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Abstract

This study contributes to insights into mechanisms that influence the successes and failures of emerging energy technologies. It is assumed that for an emerging technology to fruitfully develop, it should be fostered by a Technological Innovation System (TIS), which is the network of actors, institutions and technologies in which it is embedded. For an emerging technology a TIS has yet to be built up. The research focuses on the dynamics of this build-up process by mapping the development of seven key activities: so-called system functions. The main contribution revolves around the notion of cumulative causation, or the phenomenon that the build-up of a TIS may accelerate due to system functions reinforcing each other over time. As an empirical basis, an analysis is provided of the historical development of the TIS around automotive natural gas technology in the Netherlands (1970-2007). The results show that this TIS undergoes a gradual build-up in the 1970s, followed by a breakdown in the 1980s and, again, a build-up from 2000-2007. It is shown that, underlying these trends, there are different forms of cumulative causation, here called motors of innovation. The study provides strategic insights for practitioners that aspire to support such motors of innovation.

Keywords: functions of technological innovation systems; cumulative causation; automotive natural gas.

1 Introduction

Sustainable development requires radical structural change within the incumbent energy system. If such a sustainable energy transition is to take place, it is important that multiple sustainable energy technologies develop and eventually become embedded in the incumbent energy system (Bergek et al., 2008; Geels, 2008; Sandén and Azar, 2005). Such technological innovation processes may be considered as trajectories that involve a build-up process wherein actors, institutions and technologies are increasingly aligned to each other.

Recently, a number of studies have been conducted that aim for a better understanding of the dynamics of such a process of system build-up. The central idea in these studies is that technologies develop within the context of a network of actors, institutions, technologies and the interrelations between them (Carlsson et al., 2002). This Technological Innovation System (TIS) does not come into existence overnight but is gradually shaped over time. During a so-called formative stage, actors are drawn into the TIS, networks are formed and institutions are designed that make the technology fit better to its surrounding structures (Jacobsson and Bergek, 2004). The main contribution of this literature is that it provides insights in the dynamics that make up this build-up process. This is done by studying a set of seven key activities or ‘system functions’ (Hekkert et al., 2007). Examples are knowledge development, entrepreneurial activities, market formation.

Central to this study is the notion of cumulative causation (Jacobsson and Bergek, 2004; Myrdal, 1957; Suurs, 2009; Suurs and Hekkert, 2009a).

Cumulative causation is the phenomenon that the build-up of a TIS accelerates due to system functions interacting and reinforcing each other over time. For example, knowledge development is likely to benefit from entrepreneurial activities and entrepreneurial activities, in turn, will be induced by market formation. A number of empirical studies has now been conducted that focus on the identification of forms of cumulative causation, also called motors of innovation, in the development of sustainable energy technologies (Hillman et al., 2008; Negro et al., 2008; Suurs and Hekkert, 2009b, a).

This literature consistently shows how a rapid TIS build-up benefits from cumulative causation. Indeed, it suggests that such self-reinforcing dynamics are necessary in order to establish a broad diffusion of sustainable energy technologies into the incumbent energy system. Moreover, derived from these insights, valuable lessons are provided, mainly in the form of strategic insights, for policy makers and other practitioners. This paper adds to this literature by providing a detailed analysis of the TIS dynamics underlying the historical development of Automotive Natural Gas (ANG) technology in the Netherlands.

It may be questioned whether ANG is a sustainable energy technology at all, but this is not a question that we raise. The choice for studying ANG technology is based on the fact that it is a trajectory with a rich history of dynamics and hence provides great opportunities for learning. Moreover, ANG is currently becoming very relevant as part of the Dutch energy (transition) policy. This is because, as an alternative to petrol and diesel, the combustion of natural gas is expected to result in a lower vehicle emission of nitrogen oxides (NO_x), particulate matter

(PM) and CO_2 (Hekkert et al., 2005; TNO, 2003). Furthermore, the use of natural gas could improve security of supply by alleviating the dependency on oil (SN, 2008b). Another reason for considering ANG is that it may provide a steppingstone to more sustainable options, like hydrogen or biogas, in the future.

This study offers important insights. In the first place by adding to the currently still scarce knowledge on the nature of TIS dynamics. A main outcome from case studies done so far has been the identification of a number of motors of innovation (Hillman et al., 2008; Negro et al., 2008; Suurs, 2009; Suurs and Hekkert, 2009a). In this study we continue the search for motors, with as a goal to underline, and expand, current insights into the dynamics of TIS build-up.

A second contribution is that this study develops the idea that motors of innovation are related to the structural configuration of a TIS. In the studies done so far, structural drivers and barriers - blocking and inducement factors - were identified but these were not systematically related to motors. Also, the impact of motors on TIS structures was not explicitly taken into account. This study aims for a better understanding of the drivers and barriers that cause motors of innovation to emerge, develop and (possibly) decline and of the influence of the motors, in turn, on these structural factors.

A third contribution to the literature is related to the specific nature of Automotive Natural Gas (ANG) technology. The ANG technology is relatively mature (NGV, 2008; Verbeek, 2002) and, as far as the production and distribution of the fuel is concerned, ANG technology involves mostly incremental changes to the incumbent energy system.[1] This is because natural gas has been used for heat and power production in the Netherlands ever since the 1960s (Verbong and Geels, 2007). However, despite the availability of a strong knowledge base, a production system and even an attractive price setting of natural gas compared with petrol or diesel, the development of ANG technology has been hampered for more than 30 years. Only recently have developments around ANG technology been taking off, as a modest market for Natural Gas Vehicles (NGVs) is emerging. It will be interesting to find out how the ANG Technology Innovation System (ANGTIS) has managed to develop and overcome its barriers to realise a take-off.

The following research questions are central to this study:

RQ 1: What were the motors of innovation that (positively and negatively) constituted the development of the ANGTIS in the Netherlands between 1970 and 2007?

RQ 2: What were the underlying structural drivers and barriers that explained the emergence of the motors of innovation in the ANGTIS?

RQ 3: How did the motors of innovation in turn influence ANGTIS structures?

The remainder of this article is structured as follows: Section 2 provides an overview of theoretical concepts and of the applied methodology. Section 3 provides a technological outline of ANG technology. The actual analysis is presented in Section 4. A conclusion and discussion are given in Section 5.

2 The Technological Innovation Systems approach

The TIS approach has been explained in earlier studies (Hekkert et al., 2007; Jacobsson and Johnson, 2000; Jacobsson and Lauber, 2006; Markard and Truffer, 2008; Negro et al., 2007; Sagar and Holdren, 2002; Suurs, 2009; Suurs and Hekkert, 2009a; Van Alphen et al., 2008). Therefore, this section is limited to provide only a short explanation of the core concepts as they are applied to the analysis of the ANG case. A TIS analysis may focus on structures and/or processes. Both perspectives will be discussed separately. Specific attention will be given to some additional ideas that are developed for the purpose of this study, which is to explain how TIS dynamics are related to the structures of a TIS.

TIS structures

Structural factors represent the static aspect of a TIS; they involve elements that are relatively stable over time. Three basic categories are distinguished: actors, institutions and technologies.

- Actors involve organisations contributing to the emerging technology in focus, as a developer or adopter, or indirectly as a regulator, financer, etc. In this study a distinction is made between so-called enactors and selectors (Garud and Ahlstrom, 1997). Enactors are actors that are directly involved in the development of a particular technology and fundamentally dependent on its success, whereas selectors are actors that are engaged at a distance, for example because they have the possibility to choose between many options.

- Institutions are ‘the rules of the game’ (North, 1990) (p. 3), such as laws, regulations, norms. They also involve cognitive rules, i.e., search heuristics and shared promises or expectations (Suurs, 2009).

- Technological factors consist of artefacts and the technological infrastructures in which they are integrated. They also involve the techno-economic workings of such artefacts, including costs, safety, reliability and effects of up-scaling (Suurs, 2009).

