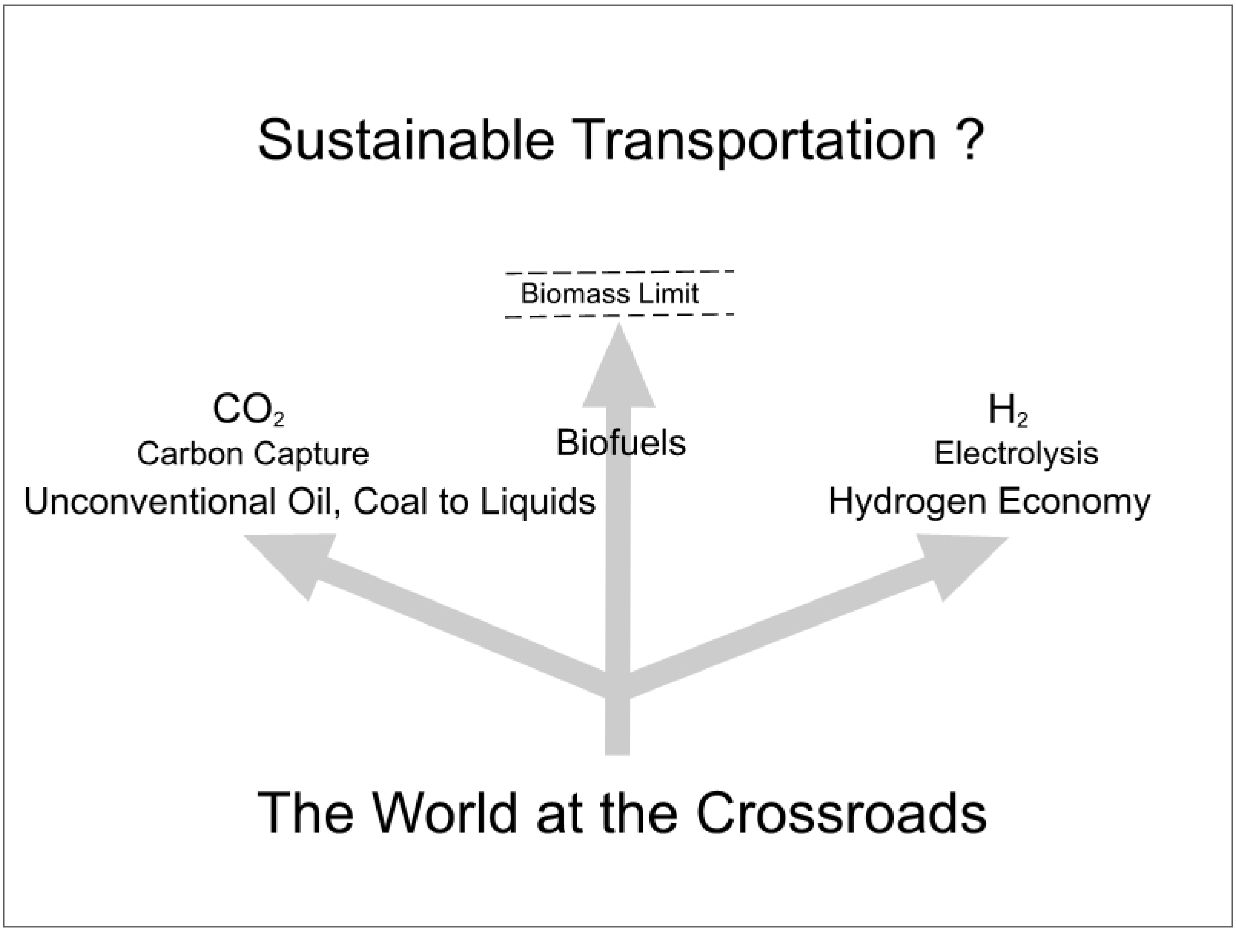
