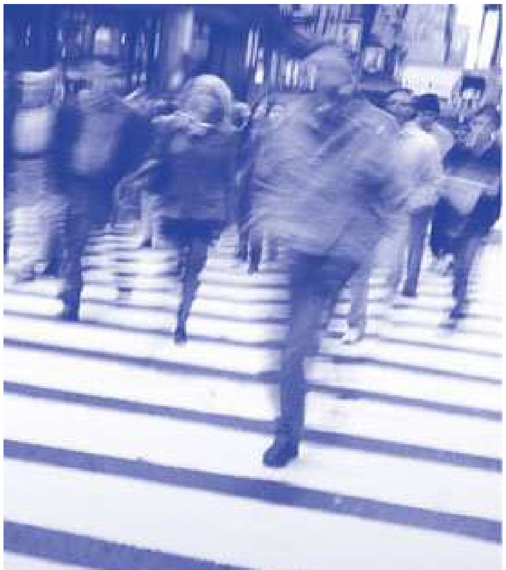

CiViTAS
Cleaner and better transport in cities

AALBORG

Aalborg

R 1.1 Study of impacts using 1G and 2G biofuels in PT and delivery service vehicles

Aalborg Kommune / Danish Technological Institute

February 2010

THE CIVITAS INITIATIVE
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Contents

1. Introduction

1.1 Background CIVITAS

CIVITAS - cleaner and better transport in cities - stands for CIty-VITAlity-Sustainability. With the CIVITAS Initiative, the EC aims to generate a decisive breakthrough by supporting and evaluating the implementation of ambitious integrated sustainable urban transport strategies that should make a real difference for the welfare of the European citizen.

CIVITAS I started in early 2002 (within the 5th Framework Research Programme);
CIVITAS II started in early 2005 (within the 6th Framework Research Programme) and
CIVITAS PLUS started in late 2008 (within the 7th Framework Research Programme).

The objective of CIVITAS-Plus is to test and increase the understanding of the frameworks, processes and packaging required to successfully introduce bold, integrated and innovative strategies for clean and sustainable urban transport that address concerns related to energy-efficiency, transport policy and road safety, alternative fuels and the environment.

Within CIVITAS I (2002-2006) there were 19 cities clustered in 4 demonstration projects, within CIVITAS II (2005-2009) 17 cities in 4 demonstration projects, whilst within CIVITAS PLUS (2008-2012) 25 cities in 5 demonstration projects are taking part. These demonstration cities all over Europe are funded by the European Commission.

Objectives:

- to promote and implement sustainable, clean and (energy) efficient urban transport measures
- to implement integrated packages of technology and policy measures in the field of energy and transport in 8 categories of measures
- to build up critical mass and markets for innovation

Horizontal projects support the CIVITAS demonstration projects & cities by:

- Cross-site evaluation and Europe wide dissemination in co-operation with the demonstration projects
- The organisation of the annual meeting of CIVITAS Forum members
- Providing the Secretariat for the Political Advisory Committee (PAC)
- Development of policy recommendations for a long-term multiplier effect of CIVITAS

Key elements of CIVITAS

- CIVITAS is co-ordinated by cities: it is a programme “of cities for cities”
- Cities are in the heart of local public private partnerships
- Political commitment is a basic requirement
- Cities are living ‘Laboratories' for learning and evaluating

1.2 Background ARCHIMEDES

ARCHIMEDES is an integrating project, bringing together 6 European cities to address problems and opportunities for creating environmentally sustainable, safe and energy efficient transport systems in medium sized urban areas.

The objective of ARCHIMEDES is to introduce innovative, integrated and ambitious strategies for clean, energy-efficient, sustainable urban transport to achieve significant impacts in the policy fields of energy, transport, and environmental sustainability. An ambitious blend of policy tools and measures will increase energy-efficiency in transport, provide safer and more convenient travel for all, using a higher share of clean engine technology and fuels, resulting in an enhanced urban environment (including reduced noise and air pollution). Visible and measurable impacts will result from significantly sized measures in specific innovation areas. Demonstrations of innovative transport technologies, policy measures and partnership working, combined with targeted research, will verify the best frameworks, processes and packaging required to successfully transfer the strategies to other cities.

1.3 Participant Cities

The ARCHIMEDES project focuses on activities in specific innovation areas of each city, known as the ARCHIMEDES corridor or zone (depending on shape and geography). These innovation areas extend to the peri-urban fringe and the administrative boundaries of regional authorities and neighbouring administrations.

The two Learning cities, to which experience and best-practice will be transferred, are Monza (Italy) and Ústí nad Labem (Czech Republic). The strategy for the project is to ensure that the tools and measures developed have the widest application throughout Europe, tested via the Learning Cities' activities and interaction with the Lead City partners.

1.3.1 Leading City Innovation Areas

The four Leading cities in the ARCHIMEDES project are:

- Aalborg (Denmark);
- Brighton & Hove (UK);
- Donostia-San Sebastián (Spain); and
- Iasi (Romania).

Together the Lead Cities in ARCHIMEDES cover different geographic parts of Europe. They have the full support of the relevant political representatives for the project, and are well able to implement the innovative range of demonstration activities.