Structural factors are merely the building blocks of the TIS. In an actual TIS, they are linked to each other. If they form configurations they are called networks (Suurs, 2009).

TIS processes and cumulative causation

The focus of this study is on the dynamic aspect of a TIS, in other words the build-up of a TIS. The idea is to consider the TIS as a system with a purpose, which is to be served through the fulfilment of a set of system functions (Bergek, 2002). These system functions are (types of) activities necessary for TIS build-up. An overview of the system function, based on Hekkert et al. (2007), is provided in Table 1.

Each system function can be fulfilled in various ways. It is also possible to consider activities that contribute negatively as the fulfilment of a system function. These negative contributions imply a (partial) breakdown of the TIS.

The notion of cumulative causation suggests that system functions may reinforce each other over time, thereby resulting in a virtuous cycle. For example, the successful realisation of a research project, contributing to *Knowledge Development*, may result in high expectations, contributing to *Guidance of the Search*, among policy makers, which may, subsequently, trigger the start-up of a subsidy programme, contributing to *Resource Mobilisation*, which induces even more research activities; *Knowledge Development, Guidance of the Search*, etc.. System functions may also reinforce each other 'downwards'. In that case a sequence may result in conflicting developments or a vicious cycle.

The relation between process and structure

It is important to understand under what conditions motors of innovation are shaped. In this light it should be noted that motors are not independent of the TIS structures. On the contrary, motors emerge from a configuration of structural factors and in turn rearrange that configuration. This mutual relation will be highlighted in the empirical analysis. Obviously, motors are coupled to developments external to the respective TIS as well.

Event history analysis

This study should result in the identification of structures and system functions within the TIS. In order to realise this the event history analysis, as developed by Van de Ven and colleagues (2000; Van de Ven, 1990; Van de Ven, 1999), was applied. This method offers the possibility to operationalise and measure system functions by relating them to events. Examples of such events are studies carried out, conferences organised, plants constructed, policy measures issued, etc. In Table 1, an overview is provided of types of events that correspond to each system function.

The interaction between system functions was measured by tracking (causal) sequences of events, like in the example of a virtuous cycle given above. These patterns were interpreted as elements of a narrative. This narrative, made up of storylines related to the system functions and their interactions, was validated by means of interviews with 'field experts'. The narrative provided the basis for further analysis. The method also allows for the identification of structures, internal and external to the TIS, that relate to the motors, either as underlying causes of change (drivers and barriers), or as targets of change (impact).

The data for this study was gathered from digitalised media (covering especially the most recent time period 1995-2007), historical reports written by stakeholders (covering the period 1970-2000) and expert interviews which covered the whole history but especially the more recent developments. For this study, ten interviews were conducted with various experts in the field. The interviews were used to identify important events and also to check the validity of the narrative as a whole.

Insert Table 1 around here.

3. Technology overview

As an automotive fuel, natural gas offers some advantages to petrol and diesel.[2] It is expected to outperform petrol and diesel in terms of emissions, especially with respect to NO_x and PM (TNO, 2003; Verbeek, 2002). Natural gas is also considered to be a welcome alternative to oil in the face of energy supply issues (Verbeek, 2002). But what is most unique, compared to other alternative automotive fuels, is that ANG technology is readily available and the cost structure of ANG technology is rather attractive, especially with respect to the fuel costs (GT, 2006). Figure 1 gives an overview of price development over the years (EnergieNed, 2006).[3]

The drawback lies in the investment costs. In order to make ANG technology a success a number of technological innovations are necessary (Verbeek, 2002). As explained above, the production and distribution infrastructure for natural gas is well developed. However, to be used in vehicles, the natural gas needs to be compressed.[4] Technically this amounts to the installation of a system of compressors, storage buffers and the adjustment of pump systems at (existing) refuelling stations.[5] For vehicles the required adjustments are small. All that is needed is a new (high-pressure) storage tank and the tuning of a regular petrol motor to the characteristics of the new fuel.

The ANG technology may build upon a readily available production and distribution infrastructure. The downside is that the production of natural gas is in the hands of the same oil industries that produce petrol and diesel (which make up 97% of the automotive fuels market). Since the growth of ANG may eat into this incumbent market, the incentives to develop this option on the part of incumbent fuel producers has been rather weak.

Since ANG technology is itself not climate neutral, nor renewable, advocates of ANG technology tend to point out possible linkages to other emerging TISs, most notably around biogas and hydrogen. The idea is that ANG could eventually be replaced by biogas, a biomass-based renewable, and this could be done without the necessity of additional infrastructure investments. A similar reasoning holds for (bio)hydrogen which could be blended with ANG in increasing amounts. This way the deployment of ANG infrastructure may provide a stepping-stone for a hydrogen economy to come.[6]

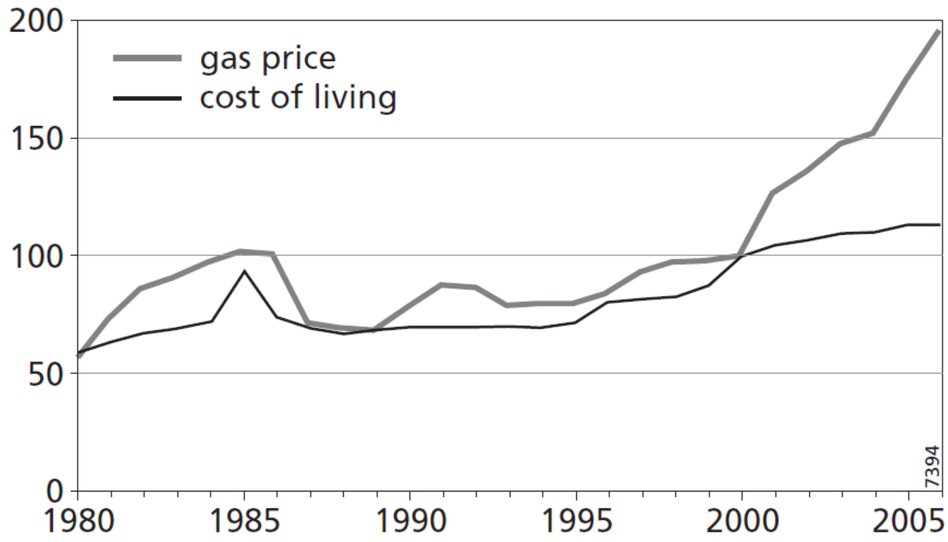

Figure 1: Natural gas price development, indexed at 2000, estimated for small users, including taxes. Source: EnergieNed (2006).

4 The event history of the ANGTIS

This section is structured as a chronological narrative consisting of four episodes. For each episode, the shifts in the external environment of the ANGTIS are sketched in the first section. Then a narrative is presented in terms of events. At the end of the episode, a reflection is given on the narrative, focusing on the motors that occurred in that episode, the structural drivers and barriers that enabled it and the impact it had on the ANGTIS.

4.1 Emergence (1970-1989)

The first use of ANG technology dates back to the 1970s when the oil crisis posits a necessity to develop alternative fuels. Natural gas is abundantly available at this time, at low cost. During the 1980s oil prices drop again but then environmental issues become more pressing.

The first experiments are initiated by utilities. Gas companies in Utrecht en Groningen start with the adoption of retrofitted NGVs (Verbeek, 2002). Driven by the promise of cheap, clean and abundantly available natural gas, the gas companies successfully build up a fleet of about 80 vehicles. They also construct their own refuelling stations. Other gas companies follow this example and in the late 1980s bus companies start adopting NGVs as well.[7] The companies are encouraged by actors involved in earlier experiments (Verbeek, 2002) and supported by the ABC programme, a subsidy programme launched by the national government.

Despite the enthusiasm of the utilities, the outcome of the experiments is generally not positive. The main problems are the reliability of the refuelling infrastructure and the limited range of the NGVs. Also, the costs of investment and maintenance are higher than expected (NGV, 2007).

