Task 59

A Report from the
Advanced Motor Fuels Technology Collaboration Programme

Technology Collaboration Programme on
Advanced Motor Fuels



Lessons Learned from Alternative Fuels Experience

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Summary / Abstract

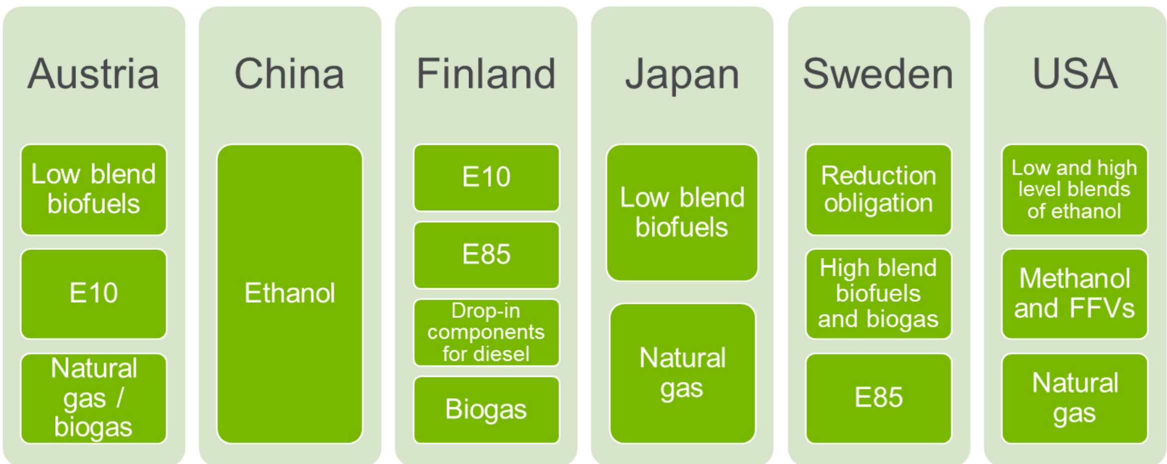
Decarbonizing the transport sector is one of the key goals of national and international climate change mitigation policies. Alternative fuels and propulsion systems are of particular importance in reducing greenhouse gas emissions from the transport sector. Many countries are actively seeking to increase the share of renewable energy sources in the transport sector.

However, experience with various attempts to introduce alternative fuels and vehicles to the market has shown that this is not always successful. Several participants in the Advanced Motor Fuels Technology Collaboration Program (AMF TCP) have therefore proposed a task on lessons learned from market launch attempts.

The questions pursued in the project "Lessons Learned on Alternative Fuels Experience" include the following:

- *Which factors determine whether the market launch of alternative fuels and vehicles will succeed or not?*
- *Can success factors and pitfalls, lessons and recommendations for better action be deduced from the experiences of different countries in the last decades?*
- *How can people involved in the development of market introduction measures be supported?*

To answer these questions, AMF Task 59 analyzed particular case studies that take into account the specific framework conditions for each country. The first step was to identify relevant case studies for each participating country.



Austria, China, Finland, Japan, Sweden and the United States collected data and information on past market introduction case studies and described these according to the developed template. In addition to the descriptions, relevant stakeholders were interviewed and their insights were collected.

The case studies' drivers for market implementation, country-specific circumstances, measures taken, and stakeholders involved were checked against the result of the market implementation as part of the analysis. Success factors and show-stoppers as identified in the case study descriptions were supplemented with the results from analysis by the task.

The findings from different case in the participating countries were presented in an expert workshop and results were discussed with experts inside the AMF TCP as well as external experts. The lessons learned and recommendations derived from our project were discussed with the workshop participants, to verify the findings. Based on the results and discussions of the expert workshop, the task determined the final lessons learned and recommendations, as well as key messages.

Key findings:

- *Policy - There is the need for long-term national and international policies with a comprehensive strategy. This includes a package of measures with financial and non-financial incentives. The coordination of government – academia – and industry within the implementation is important.*
- *Inclusion - The involvement of all groups of stakeholders along the value chain is necessary. The perception of the general public on alternative or new fuels needs to be improved. Additionally, the future transport system should include different types of alternative drive systems and fuels, suitable for different applications. Existing infrastructure should be used with increased share of renewable drop-in fuels. New fuels and drive systems can complement drop-in fuels.*
- *Benefits - It is really essential that there are visible benefits or cost benefits for all groups of stakeholders to make the alternative fuel or propulsion system attractive.*

Main conclusion:

For the successful implementation of alternative fuels and vehicles in the transport system there is the need for long-term and comprehensive policies which include markets, stakeholders and different technologies to gain benefits for all types of stakeholders along the value chain.

Authors

The case studies and report submitted under Task 59 were carried out and authored by numerous researchers from the participating countries as indicated below.

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The Advanced Motor Fuels (AMF) TCP also is an international platform of cooperation working in the framework of the IEA´s Technology Collaboration Programmes. AMF´s vision is that advanced motor fuels, applicable to all modes of transport, significantly contribute to a sustainable society around the globe. AMF brings stakeholders from different continents together for pooling and leveraging of knowledge and research capabilities in the field of advanced and sustainable transport fuels.
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Introduction

Decarbonizing the transport sector is one of the key goals of national and international climate change mitigation policies. Alternative fuels and propulsion systems are of particular importance in reducing GHG emissions from this area. Many countries are actively seeking to increase the share of renewable energy sources in the transport sector.

The utilization of sustainable alternative fuels should be seen very positive, conventional biofuels as well as advanced biofuels. Biofuels are viable in a short time and cause immediate CO_2 reductions. At the moment, the political focus in many countries is on electric mobility in transport sector. This is not an immediate solution to the carbon problem, since this needs a change in the vehicle stock. Some types of biofuels can be used in existing vehicle fleet, which is advantageous for an immediate carbon reduction in the transport sector. Other advantages are possible regional value chains, recycling of waste (waste oil or biogenic materials), additional production of feed and job creation. Advanced fuels have an economic potential for Europe and other countries, together with a positive ecological effect.

Alternative fuels and vehicles are an important element for reaching climate goals within mobility. On the road to decreasing CO_2 emissions, a bundle of measures is necessary, like extension of public transport, promotion of electromobility, an increasing car occupancy rate, utilization of biofuels and a lot more.

An important principle in the decarbonisation of the transport sector is the IEA´s Improve, Avoid and Shift approach. Advanced motor fuels and thus AMF TCP could play an important role in this transition (especially in the case of “Improve”):

In “Improve” policies, the utilisation of advanced motor fuels is included as one important measure, and so far, has been implemented in many countries. Furthermore, in the long term, it will be necessary to replace fossil fuels with alternatives in the transport sector in order to maintain high transport services. Alternative liquid and gaseous fuels for internal combustion engines, as well as electricity for electric vehicles and hydrogen for fuel cell vehicles, are possible alternatives that help to reduce greenhouse gas emissions and local pollutant emissions from the transportation sector. Since the energy crises of the 1970s, many countries have taken measures to promote the use of alternative fuels.

However, the experience of the past decades shows that these implementation attempts are not always successful. As shown in the Figure 1, Governments have politically been involved in promoting advanced motor fuels at various levels.

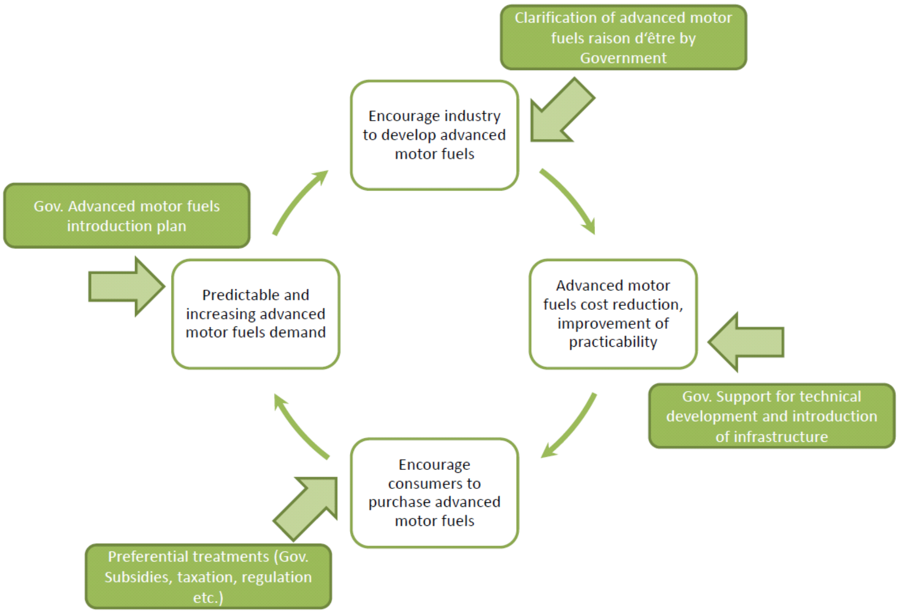

Figure 1: Involvement of Governments in promoting alternative fuels

However, there are many kinds of policies relating to private businesses, and the fuel and technology areas also face strong voices from various actors advocating their specific solutions. So, the evaluation of the policies is difficult and complicated. In order for each country to advance the commercialization of advanced motor fuels more efficiently and effectively, the commercialization policies carried out in each country should be synthesized together as unbiased information to be shared in member countries. Furthermore, it is desirable to develop a policy brief such as lessons learned and challenges on promoting advanced motor fuels.

The circumstances of the introduction of advanced motor fuels and the factors influencing their commercialization (resource, transport infrastructure, economic situation, etc.) in each country are different, and it is difficult to universally evaluate an advanced motor fuels policy. In other words, there is a possibility that a success story of a certain country does not work well in other countries, and vice versa. For this reason, this project clarifies the background and objective of the central government and local governments' introduction policy and specific measures on advanced motor fuels in the past, and summarizes the effectiveness, successes, and lessons learned regarding the promotion of advanced motor fuels in each individual case of introduction and commercialization.

Objectives

Many different groups such as vehicle manufacturers and retailers, universities, NGOs, national and local authorities, media, vehicle users and fuel suppliers are involved in the process of researching and developing advanced motor fuel products and technologies from fundamental research to successful market introduction (see Figure 2).

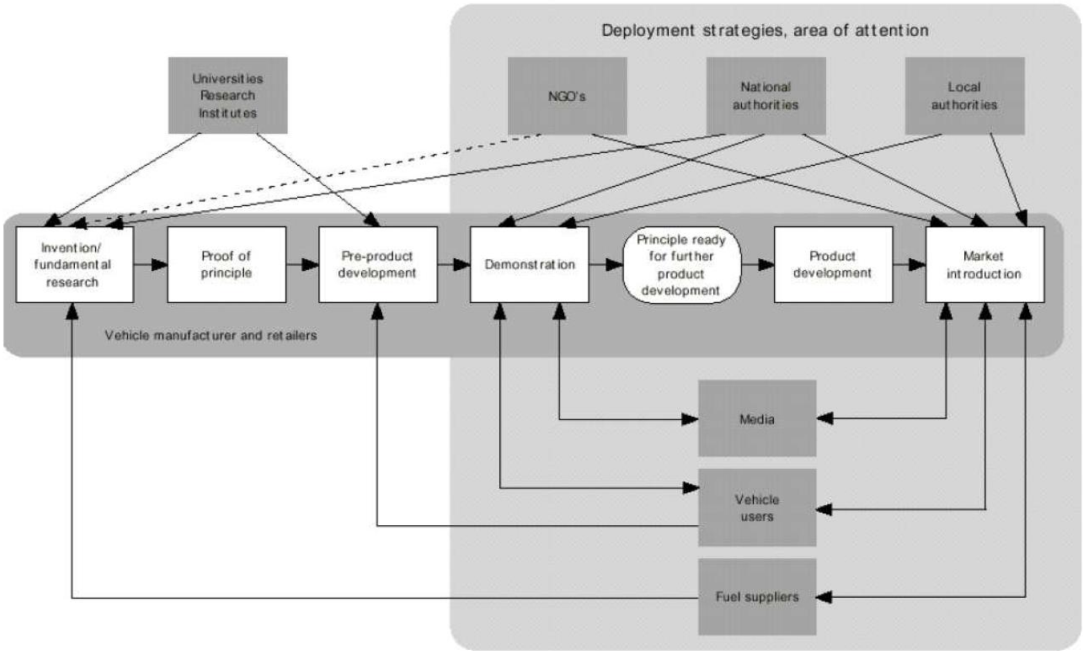

Figure 2: Interdependencies of the stakeholder networking[1]

While AMF Task XXI "Task 21: Deployment Strategies for Hybrid, Electric and Alternative Fuel Vehicles" focused on all aspects from demonstration to market introduction, the project AMF Task 59 on Lessons Learned from Alternative Fuels Experience focuses on the market introduction activities and the actions taken by national and local authorities.

Experience with various attempts to introduce alternative fuels and vehicles to the market has shown that this is not always successful. Several participants in the AMF TCP have therefore proposed an task on lessons learned from market launch attempts.

The project AMF Task 59 took a close look on the advanced motor fuels policies of the various central governments and local governments and assessed market potentials and of

[1] AMF Task 21 Final Report – Deployment Strategies for hybrid, electric and alternative fuel vehicles - Final Report

various approaches to improved vehicle energy efficiency and reduced emissions of air pollutants and greenhouse gases.

The questions pursued in the project "Lessons Learned on Alternative Fuels Experience" include the following:

- Which factors determine whether the market launch of alternative fuels and vehicles is successful or not?
- Can success factors, obstacles and lessons for better action be deduced from the experiences of different countries in the last decades?
- How can people involved in the development of market introduction measures be supported?

To answer these questions, Task 59 analyzed particular case studies that take into account the specific framework conditions for each country. The first step was to identify relevant case studies for each participating country.

Austria, China, Finland, Japan, Sweden and the United States collected data and information on past market introduction case studies and described these according to the developed template. In addition to the descriptions, relevant stakeholders were interviewed and their insights were collected.

The case studies' drivers for market implementation, country-specific circumstances, measures taken, and stakeholders involved were checked against the result of the market implementation as part of the analysis. Success factors and show-stoppers as identified in the case study descriptions were supplemented with the results from analysis by the task team.

Results and findings from the respective case studies were discussed in an expert workshop with experts from the AMF TCP and external experts. Based on the results and discussions of the expert workshop, the task determined the final lessons learned and recommendations, described in this report and summarised in the key messages.

Methodology and description of activities

For answering the questions on Lessons Learned of Alternative Fuels Experience the project was structured into activities which can be seen in Figure 3. Based on case studies developed through interviews in the participating countries and an expert workshop on the subject, examples of market launch attempts are collected and analyzed. Lessons are derived from the descriptions of these case studies and the assessment of their success.

Figure 3: Methodology project Lessons Learned

In a first step the Task Manager together with the task participants created a template with some key elements to be used for the description of the market introduction case studies of the various countries as well as fundamental points for interviewing national experts.

For the case studies, Austria, China, Finland, Japan, Sweden and USA collected data and information on past market introduction case studies and described these according to the developed template. For each case study, representatives from different stakeholder groups like ministries / authorities, automotive industry, fuel manufacturers and lobby groups / lobby organizations in the participating countries were interviewed on prior market introduction attempts. This included the measures taken, the groups involved, the budget and the duration of the measures. Finally, experts were asked to share their personal assessment, which factors were conducive to the market launch and which were of hindrance.

For the evaluation and quantification of the success of a market implementation a data sheet for the case studies was developed, including data on fuel consumption, number of vehicles, market share of suitable vehicles, quantity of fuel produced in the country and savings on GHG and local emissions as well as energy savings achieved.

All partners analysed and evaluated their own case studies. For each case study, the drivers for the market implementation, the country-specific circumstances, measures taken and stakeholders involved are checked against the result of the market implementation. Success factors and show-stoppers as identified in the case study descriptions were supplemented with the results from own analysis. Case-specific lessons learned and recommendations were created. For each case study infoboxes on key drivers of successes and key barriers of failures and infoboxes on case specific lessons learned and recommendations are given in the report.

The Task Manager analysed whether comparable measures have led to comparable results, and whether case-specific lessons learned and recommendations can be transferred to other cases. General lessons learned and recommendations were created.

The Task Manager organized and implemented an expert workshop. The workshop took place as virtual event on 30th of October 2020.

The goal of the workshop was to verify the findings and to derive key messages. Within this workshop the findings from different case studies in the participating countries were presented. The lessons learned and recommendations derived from the project were discussed with the workshop participants, interested experts inside the AMF TCP as well as external experts. The opinions of the experts were incorporated in the results. Based on the results and discussions of the expert workshop the final lessons learned and recommendations were derived.

More information on the expert workshop as well as the presentations can be found online at: https://www.iea-amf.org/content/news/expertworkshop_annex59

All activities and work were summarized and documented in this technical report. In order to disseminate the results, the lessons are published as key messages, which are, along with the final report, disseminated through the AMF network, respective national networks, conferences and social media.

Structure of report

Within this report the results of the case studies from the participating countries can be found in the following chapters, each following the same concept:

- description of case study (political framework, measures taken, data sheet …)
- evaluation of market introduction (including infoboxes on key factors of successes and key barriers of failures) and
- lessons learned (including infoboxes on case specific lessons learned and recommendations).

After the case studies from the countries there is a chapter on the comparative analysis, with a list of country specific and common implementation barriers, stakeholder interactions and results from the expert workshop.

This part of the report is followed by general lessons learned and recommendations.

Case Studies

At the beginning of the project, each country identified interesting case studies on past market launces and market launch attempts. The identified case studies are either successful or failures of market introductions including different types of alternative fuels and alternative drivetrains.

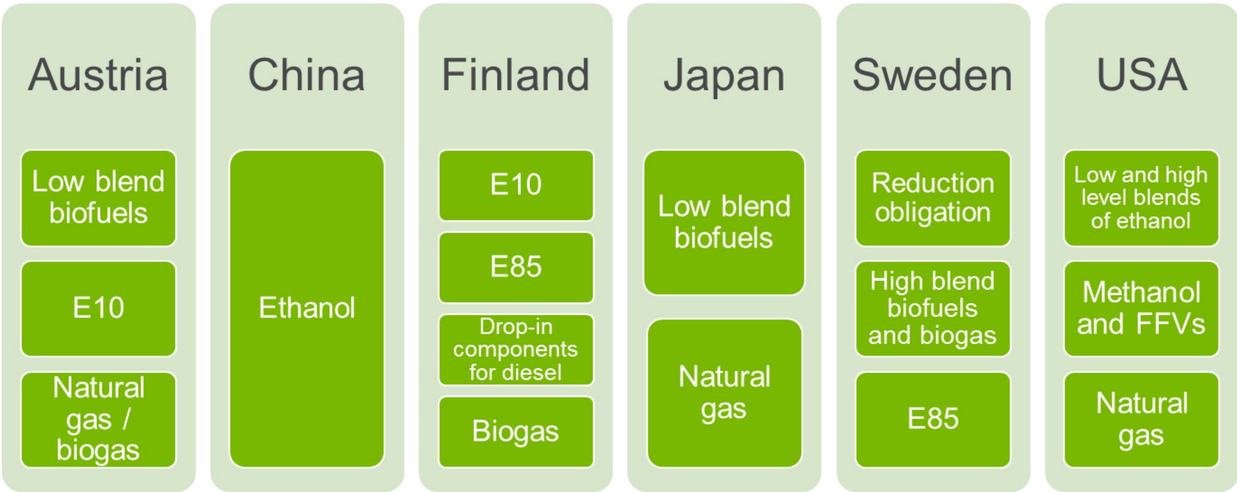

Figure 4: Task 59 – Case Studies

An overview of the identified case studies is given in Figure 4. Austria considered low blend biofuels, E10 and national gas. China had a deeper look on ethanol. Finland investigated E10, E85, drop-in components for diesel and biogas. Japan looked at low blend biofuels and natural gas. Sweden chose the reduction obligation, high blend biofuels and biogas, and E85. And the USA investigated low- and high-level blends of ethanol, methanol and FFVs, and natural gas.

Austria

For Austria three interesting Case Studies were identified with different success levels of market introduction:

- Low Blend Biofuels – example for a successful market introduction – since 2005 low blend biofuels are available and currently E5 and B7 are nationwide on the market
- E 10 – example for a prevented market introduction – the introduction process of E10 stopped two weeks before the planned market entry in 2012
- CNG – example for a market introduction with a low market acceptance – the number of gas stations decreases and the number of CNG driven cars stagnates since 2016

Transport sector in Austria

Fuels, Vehicles, energy consumption and GHG emissions

In Austria, the transport sector causes about 29 % of the annual CO_2 emissions (82.3 Mio t CO_2e) of the country. Since 1990 this sector shows the highest rise in emissions with a plus of 72 % (+9.9 Mio t CO_2e).[2] The reason for that is the long-term trend of a rising fuel demand due to an increase of road performance (kilometers driven) in passenger and freight transport and also the amount of fuel sold in Austria but used elsewhere as a consequence of higher fuel prices in neighboring countries.

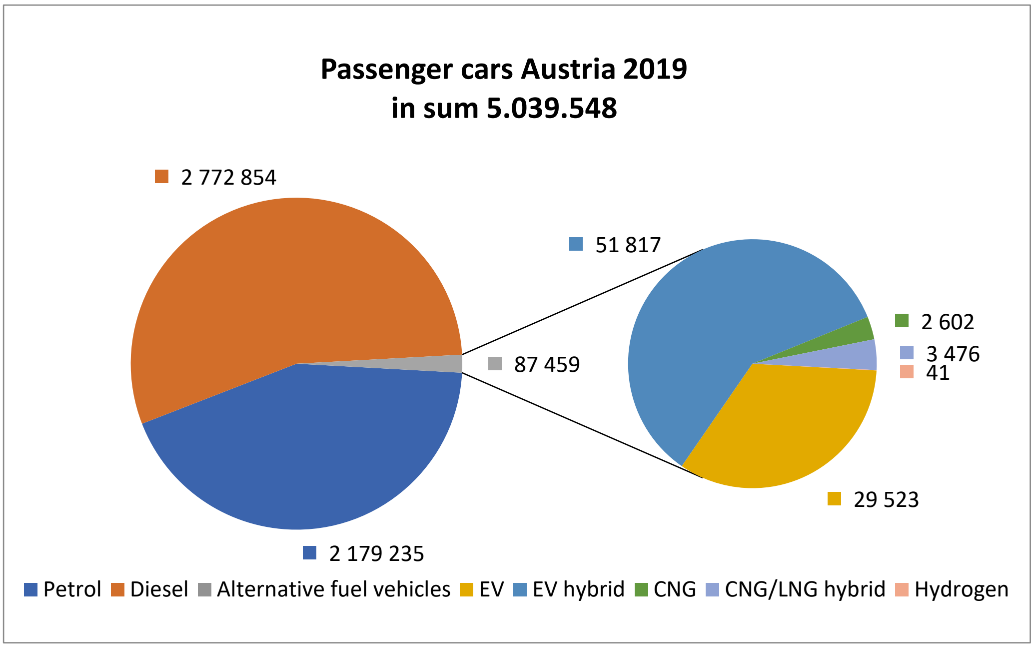

Figure 5: Number of registered passenger cars in Austria 2019

[2] Austrian Biomass Association (2019). Basis Data 2019 Bioenergy

In Austria the number of registered passenger cars is about 5 Million in 2019, that are 566 cars per 1,000 inhabitants. The main part (55 %) is diesel driven vehicles, followed by petrol driven vehicles (43 %). The percentage of alternative fuel vehicles is 1.74 %. With nearly 52,000 vehicles the hybrid EV cars are the main part, followed by pure electric vehicles (29,500). CNG/LNG Hybrid cars (3,500) are more present on the market than pure CNG vehicles (2,600). In Austria only 41 hydrogen driven cars are registered.[3]

The road transport in Austria showed an end energy consumption of 347 PJ in the year 2018. The fuel consumption increased in the last years, along with a rising consumption of diesel. The petrol consumption decreases since the 90s. Diesel fuel has the biggest share of nearly 74 % in end energy consumption compared to petrol fuel with 19 %, fuels with biogenic origin with 5.7 %, 1.5 % electric energy and 0.3 % CNG/LNG.[4] The energetic substitution of fossil fuels with biofuels accounts for 6.25 % in the year 2018.[5]

Alternative Fuel production and use and related GHG emission reduction

In Austria one large bioethanol production facility and 7 FAME (biodiesel) production facilities were operating in 2018.[6] Other fuels which are produced in smaller production facilities are pure plant oils, advanced fuels and biomethane.

Table 1: Biofuel Production in Austria 2018

Biofuel	**Production in 2018**
FAME	287,217 t
Ethanol	197,550 t
PPO	263 t
Biogas	401-630 Mio m^3 (estimation)
Advanced Biofuels	n.a.

The fuel sales in Austria in 2018 are given in Figure 6. About 75 % of all fuel sales are sales of fossil diesel, followed by 19 % fossil petrol. Biofuel are 6 % of all fuel sales with biodiesel

[3] Statistics Austria (2020). Stock of motor vehicles and trailers 2019

[4] Statistics Austria (2020). Overall energy balance 2018

[5] Federal Ministry of sustainability and tourism (2019) Biofuels in the transport sector in Austria 2019

[6] Federal Ministry of sustainability and tourism (2019) Biofuels in the transport sector in Austria 2019

as main part followed by bioethanol and ETBE, HVO and minor amounts of PPO and biogas/biomethane.

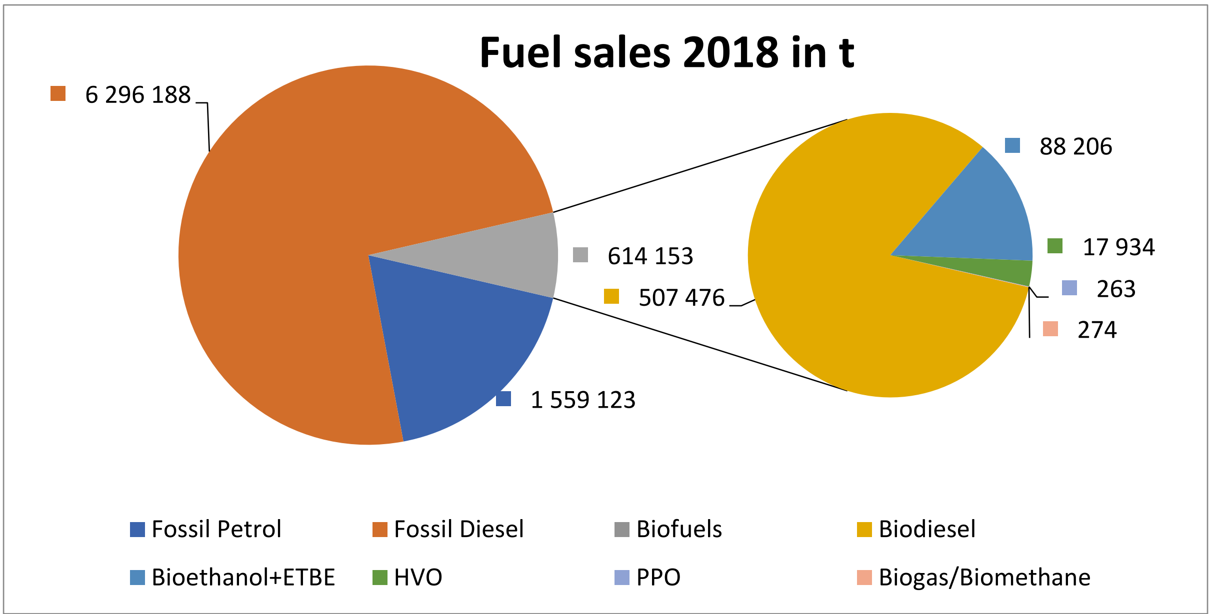

Figure 6: Austrian Fuel sales 2018 in t

The use of biofuels caused an emission reduction in the transport sector of 1.6 Mio t CO_2e in the year 2018. The used biofuels were FAME, Ethanol, ETBE, PPO, HVO and Biogas, the amounts are listed in the following table and figure.[7]

Table 2: Biofuel Use in Austria 2018

Biofuel	Use in 2018
FAME	507,476 t
Ethanol	84,895 t
ETBE	3,311 t
PPO	263 t
HVO	17,834 t
Biogas	274 t

[7] Federal Ministry of sustainability and tourism (2019) Biofuels in the transport sector in Austria 2019

Political framework

Austria's biofuel use and production is influenced by several national and EU legislations:

- EU Renewable Energy Directive (RED) 2009/28/EC
- EU Renewable Energy directive (RED II) 2018/2001/EU
- EU Fuel Quality Directive (FQD) 2009/30/EC
- EU ILUC Directive (EU) 2015/1513
- Fuel Ordinance BGBl. II Nr. 398/2012 idF BGBl. II Nr. 86/2018
- Sustainability Ordinance BGBl. II Nr. 157/2014
- Ordinance on Agricultural Feedstocks for Biofuels BGBl. II 250/2010
- Mineral Oil Tax Law BGBl. I Nr. 630/1994 idF BGBl. I Nr. 104/2018
- Bioethanol Blending Order BGBl. II Nr. 378/2005 idF BGBl. II Nr. 63/2016

Concerning biofuels, the EU has established a legal framework including the Renewable Energy Directive (RED II) and the Fuel Quality Directive (FQD), which are binding for all member states and have to be implemented into respective national laws.

In RED II the overall EU target for the consumption of renewable energy by 2030 has been raised to 32 % and there is a transport sector sub-target of 14 % to the energy consumed in road and rail transport by 2030 as renewable energy. Within this sub-target there is a dedicated target for advanced biofuels with a share of final energy consumption of at least 0.2 % in 2020 and 3.5 % in 2030. Additionally, there is a cap for biofuels produced from food and feed crops with a maximum of 7 % of final consumption of energy in the road and rail transport sectors in the member states. In Austria further legislation, transposing the new RED II Directive into national law needs to be created and will constitute the framework targets beyond 2020.

The Fuel Quality Directive requires a reduction of the greenhouse gas intensity of transport fuels by a minimum of 6% by 2020. Together with the Renewable Energy Directive, it also regulates the sustainability of biofuels.

The EU Renewable Energy Directive (RED) 2009/28/EC and the Fuel Quality Directive (FQD) 2009/30/EC were transposed into Austrian national law by amending the Fuel Ordinance in 2009, 2012, 2014 and 2018. The Fuel Ordinance stipulates:

- From 2009, 5.75% (by energy content) of all Otto and Diesel fuels should be biofuels or other renewable fuels including at least 3.4% (energetic) of ethanol to be added to gasoline and at least 6.3% (energetic) of biodiesel to be added to diesel
- Additionally from 2020 at least 0.5% of the energy content in transport sector should come from advanced biofuels
- The greenhouse gas emissions of all fuels supplied to the transport sector have to be reduced by 6% by the end of December 2020

- Fuels can only be counted towards these targets if they fulfill the sustainability criteria (same thresholds and requirements as in RED and FQD). Any feedstock produced in Austria must comply with EU regulations. Imported feedstocks or biofuels must be certified by another Member State or a voluntary scheme approved by the EC or Austrian control bodies

Prior to the most recent developments, the "Fuels Ordinance" of 2012 defined technical specifications for motor fuels as well as substitution regulations for biofuels primarily with regard to environmental performance aspects. As of December 2012, biodiesel was specifically defined as FAME (fatty acid methyl ester) and defined a maximum amount of 7 vol% FAME as a blending component in total diesel fuel.

RED and FQD biofuel sustainability criteria are being implemented into Austrian law by two separate ordinances. The cultivation of feedstock is regulated by an ordinance on agricultural feedstocks for biofuels and bioliquids, while the fuel mandate that came into force in 2011 governs the certification of commercialized biofuels.

According to the Mineral Oil Tax Law, tax concessions are now granted for fuels with a biofuel share of at least 4.4 % (by energy content) and less than 10 mg Sulphur per kg of fuel. The use of pure biofuels as fuel has been exempted from mineral oil tax since 2000. The Bioethanol Blending Order that entered into force in October 2007 allows refunding of the mineral oil duty for E75 blends. CNG is exempt from the mineral oil tax as well but is subject to the lower natural gas tax.

Starting in July 2008, NoVA – a bonus/penalty system for CO_2 emissions was introduced for taxing the acquisition of new vehicles. As of January 2020, new cars that emit less than 115 g of CO_2/km are exempt from NoVA.

Low Blend Biofuels

Background

In Austria, the EU transport biofuels directive 2003/30/EG was transposed to national law with an amendment of the fuel ordinance (BGBl.II Nr.209/2004). Since 1.10.2005, 2.5 % (energetic) of the fossil fuels in the transport sector have to be substituted by biofuels. This goal has been reached by blending of diesel fuel with 5 % FAME. The percentage of substitution increased from 1.10.2007 to 4.3 % due to the admixture of ethanol to petrol fuels. With 1.10.2008 the substitution obligation according to the fuel ordinance was increased to 5.75 %.

In 2009 another amendment of the fuel ordinance (BGBl. II Nr. 168/2009) introduced specific sub-goals for the different type of fuels. From 1.1.2009 there was the obligation to substitute 5.75 % (energy) with biofuels, 3.4 % (energy) of gasoline and 6.3 % (energy) of diesel. For reaching the higher substitution quota for diesel fuels the mineral oil industry increased the addition of FAME to 7 vol%. The sub-goal for gasoline can be reached by the blending with 5 vol% ethanol or the addition of Bio-ETBE (Ethyl Tertiary Butyl Ether).

With the amendment of the fuel ordinance in 2018 (BGBl. II Nr. 86/2018) additionally a sub-goal for advanced biofuels was created with a substitution obligation of 0.5 % (energetic) with advanced biofuels from 1.1.2020.

Table 3: Austrian biofuel obligations (% by energy content)

Since	Overall biofuel target	Ethanol	Biodiesel	Advanced biofuels
10/2005	2.50 %			
10/2007	4.30 %			
10/2008	5.75 %			
1/2009		3.4 %	6.3 %	
1/2020				0.5 %

In Austria the relevant biofuels used for blending of fossil fuels are FAME in diesel fuels, HVO in premium diesel fuels, Ethanol and Bio-ETBE in gasoline fuels.

Table 4: Biofuel Use in Low Blends in Austria 2018[8]

Biofuel as low blending component	**Use in 2018**	**Energy**
FAME	444,562 t	16,446,804 GJ
HVO	17,747 t	780,612 GJ
Ethanol	84,895 t	2,291,506 GJ
ETBE	3,311 t	119,209 GJ
Sum Low Blends	**550,515 t**	**19,638,131 GJ**

[8] Federal Ministry of sustainability and tourism (2019) Biofuels in the transport sector in Austria 2019

FAME is used since 2005 as a blending component for diesel fuels, starting with B5 and currently is used as B7 (blending of 7 vol%). HVO is used since 2013 in premium diesel fuels. The use of ethanol as blending component started in 2007 with E5. Between 2011 and 2015 ethanol consumption decreased with a simultaneous increase of Bio-ETBE consumption. The consumption of low blend biofuels over the course of time is shown in Figure 7.

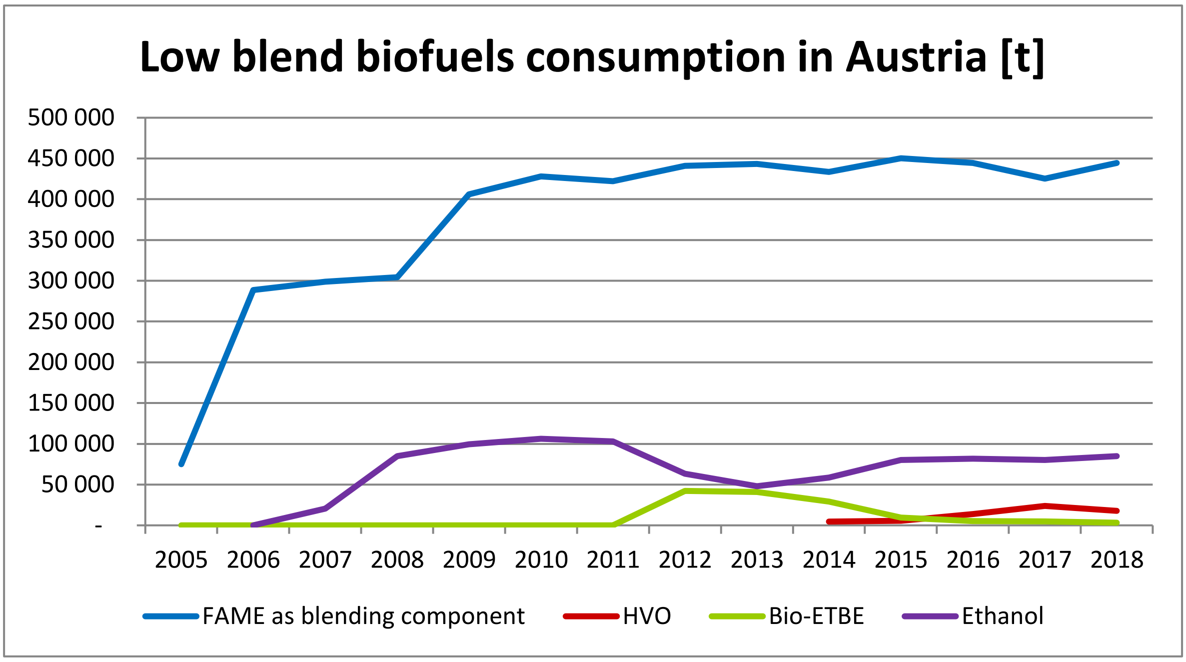

Figure 7: Biofuel consumption of blending components in Austria in tonnes

The overall consumption of biofuels in low blends in 2018 in Austria amount to 550,515 t. The number of vehicles which can use low blend biofuels is quite high with a market share of 99.36 % since all diesel and gasoline vehicles and also hybrids with electromobility or LNG/CNG are able to use low blend biofuels. The remaining 0.64 % are pure electric vehicles, pure LNG or CNG vehicles and hydrogen vehicles.

In 2018, the use of low blend biofuels (FAME as blending component, ethanol and ETBE and HVO) reduced the CO_2 emissions by 1.53 million tonnes in the Austrian transport sector. Low blend biofuels amount for nearly 90% of the total biofuels used in Austria, the other 10 % is biodiesel used neatly. There are no savings in local pollutant emissions since the biofuels are used in the common combustion process in the engine. The energy substitution of low blend biofuels is 19,638,131 GJ in 2018 which represents an energetic substitution of 5.8 %. This shows that low blend biofuels are the highest contribution to the annual energetic substitution with biofuels (in total 6.25 %).

In 2018, seven companies in Austria produced in sum 287,217 t of FAME. This amount of produced biofuel is sustainable according to the requirements of the fuel ordinance and accounts for nearly 57 % of the consumption. The national ethanol production of 197,550 t was done in one bioethanol production facility. This amount accounts for more than the double consumption of sustainable ethanol in Austria.

Table 5: Data sheet Low Blend Biofuels in Austria 2018[9]

	value	unit
consumption of fuel	550,515	t
number of vehicles using low blend fuels (2019)[10]	5,007,380	
market share of suitable vehicles	99.36	%
GHG savings achieved	1,532,970	t CO_2
local emission savings	n.a.	
Energetic substitution	19,638,131	GJ
	5.8 %	
quantity of produced fuel in the country	287,217	t FAME
	197,550	t EtOH

Evaluation

The implementation of low blend biofuels in Austria was a positive example of a market introduction. 2005 FAME was introduced as B5, which increased to B7 in 2009. Ethanol is added since 2007 nationwide as E5 to petrol. Those admixtures of low blend biofuels were successfully realized and are responsible for an energetic substitution in the transport sector of 5.8 % and for GHG savings of 1,532,970 t CO_2 in the year 2018.

One of the success factors for the market introduction of low blend biofuels in 2005 and 2007 was the absence of a public discussion on the topic. In these years there was no public discussion on food vs. fuel vs. feed and also no debate on technical performance and

[9] Federal Ministry of sustainability and tourism (2019) Biofuels in the transport sector in Austria 2019

[10] Statistics Austria (2020). Stock of motor vehicles and trailers 2019

compatibility in the engines.

Infobox 1: Key drivers of successes and key barriers of failures

Key drivers of successes:

- No public discussion on food vs. Feed vs. Fuel
- Compatibility of fuel with conventional engines
- Tax incentives for biofuels
- Substitution requirement
- Clear political will
- Coordination with Stakeholders from industry

Another positive aspect was the introduction of reduced mineral oil tax rates for diesel and petroleum blended with biofuels. Pure biofuels are fully exempt from mineral oil duty. These measures cause tax incentives and advantages for biofuel blending.

The introduction of a substitution requirement and overall biofuel targets as well as specific biofuel targets also supported the market introduction. Political decision makers need to define a regulatory frame and accompany the implementation process.

Clear political regulations on national and European level supported the introduction of low blend biofuels in Austria. RED I and RED II set a framework for the industry and pushed ahead innovations and investments.

There was a clear agreement of all political stakeholders. Stakeholders from biofuel production industry were integrated in decision processes on national and European level. Also distributers and the mineral oil industry were asked in time to provide the necessary amounts of low blend biofuels. There was a positive coordination with stakeholders from industry.

Lessons Learned

Infobox 2: Case specific lessons learned and recommendations

Policy measures like tax incentives in combination with substitution requirements as regulatory frame are very helpful for a successful market introduction.

Positive or neutral attitude of the common public is advantageous – there is the need for information dissemination and creation of knowledge and awareness.

A clear political will and consensus is necessary for a market introduction of alternative fuels.

The coordination with Stakeholders from industry on time supports a successful market introduction.