The Lead Cities are joined in their local projects by a small number of key partners that show a high level of commitment to the project objectives of energy-efficient urban transportation. In all cases the public transport company features as a partner in the proposed project.

2. Aalborg

The City of Aalborg, with extensive experience of European cooperation and having previously participated in CIVITAS I (VIVALDI) as a 'follower' city, is coordinating the consortium and ensures high quality management of the project. The City has the regional public transport authority (NT) as a local partner, and framework agreements with various stakeholder organizations.

Aalborg operates in a corridor implementing eight different categories of measures ranging from changing fuels in vehicles to promoting and marketing the use of soft measures. The city of Aalborg has successfully developed similar tools and measures through various initiatives, like the CIVITAS-VIVALDI and MIDAS projects. In ARCHIMEDES, Aalborg aims to build on this work, tackling innovative subjects and combining with what has been learned from other cities in Europe. The result is an increased understanding and experience, in order to then share with other Leading cities and Learning cities.

Aalborg has recently expanded its size by the inclusion of neighbouring municipalities outside the peri-urban fringe. The Municipality of Aalborg has a population of some 194,149, and the urban area a population of some 121,540. The ARCHIMEDES corridor runs from the city centre to the eastern urban areas of the municipality and forms an ideal trial area for demonstrating how to deal with traffic and mobility issues in inner urban areas and outskirts of the municipality. University faculties are situated at 3 sites in the corridor (including the main university site). The area covers about 53 square kilometres, which is approximately 5 % of the total area of the municipality of Aalborg. The innovation corridor includes different aspects of transport in the urban environment, including schools, public transport, commuting, goods distribution and traffic safety. The implementation of measures and tools fit into the framework of the urban transport Plan adopted by the Municipality.

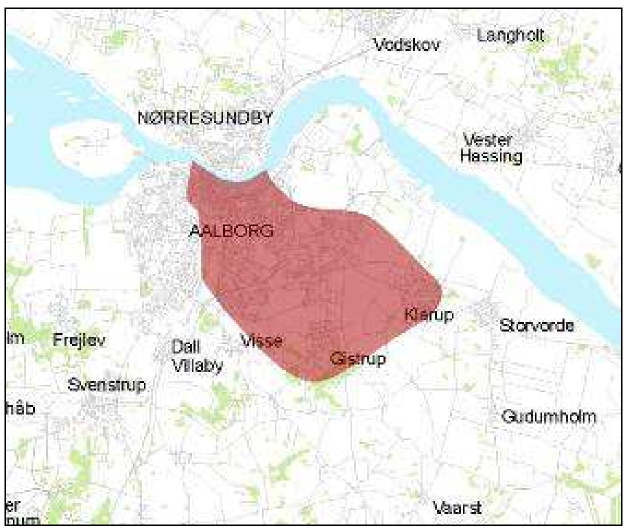


Figure 1: The ARCHIMEDES corridor in Aalborg

3. Background to the Deliverable

In Measure 1 the opportunities of using high blend biofuels in standard vehicles will be explored. The analyses will comprise buses, HGVs and distribution vehicles, with a new tourist bus line as the visible showcase. First experiences in developing a supply infrastructure for biofuels will be gathered.

As part of the measure 50 diesel buses in Public Transport and 5 HGVs and 45 vans from the Danish Mail will be operated on at least 10% biofuel.

The measure will involve key stakeholders in the deployment of biofuels and will bring knowledge on this that can contribute to national and European policy, and hopefully lead to less dependency of fossil fuels without compromising other environmental targets (e.g. on PM emissions)

3.1 Summary Description of the Task

As the first stage within measure 1, the aim for task 11.1.1 is to carry out a study on 1G and 2G bio-fuels to determine the state of the art and to find the best sources for the full scale demonstrations in tasks 1.1 and 1.2. Important criteria will be the environmental impact, impacts or requirements for vehicle engines and up-scaling potential.

4. Study of Impacts using 1G and 2G biofuels in PT and Delivery Service Vehicles

Based on the existing vehicle fleet, diesel fuels must be used. Other renewable fuels such as gases, ethers or alcohols would require either replacement or significant modification of engines. Therefore only renewable diesel fuels are investigated further.

4.1 First and Second Generation Biodiesel

First and second generation biofuels are defined by the feedstock and not the production method. First generation biodiesel are methyl esters based on eatable crops (soy beans, sunflower, palm oil and rape seed oils) whereas second generation fuels are based on residues or waste (pork and beef tallow, used cooking oils or sludge). The production method for 1st and 2nd generation biodiesel is basically the same; however purification by distillation is often required for 2nd generation feedstock.

Since 2nd generation biodiesel often contain a large proportion of saturated fatty acids from animals, rather than non saturated acids from plants, there is a difference in the response to cold temperatures. The animal-based fuels are more likely to solidify and become unusable as a liquid fuel in the cold.

In terms of combustion, 1st and 2nd generation biodiesels are very similar. Blending of 1st and 2nd generation biodiesel is also possible.

