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15 May 2008

Status of WP2

1. Introduction

At the previous CEESA seminar, it was decided to consider three different scenarios, each in two variants as illustrated in the table below. For all scenarios, it was decided to use the expected demand for goods transport in the year 2050 (high demand), while for person transport it was decided to use the demand of 2004 in the two low demand scenarios and the expected Business-as-Usual (BAU) demand of 2050 for the high demand scenario.

<table>
<tr><td>100% RES 2050 scenarios</td><td>Biomass (low demand)</td><td>Wind (low demand)</td><td>High Demand</td></tr>
<tr><td>Decentralised (grid)</td><td rowspan="2">Low person-km demand (2004)
and
High goods demand (2050)</td><td rowspan="2">Low person-km demand (2004)
and
High goods demand (2050)</td><td rowspan="2">High person-km demand (2050)
and
High goods demand (2050)</td></tr>
<tr><td>Centralised (grid)</td></tr>
</table>

Table 1: Transport demands in each scenario decided at the previous CEESA seminar.

In the following, a status of the work in WP2 is presented. The status includes:

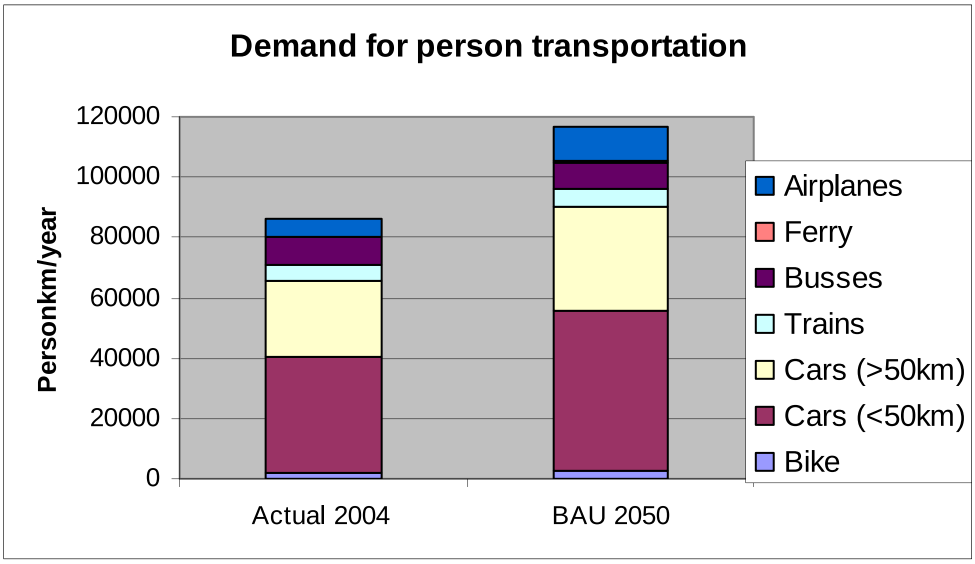
- an identification of the above-mentioned transport demands divided into relevant categories and patterns of travel (See appendix 1)
- an identification of relevant types of transport technologies with regard to renewable energy (preliminary results already presented at the previous seminar) (See appendix 2)
- a definition of four relevant transport technology scenarios and a calculation of the resulting fuel and electricity demands
- A first approach to the identification of biomass conversion technologies, crops and acres connected to the above-mentioned scenarios. (See appendix 3)

2. Transport demands

The demand for person and goods transport has been identified for year 2004 and for year 2050, as shown in the diagrams and as explained further in the attached document (See appendix 1).

The definition of demand is based on available data and the principle of geographical limitations is that all transport fuelled within the borderlines of Denmark is included. Thus, trucks, ships and aeroplanes fuelled in Denmark are included, no matter if they transport “Danish” or foreign persons or goods, while Danish goods and person transport fuelled outside the borderlines of Denmark is not included.

The data for 2004 represent actual demands and have been adjusted to energy and transport statistics. Moreover, the demands have been divided into short distance (<50 km) and long distance (>50 km) car transport.



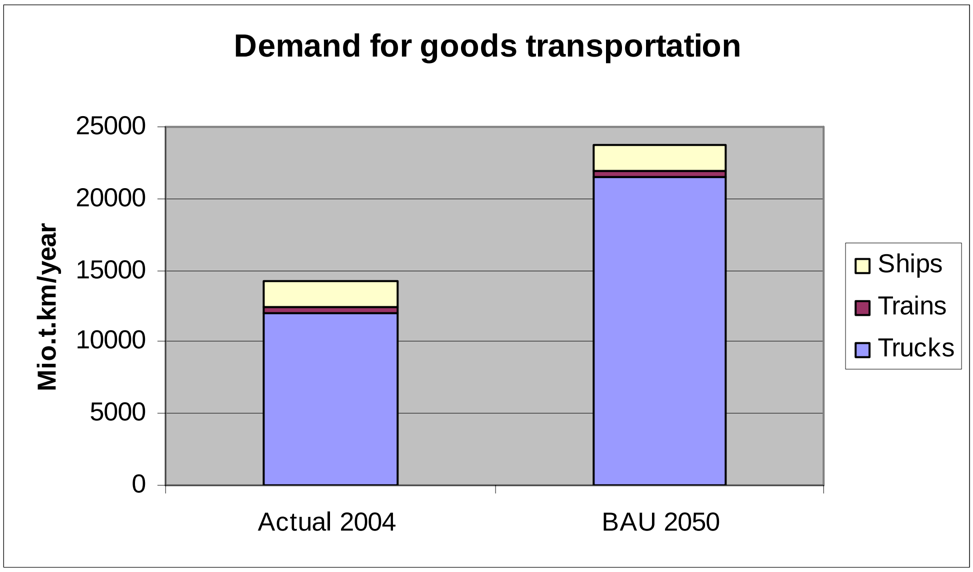


Fig. 1: Person and goods transport demands.

The data for 2050 are based on an official Business-as-Usual projection. However, the official projection does not go any further than year 2030. In this case, an expansion to year 2050 has been made using the annual rates of increase of the period up to year 2030.

As can be seen in the diagrams, person as well as goods transport is expected to increase, especially goods transport. Using the same technologies as today, such increase in transport demands would increase the present (2004) fuel consumption of 200 PJ to nearly 280 PJ and CO2 emissions would increase from 15 to 21 million t/year. In the low demand scenario (stabilised person transport), fuel consumption would be approximately 240 PJ.

3. Transport technologies

For each type of transport demand, available and possible vehicle technologies have been defined. The main principle has been both to identify present available technologies and ideal and possible future technologies in terms of efficiencies as well as characteristics such as range and duration of fuelling (See appendix 2).

The transport demands have been identified for the following modes of transport:

- Vehicle petrol (all under 2 ton)
- Vehicle diesel (all under 2 ton)
- Van petrol (between 2 and 6 ton)
- Van diesel (between 2 and 6 ton)
- Heavy vehicle diesel (all above 6 ton)
- Domestic aviation
- International aviation
- Ferry diesel
- Cargo ship diesel
- Bus diesel
- Train diesel
- Train electricity
- Fright train diesel
- Fright train electricity

The efficiencies of available car and train technologies are shown in the diagram. As can be seen, in terms of vehicle efficiencies, electric vehicles are to be preferred wherever possible.

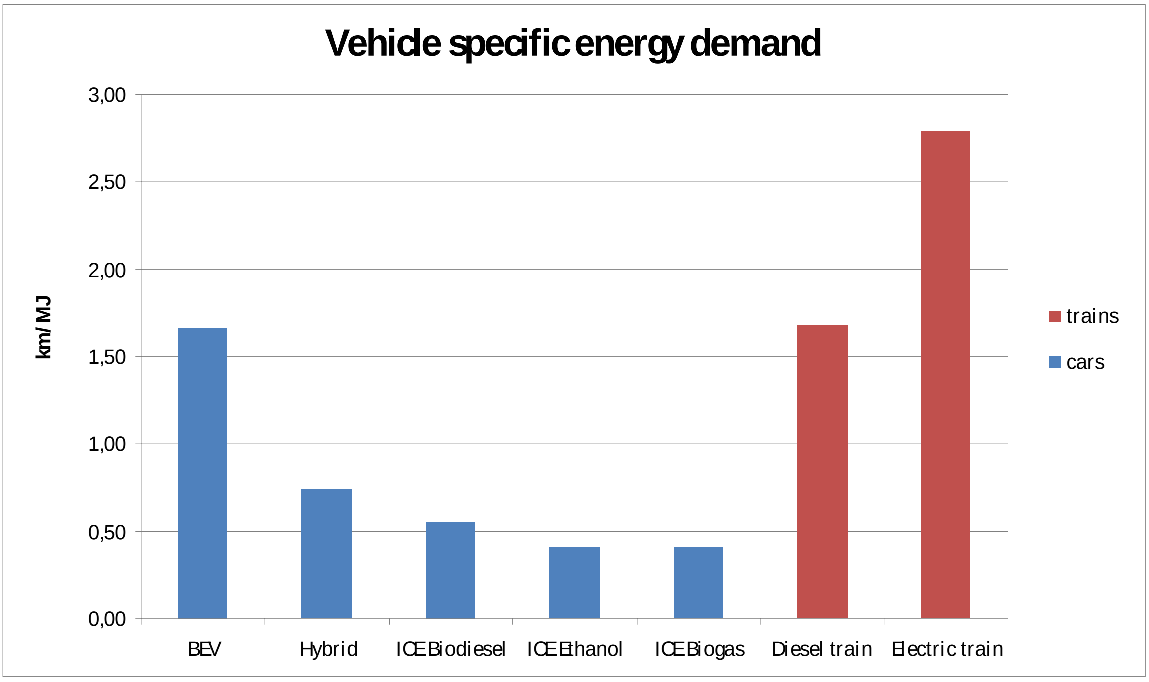


Fig. 2: Person transport technology efficiencies (preliminary first approach)

Several electric and hybrid electric vehicle technologies are already commercially available today. From a technical point of view, it thus seems realistic to implement these technologies in the near future. At least, it seems likely that several small-scale battery-electric vehicles (BEV) could be used for distances shorter than 50 km. This has been considered in the four scenarios presented in the result section.

Small-scale and low-speed vehicles as well as small-scale vehicles and larger vehicles for longer distances are available today. Several of the major car manufacturers develop and produce electric and hybrid vehicles and several new BEV will be commercially available within the following years.

One of the current commercial electric vehicles is shown below, including the basic performance information provided by the manufacturer:

Fig. 3: The "Tesla Roadster" BEV: Vehicle efficiency 2.18 km/MJ and 300 km per charge (can be fully recharged "overnight" according to the manufacturer) [http://www.teslamotors.com]. 0-100 km/h in 5 seconds. Estimated well-to-wheel efficiency based on natural gas as primary energy source is 1.14 km/MJ (assuming a well-to-tank efficiency of 52%). Based on a Li-Ion battery pack. The purchase price is approximately $110,000 and the delivery time is currently up to 15 months.

4. Renewable energy and biomass technologies and acres

A rough estimate of the area demand of different renewable energy sources has been made comparing biomass production to wind, PV and solar thermal production. Based on a surface solar radiation of 168 W/m^2:

- Crops can convert approx. ½-2 per cent radiation into biomass energy. i.e. 1-3 W/m^2 (equal to a gross area demand of 1000-3000 ha/PJ)
- PV can convert approx. 10% of the radiation. E.g. 7 m^2 of PV can produce 800-1000 kWh/year, i.e. equal to 13-16 W/m^2 (equal to a gross area demand of approx. 200 ha/PJ)
- A 10 m² solar thermal unit can produce approx. 5000 kWh/year equal to 50-60 W/m^2 (equal to a gross area demand of approx. 50 ha/PJ)
- A 150 kW wind turbine covers between 20 and 200 m^2 and produces 300.000 kWh per year equal to 200 - 1500 W/m^2 (equal to a gross area demand of approx. 10 ha/PJ)