E10

Background

In Austria the use of ethanol in the transport sector started 2007 with the blending of petrol with 5% Ethanol (E5). With 01.10.2012 the increase of blending to 10% ethanol was planned. The planned introduction of the fuel E10 was stopped two weeks before entry into the market. According to the minister for the environment the introduction should be suspended until the situation on European level was clarified. Background was a planned European draft law to tighten the environmental standards for biofuels. Since then there was no further attempt to introduce E10 into the Austrian market.

The consumption of E10 in Austria is not possible, since the market introduction of this kind of fuel did not take place. The vehicles which are able to use E10 include petrol vehicles, flex fuel and different kinds of hybrid vehicles.

Around 5% of petrol vehicles are vintage cars that are not suited to use E10, and another 3.5% of petrol vehicles are older models that have engines that are also not suited to use E10. In sum the suited vehicles are about 2 million vehicles, which is a market share of 40.5 % - 42.6 % (excluding vintage cars) in the individual transport sector.

The savings in GHG and local emissions as well as energy are not available, since E10 is not on the Austrian market.

At the moment there is no E10 production in Austria, but there is one Austrian ethanol production facility. In this production plant nearly 200,000 tonnes of ethanol are produced each year, about half of it used as E5 in the Austrian transport sector and half of it is exported into foreign countries. The capacity of the ethanol plant is 240 ML of ethanol per year, which could provide the entire ethanol demand for E10 in Austrian transport sector, and is capable of displacing 1/3 of Austria’s soy protein imports through DDGS co-production.[11]

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[11] IEA Bioenergy Task 39 (2019). Implementation Agendas: 2018-2019 Update

Table 6: Data sheet E10 in Austria 2018[12]

	value	unit
consumption of fuel	n.a.	
number of vehicles using E10	0	
number of suitable vehicles (2019)[13]	2,050,000	
market share of suitable vehicles	40.6-42.6 %	%
GHG savings achieved	n.a.	
local emission savings	n.a.	
energy savings	n.a.	
quantity of fuel produced in the country	0	t E10
	197,550	t EtOH

Evaluation

Since E5 was used nationwide for 5 years, the market introduction of E10 was planned for October 2012. But the process stopped a few weeks prior market entry. Due to several factors and points of criticism from the public the pressure on politicians increased, which ended in the decision to suspend the market introduction of E10. This is an example for a failed attempt of an alternative fuel implementation.

The environment minister gave as reason for the suspension of E10 market introduction, ongoing negotiations on EU level and new assessment of the use of E10. The plan for the introduction of E10 would be suspended until the situation on EU level is clear. But until now (2020) there was no further attempt to introduce this fuel.

An important factor for the increasing pressure on politics was the huge public discussion and public resistance. When E5 was introduced to the market there was no or not much public discussion. But in 2012 the discussion on food vs. feed vs. fuel was very intense and was pushed from many sides. Also, the price increases of raw materials and feedstock in

12 Federal Ministry of sustainability and tourism (2019) Biofuels in the transport sector in Austria 2019

13 Own calculation based on Statistics Austria (2020). Stock of motor vehicles and trailers 2019

2007/2008 had negative repercussions on public opinion towards biofuels.

Infobox 3: Key drivers of successes and key barriers of failures

Key barriers of failure:

- Possibility of new assessment of E10 at EU level
- Negative attitude of general public
- Discussion on food vs. feed vs. fuel
- Engine compatibility (10-25 % not compatible at that time)
- No tax exemption and no cost benefit
- Reserved attitude of automotive associations
- Poor acceptance of E10 in the German market
- Political disagreement

There was also a public discussion on engine compatibility – in the year 2012 about 10-25 % of all petrol driven cars were not suitable for E10 as fuel according to estimations of automotive associations. Meanwhile this number decreased because newer models have replaced older models in the vehicle stock. As of 2020 approximately 4 % of vehicles are not compatible with E10, including vintage cars this percentage is about 9 %.

Consumers and automobile clubs criticized that the utilization of E10 would not have any price advantage. There was, in contrast to the addition of E5, no planned exemption from mineral oil tax for the share of E10 and therefore no price advantage. For the automobile associations price advantage was a critical point for the successful market introduction of an alternative fuel, besides engine compatibility and sustainable production of the fuel.

The reservations of the general public increased with the reserved and negative attitude of the two big Austrian automobile associations and the high number of negative articles and bad press in the media.

Another implementation barrier was the development of the German market introduction of E10. After the introduction of E10 to the market, only 10-20 % of consumers filled up their car with E10, the main part of the potential customers used still E5 fuel. Due to the geographic and linguistic connection with the neighboring country Germany this negative example was transferred to Austria. There were a lot of discussions on engine compatibility and too little consumer information. In addition, some politicians in Germany regarded the implementation of E10 as a big mistake and recommended to undo the introduction.

Beside the negative attitude of the general public there was also no political consensus. The ministry of environment planned the E10 introduction, but from the ministry of finance there was no concession regarding tax exemptions. Also, the coalition party in the government was against the introduction. From a party-political point of few the introduction of E10 was not feasible, there was no common formation of political objectives.

According to the recent government agreement (January 2020) the implementation of E10 into the Austrian transport sector is planned. An introduction has not a fixed date but will possibly happen between 2020 and 2024.

The needed amounts for E10 production in Austria are already available. There is one ethanol production facility which already produces enough ethanol for nationwide use of E10. This would allow for CO_2 savings of 300,000 t of CO_2 per year.

Lessons Learned

Infobox 4: Case specific lessons learned and recommendations

Politics should give the right direction, there must be a political consensus on and a positive attitude towards a market implementation of an advanced fuel. Possible fears of citizens should be taken seriously and should be countersteered.
Positive information campaigns for customers are necessary – they need to be informed about the advantages, the compatibility and the environmental effects. That information should be given at the first contact points like automobile industry, garages, car dealership and filling stations.
Automotive associations and other advocates should be on board, also within the information spreading and communication.
Adequate incentives are essential and should be given as tax incentives and cost benefits compared to fossil fuels.

Natural gas vehicles

Background

At the beginning of the 1990s the first CNG driven vehicles were present in Austria[14]. In the following 20 years the vehicle stock showed a slow development. Since the year 2008 statistical data on stock of passenger cars by fuel type or power source are available. The stock of CNG vehicles consists of monovalent CNG powered vehicles and Petrol and natural gas bivalent vehicles. The historical development since 2008 is given in Figure 8.

[14] FORUM SPECIAL 5 [2011] – Sonderheft des FORUM GAS WASSER WÄRME, Oktober 2011

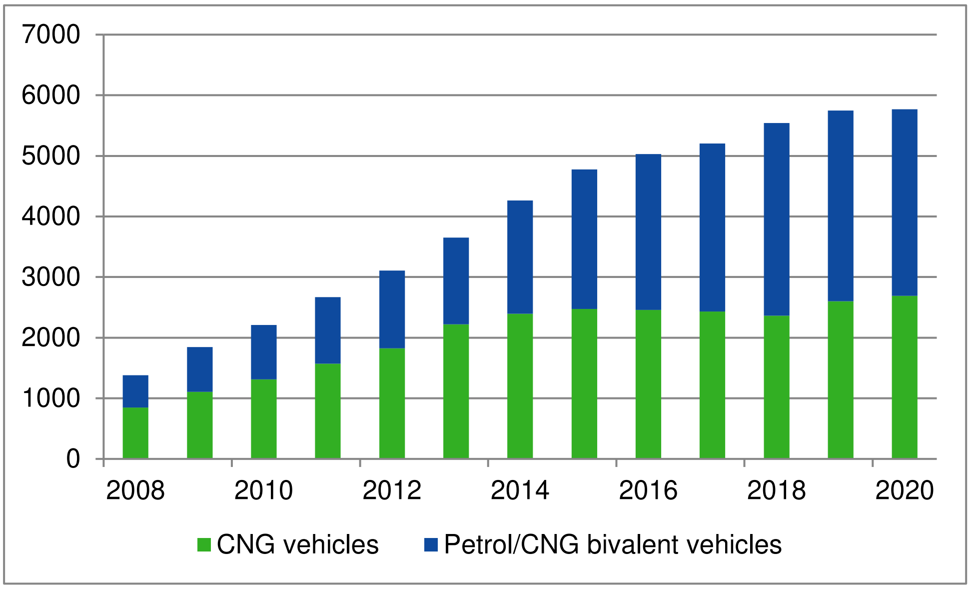

Figure 8: CNG vehicle stock in Austria from 2008-2020[15]

Data on the availability of CNG gas stations is available since 2006 and the development can be seen in Figure 9. The highest number of CNG gas filling stations was 175 countrywide in Austria. Since 2016 the number is decreasing.

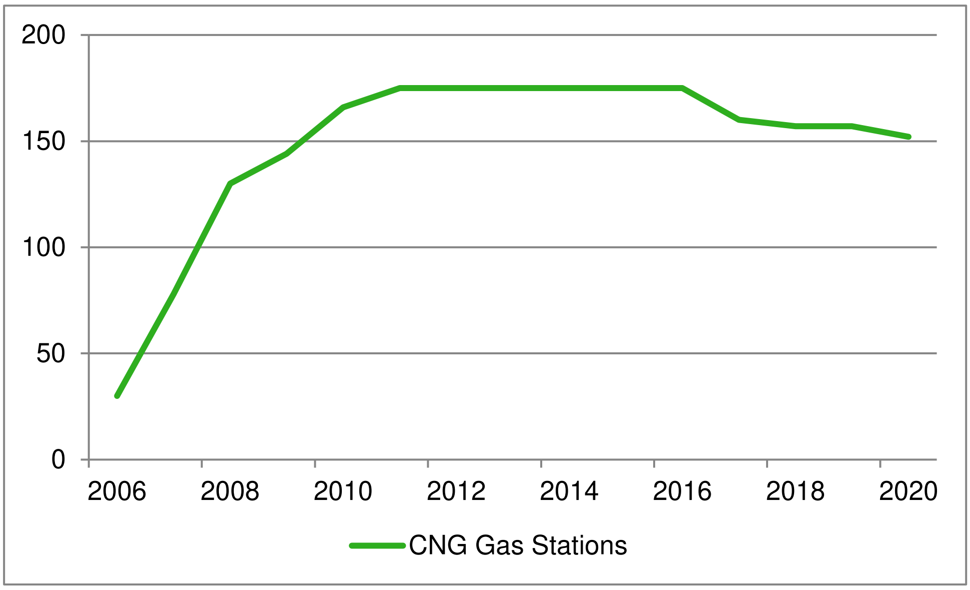

Figure 9: Number of CNG Gas Stations in Austria since 2006

[15] Data from Statistics Austria: Stock of motor vehicles and trailers [06/2020]

Table 7: Data sheet CNG in Austria 2018

	value	unit
consumption of fuel[16]	697	TJ
number of vehicles using CNG 2019[17]	5,746	
market share of suitable vehicles	0.11	%
GHG savings achieved[18]	-20 % CO_2 compared to petrol Bio-CNG -40 % compared to petrol	
local emission savings[19]	-90 % NO_x compared to diesel -80 % CO compared to petrol -95 % fine particles	
energy savings	n.a.	
quantity of produced fuel in the country[20]	19	Mio m^3 CNG
	0,4	Mio m^3 bio-CNG
	969,223	Mio m^3n natural gas production[21]

The end energy consumption of CNG in the transport sector was 697 TJ in 2018, which corresponds to 0.2 % of the total end energy consumption in the transport sector. In Austria 5,746 passenger vehicles are registered which are pure CNG vehicles or hybrid vehicles

16 Statistics Austria (2020)– overall energy balance 2018

17 Statistics Austria (2020) - Stock of motor vehicles and trailers 2019

18 FGW – Fachverband der Gas- und Wärmeversorgungsunternehmungen 2020

19 https://www.rag-austria.at/das-unternehmen/erdgas-mobil.html

20 Statistics Austria (2020). Overall energy balance 2018

21 https://www.wko.at/branchen/industrie/mineraloelindustrie/die-oesterreichische-mineraloelindustrie.html

petrol/CNG, this is only a 0.11 % share of the passenger transport sector in Austria. With CNG greenhouse gas emissions can be reduced by 20 % CO_2 compared to petrol. When using Bio-CNG the percentage can be increased to 40 % GHG emissions savings. In local emission savings CNG has a very good performance and shows fewer emissions: around -90 % NO_x compared to diesel, -80 % CO compared to petrol and -95 % fine particles. The CNG production in Austria equals the CNG consumption and amounts to 19 Mio m3 in the year 2018 with an additional bio-CNG production of 433,000 m3. Feedstock for the CNG production is fossil natural gas, with a production of about 970,000 Mio m^3n of natural gas in 2018.

There is also the option for Bio-CNG, upgraded biogas which is either used directly in a CNG vehicles or mixed with fossil CNG. Biogas produced in Austria is mainly used on site for heat and power production, with an estimated production of 308 Mm^3 of biogas per year. There are four biogas plants in Austria where the upgraded biogas is used as biomethane for transportation. At three plants the biomethane can be filled up directly into the vehicle (decentral fuel station) and in one plant the processed biomethane is distributed via the natural gas grid. In 2018 altogether 274 tons of biomethane were used in the transport sector.[22]

The advantages of CNG driven vehicles are the enormous CO_2 emission advantages, they are quieter in operation and emit no fine particles from the fuel. Also, the vehicle models on the market are suitable for everyday use and in a lot of different model variations. Approximately 85 % of first registrations in Austria are cars in the range of 55-170 hp, exactly the range of models which are CNG driven. CNG has several advantages in comparison with liquid fuels; it is a non-toxic gas, has a higher flash point than petrol and evaporates quickly coming into the atmosphere with a low risk of explosion. Another bonus of CNG driven cars is that the decarbonization can be increased by using renewable gas as feedstock for the CNG fuel without any additional measures.

Evaluation

The first CNG driven vehicles were available in Austria in the 1990s, nowadays there are a lot of different car models on the market. CNG cars suitable for everyday use are on the market since almost 10 years. But there is low engagement from most car producers and sellers to sell these vehicle models. Since 2015/2016 the number of CNG filling stations is decreasing and the number of CNG driven cars stagnates in Austria. There is the possibility

[22] Federal Ministry of sustainability and tourism (2019). Biofuels in the transport sector in Austria 2019

for and infrastructure for CNG driven mobility but CNG cars only account for 0.11 % of the passenger cars in Austria.

Infobox 5: Key drivers of successes and key barriers of failures

Key barriers of failure/stagnation:

- Infrastructure problem: decrease of gas filling stations and missing investments in infrastructure
- And thus, careful planning of long-distance travel is needed
- No tax benefit/exemption for CNG fuel or cars
- Cost benefit is not obvious for customers
- No nationwide incentives and low subsidies
- Decarbonisation with renewable gas is not appreciated as such
- Reservation of car sellers and customers towards the new technology
- Negative perception, prejudices and fears of gas used as fuel

The CNG market introduction faced the typical chicken and egg dilemma. In the 1990s the first gas stations for CNG were built, but only few partly low powered CNG car models were available. Nowadays in Austria the network of natural gas filling stations is with about 160 stations quite big. But the number of vehicles is not increasing. So, there is an existing infrastructure but there might be an infrastructure problem in the future. Operators will not invest in gas filling stations if the demand is decreasing. And if there are fewer filling stations some CNG car drivers will switch to other propulsion systems.

For consumers it is very important to have an assured cost benefit when deciding to buy a CNG driven car. But there is no tax benefit for CNG driven cars as they are taxed like common driven cars and there is no clear statement from the government on how CNG will be treated regarding taxes in future.

Customers are not really aware of the cost benefit of CNG driven cars compared to petrol or diesel cars, there should be more campaigns and marketing for that. The cost benefit is not apparent for consumers, since the price at the filling station is given in €/kg, the values are quite similar to diesel or petrol price values. Although CNG has about 1.5 fold higher energy content, this cost benefit is not clearly visible at the gas pump.

In the past there were some nationwide incentives and promotions for buying CNG driven cars; at the moment there are only some solitary incentives in some federal states. These incentives are in the range from 0-1,000 €, sometimes in kind as fuel voucher. But there are no tax incentives on the fuel.

CNG driven mobility has to face another problem, and that is the calculation of emissions and carbon reductions. In the European and Austrian law, the emission boarders are drawn at the vehicle itself. Therefore, renewable natural gas is not deductible for CO_2 targets, since there is a combustion process in the car. Only electrical power and hydrogen are considered free of emission in the transport sector, these drive systems are tax exempted.

There is also the obstacle of buying a CNG driven car in Austria. A lot of car salesmen talk the costumers into buying a diesel driven car rather than a CNG driven car. It is not obvious what are the reasons for this preference for selling diesel cars. Car dealers and customers often show ignorance and lack of knowledge towards the CNG technology and then sell or buy preferably common technologies.

Other barriers are found on the emotional level. Gas is a substance that bolsters fears in people. Negative examples of explosions which are then very prominent in the media deepen these fears. There is a negative perception of this topic combined with a fundamental skepticism.

In Austria there are also some regulations which enforce the negative attitude towards CNG cars. There are entrance bans for underground parking garages which are labelled for gas vehicles, but actually are meant for LPG driven cars. Due to this vague description a lot of people think this is for CNG driven cars and therefore think they are disadvantageous in city traffic regarding parking.

Lessons Learned

Infobox 6: Case specific lessons learned and recommendations

Tax incentives and subsidies offer chances to get customers, fleet operators and employers to use CNG driven vehicles.

Tax incentives and subsidy programmes for maintenance and an increase in density of the existing alternative gas filling infrastructure are of vital importance.

The public sector and state companies should serve as an example for the general public.

Tax reduction for CNG fuel would support the market roll-out. The taxation calculation should not only be based on tailpipe emissions but also include the fuel supply chain.

Information campaigning should be done to inform the general public and car sellers on advantages and cost benefits of CNG driven mobility.

Summary of Lessons Learned and recommendations for Austria

For Austria some lessons learned and recommendations can be derived from the examined case studies. These points are summarized in the infobox and are divided into following subjects: politics, stakeholder involvement, measures, general public, technology, future transport system.

Regarding politics a positive attitude towards alternative fuels and vehicles is essential. There is a need for a political consensus and for longterm policies. Initiatives from ministries like incentives and subsidies are very beneficial. Recurring transparent consultation with representatives from science and economy is useful. And drop-in fuels should be seen as a complementary element in the decarbonisation strategy.

There should be a clear commitment and consensus amongst all involved stakeholders along the value chain, including politics, customers, advocates, media, vehicle marketers, automotive industry, alternative fuel producers and mineral oil industry. Regarding measures there is a need of funding programmes for investments regarding building and maintenance of infrastructure as well as tax incentives to guarantee a cost benefit for consumers. Also subsidies and grants for purchase expenses are helpful.

The attitude of the general public is essential - knowledge creation and awareness raising are needed, also information campaigns to inform the general public on planned activities. In addition, the advantages of advanced fuels and vehicles should be better communicated. Regarding technology the engine compatibility has to be guaranteed by car and engine manufacturers.

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For the Austrian case studies the authors would like to thank following interview partners for their precious time, the given valuable information and input: DI Horst Hartl (Agrana Group), DI (FH) Peter Jurik (Association of Gas- and District Heating Companies), Ewald-Marco Münzer, B.A. MBA and Mag. Harald Sigl (Münzer Bioindustrie), Mag. Martin Grasslober (ÖAMTC).

Infobox 7: Lessons Learned and recommendations for Austria

Politics:

Positive attitude of politics and policy makers towards alternative fuels and vehicles is essential. There is the need for a political consensus within the government, coalition and opposition.A long-term political commitment for the market introduction of alternative fuels should be given. At the beginning steering measures and impulses are necessary. Initiatives from ministries (incentives, subsidies, information campaigns) are very beneficial. Good planning and implementation with continuous evaluation and support is desirable. Recurring transparent consultation with representatives from science and from economy is useful to develop objective information and decision bases. Drop-in fuels should be seen as a completion in the decarbonisation strategy.

Stakeholder involvement:

There should be a clear commitment and consensus amongst all involved stakeholders. All stakeholders along the value chain should be included: politics, customers, advocates, media, vehicle marketers, automotive industry, alternative fuel producers and mineral oil industry. Automobile associations are important advocates with great outreach to the general public and should be on board.

Measures:

A carefully created set of measures should provide benefits to all stakeholders. Funding programmes for investments regarding building and maintenance of infrastructure for advanced fuels and vehicles. There should be tax incentives to guarantee a cost benefit for the consumers of advanced fuels and vehicles compared to common technologies. For customers subsidies and grants for purchase expenses are helpful.

General public:

The public opinion is of greatest importance for a successful market implementation – therefore knowledge creation and awareness raising are needed. Information campaigns are necessary to inform the general public on planned activities, subsidies, technical compatibilities and to debunk and temper unfounded fears. The advantages of advanced fuels and vehicles should be better communicated. Besides the obvious advantages like GHG and PM emission reduction, replacement of fossil fuels by renewable feedstock, also not well-known advantages like waste disposal, animal feed production, regional value and job creation should be propagated.

Technology:

Engine compatibility has to be guaranteed by car and engine manufacturers. An appropriate regulatory framework has to be given by politics.

Future Transport System:

For decarbonizing the transport sector, it is essential to seize different opportunities and technologies for GHG emission reduction, also including short-term applications. In future there will be a mix of alternative drive systems and fuels suitable for different applications.

China

For China the identified interesting case study is dealing with ethanol.

Description of case study

Introduction

As an automobile fuel that could be produced from biomass, ethanol has been successfully deployed in several major countries in the world, including the United States, Brazil, and European countries. The future application prospects of ethanol fuels are also very broad. Blending ethanol into conventional gasoline may have several potential advantages including:

- Increase the fuel octane number to improve engine performance, in particular providing better energy efficiency for turbo-charged engines;
- Reduce hazardous species of gasoline fuels (in particular aromatics) that may generate ozone and secondary particulate matter pollution;
- Reduce greenhouse gases (GHGs) emissions throughout the life cycle;
- Increase the diversity of energy supply.

This chapter will focus on the recent development of ethanol fuels in China as well as the major challenges to promote ethanol fuels in the future.

Background and Objective of Early Use, Policies, and Incentives for Fuel Ethanol

The development of China's ethanol fuels started in 2001. The original intention, at that moment, was to digest huge amount of aged grains that were not suitable for food purpose, to improve air quality, and to adjust the energy structure. The central government has successively issued several important policies, such as the "Tenth Five-Year Development Plan for Ethanol Gasoline for Vehicles", the "Renewable Energy Law" and the "Twelfth Five-Year Plan for Renewable Energy Development", to support the development of ethanol fuels.

With the support of these policies, four biofuel ethanol plants were approved by the National Development and Reform Commission (NDRC) during the "Tenth Five-Year Plan" period (2001-2005). Quota subsidies were provided by the central government to support these biofuel ethanol plants to be profitable or almost breakeven. Successfully, the annual production capacity of fuel ethanol added up to 1.02 million tonnes in a short time.

After 2006, however, the policies turned to be conservative that restricted the large-scale promotion of corn ethanol, because of the concern aroused that biofuel ethanol would occupy limited land resources against food. In 2007, the NDRC completely halted the development of grain-based ethanol projects, and required that the development of biofuels in the future must meet the premise of not occupying arable land, not consuming food and not destroying the ecological environment. In 2011, the value-added tax and consumption tax incentives for designated fuel ethanol production enterprises were reduced. In 2012, the subsidies for fuel ethanol were also reduced, and consequently the growth rate of corn-based fuel ethanol production fell sharply.

Possibility of Fuel Ethanol in the Development of Conventional Gasoline Quality

In China, the efforts in improving gasoline fuel quality can be briefly summarized in the following three stages: (1) promotion of lead-free gasoline; (2) reducing sulfur content; and (3) controlling the contents of olefins and aromatics.

The early-stage gasoline in China was straight-run component of crude petroleum that was poor in the antiknock performance. Tetraethyl lead, a high-octane-number but harmful addictive, was used to meet the antiknock requirement. China began to comprehensively eliminate leaded gasoline since 2000 and Tetraethyl lead was then abandoned. Alternative additives, methylcyclopentadienyl manganese tricarbonyl (MMT) and methyl tert-butyl ether (MTBE), were introduced afterwards. MMT was also abandoned in the China 5 stage which tightens the limit of manganese content. Only MTBE has been still used in China although it is considered to have adverse impact on groundwater and has been listed as a possible human carcinogen by US EPA. There are amounting policy discussions in China to phase out MTBE from gasoline additives. Consequently, ethanol is expected to replace these high-octane-number additives to maintain the fuel quality.

China's petroleum industry has been limited by the features of crude oil from different sources. Fluid catalytic cracking (FCC) units became the mainstream gasoline refining units. According to industry experts, FCC gasoline, which has relatively higher content of S (2000-9200 mg/kg) and olefins (around 40%), occupied more than 70% of China’s whole gasoline pool in a long period. S, olefins contents in gasoline are important sources of air pollutants, so gasoline upgrade mainly focused on reducing the content of S and olefins since 2001, and the limits have been declining continuously. The control of Aromatics, another important precursor, was paid more attention until recent years.

In the China 4 and China 5 standards, the maximum limits of sulfur mass content were lowered to 50 ppm and 10 ppm, respectively. As a result, many refineries upgraded the technologies (e.g., ultra-deep desulfurization of fluid catalytic cracking (FCC) fuels, alkylation desulfurization) to produce these ultra-low sulfur gasoline fuels, which would impact the composition of hydrocarbon portions. The contents of olefins and aromatics in gasoline fuels will be lowered to 15% and 35% at the China 6b stage. This implies that alkylation gasoline will account for a greater fraction in whole gasoline pool than before. Ethanol will be more useful to compensate the octane number that is provided by aromatics. However, it is also worth noting that ethanol-blended gasoline (E10, blended with 10% of fuel ethanol) has not been provided with a summertime waiver of evaporability, as the summertime RVP ranges are limited to 42 to 62 kPa for both regular gasoline and E10 gasoline.

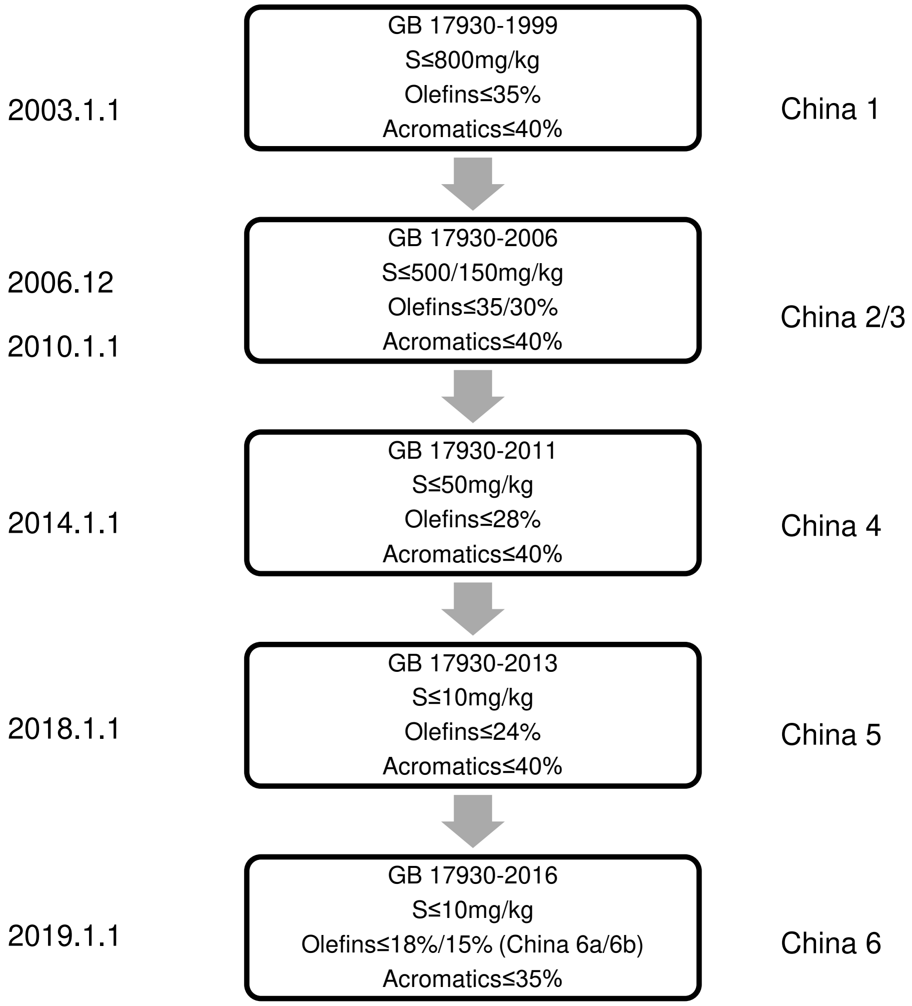

Figure 10: The development of gasoline quality in China

New Start of Fuel Ethanol since 2017

Historically, the oversupply of grain was an important driver to produce biofuel ethanol in China. During 2004 to 2015, China's grain output achieved consecutive increases. The increase of supply would naturally bring the grain prices falling, but China’s grain stockpiling policy kept the purchase and storage of grains at a price higher above market price to avoid discouraging framers from planting, thus breaking the market balance. Domestic grain kept flowing into national grain barn and international grain kept flowing into China, and such rapid expansion of costly grain stocks brought enormous pressure on public finance.

Making biofuel ethanol as automotive fuels becomes a potential solution to both upgrade gasoline quality and digest the great amount of grain stocks. Additionally, fuel ethanol can reduce dependence on imported oil and mitigate life-cycle greenhouse gases (GHGs) emissions to some degree compared with fossil fuels.

In September 2017, fifteen ministries including the National Development and Reform Commission, the National Energy Administration, and the Ministry of Finance jointly issued the "Implementation Plan on Expanding Biofuel Ethanol Production and Promoting the Use of Ethanol Gasoline for Vehicles". According to this plan, by 2020, China will basically achieve full coverage of ethanol-blended gasoline for vehicles; by 2025, large-scale production of cellulosic ethanol will be achieved. In August 2018, the State Council of China decided to expand the use of ethanol-blended gasoline fuels for on-road vehicles.

Technical Challenges

Fuel Properties

Although the Reid vapor pressure (RVP) of ethanol is lower than that of conventional gasoline, the RVP of ethanol-blended gasoline E10 added with 10% ethanol will increase compared with gasoline, which is associated with the action of hydrogen bonding. On May 30, 2019, the US EPA issued new regulations that the 7 kPa RVP exemption for E10 in summer is also applicable to E15. With the exemption, E15 can be sold throughout the year instead of only in non-summer seasons. At present, the vapor pressure limit of E10 in China is the same as that of conventional gasoline, which brings certain challenges to future promotion of ethanol-blended gasoline if there is no similar exemption.

Ethanol has a different theoretical air-fuel ratio from conventional gasoline which may put forward new requirements for automobile engine. Conventional engines can manage with E10 at present but should be modified when ethanol-blended gasoline with high blending ratio needs to be further promoted. Flexible fuels automobile (FFV) is a feasible technical approach of modification, but it has not been sold in China yet.

The lower heating value (LHV) of ethanol is 76,330 Btu/gal, only about 65.8% of conventional gasoline. Theoretically, the LHV of E10, E15 and E85 are calculated to be approximately 96.6%, 94.9% and 70.9% of conventional gasoline. Although the high octane number of ethanol is a positive factor for improving energy efficiency of turbo-charged engines, the difference in energy density might be a concern for consumers to accept ethanol-blended gasoline in China.

Fuel Cost

Now in the Chinese market, the settlement price of fuel ethanol is obtained by multiplying the factory price of No. 93 gasoline by the discount coefficient of 0.9111, which is equal to 5800-6500 RMB/tonne. The prices of imported ethanol, MTBE and coal-based ethanol are 3800-4200 RMB/tonne, 5300-5800 RMB/tonne, and 4000-4200 RMB/tonne, respectively. Although compared with these competitive products the current price of biofuel ethanol has no advantages, the future price will continue to fall since the price of ethanol feedstocks would decrease with the reform of the agricultural supply side and the general background of destocking.

Market Supply

Government policies are the main driving force of E10 promotion in Chinese market and have set up a mature pattern of E10 management during the long period of development. There are three links, from production to terminal sales, under the administration of the government: (1) approved production; (2) targeted distribution; (3) closed promotion.

First, only a limited number of plants (see Table 8) approved by NDRC (down to provincial government since 2013) have the right to produce fuel ethanol from aged grains (e.g. corn, wheat, cassava). This measure is conductive to control the overall volume of fuel ethanol production and guarantee the precise implement of subsidy policies including discount prices of feedstocks, direct subsidy for loss in production and sales, and tax breaks. Second, fuel ethanol products are required to be distributed only in pilot E10 promotion regions. Third, local government in each promotion region (province or prefecture-level city) is responsible to ensure the overall transition from conventional gasoline to E10. As a result, a lot of things need to be done including: (a) to build dispatching centers of E10 which have the functions of E10 production (with gasoline blending components and allocated fuel ethanol), E10 storage, and E10 distribution (to refueling stations); (b) to supervise the construction or upgrading of refueling stations and the selling price of E10; (c) to monitor the operation of fuel circuit cleaning companies.

Table 8: Annual output and sales of approved fuel ethanol plants in 2018

	Company	Location	Output	Sales
1	COFCO[a] Biochemical (Zhaodong)	Zhaodong, Heilongjiang	32	32
2	Jilin Fuel Alcohol	Jilin, Jilin	58	60
3	COFCO Biochemical (Anhui)	Bengbu, Anhui	55	75
4	Henan Tianguan Group	Nanyang, Henan	28	30
5	COFCO Biochemical (Guangxi)	Beihai, Guangxi	14	10.1
6	Zonergy	Bayan Nur, Inner Mongolia	0	1.5
7	Longlive	Yucheng, Shandong	0	1
8	SDIC[b] Biotech Investment (Guangdong)	Zhanjiang, Guangdong	8	11.5
9	SDIC BiotechInvestment (Tieling)	Tieling, Liaoning	0	0
10	Jiangsu Lianhai Biological Technology	Nantong, Jiangsu	5	5
11	Liaoyuan Jufeng Biochemical	Liaoyuan, Jilin	5	4
Total			205	230.1

Unit 1000 tonnes

Note: a. COFCO, China National Cereals, Oils and Foodstuffs Corp; b. SDIC, State Development & Investment Corp, Ltd

Up to 2019, having experienced a long period of tortuous development, China's pilot projects for closed sales of ethanol fuels have been carried out in 12 provinces in whole or in part. Henan and Heilongjiang started in 2002. Liaoning, Hebei, Shandong, Jiangsu followed in 2004. The pilot scale was further expanded to eight provinces in 2005. By 2016, a total of 11 provinces have ever sold ethanol-blended gasoline. In June 2018, Tianjin became the first province to follow the newly delivered plan and issue a document to promote E10 fuels before August 31, 2018. Tianjin has fully provided E10 fuels in the municipality by September 2018 to replace conventional gasoline.

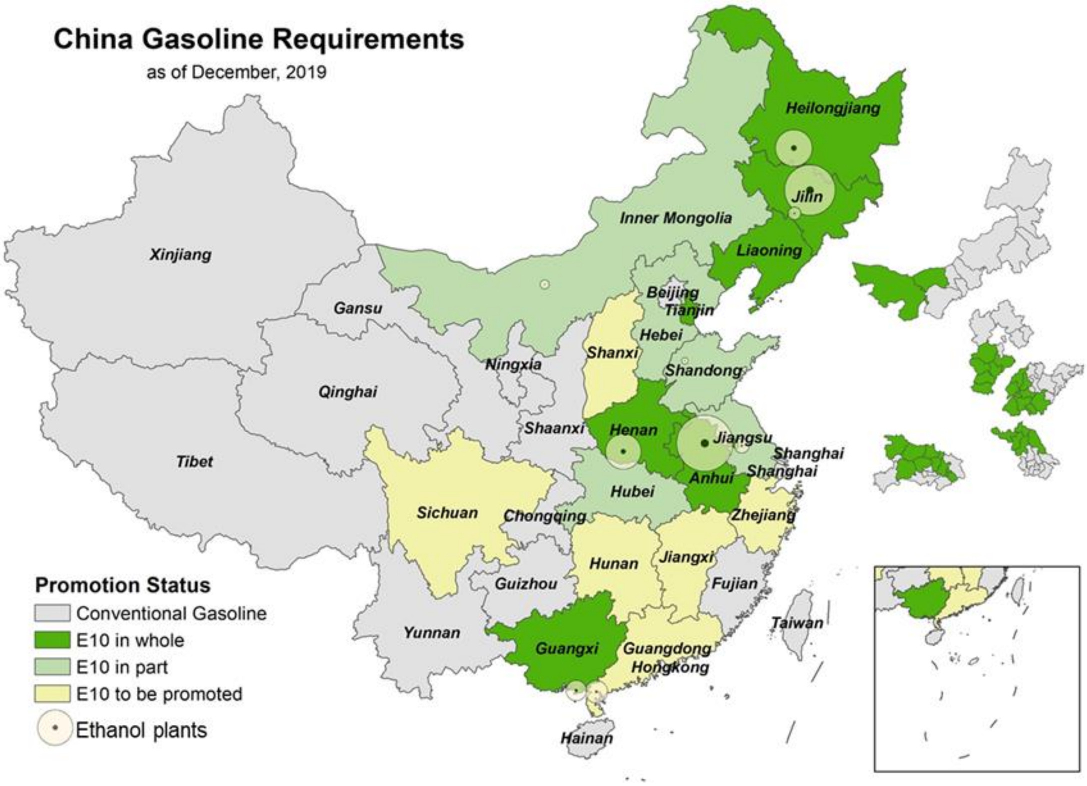

Figure 11: E10 promoted regions and adjacent ethanol plants by 2019

Refueling Infrastructure

Conventional gasoline is totally banned in E10 promotion regions, except for specific needs of military, special reserves, and industrial production. Switching from conventional gasoline to E10, the refueling stations have to be modified for the purpose of adjusting to the properties of a new fuel. First, ethanol is hydrophilic and the phase separation of E10 would occur when water content exceeds the limit. Therefore, additional measures should be taken to control the entry of water in the process of E10 loading, unloading, storage, blending, and transportation. Second, ethanol itself is a good organic solvent and there is also a small amount of acetic acid in E10. These two substances can be corrosive to some materials (e.g. polyurethane, galvanized materials) used in tanks, pumps, pipelines, valves and gaskets. Therefore, unsuitable materials need to be replaced during the upgrading of refueling stations.

Vehicle Cost/Performance

The selling price of E10 is equal to or slightly lower than that of conventional gasoline (see Figure 12), so the difference in total fuel cost is more related to the actual fuel economy (L/100km). On the one hand, the LHV of E10 is theoretically 3.4% lower than that of conventional gasoline, which may result in higher fuel consumption to provide the same power performance; on the other hand, the oxygen content of E10 is higher than that of conventional gasoline, which is helpful to achieve more sufficient combustion. Taking consideration of these two factors, the difference of E10 and conventional gasoline consumption can be very small that is hard to be detected by vehicle users.

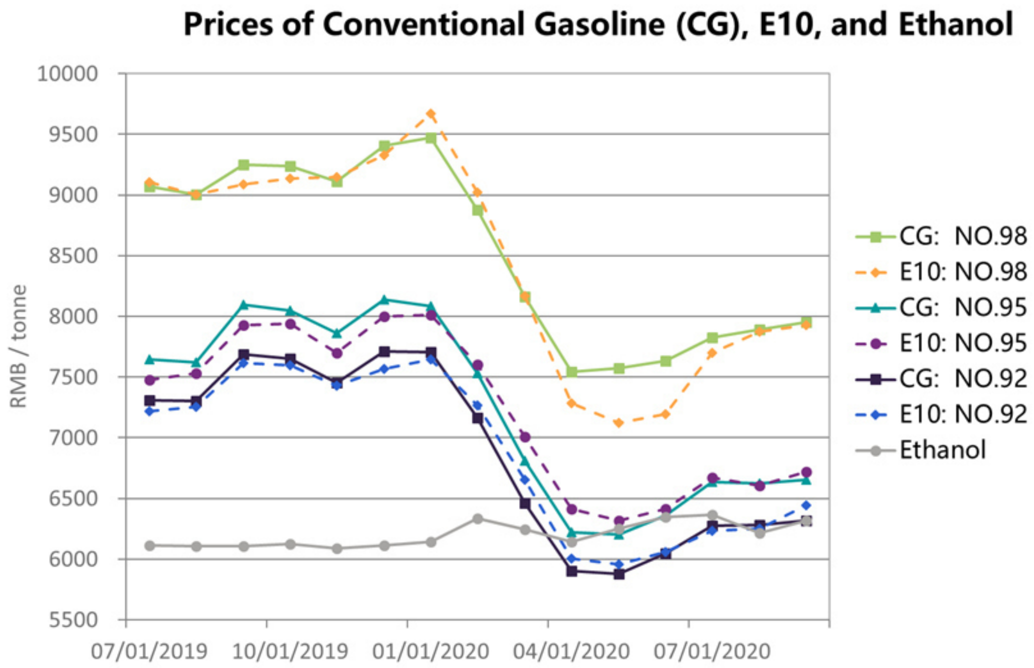

Figure 12: Market price of gasoline, E10 and ethanol

Wu et al., 2019 conducted an experiment of 9 typical vehicles (emission standard categories from China 2 to China 5, model year from 2003 to 2015, engine technologies including port fuel injection, PFI and gasoline direction injection, GDI) running on two different E10 samples. The two E10 samples are ELA (E10 with lower aromatics) and ELO (E10 with lower olefins), which are provided by Sinopec Research Institute of Petroleum Processing (RIPP) that plays a core role in developing fuel quality standards in China. Results show that overall relative changes in fuel economy were +0.6% for ELA and +0.5% for ELO, compared with China 5 gasoline. This conclusion further confirms our judgement that there is little difference in fuel economy between conventional gasoline and E10.