The advantages of 1st generation biodiesel are that it is available in large quantities and has been tested extensively for decades. The potential for 2nd generation biodiesel is not as large as for 1st generation. The 2nd generation fuel, however, is somewhat cheaper and much more sustainable. In fact, the use of 1st generation biofuel is highly controversial. Many scientists point to the fact that the raw materials can be burned with much lesser energy losses in power plants. Some even claim that certain types of 1st generation biofuels yield a negative energy balance. It has also been claimed that global demand for 1st generation biofuel has pushed the prices of food upwards in general. Although this may be difficult to prove, there is certainly an ongoing and very sensitive debate on the fuel versus food issue.

However there seems to be consensus about the fact that 2nd generation biodiesel from waste tallow is one of the most sustainable engine fuels available.

Although large variations are seen between different studies, a 1st generation biodiesel could be expected to reduce CO_2 by 70% compared to fossil diesel. 2nd generation biodiesel will reduce CO_2 by approximately 90%. The main difference is the energy needed for farming and harvesting the crops used for 1st generation biodiesel.

The certainty of supply is reasonably good for both 1st and 2nd generation biodiesel since there is a major producer of each type in the country. Both products are also available as bulk commodities. One should however pay attention to the fact that biodiesel is delivered as neat (100%) methyl ester and mixing with standard diesel requires special equipment which is not supplied from the bio fuel producer. The need for special mixing equipment is especially critical for 2nd generation biodiesel due to the temperature sensitivity.

Both production and use of biodiesel in Europe is currently dominated by 1st generation.

The use of 2nd generation biodiesel has been inhibited by requirements for temperature stability. These requirements vary from country to country as does the climate.

Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources is such that 2nd generation biofuels count twice in achieving the goals agreed upon by the member states whereas 1st generation bio fuels only count once. The actual text is shown below.

> Article 21
>
> 2. For the purposes of demonstrating compliance with national renewable energy obligations placed on operators and the target for the use of energy from renewable sources in all forms of transport referred to in Article 3(4), the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material shall be considered to be twice that made by other biofuels.

This creates a significant incentive to use 2nd generation rather than 1st.

4.2 Daka Biodiesel

Biodiesel is a common name for fatty acid methyl esters (FAME) formed by a reaction between an alcohol and oils or fats of vegetable or animal origin.

Usually methanol is used as the alcohol, but ethanol could also be used in the process. Glycerine is formed as a by product.

Daka Biodiesel is primarily produced from refined animal fat extracted from residues from slaughterhouses and dead animals from farms. Other residues such as used cooking oil or other oils not suitable for human consumption may also be used.

A thorough life cycle analysis was performed by The Technical University of Denmark in 2007[1].

From the analysis one can draw the following conclusions. CO_2 savings compared to fossil diesel are about 1.6 kg CO_2 per 10 km driven, whereas the direct cost is only 0.2 kg CO_2 per 10 km. This means a CO_2 reduction of approx. 1.4 kg per 10 km.

10 km of driving requires 17.7 MJ = 500ml of diesel fuel. The direct CO_2 emission from 500ml diesel fuel is approx 1.3 kg. Oil extraction and refining adds another 0.3 kg.

This means that roughly 90% of the CO_2 from fossil diesel fuel is avoided, without counting opportunity cost.

[1] Karsten Hedegaard Jensen Kathrine Anker Thyø Henrik Wenzel „Life Cycle Assessment of Bio-diesel from Animal Fat“ 3rd draft April 30th 2007, Institute for Product Development

However there is also an opportunity cost of 1.1 kg CO_2 from the lost opportunity to burn the raw material in heat producing boilers. When this is added to the equation the net CO_2 benefit is reduced to 0.3 kg per 10 km.

When counting the opportunity cost, according to this study, biodiesel from animal fat is in fact the only biofuel considered with a positive net CO_2 balance.

The study does not address the economic benefits from producing automotive fuels rather than boiler fuels.