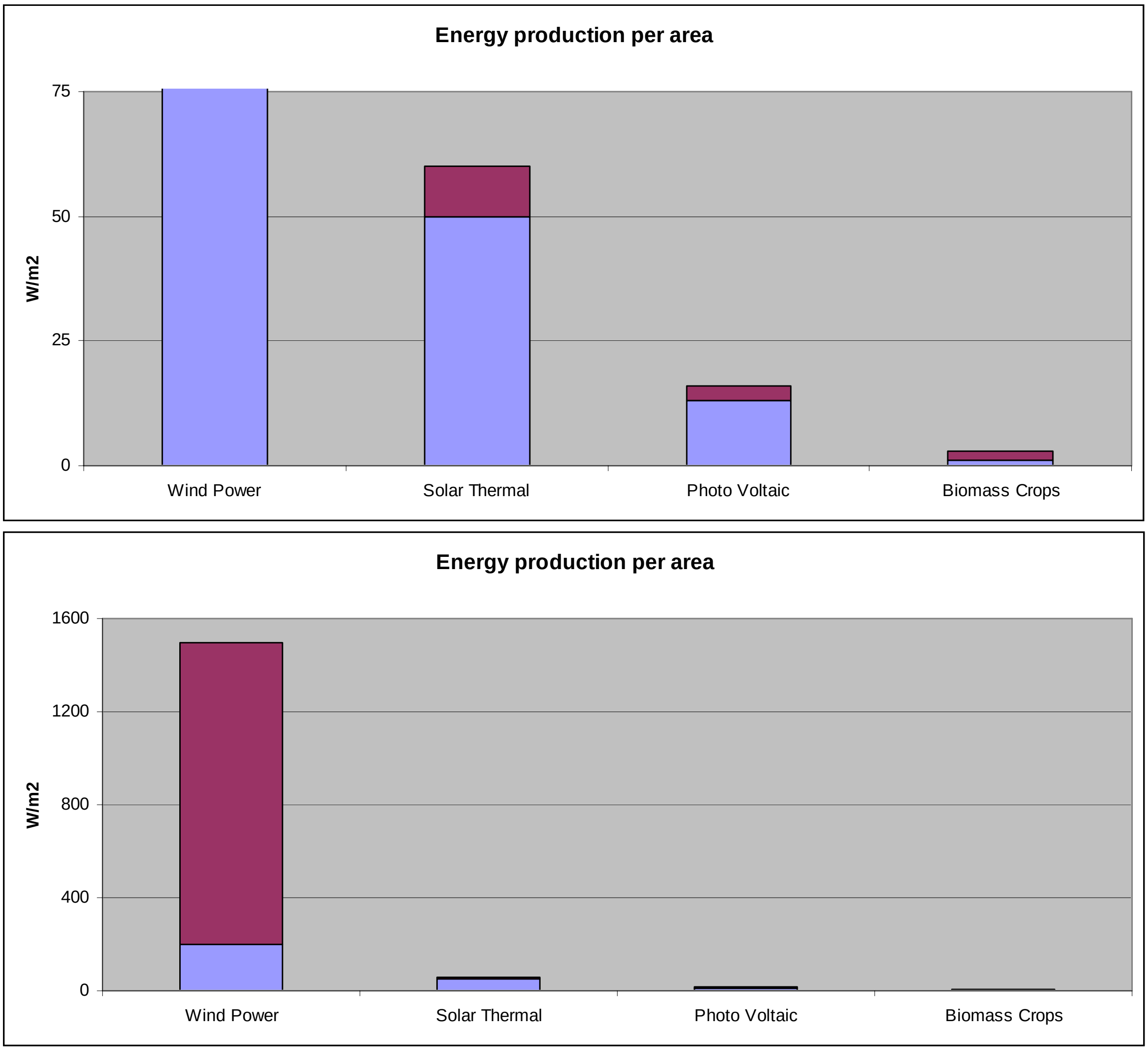


Fig. 4: Energy production per area of four different types of renewable energy sources

The results are shown in Fig. 4. As can be seen, energy production from wind power requires much fewer acres than biomass.

In Fig. 4, the area demand for biomass energy production is based on minimum estimates not including energy conversion from crops to usable types of fuels for transport. In Appendix 2, a number of relevant conversion technologies are listed and acres are calculated per PJ. The results are shown in the table below:

Ha/PJ	Actual (year 2010)		Possible (year 2050)	
	Gross area demand	Net area demand	Gross area de-mand	Net area demand
BioDiesel *)	25,000	15,000	11,000	11,000
Biogas	6,000	6,000	6,000	6,000
Methanol	9,000	9,000	9,000	9,000
Ethanol **)	18,000	12,000	14,000	8,000
Electricity (wind)	10	10	10	10

Table 2: Gross and Net area demands for bio-fuel and electricity production (See appendix 3)
***) RME/Vegetable oil based on rape year 2010 and Syn. diesel based on wood in 2050**
****) Wheat grain in 2010 and Wheat grain and straw in 2050**

The conversion is divided into actual year 2010 technologies and possible future 2050 technologies. In its present form, the scenario for year 2050 assumes the same production rates as today. Such assumption can be adjusted in the next version.

Moreover, the conversion is divided into Gross demand and Net demand. The conversion from crops to bio fuels typically produces food-related by-products (See appendix 3).
The Gross area demand includes the total area demand; while in the case of the Net area demand, the saved areas related to the by-products have been compensated.

The calculation is based on the following substitutions:

- DDGS and C5 molasses substitutes wheat
- Rape cake substitutes rape seed
- Grass is considered a non-food crop

5. Alternatives and methods of prioritisation

Five different technology alternatives have been defined for the analysis:

Actual (2010):
This alternative calculates the actual fuel consumption of existent technologies (2004-2010). Such scenario is based on fossil fuels.

Possible (2010):
This alternative calculates the consequences of converting to 100 per cent renewable energy sources (RES) using only vehicle technologies which exist today, i.e. year 2010. Aeroplanes are supplied by BioJF, even though such technology cannot be said to exist today for all aeroplanes.

BAU (Business As Usual) 2050
This alternative calculates the expected consequences of changing demands and projecting vehicle developments in a Business-as-usual operation. In this operation, no active policy is conducted in order to change the infrastructure, apart from converting to a 100 per cent renewable energy system, as defined in the "possible" scenario. The changes mainly involve the expected increase of the operation range of electric vehicles. Moreover, some technologies are expected to improve in terms of efficiencies.

Ideal 2050
This alternative calculates the consequences of a scenario in which all expected vehicle technologies prove to be viable and the possible transformation from one form of transport (e.g. truck) to another (e.g. train or ship) is implemented. The scenario seeks to identify the technically possible least energy-consuming solution.

Recommendable (2050)
This alternative seeks to identify a solution which is based on the BAU and the ideal alternatives. It is the alternative recommended by the CEESA project, considering the fact that all expected technologies may not be available or acceptable from a financial and/or political point of view.

Prioritisation
The choice of transport technologies in the alternatives has been based on the following principles:

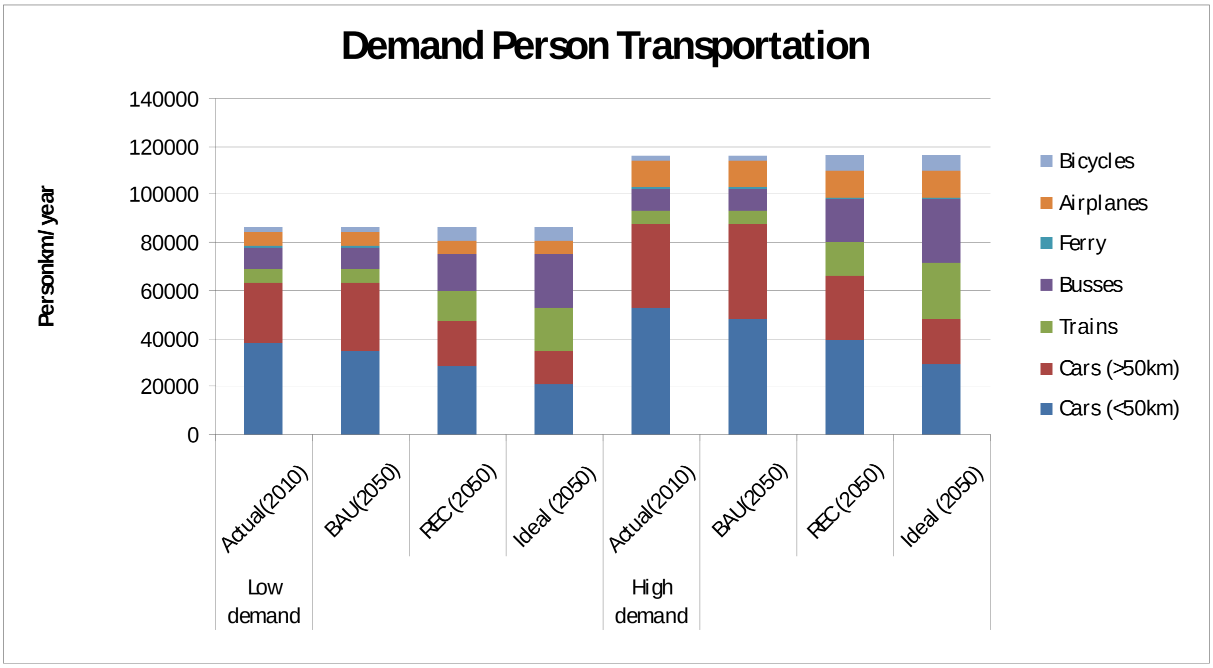
Electric vehicles have been given first priority compared to biofuel vehicles for two reasons. The electric vehicle itself is more efficient and the "harvesting" of RES electricity requires much fewer acres than biomass.

Within biomass, the following order of priority has been applied in order to minimise the demand for acreage:

1. Biogas
2. Bio-methanol
3. Bio-ethanol
4. Bio-diesel

6. Results

The results of the analysis are shown in the diagrams below. In all diagrams, the rows to the left show the low demand scenario (with regard to both person and goods transport) and the rows to the right show the high demand scenario.



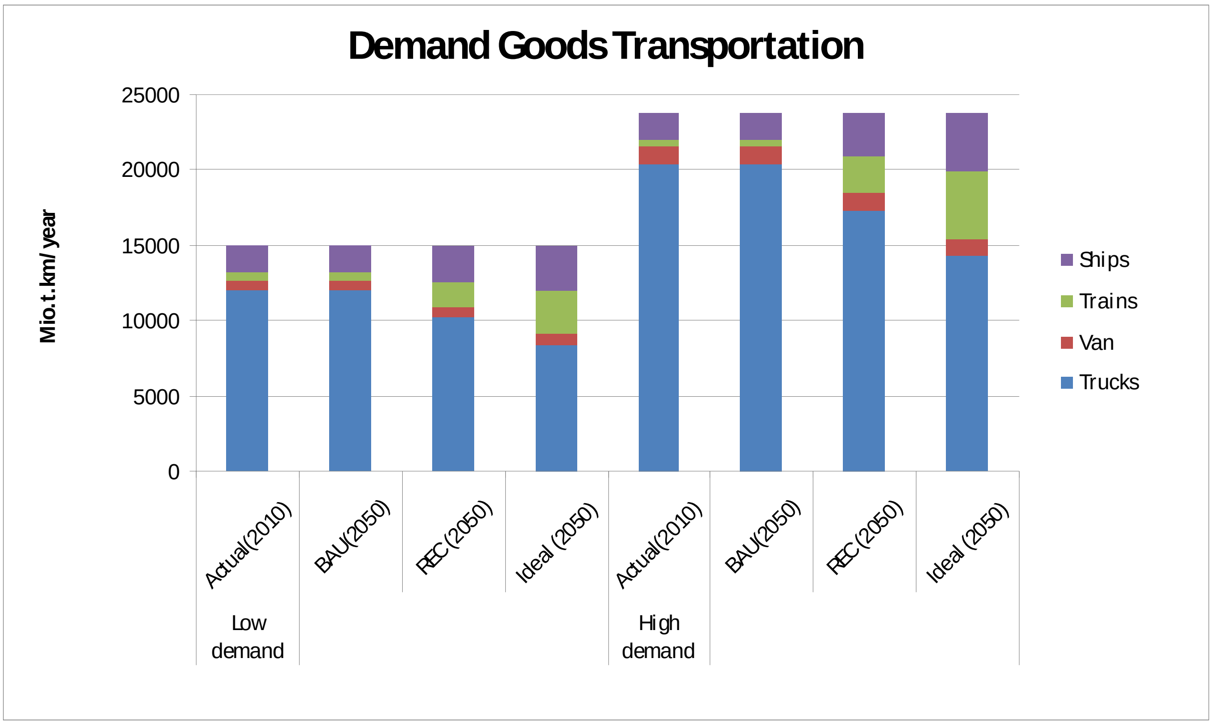


Fig. 5: Transport demands divided into modes of transport

The first two diagrams (Fig. 5) show the infrastructural changes in transport. As can be seen, cars and air person transport are partly replaced by trains and busses in the ideal and the recommendable alternatives. The transport of goods by use of trucks is partly replaced by ships and trains.

In the next diagram (Fig. 6), the resulting electricity and fuel consumptions are calculated. As can be seen, the primary energy consumption for transport is in general reduced when converting to 100 per cent RES. The main reason is the introduction of electric vehicles and the partial conversion from cars, trucks and aeroplanes to trains and ships. However, in the high demand scenario, the conversion to 100 per cent RES (in the possible alternative) increases the fuel demand mainly due to the large increase in international aviation based on ethanol.

Please note that the transport demand continues to increase in accordance with the BAU expectations; the primary energy consumption will increase even in the "ideal" technological solution. This is mainly due to the expected increase in air transport.