In real-world driving, application of E10 is not the only factor that matters. Fuel consumption and power performance are affected by other complicating factors such as road conditions, driving manners and so on, which brings different experience to vehicle users.

Consumer acceptance

Except for the fuel cost and vehicle performance issues of E10 as discussed above, customers have other concerns including: (1) whether E10 is corrosive to metal and rubber materials used in vehicle components; (2) whether vehicle needs to be modified when E10 is first used; (3) whether E10 can remain original properties after lying idle for a long period; (4) whether it is worse in cold-start performance when E10 is used.

We will first answer these questions. For (1), the content of acetic acid which may corrode metals is limited by standard and ethanol would not bring special problems to original rubber materials as well, though it is better to replace some rubber parts (e.g. oil float) if they are exposed to E10 for a long time. For (2), E10 can be directly burned in gasoline engines with no modifications of automobile structure needed. However, having run on conventional gasoline for a long period, various impurities such as rust, dirt, colloidal particles precipitated and accumulated in fuel tank and fuel circuit. These impurities would be softened and released when the vehicle fuel switches to E10, thus are necessary to be cleaned in advance. For (3), the key to long-term preservation is to prevent the entry of water. On such condition E10 can be kept for over half a year. For (4), cold start is related to fuel's flash point and latent heat of vaporization. Flash points of conventional gasoline and E10 are both below -50 ℃, which make no difference in cold start conditions. Latent heat of vaporization is higher for E10, which may prolong the time of cold start. However, research by Sun et al., 2016 shows even higher blending ratio would not bring obvious gap between the two fuels (see Table 9)[23].

Table 9: Results of cold start time at different at different temperature

	Conventional gasoline (s)	E22 (s)
-7.5 ℃	0.6	0.7
-10 ℃	0.8	1
-15 ℃	1	1.1
-18 ℃	1.3	1.2
-23 ℃	1.7	1.5
-28 ℃	5.2	5
-30 ℃	6.6	7

[23] Sun et al., 2016

Evidence has proved that E10 is surely a kind of outstanding alternative automobile fuel with some different properties. But sadly, customers tend to doubt those scientific explanations and believe the rumors or hearsay experiences. Misunderstandings will always be there, especially under the mandatory E10 promotion of the government, so continuous publicity and education for customers is an important task when E10 is to be further promoted.

Environmental/Safety

The environmental benefits of E10 consider not only the direct combustion emissions but also the fossil energy use and emissions generated in the processed of ethanol production and gasoline production. In general, the total fossil energy use and emissions are used as indicators of life cycle assessment (LCA).

For direct combustion emissions, since E10 can achieve more sufficient combustion, the corresponding exhaust emissions would decrease to some degree. Experiments results by Wu, et al., 2019[24] show that the overall relative changes in CO, THC, NMHC, NO_X emissions of E10, compared with conventional gasoline, did not have statistically significant changes on the 9 tested cars. Notably, using E10 would bring effective PM decrease, with average emission reduction of 21% for ELA and 35% for ELO. Meanwhile, the evaporative emissions will increase 16% for ELA and <1% for ELO relative to China 5 gasoline.

For LCA emissions, ethanol produced from aged corn will result in 18% reduction of total CO_2 emissions compared with conventional gasoline. However, debates on environmental benefits of E10, whose process includes production of ethanol, land use change, production and application of fertilizer, and ethanol fermentation, are still continuous in China.

Historical and Current Market Penetration

According to National Energy Administration, the total consumption of biofuel ethanol was about 2.6 million tonnes (the excess over the sum calculated in Table 8 may come from the import) in 2018, which was the equivalent of 26 million tonnes of E10 accounting for 20.6% of total gasoline consumption (126 million tonnes).

There are numerous predictions of gasoline demands in the future. According to Chen et al. 2019[25], the gasoline consumption is estimated 135 million tonnes in 2020 and 181 million tonnes in 2030. If all conventional gasoline is to be replaced by E10, the demand of ethanol would reach 13.5 and 18.1 million tonnes in 2020 and 2030, respectively.

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[24] Wu et al., 2019

[25] Chen et al., 2019

According to National Grain Trade Center, current capacity of ethanol production has reached 4.25 million tonnes, increased by 1.35 million tonnes over 2018. The growth of ethanol capacity cannot catch up with the planning development of E10, so the promotion of E10 market penetration still has a long way to go.

Summary of Lessons Learned and recommendations for China

Infobox 8: Key drivers of successes and key barriers of failures

Key drivers of successes:

- Multiple-department coordination on promotion policy to support the utilization of ethanol fuels at the national level
- Local experiments to verify the environmental/fuel economy impacts by using ethanol fuels
- Using the upgrade of gasoline fuel quality standard as a leverage to support ethanol fuels

Key barriers of failure:

- The current price of bioethanol production is not as competitive as other production pathways
- Some local governments are reluctant to promote ethanol-blended gasoline due to the concerns of some potential side environmental impacts (e.g., higher evaporative emissions or NO_X emissions)
- Customers are not fully aware of the positive benefits from ethanol-blended fuels (e.g., lower fuel consumption or higher Octane number).

Infobox 9: Case specific lessons learned and recommendations

Multiple-department coordination by involving agricultural industry, refineries, automotive manufacturers and relevant governmental stakeholders is crucial to promote ethanol fuels in a large scale. The utilization of ethanol-blended fuels should be regarded as an important way of improving fuel quality and reducing carbon emissions. In particular, effective pricing mechanism, customer/policymaker education, and technology innovation for ethanol production efficiency, are important to make the bioethanol fuel industry sustainable and acceptable.

Finland

For Finland the interesting market introductions were combined to one case study including E10, E85, drop-in components for diesel and biogas.

Description of case study Finland

Finland is relying heavily on biofuels for transport decarbonisation. Over the years there have been consistent policies to bring biofuels to the market. The case study describes how biofuels are promoted and implemented in Finland. A number of measures to promote biofuels have been taken, but the most important one is probably the biofuels obligation system, which has been in place since 2008. Now Finland has already set its ambitious biofuel obligation for the year 2029 (and thereafter), 30 %, with a 10 % (1/3) sub-target for advanced biofuels.

The biofuels currently on the market encompass E10 petrol (the dominating petrol grade), E85 for flex-fuel vehicles (limited volumes), renewable diesel used both as a blending component and as such (100 %) and biomethane (limited volumes). Drop-in type components will deliver the highest impact now and in the future. The target for 2030 is to reduce transport CO_2 emissions by 50 % compared to 2005, using a combination of high share of biofuels, electrification and energy efficiency improvement throughout the whole transport system.

The biofuels obligation system is in principle clear cut and simple. It is impartial for all fuel providers, allows the actors to optimise their long-span operations but still delivers a minimum share of biofuels and thereby desired reduction of carbon dioxide emissions. Emission reductions are in this case not dependent on consumer choices, nor do they require the choice of a certain fuel type or special vehicles. The system, which is based on energy contribution is straightforward, and can be justified as biofuels are considered zero carbon emission when calculating emissions from transport. Low overall well-to-wheel emissions are ensured by implementing the sustainability criteria for biofuels contained in the EU Directives.

Political framework

Recent guidelines for emission reductions in transport can be found, e.g., in:

- The 2015 Government Programme of Prime Minister Juha Sipilä[26]

[26] Valtioneuvosto 2015

- The 2016 national energy and climate strategy[27]
- The 2019 Government Programme of Prime Minister Antti Rinne/Sanna Marin[28]

The 2015 Government Programme of Prime Minister Juha Sipilä stated:

Ten-year objective:

- Finland is a pioneer in the bioeconomy, circular economy and cleantech. By developing, introducing and exporting sustainable solutions, we have improved the balance of current accounts, increased our self-sufficiency, created new jobs, and achieved our climate objectives and a good ecological status for the Baltic Sea.

Transport:

- The use of imported oil will be cut in half during the 2020s. The share of renewable transport fuels will be raised to 40 per cent by 2030 (this includes so called double-counting)

The 2016 Finnish national energy and climate strategy for 2030, presented in November 2016, calls for a 50 % reduction of CO_2 emissions from transport by 2030, the reference year being 2005. Three key measures to reduce emissions are listed:

- Improving the energy efficiency of the transport system
- Improving the energy-efficiency of vehicles
- Replacing oil-based fossil fuels with renewable and/or low emission alternatives

Within the three key measures, several detailed measures or sub-targets are mentioned. For renewable and low-emission energy carriers the following measures and targets are listed:

- Increasing the physical share of biofuels (factual energy content, no double counting) in road transport fuels to 30 %
- Expanding the refuelling infrastructure for alternative energies in transport (recharging of electric vehicles, gaseous fuels including hydrogen)
- Encouraging the uptake of alternative vehicles, the minimum targets set for 2030 being:
    - 250,000 electric vehicles (battery electric vehicles, plug-in hybrids, fuel cell vehicles)
    - 50,000 gas fuelled vehicles

The 2019 Government Programme of Prime Minister Antti Rinne/Sanna Marin states, among other things:

[27] Ministry of Economic Affairs and Employment of Finland

[28] Valtioneuvosto 2019

Upper level:

- Finland will achieve carbon neutrality by 2035
- Finland aims to be the world's first fossil-free welfare society
- The transition to a low-carbon economy will require additional investments, particularly in bioeconomy, circular economy, clean energy solutions, energy efficiency, emissions- free forms of energy production, energy storage solutions, carbon recovery and energy utilisation, along with research, development and innovation activities and measures to bring these solutions to the market

Low-emission transport:

- By 2030, Finland will reduce transport emissions by at least 50 per cent compared to the 2005 level. This is a step towards carbon-free transport. In order to reduce transport emissions, measures will be taken to reduce transport performances, to promote the transition towards more sustainable mobility and to phase out fossil fuels.

  Comment: In principle repetition of the 2016 national energy and climate strategy

- The transition to sustainable biofuels in heavy goods vehicles and air transport will be promoted
- A reform of taxes and payments in sustainable transport will be initiated to reduce emissions
- Sustainably produced biogas (biomethane) will be included in the scope of the biofuels distribution obligation
- In order to promote the charging infrastructure, a national obligation will be set in accordance with the Energy Performance of Buildings Directive to build a charging infrastructure for electric cars whenever a large-scale renovation is completed in a housing company or on business premises
- An obligation will be set for petrol station chains to provide a certain number of charging points for electric cars
- Piloting of carbon neutral synthetic fuels and launching of their production in Finland will be promoted
- Measures to extend the charging infrastructure and the distribution network for biogas (biomethane) by making use of the EU funding potential will be supported

In summary, in addition energy efficiency throughout the transport system, the current Government Programme highlights sustainable biofuels for heavy-duty vehicles and aviation, synthetic carbon-neutral fuels, recharging infrastructure for EVs and biogas in transport. Biogas (biomethane) is seen as an important element in the circular economy. A programme for recirculation of nutrients will be developed, and this will include increasing production of biogas and creating a market for recirculated nutrients.

Measures taken

Measures taken (by the government) to promote biofuels in transport include[29]:

- Funding on R&D in the area of biorefining, e.g. the BioRefine-programme[30] 2007-12 by Tekes, the predecessor of Business Finland, total budget 250 M€ (coordinated by VTT Technical Research Centre of Finland Ltd)
- Investment aid to demonstration of biorefinery concepts (annual level some 100 M€)
- Enhancing the development of a biofuels market by a biofuel obligation
- Structural changes to the energy tax system

There were some biofuel projects planned within the EU NER300 funding instrument, but these initiatives did not materialize.

The first **biofuels obligation** for liquid fuels was set in 2008. The obligation was revised in 2010, accompanied by a tax reform treating biofuels in a fair way. The target for 2020 is 20 % biofuels in road transport, taking into account double counting for advanced biofuels.

In the spring of 2019, the biofuels obligation was revised again, and the pathway towards 2030 was set. The target for 2021 is 18 %, without double counting. The biofuel target for 2029 is 30 %, and this time actual energy contribution without double counting. The There is also a separate sub target for advanced biofuels, 10 %, i.e., one third of the total contribution[31]. In addition, a 10 % biocomponent obligation was set for light fuel oil.

The obligation is in principle technology neutral, based on energy content and ensuring a certain minimum energy contribution from biofuels. There is one overarching target for each year, and no separate quotas for petrol and diesel. The distributors of fuels can provide biocomponents as blends or as neat fuels. The obligation is also flexible in the sense that it allows "banking" from one year to another. All in all, the system enables the fuel suppliers to operate in the mode they find most cost effective. Fuels on the Finnish market include E5 and E10 petrol, E85 for flex-fuel vehicles, diesel with HVO (hydrotreated vegetable oil) as a blending components and also 100 % HVO. Conventional biodiesel (FAME, fatty acid methyl ester) is practically non-existent on the Finnish market.

Biogas (biomethane) is currently not taxed in Finland, nor is it included in the biofuels mandate. Including methane in the biofuels obligation means that biomethane would have to be put under tax. In February 2020, the Ministry of Economic Affairs and Employment

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[29] Saarinen, J. (2013).

[30] Mäkinen et al 2012

[31] Finlex 2019

launched a tender on a study on the enlargement of the obligation to cover methane as well as renewable fuels of non-biological origin (electrofuels) and recirculated carbon containing fuels. A proposal to the Parliament on widening the scope of the obligation is expected at the end of 2020.

The reformed tax system, implemented as of 2011, is based on three components and takes into account[32]:

- energy content of the product → energy content tax (€/MJ)
- CO_2 emissions (also life cycle) of the product by setting a price on CO_2 → CO_2 tax (€/MJ),
- reduced pollutant emissions → tax reduction from energy content tax (paraffinic diesel fuel

Volume based taxation is not fair for oxygenated fuels with low volumetric energy content, e.g., ethanol, and energy based taxation is more objective. Biofuels fulfilling minimum sustainability criteria of the RED I directive[33] get a 50 % reduction of the CO_2 tax component, and the CO_2 tax component is completely waived for biofuels eligible for double counting.

Paraffinic diesel fuel, whether fossil or renewable, got a tax reduction of 0.05 €/l, based on the estimated value of reduced pollutant emissions (oxides of nitrogen NO_x and particulate matter PM). However, with progress in emission control technology (Euro 6/VI), a decision has been made to fade out the tax benefit for paraffinic diesel.

One important feature of the Finnish tax system is that it is objective and transparent, and is not considered as subsidies for biofuels nor state aid. Therefore, it can be combined with the biofuels mandate. EU regulations do not allow simultaneous implementation of tax subsidies and mandates. The Finnish tax system, however, favors the best of biofuels taking into account true energy content, waiving CO_2 tax for sustainable biofuels and providing a small incentive for paraffinic diesel fuel.

In addition, both the vehicle purchase tax (on new passenger cars) and the annual vehicle tax are related to CO_2 emissions, as of 2008 and 2010, respectively[32].

The players

In Finland, biofuels for transport is a good example triple helix cooperation, meaning cooperation between government, industry and academia. In Finland, implementation of biofuels or renewable fuels is the key measure to reach the CO_2 emission reductions

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32 Parkkonen, L. (2013).

33 DIRECTIVE 2009/28/EC

targeted for 2030, as biofuels will deliver nearly two thirds of the targeted 50 % reduction (year of comparison 2005). Biofuels are seen as an opportunity for Finland, based on Finland's biomass resources, strong forest industry and advanced fuel refiners.

The Ministry of Economic Affair and Employment is responsible for energy and innovation policy. The Ministry of Transport and Communications is responsible for transport policy. Fuel quality matters are the responsibility of the Ministry of Environment, and Ministry of Finance is responsible for taxation. In preparation of the different stages of the biofuel obligation, guiding committees with broad representation have been established.

There are several Finnish companies active in biofuels. Neste is the world leader in the production of renewable diesel (HVO), with production facilities in Finland, the Netherlands and Singapore[34].

St1 is a Nordic energy group that operates in several business areas in Finland, Sweden and Norway[35]. St1 started its biofuels activities with production of waste based ethanol, but is now expanding into renewable diesel by building a biorefinery in Gothenburg, Sweden

UPM is producing tall oil based renewable diesel at its plant Lappeenranta, Finland (some 120,000 toe/a)[36]. UPM also has plans to build a 500,000 toe/a biorefinery in Kotka, Finland.

Gasum is active in the gas sector in the Nordic countries[37]. Gasum's activities in the transport sector encompass CNG (compressed natural gas), CBG (compressed biogas/biomethane), LNG (liquefied natural gas) and LBG (liquefied biogas/biomethane). Gasum is the biggest operator in both biogas and LNG in the Nordic market.

Several universities and research organizations in Finland are working on advanced biofuels. St1 Biofuels is actually a VTT spin-off, and VTT has been working together with all the above-mentioned companies.

Notwithstanding, there has also been some conflicts of interest. The Finnish Petroleum Federation, originally founded in 1971, for a while became the Finnish Petroleum and Gas Federation. In 2011, gas was dropped, and the organization eventually became the Petroleum and Biofuels Association of Finland. The organization was dissolved at the end of 2018, because the members disagreed on the proposed biofuels mandate of 30 % in 2030,

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[34] Neste Homepage

[35] St1 Homepage

[36] UPM Homepage

[37] Gasum Homepage

some members judging this target to be too ambitious and leading to market disturbances[38].

E10 petrol has been a success in Finland. E10 was introduced in 2011. More than two thirds of the petrol sold in Finland is E10. This can partly be credited to successful information campaign by the Petroleum and Biofuels Association of Finland together with the Finnish Information Centre of Automobile Sector and Motiva, a government sponsored sustainable development company. The campaign is actually still running (Figure 13)[39].

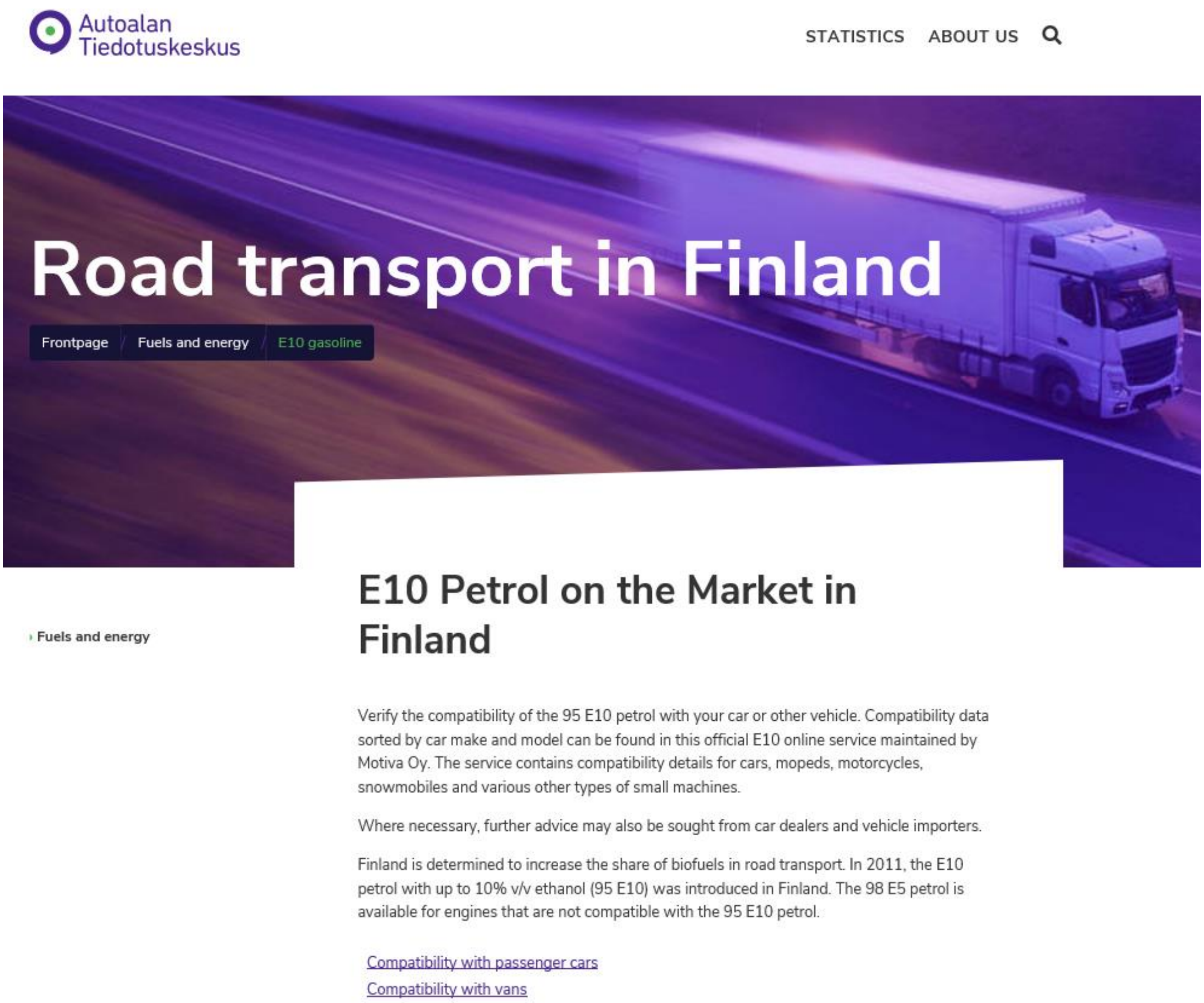

Figure 13: Screenshot of the E10 petrol information portal[39].

[38] Helsingin Uutiset

[39]The Finnish Information Centre of Automobile Sector 1

Market situation

In 2019, the energy consumption in domestic transport (all modes together) was 179 PJ, and energy consumption in road transport 162 PJ or 3.87 Mtoe (Table 10). Relative to the total final consumption of 1078 PJ the figures were 16.6 % and 15.0 %, respectively[40]. In 2019, total CO_{2eqv} emissions were 52.8 Mt. The emissions from transport were 11.0 Mt (all modes together) and 10.5 Mt (road), 20.8 % and 19.9 % of total, respectively[41,42].

Table 10: Energy in road transport in 2019.

2019	PJ	ktoe	Share of fuels	Bioshare
Petrol	51,1	1221	31,6 %	
Biocomponents in petrol	3,7	87	2,3 %	6,7 %
Diesel	92,4	2207	57,1 %	
Biocomponents in diesel	14,2	339	8,8 %	13,3 %
Natural gas	0,20	4,8	0,1 %	
Biomethane	0,27	6,5	0,2 %	57,6 %
Fuels	161,9	3866	100,0 %	11,2 %
	PJ	**ktoe**	**Share of total**	
Electricity	0,26	6,2	0,2 %	
Total	**162,1**	**3872**		

The contribution of biofuels relative to the total amount of actual fuels was 11.4 % in terms of energy, varying from 6.7 % in petrol (mostly ethanol, some ETBE and also bio-naphtha, the statistics do not give details on this) to 58 % in methane. The biocomponent in diesel was almost exclusively drop-in type renewable diesel (HVO). In 2019, the biofuels mandate (for liquid fuels) called for an 18 % share of biofuels (with double-counting). The actual amount was 426 ktoe or 11.1 % of the liquid fuels, meaning that the greater part of the biofuels used

40 Statistics Finland 1

41 Statistics Finland 2

42 Lipasto

was eligible for double counting.

Total production of biofuels in Finland is some 540 ktoe[43]. This means that Finland is more than self-sufficient in the production of biofuels.

However, it should be noted that Neste relies mainly on imported feedstocks, whereas UPM, St1 and Gasum use indigenous feedstocks. All Finnish biofuel producers have announced major increases in capacity either in Finland or abroad.

Figure 14 shows the development of biofuel volumes (absolute) in Finland, and Figure 3 shows relative shares of biofuels. There was a peak in biofuel volumes in 2014 and 2015. This is explained by the flexibility of the obligation, allowing banking from one year to another. In those years, the export markets for biofuels were not that favourable, and thus the actors temporarily overfilled the Finnish market.

When the biofuels obligation was put in place in 2008, ethanol in petrol was the dominating biocomponent. In 2019, 80 % of the biocomponents were used in diesel.

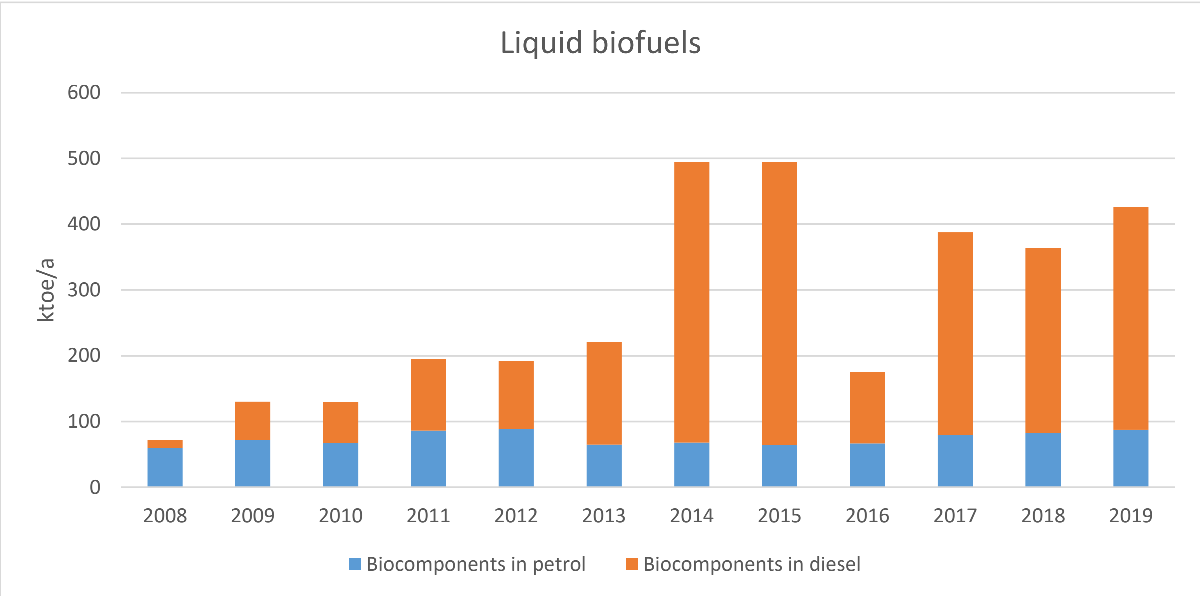

Figure 14: Development of biofuel volumes (absolute). Data from Statistics Finland 1.

43 Valtioneuvosto 2018

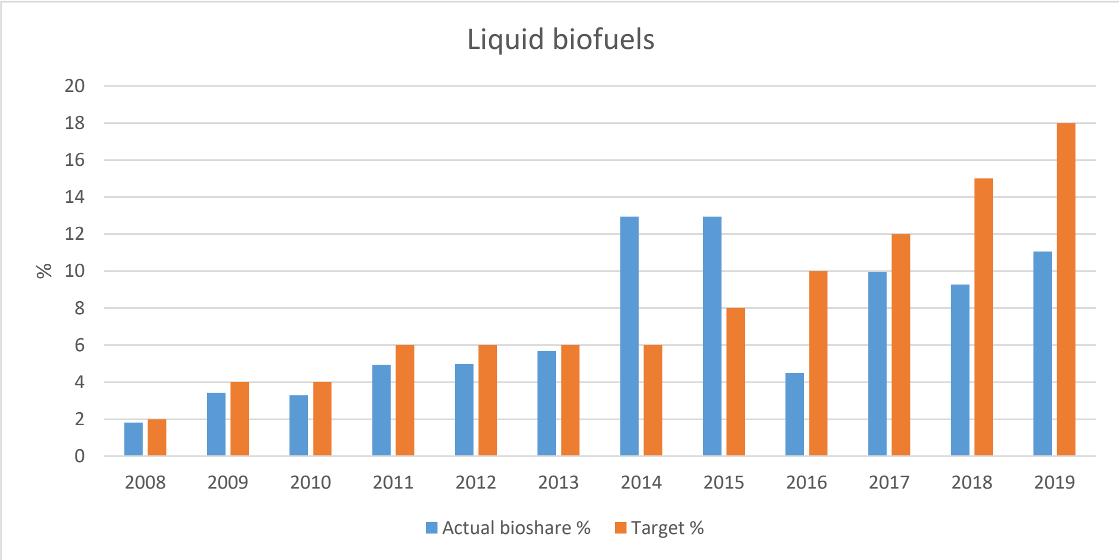

Figure 15: Relative shares of biofuels. Data from Statistics Finland 1.

Figure 16 shows CO_2 emission projections from road transport, with and without biofuels. “With biofuels” actually represents the current policies scenario, implementing the biofuels obligation towards 30 % in 2030 and anticipating some 350.000 electric vehicles in 2030, a share of some 12 % of the passenger car fleet.

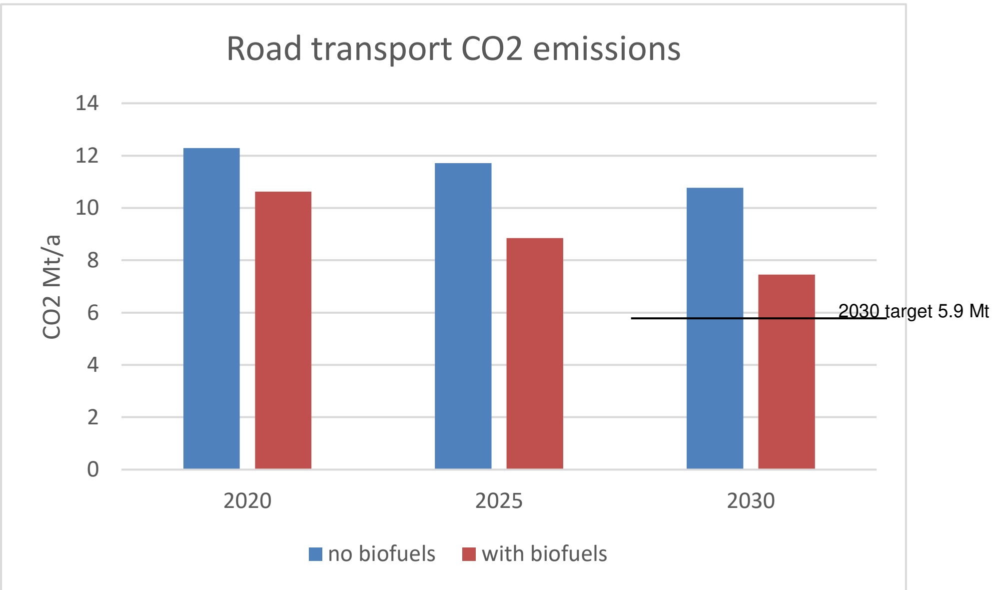

Figure 16: Road transport CO_2 emissions. Data from[44].

[44] Laurikko, J. (2020)

This scenario results in 7.5 Mt CO_2/a in 2030, a reduction of 36 % compared to the reference year 2005, but 14 % or 1.6 Mt short of the 2030 target (a 50 % reduction). The figure also shows what the emissions would be without biofuels. Without any biofuels, CO_2 emissions would be 10.8 Mt in 2030, meaning that biofuels will reduce emissions 3.3 Mt/a in 2030.

To reach the target of -50 % in 2030, we need improved efficiency throughout the transport system, more electric vehicles or more biofuels, but most probably, a combination of all these measures.

Table 11 presents the vehicle fleet in use at the end of 2019 (without two- and three-wheelers and light four-wheelers). Table 3 presents the sales figures for new passenger cars in 2015 - 2019.

Table 11: Vehicle fleet at the end of 2019 (in use, without two- and three-wheelers and light four-wheelers)[45].

Fuel	Cars	Vans	Trucks	Buses	Special vehicles
Petrol	1 916 849	9 780	1 764	26	321
FFV	4 298	9	101	0	0
Diesel	760 330	319 769	93 000	12 425	1 738
Methane	3 121	460	84	52	0
Methane bi-fuel	6 255	274	91	0	0
BEV	4 661	312	2	62	0
PHEV petrol	22 653	25	0	0	0
PHEV diesel	2 050	14	0	3	0
Other	90	28	99	9	0
Total	2 720 307	330 671	95 141	12 577	2 059

[45] Traficom 1

Fuel	Cars	Vans	Trucks	Buses	Special vehicles
Petrol	70,5 %	3,0 %	1,9 %	0,2 %	15,6 %
FFV	0,2 %	0,0 %	0,1 %	0,0 %	0,0 %
Diesel	28,0 %	96,7 %	97,7 %	98,8 %	84,4 %
Methane	0,1 %	0,1 %	0,1 %	0,4 %	0,0 %
Methane bi-fuel	0,2 %	0,1 %	0,1 %	0,0 %	0,0 %
BEV	0,2 %	0,1 %	0,0 %	0,5 %	0,0 %
PHEV petrol	0,8 %	0,0 %	0,0 %	0,0 %	0,0 %
PHEV diesel	0,1 %	0,0 %	0,0 %	0,0 %	0,0 %
Other	0,0 %	0,0 %	0,1 %	0,1 %	0,0 %

Table 12: Sales of new passenger cars in 2015 - 2019[46].

Year	Petrol	FFV	CNG	Diesel	HEV P	HEV D	PHEV P	PHEV D	BEV
2015	66248	105	158	38797	2817	29	400	15	243
2016	73251	14	165	39451	4668	11	1115	93	223
2017	70520	1	433	36060	8512	2	2401	152	502
2018	73065	0	1161	28710	11631	224	4797	135	776
2019	67751	0	2142	20871	14582	990	5807	159	1897

The share of alternative fuel vehicles (including electric vehicles) ranges from 1.6 % (cars) to 0 % (special vehicles). Within passenger cars, plug-in hybrids is the largest alternative vehicle group. With the introduction of Euro 6 emission regulations, new FFVs in practise vanished from the market. The Volkswagen Group, which currently is the main supplier of methane fuelled cars, in the spring of 2020 announced that it will stop developing new

[46] The Finnish Information Centre of Automobile Sector 2

methane engines[47]. This might cut the growth of methane fuelled cars as well.

From 2018 to 2019, petrol cars backed 7 and diesel cars 27 %, whereas registrations of BEVs increased 144 % and CNG vehicles 84 %. Registrations of PHEVs and petrol-fueled HEVs all increased some 20 %. One abnormality was diesel-fueled HEVs, as registrations increased more than 300 %.

There are some 300 alternative fuelled trucks, including FFVs and bi-fuel vehicles. The numbers for these two categories are explained by the fact that some heavy pick-up trucks and vans are registered as trucks. With the development of LNG refuelling infrastructure and increased offerings of heavy gas trucks, LNG fuelled trucks have entered Finnish roads, although still in limited numbers. In the case of buses, the number of battery electric buses has surpassed the number of gas buses.

As stated earlier, the biofuels obligation is a simple tool to drive biofuels. Use of biofuels and emission reductions associated with this are not dependent on consumer choices, nor do they require the choice of a certain fuel type or special vehicles. Consequently, most of the biocomponents used in Finland are blended in regular petrol and diesel fuel within existing fuel standards, and used in non-modified vehicles.

There are, however, some incentives for alternative vehicles:

- acquisition support for BEVs[48]
    - 2000 €, for vehicles that cost less than 50,000 €
- support for conversions of vehicles (passenger cars)[49]
    - 1000 € support for conversions to methane
    - 200 € support for conversion to high concentration ethanol (E85)

Now a proposal for supporting methane fuelled trucks has been brought to the table. In any case, a biofuels or renewable fuels mandate is a much faster approach to low carbon fuels than supporting alternative fueled vehicles.

[47] Handelsblatt

[48] Traficom 2

[49] Traficom 3

Evaluation of market introduction and Lessons Learned

Finland is relying on biofuels as a key element in transport decarbonization. Biofuels obligation has been in place since 2008. The target for 2030, 30 % energy share, has already been set. The obligation will increase gradually towards 2030. The actual share of biofuels was some 11 % in 2019 (with a calculatory share of close to 20 % using so-called double counting for biofuels based on wastes and residues), renewable diesel being the dominating alternative. As the main objective going towards 2030 is reduction on transport CO_2 emissions, double counting will be dropped as of 2021.

The biofuel obligation has been accompanied by other measures, i.e., investment aid to demonstration of biorefinery concepts, support for biofuels related R & D activities as well as a tax reform, which treats renewable fuels in a fair and objective way. Policies promoting biofuels have been consistent, providing certainty for industries to invest. In fact, Finland has a very strong international biofuels industry, focusing on biofuels from non-edible feedstocks. In addition, attention has been paid to consumer information, e.g., in the case of E10 petrol as well as in alternative energies in transport generally.

The greater part of the biofuels on the market are consumed as blending components in regular petrol and diesel. However, also high concentration biofuels are available on the market: 100 % renewable diesel (100 % HVO), E85 and biomethane. The composition of the E85 offered in Finland has been fine-tuned to perform well also in cold conditions.

Infobox 10: Key drivers of successes and key barriers of failures

Key drivers of successes

- Consistent policies to promote the use of biofuels
- A combination of measures to drive biofuels: biofuels obligation, support for investments as well as for R & D activities and a reformed taxation system
- A progressive fuels industry highly committed to renewable fuels and reduction of CO_2 emissions
- International biofuel markets are seen as an opportunity for the Finnish energy companies, a strong home market is beneficial in this game

Key barriers:

- The penetration of alternative fueled vehicles is hampered by reduced offering of new vehicles, first FFVs and now also methane fueled passenger cars (focus for methane/biomethane will turn to heavy-duty vehicles)

Infobox 11: Case specific lessons learned and recommendations

Biofuels have been a success in Finland, partly thanks to the triple helix approach: government, industry and research community Technology neutrality and cost effectiveness are important when promoting low carbon fuels Don't pick winners and losers, a better way is to set criteria for performance, environmental performance as well as cost competiveness When setting the 2030 (2029) obligation of 30 % biofuels with no double counting, cost effects were estimated. Compared to 2020 and a biofuel share of some 13 % (target 20 % but allowing double counting), the effect on fuel pump prices was estimated at a moderate +5 %.

Japan

For Japan two interesting case studies were identified and further described:

- Low blend biofuels
- Natural gas

Natural gas

Introduction

In Japan, natural gas vehicles (NGV) became popular as alternative fuel vehicles in Niigata and Chiba prefectures, where natural gas is produced, during and after World War II, when petroleum supply was poor. After that, NGV disappeared as petroleum was well supplied, but from around 1990 NGV began to be introduced into the car market again as business vehicles for gas companies and others. In December 1995, demonstration tests approved by the Ministry of Transport were completed, and then NGV became mass-produced.[50]

The penetration of NGV was expected from the viewpoints of measures against local pollution (mainly measures against roadside air pollution caused by vehicle exhaust gas), measures against global warming, and improvement in energy security. City gas companies, which aimed to expand gas demand, played the leading role in development and promotion of NGV, and then some automobile manufacturers have begun development and sales of NGV with the government support as part of policy for the air pollution measures. As a result, some users, such as truck and bus fleet operators, have actively introduced NGV.[51]

However, NGV attract less interest at present, its cumulative number has only reached 47,778. On the other hand, the number of rapid refueling stations has decreased from 344 at the peak in 2008 to 239 in March 2019.

More than 20 years have passed since NGV entered the full-scale diffusion stage, and during this time, many stakeholders were involved in its development and diffusion. By conducting interviews with these stakeholders, issues related to dissemination, obstacles, and lessons learned were investigated.

Political framework

1) Overview of major laws and regulations[52]

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[50] Japan Gas Association

[51] Central Research Institute of Electric Power Industry

[52] Next-generation vehicles guidebook (Ministry of the Environment)

a) Ministry of Land, Infrastructure, Transport and Tourism
Ministry of Land, Infrastructure, Transport and Tourism is responsible for the certification of NGV, and has revised “Road Transport Vehicle Safety Standards”, “Automobile Inspection Standards”, “Examination Regulations”, etc. regarding NGV. Circulars for NGV were issued regarding "handling", "structural standards", and "vehicle inspection methods". In addition, Ministry of Land, Infrastructure, Transport and Tourism has been subsidizing the purchase of NGV for the transportation business since 2002 as part of roadside air pollution measures.

b) Ministry of Economy, Trade and Industry
Ministry of Economy, Trade and Industry implemented a “Project to Promote the Introduction of Clean Energy Vehicles” from 2002 to 2011 to promote the use of clean energy vehicles including NGV. This project provided a subsidy for the purchase of NGV for private use, a subsidy for construction of natural gas stations, and a subsidy for operating natural gas stations.
In the certification of NGV, as there is a main jurisdiction regarding fuels in Ministry of Economy, Trade and Industry, various requirements on high pressure vessels and parts for NGV are defined under the “High Pressure Gas Safety Law” of Ministry of Economy, Trade and Industry.

c) Others
Reduction on vehicle weight tax, acquisition tax and vehicle tax are being provided for next-generation vehicles including NGV, as well as there are incentives such as low-interest financing for acquisition of fuel supply facilities and reduction of fixed asset tax.
In addition, local governments have their own subsidy programs.