Motors

The succession of events can be characterised as pivoting around *Entrepreneurial Activities*, *Knowledge Development*, *Knowledge Diffusion* and *Guidance of the Search*. The dynamics emerge when *Guidance of the Search*, arising from the enthusiasm of a handful of utilities, leads to *Entrepreneurial Activities*, in the form of adoption experiments, and *Knowledge Development* and *Knowledge Diffusion*, in the form of feasibility studies and the exchange of learning experiences. The sequence turns into a virtuous cycle as the experiments are copied by other utilities, thereby feeding back on *Entrepreneurial Activities*, *Knowledge Development* and *Knowledge Diffusion*. In so far as the results are positive, they boost *Guidance of the Search* as well. Due to the central role of the *Entrepreneurial Activities* in this motor it seems appropriate to denote this virtuous cycle as an *Entrepreneurial Motor*.

Structural drivers and barriers

The motor is constituted by government actors and utilities. Key drivers are (i) the external pressure of the oil crisis combined with (ii) the enthusiasm of a group of enactors in the form of dedicated companies aiming for an alternative to oil-based fuels. Through developing their *Entrepreneurial Activities*, the enactors manage to draw in selectors, in the form of government authorities and public transport companies. The enactors are able to do so because external conditions - high oil prices and readily available natural gas - put the selectors' interests in line with their own.

A downside is that the basis of this motor is limited to a small group of actors closely tied to the government. A key barrier that obstructs a broader development is the poor techno-economic performance of ANG technology, so far. Both weaknesses have a negative effect on *Guidance of the Search* and *Market Formation.*

Impact on TIS structures

The *Entrepreneurial Motor* characterises the development of the ANGTIS for almost twenty years, in spite of the techno-economic drawbacks that ANG technology turns out to have. A main impact is the formation by enactors and selectors of a network in which knowledge on ANG technology is exchanged. Another important outcome is the installation of government support schemes for technology demonstrations. A third impact is the gradual diffusion of ANG applications among various energy utilities. A fourth, and less positive, impact is that experiments consistently point out that ANG technology suffers from numerous technological and economic bottlenecks.

An overview of drivers, barriers and impacts is presented in Table 2.

Insert Table 2 here.

4.2 Decline (1990-1999)

In the 1990s the oil price is at a historical low but environmental issues remain pressing in national politics. The prime focus of energy policy, though, becomes the liberalisation of the energy sector. Only in the late 1990s do environmental issues, fuelled by the debate on climate change, gain a central position again.

The general tendency in this period is projects being abandoned and enthusiasm for ANG technology declining (SN, 2008a). The number of NGVs in service, reached in the 1990s, is 500-600 (Verbeek, 2002). This number now declines as gas companies tend to shift focus to their core business.[8] Also, they abandon the exploitation of refuelling infrastructure.[9] The termination of projects leads to a negative image of ANG technology among potential adopters (Verbeek, 2002).

The actors that committed themselves earlier to ANG technology nevertheless continue to contribute to the build-up of the ANGTIS. For example, Gas Company Noord-Holland and Energy Company Amsterdam adopt NGV vehicles to become part of their fleets. The companies construct refuelling stations as well (Verbeek, 2002).[10] Some other projects are started in the second half of the 1990s. An important development is the participation of municipalities aiming for clean road transport in the inner cities (LK, 2001; Verbeek, 2002). The projects are supported by a national subsidy programme and by the European Thermie programme.

The techno-economic results of these projects are still not positive. The investments remain high and technical issues keep posing problems (FEM, 2004). Nevertheless, two developments can be singled out as important precursors to a more fruitful development of the ANGTIS in the future. A first is the establishment of NGV-Holland, a platform which serves to promote ANG technology (Verbeek, 2002). The ANG advocates manage to persuade governments and intermediaries to establish licensing procedures and safety standards for ANG refuelling stations and indoor parking of NGVs (Verbeek, 2002).[11]

The second development is the emergence of small niche markets. This starts as early as 1990 when Canal Bus, a company operating boats on the Amsterdam canals, adopts natural gas for its boats. Due to the absence of noise and smell, natural gas boats are allowed in waters where diesel boats are forbidden (Verbeek, 2002). Similar benefits result in the formation of niche applications for (indoor) ice-swabbing vehicles, for forklifts and shovels that operate in glass factories (TO, 2002; Verbeek, 2002).[12]

Motors

The dominant dynamic in the 1990s is that of a declining ANGTIS, signifying a motor of decline. The abandonment of *Entrepreneurial Activities* results in negative *Guidance of the Search,* and since this affects potential ANG adopters it becomes increasingly difficult to gather support necessary for new *Entrepreneurial Activities.* The decline of *Entrepreneurial Activities* subsequently leads to a decline in *Knowledge Development* and *Knowledge Diffusion*.

It can, however, be argued that the *Entrepreneurial Motor* is still active, although it has been stripped to its core in terms of structures. A handful of enactors manages to keep up a basic level of *Entrepreneurial Activities, Guidance of the Search*, *Knowledge Development* and *Knowledge Diffusion* basically according to the same interaction pattern as in the previous period. An important augmentation is that enactors become more active in promoting ANG technology among businesses and in lobbying governments for *Resource Mobilisation* and *Guidance of the Search*. The dynamic is strengthened through emerging niche markets for applications where low emissions come with a high advantage. Note that these ANG applications are less dependent on external resources.

Structural drivers and barriers

The motor of decline is largely driven by the (external) liberalisation trend. It could be argued that when gas companies are merged into larger energy utilities, these enactors are effectively turned into selectors. These newborn energy companies typically apply an evaluative logic that puts innovation second to reorganisation. Even when innovation is considered, the meagre outcomes of the projects undertaken so far do not encourage a choice for ANG technology. This negatively affects *Guidance of the Search* and *Entrepreneurial Activities*. The few market niches provide some stability in the turbulent liberalisation context as most niche-based projects are retained throughout the 1990s.

The *Entrepreneurial Motor* observed in the previous period remains active due to the commitment of a small enactor group consisting mainly of gas companies. The enactors' main strategy is to continue their projects and to join forces with municipalities, thereby targeting *Guidance of the Search* and *Support from Advocacy Coalitions*. They also draw in selectors in the form of national and European governments; this is basically what keeps the ANGTIS alive during this episode. The selectors are mainly driven by environmental issues.

Impact on TIS structures

In terms of impact it should be stressed again that the ANGTIS declines. Only a small number of enactors remains active during this period. Nevertheless, they contribute to the build-up of the ANGTIS, particularly by setting up a platform that strengthens network relations within the ANGTIS. Moreover, the enactors manage to establish licensing and safety standards for NGVs and refuelling infrastructure.

An overview of drivers, barriers and impacts is presented in Table 3.

Insert Table 3 here.

4.3 Re-emergence (2000-2004)

The EU sharpens air quality norms, which are implemented in Dutch law by 2001 (EU, 1999). This has a large impact, especially on the level of local governments, since norms are being exceeded in many areas and this leads, via *court decisions, to a full stop on regional construction plans (MNP, 2005). As a result ANG becomes increasingly attractive as a short-term alternative automotive fuel. On top of this, the climate issue and high oil prices become increasingly pressing policy issues (SN, 2008b; Westdijk, 2003).*[13]

Municipalities are specifically interested in NG, since using it not only reduces PM but also NO_x emissions, a problem not addressed by diesel-particle filters (SN, 2008b). However, there is as yet barely a refuelling infrastructure and most ANG projects have come to a halt.[14] The developments that do go ahead are still driven by NGV-Holland. Within this network, ANG technology is supported by basically two groups of actors: a coalition around the municipality of Haarlem (and Gas Company Haarlemmermeer (RWE)) and around Gas Company Cogas (DT, 2003). These groups build upon experience gained earlier. Their activities revolve around a series of demonstration projects, the goal of which is to demonstrate the merits of ANG technology in practice (Verbeek, 2002). The projects aim to get NGV trucks on the road and to develop refuelling infrastructure.[15,16]

The gas companies and municipalities, organised within NGV-Holland, lobby for support from the national government, with the result that most projects are government-financed (NGV, 2008; SN, 2008a).[17] The projects are a success in terms of build-up as they lead a variety of actors to re-enter the ANGTIS (MoH, 2008; Van der Hoeven, 2005; Verbeek, 2002).[18] A key event is the formation of DutCH4, a developer of turnkey ANG systems. DutCH4 provides knowledge to successfully realise ANG projects. On top of this, DutCH4 invests in infrastructure and actively mobilises municipalities to adopt ANG technology (DT, 2003).[19]

By the end of 2003, government support for ANG demonstration projects is stopped because ANG technology has developed 'beyond the stage of demonstration' (SN, 2008a; Verbeek, 2002). This occurs at a time when firms involved actually demand market stimulation measures in order to continue their work.