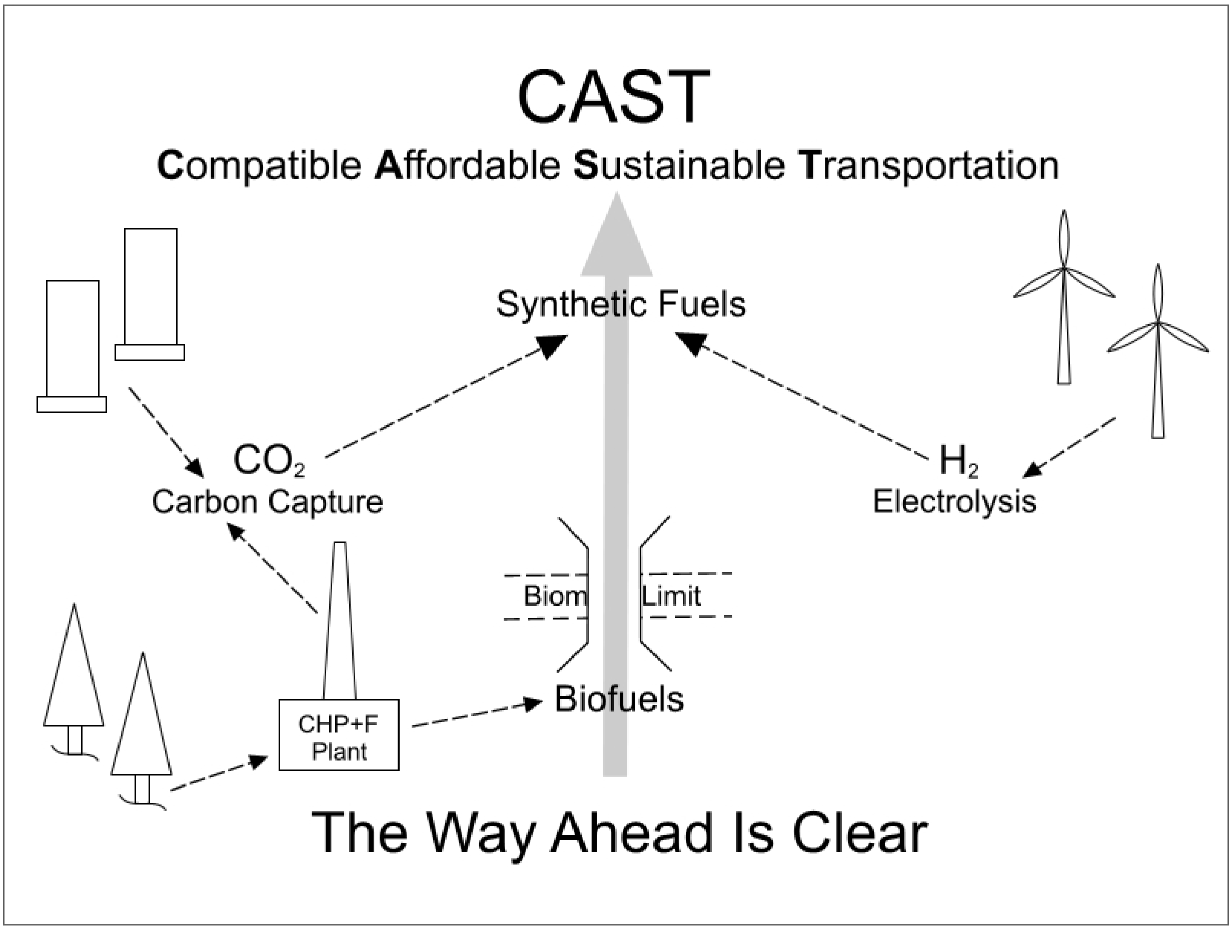