2) Overview of main subsidy programs[53]

a) Ministry of Land, Infrastructure, Transport and Tourism
A subsidy for environmentally friendly vehicles promotion
+Subsidization of purchase costs to promote introduction of next-generation vehicles including natural gas trucks and buses: subsidization of 1/3 of the price difference with conventional vehicles
Period: 2002 to present

b) Ministry of Economy, Trade and Industry

[53] Japan Trucking Association homepage

A subsidy for clean energy vehicles promotion

+Subsidization for purchase cost to promote introduction of clean energy vehicles such as NGV: subsidization within 1/2 of the price difference from conventional vehicles

+Subsidization for construction of natural gas station and its equipment: within 1/2 of installation cost

+Subsidization for operating natural gas stations

Period: 2002 to 2011

c) Ministry of the Environment

Acceleration of introduction of trucks and buses for environmentally advanced technology

+Subsidization for introduction of large natural gas trucks: 1/3 of price difference from conventional vehicles

Period: 2016 to present

d) Others

Subsidy for environmentally friendly trucks introduction (Japan Trucking Association)

+Subsidization for introduction of natural gas trucks etc.: light duty trucks 267,000 yen (2,400USD), medium-duty trucks 500,000 yen (4,500USD) and heavy-duty trucks 1 million yen (9,000USD)

Period: 1997 to present

Local governments and local trucking associations also have their own subsidy programs.

3) Overview of main tax system[54]

For NGV, exemptions and reductions of the automobile weight tax are implemented. Exemptions and reductions of the automobile acquisition tax, special provisions related to the acquisition of used vehicles, and reductions of the automobile tax and light vehicle tax are implemented.

Collection of insights from relevant stakeholders

Stakeholders involved in development and diffusion of NGV were interviewed on issues related to dissemination, promotional barriers, and lessons learned in their activities. The outline of the interview is shown below.

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[54] Ministry of the Environment Japan

- Interview period: November to December 2019
- Number of interviews: 6 (2 university professors, a gas industry: 2 companies and 1 organization, 1 automobile manufacturer)
- Each interview time: 1-2 hours
- Interview method: a free discussion was held on questions related to dissemination, promotional barriers, and lessons learned in their activities.

The responses obtained from interviewees were compiled into the following five categories based on items proposed in Task 59 text. However, some of the interview results overlapped between some categories.

1) Technical issues / Infrastructure

   a) In the future, if methane in exhaust emissions is regarded as a problem because it is one of greenhouse gases, the position of NGV may become more severe. That is to say, if hydrocarbon emission regulations changes from NMHC (non-methane hydrocarbons) to THC (total hydrocarbon), methane slip will be an issue (in overseas countries, they are not already NMHC regulations).
   Issues: after-treatment of methane in exhaust gas

   b) Reducing CO_2 emissions from vehicles will become essential, and it is highly likely that fossil fuel usage will be difficult.
   NGV can be expected to be superior in terms of environment and performance compared with diesel vehicles, but if decarbonization in road transport sector is required to 2050, it will be difficult to utilize natural gas which is fossil fuel. In this context a trend of electrification of passenger cars has already begun. However, electrification of commercial vehicles has technical problems and is expected to take much time to spread. Therefore, if new and attractive NGV in terms of environment and performance are developed, it may be used during the period of bridging to electrification. For example, diesel dual-fuel (DDF) and natural gas hybrid vehicles are new technologies and can reduce CO_2.
   In addition, if methane synthesized from renewable energy by methanation technology is put to practical use, NGV will be a power source for CO_2 neutral for heavy commercial vehicles
   Issues: possibility of restricting the use of natural gas which is a fossil fuel. New NGV which are attractive in terms of environment and performance are needed.

2) Politics / Authorities

a) Since the late 1990s, automobile emission regulations have been tightened to improve roadside air pollution in Japan. NGV, which was very attractive to reduce PM and NOx emissions at the time, has attracted attention as an air quality measure, and social needs for NGV have increased. In the 2000s, local governments lost pollution lawsuits. In this context the willingness to introduce NGV increased among automobile manufacturers and transportation companies. In addition, the Automobile NOx / PM Act (Act Concerning Special Measures for Total Emission Reduction of Nitrogen Oxides and Particulate Matter from Automobiles in Specified Areas) had banned diesel vehicles from entering 7 metropolitan cities, and at the same time restrictions on diesel vehicle traffic in cities such as Tokyo and local governments were accelerated, which has had a significant effect on the spread of NGV. Environmental measures seemed to be one of the booms of society at the time, and their introduction was actively promoted in conjunction with various introduction policies and the novelty of NGV.

b) Since then, emission regulations for diesel vehicles have continued to be tightened, and as a result of the development of emission control technologies, the exhaust emissions and fuel consumption of diesel vehicles have been significantly improved. On the other hand, NGV technology has not changed much, so its environmental advantages (exhaust emissions including CO_2) have been reduced. Since there are still practical problems such as high introduction costs and lack of infrastructure, at present the spread of NGV is stagnant.

c) Now that NGV's environmental advantages are declining, regulations and laws that focus on other advantages of natural gas, such as energy security and CO_2 reduction, will greatly contribute to its widespread use. Countries in which NGV is widespread (e.g., natural gas-producing countries) include national energy policies relating to NGV, such as obliging manufacturers to sell NGV, introducing them to users, and implementing national and local government policies like restricting current vehicle traffic in urban areas. That is to say, the purpose of disseminating NGV is clearly positioned in its own energy and also environmental policy (CO_2 reduction). It is important that owners of NGV feel a motivation and/or status that they are doing environmentally friendly efforts.

d) Some municipalities oblige transport companies with more than 200 vehicles to introduce more than a certain percentage of environmentally friendly and fuel-efficient vehicles. However, in Japan, NGV are not subject to fuel efficiency regulations and are not certified as fuel-efficient vehicles. Therefore, some major transportation companies use diesel hybrid vehicles which is defined as fuel efficient vehicles instead of NGVs.

e) One of effective policies is a subsidy for the construction of natural gas stations. This subsidy was expensive (90 million yen (USD 820K) / location) and was very effective in terms of infrastructure dissemination, but the spread of natural gas stations rapidly stagnated after the subsidy system disappeared.

3) Costs / Economics

a) Unlike passenger cars, NGV (truck) must be a vehicle that is profitable for the transport business. In the case of the transport business, the service life of vehicles is long, and the cost of fuel account for a big part of vehicle life cost. Therefore, it is very important that a fuel price is low. Based on experience in overseas NGV sales, it is believed that low fuel retail prices will lead to rapid diffusion. If the fuel price is about 10 to 20% cheaper than that of the petroleum-based fuel, a strong transport company can build its own natural gas station. However, many transport companies are small and medium-sized enterprises and cannot provide backup for the operation of the station (such as the deployment of a high-pressure gas security manager), so it is difficult for them to operate a private station. Therefore, if the retail price of compressed natural gas (CNG) is stably 30% to 40% lower than that of petroleum-based fuel, full-scale NGV diffusion to small and medium-sized transport companies may be possible.

b) In the early stage of diffusion, natural gas is not subject to the fuel tax on automobiles, and thanks to a subsidy for operating stations, CNG retail prices were favorable compared to petroleum-based fuels due to strategic cheap pricing on the fuel supply side. However, due to the end of the subsidy for a station operation cost and the slow growth of the number of NGVs, it has become difficult to continue station operation, as a result its number has decreased. In order to maintain a constant number of stations, it is necessary that stations can sell CNG at a profitable price. In gas-producing countries where NGV is widespread, the national policy will be to subsidize natural gas at lower prices, and in some EU countries, a diesel fuel price is about twice as high as that of natural gas by changing diesel fuel taxation. NGV will not continue to spread unless there is a mechanism for both a station operator and the transport business to make a profit.

c) Both natural gas import prices and oil import prices are linked to crude oil prices, but the time reflected to the retail price is different. Oil prices are reflected relatively quickly within one or two months, while natural gas prices take about six months. As a result, the retail price of CNG was sometimes more expensive than that of petroleum-based fuel when crude oil prices fell. Transport companies felt that the cost of CNG was high at that time, and it seemed that there was no cost advantage, which hindered the spread.

d) The production volume of NGV itself is small. Especially the price of CNG vessels, which are an important component of NGV, is high. Therefore, an NGV cost is high comparing to current diesel vehicles. That is a barrier for diffusion of NGV. As freight vehicles are used in business, there is a strong desire to reduce an initial investment. It is necessary for especially small and medium-sized transport companies to set a shorter payback period.

4) Consumers / Public

a) In the early stage of diffusion, modified NGV had many failures and was not well received by users. After that, the reputation was restored after the introduction of NGV manufactured by automotive manufacturers, which fuel mixing method changed from the mixer type to the MPI (multipoint injection) type. But those who have a bad image to NGV continued to have that image. This has been a barrier for diffusion of NGV.

b) Current NGV are not attractive. Many customers have a bad image to NGV so far. One of the key factors for diffusion is to make it an attractive product. When NGV became popular, it was an attractive product as an emission control measure. However, the attractiveness is fading at present. Therefore, it is essential that manufacturers make it attractive.

c) As one of the important factors for its spread, it is necessary to make efforts to properly convey an attractiveness to users, such as inviting users to a test drive of NGV.

d) In the early stage of NGV diffusion, the business domains in industries were independent for each energy type, and gas utilities did not compete with other energy providers, so it was easy for each gas company to promote NGV diffusion activities together. The Gas Association had a role on station construction, vehicle (including modified vehicle) development, and deregulation. Automotive manufacturers also participated in the examination of standards. The spread of NGV has progressed because the industries have been working together.

e) There are about 2,200 LPG stations in Japan, and about 250,000 LPG vehicles are operating nationwide. On the other hand city gas pipelines are concentrated in urban areas (approximately 6% of the country's territory), and currently over 200 and several dozen CNG stations are located in the city gas pipeline network area. Considering the above, there is a situation where the density of the CNG station is higher than that of the LPG station. Therefore, considering the station density alone, the number of NGV should be more widespread than LPG vehicles. This is too much compared with a density of a gasoline station for passenger vehicles. Perhaps there is a large prejudice that NGV has less infrastructure and less convenience. Isn't it necessary for stakeholders to reconsider their views and ways of thinking about NGV as a commercial vehicle?

5) Country specific barriers

a) The FIT (Feed-in Tariff) system started in July 2012 and is a policy for a power company to purchase electricity from renewable energy sources such as solar, wind, hydro, geothermal, and biomass for a certain period, by a higher price set by the government. Biogas has been used for electric power generation using the FIT system, and a use for biogas fuel (natural gas) to NGV has not progressed. Inhibitory factor: Since the purchase price of electricity from biogas fuel in the FIT system is superior to that of biogas fuel for NGV, using biofuels for vehicles has economic problems.

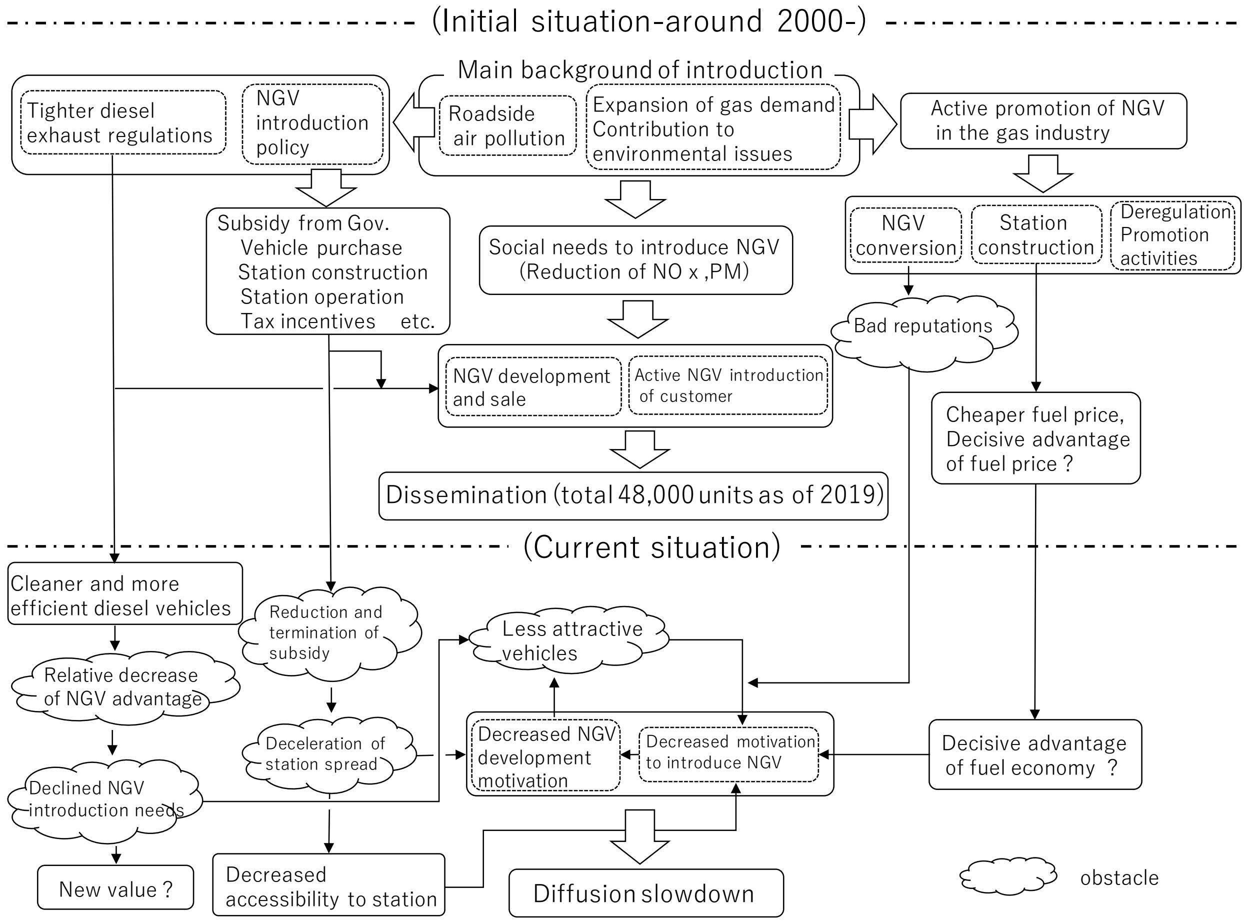

Figure 17: Summary of NGV dissemination scheme

Based on the responses obtained from the interviews, the main obstacles to the spread of NGV in Japan are shown on the above schematic figure.

In Japan, the spread of NGV has greatly increased in the early stages (from the late 1990s) due to measures against roadside atmospheric environmental problems, especially caused by commercial diesel vehicles. In particular, the strengthening of emission regulations for diesel vehicles, restrictions on the traffic of diesel vehicles in big cities, and the generous support of the government for NGV and natural gas fuel infrastructure have greatly boosted its introduction. In other words, although there were some issues such as the inconvenience of fuel filling compared to conventional fueled vehicles, following situations helped dissemination of NGV.

Improvement of atmospheric environmental issues became social need.

The use of diesel vehicles was legally restricted partly in specific areas.

The natural gas price was relatively low, therefore the economy of NGV was preferable.

There was government support for the construction and operation of natural gas stations.

At this time, it is considered that NGV became more widely introduced in the context of strengthening environmental regulations to improve roadside atmospheric environmental problems, rather than the fact that NGVs were introduced independently in a free competitive market due to economics. That is to say, important factors in the spread of alternative fuel vehicles were social need and were a circumstance to implement regulatory measures for diffusion, in addition to the support of the government, it is necessary to have a certain level of practicality on the vehicle economy and of the number of infrastructures.

Since then, by the innovation of the technology, emissions and fuel efficiency of diesel vehicles were improved significantly. As a result, the NGV's superiority for a roadside air quality measure has reduced. In addition, the diffusion of NGV has begun to stagnate due to the reduction and termination of the government support. In particular, with the termination of subsidy for the construction of infrastructure, and for operating costs which are considered to have greatly contributed to the diffusion of NGV, the decrease in the number of infrastructures was one of a turning point in the diffusion of NGV. Against this background, although there are some advantages in fuel prices, barriers such as low attractiveness of NGV, inconvenience on fueling, etc. have become apparent, and the number of NGV has slowed under competition in a free competitive market.

Quantification information

To assess if the market introduction of NGV succeeded, the consumption of natural gas for vehicles, the number of NGV disseminated, the reduction of GHG, the reduction of emissions, or the reduction in energy achieved etc. were quantified. In addition, if possible, alternative motor fuel costs, and vehicle market share were surveyed.

1) Number of NGV introduced

The figure shows the sales of NGV by vehicle type by year since 1997.
NGV has rapidly become popular since 2000. In particular, the number of trucks has been remarkably widespread in response to roadside air pollution problems caused by diesel trucks. However, the spread has been stagnant since 2009.

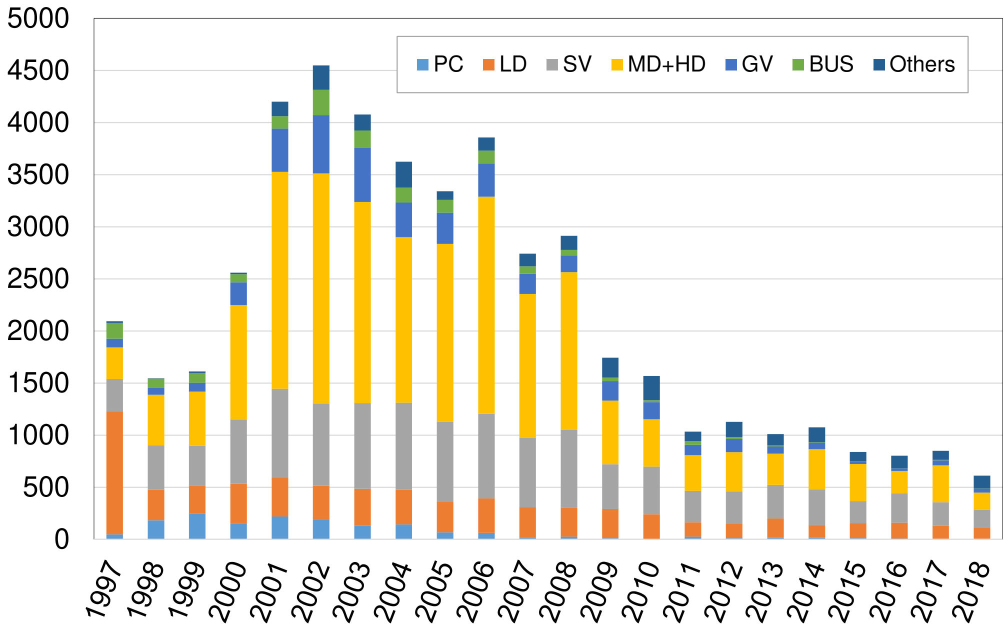

Figure 18: Sales of NGV by vehicle type

PC: Passenger Car, LD ：Light Duty Truck, SV ：Small Vehicle, MD+HD ：Medium & Heavy Duty Truck, GV ：Garbage Truck, BUS ：Bus, Others ：Fork lift etc.; Source Japan Gas Association Homepage

2) Amount of fuel introduced

The table below shows the domestic consumption of various types of automotive fuels, including natural gas, in 2018. Automotive natural gas consumption (calorific value equivalent) is about 0.07% of total automotive fuel.

Table 13: Fuel consumption in 2018

Source: Agency for Natural Resources and Energy; IEA Bioenergy Task 39 (2018)

Automotive fuel	Fuel consumption (2018)		Ratio
All	–	2,726 PJ	100 %
Gasoline	48,846,328 kL	1,630 PJ	59.79 %
ETBE	1,940,000 kL	54.7 PJ	2.01 %
Diesel	25,584,245 kL	973 PJ	35.70 %
LPG	1,323,415 kL	66.3 PJ	2.43 %
Natural gas	44,076 km^3	1.82 PJ	0.07 %

3) Reduction of emission

There is no basic unit for reducing actual emissions on roads by the introduction of NGV. So, as it is difficult to estimate the amount of emission reduction, the effect of reducing exhaust gas by NGV is described in an emission regulation mode. The table below shows the emission standards for heavy-duty diesel vehicles in JE05 mode and examples of emissions from NGV (deliver truck) sold in Japan. NGV are particularly effective at reducing NO_x and PM emissions.

Table 14 Emission standards for heavy-duty diesel vehicles and examples

*Unit: g/kWh; *Source: Isuzu Motors Limited Homepage*

Fuel	Regulation (Heavy duty)	Mode	CO	NMHC	NOx	PM
Diesel	2016	WHTC+WHSC	2.22	0.17	0.4	0.01
	2009	JE05	2.22	0.17	0.7	0.01
Natural gas	2008(Guide line)	JE05	16	0.17	0.5	-
	*Example (Delivery truck)	JE05	NA	NA	0.2	-

4) Reduction of GHG

In Japan, NGV is not subject to fuel economy regulations and there is no official CO_2 emission data. Therefore, it is difficult to evaluate CO_2 emission reduction effect by an introduction of NGV. For reference, here is the results of road tests conducted by LEVO on a heavy duty CNG truck and a diesel truck of the same type under the same conditions as possible.

Vehicle: CNG truck (Isuzu GIGA modified), Registered in 2011.12, Adapted 2009 emission regulation

Diesel truck (Isuzu GIGA), Registered in 2011.07, Adapted 2009 emission regulation

Pay load: Half load (6 tonnes) with both vehicles

Date and time: On January 13-16, 2015, tests were carried out at night on expressway to eliminate the influence of traffic congestion as much as possible.

Table 15 Results of GHG emission reduction

Vehicle	Total mileage km	Total fuel consumption CNG: Nm^3 Diesel: L	Fuel economy CNG: km/Nm^3 Diesel: km/L	CO_2 kg-CO_2/km	CO_2 reduction rate %
CNG truck	1,224	289.5	4.23	0.527	▲13.8
Diesel truck	1,191	282.4	4.22	0.612	

As shown in the table above, the CNG truck reduced CO_2 emissions by approximately 14% compared to the diesel truck.

Fuel efficiency (CO_2 emissions) during road driving varies depending on driving conditions. However, it is considered that CO_2 emissions of NGV are lower than those of diesel vehicles when heavy trucks are running on expressways.

5) Others

The table below shows changes in gasoline, diesel fuel and natural gas prices since 2007 in Japan.

The retail price of automotive natural gas changes in a similar manner several months later than those of gasoline and diesel fuel, but is generally lower than them.

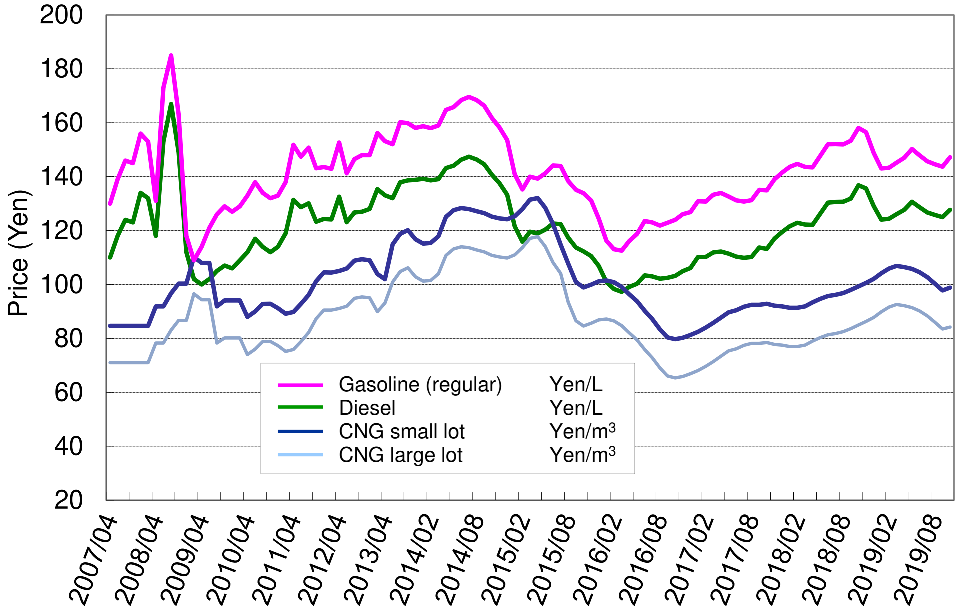

Figure 19: Prices of gasoline, diesel fuel and natural gas since 2007 in Japan

Reference: ca.110Yen=1USD

Source: The oil information center; Tokyo gas co. ltd. Homepage

Evaluation

Result of market introduction

In the early stages of the spread of NGV, a certain number of NGV became popular due to the growing awareness of improving the atmospheric environment in society against the background of exhaust gas pollution caused by vehicles. In particular, light-duty natural gas trucks with a loading capacity of 2 to 3 tons for urban areas transportation were sold around 1,500 units in a year (about 1.9% share in the light-duty truck field), and the introduction to the market had been steady. However, the advance of the technology to improve the emissions from diesel vehicles has reduced the superiority of NGV, and their use has stagnated.

Estimated factors for market introduction

There are various factors that have led to the market introduction of NGV, but the main factors that can be considered are as follows.

a. The society (for example, transportation companies, shippers, automotive manufacturers, and government etc.) has a high awareness of improving the air pollution.

b. Due to social needs, generous government incentives (subsidies for purchases, infrastructure construction, etc.) have been promoted.

c. The use of existing diesel vehicles has been regulated to improve the atmospheric environment, and the spread of NGV has increased.

Country specific situations

Since oil crisis of the 1970s, imports of natural gas as one of the alternative fuels to oil have greatly increased to reduce oil dependency, making it a large and stable fuel in Japan. Therefore, it is considered to be an important fuel from the viewpoint of ensuring energy security.

Measures taken

a. Vehicle purchase cost subsidy

b. Infrastructure construction subsidy

c. Station management subsidy

d. Various tax incentives

e. Others: Bidding conditions of local governments, etc.

Wrapping

The following summarizes which factors have helped to launch the NGV market and which factors have hindered or should have made efforts more.

Infobox 12: Key drivers of successes and key barriers of failures

Key factors for success and main barriers: + Key factors for success • Greater awareness of air pollution improvement in society (transportation companies, shippers, automobile manufacturers, government etc.). - Main barriers • In a free competition market, after the environmental performance of conventional vehicles improved, there was little reasons/motivation to provide customers attractive products with advantages regarding the performance and practicality of natural gas vehicles over conventional vehicles.

Lessons Learned and recommendations

Infobox 13: Case specific lessons learned and recommendations

The lessons learned and recommendations during the interview are summarized as follows. The number in parentheses indicates the item number of the paragraph "Collection of insights from relevant stakeholders" for natural gas. Needs of the society (for example, transportation companies, shippers, car manufacturers, and governments) such as air pollution measures is very important. Restriction on the traffic of diesel vehicles in cities to address environmental issues has greatly contributed to the spread of NGV. [2)a)] There is a decline of NGV superiority due to the innovation of technologies on diesel vehicles. It is necessary to continue an innovation of technologies for NGV. [2)b)] Policies that clarify the significance of NGV diffusion, such as energy security and CO_2 reduction, are needed. [2)c)] NGV needs to clearly demonstrate its environmental advantage in fuel efficiency regulations. [2)d)]

A great deal of infrastructure construction assistance greatly contributed to NGV diffusion. However, the recoil when assistance is lost is large. [2)e)]

In the case of commercial NGV, it is essential that a fuel price is low and also vehicle economy is excellent. [3)a)]

NGV will not spread unless both a station operator and the transport business have economic benefits. [3)b)]

It is important that CNG prices do not rise above oil prices even temporarily. [3)c)]

It is important to reduce an initial investment of users (especially transport companies). A support for that is necessary. [3)d)]

It takes time to get rid of customers' bad image to vehicles. It is necessary to confirm the quality and reliability of NGV before those are introduced into the market. Losing customer trust can be a major barrier for diffusion. [4)a)]

It is very important to provide attractive products to users. [4)b)]

Efforts to inform users that NGV is attractive need to be made. [4)c)]

Since the business domain was independent for each energy type, the gas industry worked together to carry out NGV development and diffusion activities, and also involved automotive manufacturers, which led to the spread of NGV. [4)d)]

It is necessary to consider the way of spread for passenger NGV and the way of spread for commercial NGV separately. [4)e)]

In conclusion major lessons learned is summarized as follows.

In a free competition market, it is very important to provide attractive products to customers in a timely manner according to the needs of society. If this is not the case, it will be necessary to introduce a strong policy in a regulatory way.

Low blend biofuels

Introduction

In December 1997, the Third Conference of the Parties to the Framework Convention on Climate Change was held in Kyoto, Japan, and discussions on the entry into force of the Kyoto Protocol began. This was an opportunity to foster a domestic use of biofuels to reduce CO_2. The main biofuels examined in Japan are as follows.

> Biodiesel: low concentration biodiesel fuel (raw material: vegetable oil such as rapeseed oil, waste cooking oil, etc.), 100% biodiesel fuel (raw material: same as above)
>
> Bioethanol: low concentration bioethanol / ETBE fuel (raw material: sugarcane, etc.)

However, there were many projects using biofuels that took advantage of the characteristics of the region, and mainly small-scale projects. Assuming that it is used for automobile fuel, which consumes a large amount of energy, there were many issues related to introduction effects, fuel cost, and implementation on actual diffusion. At present, its market share in automobile fuel is currently very low.

In the process of disseminating biofuels, many projects were implemented at the private level in various regions. In addition, many supports were provided to ensure smooth utilization at the national level. During this time, many stakeholders were involved in its development and diffusion. By conducting interviews with these stakeholders, issues related to dissemination, obstacles, and lessons learned were investigated.

Political framework

1) Overview of major laws and regulations

    a) Ministry of Land, Infrastructure, Transport and Tourism
    "Guideline for the Prevention of Vehicle Problems Using High Concentration Biodiesel Fuel" February 10, 2009

    b) Ministry of Economy, Trade and Industry
    + Revision of Act on the Quality Control of Gasoline and Other Fuels, May 2003
    E3, E10, and B5 were defined.
    + Sophisticated Methods of Energy Supply Structures, July 2009
    Bioethanol introduction target was set by crude oil equivalent: 500,000 kL/year, until FY2022

2) Overview of main subsidy programs

a) Ministry of Economy, Trade and Industry
   Subsidy for supporting measures to accelerate the introduction of biofuel, May 2011
   One half of the cost of infrastructure development for biofuel introduction was subsidized.

b) Ministry of the Environment
   Subsidy for Eco fuel promotion, 2007—2010
   One half of the cost of production equipment for biofuel was subsidized.

c) Ministry of Agriculture, Forestry and Fisheries
   +Demonstration project for biofuel local use model, April 2011
   One half of the cost of equipment for biofuel was subsidized.
   + Local biomass utilization grant, April 2007
   One half of the cost of equipment for biofuel was subsidized.

3) Overview of main tax system
   +Exemption from customs duties on import of bioethanol / ETBE (from 2008)
   +Exemption for gasoline tax and local gasoline tax on mixed part from gasoline blended with bioethanol and ETBE (according to mixing ratio, until FY2022)
   +Property tax exemption on biofuel manufacturing plant (1/2 tax reduction, for 3 years)

Collection of insights from relevant stakeholder

Stakeholders involved in the development and diffusion of biofuels were interviewed on issues related to dissemination, promotional barriers, and lessons learned in their activities. The outline of the interview is shown below.

Interview period: November to December 2019

Number of interviews: 4 (3 university professors, researcher: 1)

Each interview time: 1-2 hours

Interview method: a free discussion was held on questions related to dissemination, promotional barriers, and lessons learned in their activities.

The responses obtained from interviewees were compiled into the following five categories based on items proposed in Task 59 text. However, some of the interview results overlapped between some categories.

1) Technical issues / Infrastructure

   a) When 100% biodiesel fuel (BDF) is used in recent diesel engines with common-rail system, dilution of the oil by fuel occurs, leading to an engine failure. For this reason,

studies on mixed diesel fuel with high concentration BDF were conducted. Although it was thought possible to develop automotive technology (on engines, materials, etc.) that uses high-concentration BDF, it was difficult to assure the safety of the material deterioration on the fuel system of conventional vehicles which had already spread to the market. Furthermore, Due to the low possibility of mass diffusion of biofuels because of the high fuel cost, automotive manufacturers felt little interest in technological development. Therefore, the commercialization of high-concentration BDF did not progress.
Issues: The automotive manufacturers' motivation to develop biofuel vehicles was low because BDF was not suitable for existing vehicles and had low prospect of mass diffusion due to higher fuel cost.

2) Politics / Authorities

a) The FIT system started in July 2012 and is a policy for a power company to purchase electricity from renewable energy sources such as solar, wind, hydro, geothermal, and biomass for a certain period, by higher price set by the government. Biofuels and its raw materials have been used for electric power generation using the FIT system, and a use for biofuels has not progressed.
Inhibitory factor:
Since the purchase price of electricity from biofuels in the FIT system is superior to that of biofuel for vehicles, using biofuels for vehicles had economic problems.

b) When an alcohol-blended gasoline was introduced to the market, a vehicle fire occurred caused by a fuel pipe failure, which reason was that the material of the fuel pipe was deteriorated by alcohol-blended gasoline. The quality of the fuel pipe had not been properly checked. It is necessary to confirm the quality and reliability of vehicles using alternative motor fuels so as not to cause a problem in the market. Losing customer confidence in quality is a major obstacle to its spread. This led to the revision of the Act on the Quality Control of Gasoline and Other Fuels / Law Number: Act No. 88 of 1976 (Quality Assurance Law). In this context, the upper limits of ethanol and biodiesel mixed with gasoline and diesel fuel were regulated.

c) The Quality Assurance Law aimed at stably supplying gasoline, diesel fuel and kerosene of appropriate quality and at upholding consumer interests requires that the upper limit of ethanol and biodiesel mixed with gasoline and diesel fuel should respectively be E3 (3%), E10 (10%) for dedicated vehicles using E10 and B5 (5%).

Furthermore, they are said to be "mixable" and are not a mandatory measure to "must be mixed." The introduction was left to the industry because it was not a compulsory law. However, in the case of low-concentration biofuel blending, the cost of producing and the management of two fuels line were high, and the merits corresponding to them were low. As there was little merit, full scale introduction was forgotten.
"Law Concerning the Development and Introduction of Alternative Energy to Oil" (commonly known as the " Alternative Energy Law ", 1980) also states that LPG and natural gas may be "blended" up to 3%.

d) Market and consumer-oriented policies and incentives are needed. It would be effective to be a policy that allows consumers to feel benefits of reducing CO_2, or to use the Olympic Games to make them stand out. The Quality Assurance Law did not motivate consumers to buy biofuels. There were no numerical targets and no penalties for not introducing them.

e) The certification of the Eco-Mark which is a label attached to products that are recognized as having a low impact to the environment was one of the incentives. It is attached to co-ops and other delivery vehicles, but has a good image given to consumers, and is thought to have contributed to its spread.

f) In foreign countries, there are CO_2 reduction credits related to the introduction of electric vehicles (EV), and in some cases, credits are given according to the ratio between EV and passenger cars (the lower the total CO_2 emission rate, the better). Similarly, the system that the use of biofuels leads to a reduction of tax would contribute to their spread.

g) BDF production and utilization, which had been undertaken in Kyoto along with national policy, initially took off on the spread of biofuels due to the strong leader which is the government.

3) Costs / Economics

a) It was assumed that there were problems regarding a current injection system and material in B100 vehicles. Therefore, it seemed that low concentration blending such as B10 had been originally appropriate for BDF vehicles. In the Japanese taxation system, if diesel fuel is blended to biofuel, a total blended fuel is subject to a diesel fuel tax, even if amount of diesel fuel is very small. So, some municipalities have decided to disseminate the B100 vehicles in order to avoid increasing fuel prices. (For bioethanol / ETBE, there is a tax exemption in the blended fuel from 2009) Inhibitory factor: In the case of blended fuel, the entire amount is subject to tax and the cost increases.

b) If existing vehicles use B100, an infrastructure that is different from the existing petroleum fuel infrastructure is required, and high costs are expected. It also takes time to build the new infrastructure. For this reason, the possibility of B100 mass dissemination was small, and the interest of car manufacturers was also small.

4) Consumers / Public

a) Some schools offer opportunities to learn about biofuels. There are many cases where biofuels are used in local governments and companies, but the awareness to the public is not enough. More education is needed.

b) In cases where the B100 was used in construction machines etc., some local companies recognized a reputation that BDF was dangerous.

c) Subcontractors under large oil companies are reluctant to use BDF because of concerns about fuel-related equipment failures and stock issues (they are not readily available in emergencies due to their low stock volume). Even if a BDF mixing equipment is placed on the premises of the station, various measures to consumers such as answers for questions about BDF are required, which is not preferable. Inhibitory factor: Complexity of handling multiple fuel systems on site

5) Country Specific Barriers

a) Biofuels were produced and used in Miyakojima island (E3, E10 from sugar cane), Tokachi area (ethanol production from excess sugar beet, and non-standard wheat), and Osaka area (woody biomass (building waste, etc.)) for the purpose of reducing CO_2 emissions. These were done in the context of local production for local consumption, and regional promotion. In many cases, the supply was small and unstable as it was local projects, and the projects were not suitable for mass introduction.

b) Regarding biofuels, it seemed that the government recognized that there was a problem with mass diffusion, so rather than actively introducing biofuels, regulations were set up so that using non-existing fuels (alternative fuels) would not have any adverse effects. That is to say, taking precautionary measures in standards, etc. was focused on the policy.

c) The FIT system started in July 2012 and is a policy for a power company to purchase electricity from renewable energy sources such as solar, wind, hydro, geothermal, and biomass for a certain period, by higher price set by the government. Raw material for biofuels has been used for electric power generation using the Fit system, and a use for an automotive fuel has not progressed.

d) The spread of biofuels was at the mercy of fluctuations in crude oil prices. At around US $ 80 / barrel in 2006, the petroleum industry and the automobile industry were all expecting the practical application of biofuel production technology. At that time, domestic energy such as unused old rice, minimum-access rice, high-yield rice, waste paper, rice straw, and so on were being turned to ethanol, but the commercialization of biofuels have stalled by decline in crude oil prices.

e) To respond to fluctuations in crude oil prices, the petroleum industry focused on the development of technologies for the production of domestic biofuels from the above-mentioned domestic raw materials (including waste biomass such as garbage, and used cooking oil). The government's incentives for biofuels which cost of raw material was higher were inadequate and did not last long. (Preferential taxation was not enough)

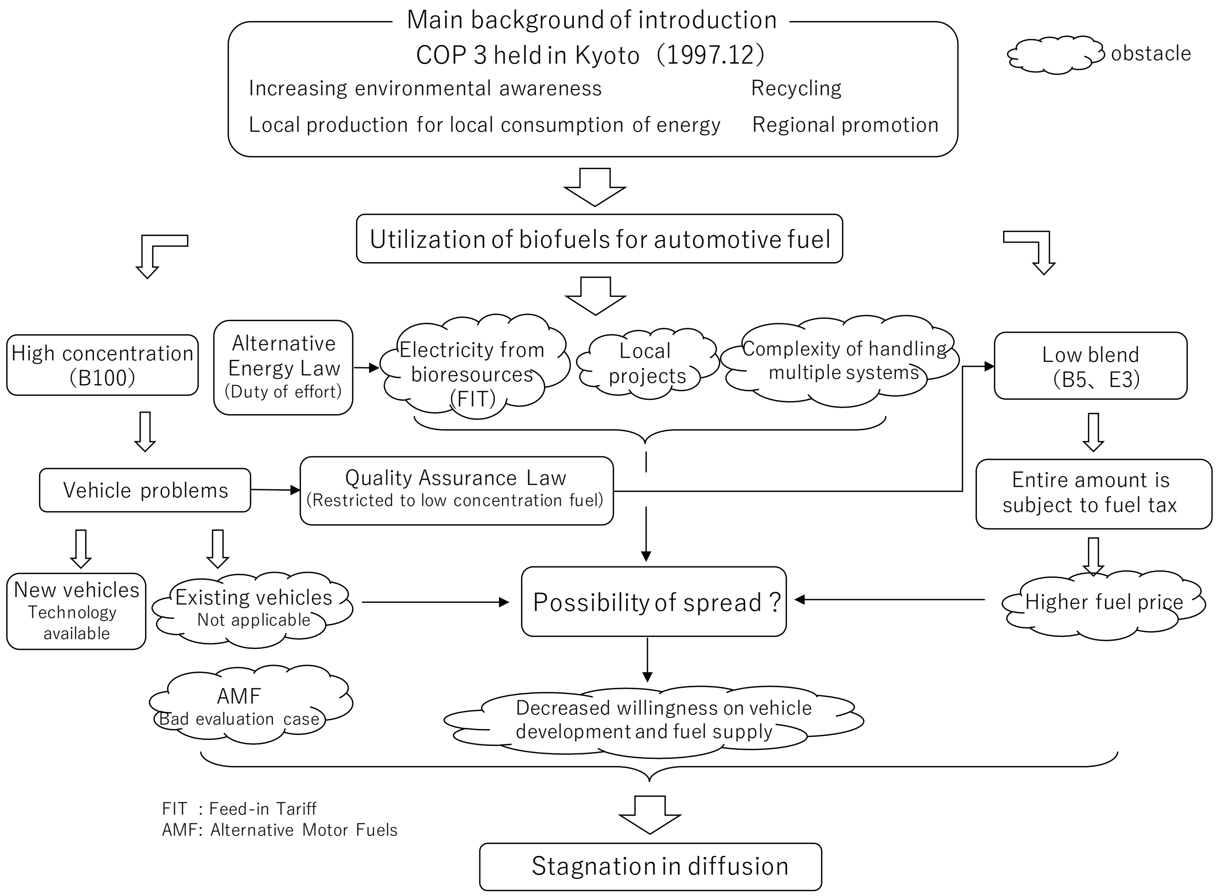

Figure 20: Summary of biofuels dissemination scheme

Based on the responses obtained from the interviews, the above chart shows the main obstacles to the spread of biofuels in Japan.