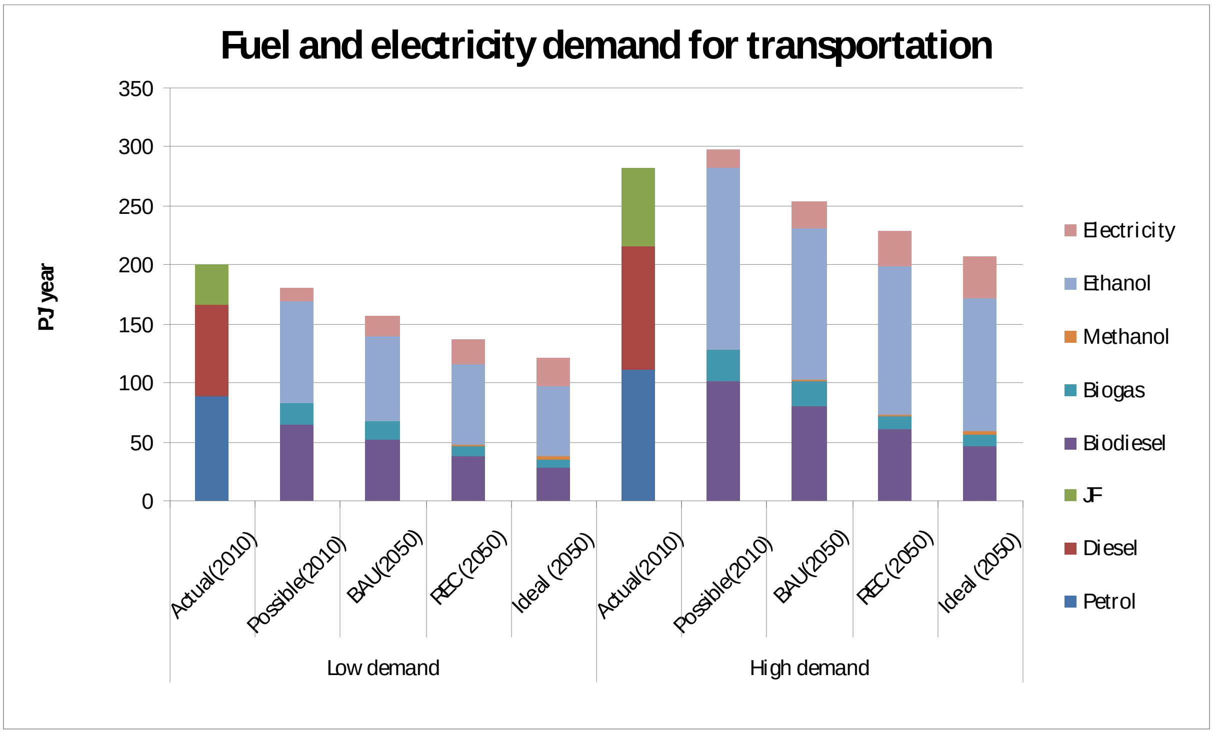
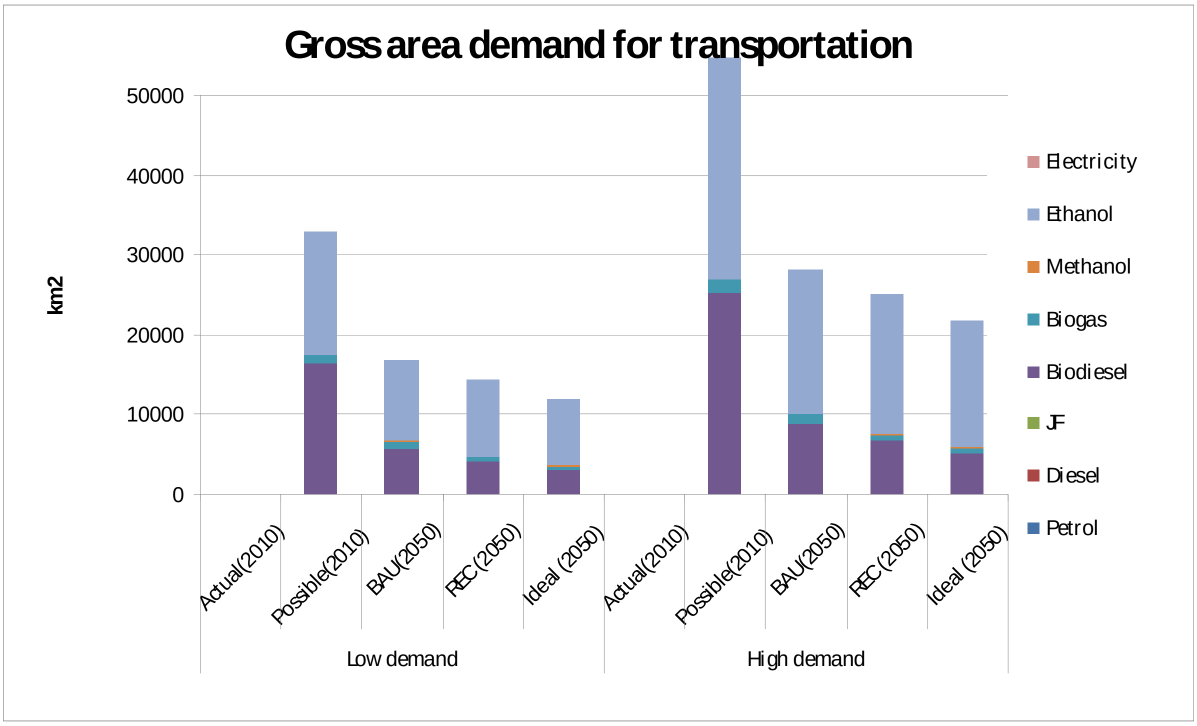


Fig. 6: Transport demands divided into modes of transport

The final diagram (Fig. 7) shows the estimated acreage use for each scenario in both a Gross and a Net area. Year 2010 (the possible alternative) is estimated on the basis of actual 2010 technologies, while year 2050 is based on possible future technologies (See table 2).

As can be seen, especially the area used for producing ethanol and bio diesel requires a lot of space. In some scenarios, the demand for space exceeds the area of Danish farming land (25-30,000 km²) and, in some cases, even the area of Denmark (approx. 45,000 km2).

In the recommendable scenario based on low demands, the space needed corresponds to 10,000 km², equal to 30-40 per cent of the Danish farming area. However, it should be noted that "area-free" residual biomass resources such as waste, straw, biogas etc. have not yet been included.



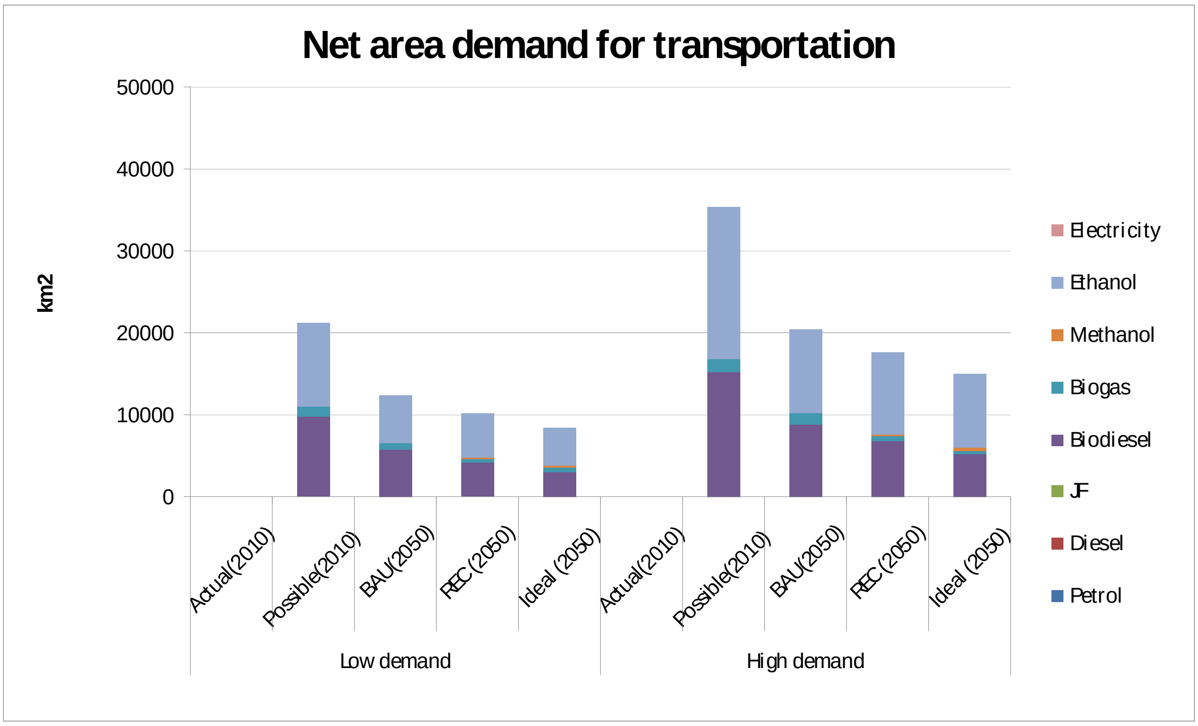


Fig. 7: Gross and Net area demands for producing renewable energy for the transport scenarios.

7. Subjects to be discussed at the Avernæs Seminar

The calculations and results described above are not accurate in detail. The details will have to be improved during the coming period of the project. Nevertheless, the results can serve as the basis for important points of internal discussion in the CEESA project.

1. The transport demand

- Can Denmark (and the rest of the world) convert to 100 per cent renewable energy if the transport demand continues to increase as expected in the BAU forecast?
- Which demand forecast will we include in the scenarios…?
- How to coordinate changes in demand with public regulation initiatives in WP4?

2. The overall methodology

- views on the overall methodology (above)
- what about waste and residual resources…?

3. Coordination with WP1 (Scenarios) and WP5 (LCA)

- the calculation seems able to provide the relevant interface between WP2 (fuel demands and electricity and heat productions and demand from conversion) and the scenarios of WP1.
- What about WP5 (LCA) …???
- What about decentralised versus centralised scenarios with regard to the electricity grid…??

4. Other issues..?

- ………..??

Brian Vad Mathiesen, Aalborg University, 11th of March 2008

Appendix I: Reference transport and energy demands now and in 2050

Internal WP2 CEESA working paper

In this working paper the basis for the first proposals for 100% renewable energy scenarios within transport are outlined. Initially a reference scenario for the development of the transport energy consumption and the transport demand is established. The character of the transport demand e.g. distances and modes of transport are elaborated in the establishment of the reference transport scenario.

1. Introduction to transport scenarios and WP2

At the annual consortium meeting in august 2007 an initial analysis of transport and energy demands in the CEESA 100 renewable energy scenarios was presented based on the IDA Energy Plan 2030 [1]. Also a vehicle/fuel matrix and drive-cycle analyses was presented containing possible future technologies. In this paper the transport demands are elaborated further, as it is necessary to divide the transport demands into "short-distance" and "long-distance". At the annual meeting in 2007 three energy system scenarios for 2050 were decided upon:

- Biomass (low demand)
- Wind (low demand)
- High demand (bio and wind)

It was also decided to analyse a centralised and a decentralised sub-scenario for each of the three scenarios adding up to 6 scenario variants in total. These overall system scenarios are constructed in WP1. The transport scenarios are outlined here in WP2 and have to contribute to these 6 scenarios. Only parts of the transport technologies may differ in the 6 scenarios or in the sub-scenarios. For the transport scenarios in WP2, it was decided to initially include the reference 2050 goods transportation demand in all scenarios and to include:

- the high person-km transportation demand (2050) in the "High demand" scenario, and
- the low person-km (2004) demand in the two "low demand" scenarios.

For WP2 it was decided that within the next year suitable transportation packages should be identified and presented at the annual consortium meeting in 2008 i.e. the tasks are:

- the identification of suitable transportation technology solutions and
- the identification of suitable biomass production solutions
- for each of the three scenarios in each of the two variants (decided in WP1)

The proposals for transport scenarios have to be presented as the outset for further discussions about transport technologies and scenarios at the meeting in June 2008.

It was also decided to work with a “closed” system, in which Denmark is self-sufficient, during the next year. Before the next meeting, each WP will send a discussion paper to the steering committee describing a potential “open” system. These papers will be discussed at the next consortium meeting. This is not taken into account in this paper.

2. The reference transport and energy demands for until 2050

The transport demands can either be found in official publication or can be calculated from information about fuel consumption, efficiencies, amount of goods and passengers pr. vehicles etc. All of these methods are connected to considerable uncertainties when defining and projecting transport demands, like other types of projections.

Here the transport demands are based on background calculations to the Energy Strategy 2025 [2] which are initially from 2002. An example of these uncertainties is, that the latest forecast of the energy demand by the Danish Energy Authority from 2008 operates with an annual increase of 1% in the transport energy demand in stead of 0,7% previously [3]. Some of the major problems in the transport demand and energy projections are elaborated in this working paper. However please note that the projections used in the Energy Strategy 2025 contains the most detailed information about relations between mode of transport, energy and transport demands etc, which is why that dataset is used for the CEESA scenarios here.

Dataset available in official publications on transport and energy demands

The 2004 energy demands for transport are the outset for the analyses of the IDA scenarios. For the scenarios in CEESA more detailed knowledge about transport demand is required. Here the transport demands behind the transport energy demands used in the IDA scenarios are elaborated. The data of the transport energy demands in Energy Strategy 2025 is based on data originally from the Danish Road Directorate from 2002 [4].

In [4] the projection methods are described but only the resulting emission data until 2010 is available. The Ministry of Transport and Energy provided the background dataset in an Excel-Sheet for the projection until 2030 in July 2007. The dataset is consistent with the energy demands for transport in the Energy Strategy 2025. This dataset consist of the following elements:

- Traffic work (km)
- Passenger transport work (person km)
- Fright transport work (ton km)
- Load factors (persons or tons pr. vehicle km)
- Emission data (NO_x, CO, HC, particles, SO_2, CO_2)
- Energy consumption pr. mode of transport divided into fuels

All these elements are divided into yearly values pr. mode of transport and pr. type of fuel. The modes of transport available in the dataset are:

- Vehicle petrol (all under 2 ton)
- Vehicle diesel (all under 2 ton)
- Van petrol (between 2 and 6 ton)

- Van diesel (between 2 and 6 ton)
- Heavy vehicle diesel (all above 6 ton)
- Domestic aviation
- Ferry diesel
- Cargo ship diesel
- Bus diesel
- Train diesel
- Train electricity
- Fright train diesel
- Fright train electricity

Key parameters in the official transport demand and energy demand projections
The key preconditions in the projection of the transport demands and energy demands are the following:

- Only adopted initiatives are taken into account (the EU agreement with the European vehicle manufactures)
- The key economic parameters in the projection are based on the Ministry of Finance's Economic Surveys and Review
- There is a clear distinction between pre-2010 and the period from 2010-2030. This is mainly due the fact that another economic prognosis is used from 2010, in which the economic development is lower [4]

For personal vehicles the transport demand projections are dependent upon a projection of the amount of vehicles and assumptions about these vehicles annual average traffic work (km pr. vehicle pr. year). The amount of vehicles includes personal vehicles, taxis, medical vehicles and vans under two tons in total weight. The amount of vehicles is dependent upon new vehicles and lifetime of existing vehicles. The elements defining the amount of new vehicles are dependent on the following economic parameters:

- Factor for cost from one year to the next
- Real interest rate in the year considered
- The price of petrol and oil in the year considered
- The price of repairs and maintenance of vehicles in the year considered
- The price of purchasing a new vehicle [4]

One significant part of transport is modified for the Energy Strategy 2025 from the data from The Danish Road Directorate from 2002. All road based transport is corrected with the EMMA model, which makes an effort at taking into account the economic development in different sectors. This was done in Energy Strategy 2025 and is also done in the latest projection from the Danish Energy Authority from 2008 [3]. Here we need detailed data about transport demand, which is not available in this latest projection.