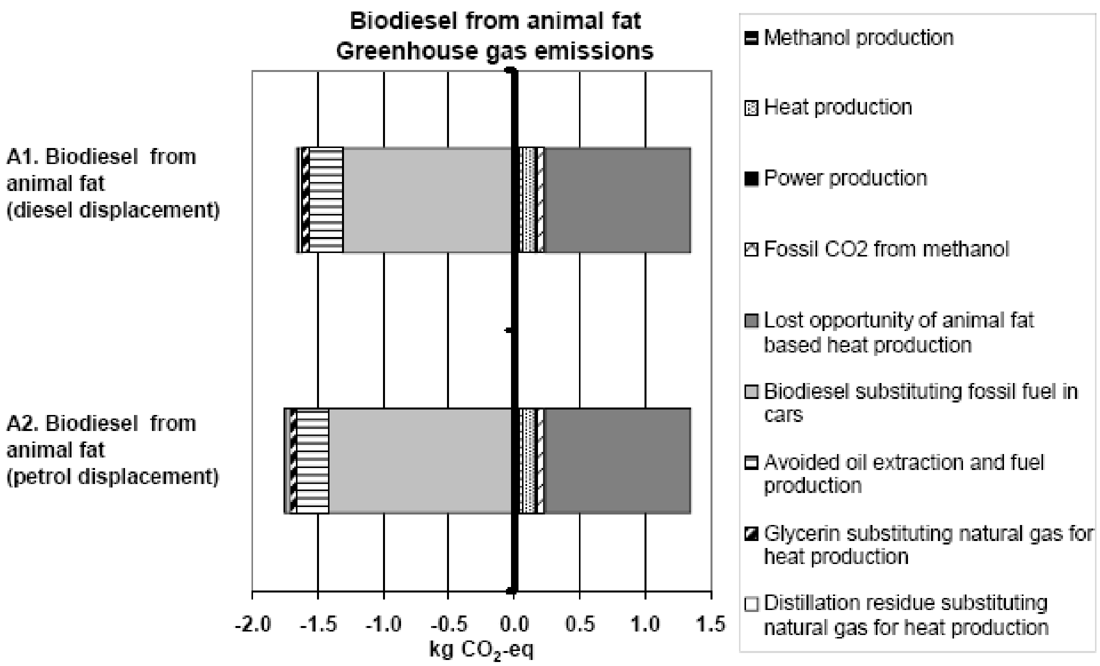


Figure 2 Net CO_2 balance of 2nd generation biodiesel versus fossil diesel (A1) and gasoline (A2). Source: Wenzel et al 2007.

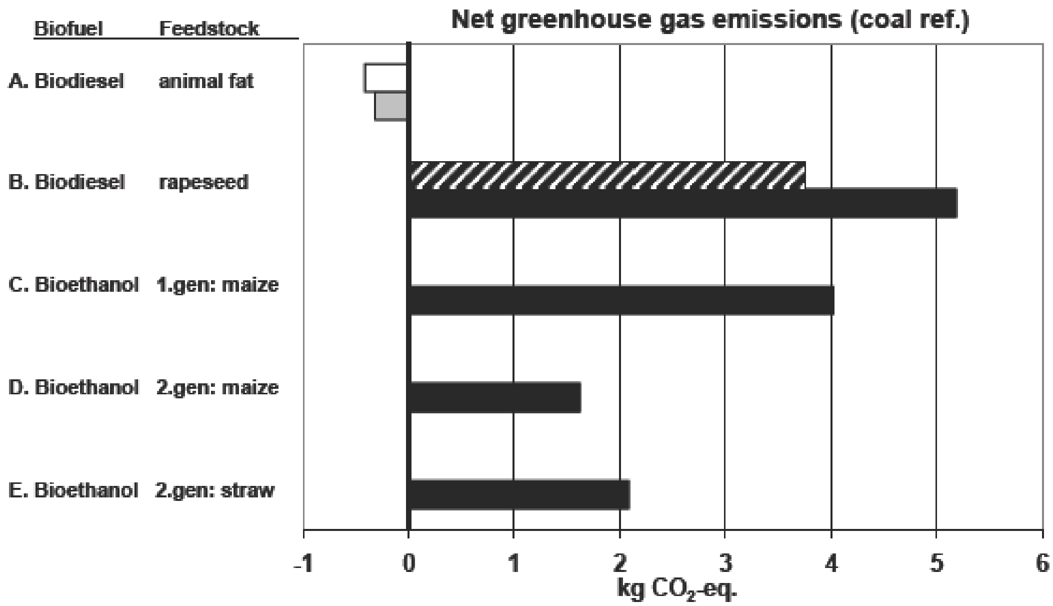


Figure 3 Net CO_2 balance of 2nd generation biodiesel (A) versus other types of bio fuels (B-E). Source: Wenzel et al 2007.

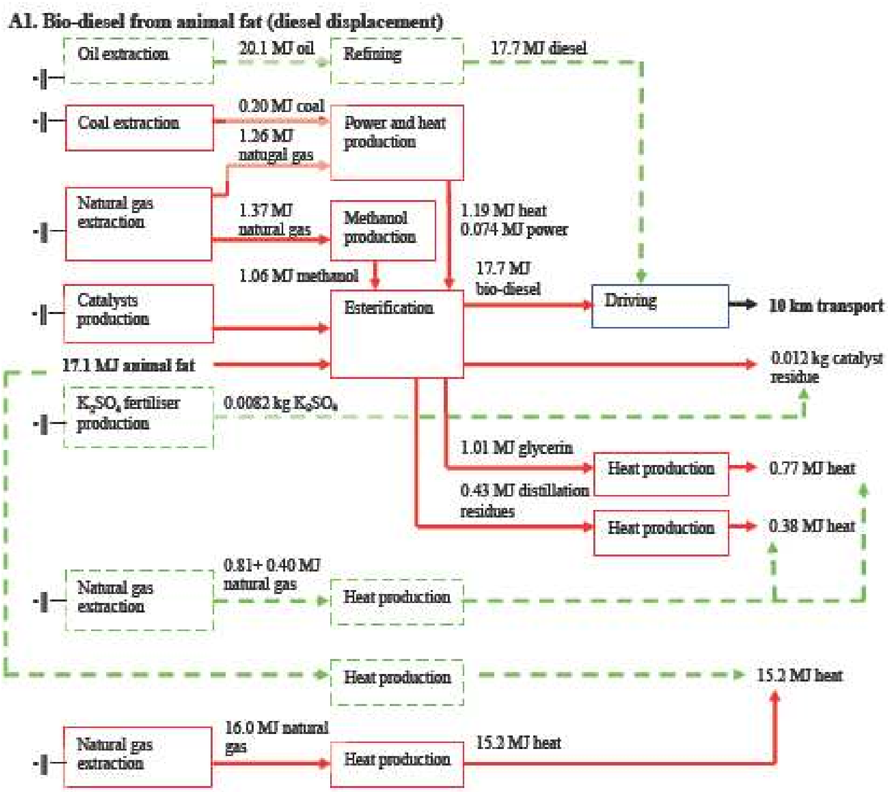


Figure 1 Material and energy flows for 2nd generation biodiesel. Source: Wenzel et al 2007.