In Japan, there were no regulations for forcible dissemination of biofuels, and were some laws and supplementary policies to support their dissemination. However, in the face of competition with existing fuels in the free competition market, although some private companies conducted promotion activities in the context of regional promotion and local production for local consumption, the high fuel retail price has been one of the major factors impeding its spread. One of the reasons for an increase in fuel retail prices was the specific tax system in Japan, that is to say, when alternative fuels were blended with petroleum fuel, a tax for petroleum fuels was also applied to the alternative fuels, resulting in higher biofuel prices.

In addition, there were many local projects with a small procurement of raw materials, and it was unlikely that inexpensive biofuels would be mass-produced. It was probable that the stakeholders, such as manufacturers, fuel suppliers, and customers, were not willing to introduce them. Under such circumstances, there was no regulation to forcibly introduce a large amount of biofuels.

As a lesson learned, it is considered that it is difficult to introduce a certain amount of biofuels in the free competitive market in Japan without continuous regulations on the introduction of biofuels.

As a method of promoting diffusion in the free competition market, a policy that costumers can feel that using biofuel (reducing CO_2) will be profitable is considered effective.

Quantification information

To assess the success of the market introduction of biofuels, the amount of bio fuels, the number of vehicles using that fuel, the reduction of GHG, the reduction of emissions, or the reduction in energy achieved etc. were quantified. In addition, if possible, biofuels costs, vehicle market share, and fuel consumption were surveyed.

1) Number of biofuels introduced

Since there is no statistical information on the number of vehicles using biofuel, the amount of fuel introduced is shown in 2) below.

2) Amount fo fuel introduced

The table below shows the annual consumption of automotive fuels in 2018. ETBE made from bioethanol is used as a base material for gasoline. However, the amount is about 0.69% of the fuel for vehicles in equivalent energy.

Table 16: Fuel consumption in 2018

Source: Agency for Natural Resources and Energy; IEA Bioenergy Task 39 (2018)

Automotive fuel	Fuel consumption (2018)		Ratio
All	–	2,726 PJ	100 %
Gasoline	48,846,328 kL	1,630 PJ	59.79 %
ETBE	1,940,000 kL	54.7 PJ	2.01 %
Diesel	25,584,245 kL	973 PJ	35.70 %
LPG	1,323,415 kL	66.3 PJ	2.43 %
Natural gas	44,076 km^3	1.82 PJ	0.07 %

3) Reduction of emissions

Popular information on emissions from biofuel vehicles is shown on the figure below.

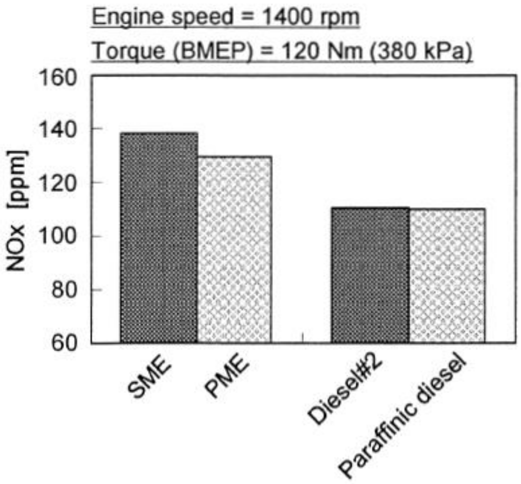

Figure 21: NO_x emissions from biofuel vehicles

Source : JSAE Transaction (2012)

The figure shows test results of NO_x emission with an engine using fatty acid methyl ester derived from soybean oil (SME), fatty acid methyl ester derived from palm oil (PME) (they are referred to as FAME), paraffinic hydrocarbons synthesized from vegetable oil, and conventional diesel fuel. The paraffinic hydrocarbons include hydrotreated biofuel (HVO), and synthetic diesel fuel (BTL: Biomass to liquid) that has been produced by gasifying biomass and synthesizing it by the Fischer-Tropsch method.

If FAME is used as an alternative fuel for diesel vehicles, NO_x emissions is increased with SME and PME. On the other hand, that of paraffinic hydrocarbons are equivalent to diesel fuel.

In case of FAME, it is considered that NO_x can be reduced by adapting the engine conditions. However, for use in conventional vehicles, paraffin-based hydrocarbons such as HVO and BTL that emit the same amount of NO_x and have low PM are preferable.

Also, when using neat biofuels, it is necessary to keep in mind that exhaust emissions may be worse and an after-treatment device may be clogged though they depend on a type of a fuel injection device or a after-treatment device.

FAME, which is an oxygenated fuel, and the paraffinic hydrocarbons HVO and BTL, which are aromatic-free fuels have the advantage of low PM emissions.

4) Reduction of GHG

GHG emissions from biofuels need to be assessed by LCA.

Results of Well-to-Wheel analysis in a JE05 mode operated at a half load using a truck which payload is 4 tonnes on various alternative fuels (hydrogen, methanol, DME (dimethyl ether) and FTD (Fisher-Tropsch diesel fuel), which are produced from woody biomass (cedar wood) are shown on a figure.

In addition, hydrogen shows a case by an internal combustion engine using a 35 MPa H_2 vessel.

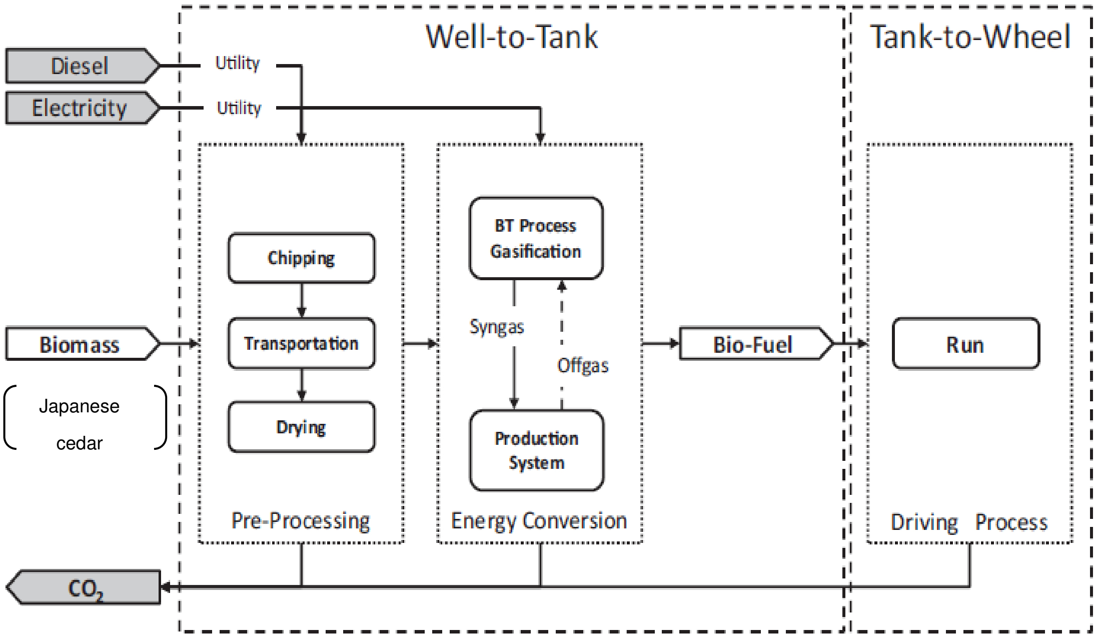

Figure 22 Well to Wheel analysis scheme

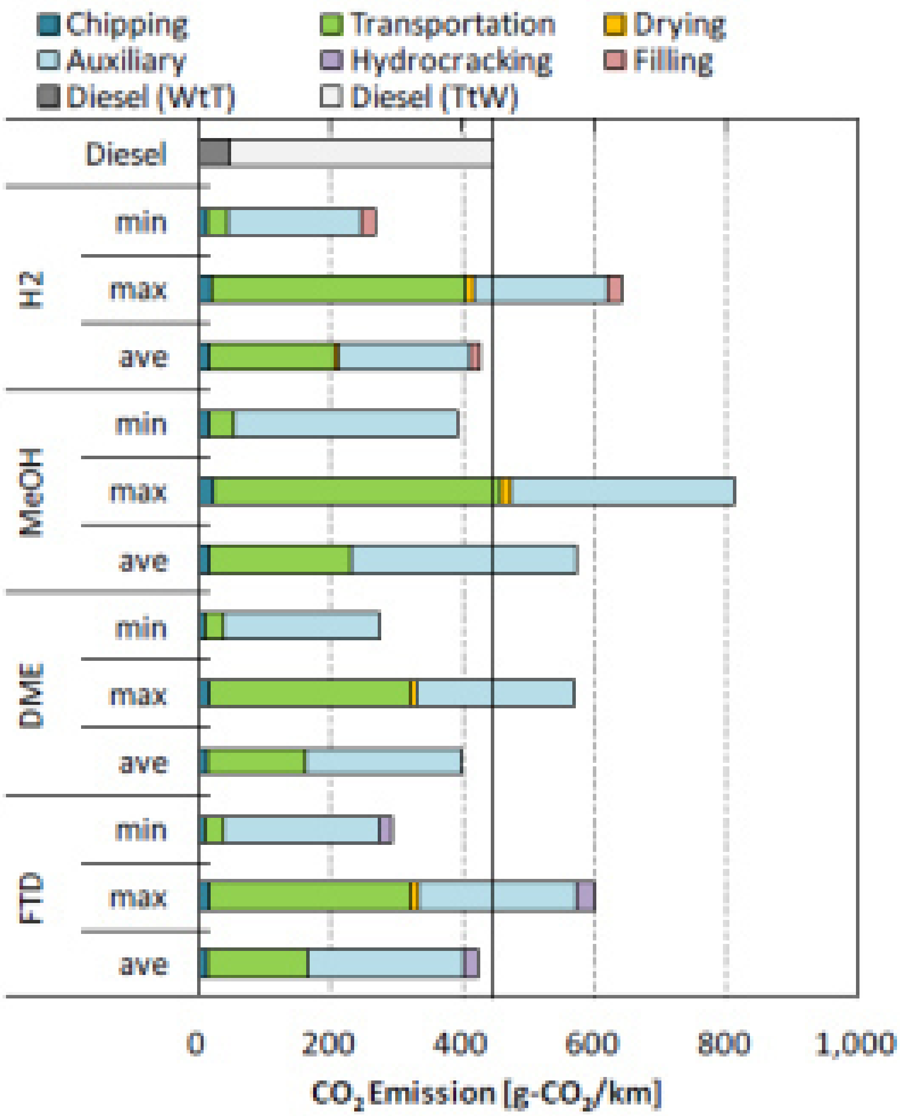

Figure 23: CO_2 emission in various fuels

Source: Journal of Life Cycle Assessment Japan, 2013

Although the difference between the minimum and maximum values is large, CO_2 emission in a case of methanol results in a higher average value than that of diesel fuel. A slight decrease in FTD is shown and a further decrease in hydrogen and DME. In this example, it is described that CO_2 emission is large in the raw material transportation process in Japan.

5) Others

As an example of biofuel prices in Japan, BDF prices produced from waste cooking oil in Kyoto City are shown.

145 yen/L (as of February 2013) diesel fuel 128 yen/L

Source: Kyoto City Homepage

Evaluation

Result of market introduction

The most widespread case is ETBE made from bioethanol for a gasoline base material. However, the amount is about 0.69% of the fuel for vehicles in energy basis, and other cases of market introduction are almost converged, so it cannot be said that it has spread enough.

Estimated factors for market introduction

In December 1997, the Third Conference of the Parties to the Framework Convention on Climate Change was held in Kyoto, Japan, and this was an opportunity to foster the domestic use of biofuels to reduce CO_2 emissions. In addition, it is thought that the momentum of local production and local consumption of energy in the background of recycling of waste cooking oil and of regional development was a factor in the introduction of biofuels to the market.

Country specific situations

Japan has scarce energy resources, and most of it relies on imports from overseas. In order to use biofuels as fuel for automobiles which consume much energy, it is necessary to procure a certain amount of resources stably. Although there is a possibility that a certain amount of biofuel resources can be procured in Japan, there is no system for procurement in large quantities, and it is also hard to import a certain amount of bioresources which worldwide trade is small. Therefore, it was difficult to disseminate it throughout the country.

Measures taken

a. Subsidy for biofuel infrastructure development, manufacturing facilities, etc.

b. Tax incentives

Wrapping

The following summarizes which factors have helped to launch biofuels market and which factors have hindered or should have made efforts more.

Infobox 14: Key drivers of successes and key barriers of failures

Key factors for success and main barriers:

- Main barriers

- Japan relies on imports for most of its energy resources.
- Therefore, in a free competition market, it has been difficult to disseminate biofuels in view of higher cost, difficulty to procure a certain amount of raw material of biofuels, and convenience of its use.

Lessons learned and recommendations

Infobox 15: Case specific lessons learned and recommendations

The lessons learned and recommendations during the interview are summarized as follows. The number in parentheses indicates the item number of the paragraph "Collection of insights from relevant stakeholders" for biofuels.

The diffusion of the alternative motor fuels may be affected by other alternative energy diffusion policies. [2)a)]

It is necessary to confirm the quality and reliability of alternative fuels sufficiently before dissemination to the market. Losing customer confidence in quality is a major drag on adoption. [2)b)]

It would be difficult to disseminate high concentration biofuels unless law that requires the progressive dissemination of high concentration biofuels would be set. In Europe, the blended fuel at 1% began first on a mandatory basis and gradually mixing rate increased. [2)c)]

There is a need for policies and incentives that will benefit consumers if they reduce CO_2. [2)d)]

If there is a credit system for CO_2 emissions from vehicles as one of the incentives for CO_2 emissions reduction, it will lead to the production of vehicles using biofuels. [2)f)]

Lessons learned: Strong governmental initiatives are needed to promote alternative fuels. [2)g)]

In a free competition market, the cost of alternative fuel and the time required for introduction are very important. [3)b)]

It is important to focus on education regarding biofuels to the public. [4)a)]

If correct information on BDF is not passed on to end users, it will be a negative effect of dissemination. [4)b)]

For widespread use it is necessary to procure raw materials, and to supply alternative fuels stably. [5)a)]

Active diffusion policy of the government is necessary for diffusion of biofuels. [5)b)]

The dissemination of alternative motor fuels may be affected by other alternative energy dissemination policies. [5)c)]

The spread of alternative fuels is greatly affected by trends in crude oil prices. [5)d)]

In the case of Japan, incentives to reduce fuel prices for domestic raw materials are important. [5)e)]

In conclusion major lessons learned is summarized as follows.

In a free competition market, cost, supply stability, and convenience of alternative fuels are important compared to conventional fuels.

Sweden

For Sweden the interesting Case Studies identified, described and evaluated are:

- Tax exemption for high blend biofuels and biogas
- Reduction obligation
- Ethanol fuel E85

Tax exemption for high blend biofuels and biogas

Description of Case Study

Energy tax was first introduced in Sweden in the 1950's and was later followed by a carbon tax in 1991 (The Swedish Government, 2017), which is based on the emission of carbon dioxide (CO_2) from the fuel (Svebio, 2019). Historically, the carbon tax has been the main measure steering towards the climate target of 2020 and 2030 in a cost-effective way[55].

Biofuels (low blend biofuels and high blends of biofuel) have been completely or partially exempted from energy and CO_2 tax in Sweden for about fifteen years. In 2018 the reduction for low blends was replaced by a reduction obligation scheme, which is described in a separate case study. High blends of biofuels are still subject for tax reduction.

The tax exemption started as an exemption for pilot-plants for biofuels, like a production support. The purpose was to reduce CO_2 emissions and promote domestic production of biofuels. This drifted towards becoming general tax-exemption (or reduction) for all biofuels [56]. Due to the energy tax directive, which does not allow for a lower tax on biofuels compared to fossil fuels, the tax reduction need approval from the EU. The approval is conditioned by Sweden making sure that the support level is compliant with state aid rules, which in practice means that the tax reduction cannot lead to that the cost of biofuels is lower than the market price for its fossil equivalent. The Swedish Energy Agency reports on the market situation twice a year and if the tax reduction has been too high, the tax needs to be adjusted accordingly. The current tax exemption is approved by the EU until end of 2021 (except for biogas for which the exemption is approved for 10 years). It is uncertain how the high blend biofuels will be handled in the future.

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[55] The Swedish Government, 2017

[56] Lewald, 2019

Table 17 shows the reduction levels for energy taxation from 2015 up until today. As can be seen, the level of reduction has varied during the past years. Currently, all high blend biofuels have a tax exemption of 100 % under the conditions that they fulfill the sustainability criteria for biofuels.

Table 17: Energy tax reduction levels 2015-2019[57]

	2015-01-01	2015-12-01	2016-01-01	2016-08-01	2018-07-01
Low blend ethanol	89%	79%	74%	88%	0%
Ethanol in E85	100%	78%	73%	92%	100%
Low blend RME/FAME	8%	8%	36%	36%	0%
High blend RME/FAME	44%	44%	50%	63%	100%
Low blend HVO and biopetrol	100%	100%	100%	100%	0%
High blend HVO and biopetrol	100%	100%	100%	100%	100%
Biogas	100%	100%	100%	100%	100%

[57] Skatteverket, 2019

In Table 18 the tax exemption for high blend biofuels and biogas in Sweden is summarized.

Table 18: Data concerning tax exemption for high blend biofuels and biogas in Sweden.

	Value	Unit
consumption of fuel (in 2017)[58]	Biodiesel (HVO and FAME): 636 Ethanol: 49 Biogas: 133,220 Total:133,905	1,000 m^3
number of vehicles	See Table 19.	
market share of suitable vehicles**	See Table 19	
GHG savings achieved	1,463,974*	Tons of CO_2-equivalent
local emission savings	N/A	
energy savings	N/A	
production costs of fuel[59]	12.9 – 14.3	SEK/liter petrol or diesel equivalent
Share of domestically produced fuel (2017)[60]	Biodiesel: HVO: 5%, FAME: 6% Ethanol: 16% Biogas: 71%	% Share of the consumption of biofuels in 2017**
*An estimation based on the consumption of fuel above[61] and the emission values form a well to wheel perspective defined by the Swedish Energy Agency[62]. The emissions are based on the assumption that the volume of biofuel replaces a fossil equivalent (diesel for FAME and HVO100 and petrol for ethanol and biogas). ** The share of domestically produced is reported for the biofuel volumes in total, both high-blend and low-blend. It reports the country of origin of the raw material.		

[58] Energimyndigheten, 2019

[59] Energimyndigheten, 2019d

[60] Energimyndigheten, 2019a

[61] Energimyndigheten, 2019

[62] Energimyndigheten, 2019a

In Table 19, the number of vehicles and market share of different categories of vehicle types are summarized. The share of diesel vehicles certified for HVO100 is not known, but is probably quite large as many vehicle producers nowadays (especially for heavy duty trucks but also an increasing share of passenger cars) allow for HVO100.

When it comes to ethanol driven passenger cars the market share is high in comparison to other renewable alternatives. However, in the new sales the share is very low. During 2018 only 1,020 ethanol driven passenger cars were registered, corresponding to a share of 0.3% of the total number of sold passenger cars the same year.

Note that the vehicles can use fossil fuels to a varying extent.

Table 19: The total number of vehicles and market share of each vehicle type suitable for operating with high blend biofuels or biogas[63]

	Passenger cars		**Heavy duty trucks**		**Light duty trucks**		**Buses**	
	Number of vehicles	**Market share**	**Number of vehicles**	**Market share**	**Number of vehicles**	**Market share**	**Number of vehicles**	**Market share**
Biodiesel*	-	-	-	-	-	-	1,365	9.5%
Ethanol	212,385	4.4%	66	0.1%	1,481	0.3%	178	1.2%
Gas	42,463	0.9%	920	1.1%	8,447	1.5%	2,522	17.5%
Total	**254,848**	**5.2%**	**1,141**	**1.4%**	**9,928**	**1.74%**	**4,065**	**28.3%**

*A substantial share of the vehicles, especially heavy duty trucks and buses, are certified for biodiesel (e.g. HVO100). However, there is no statistics available on the share.

63 Trafikanalys, 2019

Evaluation

Infobox 16: Key drivers of successes and key barriers of failures for the tax exemption

Key drivers

- A clear political ambition with targets to reduce the climate impact and be a country that leads the way in phasing out fossil fuels.
- Potential for domestic production of climate efficient biofuels with raw material from forestry and agricultural sector (waste and by-products).
- Political unity for promoting biofuels due to their contribution to (i) GHG reduction targets, (ii) regional development (job creation) and (iii) energy security (in this order).

Key barriers/failures

- The short-term perspective create uncertainty in the market and limits the domestic production of fuels.
- No incentive for promotion of new biofuel technology options
- Decrease in tax revenue due to an increased volume of biofuels

Lessons Learned

The tax reduction for high blend biofuels and biogas in Sweden has probably been a prerequisite for research, development and demonstration projects to take place in Sweden during the past couple of decades. The subsidies for high blends have been a signal to the market that there is a political ambition to create a market for biofuels. However, the effect on increased production of advanced biofuels in Sweden on a larger scale has not been seen yet[64]. This can partly be explained by the short-termism of the system.

However, the tax reduction has had a strong effect on the use of biofuels. This policy instrument has also provided strong support for the diffusion of mature biofuels options (including HVO).

The EU Energy Tax Directive does not in general allow for tax reduction/exemption for biofuels. However, through approvals from the EU, given for a couple of years at the time, Sweden has been allowed to use the support system under the condition that the country can show that the support does not over-compensate the fuel producers and suppliers. The question of over-compensation is problematic. This has created an insecurity in the market[65] where the tax regulations can be changed on short notice if the subsidy is too high.

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[64] Hansson, Hellsmark, Söderholm, & Lönnqvist, 2018

[65] Riksrevisionen, 2011

An analysis made by the Swedish National Audit Office (SNAO) in 2011 concluded that the tax exemption has been a relatively expensive way of steering the use of fuel towards renewable alternatives. The cost is not considered reasonable according to the study, but it also states the tax reduction has been necessary in order to create a market for low-blend for biofuels. The analysis also states that the tax reduction has not been technology neutral, in the sense that the reasons for granting a tax relief has varied. In addition, it has not had a significant effect on technology development since it mainly has led to low-blend biofuels and thereby not development of new fuels[66].

Infobox 17: Case specific lessons learned and recommendations for the tax exemption

- Long-term policy instruments and high ambitions for the total reduction of GHG emissions in the transport sector are a key for creating the right prerequisites for a biofuel market.
- This policy instrument did not seem to have had any significant effect on technology development and increased domestic production of advanced biofuels. Thus, supplementary policies specifically promoting domestic biofuel production of advanced biofuels are needed.
- Tax exemption/reduction initiated the introduction of biofuels in Sweden and contributed to a relatively large introduction (compared to other EU countries) mainly in terms of low-blend biofuels but also high-blend biofuels thus supporting several different biofuels.
- The drawbacks of the tax exemption/reduction in Sweden is that
    - (i) it did not represent a long-term policy,
    - (ii) is relatively expensive for the government,
    - (iii) it was not technology neutral,
    - (iv) did not differentiate between fuels of the same kind with different raw materials and their relative GHG impact and
    - (v) did not clearly lead to technology development for new biofuels.
- The price of the biofuel compared to fossil options and dedicated vehicle is crucial for successful implementation.
- Local and regional incentives are important for the introduction of advanced biofuels.
- A package of policies promoting biofuels and innovation is needed to achieve success. The mix should include policies addressing both research & development, demonstration, up-scaling and diffusion of advanced biofuels and consider production, use, infrastructure and sustainability criteria. However, a main policy instrument e.g., a reduction obligation or quota system is crucial for the development. In order to specifically support dedicated fuels and vehicles it is particularly crucial with policies for vehicles and infrastructure.

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[66] Riksrevisionen, 2011

Reduction obligation

Description of Case Study

The reduction obligation for road transport was introduced in Sweden on the 1st of July 2018. It requires fuel providers to reduce the emissions of greenhouse gases (GHG) from petrol and diesel every year with a certain percentage. This policy instrument is an on-going measure to ensure that the goal of reducing the emissions of GHG from the transport sector is achieved by 2030. The obligation replaces the tax exemption for low blend biofuels while tax exemption/reduction still applies for high-blend biofuels, at least until the 31st of December 2021, as mentioned above. The reduction obligation is thought to represent a more long-term policy solution than tax reductions and aims to contribute to the production of biofuels with lower climate impact.[67]

The reduction obligation separates gasoline and diesel and the current proposal (spring 2021) from the government is that the levels will increase successively to 2030, see Table 20. All biofuels need to fulfil the EU sustainability criteria. Suppliers not fulfilling the reduction obligation will be subject to a duty fee. The reduction of GHG for a specific biofuel is calculated by comparing the climate impact (from a life cycle perspective) of the fuel with a fossil counterpart. The system is calculated to increase tax revenue by 560 million SEK in 2020[68] compared with the tax exemption which costed approximately 6 210 million SEK in 2016[69].

Table 20: Required level of reduction in GHG emissions for the reduction obligation for diesel and petrol respectively, from a well-to-wheel perspective[70]

År	Bensin	Diesel
2020	4,2	21
2021	6	26
2022	7,8	30,5
2023	10,1	35
2024	12,5	40
2025	15,5	45
2026	19	50
2027	22	54
2028	24	58
2029	26	62
2030	28	66

67 Energimyndigheten, 2019c

68 The Swedish Government, 2017

69 Regeringskansliet, 2017

70 Sveriges Riksdag, 2017

Table 21 summarizes information on the reduction obligation in Sweden.

Table 21: Data concerning reduction obligation in Sweden

	value	unit
consumption of fuel (2018)	7,050 (the sum of biofuel energy content in petrol and diesel in 2018)	GWh (2018)
number of vehicles	See Table 19.	
market share of suitable vehicles	See Table 19	
GHG savings achieved	See Table 20	
local emission savings	N/A	
energy savings	N/A	
production costs of fuel	12.3 – 15.7 (Energimyndigheten, 2019d)	SEK/liter petrol or diesel equivalent excl taxes
quantity of produced fuel in the country	Biodiesel: HVO: 5%, FAME: 6% Ethanol: 16% (Energimyndigheten, 2019a)	

Evaluation

Infobox 18: Key drivers of successes and key barriers of failures for the reduction obligation

Key drivers

- A clear political ambition with targets to reduce the climate impact and the need for a more long-term framework to reach the targets.
- Potential for domestic production of climate efficient biofuels with raw material from forestry and agricultural sector (waste and by-products).
- Political unity for promoting sustainable biofuels and in particular to promote biofuels with relatively low GHG emissions in relation to the production cost.
- Decrease in tax revenue due to an increased volume of biofuels when using the tax exemption as a support system
- A quota or reduction obligation system was a solution that several other EU-countries had chosen.

Key barriers/failures

- A more complex policy compared to the tax reduction
- The reduction quota is still fairly short-term since there is no long-term target levels decided yet (the current proposal from the government with targets up to 2030 has however potential to create a more long-term system)
- Still unclear if the reduction quota will be enough to promote the diffusion and distribution of new promising biofuel technology options or if specific policies for promoting domestic biofuel production of advanced biofuels are needed.

Lessons Learned

So far, the reduction obligation seems to be working as planned and none of the suppliers has missed the reduction target yet, thus, it has been effective in achieving the target[71].

The reduction obligation is effective in steering towards the use of fuels with the lowest climate impact in relation to the production cost. The obligation provides a strong incentive for the diffusion of mature biofuels options with relatively high GHG performance (based on prioritized biofuels in RED)[72]. However, the effects on up-scaling biofuel reduction is, so far, low. The system will probably not be enough for the technology development needed for introducing cellulosed based biofuels in large-scale and therefore supplementary incentives

[71] Energimyndigheten, 2019c

[72] Hansson, Hellsmark, Söderholm, & Lönnqvist, 2018

will be needed[73]. The obligation also seems to have increased the focus on drop-in fuels and decreased the interest in high blend biofuels within research, development and demonstration.

The reduction obligation is both “a floor” and “a ceiling” for the biofuel use. The suppliers of biofuels do not have an incentive to increase the volume of renewable fuel to a higher level than what is required by the reduction obligation system[74]. The obligation has also affected the market for high blend biofuels, especially HVO100. After the introduction of the obligation in mid 2018, the price of HVO100 increased significantly and the volumes decreased, see figure 1, even though there were no changes in the policy for HVO100. One explanation could be that fuel suppliers reduced their sale of HVO100 in order to ensure available HVO for the low blend necessary to fulfill the reduction obligation[75]. Another reason could be the lack of competition on the market, with one large market-leader being very dominant on the HVO100 market. Due to the very interconnected markets, it has been discussed to include HVO100 within the obligation system. However, so far HVO100 is separated from the obligation system.

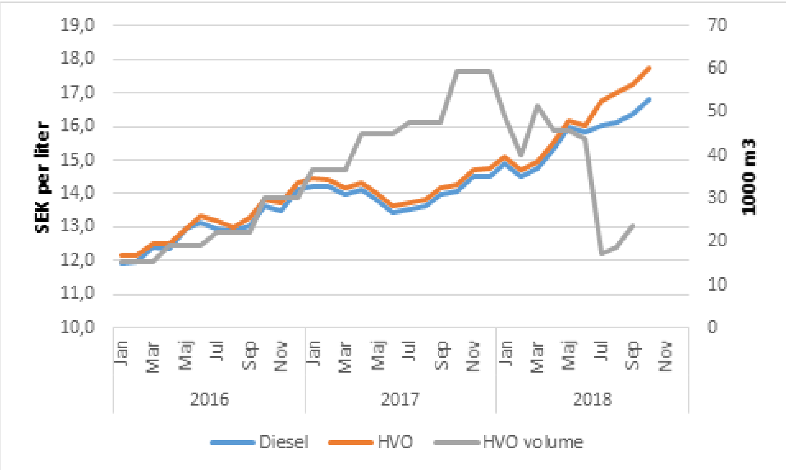

Figure 24: Pricing on diesel and HVO100[76] and volumes of HVO100 respectively[77]

[73] Hansson, Hellsmark, Söderholm, & Lönnqvist, 2018

[74] Fagerström, Anderson, & Lindblom, 2019

[75] Energimyndigheten, 2019d

[76] Preem AB, 2018

[77] Statistiska Centralbyrån, 2018

Infobox 19: Case specific lessons learned and recommendations for the reduction obligation

- High ambitions for the total reduction of GHG emissions in the transport sector are a key to create the right prerequisites for a biofuel market.
- So far, the reduction obligation does not seem to have had any significant effect on technology development and increased domestic production of advanced biofuels. Still unclear if the reduction quota will be enough to promote the diffusion and distribution of new promising biofuel technology options in Sweden or if specific policies for promoting domestic biofuel production of advanced biofuels are needed.
- The reduction obligation will specifically promote biofuels with low GHG emissions in relation to their prices, but it is too early to assess the actual effect. The policy instrument gives no incentive to further increase the reduction above the level required.
- The reduction obligation provides clear guidance towards reduced CO_2 emissions from fuel use which is the overall target and is less costly for the government than tax exemption/reductions.
- The reduction obligation might decrease the willingness to invest in pure biofuels.
- A reduction obligation (or quota system) may represent the main policy instrument promoting biofuels but need to be supplemented by other policies.
- The reduction obligation is a more complex system than tax reduction

Ethanol fuel E85

Description of Case Study

Ethanol fuel can be used in different blends, the focus for this case study is E85 for passenger cars and light duty vehicles which consists of 85% ethanol and 15% petrol. During winter the share of petrol is increased to 25% in order to improve the cold start characteristics of the vehicle[78]. A combined portfolio of different support systems was the reason for growing production and use of ethanol in Sweden in the mid 1990’s. The tax reduction was one driver, but other support systems like the “Pump Act”, reduced benefit value for company cars, reduced vehicle tax for “green” cars (environmentally friendly vehicles), green-vehicle-bonus as well as local initiatives such as free parking for “green” vehicles and “green”-taxis at Arlanda Airport, created the growth of the market. In the same way, the quick removal of some support systems had a strong opposite effect and led to the

[78] SPBI, 2019

volumes leveling out during the 2010's[79].

The so-called Pump Act (introduced in 2006) regulates that every filling station, above a certain annual level of fuel sold, must provide at least one renewable fuel. The regulation as such was technology-neutral, but the result was a large increase in availability for E85 pumps in Sweden, as this was the cheapest solution for most fuel suppliers. The regulation was later complemented with a support system for biogas fuel infrastructure.

The reduced benefit value for company cars, which promoted for example E85 cars, was introduced in 2002. For vehicles running on high blends of biofuel the value was reduced with 20% up to a maximum value of 8,000 SEK per year. The specific incentive for E85 cars was removed in 2012.

In 2006, a reduction in vehicle tax for vehicles running on high blends of biofuels like ethanol or biogas was introduced. In 2018 this was replaced by the current bonus-malus vehicle tax system. In both schemes, the tax is based on the emission of carbon dioxide from the vehicle.

The green-vehicle-bonus was 10 000 SEK for individuals who purchased a "green-vehicle" during 2007 to 2009. In terms of ethanol, the definition of "green" was a vehicle using renewable fuel with a consumption below 0.92 liter petrol/10 km[80].

One example of a local measure to promote ethanol cars was the requirement set by Arlanda Airport (Stockholm), that only "green taxis" were allowed to enter the airport area. Prior to this, environmentally friendly vehicles had a priority at the airport but this was changed to an exclusive access in 2007. There have also been local initiatives in municipalities and regions, e.g. free parking for green vehicles in the city of Gothenburg and exemption from congestion tax in Stockholm for certain time periods[81].

In

[79] Kastensson & Börjesson, 2017

[80] Kastensson & Börjesson, 2017

[81] Kastensson & Börjesson, 2017

Table 22 the data concerning E85 is summarized for the years 2011 and 2018. The two years are chosen to show the decline in E85 use.

Table 22: Data concerning E85 development in Sweden

	2011	2018	unit
consumption of E85[82]	220	49	1,000 m^3
number of vehicles[83]	Passenger cars: 218,000	212,000	Vehicles
	Buses: 850	200	
	Heavy duty trucks: 30	70	
	Light duty trucks: 1,600	1,500	
market share of suitable vehicles[84]	Private cars: 5.0	4.4	%
	Buses: 5.9	1.2	
	Heavy duty trucks: 0	0	
	Light duty trucks: 0	0	
GHG savings achieved	1,009,925 (in 2011)		Tons from a well-to-wheel perspective*
local emission savings	Not known		
energy savings	Not known		
production costs of fuel[85]	14.3		SEK/liter petrol or diesel equivalent
quantity of produced fuel in the country[86]	16%		
	* Calculations are based on the volumes in "Consumption of fuel" and emission factors from a well to wheel perspective in the following source[87]		

[82] Energimyndigheten, 2019

[83] Trafikanalys, 2019

[84] Trafikanalys, 2019

[85] Energimyndigheten, 2019d

[86] Energimyndigheten, 2019a

[87] Energimyndigheten, 2019a

Evaluation

Infobox 20: Key drivers of successes and key barriers of failures for E85

Key drivers

- A clear political ambition with targets to reduce the climate impact
- Potential for domestic production of climate efficient biofuels with raw material from forestry and agricultural sector (waste and by-products).
- Political unity for promoting biofuels due to their contribution to (i) GHG reduction targets, (ii) regional development (job creation) and (iii) energy security (in this order).
- Other drivers include domestic vehicle manufacturers that started to build E85-vehicles. There was thereby a demand to support these vehicles, fuels and infrastructure.

Key barriers/failures

- The short-term perspective created uncertainty in the market
- The pricing of E85 not always lower than the fossil option, leading to use of fossil fuels instead of E85 to some extent.
- Uncertainty from consumers concerning the sustainability of ethanol and whether ethanol causes engine technical problems or not.
- Relatively rapid removal of policy instruments and incentives
- Sweden relatively alone in promoting E85 (at least in the EU).

Lessons Learned

Ethanol made a relatively quick entry on the Swedish market. It was to a large extent made possible thanks to a combination of political measures; the tax exemption for high blend biofuels, the Pumping Act securing infrastructure for renewable fuels whilst the reduced benefit value for company cars and reduced vehicle tax supported the introduction of vehicles. However, the removal of the same support systems led to the development leveling out.

Policies for the introduction of E85, except the tax exemption/reduction (discussed earlier), do not seem to have had any direct significant effect on research and development or demonstration of advanced biofuels in Sweden[88]. However, the policies have had a strong effect on the diffusion of E85 in Sweden including vehicles and increased use while a relatively low effect on the up-scaling of biofuel production.

The Pump Act was introduced in 2006. Prior to the introduction of the so-called Pump Act all

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[88] Hansson, Hellsmark, Söderholm, & Lönnqvist, 2018

agencies and affected bodies were questioning the policy which was in many aspects a political compromise. From the beginning this policy was introduced in combination with other policies but is today almost the last one standing of the implemented policies for E85. The measure as such was technology neutral but led to a large establishment of fuel stations for high blends of ethanol in this case E85, since these solutions were the cheapest alternative for the filling stations. This had a positive effect since it led to a rapid growth of infrastructure with filling stations. However, few other alternatives than E85 was favored by the policy (and a specific policy supporting pumps for other fuels was introduced). The prior apprehension that the measure would lead to “death of filling stations”, due to the economic burden of providing a renewable fuel, was not as extensive as anticipated[89].

Studies and surveys with E85 vehicle-drivers have shown that the price, of both the fuel and the vehicles, was an important motivating factor when choosing a vehicle running on E85. The volumes of ethanol continued to grow as long as the price of E85 was lower than petrol. This was a larger motivator than the environmental reasons for choosing E85. The price of the fuel and vehicles were to a large extent controlled by policies[90].

There was also a discussion in Sweden regarding ethanol’s sustainability. Different experts, scientists, politicians etc. were questioning the use of ethanol in the transport sector. The discussions regarding competition between food and fuel production was extensive, which now is further regulated through EU-regulations for sustainability criteria for biofuels. These define the share of biofuels from agricultural crops and the inclusion of indirect land use change-factors. Media also played a role in how the fuel was perceived in terms of sustainability. Although, studies have shown that the media’s “branding” of ethanol did not influence the abatement of E85 for consumers as much as the pricing compared to petrol. However, the image of E85 as questionable still is present[91].

When the company car benefit was removed in 2012 this was interpreted as a signal from politicians that E85 might not be a sustainable alternative. With different opinions concerning the sustainability of ethanol spread by different experts, the removal of the tax benefit became a signal that E85 was no longer prioritized by policy makers[92].

The experience from E85 in Sweden also states that technical issues in the vehicles is an

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[89] Kastensson & Börjesson, 2017

[90] Kastensson & Börjesson, 2017

[91] Kastensson & Börjesson, 2017

[92] Kastensson & Börjesson, 2017

obstacle where vehicle manufacturers have a responsibility. Studies have shown that the rapid implementation of E85-vehicles on the Swedish market led to the introduction of vehicle models that weren't technically fully developed for widespread introduction.

In recent EU regulation there is also to some extent a larger focus on energy efficiency and electrification as well as in infrastructure for electricity and hydrogen.

Infobox 21: Case specific lessons learned and recommendations for E85

- Long-term policy instruments and high ambitions for the total reduction of GHG emissions in the transport sector are a key to create the right prerequisites for a biofuel market.
- Political instruments and incentives promoting use, vehicles and infrastructure enabled a fast introduction and expansion of E85. For example, there was
  - a rapid increase in available infrastructure,
  - a range of available vehicle models,
  - Economically competitive pricing of the fuel and vehicles (at times)
- Relatively rapid removal of policy instruments and incentives lead to loss of legitimacy for E85. This in combination with other factors led to the reduction in E85 use including
  - Not always favorable pricing of E85 in relation to fossil option
  - Technical issues with vehicles
  - Media exposure discussing the sustainability of the fuel, for example in terms of competition between fuel and food production but also linked to the GHG performance.
- The Pump Act was efficient in creating infrastructure for biofuels in the entire country however despite the technology neutral design, mainly one type of fuel (E85) was promoted.
- The price of the biofuel and dedicated vehicle is crucial for successful implementation. For dedicated vehicles it is also important to avid technical problems.
- Local and regional incentives are important for the introduction of advanced biofuels.
- A package of policies promoting biofuels and innovation is needed to achieve success. The mix should include policies addressing both research & development, demonstration, up-scaling and diffusion of advanced biofuels and consider production, use, infrastructure and sustainability criteria. In order to specifically support dedicated fuels and vehicles it is particularly crucial with policies for vehicles and infrastructure.

Evaluation of market introduction

For each case study, the drivers for the market implementation, the country-specific circumstances, and lessons learned are identified. The assessment is based on literature review and input from biofuel policy experts.

What were the drivers for the market implementation?

The largest driver for the market implementation of biofuels is the overall political ambition to build a sustainable society where the environmental issues at large have been solved for coming generations. The ambition is that Sweden will be a fossil-free welfare country. In order to achieve this, Sweden needs to cut the dependency on fossil fuels. There are mainly three strategies for this; (i) through a more transport effective society (where e.g., unnecessary trips are avoided), (ii) a shift towards more energy and carbon efficient modes and (iii) increasing the share of renewable and low carbon alternatives[93]. Today domestic transport accounts for almost a third of the national emissions of CO_2. Road traffic is responsible for 95% of these emissions, of which passenger cars accounts for two-thirds[94].

In 1999, Sweden adopted 16 environmental goals, which includes goals regarding reduced emission of GHG and cleaner air. They are the basis for all national environmental commitments and is the motivator behind many initiatives.