The passenger transport demand for busses is expected to be constant. Bus transport has not been modelled, as the development has been rather stable historically and because of lack of knowledge about decisive parameters. Passenger transport demand in trains and ferries and goods transport in fright trains and cargo ships is expected to be constant. The demand for domestic aviation is expected to increase considerably, i.e. more than 2.5 per cent annually until 2030.

The transport demand for vans (between 2 and 6 tons) is connected to the projected GNP, while heavy vehicles (above 6 tons) are also dependent on the economic development within different commercial sectors [4]. For heavy vehicles the amount of goods transported pr. vehicle is expected to increase which influences the projected goods transport demands.

International aviation and bicycle transport are not included in the data from 2002 acquired from the Ministry of Transport and Energy, but are added from other sources for the analyses here. For bicycle transport demand, data from the Danish Transport Research Institute's examination of Danish transport habits from 1993-2006. The bicycle transport demand is assumed to be constant from 2006 in the transport reference here.

International transport
For road based passenger transport the dataset presented here by definition includes both national and international transport. International aviation and international ferry transport is not included.

The international aviation transport demands are not included in the dataset from the Danish Road Directorate from 2002. International passenger transport demand has been added to the dataset from the Energy Strategy 2025 [5] which is based on data from the European Commission.

Here the development in international aviation fuel consumption from the Energy Strategy 2025 is connected to the person km travelled pr. energy unit in domestic aviation in order to derive the transport demand.

For goods transport only domestic transport is initially included in the reference here. Domestic transport is defined as trips with both start and end points in Denmark. This means that the international freight of goods by cargo ships and heavy duty trucks is not included in the reference. According to Danish Statistics the international freight in heavy duty vehicles is of the same magnitude as the domestic transport of goods (in ton km). For trains the domestic data used here represents a fourth of the total transport of goods. Another quarter of the total transport in freight trains is import and export and half is transit transport. This part of the goods transport has to be investigated further.

The reference transport demands for 2030
The dataset is divided into traffic work on one side and passenger or goods transport demands on the other side. In fig. 1 and 2 these transport demands from 1988 until 2030 are illustrated. Both the passenger and the goods transport demands are dominated by road based modes of transport.

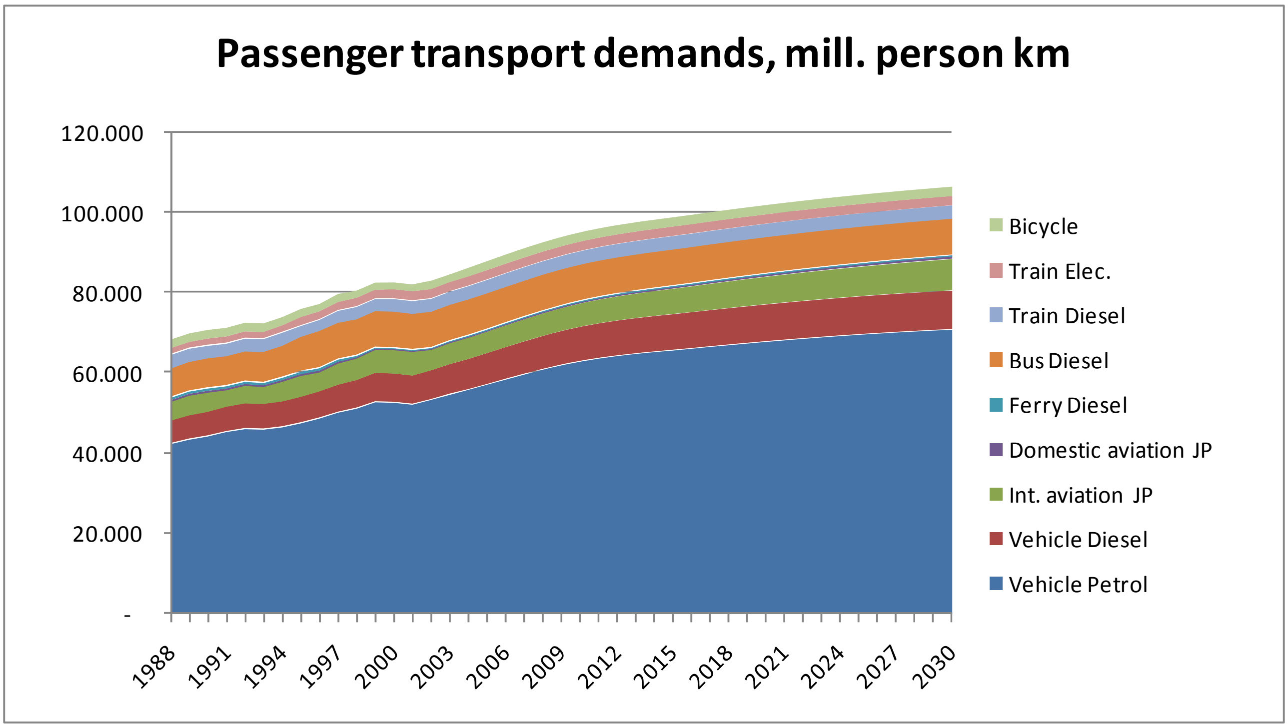


Fig. 1, Passenger transport demands in person km pr. year pr. mode of transport.

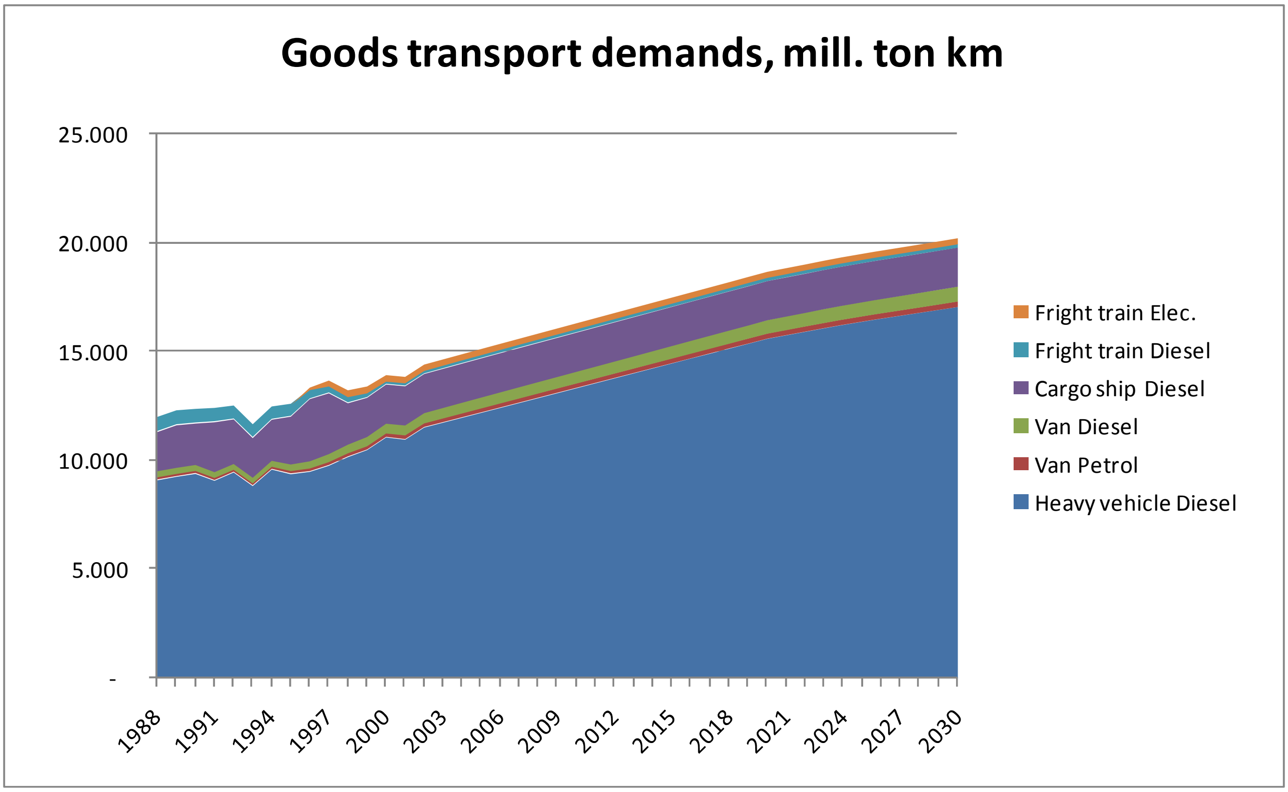


Fig. 2, Goods transport demands in person km pr. year pr. mode of transport.

The reference transport demand until 2050

No official or unofficial projections of transport or energy demands are available after 2030. For the CEESA project, the transport demands are projected until 2050. A conservative measure is to use the same rate of increase as for the last ten years in the official projection period, i.e. from 2020 to 2030, for the transport demands for 2030 until 2050. These rates of increase are the lowest in the projection period. In table 1 and 2 the transport demands and rates of increase for each mode of transport is listed for 2030-2050. Passenger transport in vehicles, airplanes and ferries is expected to increase. Goods transport in heavy vehicles and vans is also expected to increase. All other modes of transport are expected to be constant after 2030. The transport demands until 2030 from the dataset from the Ministry of Transport and Energy is also listed in table 1 and 2.

Mode of pass. transport		Vehicle	Bus	Train	Domestic aviation	Int. aviation	Ferry	Bicycle	Total
Mill. person km / year									
Ref.	2000	59.835	9.133	5.381	363	5.875	247	1.707	82.541
Ref.	2004	63.465	9.031	5.611	407	5.274	262	2.102	86.151
Ref.	2010	71.523	9.031	5.668	491	5.748	295	2.325	95.082
Ref.	2020	77.167	9.031	5.668	648	6.803	319	2.325	101.961
Ref.	2030	80.598	9.031	5.668	799	7.741	333	2.325	106.495
Ref.	2040	84.181	9.031	5.668	985	8.809	348	2.325	111.346
Ref.	2050	87.923	9.031	5.668	1.214	10.023	363	2.325	116.548
Annual rate of increase 2030-2050		*0,44*	*0,00*	*0,00*	*2,12*	*1,30*	*0,44*	*0,00*	*0,45*

Table 1, Passenger transport demands and annual rates of increase from 2030 used for constructing the reference transport demands for 2050.

Mode of goods transport		Heavy vehicle	Van	Fright train	Cargo ship	Total
Mill. ton km / year						
Ref.	2000	11.052	644	456	1.800	13.952
Ref.	2004	11.959	706	456	1.800	14.920
Ref.	2010	13.318	768	456	1.800	16.342
Ref.	2020	15.584	865	456	1.800	18.705
Ref.	2030	17.047	946	456	1.800	20.250
Ref.	2040	18.648	1.035	456	1.800	21.939
Ref.	2050	20.399	1.132	456	1.800	23.788
Annual rate of increase 2030-2050		*0,90*	*0,90*	*0,00*	*0,00*	*0,81*

Table 2, Goods transport demands and annual rates of increase from 2030 used for constructing the reference transport demands for 2050.

The reference energy for transport demand until 2050

The transport demands elaborated above can be converted into energy demands for each mode of transport. This has been done by the Ministry of Transport and Energy until 2030. For the period from 2030-2050 energy demands have been projected for the purposes in CEESA. In table 3 and 4 the efficiency of the different modes of transport in this investigation is presented. These efficiencies have been calculated from the dataset mentioned and the projected energy demand for 2050. The efficiencies are connected to considerable uncertainties as the road based transport is based on assumptions about the km travelled pr. personal vehicle and for heavy vehicles, upon samples of reported mileages. However this resulting energy consumption constitutes a comprehensive set of technologies, which is not available from elsewhere.