Sustainable Transportation ?
Biomass Limit
CO2
Carbon Capture
Unconventional Oil, Coal to Liquids
Biofuels
H2
Electrolysis
Hydrogen Economy
The World at the Crossroads


CAST
Compatible Affordable Sustainable Transportation
Synthetic Fuels
CO2
Carbon Capture
H2
Electrolysis
Biom
Limit
CHP+F
Plant
Biofuels
The Way Ahead Is Clear

The CAST Proposal
Compatible Affordable Sustainable Transportation

Gordon Taylor, G T Systems, and Richard Pearson, Lotus Engineering

Summary

All transport vehicles with piston and gas turbine engines have good energy efficiencies and further development potential. Moreover their energy and money costs of production are very low. However with oil-based fuels, cars cannot emit much less than about 100 gCO_2/km and even with the development potential, trucks, buses, ships and aircraft all have corresponding minima. Moreover, meeting worldwide transport fuel demands much bigger than today's will not be possible using only 'conventional' oil, which is near to peak production. Also, for most developed countries, indigenous biofuels could only supply at most 10 to 30% of the present transport fuel demand. Hence fully renewable synthetic fuels will be needed to meet the challenges of energy security and climate change. As well as sustainable ethanol and methanol, the CAST proposal includes sustainable synthetic kerosene and diesel. This means that international air and marine transport could be brought within Kyoto 2.

Such sustainable fuels could be produced from CO_2 captured from the air and electrolytic hydrogen from renewable electricity. A world transport fuel demand equal to today's oil-based demand could be met entirely with wind electricity for fuel synthesis. Moreover all countries should have a substantial indigenous wind resource, thus offering security of supply. Such air capture, if followed by sequestration, could also be used to reduce the atmospheric CO_2 concentration, as suggested by Hansen et al.

The transition to sustainable transportation, with energy security and zero GHG emissions, would take at least 30 years, whatever the fuel and vehicle technologies. Therefore policy measures should mandate a GHG reduction rate of 3% per year, with the sustainable fuel chain being paid for by the oil/energy companies.

By putting forward the CAST proposal at COP 15, Denmark could announce a response to the challenges of energy security and climate change with a sustainable solution for the whole transport sector.

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In the lower Figure on the front cover, the objects in the upper left are 'air contactors' for capturing CO_2 from the air. [1] [2]

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DONG Energy, DK	Charles Nielsen, Head of R&D
SEKAB, SE	Per Carstedt, CEO
CHOREN, DE	Tom Blades, CEO
BioMCN	Rob Voncken, CEO