A climate act was approved in 2017 with a long-term goal set for by 2045. The goal is that Sweden will have no net emissions of GHG, specified as a reduction of 85% compared to the levels in 1990. The remaining emissions is to be compensated through supplementary measures such as absorption of CO_2 in forest and soil, emission reductions outside of Sweden's borders and CCS-solutions (Carbon Capture and Storage solutions). For domestic transport (excluding aviation) the goal for 2030 is to reduce emissions by 70%, compared to 2010.

Tax exemption for high blend biofuels

The drivers behind the Swedish tax exemption for biofuels was initially the potential for reduction of CO_2 emissions from the transport sector, but also to promote domestic production of biofuels. The domestic production of high blends biofuels was considered to need specific support due its higher cost. There were also vehicle manufacturers investing in the development of vehicles using high blends of alternative fuels with a desire of reduced costs for the customer for these renewable fuels[95].

Reduction obligation

The main driver for the reduction obligation was the need for a long-term framework to reach the targets for reducing the CO_2 emissions from the transport sector. With the previous tax

[93] Energimyndigheten, 2019c

[94] Fagerström, Anderson, & Lindblom, 2019

[95] Fagerström, Anderson, & Lindblom, 2019

reduction for low blends, the decrease in tax revenue due to increasing volumes of biofuels led to a discussion on alternative policies. In addition, the short-term perspective for the tax reductions, due to the approval process within EU, resulted in an uncertainty for producers, suppliers and consumers. A quota or reduction obligation system was a solution that several other EU-countries had chosen[96].

E85

The drivers behind support systems for E85 was more or less the same as for the tax reduction for high-blend biofuels.

What were the country-specific circumstances?

Sweden has tried to reduce oil dependency for a long time. After the oil crisis in the 1970's, the government introduced different measures to reduce the oil use for heating, including an extensive establishment of district heating[97]. Heat and power production in Sweden are almost completely fossil free through hydropower, nuclear power and combined heat and power from biomass and waste[98].

Sweden has several vehicle manufacturers including Volvo Cars, AB Volvo and Scania. In the development of new vehicles for renewable fuels these companies can have an advantage if there is an available domestic market in order to test and develop new products.

A large access to biomass for biofuel production has also resulted in a range of initiatives within production of biofuels such as ethanol and biogas, for which Sweden has been regarded as one of the pioneers. There is also a large forestry and agricultural industry that can supply raw material for fuel production. Despite these conditions only a fraction of the biofuel used in Sweden today is domestically produced. 84% of the total amount of ethanol used in Sweden 2016 was imported, and only 3.8% of the total amount of HVO used was produced in Sweden[99].

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[96] Energimyndigheten, 2019c

[97] Gullberg & Ingelhag, 2017

[98] Energimyndigheten, 2019b

[99] Energimyndigheten, 2018

Summary of Lessons Learned and recommendations for Sweden

In order to reach an effective policy system for biofuels several important conditions have been identified. It is crucial with long-term policies for biofuel and clear ambitions for the reduction of GHG emissions in the transport sector. This is a key factor for all the involved stakeholders: fuel producers, fuel providers, vehicle manufacturers, consumers etc. in order to increase the willingness to invest in the solution. In particular, the lack of long-term political decisions is what has prevented a more progressive development of biofuels production in Sweden, not limitations in technology development, according to the Swedish biofuel industry actors[100]. The removal of a subsidy is also an important signal, which affects the view of the fuel and can create skepticism from stakeholders when implementing new policies in the future, since there is an insecurity in whether or not the new policy is here to stay for a longer period of time[101].

There is a need for a mix of different policies to complement each other in order to promote innovation and an effective introduction of biofuels with low GHG emissions. The mix should include policies addressing both research & development, demonstration, up-scaling and diffusion of advanced biofuels and consider production, use and infrastructure[102]. However, one overall key policy is crucial. From a theory perspective, a CO_2-tax would be preferable but in reality, reduction or quota obligations are more feasible. The key policy needs to be supplemented by other policies. In Sweden the reduction obligation represents the overall key policy that is supplemented by other policies. This policy supports biofuels with high GHG reduction performance[103].

Thus, policy instruments have a better turn-out if they are designed as “package of policies”, supporting different areas of the value chain for a renewable fuel. It needs to steer the implementation of vehicles and infrastructure as well as the usage of biofuels in order to be successful. This was the initial motive in Sweden but different policies have been reviewed for different reasons[104]. One experience is that the pricing of both the fuel and the vehicle has to be in favor compared to the fossil alternative in order to succeed, yet this is partly hindered by the EU directive on energy tax, liming the possibility of setting the CO_2 tax to

[100] Grahn & Hansson, 2015; Ekbom, 2019

[101] Kastensson & Börjesson, 2017

[102] Hansson, Hellsmark, Söderholm, & Lönnqvist, 2018

[103] Furusjö & Lundgren, 2017

[104] Kastensson & Börjesson, 2017

zero for biofuels. The pricing level is to a large extent controlled by policies[105].

In addition to EU policies such as the renewable energy directive (RED), Sweden has and has had several different national policies stimulating the production and use of renewable fuels for transport, as well as policies for associated vehicles. Some of the Swedish biofuel polices have overlapped with other national biofuel policy instruments in use in the same time, potentially reducing their individual effectiveness[106]. Since the mix of policies and specific design of the different policies influences the effect, national biofuel policies must be better coordinated. There is also a need to strengthen the knowledge and research linked to policy assessments and implementation.

It can also be important with policies steering towards domestic production of fuels, for which none of the above-mentioned subsidies have been particularly successful. The subsidies mainly support the usage and expansion of infrastructure and give no incentive for domestic production[107]. To increase the domestic production of biofuels it is important that national ambitions for industrialization linked to biofuels and biorefineries are clarified and not only vaguely included and "hidden" in the general climate policy. There is likely a need for specific instruments promoting domestic biofuel production of advanced biofuels such as off-take guarantees, or a specific prize premium[108].

Another documented effect in the development of the use of biofuel driven passenger cars is that many of these vehicles, which are subject to subsidies at the time of purchase, are exported to other countries after a few years. This is particularly prominent for gas driven vehicles but also occurs for electric vehicles and chargeable hybrids (which has increased in recent years). This is a small amount compared to the total number of vehicles but can potentially have a large impact if it continues[109].

There have also been goals and investments on local/regional level that have been important for the development. One example is the regional commitment to use biogas as a fuel in public transport in Skåne (a region in southern Sweden) which led to investments in biogas production and upgrading. This large possible offset provided a security for producers

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[105] Kastensson & Börjesson, 2017

[106] Grahn & Hansson, 2015

[107] Ekbom, 2019

[108] Hansson, Hellsmark, Söderholm, & Lönnqvist, 2018

[109] Trafikanalys, 2017

and made the fuel available also to passenger cars[110]. The demand from passenger cars alone would be too small to motivate the investment. The interest from the regional public transport is now shifting more towards electrification and the effect of this transition should be assessed.

To summarize, political policies are crucial for the introduction of renewable fuels in the transport sector. It is difficult to isolate the effect on one specific measure. Rather, it has to be analyzed in the context of other policy instruments on a national and EU level where they create the conditions in which the result will be given. It is necessary with a system that supports all parts of the value chain in order to achieve large scale transition.

For Sweden some lessons learned and recommendations can be created from the examined case studies. These points are listed summarized in the infobox and are divided into following subjects: politics, stakeholder involvement, measures, general public, technology, future transport system.

Infobox 22: Lessons Learned and recommendations for Sweden

Politics:

There is a need for a mix of different policies to complement each other in order to promote innovation and an effective introduction of biofuels with low GHG emissions. The mix should include policies addressing both research & development, demonstration, up-scaling and diffusion of advanced biofuels and consider production, use and infrastructure.

Stakeholder involvement:

It is crucial with long-term policies for all the involved stakeholders: fuel producers, fuel providers, vehicle manufacturers, consumers etc. in order to increase the willingness to invest in the solution

Measures:

There is a need for a mix of different policies to complement each other in order to promote innovation and an effective introduction of biofuels with low GHG emissions

General public:

Pricing is an important element toward the general public. Pricing of both the fuel and the vehicle has to be in favor compared to the fossil alternative in order to succeed.

Future Transport System: It is necessary with a system that supports all parts of the value chain in order to achieve large scale transition.

[110] Anderson, Westling, Hising, & Yelistratova, 2018

USA

For the USA three Case Studies were identified, described and evaluated:

- Ethanol
- Methanol
- Natural Gas

Ethanol

Introduction

The circumstances of the introduction of advanced motor fuels and the factors influencing their commercialization (resource, transport infrastructure, economic situation, etc.) in each country are different. This section discusses the U.S. experience with ethanol as a component of the transportation fuel supply, acknowledging its benefit as a renewable fuel, a potentially net-zero carbon fuel, and its favorable properties for reducing air pollutant emissions and enhancing motor fuel octane number.

Background and Objective of Early Use and Policies for Fuel Ethanol

In the U.S., ethanol as a fuel for vehicle propulsion developed along a pathway somewhat parallel to that of electric propulsion in its early years. No one fuel in the automobile's early era was identified as superior, and there were many competing candidates. In fact, gasoline was initially considered merely a low-value co-product of kerosene production (kerosene being important for home lighting and heating) in the beginning of the 20th century. Moreover, recognizing its beneficial properties for spark ignition combustion, Henry Ford had designed the first Model T to run on ethanol; but by the second decade of the 20th century alcohol (and electricity) had lost out to lower-cost gasoline as the preferred automotive fuel[111], as the energy density and power superiority of gasoline became apparent. Subsequently, ethanol as an additive came to fill the role of engine knock reducer and fuel octane enhancer.

In 1918, Prohibition (18th Amendment to the U.S. Constitution) limited access to even denatured alcohol and opened up the opportunity for the Ethyl Corporation to increase market share for its tetraethyl lead knock reduction additive. By the 1970s, Ethyl® was the premium standard for octane enhancement of high-performance fuel. However, during the era of the "oil crisis" (1973-1983), the call for "energy independence" created a market for the so-called gasohol, a mixed blend of gasoline (usually 90% by volume) and domestically produced ethanol. The role of

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[111] Stolark 2016

gasoline as a significant contributor to the ambient precursors of ground-level ozone (reactive hydrocarbons [HC] and nitrogen oxides [NO_x]) was not a factor in national pollution control regulations until 1969.

In 1973, lead phase-out from gasoline began (later codified in 40CFR80.22), responding to both lead's established negative health effects (especially to developing human brains) and the fact that lead contamination from gasoline would render the new oxidizing catalyst technology for emissions control. By 1996, federal fuel regulations essentially banned lead from gasoline in on-road vehicles. Over the years, petroleum refiners incorporated other octane-enhancing compounds into gasoline, but these were eventually rejected, for reasons discussed below.

History of Policies, Incentives, Regulations and Mandates

The lead phase-out, coupled with the development of the catalytic converter as the principal means of controlling carbon monoxide and reactive HC (and later, NO_x) emissions from vehicle engine combustion, re-opened the market for fuel oxygenates, as well as aromatics such as benzene, as octane boosting additives. Oxygenates were also touted as an exhaust pollution-reducing component and a contributor to increased domestic energy security. Then, the *Clean Air Act* Amendments (CAAA) of 1990 (PL 101-549) gave rise to the next major regulation of fuels. Among other things, the CAAA required areas that do not meet ground-level ozone standards to use reformulated gasoline (RFG); subsequently, additional areas opted into the program. RFG has an increased oxygenate content, which helps it burn more completely. As a result, RFG lowers the formation of ozone precursors and other air toxics during combustion.

Several oxygenates were incorporated for octane enhancement and pollution reduction: 1) first methanol; 2) then methyl tertiary butyl ether (MTBE) due to its ease of transport and blending in conjunction with increased aromatics; and 3) denatured ethanol, after an MTBE-related California water contamination scare. When faced with the removal of lead as the primary octane provider in gasoline, refiners had two available alternatives, BTEX (a hydrocarbon mixture of benzene, toluene, ethyl-benzene, and xylene) and ethanol. After it supplanted lead for octane enhancement, BTEX volume rose from 22% to roughly a third of the gasoline blendstock pool by 1990; but then the CAAA, incorporating evidence of negative health effects of benzene exposure, required lowering the gasoline content of benzene in areas that do not meet ground-level ozone standards. By 2007, EPA capped the total content of benzene in gasoline at 0.62%, down from an average of 1.3%. In addition, EPA declined to extend liability protection to MTBE as an additive in the Energy Policy Act of 2005. As of 2006, EPA reported that MTBE was not being used in significant quantities in the United States[112].

Ethanol, at an octane rating of about 110, finally won both the octane booster and oxygenates competition. However, first it was necessary that the volatility (Reid Vapor Pressure--RVP) of its gasoline combinant (the so-called *reformulated blendstock for oxygenate blending*, or “RBOB”) be reduced to a level such that match (*not* splash) blending with up to 10% ethanol did not cause the fuel to exceed summer gasoline volatility limits, as required in many U.S. metropolitan areas. This was demonstrated to be a necessity when the unusually hot summer of 1988 across much of the nation resulted in scores of ambient ozone violations that were owed to excessive evaporative emissions from high-volatility gasolines (including splash-blended oxygenates).

The Energy Policy Act of 2005 (PL 109-58) essentially mandated the incorporation of bio-ethanol (certifiably a renewable fuel) into gasoline. It put forward a set of targets for renewable fuel (i.e., biofuel) use in U.S. transportation up to year 2020. The Energy Independence and Security Act of 2007 (PL 110-140) increased these targets to 36 billion gallons (now 19.9 billion gallons/yr.). The EPA created the Renewable Identification Number (RIN) system to track RFS compliance of obligated parties and other biofuel producers. A RIN is a 38-character number assigned to each physical gallon of renewable fuel produced or imported. Biofuel producers that produce or own RINs must register with EPA and comply with RIN record and reporting guidelines on a quarterly basis. The RIN is attached to the physical gallon of renewable fuel as it is transferred to a fuel blender.

After blending, RINs are separated from the blended gallon and are used by obligated parties (refiners or fuel importers) as proof that they have sold renewable fuels to meet their RFS mandated volumes. Any entity blending ethanol and gasoline may sell RINs to one another. As a hypothetical example, Refiner A has already fulfilled its annual RFS requirement, but continues to buy and blend renewable fuels and, therefore, has excess RINs. Refiner A can sell the excess RINs to Importer B, who has not purchased sufficient renewable fuels to meet its RFS requirement. RIN prices are determined by market factors typical of other commodities[113].

Currently, about 30% of gasoline sold in the United States is reformulated gasoline. However, despite the alternative fuel incentives (tax credits on both fuels and the vehicles capable of using them) included in the Energy Policy Act of 1992 (PL 102-486), this mandate, somewhat neutralized by EPA’s 2013 decision to reduce the renewables volumetric obligation (RVO) in gasoline, did not drive the market for E85 fuels or the sale of so-called flex fuel vehicles, i.e.,

[112] Stolark 2016

[113] AFDC 2019a

those capable of operating on any ethanol-gasoline blend up to 85% of ethanol by volume. This was principally because the price point for such fuels per mile driven—and their lower energy density, resulting in reduced range—was not sufficiently attractive to prompt a major switch (see Technical challenges).

Instead, ethanol has been used in E10 blend (so-called low-level ethanol blend). Because of the increased ethanol production volume and reduced gasoline demand in the U.S., the E10 market became a blending wall to limit further increase in ethanol use in gasoline. This changed in 2011, when EPA permitted winter use of E15 for MY 2001 and newer vehicles. In 2019, EPA allowed nationwide all-season use of E15.

A relevant timeline of regulations is provided below.

- 1975: Congress passes the Energy Policy and Conservation Act (EPAct), establishing Corporate Average Fuel Economy (CAFE) standards for cars and trucks.
- 1988: The Alternative Motor Fuels Act establishes incentives under CAFE for alternative fuel vehicles.
- 1992: The Energy Policy Act of 1992 defines alternative fuels and establishes programs at the federal level to increase the use and research of alternative fuels.
- 2005: Congress passes the Energy Policy Act of 2005, establishing the Renewable Fuel Standard (RFS). RFS sets a minimum volume of renewable biofuels to be blended into the transportation fuel supply.
- 2007: Congress passes the Energy Independence and Security Act (EISA), significantly increasing the volume of renewable fuels mandated under the RFS, to 36 billion gallons by 2022.
- 2015 to present: In 2015, EPA sets renewable fuel volumes for 2014 – 2016, with volumes for 2016 at 18.11 billion gallons. This is approximately 1 billion gallons higher than the 2013 proposal, and at just over 10% of the fuel supply. This includes the categories of renewable fuels, cellulosic biofuels, advanced biofuels and biomass-based diesel[114]. The EPA continues to set renewable fuel volumes annually.

Technical Challenges

Fuel Properties

The chemical formula for neat ethanol (E100), a liquid fuel at ambient temperature, is

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[114] Stolark 2016

CH_3CH_2OH. Its principal feedstocks in the U.S. are corn and a few other grains (predominantly sorghum) and cellulosic agricultural waste. Neat ethanol has an energy content of 76,330 Btu/gal (LHV); therefore, a blend of 85% ethanol and 15% gasoline (E85) has an energy density 73% that of neat gasoline[115]. By contrast, the energy density of E10 is almost 97% that of neat gasoline. Because of its ignition properties and volatility, E100 or high-level blends are best suited for use in Otto cycle engines with compression ratios tuned higher than for neat gasoline (i.e., > 10:1). Neat ethanol has a lower RVP than gasoline (about 2 psi), so when used as a fuel in spark ignition transportation engines it is blended with at least 15% gasoline, which enables it to ignite efficiently and provides a denaturant/odorant. E70—85 is a drop-in fuel for gasoline engines if mild steel in the engine components is replaced by stainless steel, corrosion-resistant seals and elastomers and special lubricants are used to protect components from erosion or embrittlement, and compression ratio is modified. FFVs are capable of running on any blend of gasoline and EtOH between 0 and 85% EtOH—however, splash mixing of these fuels in the tank mobilizes the gasoline component to a higher volatility and thus for warm season air quality purposes it should be avoided.

Fuel Cost

Although gasoline in its customary blend (10% ethanol) generally tracks the pump price of alcohol-free gasoline (where available) very closely, E70-85 has historically been priced at a savings of up to 20% *per gallon*. This is because blenders would pass along tax credits and RIN values for renewable fuel established under PL 102-486 to retail end users. Although these tax credits were eliminated and RIN values have diminished owing to subsequent legislation and the decline in RIN prices due to reduction in the RVO, fuel sold as E85 may still be priced at 40 to 50 cents less per gallon[116] where available, especially in the Midwest, recognizing its lower energy density.

Refueling Infrastructure

Historically, all retail fueling stations in ozone nonattainment areas dispense RFG or a “boutique” oxygenate/gasoline blend, depending on regional air pollution requirements, as seen in Figure 25. At present, virtually all stations in the U.S. serving both conventional gasoline and RFG provide E10 fuels.

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[115] AFDC 2019b

[116] AFDC 2019c

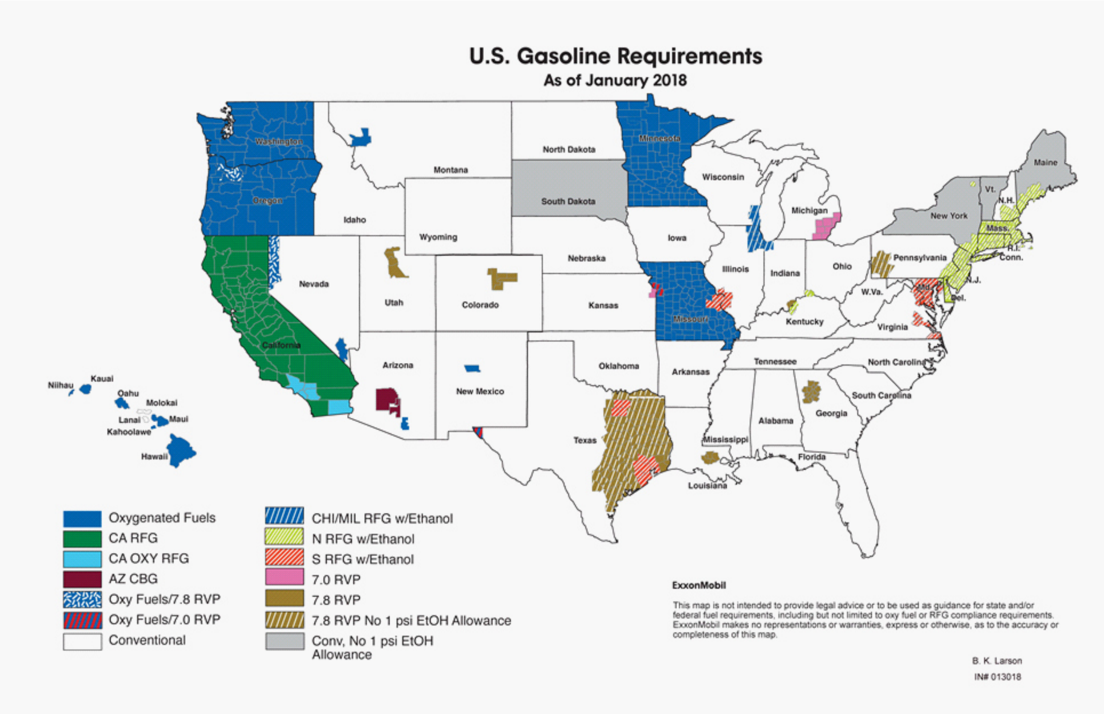

Figure 25: Gasoline Requirements[117]

Retail fuel outlets in both RFG and conventional gasoline areas may now offer an E15 fuel year-round at many station pumps, for use in model year 2001 and later cars and light trucks. In 2019, EPA allowed summertime E15, in recognition of the fact that higher ethanol/RBOB blends do not increase the RVP of the blended fuel because the RBOB is refined to an RVP of 7.0 or less. About 95% of cars and trucks now on the road can accept this fuel without violating warranties, and only a few manufacturers have not yet accepted it under current warranties[118] This fuel is rated at 88 octane (motor octane number, MON), slightly higher than conventional RFG.

E85 as a stand-alone fuel is currently available for dispensing at just under 3,500 public refueling stations nationwide, predominantly clustered in major corn-growing states in the northern Midwest (and adjacent states) from eastern South Dakota and Nebraska through Minnesota, Iowa, Wisconsin, Illinois, Indiana, Michigan, Ohio, and Pennsylvania. There are also clusters of stations in Virginia, North Carolina, southern Florida, south Texas, and the San Francisco and Los Angeles (CA) metro areas[119]. In the early years of E85 availability, the four

[117] API 2018

[118] Lewandrowski 2019

[119] AFDC 2019d

Midwest states with the highest corn production totals (Iowa, Illinois, Minnesota, and Indiana) contained most public dispensing pumps. Supplier locations today are approximately divided in number 50/50 between independent small retail establishments and major outlets like Marathon and BP. Adding an E85 tank and dispenser is not a prohibitive "showstopper"[120]. However, investing in a new E85 dispenser is more challenging for the former category of provider, even though independent chains such as FS continue to be an important source of E85, and would not be prompted by anything short of a major uptick in demand for that fuel[121].

Vehicle Cost/Performance

Manufacturers of FFVs have tried to maintain parity with conventional-fuel versions of the same models, but the required use of stainless steel and special materials in key engine parts in early years resulted in a $100-200 price premium. There have been relatively few complaints about abnormal or inferior FFV performance and reliability beyond customary experiences with conventional vehicles. Moreover, significant differences in FFV performance have not been noted and range (MPG) is obviously a function of how much of the time the vehicle uses E85 versus lower blends.

Environmental/Safety

RFG raises approximately the same safety issues as regular gasoline, although its ozone production potential is less (an advantage mostly eliminated by modern emission control equipment on all spark-ignition highway vehicles). Much of the recent impetus for ethanol in blends relates to its benefits in reducing net life-cycle greenhouse gas emissions relative to gasoline. As a neat fuel, ethanol offers reduced fire danger, although if ignition occurs flames may not be visible. The presence of ethanol can increase gasoline's miscibility in surface water in the event of a spill.

Consumer acceptance

FFVs are generally available but have not caught on in significant mass market demand, in part because marketing them as a "patriotic" choice never gained much traction, given lower E85 range per gallon (and despite the fact that AFV credits for purchase could be obtained without actually using E85). Given the substantial quantity of domestic petroleum now available, the "patriotic choice" argument bears much less weight. Recent administrative policies have increased the target for volumetric ethanol content of gasoline to 15 billion gallons by 2020, and

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[120] Moriarty 2018

[121] Lewandrowski 2019

endorse greater promotion of E15 and higher ethanol blends at the pump[122]. Nevertheless, as shown in the graphic below, the pump price of E85 as a gasoline-gallon (energy density) equivalent to conventional gasoline and RFG has tracked consistently higher for the past 20 years, when most FFVs entered the market.

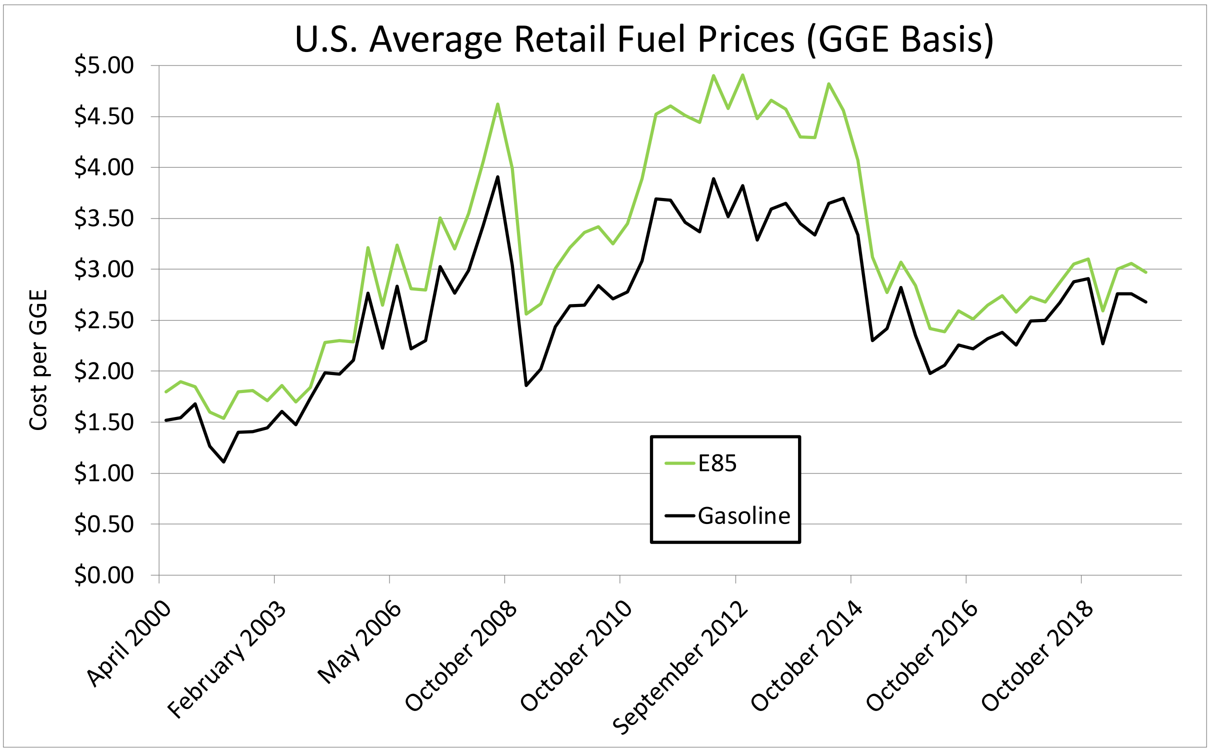

Figure 26: E85 and Gasoline Public Station Fuel Prices[123]

Historical and Current Market Penetration

Ethanol produced for fuel has risen from about 3.9 billion gallons in 2005 to a plateau of just under 16 billion gallons as of 2018; domestic consumption has generally tracked production[124]. As of 2017, the industrial consulting firm IHS Markit® estimated that there were more than 21 million FFVs in the United States. FFV market penetration by year is shown in Figure 27. Sales of these vehicles commenced pursuant to their definition as alternative fuel vehicles (AFVs) under the Energy Policy Act of 1992 (PL 102-486). Because flex fuel vehicles are factory made and are capable of operating on gasoline and gasoline-ethanol blends in any combination, many vehicle owners do not realize their car is an FFV and that they have a choice of fuels to use.

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[122] Smith 2019

[123] AFDC 2019h

[124] EIA 2019d

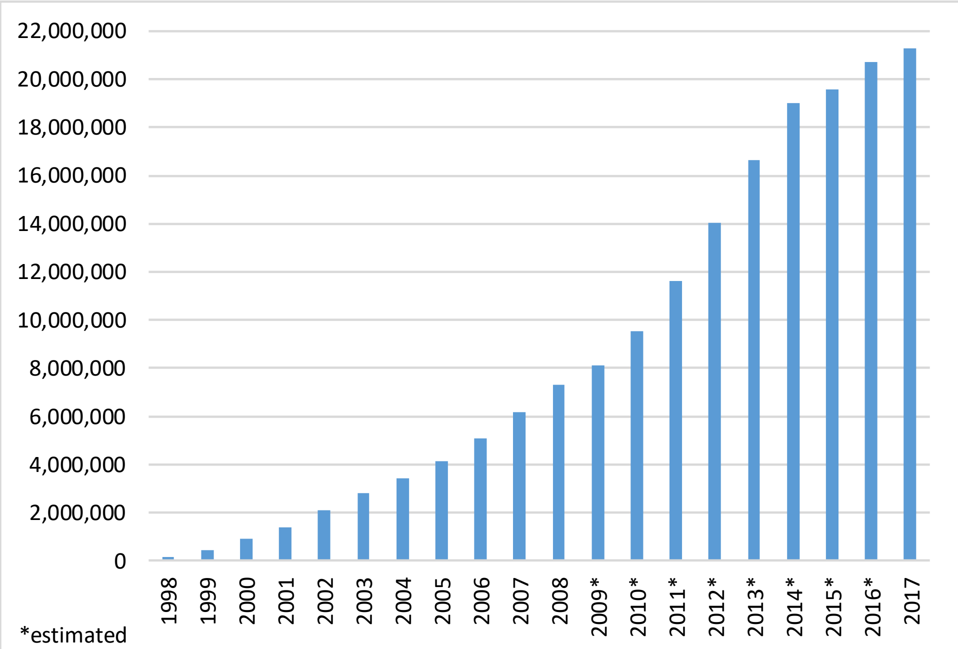

Figure 27: E85 FFV Market Penetration – number of vehicles[125]

Policy Effectiveness

Successes

We have seen that the eventual triumph of bio-ethanol as an alternative motor fuel depended predominantly on four factors:

- state and federal regulation that did not specifically require it to be a stand-alone fuel, but was aimed at targets for ozone and aromatics reduction for which alternative solutions could be provided but later proved deficient with respect to certain properties;
- active advocacy by stakeholders to increase domestically produced ethanol in the transportation fuel market under policies such as the federal renewable fuel standard;
- positive production margins and price-competitiveness in fuel octane enhancers; and
- the positive role of ethanol in reducing carbon intensities of transportation fuel pools in state-level low-carbon fuel standards such as the California Low Carbon Fuel Standard and the Oregon Clean Fuel Program.

Ethanol's current positioning in the U.S. fuel supply offers it the flexibility to increase market share without significant new investment in production (through corn and sorghum processing--

[125] AFDC 2013 & 2019e

in fact, some dry mills once in steady production have been scaled back or “mothballed” due to demand curtailed by small refinery blending exemptions and trade barriers). However, an extensive refueling infrastructure is already in place, and needs to be augmented to accommodate E15. Petroleum refiners and blenders have already adjusted their infrastructure to accommodate ethanol as an additive. However, with the demise of the “oil crisis” of a few decades ago thanks to higher domestic petroleum production, we are unlikely to see major new ethanol production projects in the near future, with the unfortunate consequence that a market-driven supply shift to enzymatic conversion of cellulosic agricultural waste and grass is unlikely (see below), except that the U.S. gasoline octane number is required to be increased for new generation engine technologies and ethanol can help increase gasoline octane.

Challenges

Now that the future of bio-ethanol as a significant constituent of the fuel supply pool relies almost completely on its role in meeting RFG requirements and boosting octane, it is appropriate to examine the net benefit of oxygenate-based RFG itself. Recent studies have shown that ethanol blends help reduce PM emissions through its effect of lowering aromatic content in gasoline. On the other hand, given what has become reduced concern about the adequacy of domestic reserves of petroleum, the most significant advantage of oxygenates in RFG appears to be a displacement of some toxics (e.g., benzene) and aromatics from the RFG blend, now a requirement under EPA fuel regulation, which results in a decrease in toxic emissions. However, not all air toxics are decreased; ethanol blends may lead to increased emissions of acetaldehyde (C_2H_4O)[126].

An important justification for continuing to support ethanol as a motor fuel was that transition to alternative, non-food feedstocks such as agricultural waste and grasses processed through enzymatic conversion would eventually come to dominate the market and take the pressure off food crop sources of starch. In this way, the need for octane enhancing oxygenates combined with domestically produced sourcing in a manner that significantly reduced total greenhouse gas emissions.

This transition has not yet occurred with much success. Several enzymatic conversion process pilot plants have been constructed over the years, but processes must still overcome pretreatment issues of cellulosic biomass. One producer of ethanol at a dry mill facility has succeed in routing a component of its DGS co-product’s waste stream (kernel hulls and fiber) to

[126] NRC 1999

ethanol, increasing the plant's ethanol output by about 7%[127]. Otherwise, momentum toward adding cellulosic processing to the ethanol supply has been stymied both by shortfalls in technology progress and persistently low petroleum prices. Meantime, the wet and dry milling infrastructure for converting raw corn to ethanol and co-products (germ, gluten meal, and distillers' grains and solubles, all desirable animal feeds) has grown and remains largely solvent, thanks initially to strong regional support from farm organizations and state governments but more recently due to favorable economics, and from regulations such as low-carbon fuel standards. The availability of that fuel remains variable across the retail sector.

Table 23: Data sheet Ethanol in the United States

	value	unit
consumption of fuel	2018 = 14.4 billion U.S. gallons = 9.5 billion GGE ~ 6% of highway fuels (energy basis)	EIA 2019d
number of vehicles	All gasoline vehicles in current fleet may use 10% ethanol blend fuel All MY2001 and later gasoline vehicles may use E15 Population of FFVs (E85-capable) is approximately 21 million (2017)	AFDC 2019e
market share of suitable vehicles	100% on low-blend basis; approx. E85 for FFVs: about 4% of total annual LDV and LDT sales, but this share has been dropping	AFDC 2019e
GHG savings achieved	2018 = ~45 million tons	GREET 2019
local emission savings	variable; more specifically related to on-board emissions aftertreatment than fuel properties	GREET 2019
energy savings	2018 = 9.5 billion GGE displaced	EIA 2019d
production costs of fuel	approx. $1.40 per U.S. gallon	Richman, 201
quantity of produced fuel ir the country	approximately 16 billion gallons (2018)	EIA 2019d

[127] Lewandrowski 2019

Lessons Learned

Fuel ethanol has played a key role in the U.S. transportation fuels market for emissions reductions, petroleum reduction, greenhouse gas emission reductions, as well as use of domestic agricultural products to help rural American economy. Further, a strong constituency for ethanol's use as a fuel or fuel extender existed across the U.S. Midwest for much of the last third of the 20th century. Stakeholders including agricultural interests (including corn processors) and auto makers were a strong promoters of ethanol. These developments may be summarized:

- Competing solutions to solve the joint problem of octane enhancement and domestic sourcing failed in some particulars, leaving ethanol as the only choice for 1990s automotive technology that could provide a renewable domestic component in gasoline and contribute to improved octane and reduced ozone precursor emissions.
- With advances in on-board emissions control technology, arguments for ethanol as a necessary gasoline component for ozone control have become less persuasive. This created a situation that diminished ethanol's role in air pollutant emission reductions. However, as the nation moves to further air quality improvements, especially PM air quality improvement, ethanol may again play an important role.
- To some extent, the stronger case for ethanol has now shifted to its property as a net reducer of greenhouse gas emissions, relative to petroleum, across the entire life cycle. However, the recent debate of potential land use changes from corn ethanol has caused confusion about the degree of overall GHG reductions (which has been reliably estimated at about 40%), while the cellulosic ethanol production pathway has significant GHG reductions but needs to mature in order to become dominant.

The case for renewable and domestically-produced fuels achieved its greatest momentum around the turn of the 21st century, and ethanol was a ready answer to both concerns. Having attained a comfortable niche in the U.S. fuels market as a low-level blend (E10 and soon, E15), ethanol's greater challenges ahead will be posed by competition from other alternative fuels (e.g., electricity), and strong domestic petroleum production.

Infobox 23: Key drivers of successes and key barriers of failures

- Ethanol won the competition as oxygenate and octane booster as competitors faltered for primarily environmental reasons
- Advocacy of corn production interests and ethanol's energy security enhanced this result and regulation ultimately mandated it as a gasoline blendstock
- EPA allowance of E15 will allow for the expansion of ethanol use, but high-level blends like E85 have not had market success due to their per-distance high fuel costs
- Transition from corn to cellulosic feedstocks has not occurred yet due to shortfalls in technology progress and persistently low petroleum prices

Methanol

Introduction

The circumstances of the introduction of advanced motor fuels and the factors influencing their commercialization (resource, transport infrastructure, economic situation, etc.) in each country are different. This section provides background relating to the introduction of methanol as a highway vehicle fuel in the United States; describes the objectives of U.S. Federal Government and various state government policies relating to advancing its use; and summarizes the effectiveness, successes, and lessons learned regarding the promotion of methanol as a motor fuel.

Background and Objective of Early Use and Policies for Fuel Methanol

In the U.S. (and the world), the 1970s was a period of Middle East turmoil and rapidly rising oil prices, feeding concerns about both transportation fuel availability and prices. The first crisis, the Yom Kippur War that ushered in the Arab Oil Embargo, yielded a huge increase in crude oil prices. The Iranian Revolution ushered in a period of still higher oil prices and, further, engendered gasoline rationing and long lines at refueling station pumps. Simultaneously, despite passage of multiple pieces of air pollution legislation beginning with the Clean Air Act of 1970, there were growing concerns about rising ground-level ozone concentrations in urban areas, driven by ozone-precursors NOx and hydrocarbon emissions from the U.S.'s rapidly growing fleet of passenger cars. In addition, oil companies were searching for octane enhancers for the unleaded gasoline needed to protect the catalytic converters on all 1975 and later model cars. These conditions led to calls for the introduction of methanol into the U.S. transport fleet, both as an octane-enhancing blending component of gasoline and as a primary fuel with superior environmental properties – including a reduction in emissions – and with a large and domestic resource base, as it is largely produced from natural gas.

History of Policies and Incentives

In 1979, The California Energy Commission (CEC) initiated a $10 million study of "the practicality and cost-effectiveness of alternative motor fuel" in response to California Senate Bill 620, an omnibus mass transit measure[128]. The study included a demonstration program for methanol (and ethanol) and partnerships with other State and local agencies to explore incentives for alternative fuels and overcome institutional barriers. An early part of this effort was California's 1981 reduction of fuel taxes on methanol to half of the gasoline rate, to account for methanol's lower energy density. The Federal government soon followed California's action by reducing the Federal excise tax on methanol.

The earliest (1979) penetration of methanol into the automobile fleet was the experimental use of methanol as a blending agent (5-15%) in gasoline – primarily to serve as a fuel extender in case of emergencies. However, the CEC's Alcohol Fleet Test Program was the prime mover for the introduction of methanol as a primary automotive fuel. The CEC agreed to purchase dedicated methanol vehicles for its fleets and set up methanol refueling stations (eventually there were 18 retail methanol stations participating in the test program[129]) if auto companies would supply the vehicles[130]. In response to this offer, Volkswagen produced 39 alcohol fuel Rabbits, and 40 Ford Escorts were converted to methanol fuel by aftermarket converters. The CEC added 500 dedicated Escorts in 1983; in all, ten automakers provided over 900 vehicles with 16 models including vans and buses[131].

Generally this program was a technical success in that the vehicles performed well (for the Escorts, 20% increase in power and 15% increase in fuel efficiency[132]), but the lower range of the vehicles, the limited number of refueling locations and the poor locations of the stations led to driver anxiety about running out of fuel. This led to the decision to focus on flexible fuel vehicles (FFVs) that could operate on either alcohol or gasoline fuels in the same fuel tank, with

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128 Ward and Teague 1996

129 Ward and Teague 1996

130 Fuel Freedom Foundation 2013

131 Bromberg and Cheng 2010

132 Nichols 2003

methanol and/or ethanol levels of up to 85% with 15% gasoline by volume (M85 or E85). The objective was to build a large FFV fleet with expanding M85 infrastructure, and then to move to dedicated methanol vehicles[133].

Although Ford had delivered hundreds of experimental FFVs in several models starting in 1985, it had three conditions to begin large scale production: credits toward satisfying its fleet fuel economy standards; funding to buy down added costs; and provision of numbers of refueling stations[128].

In 1988, the Alternative Motor Fuel Act (AMFA) provided a waiver to EPA regulations that allowed methanol to be used in cars[130], and awarded credits to auto companies to count methanol use as a subtractor to gasoline use in estimating their Corporate Average Fuel Economy (CAFE) value (satisfying Ford's first condition). There was no limit to the credits that could be awarded to dedicated methanol vehicles, but methanol use in FFVs could reduce fleet fuel economy by no more than 1.2 MPG per automaker[134]. However, AMFA assumed that methanol (as M85) would be used 50% of the time in FFVs, which was generous given the limited methanol refueling infrastructure. Despite unlimited CAFE credit potentially available for dedicated vehicles, the auto companies chose to focus on FFVs.

