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Potential technologies for 100% renewable energy scenarios

Internal WP2.1 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. The next step in WP2.1 is to identify efficiencies and to construct the first scenarios.

The required scenarios from WP2

At the annual meeting three 2050 scenarios 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. The transport scenarios outlined in this WP has to contribute to these six scenarios. Some technologies may not be different in the six scenarios or in the sub-scenarios.

Moreover, it was decided to include the BAU-2050 goods transportation demand in all three 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 meeting next year i.e. the tasks are:

- the identification of suitable transportation technology solutions and
- the identification of suitable biomass production solutions
- for each of the 3 scenarios in each of the two variants (decided in WP1)

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.

Transport demands

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. This will be done when the scenarios are constructed. If new projections are published and are detailed enough these new projections will be used instead.

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.

Modes of transport

BVM and MPN propose to divide the conveying solutions 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+	

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On-board renewable supply technologies??

Opdeling: Færger, godstransport, hurtig transport, effektiv transport

Sikkerhed og komfort vs. energieffektivitet.

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+