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Glossary

A100	E100 or M100. Some countries may supply one or the other, and some both. (See text)
ADAC	German Automobile Club
Allothermal	In an allothermal process, the energy comes from another source (See Autothermal)
Alcohol	Here taken as Ethanol and/or Methanol
Autothermal	In an autothermal process, the energy is taken from the biomass (See Allothermal)
Avtur	Aviation Turbine Fuel, here taken as Kerosene (qv)
bbl	Barrel (usually of oil or petroleum) – 42 US gallons, 35 UK gallons, 159 litres
BEV	Battery Electric Vehicle – has large electric motor and very large traction battery
Biofuel	Fuel – usually liquid but may be gas – made from biomass
Biomass	Here taken as plant matter – food or non-food
BR	Brazil
BtL	Biomass to Liquid – biofuel, usually diesel or kerosene made by FT process
C	Carbon
CAST	Compatible Affordable Sustainable Transportation
Catalyst	Chemical that assists synthesis process, but is not in final product
Cetane Value	Measure of auto-ignition of fuel in CI engine
CHP	Combined Heat and Power plant – fuel generates power then useful heat (See also DH)
CHP+F	CHP plant integrated with bio- or synthetic fuel production
CI	Compression Ignition (Diesel cycle)
CN	China
CO_2	Carbon Dioxide
Coal-to-Liquids	These are usually gasoline, kerosene and diesel by FT (qv) and methanol, possibly gasoline.
CONCAST	Consensus on Compatible Affordable Sustainable Transportation
DE	Germany
Dedicated	Here a vehicle using only a fully sustainable fuel (See FFV)
DH	District Heating – piped hot water utility for heating buildings (See also CHP)
Diesel	Here 'Diesel' is taken as the CI engine cycle
diesel	Here 'diesel' is taken as the fuel for CI engines. Carbon Number C11 to C22
DK	Denmark
ED95	95 per cent ethanol with 5 per cent ignition improver – for certain Scania CI (Diesel) engines
E0, E20, E85, E100	Percentages of ethanol blended with gasoline
EGR	Exhaust Gas Recirculation (in piston-type ICEs)
EJ	ExaJoule – 10^18 Joules
Electrolysis	Using electricity to split water into hydrogen and oxygen
Energy Crop	Biomass grown for (non-food) energy use – as fuel or feedstock for fuel production
EROI	Energy Return on (Energy) Invested
Ethanol	C_2H_5OH – the second simplest alcohol
EU	European Union
FC	Fuel Cell – uses fuel (usually hydrogen) and air to produce electricity
FCV	Fuel Cell Vehicle – uses Fuel Cell and large electric motor
Feedstock	Raw material – e.g. biomass, CO_2 and H2 - for process – here fuel production
Fermentation	Process for converting biomass into alcohol fuel by 'biological' means (See Gasification)
FFV	Flex-fuel vehicle – able to use E0-85 or M0-85 (sometimes E0-100 and/or M0-100)
FIA	Federation Internationale de l'Automobile
First Generation	Term applied to biofuel made from food crop
FR	France
FT	Fischer-Tropsch - gasification and catalysis route for fuel synthesis
FT diesel	Fischer-Tropsch diesel fuel
FTD	Fischer-Tropsch diesel fuel
Gasification	Process for treatment of feedstock, then catalytic synthesis of fuel (See Fermentation)
Gasoline	Motor fuel for SI engines, also known as petrol. Carbon Number C5 to C12
GHG	Greenhouse Gas (CO_2, CH_4 etc)
GW	GigaWatt – 10^9 Watts
H, H2	Hydrogen – often used as fuel by Fuel Cells
HDV	Heavy Duty (Road) Vehicle – e.g. truck, bus
HEV	Hybrid Electric Vehicle – has ICE, electric motor and small traction battery
HHV	Higher Heat Value - calorific value of fuel including latent heat of water formed (See LHV)
ICE	Internal Combustion Engine – usually piston, could be gas turbine
ICEV	Internal Combustion Engine Vehicle
J	Joule – SI unit of energy = 1 Watt-second

JP	Japan
Kerosene	Here aviation turbine fuel (See Avtur). Carbon Number C9 to C15
kW	kiloWatt – 10^3 Watts
LDV	Light Duty (Road) Vehicle – car, van, light truck (used as car)
LHV	Lower Heat Value - calorific value of fuel excluding latent heat of water formed (See HHV)
Life Cycle	Here taken as energy of vehicle production plus that of fuel production and use (See WTW)
Load Factor	Actual - e.g. annual - output divided by theoretical output at continuous full load
M0, M20, M85, M100	Percentages of methanol blended with gasoline
mbpd	million barrels per day – usually applied to petroleum oil production rate
Methanol	CH_3OH – the simplest alcohol
Mtoe	Million tonnes oil equivalent – here taken as 4.1868 x 10^4 TJ = 41.868 PJ (See Appendix A)
MW	MegaWatt – 10^6 Watts
NEDC	New European Driving Cycle – for assessing vehicle fuel economy and CO_2 emissions
NL	Netherlands
O	Oxygen
Octane Number	Measure of knock-resistance of fuel in SI engine
PGM	Platinum Group Metals – Platinum, Palladium, Rhodium (often used in Fuel Cells)
PHEV	Plug-In Hybrid Electric Vehicle – as HEV but with large traction battery
Powertrain	Engine, transmission, and fuel system - or the functional equivalent
RME	Rape Methyl Ester – biodiesel, made from Rape Seed Oil esterified with methanol
SE	Sweden
Second Generation	Term applied to biofuel made from non-food crop
SI	le Systeme International d'Unites – coherent system of units, often termed 'Metric'
SI	Spark Ignition (Otto cycle)
Synthetic Fuel	Here taken as fuel made from non-biomass feedstocks – e.g. CO_2 and H_2 making alcohol
Synthesis	Combination of elements and compounds – e.g. CO_2 and H_2 – to make e.g. fuel
Total-flex	Vehicle able to use E0-100 (generic usage) 'TotalFlex' is used by VW do Brasil
Tri-flex	Vehicle able to use E0-100 and M0-100 – i.e. any blend of gasoline, ethanol and methanol
TFV	Total-flex Vehicle
3FV	Tri-flex Vehicle (generic usage)
TTW	Tank-To-Wheels – often implies energy efficiency of fuel use – e.g. on NEDC
TW	TeraWatt – 10^12 Watts
UK	United Kingdom (of Great Britain and Northern Ireland)
US	United States of America
US DOE	United States Department of Energy
US EPA	United States Environmental Protection Agency
W	Watt – SI unit of power = 1 Joule per second
WTT	Well-To-Tank – often implies energy efficiency of fuel production
WTW	Well-To-Wheels – often implies overall energy efficiency of fuel production and use
WTW	Wind-To-Wheels – overall energy efficiency of fuel production from wind energy, then use