Despite the absence of supportive national policies, some direction is provided to the field when the results of a vehicle emission test, issued by MinVROM,[20] show that ANG is, on all dimensions, favourable to diesel, petrol and LPG (Dutch4, 2007; TNO, 2003). The decision to take up NGVs into the test at all is taken after a lobby by NGV-Holland (NGV, 2007). More generally, the wide use of ANG technology results in important improvements to the techno-economic feasibility of ANG applications. This is for a large part the result of international developments as well. The near-commercial status of ANG technology provides an additional boost to the willingness of actors to enter the ANGTIS (FEM, 2004; Verbeek, 2002).

Due to the building prohibition, high oil prices and the lobbying of the ANG community, an increasing number of municipalities adopt NGVs for their fleets and stimulate businesses and utility companies to do so as well.[21] These developments are supported by DutCH4 as it is taking over the business of Cogas.[22] The gas company's original plan was to provide ANG infrastructure coverage in the Twente region, but this is now turned into a plan to set up nationwide coverage (DTC, 2004b). Funding for these projects is (additionally) provided through generic energy subsidy programmes (NGV, 2007).[23] As part of these projects, feasibility studies are conducted with the purpose of revealing the economic advantages of ANG technology to potential adopters across the country (DG, 2004a; FD, 2005a; LC, 2005).[24] The results are now generally positive (MoH, 2008; SN, 2008a).

On the basis of these positive experiences, a growing ANG community successfully lobbies national policy makers for supportive tax policies (DTC, 2005). Also, multiple provincial governments and incumbent industries are becoming involved. The provinces set up conditions for concessions, compelling public transport companies to use NGVs (AC, 2006; Connexxion, 2007).[25] Instances of large incumbents getting involved are three major Dutch energy companies (Gasunie, Eneco, Essent). These incumbents have so far been sceptical about ANG technology but now they prepare a manifesto envisioning the dawn of ANG technology in the Netherlands (FEM, 2004; WNGB, 2007).

Insert Table 4 around here.

By 2004, the ANGTIS accounts for about 120 NGVs - approximately 40 in the Haarlem-Schiphol region and 80 in the Twente region - which are supported by six refuelling stations; see Table 4. This is undeniably a positive trend, however, these figures pale compared to the 70,000 NGVs utilised in Germany at the same time (DTC, 2004b).

Motors

It is again the gas companies and local governments which provide momentum to the ANGTIS by contributing to *Entrepreneurial Activities*, *Knowledge Development*, *Knowledge Diffusion* and *Guidance of the Search*. A key difference however, compared with the previous period, is that *Support from Advocacy Coalitions* and *Resource Mobilisation* are becoming very strong. At first this is mainly reflected in lobby activities aimed at generating subsidies for single projects. But later on, these activities are increasingly directed at *Market Formation* and *Guidance of the Search*, in the sense that they embody a plea for top-down government policies. When successful, these efforts result in a boost to *Guidance of the Search*, leading to new *Entrepreneurial Activities*.

The conscious orientation of the enactors on the ANGTIS as a whole is a reason to denote this dynamic as a *System Building Motor*. A key feature of this new motor is that entrepreneurs are organising themselves, forming networks, and drawing new enactors and selectors into the TIS, especially local governments, intermediaries and interest groups. With this strong *Support from Advocacy Coalitions* they attempt to enforce the creation of a mass market for the emerging technology. Note that the rise of this motor is largely the result of the *Entrepreneurial Motor* which has paved the way in terms of actors (more selectors), institutions (more aligned), technologies (more mature) and networks (more integrated).

Structural drivers and barriers

As environmental issues become more urgent, a number of selectors - in this instance, numerous municipalities - become more receptive to positive results as communicated by the enactors. This strengthens especially *Guidance of the Search*. A related driver is the technological progress established. Encouraged by this, enactors provide a boost to the ANGTIS by organising themselves into networks that actively pursue marketing, promotion and lobbying strategies, thereby targeting a whole range of system functions, most notably *Support from Advocacy Coalitions*.

Note that the marketing activities are as yet stimulated with a rather limited budget (i.e., not by fiscal regulations) insufficient for a large scale infrastructure deployment. A related barrier is the poorly developed demand for ANG technology. Commercial organisations and private drivers are as yet not interested in adopting ANG technology. This is due to the absence of a clear fiscal policy framework. As long as ANG pricing remains uncertain, commercial parties will remain hesitant to invest in infrastructure required for large-scale ANG diffusion. These barriers particularly hamper *Resource Mobilisation* and *Market Formation*.

Impact on TIS structures

The most important impact of the *System Building Motor* is its tendency to draw selectors - governments and firms - into the ANGTIS, in this case these involve (formerly uninvolved) municipalities, car dealers and, most recently MinVROM. The involvement of these actors results in a bandwagon effect. A related structural change established during this period is that ANG technology has become more mature, meaning that it is ready for widespread application.[26] The inclusion of selectors and the diffusion of ANG technology relates to a third impact; a renewed belief in the techno-economic feasibility of ANG technology among enactors and selectors not yet part of the ANGTIS.

An overview of drivers, barriers and impacts is presented in Table 5.

Insert Table 5 here.

4.4 Take-off? (2005-2007)

Local air quality standards continue to be the main driver for ANG development. In conjunction with this, the political priority of climate change reaches an all-time high. The climate issue becomes especially important by the end of 2007 when biofuels, which have so far been embraced internationally as the most attractive short-term alternative car fuel, are increasingly contested. As a result ANG becomes the last refuge of the green (SN, 2008b).[27]

As the ANGTIS develops, incumbents become a larger part of the system but there is an increasing resistance among incumbents as well, primarily from oil companies (MoH, 2008; WNGB, 2007).[28] Also, MinVROM is unwilling to support ANG technology with market creation measures (MinVROM, 2004; Van der Knoop, 2005).[29] Its viewpoint is that ANG technology is not a long-term solution, either for reducing NO_x or PM, or for reducing CO_2.[30] However, the ministry's vision receives much criticism, especially from a working group within the Energy Transition Platform on Sustainable Mobility (PSM), a public-private partnership connected to a variety of ministries.[31] The working group, backed by 40 companies, including four major energy companies, municipalities and NGOs, succeeds in convincing MinVROM to provide specific policy support for ANG technology after all (AC, 2005; SN, 2008b; Van der Knoop, 2005).[32] By the end of 2005, MinVROM announces a policy package to support ANG technology.[33]

By the end of 2006 the government announces two fiscal measures.[34] Firstly, it sets a low excise rate specifically for ANG.[35] It does not announce, however, for how long this rate will hold (SN, 2008b). Secondly, it sets a purchase tax-rate (BPM) that benefits energy efficient cars (DutCH4, 2006b). This results in the adoption of more NGVs among municipalities.[36] NGVs are adopted as fleet vehicles and refuelling stations are installed or planned. Many of these municipalities prepare regulations to provide cheap parking permits and (in some cases) financial incentives for purchases of NGVs (DT, 2006; DutCH4, 2006b; DV, 2006; LC, 2006). The involvement of provincial governments grows stronger as well, supporting the deployment of ANG infrastructure (DutCH4, 2006c; SN, 2006a).[37] They also design concessions that favour ANG in public transport (DG, 2006; DvhN, 2006; PZC, 2006).[38]