The current production of DAKA biodiesel is 50 000 tonnes per year. The entire production is sold at world market price. Since there is virtually no domestic demand at the moment there is no shortage of supply at present time.

Potential production at DAKA is 100 000 tonnes per year. Due to mandatory admixing, driven by EC directives, demand will rise in 2011 to about 100 000 tonnes (~5% of the Danish domestic diesel market) but it is unlikely that DAKA will have to serve this market alone. Germany also has significant production capacity. Also 1st generation fuels will take a share of the market.

DAKA Biodiesel fulfils EN14214 the quality standard for biodiesel.

DAKA Biodiesel and other tallow based diesel fuels are usable up to 100% in appropriately modified vehicles. This requires a twin tank system which is available from Germany.

In standard vehicles admixing of 7% is allowed according to EN590. This means it can in principle be used with no further notice. However regional amendments to EN590 may limit the percentage to 3-5% for Denmark due to the winter conditions.

Admixing of up to 30% in summer time is possible in many vehicles, but only a few manufacturers approve this blend with no further requirements. The B30 is most likely unsuited as winter fuel for Denmark.

Mixtures of 10-15% seem ideal for Danish conditions. They have the potential to work year round and are unlikely to cause any serious engine trouble.

Service intervals have to be adapted in any case when a non EN590 compliant fuel is used. A competent evaluation of the fleet is necessary.

In terms of infrastructure the DAKA biodiesel may be transported in unheated tank trucks over moderate distances, e.g. from the DAKA plant in Hedensted to Aalborg would be no problem. However storing of the product should only be in heated installations. After mixing with base diesel fuel the storage and handling is different very little from 1st generation biodiesel.

Users need to pay attention to moisture and fouling in fuel tanks as this can form bacteriological growth if neglected. Also rubber seals and hoses must be suitable for biodiesel.

Otherwise tanks and refuelling equipment are no different from standard diesel equipment.

5. Previous Research Projects

With the recent update of the diesel fuel standard EN590:2009 to allow an admixture of 7% biodiesel, it is to be presumed that vehicle manufacturers will accept this 7% blend, in short B7. However, higher blend biofuels are not covered by the standard and are not generally accepted by the industry.

To investigate the possibilities for a broad introduction of higher blend biofuels Denmark's Road Safety and Transport Agency recently initiated 4 pilot projects. The projects have a total budget of DKK 60 million and are still ongoing.

The 4 projects were differentiated mainly in term of the type of biofuel used. To allow comparison between the projects all measurement techniques, such as emission and efficiency measurements, were aligned as much as possible.

The first project (Biodiesel DK) is managed by the Danish Technological Institute. The fuels are Tallow Methyl Ester (TME) based B10, B15 and B30. The fuels are not EN590 compliant and fulfill only the mandatory requirements of the European Fuel Quality Directive.

There are 3 fleets involved in Holstebro, Esbjerg and Odense with a total of 160 buses, Heavy Goods Vehicles (HGVs) and delivery vans. The project focuses heavily on measurements with a test program on the road and on the chassis dynamometer. Engine oils are analyzed frequently. The fuel is characterized as 2nd Generation.

The second project (NIRAS RME) is managed by NIRAS consulting engineering company. The fuels are vegetable based B10, B30 and B100, consisting mainly of RME (Rapeseed Methyl Ester-based biodiesel). The fleet consists of 100 buses, HGVs and delivery vans primarily in Eastern Denmark. A chassis dynamometer test program equivalent to Project 1 (Biodiesel DK) is defined for 4 vehicles. The fuel is characterized as 1st Generation.

The third project (B5Next) is managed by Centre for Biomass Innovation CBMI in cooperation with The Danish Petroleum Association (EOF), DAKA Biodiesel and the County of Region Midt. The project establishes a full scale roll-out of fuel with 5% TME which complies in full with the EN590 standard for diesel fuels, at 75 selected filling stations in the Aarhus area. The fleet is not limited. All passenger cars and delivery vans in the area as well as 300 buses in the Aarhus area are included. Since the fuel complies with current diesel standards it is has been decided that no test or measurement program is needed in the project. The fuel has a Cold Filter Plugging Point (CFPP) of -24℃, which is the common winter diesel specification in Denmark. The fuel is characterized as 2nd Generation.

The fourth project (Odense KRO) is managed by the Technical University of Copenhagen DTU, the Municipality of Odense and the Danish Technological Institute. The fuel is 100% straight vegetable oil (SVO) which is not classified as diesel. The fleet consists of 16 buses and 15 delivery vans in Odense City. Since the fuel does not conform to standard diesel, it is necessary to modify the vehicles. This is done with specific conversion kits. The fuel is characterized as 1st Generation.