Mode of pass. transport		Vehicle	Vehicle	Bus	Train	Train	Domestic aviation	Int. aviation	Ferry
km/ liter or km/kWh		Petrol	Diesel	Diesel	Diesel	Elec.	JP	JP*	Dielsel
Ref.	2000	14,5	16,4	2,7	0,53	0,08	0,31	0,31	0,033
Ref.	2004	14,7	16,6	2,7	0,53	0,12	0,30	0,30	0,042
Ref.	2010	15,3	17,2	2,7	0,54	0,14	0,30	0,30	0,046
Ref.	2020	16,3	18,3	2,7	0,54	0,14	0,30	0,30	0,046
Ref.	2030	16,4	18,4	2,7	0,54	0,14	0,30	0,30	0,046
Ref.	2040	16,6	18,6	2,7	0,54	0,14	0,30	0,30	0,046
Ref.	2050	16,7	18,7	2,7	0,54	0,14	0,30	0,30	0,046

Table 3, Efficiencies for modes of passenger transport in the 2050 reference

Mode of goods transport		Heavy vehicle	Van	Van	Train	Train	Cargo ship
Mill. ton km / year		Diesel	Petrol	Diesel	Diesel	Elec.	Diesel
Ref.	2000	2,3	6,8	5,7	0,25	0,14	0,12
Ref.	2004	2,3	6,8	5,7	0,27	0,14	0,12
Ref.	2010	2,3	6,8	5,7	0,27	0,14	0,12
Ref.	2020	2,3	6,8	5,7	0,27	0,14	0,12
Ref.	2030	2,3	6,8	5,7	0,27	0,14	0,12
Ref.	2040	2,3	6,8	5,7	0,27	0,14	0,12
Ref.	2050	2,3	6,8	5,7	0,27	0,14	0,12

Table 4, Efficiencies for modes of goods transport years in the 2050 reference.

In fig. 3 the resulting fuel consumption in a business-as-usual (BAU) scenario is presented. The total demand is expected to increase to 249 PJ in 2030 with the given assumptions. In the projection from 2030 until 2050 the total fuel consumption increases to 283 PJ. Please note that in the latest projection from the Danish Energy Authority the total fuel consumption is expected to be 247 PJ in 2020 and 262 PJ in 2025 [3]. Please also note that international freight of goods is not included in this projection.

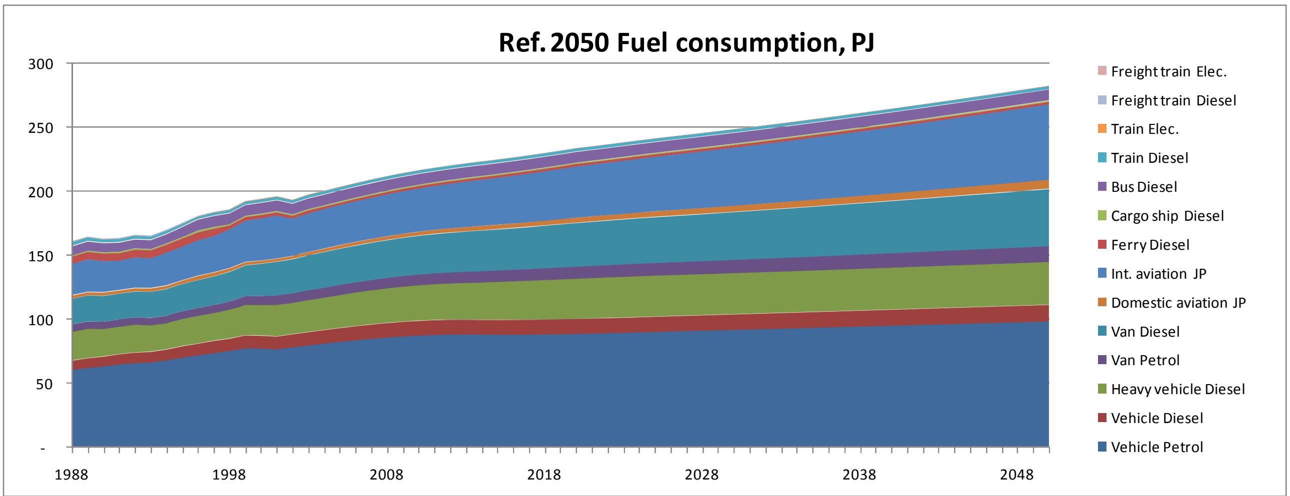


Fig. 3, Historic and projected energy consumption for divided into modes of transport

Considerations for future projections of transport and energy demands

As mentioned, the projection of transport demands are connected to considerable uncertainties. The described projection of the transport demands is nevertheless the most comprehensive available at this stage. Apart from the uncertainties in the models used for the projections by the Ministry of Transport and Energy and by the Ministry of Finance some other uncertainties are:

- Future investments in expanding the infrastructure - either road or rail tracks - is not a parameter in the projection. Thus traffic leaps and the perceived distances for travellers are not included in the projection.
- One of the key assumptions behind the development in the passenger transport in vehicles is how far each car is expected to drive every year. The outset in the analyses from the Ministry of Transport and Energy is that every vehicle travel 20,000 km in 2002 and develops app. 2 per cent annually. Later studies have indicated that vehicle travel app. 17,000 km annually. Thus the efficiencies for vehicles in table 3 can be lower in reality today as the fuel consumption, found in statistics from the Danish Energy Authority, is the same while the length travelled is shorter.
- According to the Ministry of Transport and Energy the rate of increase in the domestic aviation is too large.
- The effect of the EU agreement with the European vehicle manufactures has not had the effect hoped for, thus new vehicles have lower efficiencies than expected in the future.

The Ministry of Transport and Energy expects to create a more dynamic model for energy and transport projection which can be updated annually and which can be used to create alternative scenarios. The work on creating a model was expected to start in the autumn of 2007 and to finish in the spring of 2008, but has not commenced yet. It could be possible for the CEESA project participants to give inputs and contribute to the parameters included in this modelling. If this is of interest the Ministry of Transport and Energy has to be contacted.

Separation of short-distance and long-distance transport demands

For the construction of the transport scenarios in the CEESA project it is necessary to separate short and long-distance transport. Notably regarding road based modes of transport, which can be replaced by other technologies such as hybrid cars and electric vehicles. For goods transport (both cargo ships and heavy duty vehicles the separation into short-distance and long-distance has not been possible at this point in time. However the data presented here represents domestic transport of goods, which can, to some extend, indicate the maximum distances transported. International aviation it may also be possible to shift to international high speed trains. This requires knowledge about the destinations and distances in international aviation and has not yet been investigated. The distances in road based passenger transport is investigated below.

For vehicles Statistics Denmark has found that the average distance from home to work is app. 17 km in 2006. Other trips may be of interest. The Danish Transport Research Institute at DTU Transport performs National Travel Surveys for passenger transport. The data is gathered through telephone interviews and recently via the internet. The earliest data is from 1975 the latest from 2006 and the data is available online. Here selected dataset from 2006 is used which is based on app. 2.000 persons transport habits.

The dataset in the National Travel Surveys contains detailed information about modes of transport, length of trips, transport time, purpose of trips, age, income, residence and much more.

In this context the most important data is on the length of trips in road transport, however data on other modes of transport is also available.

The transport data from The Ministry of Transport and Energy which was presented above is not directly comparable to the dataset from the National Travel Surveys. This is due to the fact that the data about transport work has been gathered from different sources and both are connected with uncertainties.

In table 3 the transport work from both sources are listed for a selection of modes of transport. Although the data is gathered differently, the data found are within the same range.

2006	Driving car	Passenger in car	Vehicles	S-Train, metro	All trains
Ministry of Transport & Energy			66.425		5.668
National Travel Survey	38.762	11.392	50.154	1.288	6.504

Table 3, Transport work in mio. person km from to set of data.

In table 4 and table 5 some of the data from the National Travel Survey from 2006 is presented. In table 4 it is evident that more than 60 per cent of all travelled km in vehicles is for trips below 50 km. For trains 80 per cent of the km travelled is on trips longer than 50 km. Km travelled in busses and S-trains have more than 70 per cent shorter trips than 50 km. The category other consists of ferry and plane trips among others.

Length of trip Mio. km	**Other**	**Walk**	**Bicycle**	**EU-moped / motorbikes**	**Driving car**	**Van / truck**	**Passenger in car**	**Bus**	**S-Train, metro**	**Train**	**Sum**
1-2 km	4	612	528	18	618	18	93	34	4		1.929
3-4 km	7	233	519	33	1.466	78	288	87	17		2.728
5-6 km	20	110	404	39	1.250	73	340	145	32	5	2.418
7-10 km	38	32	378	91	3.076	170	780	295	71	14	4.945
11-15 km	59	12	210	87	3.472	166	969	303	151	47	5.476
16-20 km	60	3	82	66	2.981	272	891	178	177	131	4.841
21-30 km	50	5	68	69	4.767	367	1.304	208	380	170	7.388
31-40 km	47	6	31	35	3.479	252	802	147	309	305	5.413
41-50 km	18		64	20	2.652	332	839	16	84	291	4.316
51-100 km	193		42	33	6.838	968	2.138	100	63	1.040	11.415
101-200 km	293				6.099	740	2.105	119		1.423	10.779
201-300 km	649			49	1.072	416	556	102		883	3.727
301 km -	503				991	775	288	210		906	3.673
Sum	1.941	1.013	2.326	540	38.761	4.627	11.393	1.944	1.288	5.215	69.048
% under 50 km	16	92	98	85	61	37	55	73	74	20	57

Table 4, Length of trips and modes of transport in mio. km for Denmark in 2006. Errors in the original data within walking and S-trains has been corrected in collaboration with Carsten Jensen, DTU Transport in Feb. 2008.

In table 5 the transport work on each mode of transport is divided into the purpose of each trip. Please note that 34 per cent of the transport work in vehicles is work/education related. For S-Trains, trains and for busses the percentage of work related trips is much higher. For leisure vehicles is most frequently used when disregarding to walk for leisure.

	Sum	Other	Walk	Bicycle	EU-moped	Driving car	Vare- / lastbil	Passsenger in car	Bus	S-Train, metro	Train
Home	28704	951	355	947	268	15759	1158	5081	824	629	2732
Work / Education	11125	273	38	504	105	6581	1088	578	457	475	1024
Shopping / errand	10589	64	218	349	48	7357	392	1638	230	148	145
Leisure	14419	484	398	504	119	7240	164	3970	358	351	829
Business	4211	168	3	21	.	1825	1824	124	74	49	122
Sum	69048	1941	1013	2325	540	38762	4626	11392	1944	1652	4852
% home – work/education - home	32	28	8	43	39	34	47	10	47	58	42
% home- work / education + shopping /errand - home	48	31	29	58	48	53	56	25	59	66	45

In the survey it was also found that the average transport work pr. person pr. day is app. 45 km and lower than 50 km except for people living in the country side, where the average is 57 km pr. day pr. person.

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Mads Pagh Nielsen and Brian Vad Mathiesen, 16th of November 2007

Appendix II: Potential technologies for 100% renewable energy scenarios

Internal WP2 CEESA working paper

At the annual meeting in august 2007 an initial analysis of transport and energy demands in the CEESA 100 renewable energy scenarios was presented. Also a vehicle/fuel matrix and drive-cycle analyses was presented containing possible future technologies. In this working paper, the technologies for the scenarios are elaborated.

Modes of transport

The transport demands have been identified for the following modes of transport:

- Vehicle petrol (all under 2 ton)
- Vehicle diesel (all under 2 ton)
- Van petrol (between 2 and 6 ton)
- Van diesel (between 2 and 6 ton)
- Heavy vehicle diesel (all above 6 ton)
- Domestic aviation
- International aviation
- Ferry diesel
- Cargo ship diesel
- Bus diesel
- Train diesel
- Train electricity
- Fright train diesel
- Fright train electricity

The transport demands have not been identified for mopeds and for tractors. The importance of these modes of transport and potential solutions are investigated at a later stage.

Transport technologies

A number of propulsion technologies have been considered for along with the relevant fuelling options, including batteries. These:

- PISI (Port Injection Spark Ignition engines)
- DISI (Direct Injection Spark Ignition engines)
- DICI (Direct Injection Compression Ignition engines)
- Gasturbines (Planes and Ships)
- Hybrid PISI (PISI + battery or super capacitor)
- Hybrid DISI (DISI + battery or super capacitor)
- PEM/HTPEM Fuel Cell Hybrids
- PEM/HTPEM FC+On Board Reformer Hybrid (HTPEM's are of particular interest w. reformers)
- SOFC Hybrid

PISI engines offers advantages over DISI engines in the case of some particular fuelling options, including biogas and hydrogen. It is expected by automotive manufacturers that this technology will improve significantly over the next decade. The DICI engine is currently the most efficient in terms of fuel utilization but prospects are that PISI and DISI engines in the future will offer similar efficiencies due to improvements of the technologies and due to the fact that diesel particulate filters most likely will be compulsory.

In the case of trucks, heavy duty vehicles ships and planes operation in APU-mode (Auxiliary Power Units) most also be considered. In the case of hybrid technologies also recharging strategies and the implementation with the power grid should be considered (for instance Plug-In Hybrid Vehicle Technologies). In the case of fuel cell based technologies pure hydrogen vehicles require hydrogen storage.

Additional auxiliary technologies aiding to optimize the above units could also be considered. For instance the use of TEG's (Thermo Electric Generators) could possibly in the future be used to optimize systems along with other bottoming cycles for utilizing for instance excess heat from combustion products.

The means of propulsion for mopeds and scooters can be 2-stroke cycle engines, fuel cells, batteries and hybrids. Mopeds currently contribute to a significant part of emissions – not least in city environments.

Transport technology categories

Here the transport technologies are divided into the following six general categories:

i. Passenger cars and light duty vehicles (including mopeds and scooters)
ii. Trucks and heavy duty vehicles
iii. Busses and trains (and similar means of transportation)
iv. Ships (have significantly different transient requirements than passenger cars)
v. Off-road vehicles (tractors, forklifts, lawnmowers, excavators etc.)
vi. Airplanes

For passenger and light duty vehicles the ICE alone option is not considered to be an option. The hybrid technologies with different combinations of FC and ICE on one hand and electric drive and batteries on the other hand can facilitate an efficient conversion of fuels. This is considered to be possible without jeopardising safety and maintaining the same level of comfort i.e. acceleration and speed. These can be configured as plug-in solutions. Also the fully electric vehicle (EV) is an option. This technology will be included in all scenarios for commuter traffic, as this technology can already now ensure the required range. Pure hydrogen hybrid vehicles are also an option for 2050 but this requires significant advances in hydrogen storage technologies.