1 Introduction

1.1 The Price of Oil

'Oil could hit $ 200 within years'. [3] Such high prices are partly because the peak of world oil production has passed or is imminent. [4] It is also a measure of the lack of alternative fuels. There has been little effort at providing replacements – particularly for a complete sustainable transportation solution. [5] Yet the need will soon be acute for every country save the Middle East oil states and Russia. Danish oil production peaked in 2004 and self sufficiency is expected to last only up to 2025. [6] Of the other countries considered here, SE, NL, DE, CN, JP and FR have little or no oil, while BR, US and UK have some oil, but still need to import – already two-thirds in the case of US. All are experiencing ever-increasing foreign currency outflows - $250 billion in 2005 for the US. Only BR, SE, DE, and NL seem to have plans and be making provisions that approach sufficiency and sustainable transportation.

1.2 Climate Change

Denmark is a low-lying country, so has a great interest in minimising sea-level rise. This means limiting global warming and the melting of polar and glacier ice. At COP 15 in Copenhagen, Denmark could lead the way to Kyoto 2, and to a worldwide sustainable transportation solution. This would complement the lead Denmark has already given in building energy with District Heating from Combined Heat and Power plants and in renewable electricity from wind turbines. Indeed, the proposed 'CAST' solution builds on these leads, by enhancing the CHP plants to produce liquid fuels, with renewable energy inputs from biomass and wind electricity.

1.3 The Context

A transition to sustainable energy systems is necessary, but the plant will be capital - and therefore energy - intensive. So if action is delayed, more of the low-cost fossil energy endowment would be used in current consumption, less would be left to invest in such plant and the lower would be the final standard of energy. **(See Fig. 1)**. [7]