Ford's other two conditions were met soon after, with approval by the California legislature to subsidize FFV vehicles and new refueling facilities, and an agreement between CEC and ARCO to establish up to 25 M85 stations. Chevron agreed to similar terms, and other fueling station companies joined as well. Eventually, there were upwards of 50 such stations. Also, 13 fleet sites were built, with 7 open to the public. CEC actually purchased the equipment for the stations, with the companies responsible for installation and all other costs typically under 10-year lease arrangements.

Also in 1988, CEC established the California Methanol Fuel Reserve in cooperation with several methanol suppliers in order to stabilize methanol prices and guarantee supply availability. Between 1990 and 1995, the Reserve was generally successful at stabilizing methanol prices despite significant fluctuations in methanol prices on the commodity market[135]. In 1997, CEC announced that the primary methanol supplier would price M85 at levels of mid-grade gasoline (adjusted for energy content)[136].

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[133] Bechtold, et al 2007

[134] Alson 2019

[135] Ward and Teague

[136] California Energy Commission 1997

Both the California Energy Commission and local Air Quality Management Districts (AMQDs) provided vehicle and station subsidies. For example, Hertz's FFV purchases of over 1900 FFVs as well as refueling stations had subsidies as follows:

- 1993 Sacramento AMQD $1000/FFV for 100 FFVs
- 1994 California Energy Commission $400/FFV for 200 FFVs
- 1995 South Coast AQMD $50,000 for methanol stations
- 1996 American Methanol Institute $100/FFV for 100 FFVs

In 1989, ARCO announced the advent of reformulated gasoline capable of meeting Federal and California emissions standards in combination with 3-way catalysts, eliminating one of the key advantages of methanol. Up until this time, the refining industry had claimed that significant reformulation of gasoline would be too difficult and expensive. It is interpreted by many familiar with the California experience that the threat of methanol fuels was a significant influence on this change of heart[137].

Technical Challenges

Methanol has many properties that make it attractive as a transportation fuel: it is a liquid fuel that can be blended with gasoline and ethanol and can be used with today's vehicle technology at modest incremental costs; its high octane level can allow engines specifically designed for methanol to match diesel efficiencies, with reduced emissions; it biodegrades more quickly than gasoline if spilled; and it is widely produced today and its source materials -- natural gas, coal, and biomass (and potentially with renewable electricity together with waste CO_2 in the future with near-zero GHG emissions) – have large resource bases[138] However, the attempt during the 1980s and 1990s to move it into the passenger vehicle fleet faced several important technical challenges, some of which it would still face today.

Fuel Properties

Methanol, or wood alcohol, is a liquid fuel with high octane (98.7 anti-knock index vs. regular gasoline's 87 and premium's 93), yielding the potential for high efficiency in engines specifically designed for it. It can be used as a blending agent (at low concentrations) in gasoline. Methanol has a low vapor pressure (4.6 psi), creating cold start problems and potentially allowing it to

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[137] Alson 2019

[138] Bromberg and Cheng 2010

ignite in the fuel tank[139], although such ignitions have not been shown to be a problem in actual operation. Methanol is a key ingredient of MTBE (manufactured from the chemical reaction of methanol and isobutylene), which also can serve as an octane enhancer without methanol's corrosive properties. However, MTBE has been banned by several States because its leakage into groundwater caused major drinking water problems, and it is likely that methanol's association with MTBE has adversely affected public perception of methanol[140].

A key challenge of introducing methanol into the vehicle fleet was its incompatibility with several materials used in fueling systems and vehicle drivetrains. It is corrosive to certain metals, elastomers and other materials, its small molecular structure (coupled with adverse effects on materials) increases potential for leakage, and it can adversely affect engine durability and emissions system performance[141]. For example, ARCO introduced Oxinol, a blending agent with as much as 4.75% methanol, into some of its own gasoline and marketed it to other companies. ARCO discontinued using or selling Oxinol within a few years, with reports by customers of fuel phase separation and damage to fuel system materials[142]. Later, EPA regulations about fuel volatility (1989) and other actions made it difficult for methanol to be again used as a blending agent.

In addition, methanol-caused corrosion to refueling infrastructure (especially aluminum dispenser nozzles and elastomers in dispenser hoses) contaminated the fuel for the California Department of Transportation's fleet of 299 Lumina FFVs and damaged the vehicles' fuel systems[143]. Although these problems were eventually corrected (for example, by nickel-plating vulnerable fuel dispenser components), they demonstrate the problem of introducing a new fuel to a long-established fuel system.

Methanol was also found to be incompatible with polybutylamines, a gasoline detergent agent[144], another example of the need to do careful research into materials compatibility before widely introducing new fuels into the fuel system. The methanol industry has learned a great deal about appropriate material selection to address material compatibility issues in the past several decades.

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139 Nichols 2003

140 Alson 2019

141 Jackson 2017

142 Bechtold 2007

143 Ward and Teague 1996

144 Ward and Teague 1996

Fuel Cost

Although early dedicated methanol vehicles demonstrated power and efficiency superior to their gasoline counterparts, the FFVs that dominated the methanol fleet, generally had performance similar or a bit better (usually power is a bit better on M85) than their gasoline counterparts. Since they were otherwise identical (except for lower range), FFV owners or potential owners had little incentive (other than perhaps environmental consciousness) to buy the vehicles or refuel them with methanol (as M85) unless they gained an economic advantage in doing so. Because both M85 and gasoline prices depended on natural gas and oil prices (most methanol was made from natural gas during the 1980s and 1990s, and still is), the competitive advantages of the two fuels varied over time. However, generally methanol did not represent superior pricing. Ward and Teague (1996) developed the following table of comparative fuel prices, for California at 1995 fuel costs. According to their analysis, the average cost of methanol fuel, on a "per mile" basis, was consistently higher than gasoline cost during this time period. In Ward and Teagues's analysis, key assumptions and results for the mid-1990s included:

Table 24: Ward and Teagues's analysis – key assumptions and results

California Fuel Methanol Reserve methanol price	$0.50/gallon
Unleaded regular gasoline wholesale rack price	$0.69/gallon
M85 pump price	$0.99/gallon
Energy equivalence factor (to account for differences i fuel energy content and vehicle efficiency)	1.6
MPG energy equivalent M85 pump price	$1.56/gasoline gallon equivaler
Average California gasoline pump price	$1.35/gallon
Sacramento, CA gasoline pump price	$1.08-$1.16/gallon

The 1.6 energy equivalence factor compares to an equivalence factor ignoring differences in vehicle efficiency of about 1.74. In other words, the analysis assumes that the M85 FFVs operating on M85 are about 9% more efficient than the gasoline vehicles, which may have been optimistic for the FFVs available at the time and should be considered a "best case."

Similarly, Hertz, which purchased a total of 1,900 methanol FFVs, found that its rental fleet had a fuel cost of 6.4 cents/mile on methanol vs. 5.5 cents/mile on gasoline (for Dodge Intrepid and Ford Taurus FFVs); customers reported "superior acceleration" on methanol, with no other difference[145].

More recently, methanol should be far more competitive with gasoline, primarily because the surge in natural gas supplies (natural gas is the primary feedstock for methanol) has decoupled natural gas prices from oil prices. A 2010 analysis, undertaken well after U.S. natural gas supplies surged, concludes that methanol prices at that time were competitive with gasoline on an energy basis[146], and presumably less expensive when methanol's advantages in engine efficiency are taken into account. Also, in the table above, for which methanol pricing (on a "per mile" basis) was slightly higher than gasoline price, gasoline cost about 40% more than methanol on a per gallon basis. Today, the methanol rack (i.e. wholesale without taxes) price is about $1.00/gallon[147] vs. about $1.80 for regular gasoline[148].

Refueling Infrastructure

As noted above, methanol's corrosive effect on certain materials present in refueling infrastructure represented a challenge to developers of methanol stations. These problems basically were learning problems that were overcome over time, although the costs of repairing vehicle systems were substantial. In addition, U.S. methanol production was robust in this time period: 1990 production, mostly from natural gas, was 3.75 million metric tons, or about 1.25 billion gallons (at about 6.6 lb/gallon). A fleet of 100,000 FFV vehicles might have been expected to use about 64 million gallons of M85 (25 MPG on gasoline, 1.6 equivalence factor with gasoline for M85) or 54 million gallons of methanol, about 4% of U.S. production. The maximum number of methanol vehicles was 21,000 in 1997, a fifth of this value. Therefore, methanol supply would not have been an issue, although transporting large quantities of methanol would have been problematic since pipeline transport without measures to reduce materials corrosion was not possible. The primary issue, however, was the limited number of refueling stations, and this seems to have been caused not by technical issues but instead by a combination of poor economics and the reluctance of fuel retailers and oil companies to compete with their primary product, gasoline.

Vehicle Cost/Performance

Because of methanol's corrosive properties, it cannot be used in existing vehicles without considerable modification of their fuel systems and some engine components, except for low-

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145 Hertz Corporation, undated

146 Bromberg and Cheng 2010

147 Methanex 2019

148 EIA 2019e

level methanol blending with gasoline (e.g., less than 5% of methanol in gasoline). Nichols (2003) reports that the first generation of dedicated methanol vehicles – modified Ford Escorts – using neat methanol attained 20% more power and 15% greater efficiency than conventionally fueled Escorts, at an increased cost of $2200/vehicle. Also, NO_x emissions were considerably lower than the gasoline versions. It is expected that vehicles specifically designed for methanol and using modern technology could do much better – light-duty engines using M100 could attain efficiencies comparable to or greater than diesel engines, at lower cost because of their low-pressure port fuel injection systems and simpler emission control systems[149]. And methanol engines in medium and heavy-duty services could similarly achieve higher efficiency and lower cost than competing diesel engines, while also offering substantially reduced weight[149]. For example, substituting a smaller-displacement spark-ignition methanol-fueled engine for a diesel in heavy-duty applications could potentially save $10,000-15,000 in engine system costs[149].

Requirements for FFVs (which would probably use M85) are considerably simpler. A methanol-capable FFV requires alcohol sensor monitors to insure proper timing and fuel flow rate, stainless steel fuel system, improved piston rings and some other materials changes, at a cost of less than $100[149]. If better range comparability is needed, a larger fuel tank may be added.

Another issue, quite possibly attributed simply to lack of experience with designing and maintaining methanol engines, has been increased maintenance requirements. For example, the Los Angeles Metropolitan Transportation Authority, which operated a fleet of 333 methanol buses, decided to convert the buses to ethanol or other fuels due in part to increased operational expenses for the methanol engines[149].

Environmental/Safety Impacts

Introduction of methanol into the vehicle fleet will have important environmental and safety impacts:

- Used as a neat fuel (M100), methanol burns with an invisible flame in sunlight, and its low vapor pressure means that methanol could ignite in a gas tank (addition of gasoline, as in M85, negates these potential problems). Machiele (1990) concludes, however, that neat methanol's lower volatility and higher flammability limits would yield a 90% reduction in vehicle fires and, coupled with its lower heat rate in a fire, yield a 95% reduction in fatalities and injuries. He also concludes that use of M85 could yield up to a 70% reduction in fatalities and injuries from vehicle fires. At the time of its introduction, M100's use in vehicles offered superior emissions performance to gasoline vehicles,

[149] Ward and Teague 1996

with low NO_x emissions and hydrocarbon emissions that were less reactive and produced less ozone. However, the use of 3-way catalysts and reformulated gasoline largely eliminated methanol's emission advantage[150].

- Methanol use in FFVs could cause problems when methanol concentrations were low (i.e., when gasoline was the primary fuel), because vapor pressure would increase substantially. Evaporative emission controls in FFVs must be sized to account for such situations.
- Methanol generally should pose less danger to the environment than a gasoline or diesel spill. Methanol is water-soluble and will spread – and be diffused – in the environment at a much faster rate than gasoline or diesel fuel; it also biodegrades much faster than these fuels[151].
- Methanol, like gasoline, is a toxic chemical; ingesting small amounts can cause blindness (10 ml) or death (50-100 ml). Generally, its toxicity is similar to gasoline: virtually identical in terms of ingestion and dermal contact, and less toxic in terms of inhalation. However, pure methanol has little taste and smell, so if used improperly or spilled it could be considerably more dangerous than gasoline, for example it is less likely than gasoline to be thrown up if someone swallows it.

Consumer acceptance

Methanol is widely used as windshield washer fluid without major calls for its elimination, and it was used in California methanol test program for 200 million miles of driving with no accidental methanol poisoning (Bromberg and Cheng). However, there has been considerable negative public perception of methanol due to its reputation as a poison and because it is the feedstock for MTBE, which was banned by several States (including California and New York) for use as an oxygenate after storage tank leaks caused widespread damage to groundwater and drinking supplies.

The primary problem with consumer acceptance, however, was the decreased range, limited availability of refueling options, and higher fuel costs, as discussed earlier. The increased performance using methanol, even with FFVs, apparently could not overcome the issue of shorter range and poor economic incentives. With current fuel prices, presumably consumers might be more interested in methanol vehicles, if a robust refueling infrastructure were to be

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[150] Bromberg and Cheng 2010

[151] Bromberg and Cheng 2010

built.

Historical and Current Market Penetration

Although California and other states attempted to jump start a shift to methanol-fueled vehicles, the effort failed to catch on, and market penetration peaked at 21,000 vehicles in 1997 and eventually collapsed. The history of methanol penetration is as follows:

1965 Introduction to Indy car competition, including the Indianapolis 500

1979 Introduction of methanol as a gasoline blending agent, in concentrations of 5 to 15%, in 1979 Honda Civics (Ward and Teague 1996)

1981 Introduction of dedicated methanol vehicles (40 Ford Escorts, 39 VW of America Rabbits) (Bromberg and Cheng 2010); 500 Escorts in 1983 (Jackson 2017)

1981-1990 Period of dedicated methanol vehicles (16 models, including transit buses); total over 900 vehicles

1985-1992 Ford delivers about 500 experimental FFVs, including Escort, Taurus, and Crown Victoria LTDs, plus a few 5L Econoline vans (Nichols 2003)

1988 150 methanol (both M100 and M85) school buses delivered to California schools

1991 First production M85 vehicles (GM Lumina)

1992 Ford begins delivering production M85 FFV Taurus (1st production run of 2800 vehicles)

1992-1995 ARCO, Shell and Chevron pull back on their refueling station commitments

1993-1996 Hertz begins renting M85 FFVs, starting with 100 Ford Taurus's in 1993, maximum purchases of over 700 vehicles in both 1995 and 1996

1997 Maximum methanol vehicle fleet of over 21,000 vehicles, 15,000 in California

1998 Methanol vehicle production ends

Today No production methanol vehicles in the U.S.

The figure below gives the 1992-1998 market penetration of M85 vehicles[152].

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[152] EIA 1998

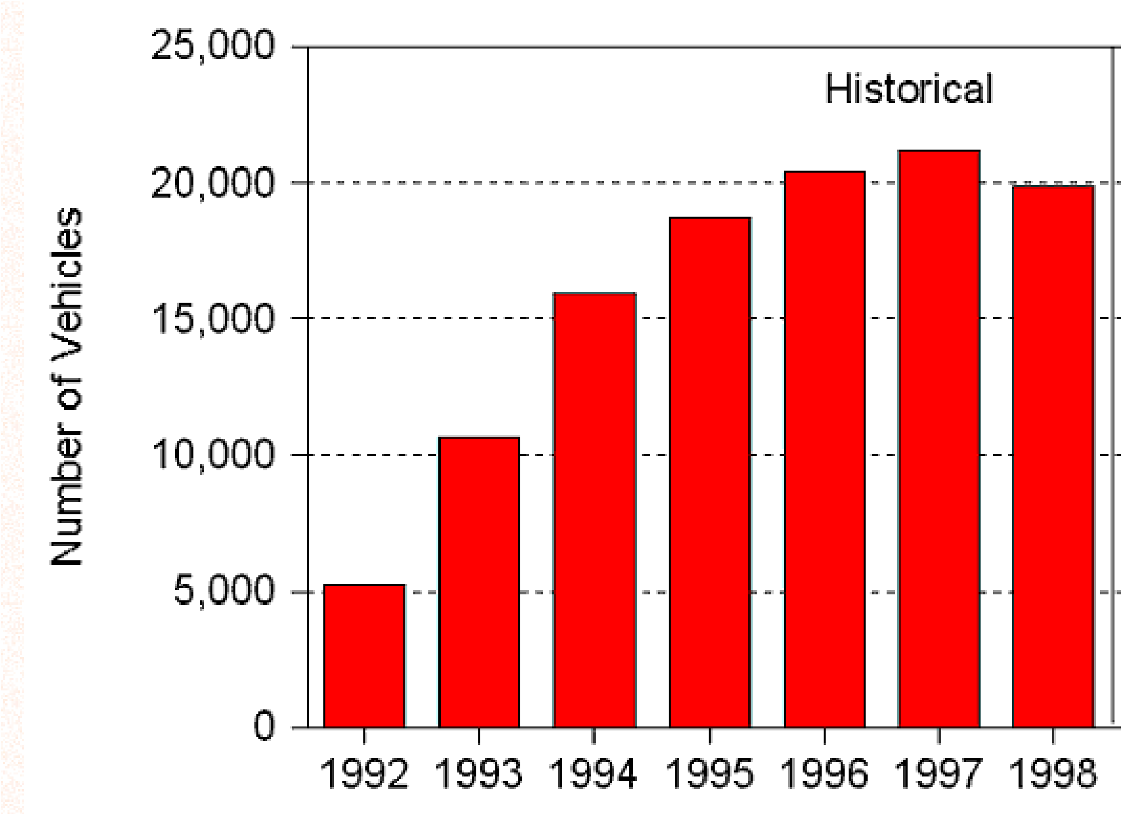

Figure 28: Market penetration of M85 vehicles[153]

Policy Effectiveness

Successes

Despite the eventual collapse of the methanol vehicle market, many of the early policy initiatives were at least partially successful. The California Energy Commissions Alcohol Test Fleet Program proved that methanol could be a viable and attractive vehicle fuel. The CEC's cooperative efforts with other State and local entities, coupled with targeted subsidies, succeeded in convincing several fuel providers to establish methanol stations and got automakers to manufacture thousands of viable fuel flexible methanol vehicles. In addition, the CEC's California Methanol Fuel Reserve was successful in providing ample methanol supplies at stable prices over a number of years.

Challenges

As discussed below, these efforts eventually failed to produce a viable methanol market. The key headwinds included:

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[153] EIA 1998

- Introduction of reformulated gasoline, which essentially canceled methanol's emissions advantages
- Reluctance on the part of fuel providers to embrace methanol as a fuel option (largely based on their existing huge investment in gasoline)
- The environmental failure of MTBE and its tarnishing of its methanol feedstock

Table 25: Data sheet Methanol in the United States

	value	unit
consumption of fuel	0	
number of vehicles	21,000	1997
market share of suitable vehicles	0.01%	199,972,786 total vehicles in 1997 (BTS 2019)
GHG savings achieve	-	
local emission saving	-	
energy savings	-	
production costs of fu	-	
quantity of produced fuel in the country	-	

Lessons Learned

Methanol was first introduced during a period of rising oil (and gasoline) prices, concerns about world oil supplies, and challenges to auto manufacturers to meet vehicle emission standards. Methanol seemed to provide potential answers to all of these concerns. However, almost immediately after methanol vehicles were introduced, world oil prices fell and supply concerns diminished. Also, the introduction of reformulated gasoline and the availability of new three-way catalysts allowed automakers to comply with tightened emission standards with gasoline-fueled vehicles (further, advances in on board diagnostics and sophisticated fuel, engine and transmission controls have allowed continued improvements in automotive emission controls). In other words, the broad societal challenges that methanol appeared to address proved to be ephemeral. However, in addition to the lessening of these societal concerns, policymakers appeared to have ignored or downplayed a number of other issues.

- Gasoline vehicles perform well, are highly reliable, have a robust repair infrastructure, and have very good range due to gasoline's high energy content. In addition, gasoline refueling infrastructure is ubiquitous. This was true in the 1980s, when methanol was first introduced, and today gasoline vehicles are extraordinarily reliable, and vehicle performance has grown robustly in the intervening years. In contrast, newly introduced alternative fuel vehicles may at first be less reliable than their gasoline counterparts because they will have had far less opportunity for "learning;" they may have a lesser repair infrastructure; and, unless home refueling is an option, in the early years of deployment they will have far fewer refueling options (except for niche or fleet vehicles that stay close to home). The familiarity with gasoline and likely difficulties adjusting to a new fuel affects fuel suppliers, vehicle manufacturers, consumers, and the infrastructure of fuel retailers, repair facilities, and even fire departments.
- Fuel marketers may have little incentive to cooperate with the rollout of an alternative fuel. In the early years of a rollout, there will be few customers to support the expensive new refueling infrastructure, and there will be uncertainty that sufficient customers will ever appear. In the case of California's methanol rollout, retailers lobbied against methanol, generally refused to undertake marketing efforts to promote their own methanol stations, and some fuel retailers would not allow methanol pumps at regular refueling locations in the stations.
- Any problems that arise from lack of experience with the new fuel will be magnified by the comparison with the current system. For example, the lack of experience with methanol's interaction with existing materials in the refueling infrastructure led to fuel contamination and high warranty costs to vehicle manufacturers during the early period of the rollout.
- Oil companies' immense sunk costs in the existing petroleum and gasoline system virtually guarantee that they will continue to embrace use of existing fuel production and distribution infrastructure. Similarly, auto companies have little incentive to embrace a new fuel that may require major new investments and may create unforeseen problems with maintenance and reliability. In the case of methanol, ARCO and other companies quickly rolled out reformulated gasoline that reduced any emissions advantage that methanol might have, and the use of three-way catalysts virtually eliminated any such advantage. It is worth noting that, prior to the introduction of methanol, U.S. oil companies firmly resisted any requirements to reformulate gasoline, as impractical and

expensive[154].

- The difficulties of replacing gasoline with an alternative fuel implies that strong advocacy must be present for a replacement to have any chance at all. In the case of methanol, the strongest potential advocates were the environmental community and the methanol chemical industry. As noted above, the introduction of reformulated gasoline and three-way catalysts diminished environmental enthusiasm for methanol, and problems with MTBE may have tarnished methanol's reputation as well; and although vehicle use of methanol would have greatly increased demand for its product, the chemical industry would then be faced with strong competition from the oil industry. In addition, methanol had to face strong advocacy for a competing fuel – ethanol – which had the support of the agriculture community and their members of Congress.
- Finally, during the period in which methanol was being rolled out, it was more expensive (on a "per mile" basis) than regular unleaded gasoline, thus yielding little incentive for owners of flex-fueled vehicles to purchase the fuel and little incentive for potential methanol-capable vehicle purchasers to buy them.

Infobox 24: Key drivers of successes and key barriers of failures

Successes

- Policy initiatives were successful to incentivize the initial demonstration and production of methanol vehicles

Barriers

- Introduction of reformulated gasoline essentially canceled methanol's emissions advantages
- Fuel providers reluctance to embrace methanol due to existing investments in gasoline
- Environmental failure of MTBE and its tarnishing of its methanol feedstock

[154] Alson 2019

Natural Gas

Introduction

The circumstances of the introduction of advanced motor fuels and the factors influencing their commercialization (resource, transport infrastructure, economic situation, etc.) in each country are different. This section provides background relating to the introduction of natural gas (NG) as a highway vehicle fuel in the United States; describes the objectives of U.S. Federal Government and various state government policies relating to advancing its use; and summarizes the effectiveness, successes, and lessons learned regarding the promotion of NG as a motor fuel.

Background and Objectives of Policies for NGVs

In the U.S., natural gas was recognized as a potential highway vehicle fuel in the 1960s, but few initiatives immediately followed. The Arab oil embargo of 1973-74 and 1979 Iranian revolution raised petroleum fuel prices significantly, which created a push to reduce U.S. petroleum consumption and find alternative fuels for highway vehicles. In the 1980s, efforts with natural gas as a feedstock focused primarily on finding a liquid fuel (e.g. methanol) that would require minimal modification to vehicles and refueling infrastructure. Beginning in the late 1980s, various Federal policies began to generate increased interest in natural gas vehicles (NGVs). In the late 2000s, the rapid increase in NG production from shale formations substantially lowered NG prices and now the U.S produces more NG than its internal demand[155]. This has led natural gas price to be decoupled from petroleum prices and has increased interest in NG as a transportation fuel.

Aside from reducing petroleum consumption, natural gas-based fuels were seen as a means of improving air quality. When the U.S. Environmental Protection Agency (EPA) established National Ambient Air Quality Standards (NAAQS) under the 1990 Clean Air Act Amendment (CAAA), several California metropolitan areas did not meet these standards. The State of California established air quality management districts (AQMDs), providing them with funding to curb vehicular emissions. In addition, the Energy Policy Act of 1992 required government fleets and utilities to acquire alternative fuel vehicles (AFVs), which included NGVs. In the mid 2000s, both the EPA and California set strict standards to reduce ozone forming pollutants and particulate matter (PM) from heavy-duty vehicles (HDVs). The push for improved air quality was a significant driver in the development and deployment of vehicles that directly use natural gas (i.e. compressed natural gas [CNG] vehicles). In addition, a more recent incentive for natural

[155] EIA 2019a

gas-based fuels is the ability of renewable natural gas (produced from biologic sources) to significantly lower greenhouse gas emissions.

History of Policies and Incentives Promoting NGVs

The history of NGV policies and incentives can be broken down into several periods: 1) an initial period (late 1960s through about 1990) of private market initiatives that yielded only modest numbers of vehicles; 2) a later (acceleration) period (1990 through early 2000s for vehicles, through about 1997 for stations) where strong Federal and State (primarily California) initiatives rapidly increased both vehicle numbers and refueling stations (although at modest scale compared to the total U.S. vehicle fleet and refueling infrastructure); 3) a period of stagnation from the early 2000s to the late 2000s where both the number of vehicles and stations either dropped or were relatively stagnant; and 4) a second growth period starting in the late 2000s after a boom in shale gas production and significant Federal funding of vehicles and stations. Seisler (2014) has plotted this history as shown below:

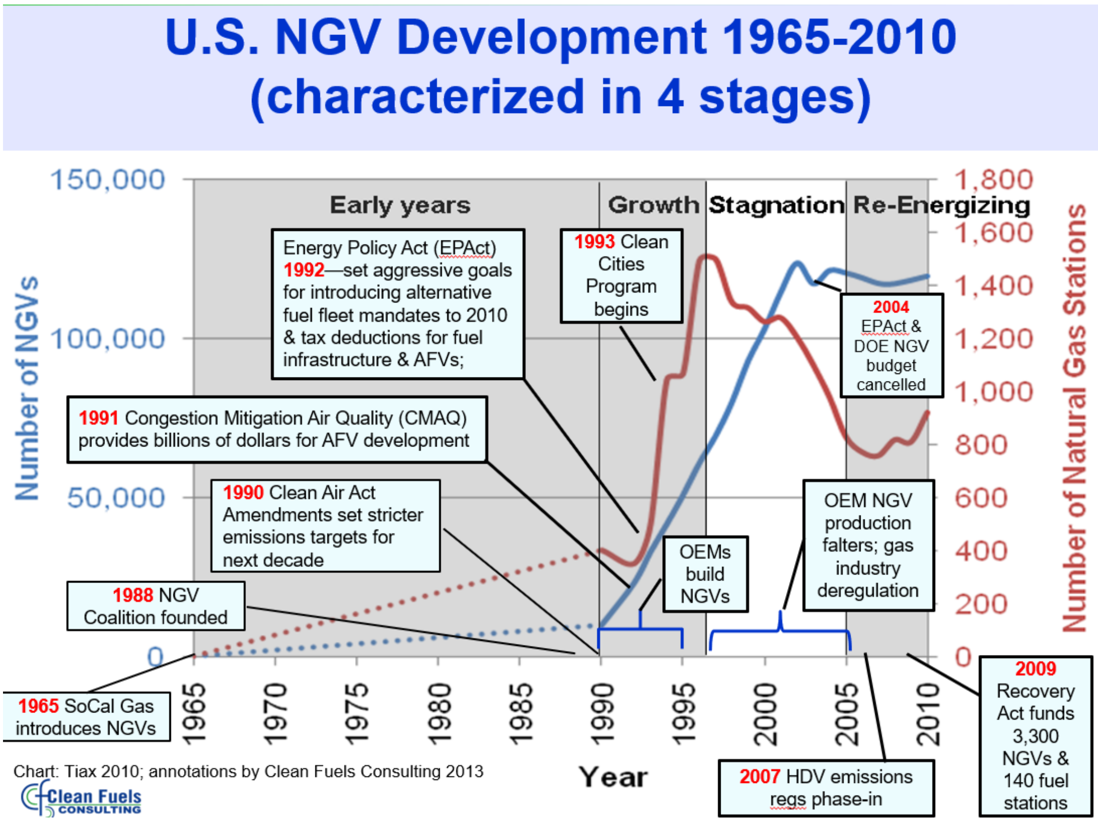

Figure 29: US NGV development 1965-2010[156]

156 Seisler 2014

Early Years (1965-1990)

The first substantial initiatives to bring NGVs to the market were private, primarily gas utilities incorporating NGVs into their own fleets but also attempting to get their customers to adopt such vehicles. In 1969, the Southern California Gas Company (SoCalGas) imported Italian conversion systems to convert its company vehicles to natural gas. The California Public Utility Commission did not allow SoCalGas to count the conversion costs of customer vehicles as utility costs, so SoCalGas formed the Dual Fuel Systems company to convert customer vehicles. However, the company was unable to provide the full range of conversion, downstream maintenance, and servicing to customers, and CNG fueling stations were limited because the utility regulators refused to allow SoCalGas to count those investments as utility costs. As a result, the effort remained small in scale[157].

Another private effort was the 1988 formation of the Natural Gas Vehicle Coalition (NGVC), which created U.S. standards for CNG cylinders and a common fuel connector, advocated for policies for NGVs in the 1990 Clean Air Act Amendments and the 1992 Energy Policy Act, and undertook research that helped U.S. automakers to launch original equipment maker NGVs[158]. These private efforts led to about 10,000 NGVs on the road in 1990, mostly light-duty vehicles (LDVs) in gas utility fleets.

Acceleration Period (1990-1997)

Starting in the late 1980s, the U.S. government took several legislative actions that promoted increased use of alternative fuels by highway vehicles.

An early Federal effort aimed at alternative fuels was the 1988 Alternative Motor Fuels Act (AMFA), which awarded credits to auto companies to count NG use as a subtractor to gasoline use in estimating their Corporate Average Fuel Economy (CAFE) value; in other words, automakers could offset a less efficient (than required) gasoline fleet by selling NG or other alternative fuel vehicles[159]. Despite a credit for NGVs of 300 miles per gallon toward CAFE credits, the initiative did not spark enthusiasm among the U.S. automakers at that time to build more NGVs.

Beginning in 1989, the Urban Mass Transit Administration within U.S. Department of

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[157] TIAX, 2010

[158] TIAX, 2010

[159] Congress 1988

Transportation began providing grants for NG transit buses[160]. Further supporting and expanding this initiative, the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) provided funding for Congestion Mitigation and Air Quality (CMAQ) projects[161]. NGVs, with an emphasis on transit and school buses, qualified for this funding and these efforts resulted in a significant increase in awareness about natural gas buses by municipalities.

The 1990 Clean Air Act Amendments (CAAA) set standards for non-methane hydrocarbons that benefited NGVs. Under CAAA, the U.S. Environmental Protection Agency (EPA) set National Ambient Air Quality Standards (NAAQS) and identified areas that exceeded ozone and particulate matter (PM) thresholds. NAAQS allowed states to take credit for promoting the use of alternative fuel vehicles (e.g. NGVs) that emitted lower ozone precursors and PM[162].

The Energy Policy Act (EPAct) of 1992[163] set targets for the displacement of petroleum fuels, and the increased production of AFVs, while also requiring government fleets, utilities, and private fleets of 10 or more vehicles to acquire AFVs. The percentage of new vehicles purchased in 1999 that were to be fueled by alternative fuels was 90% for energy providers, 75% for Federal fleets, and 50% (later raised to 75%) for State fleets[164]. From 1993 to 2004, nearly 31,000 NGVs were purchased by regulated fleets, about 2,500 per year.

EPAct provided funding to offset the increased cost of AFVs to its federal agencies and tax incentives to private entities for infrastructure investment and AFV purchases: tax deductions for conversions of up to $2,000 for LDVs, $5,000 for MDVs and $50,000 for HDVs, and up to $100,000 for fueling station construction. The Act also required the U.S. Department of Energy to start funding NGV engine and storage research and development. At about the same time, the state of California increased funding for NGV R&D.

Also as part of EPAct, the U.S. Department of Energy launched the Clean Cities Program in 1993 to provide informational, technical, and financial resources to EPAct-regulated fleets and voluntary adopters of alternative fuel vehicles. The Clean Cities program has funded projects relating to NGV deployment, NG refueling infrastructure development, and NGV related training. Since 2009, the program provided $255 million for NGV-related projects (some included multiple

[160] TIAX 2010

[161] Congress 1991

[162] EPA 2017

[163] Congress 1992

[164] Seisler 2014

fuels), which resulted in $425 million in cost share by non-federal funding sources[165].

These measures yielded a sharp spike in NGVs on the road beginning a few years later, as both light-duty and heavy-duty OEMs began developing bi-fuel and dedicated natural gas engines, including:

- 1991: Chrysler with 25 dedicated vehicles
- 1992: 40 Ford Crown Victoria demos, 41 additional in 1993 for lease
- 1992: GM Sierra bi-fuel pickups (2,500 for model years 1992-93)
- 1993: Cummins L-10 engine certified for transit buses
- 1994: Detroit Diesel Series 50 8.5-L engine certified for buses and trucks
- 1994: Ford bi-fuel pickup (dedicated pickups introduced in 1997)
- 1995: Cummins B 5.9-L engine certified for buses and trucks
- 1995: Chrysler offers full size van and minivan to fleets and public
- 1998: Honda Civic GX CNG (available through 2015)

Stagnation (1997-2005)

By the early 2000s, light-duty NGVs accounted for a large portion of NGVs largely due to EPAct purchases. However, EPAct fleets began purchasing flexible fuel LDVs (50,000 between 1997 and 2005) designed to operate on up to 85% ethanol, but in reality were operated on gasoline. This allowed these fleets to meet their requirements at a low cost, significantly reducing the demand for NG LDVs. At this time, most U.S. automakers stopped manufacturing light-duty NGVs due to lack of purchase from both public and fleet customers, resulting from the high cost of storage tanks, high cost of home refueling stations, and the limited public refueling network. The EPA also tightened certification requirements for conversions, eliminating many of the conversion systems suppliers. In addition, deregulation of gas utilities reduced incentives for the new entities to support NGVs as a public service.

Re-energizing (2005+)

Despite the stagnation and eventual decline of the light-duty NGV market, interest in heavy-duty NGVs, especially transit buses, continued to be strong. For example, the number of light-duty NGVs in EPAct regulated fleets dropped from 34,800 in 2003 to 6,500 in 2017, while HDVs increased from 14,700 to 19,800 over the same time. Several policies were enacted that

[165] Clean Cities 2019

supported heavy-duty natural gas vehicles with intense duty-cycles and the potential for reduced emissions. For example, in 2005, an updated Energy Policy Act provided tax credits (considerably more valuable than earlier tax deductions) for qualified heavy-duty AFVs, including CNG and liquefied natural gas (LNG) vehicles, ranging from $2,000 to $32,000[166]. The 2005 EPAct also paid 30% of the cost, not to exceed $30,000, of NG fueling equipment installed between January 1, 2006 and December 31, 2017. The Safe, Accountable, Flexible, Efficient Transportation Equity Act of 2005 (SAFETEA-LU) provided a tax credit of $0.50 per gasoline gallon equivalent (GGE) of several alternative fuels, including CNG and LNG, between October 1, 2006 and December 31, 2009. The tax credit was extended retroactively in separate legislation each year until finally expiring December 31, 2017[167].

The EPA adopted stringent emission standards on heavy-duty engines, which took effect in 2007 for PM and were phased-in between 2007 and 2010. Natural gas engines were the first to meet the standard and were able to do it using a simpler aftertreatment system (three-way catalyst). Diesel required advanced aftertreatment systems (i.e. diesel particulate filter and selective catalytic reduction) that added significant costs to these engines, narrowing the incremental cost for NGVs. In addition, the California Air Resources Board (CARB) optional low-NOx standards for heavy-duty NO_x emissions took into effect in 2014. Several natural gas engines have met these standards, which have made them eligible for clean vehicle funding in the state.

Renewable Natural Gas

EPAct of 2005 created the Renewable Fuels Standards (RFS) program, which was significantly expanded in the 2007 Energy Independence and Security Act (EISA), whereby the long-term goal of 36 billion gallons of renewable transportation fuel by 2020 was set. In addition, EISA established mandatory GHG reduction thresholds for the four categories of renewable fuels allowed in the program. In 2014, the EPA certified that renewable natural gas (RNG) qualified for the most valuable category, cellulosic biofuel. Under this category, the renewable fuel credit of RNG has been worthy of $1.00-$3.00 per GGE over the past five years in the market where these credits are traded. In addition, California instituted the Low Carbon Fuels Standard (LCFS) in 2009 to reduce the greenhouse gas emissions in transportation in the state, through a system of fuel credits and deficits based on their GHG intensity. LCFS credits depend on the type of RNG feedstock but have been worth about $3.00-$5.00 per GGE.

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[166] Seisler, 2014

[167] AFDC 2019f

RNG production has also been supported by the Rural Energy for America Program (REAP), which had its start in the 2002 Farm Bill. REAP provides grants of up to 25% and loan guarantees of up to 75% of the total cost of commercially available RNG production systems, like anaerobic digesters. The RNG grants are capped at $500,000 and the loan guarantee is capped at $25 million per applicant. Moreover, grants are offered to organizations that help farmers, ranchers, and small businesses operate these RNG projects.

These incentives, especially the RFS and LCFS, have created substantial development of RNG resources, growing from about 2 million GGE in 2011 (LCFS) to 200 million GGE in 2018 (RFS). Due to these incentives, fuel providers typically provide RNG at similar costs to fossil NG, which is a major benefit for fleets working to lower their GHG footprint.

State Incentives

While there are no longer direct Federal tax incentives, many states provide incentives for NGVs including Texas, California, Colorado, Oklahoma, Pennsylvania, and Utah[168]. The Texas Emission Reduction Plan (TERP) provides financial incentives to reduce vehicle emissions, with its NGV grant program providing more than $53 million between 2016 and 2019. California's Carl Moyer Program has provided nearly $1 billion since 1998 to promote cleaner than required engines and equipment. In addition, under its Public Interest Energy Research (PIER) program, California Energy Commission has developed a Natural Gas Vehicle Research Roadmap that provides funding for NGV engine, storage, and infrastructure research and development (CEC 2009). In addition to improving NGV market penetration and NGV refueling infrastructure within California, the results of this research and development program would help further the cause of NGVs in other states.

Technical Challenges for NGVs

Fuel Properties

In the U.S., methane (CH_4) constitutes a majority (87-96%) of NG while ethane (C_2H_6) and other gases constitute the remainder. Most U.S. NG pipeline providers claim methane contents between 93% and 95%. NG has very low energy density and needs to be either compressed or liquefied to provide adequate onboard vehicle storage. CNG is usually compressed to a pressure of 3600 pounds per square inch (psi) and stored in cylinders on NGVs. LNG is cooled to -260°F and stored in double walled, vacuum insulated tanks. Both CNG and LNG onboard storage add substantial costs to NGVs, while also causing refueling infrastructure to be much

[168] AFDC 2019f

more expensive to build than for petroleum-based fuels.

Fuel Cost

As seen in Figure 30, CNG prices have remained relatively steady (about $2.00 per GGE from 2005 to 2018), as the NG commodity cost is a relatively small portion, about 10-15%, of the fuel's price. In contrast, for petroleum fuels the commodity cost can account for 60-80% of the fuel's price and can cause significant price volatility[169]. Thus, in times when the price of crude oil drops, the incremental price advantage NG is diminished, as is interest from fleets in purchasing NGVs. However, this price volatility has more often been in CNG's favor, with higher oil prices pushing the interest in NGVs. LNG costs about $0.50 per GGE higher than CNG, which, coupled with higher costs for fuel stations, has limited its appeal.