The ANGTIS becomes stronger on the supply-side where DutCH4, Gasunie and partnerships, like the Energy Valley cluster, support ANG technology by financially and politically stimulating infrastructure development, but also by issuing discounts on fuel and NGVs (SN, 2006b). A key event contributing to this development is the start-up of Aardgas Mobiel, a network that promotes ANG technology on behalf of car manufacturers (Dutch4, 2007). A related development is the formation of CNG-net, a joint venture of DutCH4 and Ballast-Nedam, a large (infrastructure) construction company. CNG-net plans to realise 50 refuelling stations by the end of 2008, and 200 more in the years to come (Dutch4, 2007).[39]

In general, it can be stated that incumbents of the mobility sector, including branch organisation BOVAG, car dealers and manufacturers, now expect ANG demand to rise explosively (Bovag, 2007). The result is the entry into the system of so-called system integrators, mostly incumbent companies that arrange import and assembly of NGVs and ANG refuelling stations (SN, 2008b).[40]

A drawback is that private drivers are still absent since a refuelling infrastructure is still absent in most places, even though this is something that is now worked on.[41] A related problem is the uncertainty on the trade-in value of second-hand NGVs (SN, 2008b). This is especially relevant for fleet owners that may be obliged, in the near future, to renew all their vehicles if even stricter conditions are to be met (PZC, 2006). Due to this uncertainty a number of public transport companies protest against the concession policies set up by provincial governments (Connexxion, 2007; FD, 2005b).[42]

Motors

It becomes clear that *Guidance of the Search* and *Market Formation* - both in the form of national government policies - have a strong effect on *Entrepreneurial*

Activities and, resulting from these, on *Resource Mobilisation* in the form of large investments, particularly in ANG infrastructure. The latter two system functions are now stronger than before. The promise of a mass market for ANG applications means that *Entrepreneurial Activities* now arise due to the anticipation of actors - enactors and selectors alike. In some cases these even result in new contributions to *Market Formation* in the form of (lower-level) policies such as concession policies, lease plans or green parking zones. With the promise of a market, the importance of *Support from Advocacy Coalitions* lessens as firms are willing to make investments, even without (additional) government support. This means that a new form of cumulative causation has emerged. Given the primacy of the promise of a market, it seems fit to label it as a *Market Motor*.

Structural drivers and barriers

The ANGTIS developments are still externally driven by air quality norms and increasingly also by the climate issue. The most important internal driver of this motor is a shared belief, among enactors and selectors, translating into a joint *Guidance of the Search*, in the future of ANG technology as a means to contribute to mitigate both problems. This belief is underpinned by the national government putting up a regulatory framework that reduces uncertainty, thereby contributing to *Guidance of the Search* and *Market Formation*. The key to the dynamic that arises is that enactors and selectors do not need to put as much energy into lobbying efforts anymore. Instead they contribute directly to *Entrepreneurial Activities* and *Resource Mobilisation*. Selectors - most notably provinces and municipalities formerly not involved - are increasingly active to improve the policy environment as well, thereby contributing to *Guidance of the Search* and *Market Formation*. Among these selectors are incumbent firms and system integrators willing to invest in the ANGTIS.

An important barrier is (still) the lack of a long-term policy perspective as the duration of the excise-rate remains uncertain. Also, demand for ANG technology remains weak as it depends heavily on local government authorities as fleet owners; private users are barely present. Another barrier is that some of the support policies - especially the concession policies - cause resistance among selectors, thereby contributing negatively to *Guidance of the Search* and *Support from Advocacy Coalitions*.

Insert Table 6 here.

Impact on TIS structures

A take-off has occurred. A key impact is the entrance of selectors that constitute a demand for ANG technology. With the presence of infrastructure contractors and numerous fleet owners, a modest market diffusion process has started. This is underlined by the numbers in Table 6 which show that numerous refuelling stations are being built.

An overview of drivers, barriers and impacts is presented in Table 7.

Insert Table 7 here.

5 Conclusion and discussion

The aim of this chapter was to analyse the development of the Dutch ANGTIS and, thereby, to provide insights into the dynamics of TIS build-up. This section provides a summary of the results and a discussion of their implications for intervention strategies intended at supporting TIS dynamics within the context of sustainable, or emerging, energy technologies.

5.1 The Entrepreneurial Motor

Three motors of innovation were identified. The *Entrepreneurial Motor*, the first one observed, emerged in the 1970s and was active until well into the 1990s. It was characterised by interactions between *Entrepreneurial Activities*, *Knowledge Development*, *Knowledge Diffusion* and *Guidance of the Search*. It was connected to *Support from Advocacy Coalitions* and *Resource Mobilisation* as well.

The event sequence was characterised by utility companies and firms entering the TIS and venturing into *Entrepreneurial Activities*. This especially led to *Knowledge Development* and *Guidance of the Search*, which in turn reinforced *Entrepreneurial Activities*. On most occasions *Resource Mobilisation* was the result of firms lobbying for government subsidies. This contributed strongly to the *Support from Advocacy Coalitions* function.

The following structural drivers, barriers and impacts were identified:

- In terms of structural drivers, the basis of this motor was formed by a group of enactors, involving utilities and municipalities, that managed to persuade an increasing number of selectors (bus companies, boating companies, governments) into supporting demonstrations of ANG technology.

- A structural barrier of the *Entrepreneurial Motor* was its narrow actor basis, especially the lack of firms willing to adopt ANG technology. A related barrier was formed by persistent (unexpected) techno-economical problems of ANG technology.

- Important impacts of this motor were the formation of networks that strengthened the intermediary structure of the TIS, the application of safety standards, licensing procedures and the allocation of subsidies, thus supporting the institutional structure of the ANGTIS. Another impact was the (gradual) development of the emerging ANG technology into (more) reliable applications.

5.2 The System Building Motor

The system functions that formed the *System Building Motor* are *Entrepreneurial Activities*, *Knowledge Development*, *Knowledge Diffusion*, *Guidance of the Search*, *Resource Mobilisation*, *Support from Advocacy Coalitions* and *Market Formation*. All seven system functions were involved. Note that the *Market Formation* function was barely present in the *Entrepreneurial Motor*. Another difference lies in the connection between *Support from Advocacy Coalitions* on the one hand, and *Market Formation* and *Guidance of the Search* on the other. These connections were established through entrepreneurs that organised themselves in networks and managed to draw new enactors and selectors into the TIS, especially local governments, intermediaries and interest groups. They did this by lobbying the government, not for project-specific support measures, but for systemic policies aimed at *Resource Mobilisation* or *Guidance of the Search* beneficial to the emerging technological field as a whole. With this strong *Support from Advocacy Coalitions*, they attempted to enforce the creation of a mass market for the emerging technology. The outcome of these system-building attempts affected *Guidance of the Search* and *Resource Mobilisation*, with as a subsequent effect that even more *Entrepreneurial Projects* were developed by an increasing number of firms.

- This motor was driven by enactors and supportive selectors forming platforms and other networks. By strengthening the existing structures of the ANGTIS they managed to incorporate a multitude of selectors, for example, national government ministries and incumbent firms. Another driver was the increased reliability of ANG technology and its fit with the policy environment (standards, licences).

- A main structural barrier of the *System Building Motor* was the absence of a refuelling infrastructure and the lack of long-term (fiscal) policies to support its development. Another barrier was the rise of resistance among incumbent firms and governments. Since the growth of ANG technology would eat into the incumbent markets, incentives to support this technology on the part of incumbent fuel producers were weak or even negative.

- In terms of impact, this motor drove the ANGTIS from a local fragmented ANGTIS into a national integrated ANGTIS. A multitude of enactors and selectors were drawn in and networks were established across various components of the TIS. The most important outcome was the political breakthrough that resulted in the issuance of top-down market creation policies.