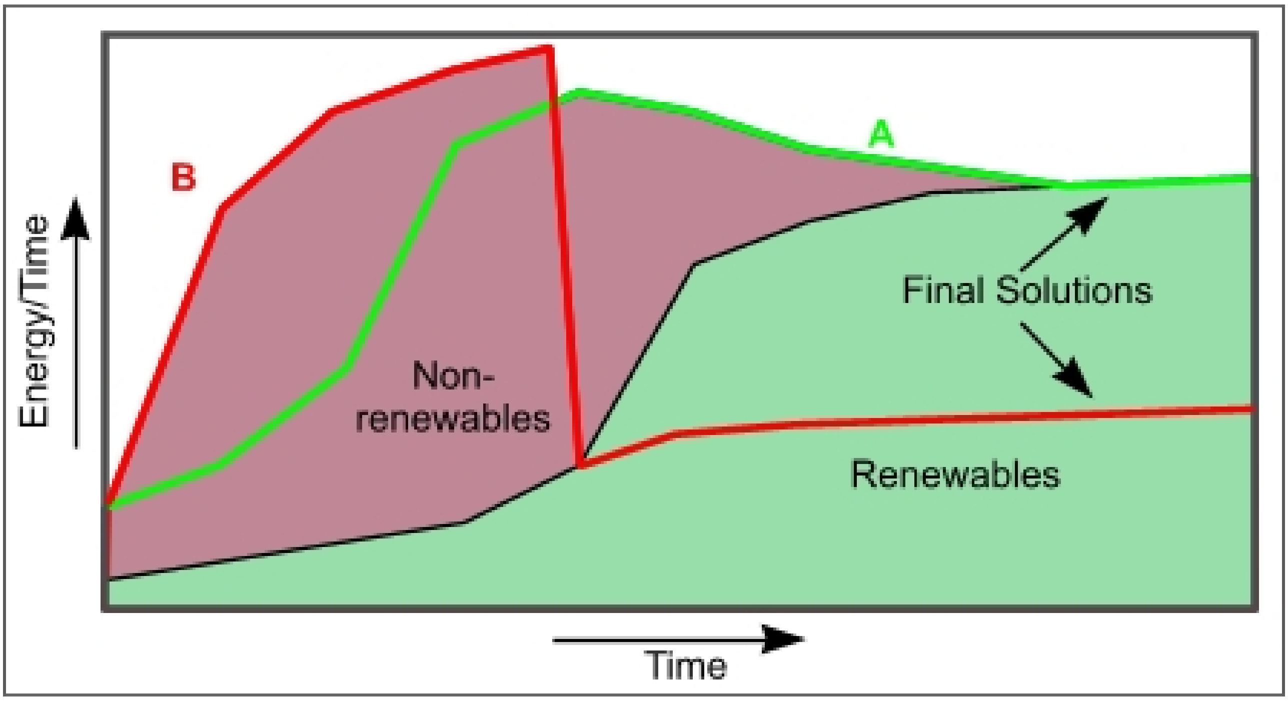


Fig. 1.

Oil production over time, known as Hubbert's Peak, is usually shown as symmetrical. **(See Fig. 2)**. [8]

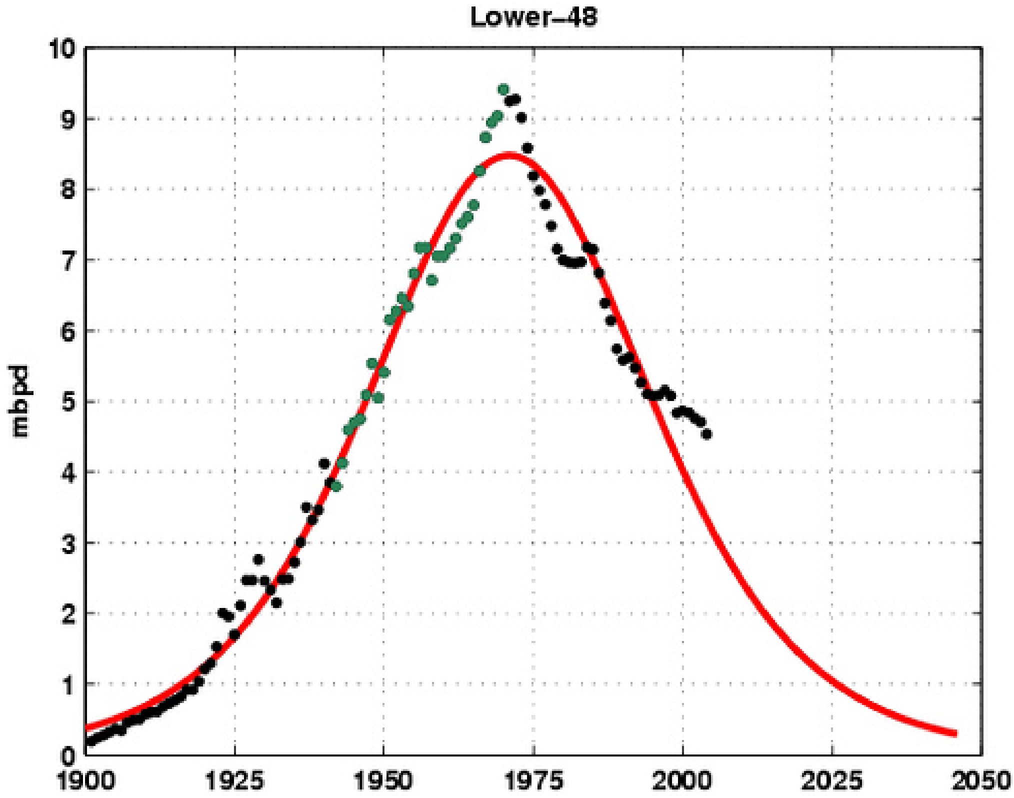


Fig. 2.