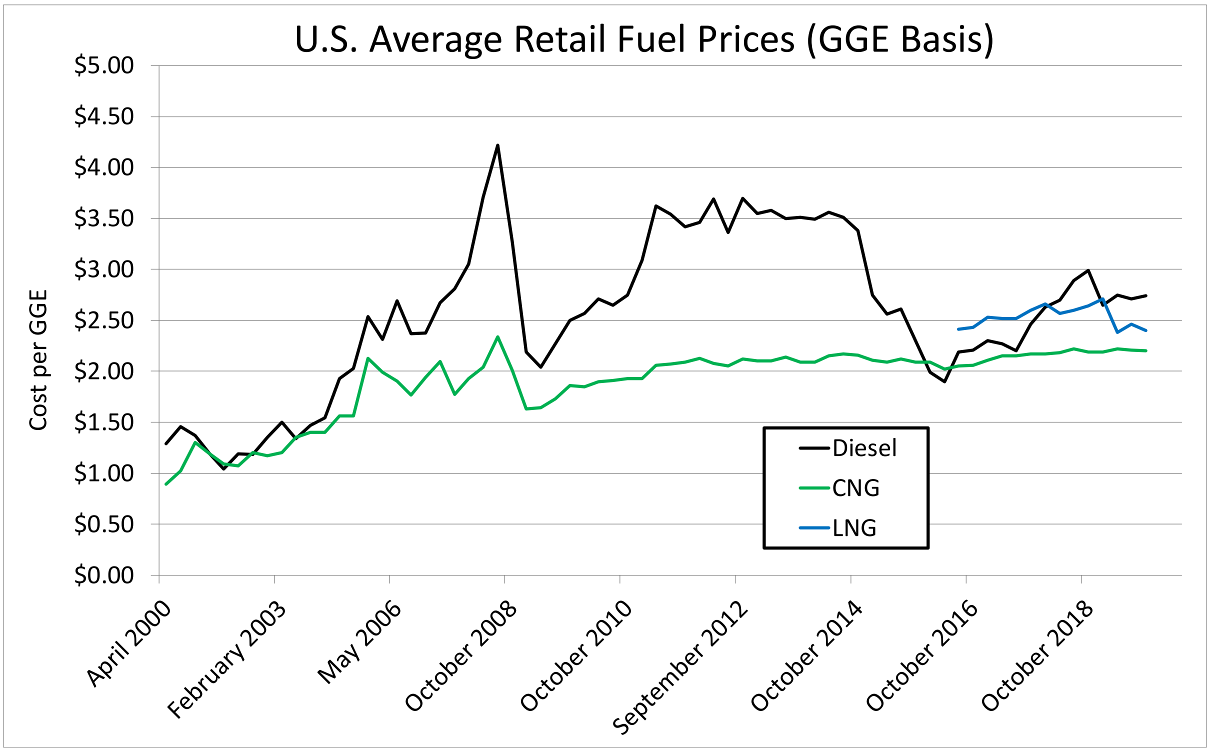

Figure 30: Natural Gas and Petroleum Public Station Fuel Prices[170]

Many private NGV fleet owners have installed their own CNG fueling infrastructure and experience prices lower than the above-mentioned prices at public stations. Fuel prices vary by geographic regions due to varying local fuel quality requirements and/or taxes. For example,

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[169] Ward 2012

[170] AFDC 2019b

California consistently has higher diesel prices.

Refueling Infrastructure

CNG refueling involves delivery of low-pressure NG through pipeline to the stations, compressing it to high pressure and storing in tank(s), and then dispensing to NGVs. LNG is delivered by trucks to refueling stations from LNG production facilities, stored in insulated tanks, and delivered to NGVs. As of 2019, there were 895 public and 696 private CNG refueling stations, a total of 1591; and 64 public and 55 private LNG refueling stations, a total of 119[171]. LNG stations are located in areas that serve long-distance heavy-duty LNG-powered trucks. The private stations support fleet operations and NGVs that start out from and return to the base, such as transit buses and refuse trucks.

The high cost to build and operate NG fueling infrastructure is a barrier to increased NGV adoption. A large fast-fill CNG station can cost $1 million or more, primarily because high-flow compressors are expensive and failure-prone, necessitating redundant units and/or additional storage. Depending on the duty cycle of fleet vehicles, cost reduction of CNG stations is possible (~20%) by using a combination of slow-fill and fast-fill fueling.

LNG stations have similar cost challenges, as capital costs remain high ($2 million or more per station). Large public stations typically require an anchor tenant with guaranteed large fuel requirements to make economic sense. In addition, fleets using HDVs are often capital-constrained, so investing in private stations can be a risky endeavor.

Vehicle Cost/Performance

As mentioned previously, light-duty NGVs are not currently offered by any automakers in the U.S., requiring their acquisition through aftermarket conversions. In addition, only one major U.S. automaker currently produces heavy-duty NG engines. The lack of automakers is caused by a variety of factors: the high cost of on-board NG storage, including both the cost of the tanks and the cost of adapting vehicles to their shape and weight; and the lack of a refueling infrastructure, which limits the market for the NGVs. CNG tanks vary in cost and design, including full metal (typically steel) construction (Type 1), hoop-wrapped composite with a metal liner (Type 2), full composite wrap with a metal liner (Type 3), and full composite wrap with a plastic liner (Type 4). Going from Type 1 to Type 4, the weight of the storage tank decreases but the cost increases substantially.

In the U.S., weight and space are important considerations; thus, NGVs typically use the lightest

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[171] AFDC 2019h

types of tanks (e.g., Type 3 and Type 4). Even at 3,600 psi, CNG has a lower energy density than either gasoline or diesel, so vehicle range is reduced unless the vehicle carries a significant number of cylinders. A typical HD CNG freight truck costs $40,000 more than its diesel counterpart, with a 400 mile CNG tank package costing about $35,000; while a diesel fuel tank providing equivalent range costs less than $1,000[172]. Moreover, the rated life of CNG tanks range from 15 to 20 years, while many fleet vehicles are operated for 25 years. LNG is used by HDVs requiring extended range, as it has a higher energy density than CNG and can obtain ranges of as much as 1000 miles with a 2-tank package. However, they are about as expensive as CNG vehicles of similar range, e.g. fuel systems cost about $30,000 for a 400-mile tank package.

In the past few decades, NG engines have undergone significant changes in their performance, emissions, and fuel economy. Testing has shown that spark-ignited NG engines have a lower efficiency than compression ignited diesel engines because of their lower compression ratio, slower combustion speeds, and need for throttling at partial loads. Currently available NG engines have exhibited improved fuel economy (but still 10–15% reduction in fuel economy versus diesel) compared with older NG models (20–25% reduction versus diesel), largely owing to the introduction of closed-loop control and optimization of the air-fuel control system. Nonetheless, the gap in efficiency between NG and diesel for HDVs continues to negatively impact the economics and environmental performance of NGVs.

Environmental Issues and Safety

Historically, the development and adoption of NGVs has been closely associated with NG's ability to provide environmental benefits; however, strict air pollutant emission standards for both LDVs and HDVs have forced conventional vehicles to develop advanced engine controls and aftertreatment systems to meet them. As a result, the emissions gap between NGVs and gasoline and diesel vehicles has narrowed. However, recent research suggests heavy-duty NGVs can have large in-use NO_x benefits in certain duty-cycles, driving NGV interest in California, which faces significant air quality concerns[173].

NGVs can reduce greenhouse gas (GHG) emissions because NG has a lower carbon content than petroleum fuels. However, methane leakage in the supply chain and to a lesser extent from the vehicle reduces the potential benefit when using fossil NG to GHG reductions of ~5-15%

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[172] Deal 2012; 4 State Trucks 2018

[173] Burnham, 2015

versus gasoline vehicles[174]. However, RNG-fueled vehicles achieve large well-to-wheel GHG reductions, ranging from 80-115% depending on the RNG's feedstock.

Similar to other transportation fuels, NG is flammable but due to its gaseous nature, it has different safety challenges than petroleum fuels. The National Fire Protection Association (NFPA) has developed safety requirements for CNG and LNG storage, dispensing, and vehicle maintenance. The Federal Motor Carrier Safety Administration (FMCSA) within the U.S. Department of Transportation evaluated 138 NGV safety related incidents during the period 1999-2009[175]. A majority of the incidents involved cylinders being weakened by road debris and/or other direct impact. Reports of cylinder and fuel line failures created negative publicity for NGVs and affected consumer acceptance. FMCSA found that most of incidents were due to human error, ignorance, neglect, or mishandling.

Consumer acceptance

In the U.S., the personal use of NGVs is basically non-existent. When Honda introduced its NG version of Civic in 1998, initial annual sales were around 3,000. However, sales declined quickly and Honda discontinued the NG version of Civic in 2015. The high cost of the vehicle storage tank and relatively low usage of personal vehicles (which makes significant fuel savings difficult to achieve), damages the economics of these vehicles. In addition, the reduced cargo space, high cost of home-refueling appliances, sparse public refueling infrastructure are reasons for lack of interest in NGVs for personal use. Light-duty vehicles in fleet use with high annual fuel consumption are a better market for NG. This can be seen by the fact that the vast majority of conversion options for LDVs are pickup trucks and cargo vans for use in fleet applications, with passenger cars typically being converted to high fuel use applications like police and taxi fleets[176].

While LDV use has decreased, the heavy-duty NGV population has increased over the past decade. NGV's environmental benefits and potential for stable and low fueling costs lead first to interest from fleets that return to central bases, which could take advantage of lower cost time-fill fueling stations. That is the case for transit buses where NGVs recently accounted for about 20% of fuel use and 25% of new bus sales, and refuse trucks where they accounted for about 50% of new refuse truck sales[177]. As natural gas supply increased in the late 2000's and diesel

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[174] Burnham, 2018

[175] FMCSA 2013

[176] EPA 2019

[177] APTA 2014; Boyce 2013

prices simultaneously increased, regional haul freight truck fleets began to have significant interest in NGVs. In 2015, diesel prices dropped significantly, which slowed NGV adoption in trucking.

Historical and Current Market Penetration

By 1990, there were approximately 10,000 NGVs and almost 400 CNG stations. These were primarily after-market, converted bi-fuel vehicles operating mostly on natural gas; about 95 percent were LDVs, mostly in gas utility fleets. In 1996, there were nearly 55,000 NGVs and more than 1,250 CNG stations[178].By 2005, the number of NGVs had increased to 130,000[179]. Currently there are about 175,000 NGVs in the U.S.[180]. As mentioned previously, the growth in NGVs recently has been in HDVs, as there were only about 30,000 light-duty NGVs as of 2017[181]. For example, the number of transit buses fueled by CNG, LNG and blends rose from about 10,000 in 2007 to over 16,000 in 2015[182].

As a result of this shift in vehicle size, the amount of energy used by the NGV fleet has increased dramatically. Although lack of data precludes comparing the total national fleet, the Clean Cities NG fleet increased from about 76,000 vehicles in 2004 to 104,000 vehicles in 2017, an increase of 36%. On the other hand, the increase in energy shifted from petroleum-based vehicles by that fleet was 89 million GGEs in 2004 and 486 million GGEs in 2017, an increase of 448%, implying a major shift to HDVs[183].

These NGV numbers for the U.S., while significant, represent a very small fraction of the U.S. fleet of over 263 million registered light- (251 million excluding motor cycles) and heavy-duty (12 million) vehicles in 2017[184].

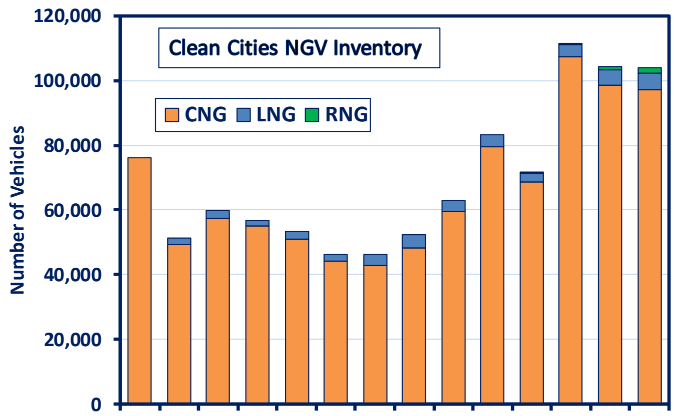

Figure 31: Inventory of Clean Cities Program Funded NGVs[1]

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178 TIAX 2010

179 Seisler 2014

180 NGVA 2019

181 AFDC 2019i

182 AFDC 2019i

183 AFDC 2019i

184 FHWA 2019

Policy Effectiveness

Successes

Among the various policies implemented by the U.S. government, the 1992 EPAct and research projects by the U.S. Department of Energy (DOE) have been successful. The 1992 EPAct required NG utilities, government fleets, and private fleets with 10 or more vehicles to have an increasing percentage of their vehicles powered by alternative fuels. This requirement, along with several regulations providing incentives, caused the NGV population to increase from a few thousand in 1991 to over 100,000 by the early 2000s[185]. EPAct would have been even more impactful without loopholes in the legislation, such as exempting fleets due to vehicle and infrastructure availability. DOE funded research to develop improved NG engines and CNG tanks. This research has helped increase the number of NG engine offerings and produce lighter CNG storage tanks.

The State of California has instituted policies to restrict smog-forming vehicular emissions, such as its heavy-duty low-NOx standards, and simultaneously offered incentives for AFVs that could meet these policies. Their incentive programs are a major reason why the state has the largest number of NGVs in operation. The ongoing California Energy Commission's NGV research and development program has improved NGV attractiveness within the state. In addition, California has passed laws that promote vehicular methane emissions reduction and encourage increased production of RNG. EPA's RFS program and California's LCFS program provide credits for RNG production and use. RNG production has increased to 304 million ethanol equivalent gallons by 2018[186]. Aside from qualifying as a renewable fuel under RFS, RNG provides substantial GHG emissions benefits.

Challenges

The U.S DOE has identified the key technical and economic challenges to further the use of NGVs in transportation, including: (1) high onboard storage cost and limited range; (2) high NG fueling station cost; and (3) modest NGV engine efficiency[187]. An economic case for light-duty passenger NGVs is challenging and would require major technical breakthroughs on storage. The economic case for heavy-duty vehicles is much stronger due to the potential fuel savings in

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185 Seisler 2014

186 Bates White 2019

187 DOE Forthcoming

high-use applications. However, a large percentage of HDVs move freight, which is a low margin business. Therefore, the high cost of onboard storage is still a major challenge to these capital-constrained businesses, especially at times of low petroleum fuel prices. The DOE has identified R&D opportunities that can address major technical challenges, with a focus on reducing NGV total cost of ownership of NGVs.

Table 26: Data sheet Natural Gas in the United States

	Value	unit
consumption of fuel	2018 = 50 Billion cubic feet = 440 million GGE = 0.2% of highway fuels (energy basis); 130 million GGE of th total was RNG	EIA 2019c; CARB 2019
number of vehicles	175,000 in total (30,000 LDV & 145,000 HDV)	NGVA 2019; AFDC 2019i
market share of suitable vehicles	0.07% in total (0.01% LDV & 1.3% HDV)	FHWA 2019
GHG savings achieved	2018 = ~1.4 million tons	EIA 2019c; CARB 2019; GREET 2019
local emission savings	2018 = ~5000 tons of NOx	EIA 2019c; CARB 2019; GREET 2019
energy savings	2018 = ~400 million GGE of petroleu displaced	EIA 2019
production costs of fuel	$2 per GGE for CNG (including compression cost)	AFDC 2019g
quantity of produce fuel in the country	2018 = 30,600 Bcf	EIA 2019c

Lessons Learned

The lessons learned from U.S. experience with NGVs can be summarized as follows.

There are strong barriers to moving natural gas into transportation markets – the strength of the current petroleum-based vehicle and fuel infrastructure; high vehicle and refueling station costs; and the “chicken and egg” problem of introducing a new fuel, in which (at first) new fueling stations may face years of inadequate demand whereas new vehicles may face an inadequate refueling infrastructure. Strong policies would be needed to overcome these barriers.

- Of the three primary reasons for introducing NG to the vehicle fleet – fears of petroleum dependency, the need for reducing vehicle health-related emissions, and the desire to reduce emissions from the vehicle fleet – the first two have become less important due to new U.S. oil production and major improvements in fuel quality and emissions control performance of conventional vehicles. However, continued concerns about diesel emissions do continue to provide an incentive for NG and other alternative fuels for heavy-duty vehicles.
- Policies to increase market share are most effective when part of a long-term comprehensive strategy that uses both financial and non-financial incentives. Mandates, such as EPAct can work; however, they are always best implemented along with incentives in early introduction stage. Financial incentives should be reduced gradually over time, instead of at once to make sure the fuel and vehicle industries are not dislocated. Tax incentives for fuel and vehicles have often lasted only for a few years and then allowed to expire, while then being re-instituted retroactively for the previous year. This makes it difficult for potential buyers to properly plan.
- Having a Federal program aimed directly at supporting deployment of NGVs helps to build partnerships between private and public stakeholders and provide unbiased information to those stakeholders and the general public. Government must also play a strong role along with industry in developing, implementing and enforcing standards for safety, emissions, component testing and other aspects of AFV commercial development. NGV experts we talked to pointed to Clean Cities Program as the most beneficial program motivating the growth of NGVs.
- Having a robust private coalition for an alternative fuel can enhance the probability of a successful rollout by creating vehicle and refueling standards and by advocating for State and Federal incentives.
- The role of utility regulators can be crucial to the success or failure of an NGV rollout. For example, SoCalGas’s effort was hindered by the unwillingness of its regulator to

allow it to count refueling station costs and conversion costs for private vehicles as part of its utility costs.

- Heavy-duty fleets are the most attractive targets for natural gas because their high fuel use can lead to significant operational savings from low price NG. However, in many cases, the economic arguments for NGVs are a challenge due to the high cost of the vehicles. In addition, fluctuations in oil prices can have strong impacts on the enthusiasm for such vehicles.

Infobox 25: Key drivers of successes and key barriers of failures

Successes
- Federal policies were successful in developing the initial market for NGVs
- Federal research improved NGV technology, specifically engines and storage tanks
- The State of California emission standards and incentive programs increased the adoption of NGVs due to their low emissions
- Federal and California programs have provided significant incentives for the production and use of renewable natural gas, due to RNG's significant GHG emissions benefits

Challenges
- High onboard storage cost and limited range reduce NGV demand, especially when petroleum fuel prices are low
- High NG fueling station costs are an impediment to capital constrained businesses
- Lower NGV engine efficiency compared to diesel impacts the potential fuel savings from NGVs

U.S. Case Studies Lessons Learned and Recommendations

Gasoline and diesel vehicles perform well, are highly reliable, have a robust repair infrastructure, and have very good range due to their high energy content. In addition, their refueling infrastructure is ubiquitous. In contrast, newly introduced alternative fuel vehicles may at first be less reliable than their gasoline and diesel counterparts because they will have had far less opportunity for "learning;" they may have a lesser repair infrastructure; and, unless home refueling is an option, in the early years of deployment they will have far fewer refueling options (except for niche or fleet vehicles that stay close to home). The familiarity with petroleum-based fuels and likely difficulties adjusting to a new fuel affects fuel suppliers, vehicle manufacturers, consumers, and the infrastructure of fuel retailers, repair facilities, and even fire departments.

Fuel marketers may have little incentive to cooperate with the rollout of an alternative fuel. In the early years of a rollout, there will be few customers to support the expensive new refueling infrastructure, and there will be uncertainty that sufficient customers will ever appear. Any problems that arise from lack of experience with the new fuel will be magnified by the comparison with the current system. Oil companies' immense sunk costs in the existing petroleum system virtually guarantee that they will continue to embrace existing fuel production and distribution. Similarly, auto companies have little incentive to embrace a new fuel that may require major new investments and may create unforeseen problems with maintenance and reliability.

The difficulties of replacing petroleum-based fuels with an alternative fuel implies that strong advocacy must be present for a replacement to have any chance at all, typically the environmental and domestic fueling groups. Incentives are crucial for the early demonstration and deployment of AFVs as they need to be cost-competitive with petroleum-based fuels even in the early stages. As the alternative fuel technology matures, incentives can gradually be reduced. Finally, government vehicle and fuel research, development, and demonstration is needed to reduce costs and improve performance of an alternative fuel to create the opportunity for it to be successful in the marketplace.

Results - Comparative Analysis of all case studies

This chapter first lists the country specific implementation barriers and lessons learned country by country. Then the implementation barriers are summarized. The importance of stakeholder interaction and the results from the expert workshop are each presented in a specific subchapter.

Country Specific implementation barriers and lessons learned

The case studies reveal implementation barriers for the market launch of alternative fuels and vehicles and lessons learned. Our project tried to identify barriers to the market launch of alternative transport fuels from our findings and the specific market launch examples in the respective countries. In the following paragraphs the country specific implementation barriers and the country specific lessons learned and key messages are described. This part of the report was also used for the Report on Deployment Barriers and Policy Recommendations in the project AMF Task 58 "The Role of Renewable Transport Fuels in Decarbonizing Road Transport"[188].

Austria

In Austria the introduction of E10 was stopped weeks before market entry. The main implementation barriers were the public discussion on food vs. feed vs. fuel and a discussion on engine compatibility. In addition, the reactions of the market introduction in Germany influenced the public opinion.

Another case study dealt with CNG vehicles. They were successfully introduced into the market but due to missing acceptance of the general public the number of vehicles and gas stations currently decreases. These two case studies indicate that the public opinion and acceptance as well as the political will are essential for a positive market implementation.

Lessons learned from case studies in Austria:

- A long-term political commitment for the market introduction of alternative fuels and vehicles is necessary.

[188] AMF Task 58 / IEA Bioenergy Task 41 Project 10 - Deployment Barriers and Policy Recommendations

- There is the need to involve all stakeholders along the value chain into the process of market implementation.
- A carefully created set of measures should provide benefits to all stakeholders.
- The public opinion is of greatest importance for a successful market implementation – information campaigns are needed.
- For decarbonizing the transport sector, it is essential to seize all opportunities and technologies for GHG emission reduction, also including short-term applications. In future there should be a broad mix of alternative drive systems and fuels.

China

Lessons learned from case studies in China:

- Compared with the projected demand of ethanol fuels, the current production capability is relatively low. This implies the concern regarding policy uncertainty in the future.
- The possible variabilities in grain stock and concerns about food security could be barriers for central and local governments to implement further policies and supplementary actions to promote ethanol fuels.
- The current price of bio-ethanol is not favorable. Supervision mechanisms should be developed to prohibit coal-based ethanol from the market.
- Acceptance by gasoline producers and consumers need to be improved.
- Specifically, governmental officers in environmental authorities have their concerns about the increase of evaporative emissions and uncertainty in NO_x emissions, which lead to a concern on ozone and SOA (secondary organic areasols) issues.

Finland

In Finland the main implementation barriers are a tax problem and the availability of FFVs (Flex Fuel Vehicles). On the EU level, minimum taxes are set in €/l. Finland has a transparent and fair tax system for liquid fuels consisting of energy tax, CO_2 tax and bonus for reduced local emissions. This system also considers heating value and CO_2 emission. The EU minimum tax is higher than the Finnish tax system sets and therefore unfair for some biofuels (with a low heating value). This tax problem makes commercial utilization of some kinds of biofuel impossible. In Finland E85 is available in most parts of the country. However, sales of E85 has stagnated, as there is no offering of new flex-fuel vehicles anymore.

The Finnish case study is an example of successful implementation of biofuels including factors as consistent policy, funding on R&D in the area of biorefining, investment aid to demonstration of biorefinery concepts, structural changes to the energy tax system and enhancing the development of a biofuels market by a biofuel obligation.

Lessons Learned from the Finnish case study:

- The triple-helix approach (government, industry, academia) has contributed to the success of biofuels in Finland
- Technology neutrality and cost effectiveness are important when promoting low carbon fuels
- Criteria for performance should be set, including environmental performance as well as cost competitiveness

Japan

The implementation barriers found in Japan can be divided into legal issues, consumer (market)-driven policies and external factors. In Japan the Quality Assurance Law and Alternative Fuel Law were enacted to spread biofuels in Japan since 2010. However, these laws do not force the introduction of alternative fuels, they only create the possibility and set the framework and standards. If the introduction is not obligatory, incentives that make consumers feel more attractive to the introduction are necessary, but incentives were missing for biofuels for consumers. The external factor was the nuclear accident in 2011, since then the top priority is on securing electric power supply, and the spread of biofuels has a low priority. This shows how important policy measures are and that they have to interlock to overcome this first big peak of implementation barriers.

Lessons Learned from the case studies in Japan:

- Greater awareness of air pollution improvement in society (transportation companies, shippers, automobile manufacturers, government etc.) is a key factor of success
- In a free competition market, cost, supply stability, and convenience of alternative fuels are important compared to conventional fuels.
- In a free competition market, it is very important to provide attractive products to customers in a timely manner according to the needs of society.
- Otherwise, it will be necessary to introduce a strong policy in a regulatory way.

Sweden

The reduction obligation in Sweden is very dependent on availability and price of drop-in fuels and sets both a floor and roof on the use of biofuels for low blends. There are no incentives to go above the reduction obligation. The fuel tax exemption for biofuels is not in line with EU regulation and therefore very short term and can only be given if biofuels are more expensive than fossil fuels. For E85 the barriers are the small market for dedicated vehicles and negative public attitude combined with reports on technical problems. This shows that knowledge and information are important as well as long-term perspective in policy instruments.

Lessons learned from Swedish case studies:

- It is crucial to establish long-term policies for biofuel and clear ambitions for the reduction of GHG emissions in the transport sector
- Policy instruments are likely to have a better turn-out if they are designed as "package of policies", supporting different areas of the value chain for a renewable fuel – vehicles, infrastructure and use of biofuels
- None of the cases have been particularly successful as incentive for domestic production of biofuels. Other types of measures are probably needed.
- Some of the Swedish policy has not been compliant with EU regulation which probably makes it harder to sustain the policies over time.

USA

In the USA the changing priority of policies and government make a market implementation of biofuels difficult. In the US the societal benefit the government most prioritized has changed over the past several decades. Moving from energy security from oil embargo and energy diversity in the 1970s and 80s to air quality benefits in the 90s. In the 2000s and 2010s the priority changed to GHG benefits and most recently to economic advantages. In addition, the relative societal benefits of alternative fuels have changed because of technology improvements in the baseline (gasoline and diesel vehicles became cleaner and more efficient) and new competing technologies like battery electric vehicles or plug-in hybrid electric vehicles. At the moment with economic advantages prioritized there is a low and fluctuating political driver for alternative fuels.

Lessons learned from the case studies in the USA:

- Policies to increase market share are most effective when a long-term comprehensive strategy uses both financial and non-financial incentives
- Fuel marketers may have little incentive to cooperate with the rollout of an alternative fuel
- Inconsistent societal goals make it difficult for alternative fuels or vehicles to persist on the market
- The building of partnerships between private and public stakeholders and providing unbiased information to those stakeholders and the general public is advantageous
- Arguments for increasing advanced biofuels shares remain strong, because of its property as a net reducer of greenhouse gas emissions

Summary of implementation barriers

The findings regarding implementation barriers from the country case studies were clustered into 5 groups in an echo of the Argonne checklist categories. Many of the implementation barriers are interconnected. Some of the listed points are influenced or even caused by other listed implementation barriers from a different category. The main implementation barriers which could be found in most of the partner countries and some country specific barriers are listed in the following:

Table 27: General and country specific implementation barriers (worked out for Task 58)

Technical issues / Infrastructure
•Assurance of technical performance and compatibility •Availability of dedicated vehicles (e.g. FFV) •Access to repair infrastructure and refueling infrastructure for dedicated vehicles
Politics / Authorities
•Negative basic attitude of politics and push of electromobility •No obligation for alternative fuels •Inconsistent and changing policy and priorities •Lack of long term perspective in policy instruments
Costs / Economics
•Missing incentives for consumers and unclear tax incentives/legislation in future •Investment costs for dedicated vehicles and second-hand value •Alternative Fuel infrastructure cost, production costs and capacity •Comparably low prices for fuels and mobility •Inertia in the market
Consumers / Public
•Missing awareness and/or acceptance in general public •Negative perception in public and fundamental scepticism •Public discussion on Food/Feed/Fuel •Discussion and rumours on engine compatibility •Missing incentives for consumers
Country Specific Barriers
•Austria: Influence of market introduction in Germany (E10) •Finland: transparent and fair tax system versus minimum taxes set on EU level (e.g. ED95 0.16 €/l vs. 0.33 €/l) •Japan: no obligation for alternative fuels, low priority of spreading biofuels •Sweden: reduction obligation sets a roof on the use of biofuels, tax reduction for high blends only when biofuels are more expensive •USA: Economic advantages are prioritized, fluctuating political driver

Stakeholder interaction

The interaction and also the inclusion of stakeholder groups along the value chain within the implementation of alternative fuels and vehicles in the transportation system is very important. This could be seen in literature research (including the Argonne Checklist), during the expert interviews and in some workshops like expert workshop of AMF Task 59[189] but also workshops from AMF Task 58[190].

The Argonne National Laboratory published checklists to assess transitions to alternative fuels[191]. Those checklists are a general guide for conducting analysis of the potential for an alternative fuel. To help the transition process it is important to analyse the needs of the primary stakeholders which are divided into 5 groups (Figure 32). For a successful market introduction the major concerns of all these groups must be addressed. These checklists allow everyone to obtain insights into the priorities and concerns of other stakeholders .

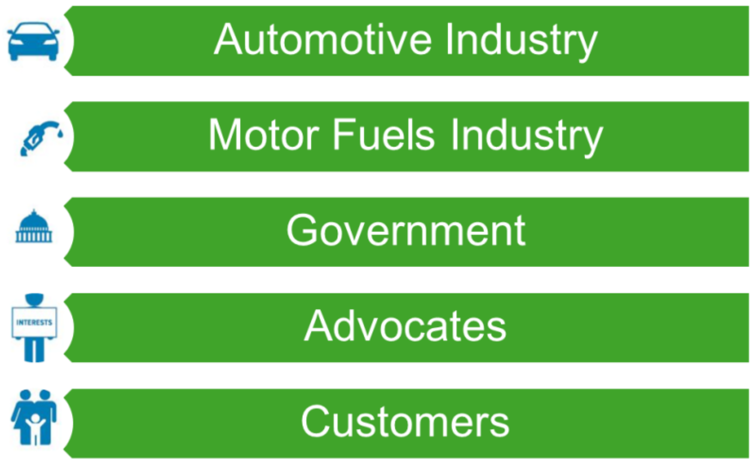

Figure 32: Stakeholder groups according to Argonne checklist

For the AMF TCP these groups were transferred into a system of stakeholders in the established transport sector, shown in Figure 33. This system includes the automotive industry, the fossil fuel industry and fuel marketers, vehicle marketers, and on the customer side the freight sector and private car owners. The policy and political stakeholders are in the center of this system, as they have influence on all other stakeholder groups. Advocates are related to the private car owners since they affect public opinion. This system also includes

[189] AMF Task 59 Expert Workshop

[190] AMF Task 58 Transport Decarbonisation Workshop

[191] Risch, C. E., et al. 2016.

new groups of stakeholders, like the agriculture and forestry with biomass producers and biofuel producers.

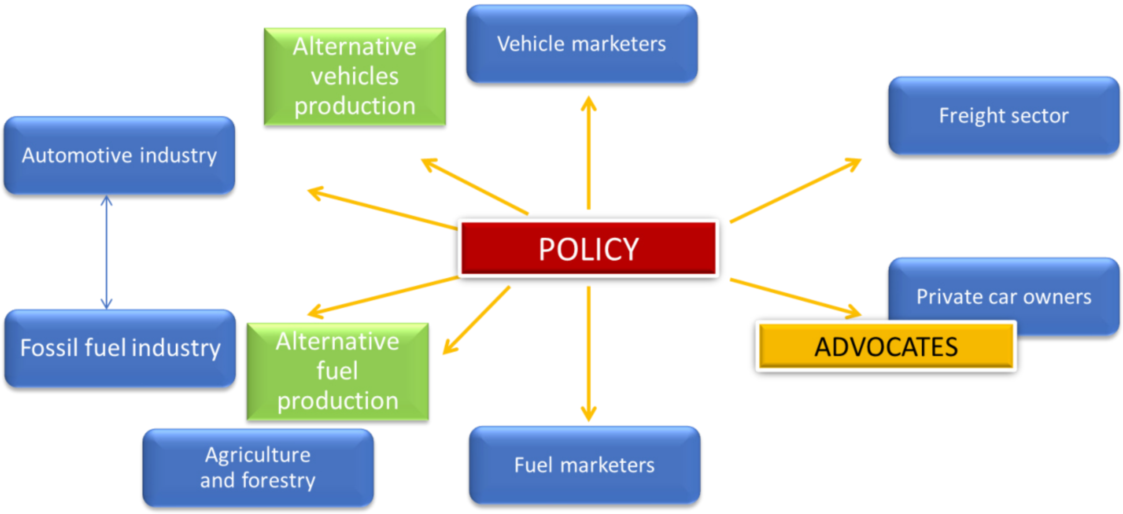

Figure 33: Multitude of stakeholders involved in the market implementation of alternative fuels and vehicles[192]

One result from the work in AMF Task 58 was that the biofuels market depends strongly on political interventions and policy needs to send strong signals and keep up the support for renewable fuels over a long period of time.

With the case studies investigated in AMF Task 59, it was also shown that the inclusion of all groups of stakeholders is of major importance. It is also important to be aware of the fact that each group of stakeholders focusses on other benefits. Therefore, these groups and also the different benefits needed should be included in the planning and implementation process of market introductions of alternative fuels and vehicles.

A key issue is the involvement of all groups of stakeholders, for a general consensus on the importance of measures and also the long-term intention of the measures. Within this context the policy makers should not forget the consumers as the general public opinion is of greatest importance for the success of an alternative fuel or vehicle.

[192] AMF Task 58 / IEA Bioenergy Task 41 Project 10 - Summary Report

Results from the expert workshop

In the expert workshop the case studies from all participating countries and the respective lessons learned were presented. In the discussion the most important points seen in the variety of case studies were discussed. There is the need for long-term policies and comprehensive strategies to really guarantuee a successful implementation of alternative fuels or vehicles. This also needs to be a package of policies and measures with financial and non-financial incentives. Alternative fuels need to show benefits regarding costs, domestic production or convenience compared to conventional fuels. Also the different types of stakeholders are important, they should be involved and gain some kind of benefit from the market introduction of alternative fuels. Small countries can more easiliy bring together all stakeholders. The coordination between government, academia and industry is necessary for a successful implementation. A very important aspect is the public perception. Very few cases of non-compatibility fo the legacy fleet with the new fuel can spoil public perception and thus hinder its market introduction.There is also the need for improving the acceptance within the general public and among other stakeholders by education work and information campaign. Other important issues were the opportunity of international biofuel market and the availability of vehicles and technology.

Lessons Learned and Recommendations

The work on our project and the analysis of the country specific case studies exposed some key findings and lessons learned listed here:

Stakeholder interaction

One of the first insights of the project was the complexity of the interaction of the different stakeholder groups. The **different groups of stakeholders** include automotive industry, motor fuels industry, fuel and vehicle marketers, customers, government and advocates. For a successful market introduction, the major concerns of all these groups must be addressed. All types of stakeholders need to be involved and gain **some kind of benefit** from the market introduction of alternative fuels. The coordination between government, academia and industry is necessary for a successful implementation. There is also the need for improving the acceptance within the general public and among other stakeholders by education work and information campaign.

Implementation barriers

There are many implementation barriers which can occur within, prior to, or after market introduction of alternative fuels. The findings from the country case studies in the AMF Task 59 project were clustered into five **groups of implementation barriers**: Technical issues/Infrastructure, Politics/Authorities, Costs/Economics, Consumers/Public, and Country Specific Barriers. Alternative fuels need to show benefits regarding costs, domestic production or convenience compared to conventional fuels.

Importance of policies

Policies are a very important instrument for transitioning to the future transport system. A constant political driver is necessary to overcome implementation barriers. There is the **need for long-term policies and comprehensive strategies** to really guarantee a successful implementation of alternative fuels or vehicles. This also needs to be a package of policies and measures with financial and non-financial incentives.

Consistent policy and integration of all stakeholders are both necessary to overcome implementation barriers for a successful market implementation of alternative fuels and propulsion systems.

From these findings recommendations could be derived and led to the definition of 3 important pillars for a successful market introduction of alternative fuels: policy, inclusion and benefits.

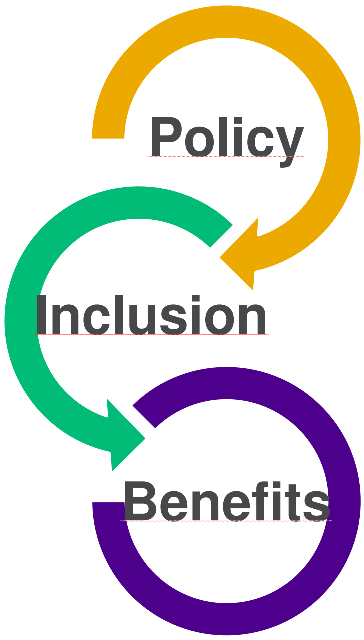

Figure 34: Important pillars created from lessons learned from alternative fuels experience

Policy

- Long-term policies
- Comprehensive strategy
- Package of measures
- Coordination government-academia-industry

The basic pillar is the **policy**. There is the need for long-term policies with a comprehensive strategy. These policies need to be done at national level as well as on EU/international scale. This includes a package of measures with financial and non-financial incentives. Therefore, strong long-term policy is important as well as support of different areas of the value chain – vehicles, the infrastructure and the use of biofuels. Another policy aspect is the coordination of government – academia – and industry within the implementation and also evaluation processes are essential.

The second pillar is called **inclusion**. It comprises points like the involvement of all groups of stakeholders along the value chain. Also, larger or even the international market needs to be included. This is particularly important for small countries with low domestic biofuel production. Several examples from the case studies showed that the perception of the general public on alternative or new fuels is often very bad and needs to be improved. Inclusion additionally means that the future transport system should include different types of alternative drive systems and fuels, suitable for different applications. Existing infrastructure should be used with increased share of renewable drop-in fuels. New fuels and drive systems can complement drop-in fuels.

Inclusion

- Involvement of all groups of stakeholders
- Larger or even international market
- Improving perception of general public
- Different alternative drive systems and fuels for different applications

Benefits

- (Cost) benefits for all stakeholders
- Cost benefits compared to fossil fuels

The prior pillars should lead to **benefits**. It is really essential that there are visible benefits or cost benefits for all groups of stakeholders to make the alternative fuel or propulsion system attractive. At the moment alternative fuels are not price competitive with fossil fuels, because the costs do not include all points; there are no costs for GHG emissions or other climate relevant effects. So it's very hard for alternative or biofuels to be more attractive than fossil ones. What really could drive biofuels is a high price of fossil fuels and a fair price calculation.

Comprising these results to a main conclusion leads us to the following key message of our project:

> For the **successful implementation of alternative fuels and vehicles** in the transport system, there is the need for **long-term and comprehensive policies** which **include markets, stakeholders and different technologies** to gain **benefits for all types of stakeholders** along the value chain.

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Abbreviations

AFV	Alternative fuel vehicles
AMF	Advanced Motor Fuels
AMQDs	Air Quality Management Districts
B5, B7,…	Diesel blends with x% FAME
BDF	Biodiesel fuel
BEV	Battery electric vehicle
BTEX	a hydrocarbon mixture of benzene, toluene, ethyl-benzene, and xylene
BTL	Biomass to liquid
CAAA	Clean Air Act Amendments
CAFE	Corporate Average Fuel Economy
CEC	California Energy Commission
CG	Conventional Gasoline
CNG	Compressed Natural Gas
DDF	Diesel duel-fuel
DDGS	Dry distillers grains and solids, by-product of ethanol production
DME	Di-methyl ether
E5, E10, …	Gasoline blends with x% ethanol
ELA/ELO	E10 with lower aromatics/E10 with lower olefins
EPA	Environmental Protection Agency (USA)
ETBE	Ethyl tert-butyl ether, ethanol-containing gasoline additive
EV	Electric vehicle
FAME	Fatty acid methyl ester
FCC	Fluid catalytic cracking
FFV	Flex-fuel vehicle, capable of using either gasoline or high-blend ethanol
FIT system	Feed-in Tariff system (Japan)
FQD	Fuel Quality Directive
FTD	Fischer Tropsch diesel fuel
GDI	Gasoline direction injection
GGE	Gasoline-gallon-equivalent
GGE	Gasoline gallon equivalent
GHG	greenhouse gases
HDT	Heavy duty truck
HDV	Heavy duty vehicles
HEV	Hybrid electric vehicle
HVO	Hydrotreated vegetable oils
IEA	International Energy Agency
ILUC	Indirect land-use change
LCA	Life-cycle assessment

LDT	Light duty truck
LDV	Light duty vehicles
LHV	Lower heating value
LPG	Liquefied petroleum gas (auto gas)
M85	Gasoline blend with 85% methanol
MMT	methylcyclopentadienyl manganese tricarbonyl
MPG	Miles per Gallon
MPI	Multipoint injection
MTBE	Methyl tert-butyl ether, methanol-containing gasoline additive
NDRC	National Development and Reform Commission (China)
NGO	Non Governmental Organisation
NGV	Natural gas vehicle
NMHC	Non-methane hydrocarbons
OEM	Original equipment manufacturer
PC	Passenger car
PFI	Port fuel injection
PHEV	Plug-in hybrid electric vehicle
PM	Particulate matter
PME	fatty acid methyl ester derived from palm oil
PPO	Pure Plant Oil
RBOB	reformulated blendstock for oxygenate blending
RED	Renewable Energy Directive, EU regulation
RED-II	Recast of the Renewable Energy Directive, EU regulation
RFG	reformulated gasoline
RFS	Renewable Fuel Standard, US regulation
RIN	Renewable Identification Number, used in US regulation
RIPP	Sinpec Resarch Institute of Petroleum processing
RMB	Renminbi, Chinese yuan, currency
RME	fatty acid methyl ester derived from rapeseed oil
RNG	Renewable natural gas
RVO	Renewable Volume Obligation, used in US regulation
RVP	Reid vapor pressure
SEK	Swedish krona, currency of Sweden
SME	fatty acid methyl ester derived from soybean oil
TCP	Technology Collaboration Programme (of the IEA)
THC	Total Hydrocarbon
USD	United States (of America) Dollar