Table 1 Overview of the 4 pilot projects

Project title	**Biodiesel DK**	**Niras RME**	**B5Next**	**Odense KRO**
Biofuel content	10-30%	10-100%	5%	100%
Biofuel type	2G TME	1G RME/SME	2G TME	1G SVO
Blending	Central blending	Local blending	Central blending	No blending
Vehicles	Standard vans, HGVs and buses	Standard vans, HGVs and buses	All vehicles	Converted vans and buses
Number of vehicles	~160	~100	Unlimited	~30
Measurements	DTI	DTI	None	DTI

The 4 projects started around May 1st 2008. The drafting of tank installation etc. began immediately after project kickoff. The **Niras RME** project, which aims at small scale decentralized blending, was first to set vehicles into operation and this happened approximately 6 months after the project kickoff. **Biodiesel DK** could distribute from a central installation after around 7 months, on November 20th. In **Odense KRO** the tank installations went into operation on January 19th which is nine months after the project started. **B5NEXT** faced the biggest challenges because the fuel had to comply completely with the prevailing standards. Thus the first vehicles were filled on February 18th 2009 which was ten months after project kickoff. (Distribution from the filling stations open to the public took place during March 2009 which is after 11 months.)

Project 1, Biodiesel DK is now described in further detail.

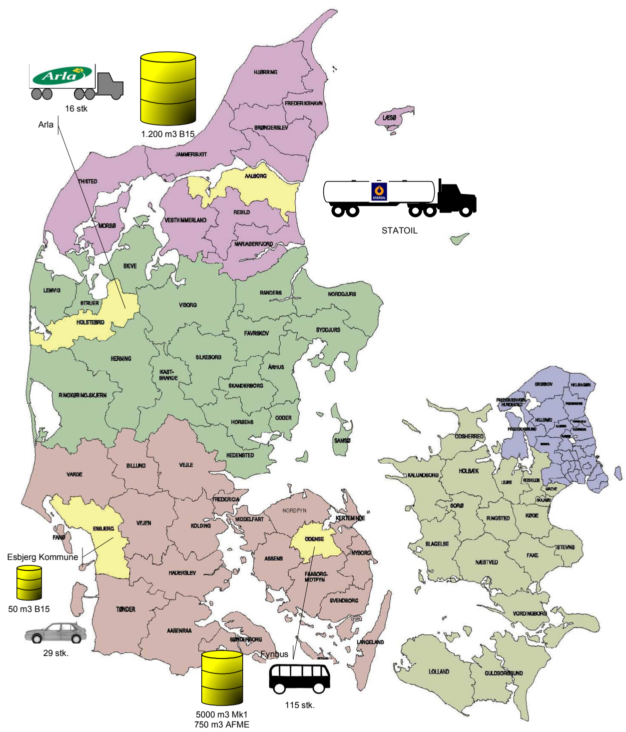


Figure 5: The Biodiesel DK project

One of the challenges in Biodiesel DK was that the required fuel density for B30 could not be obtained by using a Danish quality diesel and it was therefore necessary to import a special base diesel from Sweden. All blends were required to comply with the European Fuel Directive 98/70/EC including the density requirement found in EN590. Therefore, a light base fuel, Swedish MK 1, was selected. The MK 1 also has quite good cold weather properties. However a CFPP of -24℃ could not be reached in any of the blends. During the project it was discovered that a base fuel mixture of MK 1 and standard winter diesel performed better in the cold than the original MK 1 based fuel. Therefore the main part of the road test was carried out with a mixture of MK 1 and standard winter diesel in the base fuel. Only standard diesel additives were used.

- C16 palmitic & C18 stearic

- Improved formula

Figure 6: Deposits in B30 TME biodiesel at cold winter conditions

As it appears from the above pictures there is a distinct deposition of waxy substances (C16:0 palmitic and C18:0 stearic acid) in a B30 biodiesel that has been exposed to a temperature of -5 ºC for 24 hours. The problems can be reduced by using a different kind of base-diesel as shown on the left photo. However the project showed that B30 TME is still unsuited as winter fuel.

5.1 Fuel Cost

Project Biodiesel DK covers surplus cost because the fuel used in the project is more expensive than standard fuel. This is partly because the distribution is not optimized and because the demand is not nationwide. The fuel is only produced/mixed in the quantity that is used in the project. The estimate is 4 million litres.

Figure 2 shows an example of the cost structure when using B15 TME. It is important to note that this picture is only prevailing because it is a pilot project. The cost structure was not dominated by the cost of TME, which is actually moderate. However procurement of Swedish MK 1 fuel, additional logistics, surplus consumption due to a slightly lower calorific value per volume, rising service cost along with the lost opportunity to strategically negotiate fuel prices were the main cost issues. The term *opportunity cost* represents the difference in fuel price between the current supplier and the lowest bidder. The opportunity for each fleet owner to go for the lowest bidder is sometimes lost when engaging in long term projects like this.