5.3 The Market Motor

The third motor of innovation observed was the *Market Motor*. Its dynamics, which emerged only recently, were characterised by a strong contribution to *Entrepreneurial Activities*, *Knowledge Development*, *Knowledge Diffusion*, *Guidance of the Search*, *Resource Mobilisation* and *Market Formation*. All system functions were fulfilled, except for the *Support from Advocacy Coalitions*. The main reason was that *Market Formation* was no longer an issue of politics; a market environment had been created as the result of formal regulations. Instead, *Market Formation* was taken up as part of regular business activities, i.e., marketing and promotion strategies that are directly linked to *Entrepreneurial Activities*.

- The most important structural driver of this motor was that an institutional basis was formed that induced market creation for ANG technology. This means that firms did not need to lobby for (additional) resources anymore.

Instead they could take the opportunity to start investing in a refuelling infrastructure and to develop marketing strategies of their own.

- The *Market Motor* was not entirely developed yet, as both government institutions and markets were underdeveloped. This manifested itself in the limited role of private end-users and in the absence of refuelling infrastructure and long-term fiscal policies. Another barrier was (still) the resistance among a number of selectors.

- The most important impact of this motor was the increasing diffusion of ANG technology and the powerful promise of a mass market for NGVs and ANG technology.

5.4 Breakdown

Besides motors of innovation, vicious dynamics were also observed. This happened in the 1990s when a combination of internal and external conditions (a low priority of environmental issues, liberalisation policies in the energy sector, a disappointing techno-economical outcomes and a narrow actor base), led to a rapid breakdown of the ANGTIS. During this episode, developments were nevertheless supported by a small number of dedicated enactors which found refuge in niche markets. When external conditions shifted, the enactors managed to start a build-up again. Even when selector support was discontinued, enactors continued pro-actively to develop a TIS by consolidating the build-up already established, and waiting for better conditions to arise.

5.5 Concluding remarks

At the outset of this article it was suggested that the analysis of the ANGTIS could provide important insights regarding the take-off of a formative TIS. The analysis has pointed out that the take-off of the ANGTIS occurred only after a long period of developments characterised by different motors of innovation, and a period of severe decline. It was shown that each motor was driven (and hampered) by a particular configuration of structures. In turn, each motor contributed to the build-up and adjustment of these structures.

All the motors were coupled to developments external to the ANGTIS as well. These involved policies (environmental regulations, liberalisation policies, EU subsidies), economic trends (oil prices) and technological developments (the biofuels debate). However, it was primarily the TIS structures, including dominant strategies taken by enactors and selectors, that determined the specific effect of these external factors on the dynamics within the ANGTIS.

An important observation, in the light of a take-off, was that the more advanced motors arose from more developed TIS structures, for example, the *Market Motor* developed on the basis of a relatively mature technology which was embedded in supportive regulations and supported by a strong network of enactors and selectors. However, these advanced TIS structures were established by less advanced motors. The *Market Motor* could arise on the basis of the build-up established by the *System Building Motor* - i.e., market creation policies and government structures - and likewise, the *System Building Motor* could arise due to the build-up established by the *Entrepreneurial Motor* - i.e. the formation of strong networks, intermediary structures and demand-side structures.

With respect to the take-off, the *System Building Motor* was especially important. The driving force of this motor has been an inner core of dedicated enactors that were able and willing to organise themselves in networks, and to address not single projects but the TIS as a systemic whole, for instance, by lobbying for top-down market creation policies. The enactors managed to reach their goal by luring in selectors. The more support from selectors, and the larger their variety, the better. However, selectors could only be reached if internal and external conditions were sufficiently attractive compared with other options available to them. In this case, the *Entrepreneurial Motor* had largely provided such conditions. After all, enactors could rely on mature ANG technologies and institutions and actor networks that were established as part of the *Entrepreneurial Motor*.

A key barrier of the *System Building Motor* was the resistance from selectors residing in the incumbent energy system, including important national government structures. When this resistance was overcome, the ANGTIS developed further towards a take-off. Still, even after the rise of a *Market Motor*, the dynamics of the ANGTIS were hampered, most importantly by the absence of long-term government policies and, related to this, the absence of private end-users. Despite all the advantages that a mature technology offers, a complete ANGTIS has not yet been created. The *Market Motor* is powerful and effective as a promise for the (near) future, but it remains to be seen whether the high expectations that it raises will actually be fulfilled.

Policy makers, and other practitioners, may use the kind of insights developed here to develop strategies that target the dynamics of TIS build-up around particular sustainable energy technologies. This could be done by monitoring TIS dynamics, by supporting the conditions that drive motors of innovation and by overcoming the barriers that hamper them.

A next step of research should be to find out more precisely what structural combinations lead to what motor of innovation and to find out whether motors of innovation tend to follow on each other, in general.

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Tables

Table 1 Functions of technological innovation systems.

System Function	Description	Event types associated
F1. *Entrepreneurial Activities*	At the core of any innovation system are the entrepreneurs. These risk takers exploit business opportunities and perform innovative commercial and/or practice oriented experiments.	Projects with a commercial aim, demonstrations, portfolio expansions
F2. *Knowledge Development*	Technological research and development (R&D) are a source of variation in the system and are therefore prerequisites for innovation processes to occur. Non-technological knowledge is also of key importance.	Studies, laboratory trials, pilots
F3. *Knowledge Diffusion*	The typical organisational structure of an emergent innovation system is the knowledge network, primarily facilitating information exchange.	Conferences, workshops, alliances
F4. *Guidance of the Search*	This system function represents the selection processes necessary to facilitate a convergence in development.	Expectations, promises, policy targets, standards, research outcomes
F5. *Market Formation*	New technologies often cannot outperform established ones. In order to stimulate innovation it is necessary to facilitate the creation of (niche) markets, where new technologies have a possibility to grow.	Market regulations, tax exemptions
F6. *Resource Mobilisation*	Financial, material and human factors are necessary inputs for all innovation system developments.	Subsidies, investments
F7. *Support from Advocacy Coalitions*	The emergence of a new technology often leads to resistance from established actors. In order for an innovation system to develop, actors need to raise a political lobby that counteracts this inertia, and supports the new technology.	Lobbies, advice

Table 2: ANGTIS drivers, barriers and impacts underlying an *Entrepreneurial Motor* in 1970-1989.

	Actors	Institutions	Technologies
Drivers	• The main enactors are gas companies attempting to draw in ANG technology selectors. • Important selectors backing up ANG technology are governments and bus companies. • The enactors manage to draw in selectors by giving practical demonstrations of the possibility of ANG technology and promising a solution to pressing policy issues.	• High oil prices (external). • Environmental issues (external). • Promise of cheap and clean technology, partly based on US experience (external). • Specific subsidy programmes.	• Low variable costs of natural gas. • Availability of natural gas and ANG technology. • Low emission characteristics.
Barriers	• The group of enactors and selectors supporting ANG technology is small and closely linked to public services, i.e., utilities.		• Reliability problems. • High investment and maintenance costs. • Limited range of NGVs.
Impacts	• A network is established consisting of a small number of enactors and selectors.	• The setting up of governmental support programmes.	• The first applications of ANG technology provide insights in (unexpected) technological bottlenecks.

Table 3: ANGTIS drivers, barriers and impacts underlying an *Entrepreneurial Motor* in 1990-1999.

	Actors	Institutions	Technologies
Drivers	• Only a few dedicated enactors remain active, mostly gas companies and municipalities. • The selectors are governments, especially municipalities. • The enactors manage to join forces with the selectors by promising a solution to pressing policy issues. Their strategy is to develop a policy environment, e.g., licensing procedures, safety standards. • Selectors remain active in niche markets.	• Environmental issues (external). • EU Thermie programme (external). • Market niches provide stability.	• Low variable costs of natural gas. • Availability of natural gas and ANG technology. • Low emission characteristics.
Barriers	• Many of the enactors (gas companies) turn into selectors after a series of mergers. • Massive exit of enactors and selectors.	• Lowering oil prices (external). • Liberalisation in the energy sector (external). • Risk-averse attitude of selectors. • The belief in the feasibility of ANG technology has diminished and even turns negative.	• Reliability problems. • High investment and maintenance costs. • Limited range of NGVs.
Impacts	• Most enactors and selectors have abandoned the ANGTIS. • Networks are established by a handful of remaining actors, including municipalities and gas companies.	• A policy environment is established (licences, standards).	• ANG technology diffusion is reversed.

