more actors proved that achievements and visions spread also outside of the established social network. This new setup of three stakeholders (TVAB, Farmek and LRF) started an associated company to TVAB with shared ownership, and a state grant was received to establish a first production facility for bio-methane in 1995. The plant was established during 1996 and provided a new space for further learning processes, so that the efforts made during the pilot study could be continued but on a larger scale [9].

In late December 1996, the first batch of substrate was loaded into the plant. During the first years of operation, experiences and breakthroughs were made about the operation of the whole system; from the controlling of digestion chambers, via the upgrading system and refilling stations to the everyday maintenance and operation of the bus fleet running in the inner city. Pioneering work became a part of the workforce's everyday and a strategy to allocate investments in personnel and to tie competence and not only technology to the project, was complemented with the sharing of experiences from other projects in Sweden [9].

Actors other than just the locally concerned thus shared the visions around the project, and the project gained a lot of attention both regionally and nationally. Between 1997 and 2008 the plant managed to manifold its production of bio-methane due to conquests in process techniques and managed to keep the production steady by relocation during a period of difficulties in substrate deliverance. The plant also had to continuously increase the

production of bio-methane in order to meet the launching of converted bio-methane buses [9]. That the project had been able to manage and overcome these hardships, can be seen a sign of the niche trajectory building up a momentum. This was going to be put to the test when the project was seriously questioned for the first time since the start in 1990.

4.6. Reverse salients

The problem stemmed from the odor from the production site and proved very hard as well as important to solve, not the least since its solution was important in relation to the inhabitants of Linköping. A costly process was initiated by boxing in the incidence and an odor panel of local citizens was assembled to derive the cause of the problems and thereby undertake necessary measures at the plant. It took several years with an odor-reducing program until better levels for the surroundings were achieved [9].

At the same time as this process went along, the top management was changed and a new CEO was installed. The bio-methane production was not profitable enough so a new business idea was badly needed. A face-lift into yet another expansion phase was figured out to get more economically beneficial through size advantage. The expansion required large investments in both technology and personnel, and a crucial decision was taken to expand regionally and into the private market. The new CEO pushed the expansion plans through, although the political opinion was not throughout positive. This was due to that TVAB at the moment generated much better profit to the municipality than their other business areas [9].

Already during 2001 and 2002, two large investments were done in new upgrading units and the first public filling station. The entrance to the private market was announced through a public statement that bio-methane should be a fuel you can rely on in Linköping also for your private car. LRF and Farmek was not interested in this expansion and sold their ownership to TVAB, which became full owner of the new company that was now formed [9].

In 2003 TVAB planned to establish filling stations for private cars in every regional city to create a demand for bio-methane as quick as possible with as little investments as possible. The change of the name to Svensk biogas (Swedish biogas) coupled with logotype change packaged their new business idea, and the expansion first aimed at building a new production facility in the neighboring city of Norrköping. At the same time, they had also showed the possibility to transport compressed bio-methane to newly established bio-methane markets without local production, which was a new business practice by then. During the period of 2003-2006 Svensk biogas established 14 public fuelling stations regionally and grew the public market from 300 000 to 3 100 000 Nm³ [9]. During these later stages of niche trajectory development, signs of a stabilizing momentum can be seen as more and more reverse salients are conquered and the socio-technical system achieves an expansive dynamic.

5. Results

The Linköping biogas case provides insights of how the intertwined process of social networking, learning processes and the articulation of expectations and visions can be configured for a technological niche development. Two initially important factors can be highlighted: the initial pilot study and the creation of an offset market in the form of the local bus fleet. This constructed an “incubation room” or niche, which could act as a protected arena for interactions and a starting point from which a trajectory could be developed.

Characterized by a steep learning curve, the pilot study years was successful enough in creating expectations and visions to overcome the crucial moment to further expand into a

second pilot study. At that point, the expectations created within the social network were strong enough to dare go into an even greater expansion than first planned for; 65 instead of 20 buses. Furthermore, the visions surrounding the project seemed hopeful enough to successfully enroll more actors to the network to provide a larger resource base of organic waste needed for the expansion.

The reconfigured social network and the larger second project provided yet another and extended arena for learning processes. New expectations and visions were in this process created around the project, which lead to the expansion into the private market. The dynamic expansion of the biogas project had begun to show signs of a technological momentum, as the enrolled actors had to adapt their processes to the biogas development. Furthermore, it conquered the first encounter with a reverse salient; the odor problems from the factory.

The biogas niche trajectory in Linköping was the combined result of the three processes. The relationship between the actors from different socio-technical regimes created a stabilized yet diverse local network. Although they had different incentives, they learned and developed the biogas technology and created a momentum through co-operation and a shared vision.

6. Discussion and Conclusions

An interesting feature in Linköping is the way that different socio-technical regimes affected the development of a biogas trajectory. Initially, pressure came from landscape change inflicted by the oil crises. Furthermore, the national gas pipeline project (the energy regime) had its implications as well as the earlier attempts and projects with other biofuels (the transportation regime) made in Sweden. These pressures, together with the local trigger event of bad air quality, opened up a window of opportunity for changes to occur locally. The biogas niche trajectory could develop as actors from different socio-technical regimes became enrolled and involved in the process: the wastewater treatment plant and agricultural sector found offsets for their by-products, while slaughterhouse waste became a resource provided by the food industry. Of course, the possibility of networking across regime borders stems from the fact that biogas (upgraded methane) is an energy source found as organic by-product in many different industrial processes. Still we believe it important, both for researchers and practitioners interested in socio-technical niche development, to look over the regime fences for possible exchanges as well as useful pressure mechanisms and offset markets.

The findings of this article furthermore suggest it reasonable for a slightly altered "development pair"-concept to describe the development of biogas in Linköping. The co-operation between the municipally owned bus company customer on one side, and the municipally owned producer (TVAB) and the private actors they enroll to their network on the other, form the starting point for a niche trajectory. This cooperative pair-arrangement and their long-term collaboration form the basis of the development. It is important to stress that one observation alone is not enough to generalize any conclusions to be applicable also to other biogas cases in Sweden. Still, it is so that municipally owned companies run most biogas facilities and have the largest embodied competence on the subject in Sweden. We believe that it would be fruitful to conduct further research to seek out whether a local Swedish "style" for technological niche development for biogas can be detected.

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