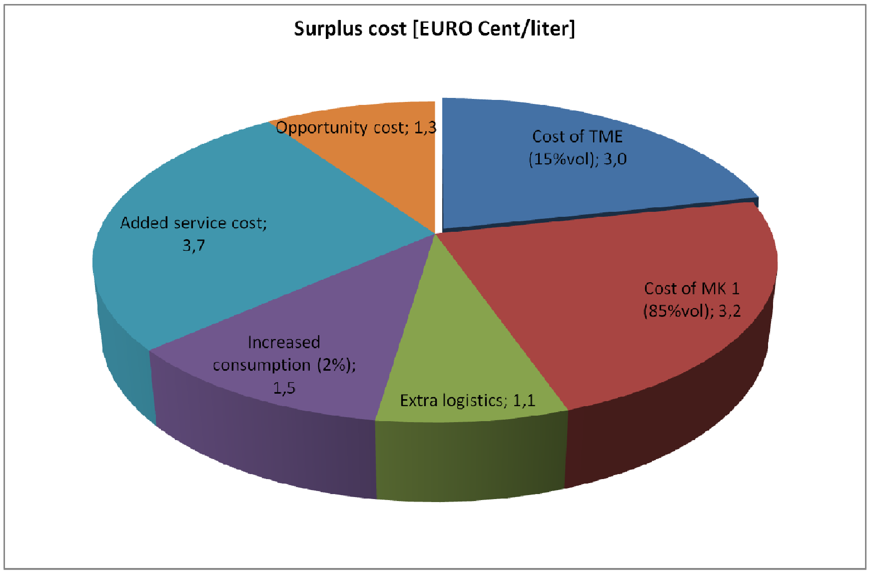


Figure 2: Surplus cost structure

5.2 Maintenance

Vehicles in the project were not covered by engine warranty, so a custom insurance policy was supplied. As of November 2009 no actual insurance claims were raised. All vehicles were monitored on a daily basis by local maintenance staffs. The maintenance plans for all the vehicles are adjusted to the usage of biodiesel. The main parameter is reduced intervals for oil and filter change. The maintenance plans are prepared in cooperation with the suppliers of the vehicles and here the requirements concerning the usage of biodiesel might be different. Data related to the drive trains were collected in a central database accessible from the Internet. Investigations also included some engine inspections with endoscope and dismantling one set of high pressure fuel injectors. As of November 2009, however, no unusual wear was detected.

Below an example of a database registration (in Danish language) can be seen.

TEKNOLOGISK INSTITUT — ENERGI

<<< Til hovedsiden

Statusrapport - Stamdata og brændstofforbrug									
Operatør	**Køretøj**	**Reg. nr.**	**Internt nr.**	**Smøreolie prøveID**	**Brændstof påfyldt fra projektstart**	**Kørte km fra projektstart**	**km/liter fra projektstart**	**Seneste servicedato**	**Seneste periode**
Arla	Scania P 380	XD 96400	1178	1646128	34754	101656	2,93	30-09-2009	2009-9
Planlagt service (olieskift, filterskift, rensning af partikelfilter mv.)									
Service #1									Dato: 31-03-2009
Km	5483	**Olieskift**	0 liter	**Oliefilter**	nej	**Brændstof filter**	nej	**Partikel filter**	nej
Øvrig planlagt service									
Service #2									Dato: 30-04-2009
Km	20027	**Olieskift**	34 liter	**Oliefilter**	ja	**Brændstof filter**	nej	**Partikel filter**	nej
Øvrig planlagt service									
Service #3									Dato: 31-05-2009
Km	34983	**Olieskift**	34 liter	**Oliefilter**	ja	**Brændstof filter**	nej	**Partikel filter**	nej

Figure 8: Database registrations file (Danish language)

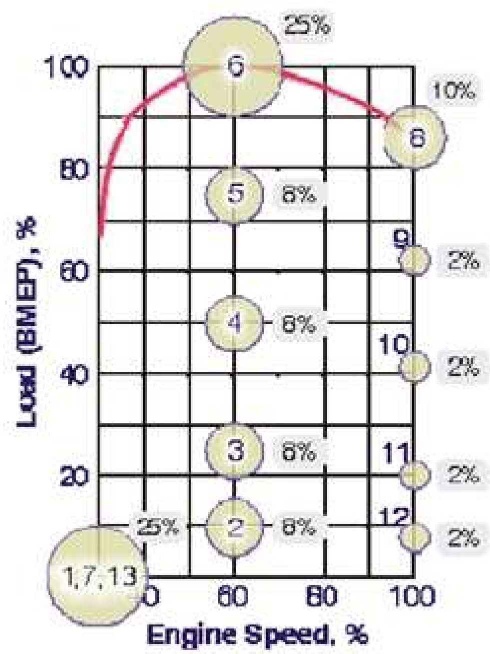
5.3 Chassis Dynamometer Test

To investigate long term changes in emissions and engine performance 8 vehicles were examined on a Heavy Duty chassis dynamometer. Measurements of engine output, specific fuel consumption, CO, NO, NO_2, HC and PM were carried out with reference diesel and with biodiesel.

The chassis dynamometer test is a comprehensive test where setup, preparation, test and termination last up to 4 days depending on the number of measuring points. If the vehicle is fitted with a NOx reducing catalyst system or a particulate filter the measurement is repeated without these systems to assess the real effectiveness of the systems.