1 **Table 4: ANG refuelling sites available in the Netherlands by 2004.**

Location	Owner	Users
Haarlem	Nuon	Nuon, Municipality of Haarlem
Velsen	Nuon	Local refuse collection services
Schiphol	Schiphol Airport	Schiphol Airport / public
Amstelveen	Eneco Energy Amstelland	Eneco Energy Amstelland, Municipality of Amstelveen
Almelo	Gas Company Cogas	Gas Company Cogas / public
Amsterdam	Canal Bus	Canal boat operators

2 **Source: NGV (2007, 2008), SN (2008a).**

Table 5: ANGTIS drivers, barriers and impacts underlying a *System Building Motor* in 2000-2004.

	Actors	Institutions	Technologies
Drivers	• The enactor group has grown and consists of gas companies and a number of municipalities looking for a solution for local environmental issues. • A number of municipalities have turned from selectors into enactors. • The enactors form a network and develop strategies to draw in enactors and selectors from outside the TIS. • The strategy of the network is to connect with municipalities, car dealers, governments and other selectors. They persuade these selectors on the basis of successful demonstrations of ANG technology in practice. They also promise a technological solution to important policy issues. Moreover they make attempts to create markets for NGVs.	• Air quality regulation (external). • Adapted policy environment (licences, standards). • Support for demonstration programmes (EU, national).	• Low variable costs of natural gas. • Availability of natural gas and ANG technology. • Low emission characteristics. • The ANG technology has matured, meaning that reliability is no longer a problem.
Barriers	• Lack of launching customers.	• Limited budgets for infrastructure development. • Lack of long-term (fiscal) policy support.	• High investment costs. • Lack of refuelling infrastructure.
Impacts	• Selectors are increasingly drawn in, governments (local and national) as well as firms.	• A strong belief in ANG technology among enactors and selectors.	• Adoption of NGVs and natural gas refuelling infrastructure increases. • The ANG technology is ready for widespread application.

Table 6: Number of NGVs in the Netherlands and Germany measured in March 2007 and May 2007 respectively.

	Total NGVs	NGVs / 1000 inhabitants	NGV share of total vehicles	Number of refuelling stations: Constructed	Under construction
Netherlands	603	0.04	0.01 %	8 (1:75 cars)	22
Germany	60,000	0.73	0.12 %	720 (1:83 cars)	13

Source: GVR (2007).

Table 7: ANGTIS drivers, barriers and impacts underlying an emerging *Market Motor* in 2005-2007.

	Actors	Institutions	Technologies
Drivers	• Enactors and selectors have established strong networks across the ANGTIS. • A variety of new selectors is drawn into the ANGTIS, including provinces, municipalities and system integrators. • The strategy of enactors and selectors is to exploit the benefits offered by the promise of a mass market and develop plans to construct a nationwide refuelling infrastructure.	• Air quality regulation (external). • Building prohibition (external). • High oil prices issue (external). • Climate change issue (external). • Fiscal regulations benefit ANG use. • Local market creation policies benefit ANG use.	• Profits from bad reputation biofuels (external). • Low variable costs of natural gas. • Availability of natural gas and ANG technology. • Low emission characteristics. • The ANG technology has matured, meaning that reliability is no longer a problem.
Barriers	• Private users are barely involved as selectors. • Resistance rises among selectors and enactors not willing to support ANG technology but 'forced' to do so.	• Lack of long-term (fiscal) policy support. • Concession policies cause resistance.	• High investment costs. • Lack of refuelling infrastructure.
Impacts	• Selectors are now constituting a significant demand for ANG technology. These include infrastructure contractors and numerous fleet owners.	• The promise of a mass market for NGVs and ANG technology.	• Diffusion of ANG technology increases. Applications include buses and other highly visible environments. • Refuelling infrastructure is being deployed.

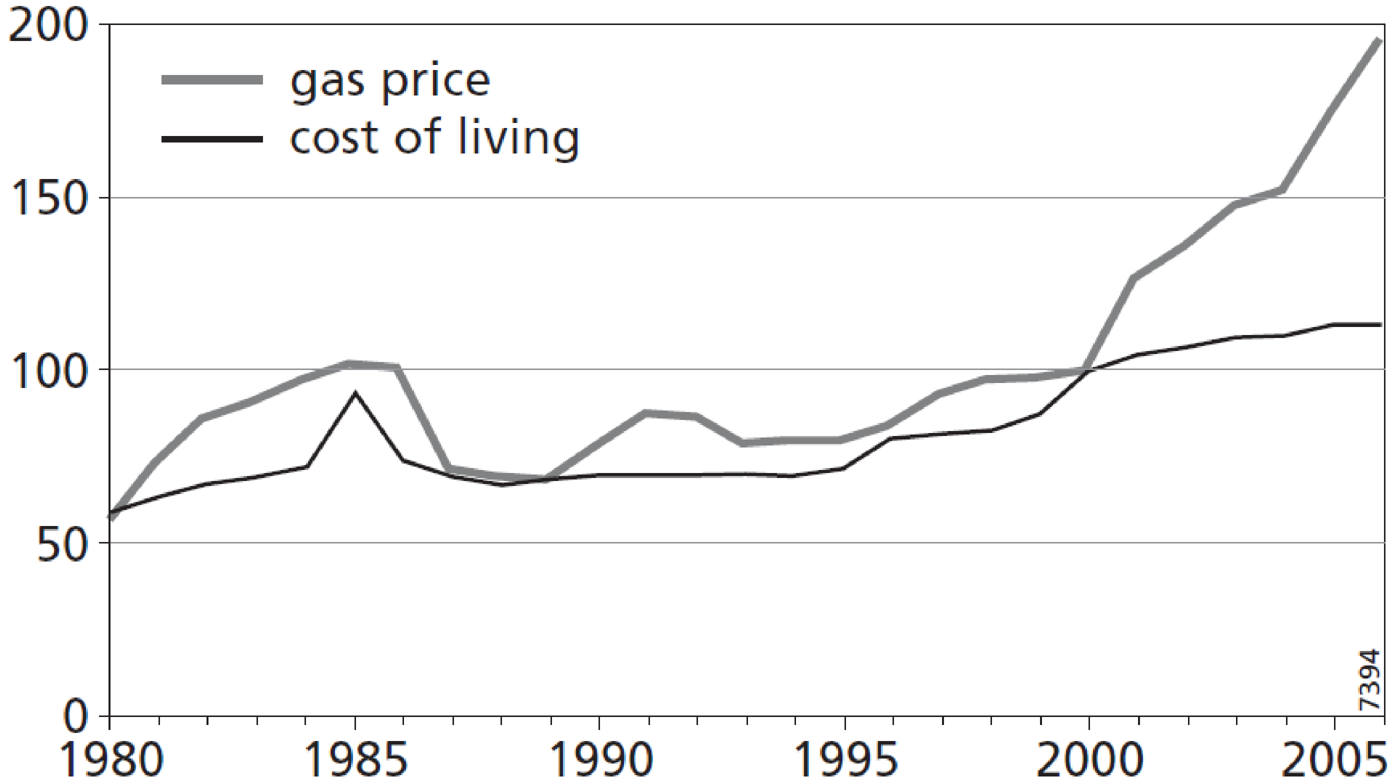

Figure 1: Natural gas price development, indexed at 2000, estimated for small users, including taxes. Source: EnergieNed(2006).

Notes

[1] This contrasts with many other technologies for which TIS development has been studied so far.

[2] Natural Gas as used for automotive purposes is identical to the natural gas (also methane or CH_4) used for the production of heat and power.