For trucks and heavy duty vehicles the options include the (pure) ICE solutions for long distance transport. For domestic transport the options are hybrid solutions with ICE or FC. APU's are also considered to be essential when considering the technologies in this category. The pure electric solution is not considered to be an option.

For busses, trains and trams the solutions are considered to be the same as for passenger vehicles except that for trains (and trams), the pure electric drive is an option while this is not an option for busses. Hybrid solutions will also be an important part of the technologies for busses; however it is possible to include more fuels and a larger FC because of the driving patterns of e.g. local busses.

For ships, bio-diesel and biogas is not considered to be an option. For ships SOFCs and gas turbines are also an option, which has to be considered. There is a difference in the required service for cargo/ships and for ferries which will be taken into account.

For off-road vehicles emphasis will be put on tractors. Because of the issues of biomass vs. wind in this research programme, the inclusion of tractors is important even though it is not a significant part of transportation demand. These may be hybrids or pure electric vehicles. Bio-diesel is also considered an option here because of the location of the transport demand. Other types of transport include fork-lift truck, lawnmowers, excavators, golf cars etc. these are not included here.

For planes the only fuel considered is bio-jet fuel and the only two technologies are gas turbines and DICI.

The following pages show technology matrix setups for the six categories listed above along with relevant fuels. Existing technologies are indicated with ‘2007’ and future (non-existing) technologies with ‘2010+’. The combinations marked with green are considered to be options that will be included in the transport scenarios.

Vehicle Type and Fuel Matrix (Passenger Cars & Light duty vehicles)

Powertrains	***PISI***	***DISI***	***DICI***	***Mopeds&Scooters***	***Hybrid PISI***	***Hybrid DISI***	***Hybrid DICI***	***Pure EV***	***PEM/HTPEM FC Hybrid***	***PEM/HTPEM FC+Reformer Hybrid***
Fuels										
Gasoline	2007 & 2010+	2007 & 2010+		2007 & 2010+	2007 & 2010+	2007 & 2010+				2010+
Diesel			2007 & 2010+				2007 & 2010+			
Electricity (various sources)				2007 & 2010+				2007 & 2010+		
Methanol	2010+	2010+		2010+	2010+	2010+				2010+
Ethanol	2010+	2010+		2010+	2010+	2010+				
LPG	2007 & 2010+									
CNG (Bi Fuel/Multi Fuel)	2007 & 2010+									
CNG (Dedicated engine)	2007 & 2010+			2010+	2010+					
Biogas (Multifuel)	2007 & 2010+									
Biogas (Dedicated engine)	2007 & 2010+			2010+	2010+					
Diesel/Biodiesel blend			2007 & 2010+				2007 & 2010+			
Gasoline/Ethanol blend	2007 & 2010+	2007 & 2010+		2010+		2007 & 2010+				
Biodiesel (Rape Seed etc.)			2007 & 2010+				2007 & 2010+			2010+
DME			2010+				2010+			2010+
Diesel/DME blend			2007 & 2010+				2010+			
Fischer-Tropsch Diesel			2007 & 2010+				2010+			
Naphta										
Compressed Hydrogen	2010+			2010+	2010+				2010+	
Liquid Hydrogen	2010+			2010+	2010+				2010+	
Hydrogen in MeH's	2010+			2010+	2010+				2010+	

PISI: Port Injection Spark Ignition
DISI: Direct Injection Spark Ignition
DICI: Direct Injection Compression Ignition
FC: Fuel Cell
Hybrid vehicles cover following categories: PHEV, PEV + Systems with Supercaps. And Battery technologies.

HCCI??
ISO ENGINES??
2050

Sikkerhed må der ikke gives køb på.
Nogle transporttyper kan der gives køb på rækkevidden.
Der kan gives køb på "køreglæde".

Vehicle Type and Fuel Matrix (Trucks & Heavy Duty Vehicles)

Powertrains	***PISI***	***DISI***	***DICI***	***Hybrid PISI***	***Hybrid DISI***	***Hybrid DICI***	***Hybrid DICI+APU***	***SOFC Hybrid+APU***	***PEM/HTPEM FC Hybrid+APU***	***PEM/HTPEM FC+Ref. Hybrid+APU***
Fuels										
Gasoline	2007 & 2010+	2007 & 2010+		2007 & 2010+	2007 & 2010+					2010+
Diesel			2007 & 2010+			2007 & 2010+	2007 & 2010+			2010+
Methanol	2010+	2010+						2010+		2010+
Ethanol	2010+	2010+		2010+	2010+			2010+		2010+
LPG	2007 & 2010+							2010+		
CNG (Bi Fuel/Multi Fuel)	2007 & 2010+							2010+		
CNG (Dedicated engine)	2007 & 2010+			2010+				2010+		
Biogas (Multifuel)	2007 & 2010+							2010+		
Biogas (Dedicated engine)	2007 & 2010+			2010+				2010+		
Diesel/Biodiesel blend			2007 & 2010+			2007 & 2010+	2007 & 2010+	2010+		
Gasoline/Ethanol blend	2007 & 2010+	2007 & 2010+			2007 & 2010+			2010+		
Biodiesel (Rape Seed etc.)			2007 & 2010+			2007 & 2010+	2007 & 2010+	2010+		2010+
DME			2010+			2010+	2010+	2010+		2010+
Diesel/DME blend			2007 & 2010+			2010+	2010+	2010+		
Fischer-Tropsch Diesel			2007 & 2010+			2010+	2010+	2010+		2010+
Naphta										2010+
Compressed Hydrogen	2010+			2010+				2010+	2010+	
Liquid Hydrogen	2010+			2010+				2010+	2010+	
Hydrogen in MeH's	2010+			2010+				2010+	2010+	

PISI: Port Injection Spark Ignition
DISI: Direct Injection Spark Ignition
DICI: Direct Injection Compression Ignition
FC: Fuel Cell

Skelne mellem nær- og fjerntransport.

Vehicle Type and Fuel Matrix (Busses,Trains&Trams)

Powertrains	***PISI***	***DISI***	***DICI***	***Hybrid PISI***	***Hybrid DISI***	***Hybrid DICI***	***Pure EV***	***SOFC Hybrid + APU***	***PEM/HTPEM FC Hybrid***	***PEM/HTPEM FC+Reformer Hybrid***
Fuels										
Gasoline	2007 & 2010+	2007 & 2010+		2007 & 2010+	2007 & 2010+					2010+
Diesel			2007 & 2010+			2007 & 2010+				2010+
Methanol	2010+	2010+					2007 & 2010+	2010+		2010+
Ethanol	2010+	2010+		2010+	2010+			2010+		2010+
LPG	2007 & 2010+							2010+		
CNG (Bi Fuel/Multi Fuel)	2007 & 2010+							2010+		
CNG (Dedicated engine)	2007 & 2010+			2010+				2010+		
Biogas (Multifuel)	2007 & 2010+							2010+		
Biogas (Dedicated engine)	2007 & 2010+			2010+				2010+		
Diesel/Biodiesel blend			2007 & 2010+			2007 & 2010+		2010+		
Gasoline/Ethanol blend	2007 & 2010+	2007 & 2010+			2007 & 2010+			2010+		
Biodiesel (Rape Seed etc.)			2007 & 2010+			2007 & 2010+		2010+		2010+
DME			2010+			2010+		2010+		2010+
Diesel/DME blend			2007 & 2010+			2010+		2010+		
Fischer-Tropsch Diesel			2007 & 2010+			2010+		2010+		2010+
Naphta										2010+
Compressed Hydrogen	2010+			2010+				2010+	2010+	
Liquid Hydrogen	2010+			2010+				2010+	2010+	
Hydrogen in MeH's	2010+			2010+				2010+	2010+	

(*) No existing or inferior prototypes for cars (due to dynamics and cost) but might be possible on ships

PISI: Port Injection Spark Ignition
DISI: Direct Injection Spark Ignition
DICI: Direct Injection Compression Ignition
FC: Fuel Cell

Vehicle Type and Fuel Matrix (Ships)

Powertrains	***DICI***	***Gasturbines***	***Hybrid DICI***	***SOFC Hybrid + APU***	***PEM/HTPEM FC Hybrid***	***PEM/HTPEM FC+Reformer Hybrid + APU***
Fuels						
Gasoline		2007 & 2010+	Hybrid DICI			2010+
Diesel	2007 & 2010+	2007 & 2010+	2007 & 2010+			2010+
Methanol		2010+		2010+		2010+
Ethanol		2010+		2010+		2010+
LPG		2007 & 2010+		2010+		
CNG (Bi Fuel/Multi Fuel)		2010+		2010+		
CNG (Dedicated engine)		2007 & 2010+		2010+		
Diesel/Biodiesel blend	2007 & 2010+	2010+	2007 & 2010+	2010+		
Gasoline/Ethanol blend		2010+		2010+		
Biodiesel (Rape Seed etc.)	2007 & 2010+	2010+	2007 & 2010+	2010+		2010+
DME	2010+	2010+	2010+	2010+		2010+
Diesel/DME blend	2007 & 2010+	2010+	2010+			2010+
Fischer-Tropsch Diesel	2007 & 2010+	2010+	2010+	2010+		2010+
Naphta				2010+		2010+
Compressed Hydrogen		2010+		2010+	2010+	
Liquid Hydrogen		2010+		2010+	2010+	
Hydrogen in MeH's		2010+		2010+	2010+	

PISI: Port Injection Spark Ignition
DISI: Direct Injection Spark Ignition
DICI: Direct Injection Compression Ignition
FC: Fuel Cell

Opdeling: Færger, godstransport, hurtig transport, effektiv transport

Sikkerhed og komfort vs. energieffektivitet.

On-board renewable supply technologies??

Vehicle Type and Fuel Matrix (Off Road Vehicles)

Powertrains	***PISI***	***DISI***	***DICI***	***Hybrid PISI***	***Hybrid DISI***	***Hybrid DICI***	***Pure EV***	***PEM/HTPEM FC Hybrid***	***PEM/HTPEM FC+Reformer Hybrid***
Fuels									
Gasoline	2007 & 2010+	2007 & 2010+		2007 & 2010+	2007 & 2010+				2010+
Diesel			2007 & 2010+			2007 & 2010+			
Electricity (various sources)							2007 & 2010+		
Methanol	2010+	2010+							2010+
Ethanol	2010+	2010+		2010+	2010+				
LPG	2007 & 2010+								
CNG (Bi Fuel/Multi Fuel)	2007 & 2010+								
CNG (Dedicated engine)	2007 & 2010+			2010+					
Biogas (Multifuel)	2007 & 2010+								
Biogas (Dedicated engine)	2007 & 2010+			2010+					
Diesel/Biodiesel blend			2007 & 2010+			2007 & 2010+			
Gasoline/Ethanol blend	2007 & 2010+	2007 & 2010+			2007 & 2010+				
Biodiesel (Rape Seed etc.)			2007 & 2010+			2007 & 2010+			2010+
DME			2010+			2010+			2010+
Diesel/DME blend			2007 & 2010+			2010+			
Fischer-Tropsch Diesel			2007 & 2010+			2010+			
Naphta									
Compressed Hydrogen	2010+			2010+				2010+	
Liquid Hydrogen	2010+			2010+				2010+	
Hydrogen in MeH's	2010+			2010+				2010+	

PISI: Port Injection Spark Ignition
DISI: Direct Injection Spark Ignition
DICI: Direct Injection Compression Ignition (Tractors, Fork lifts, Lawnmowers, Excavators, Golfcars etc…)
FC: Fuel Cell

Vehicle Type and Fuel Matrix (Airplanes)

Powertrains	***DICI***	***Gasturbines***
Fuels		
Bio-Jetfuel	2007 & 2010+	2010+
Jetfuel (JET-A, JP4, JP8 etc.)		2007 & 2010+

Pathways for conversion of bio-mass to transport fuels

Niclas Scott Bentsen

The purpose of this paper is to analyse mass and energy balances in different pathways for conversion of bio-mass to transport fuels. We focus on the transport fuels identified as potential substitutes to fossil transport fuels through the scenario work by Mads and Brian.
7 alternative fuels have been identified:
Vegetable oil
Bio-diesel
Biogas (upgraded)
Ethanol
Synthetic diesel (FT-diesel)
DME
Electricity

Conversion pathways
All 7 transport fuels may be derived from biomass and for most several possible conversion pathways exists and thus several possible bio-mass feed stocks.