Figure 9: Example of a bus on rolling road during the 5-mode test

5-mode test



Mode	Rpm	Load
1	Idle	0 %
3	Max torque	25 %
4	Max torque	50 %
6	Max torque	100 %
8	Max power	100 %

Figure 10: Specific load points used in the 5-mode test

The test procedure was a simplified 88/77/EEC procedure known as 5-mode test. Similarly to 88/77/EEC the result of the test is obtained as a weighted average of the 5 modes, only with different weighing factors.

The rolling road tests show that a moderate decrease in the engine power and torque takes place when using biodiesel. Normally, the drivers do not notice this.

The emissions from the engine are, to a lesser extent, changed towards a lower CO, HC and PM but with a slightly higher NO_X. The standard emission control equipment in the vehicles can still be used.

The fuel consumption measured on a mass basis remains unchanged. However, volume flow is influenced because the energy content per litre is approximately 2 % lower depending on the mixing ratio, although this also depends on the base-diesel.

In the project Biodiesel DK neither engine failure nor abnormal wear of the tested vehicles have been found.

The B10 and B15 blends performed satisfactorily even in the harsh winter period of 2010 where temperatures reached -15℃ several times.

6. CONCLUSIONS

About 2.500 m^3 of TME based B10, B15 and B30 has successfully been used in Denmark so far.

Cold temperature properties of biodiesel are very different from fossil diesel. Tallow biodiesel especially typically requires heated tank installations for handling in pure form (B100). The problem is reduced when mixing with ordinary diesel or with additives. The B5Next project has shown that it is possible to produce a tallow-based B5 that is usable under the same conditions as standard Danish winter diesel. B10 and B15 should be limited to approx -10℃, whereas B30 should not be relied on during winter. Low temperature stability is not consistently dependent on base fuel cold properties. It is absolutely necessary to measure cold weather properties in the ready mixture, not only in the base components. While B10 and B15 TME can be derived from domestic diesel qualities, B30 TME requires a special low density base-diesel to comply with the density requirement of the Fuel Quality Directive. This makes B30 significantly more expensive.

Biodiesel might need heating before the admixing process with diesel. Tallow biodiesel requires heating at approximately 25 ºC when mixed; otherwise a deposition in the finished mix could result.

The need for two-stage mixing could arise in the case of long transport distances where, for example, due to the cold temperature properties, neat TME must be diluted to B50 before transportation.

A diesel engine is an internal combustion engine with a high compression ratio that brings about a fuel dilution of the engine lubricating oil – especially in the engine warm-up period – because the fuel seeps down past the piston and dilutes the engine oil. Biodiesel has been shown, according to various international experiences, to increase this dilution. When using B30 or lower blends however, no significant deterioration of engine oils is likely to occur, when service intervals are adapted according to the manufacturer's specifications. Typically this means that engine oil has to be changed twice as often.

In the Biodiesel DK project, analyses of the motor oil in the vehicles have regularly been made – partly to protect against engine failure and partly to test possible engine oil change intervals. No critical fuel/oil dilution has been detected.

Fuels like B10 and B15 TME are not likely to damage factory mounted or retrofit exhaust after treatment equipment.

Power and torque can be expected to drop consistently with volumetric energy content in the fuels. This was not noticed by most drivers. Laboratory tests indicated a slight improvement of engine thermal efficiency. Emissions of CO, HC and PM decreased while NO_X was slightly increased.

The cost of TME is not the only cost issue. Also to be considered is the cost of extra service, base diesel price and fuel logistics. A surplus consumption due to lower volumetric energy content may also be expected.

Approval of new tank installations is a time consuming process. The two pilot projects that for the past year have worked with centralized admixture have spent seven and ten months respectively on the design and completion of the mixing plants.

Special requirements on equipment, pumps, gaskets, coating etc. are often the result of rubber materials that lack compatibility with B100 biodiesel. The problem is not so predominant for concentrations below B30 and can therefore often be neglected in the vehicle when using a lower admixture. However, the mixing plants that are in contact with B100 must have the appropriate hose and gasket material.

For biodiesel it is particularly important to consider the storage and mixing temperatures which for tallow biodiesel in particular is a critical parameter. Therefore it is even more important that the mixing takes place under controlled conditions. On the other hand the ready-mixed B10 or B15 will be rather unproblematic to transport – also by ship if needed.

6.1 Recommendation of Choice Between 1st or 2nd Generation

According to the recent LCA study from the Technical University of Denmark 2nd generation tallow-based biodiesel is the only engine fuel which gives without a doubt a positive CO_2 displacement in the overall Danish energy system. This is a very important reason for choosing this fuel.

According to tests carried out by DTI blended DAKA-based fuel has practically no negative environmental impacts compared to standard diesel.

Experiences from field tests show no need for conversion of vehicle engines. Standard vehicles can be used with little or no modification.

Local production of tallow based 2nd generation biodiesel was established in 2008 and the plant is already prepared for up scaling. Potentially it will be able to deliver 5% of all diesel in Denmark.

The experiences from other projects so far are good and the fuel from DAKA - or equivalent fuel from other suppliers - can therefore be recommended for large scale demonstration.