[3] See also ECN (1997a) Since the 1970s, the price of natural gas has been coupled to the oil price (ECN, 1997b; GT, 2006). Prices rose in the 1970s and in the early 1980s as a consequence of the oil crises (ECN, 1997b). From the late 1980s to the late 1990s prices remained stable, only to increase again when oil became scarcer again from 2000 on (primarily due to a rapidly increasing demand).

[4] Typically from 0.2-8 bar to 200 bar. Another possibility is to produce Liquefied Natural Gas (LNG). This can be produced by cooling and/or pressurising NG. It has a higher energy density than compressed natural gas and is therefore economically attractive when the fuel has to be distributed over large distances.

[5] An alternative to the construction of public refuelling stations is the construction of private ones. The idea is that private drivers connect their car to the mains gas supply at home, which is widely used in the Netherlands for heating and cooking. The drawback of these slow-fill systems is that it takes a long time to fill the tank, meaning that refuelling has to take place overnight.

[6] Alternative emerging TISs may also be a disruptive factor in the development of ANG. For example, if liquid biofuels should provide a successful alternative to petrol and diesel, the need for natural gas could rapidly vanish.

[7] GVB Groningen, RET Rotterdam, HTM The Hague and (later) GVB Amsterdam.

[8] They embrace regular fossil fuels or, when it comes to innovation, LPG or a combination of diesel and particulate filters.

[9] Take, for instance, ENW, an energy company which, as a result of mergers, possesses a large part of the existing ANG refuelling infrastructure. When ENW merges into energy company Nuon, it abandons the project and tries to sell the refuelling stations in Velsen, Haarlem, Alkmaar and Amsterdam (Verbeek, 2002).

[10] Another example is Cogas planning the first public ANG refuelling station at a Shell outlet in Almelo, to be finished in 2001 (Cogas, 2007).

[11] Cogas' ANG pump, for example, becomes a reference installation to the field, but only after Cogas convinces the relevant normalisation institute that it is safe (Cogas, 2007).

[12] The developments are stimulated by gas companies around Amsterdam and Rotterdam which provide the ANG refuelling stations. As in the abovementioned projects these firms run into difficulties when gas companies become subject to reorganisations, but most niches are eventually retained (Verbeek, 2002).

[13] This is underlined by the EU through its announcement of a goal of 20% utilisation of alternative automotive fuels, including NG, by 2020.

[14] The poor condition of the ANGTIS becomes clear when compared with developments in other European countries where ANG technology is emerging. In Germany, for instance, top-down policy directives have been imposed to develop a refuelling infrastructure (Verbeek, 2002; WNGB, 2007) and a low excise rate has been fixed to last until 2020.

[15] The first demonstration project, called GAIA (Gas Als Ideale Aandrijving) is initiated by the municipalities of Haarlem, Amstelveen and the Province of North Holland. The parties involved are refuse-collection companies, recycling businesses and the operator of Schiphol airport; the latter provides a site for a second refuelling station to be constructed by RWE (DT, 2003; Verbeek, 2002). A second project, called PRO-Aardgas, is specifically aimed towards private drivers. To accomplish this, a network is established with car dealers in the area (Fiat, Opel, Volvo). A scheme is installed in which a 25% discount is offered on the extra costs of purchasing a new NGV. Up to 350 consumers may benefit from the subsidy scheme. Support is also provided for the installation of refuelling stations at public sites (SN, 2008a).

[16] The Cogas project is situated in the rural region of Twente (province of Overijssel). Cogas has converted its own car fleet and installed a public refuelling station in Almelo (DTC, 2004b). The gas company releases a plan to diffuse NGVs and ANG refuelling stations throughout Twente. The aim of '*Mobiliteitsplan Twente Schoon*' is the conversion of 100 vans and 210 personal cars within two years (SN, 2008a). To support this, Cogas plans the set up of a second ANG refuelling station. This refuelling station will be installed in Hengelo by the end of 2004 with the support from DutCH4 (2004a). It provides users with a 50% discount on ANG. The project is backed by car dealers and by the Almelo municipality (SN, 2008a).

[17] They are financed through the national government's DEMO programme, a subsidy scheme executed by SenterNovem The project budgets are in the order of 4 M € (NGV, 2008; SN, 2008a).

[18] A case in point is NGV-Holland coming up with a strategy of lobbying the government and breeding commitment with new parties (NGV, 2008; Verbeek, 2002).

[19] It does this by buying up existing refuelling stations and by constructing new ones in the Haarlem-Schiphol area and in Twente (FEM, 2004).

[20] Ministry of Spatial Planning and the Environment (Dutch: *Volkshuisvesting, Ruimtelijke Ordening en Milieu*: VROM).

[21] For instance, projects are started in Nijmegen, Tilburg and Breda (in the province of North Brabant) (DG, 2004a, b; FD, 2005a) and in Groningen, Leeuwarden and Drenthe (the northern provinces) a number of municipalities organise themselves into a public-private partnership called Energy Valley (DvhN, 2005; LC, 2005).

[22] Cogas remains active as a lobby organisation but decreasingly so (Cogas, 2007).

[23] Such as the UKR, EOS and the Energy Transition Programme. For instance, DutCH4 manages to gain financial support through the UKR scheme for the construction of the first ten pumps in the northern provinces.

[24] Some even study the possibility of utilising biogas, a climate-neutral renewable (TW, 2005a).

[25] Examples of provinces getting involved are Gelderland, Utrecht, Friesland and North-Holland (NGV, 2007; TW, 2005b).

[26] It should be noted that this effect is largely the outcome of international learning activities, although with a strong contribution from Dutch companies, and therefore not entirely the result of the ANGTIS.

[27] Another external factor is that the security of gas supply becomes a political issue, the most significant event being that Gazprom briefly cuts off gas supply to Ukraine, and thereby to the rest of Europe. However, the ANGTIS actually does not seem to be affected by this threat; instead it seems that so-called clean fossil energy sources gain ground.

[28] The oil companies consider ANG a competitor to existing technological options such as diesel. They attempt to obstruct the covenant but in the end they effectively fail to do so. Resistance also grows among municipalities and public transport companies, mostly where they are obliged to adopt ANG technology because of concession policies (Dutch4, 2007; NGV, 2007).

[29] As articulated in its White Paper on traffic emissions.

[30] The White Paper states that ANG may be an interesting alternative car fuel for the short term, but that, as petrol and particularly diesel combustion techniques are continuously improved, the environmental performance of ANG will be offset within years.

[31] Within the Energy Transition Programme, such platforms were installed as a means to circumvent the rather inert organisational structures of the ministries.

[32] A majority of political parties is supportive of specific policy measures as well (HP, 2005; NGV, 2005).

[33] For the next year 12 M € is to be provided for the greening of buses and service vehicles of local governments. Also, MinVROM promises to approach the Ministry of Finance to design a fiscal framework supportive of ANG. The 12 M € subsidy is considered meagre by the ANG community (DT, 2005; NGV, 2007). In comparison, MinVROM is allocating 400 M € to a stimulation package for particle filters (Dutch4, 2007; MoH, 2008), which is regarded as an unsustainable end-of-pipe solution.

[34] The national government provides other stimuli as well: licensing procedures for the construction of ANG refuelling stations are simplified and MinVROM purchases eight NGVs for its own fleet (DutCH4, 2006a).

[35] The excise level is set at 3 €cents/m^3.

[36] In Leeuwarden, Groningen, The Hague, Nijmegen, Hengelo and Tilburg.

[37] The provincial governments of Gelderland, Zeeland and Utrecht decide to stimulate NG.

[38] This is the case in North Holland (Haarlem/IJmond), Groningen and Gelderland.

[39] Formerly, such activities were undertaken by DutCH4 alone but, due to limitations of capital, only on a limited scale. Now DutCH4 provides the knowledge and Ballast-Nedam the additional money needed.

The project amounts to an investment of about 10 M € in the next year and up to four times as much thereafter.

[40] Examples are PON (importer of NGVs) and Teesing (infrastructure development).