Feed stock	**Conversion tech.**	**Substitute**	**Reference**
Vegetable oil (rape seed)	Transesterification	Bio-diesel	Diesel
	Pressing	Vegetable oil	Diesel
Sugar/starch/lignocellulosics	(Hydrolysis +) fermentation	Bio-ethanol	Gasoline
Lignocellulosics	Gasification + FT	Syn. diesel	Diesel
	Gasification + catalysis	DME	Diesel
	Combustion	Electricity	Fossil elec./gasoline
Wet biomass (grass)	Anaerobic digestion	Biogas (upgraded)	Gasoline

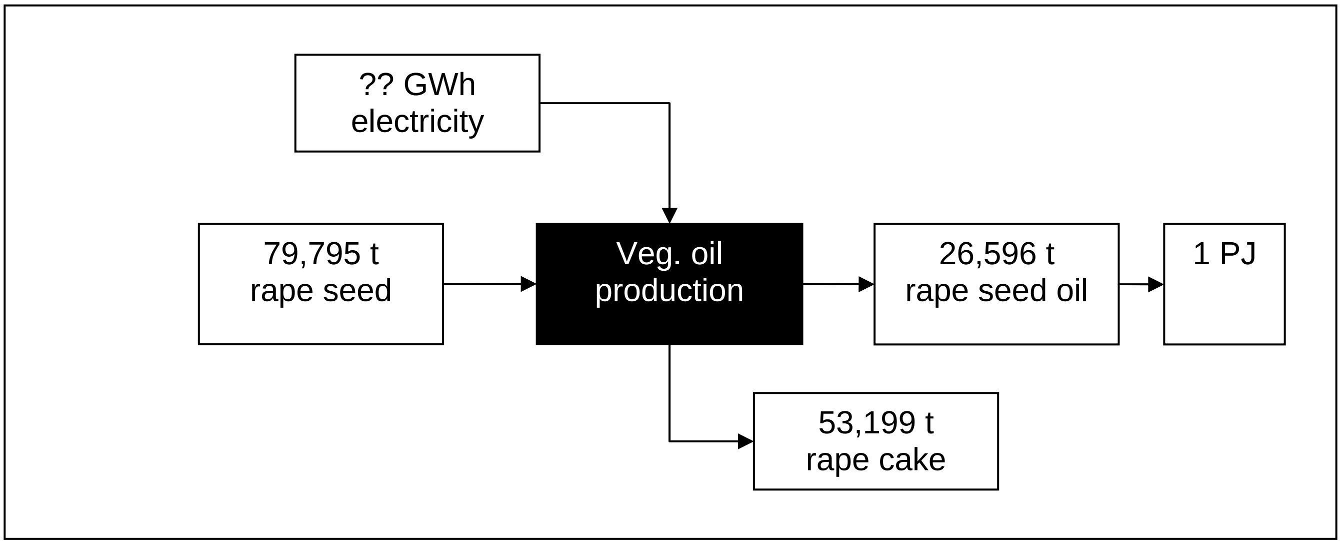
The table above shows the obvious conversion routes for biomass to transport fuels and the conversion technologies that will be analysed in this project.

Mass and energy flows in considered conversion pathways
The conversion pathways considered in this paper can be grouped into 3: Physio-chemical, thermo-chemical and bio-chemical pathways. Mass and energy flows are presented in the following. For comparison different pathways have an equal output of transport fuel of 1 PJ. By-products are quantified as far as possible, but the potential value as energy source is not considered here. This follows at a later stage.

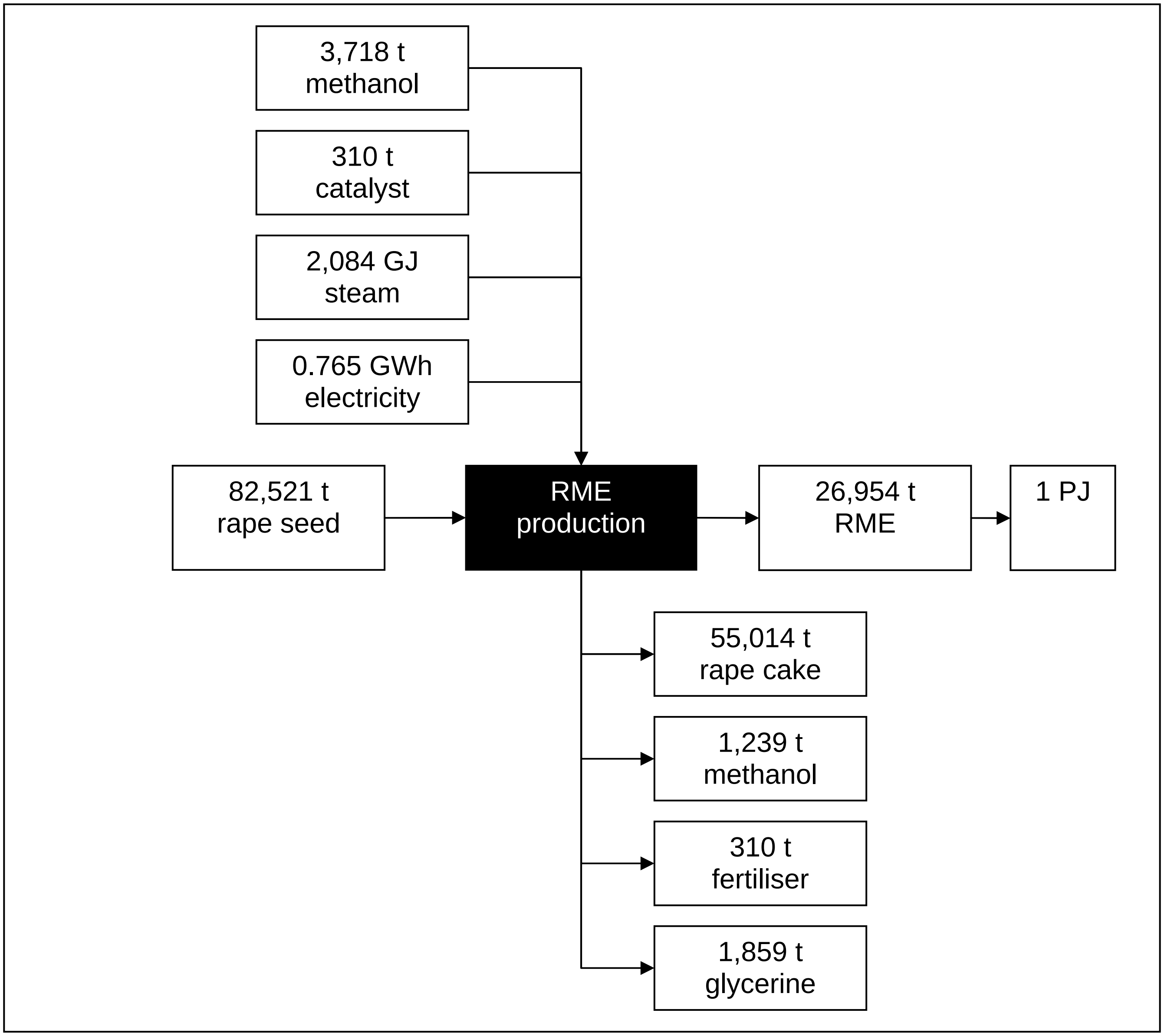
Physio-chemical pathways

In this paper we include production of vegetable oil and bio-diesel in the group of physio-chemical pathways. In both cases rape seed is assumed as the feed stock as this crop is well integrated in Danish agriculture. Other potential crops are sunflower and soy bean, but those are not well suited for the climatic conditions in Denmark.

Production of rape seed oil



Production of RME

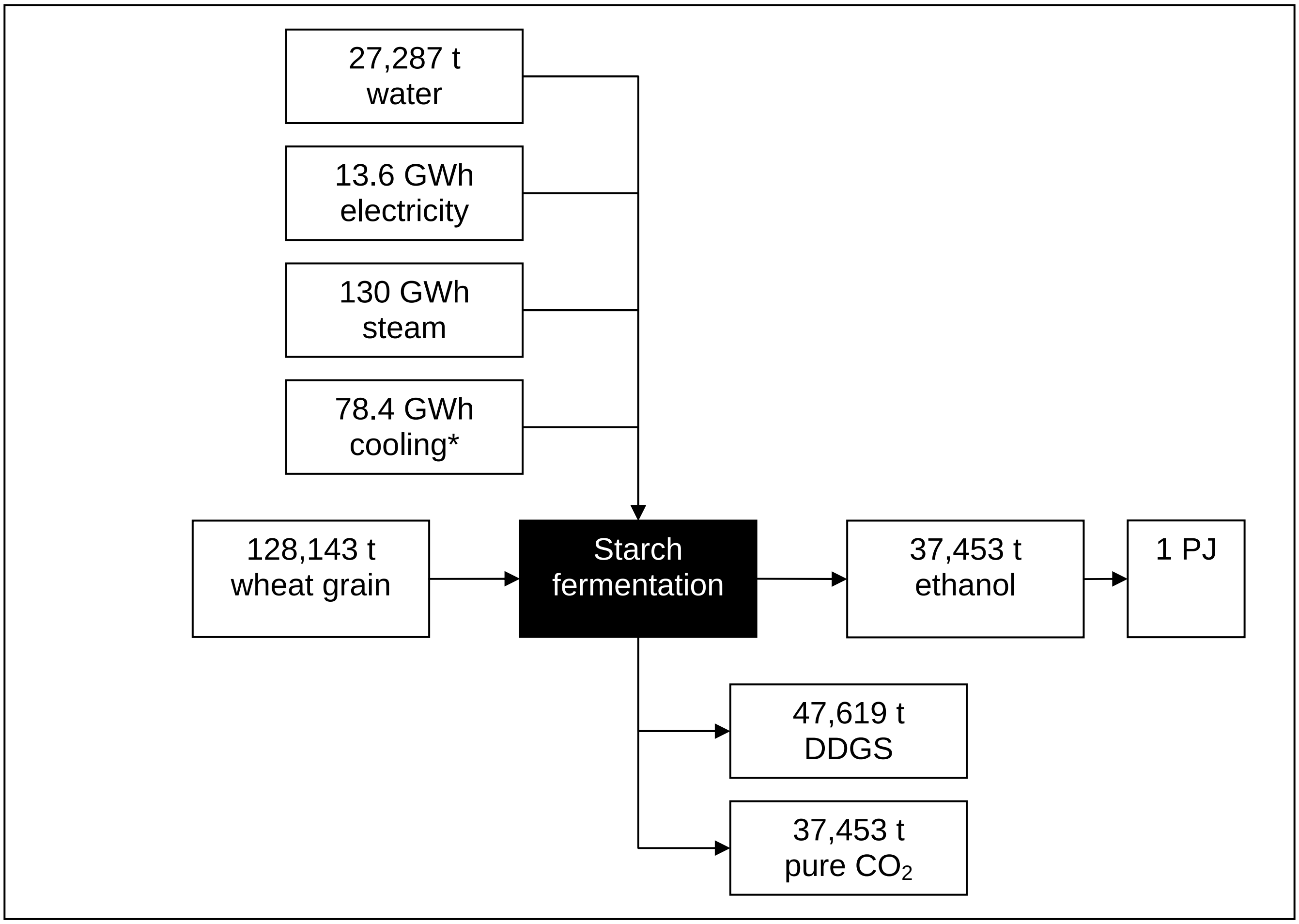


Bio-chemical pathways
This group covers fermentation of bio-mass to alcohol/ethanol and anaerobic digestion of biomass to biogas.

Fermentation of biomass to alcohol is a very old technology, but its role in the transport sector is somewhat more recent. Sugar, starch, cellulosis and hemicellulosis are saccharides - some more complex than others - that can be fermented to alcohol. Sugar can be fermented directly whereas starch, cellulosis and hemicellulosis requires hydrolysis before fermentation. In the case of cellulosis and hemicellulosis pre-treatment is required prior to hydrolysis.

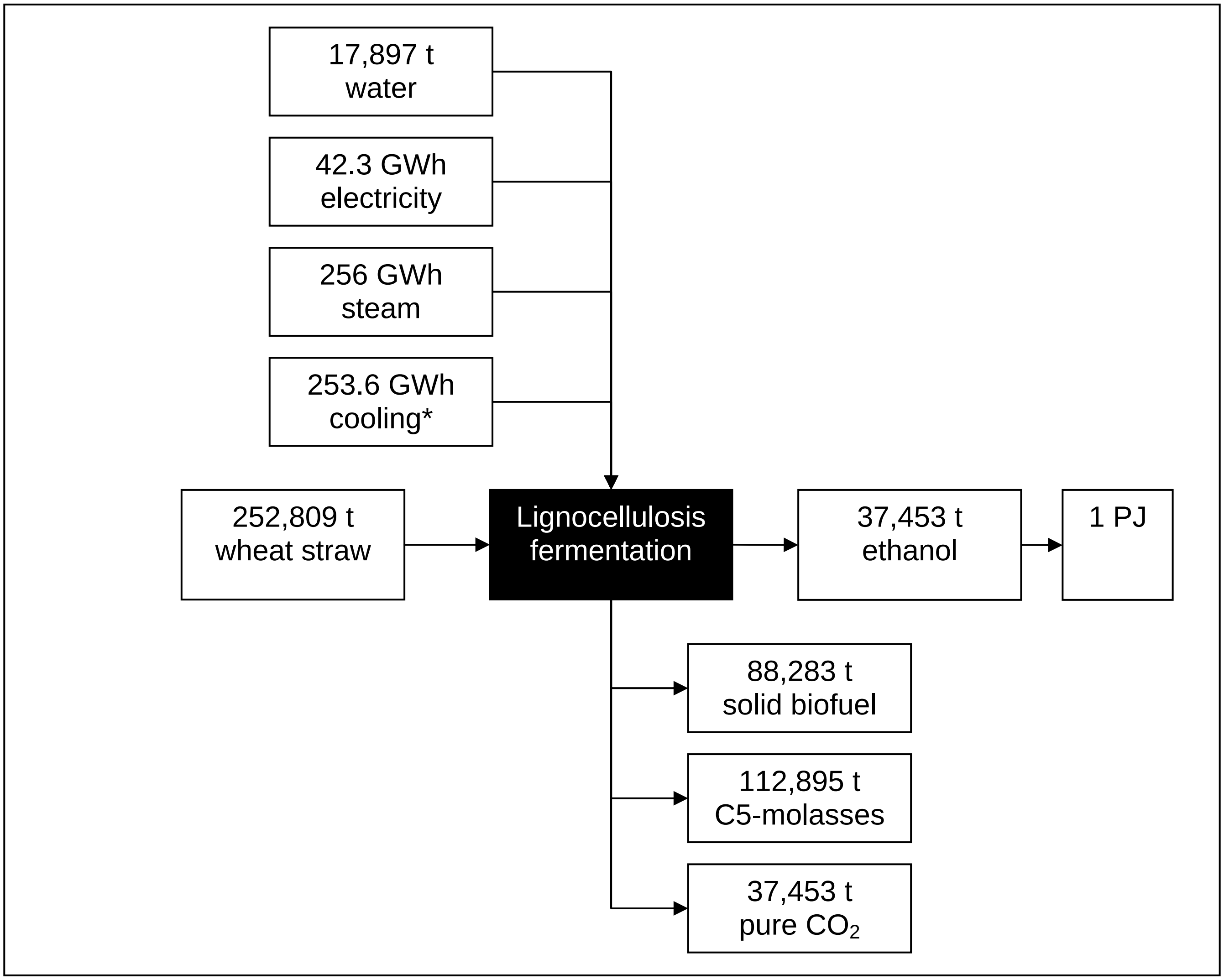
As wheat is the most common feed stock for ethanol production in Europe we start up with this species. Later on we'll include more species in the analyses.

Fermentation of starch

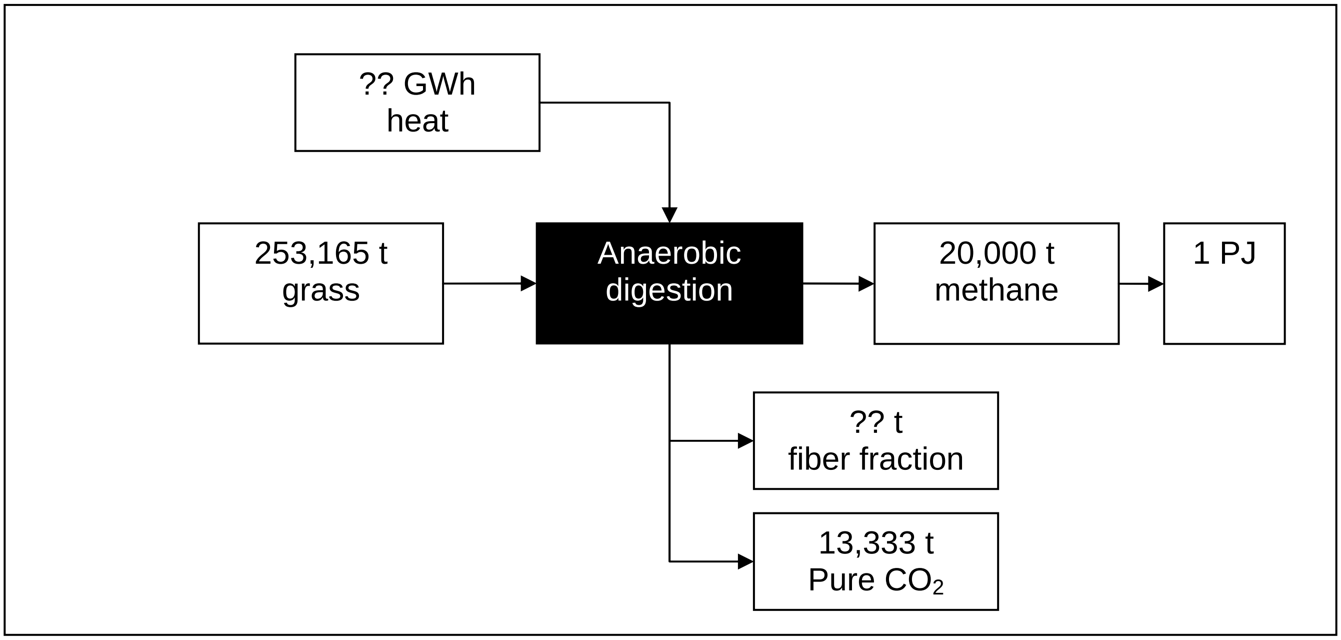


*) When sea water cooling is not an option

Fermentation of lignocellulosis (straw)

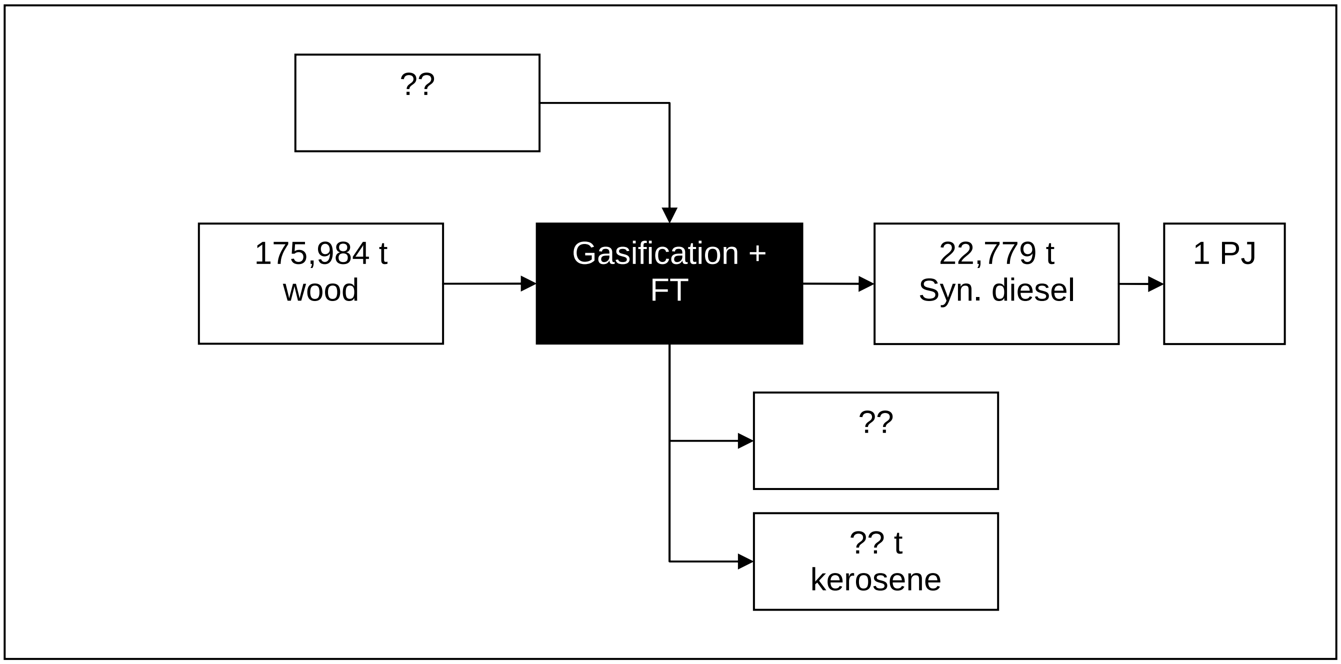


Anaerobic digestion of grass

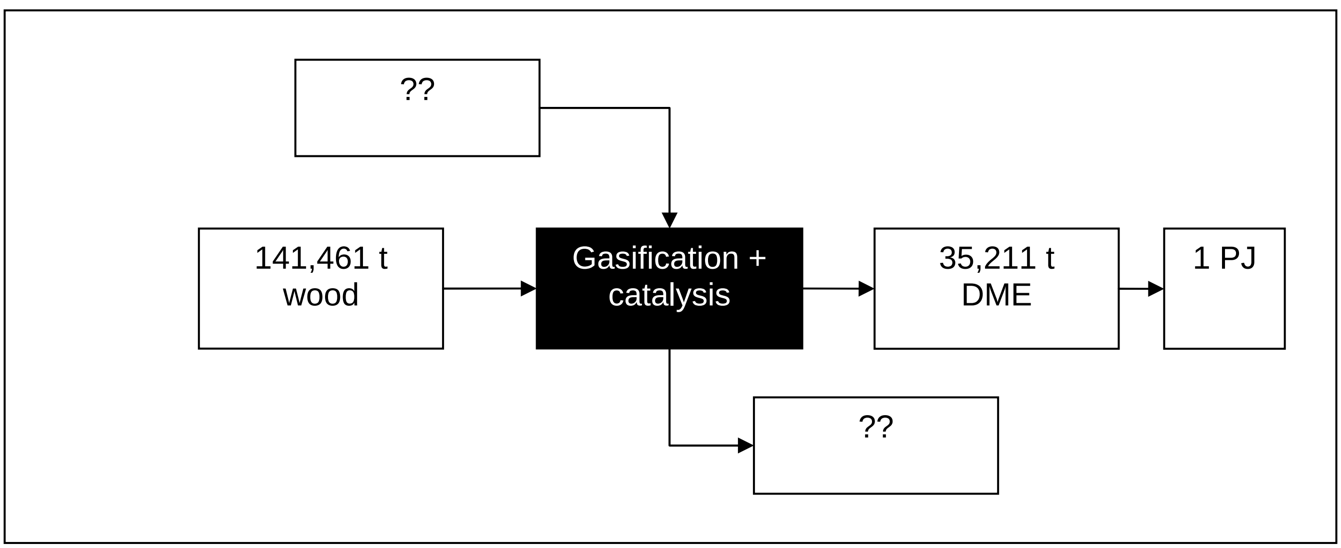


Thermo-chemical pathways
This group covers conversion processes where biomass is decomposed through heating under more or less addition of oxygen.

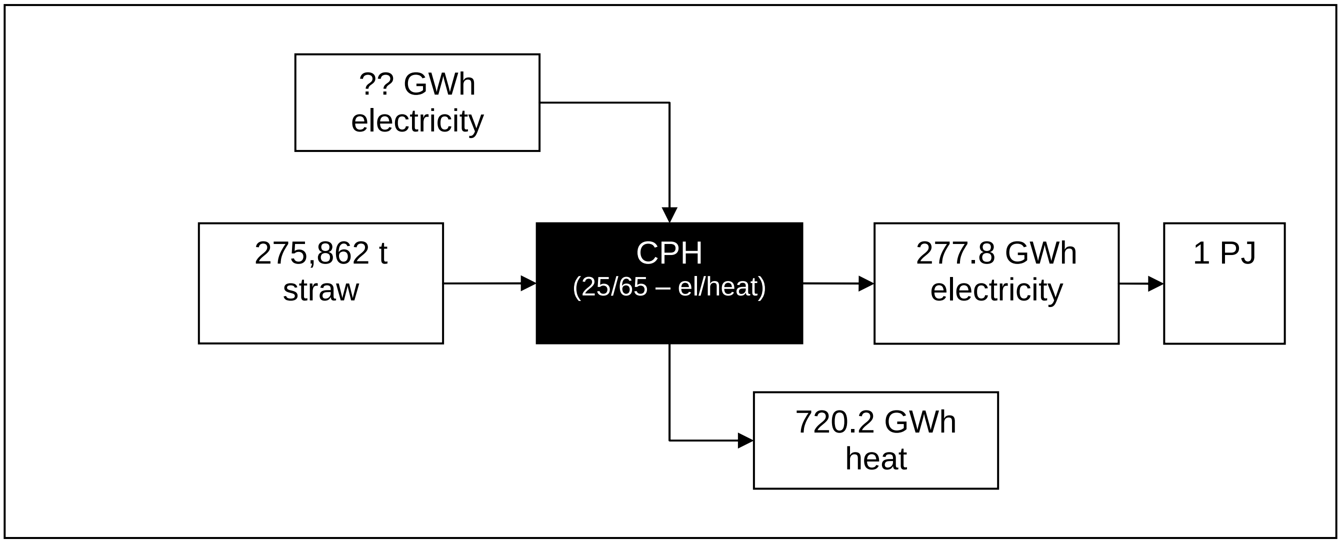
Gasification + FT catalysis to synthetic diesel
Gasification is thermo-chemical decomposition of biomass under partial oxidation of the primary products. The product mix from gasification is 85 % gas, 10-15 % char and 0-5 % liquid. The pathway to transport fuels goes via synthesis of syngas to a diesel like fuel via the Fischer-Tropsch process. During World War 2 gasified wood was used as transport fuel by direct combustion of syngas in the engine. This is probably not a very clean combustion and is most suited for low compression engines, and as such probably not an option with today's engine technology and emission regulations.



Gasification + catalysis to DME
Syngas may also be transformed to methanol or DME using other catalysts.



Combustion
Combustion is the most common thermo chemical decomposition of biomass. The role of combustion of biomass in the transport sector goes via production of electricity to electricity driven vessels.



Induced area consumption
All though all the above described pathways can provide fuels for transport they differ greatly in their requirements for area. In the table below is shown the gross area demand for providing biomass for 1 PJ of considered transport fuels. For all pathways there are derived effects on area demand as some of the pathways utilise by-products from feed production and other utilise the total production on a given area. Also some conversion processes has by-products with feeding values, which can induce area substitution elsewhere.

Feed stock	Transport fuel	Quantity	Gross area demand (ha)	Net area demand (ha)
Rape	RME	1 PJ	25,492	14,952
Rape	Vegetable oil		25,495	14,916
Wheat grain	Ethanol		17,839	11,563
Wheat straw	Ethanol		60,426	54,630
Wheat grain + straw	Ethanol		13,773	8,372
Straw	Electricity		77,424	77,424
Grass	Methane		6,106	6,106
Wood (salix)	DME/methanol		9,068	9,068
Wood (salix)	Syn. diesel		11,281	11,281