However, after taking account of the declining Energy Return on Energy Invested (EROI) of oil production, the net energy curve becomes markedly asymmetrical, with an 'energy cliff'. **(See Fig. 3)**. [9]

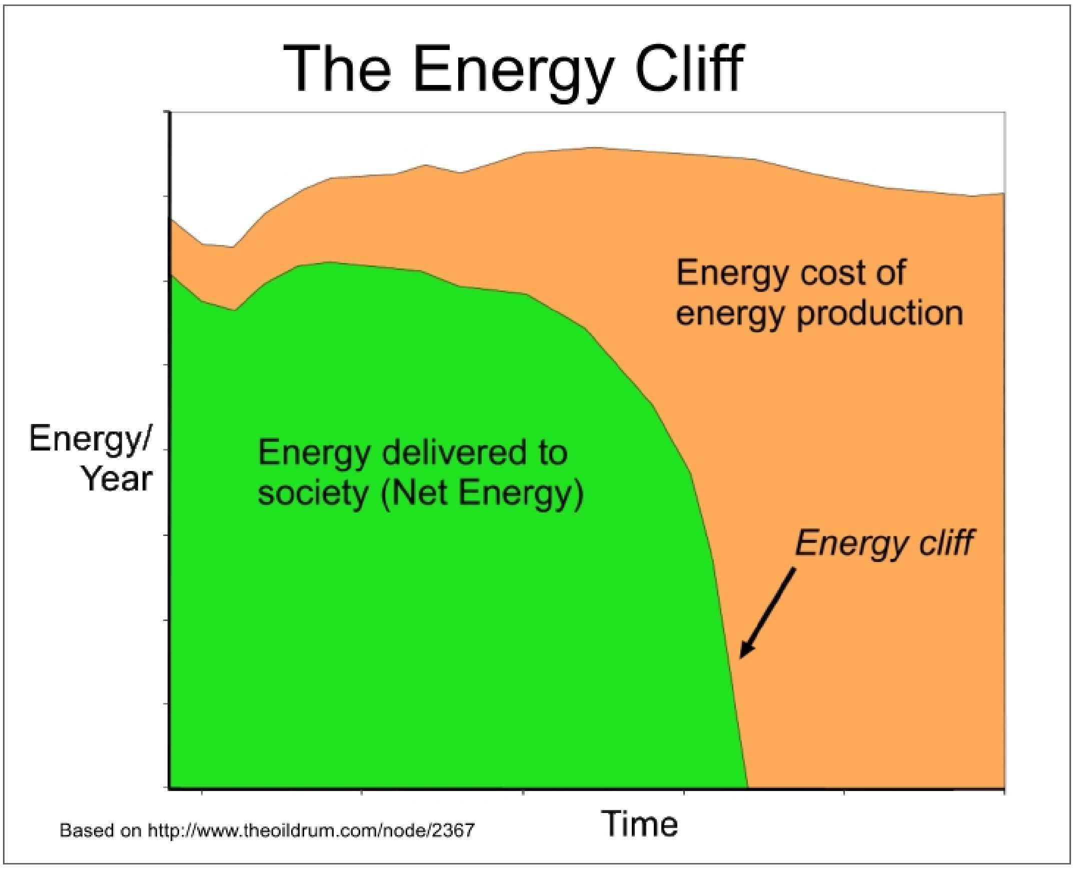


Fig. 3.

Thus after the peak, the fall in effective oil production will be increasingly rapid. Hence 'Climate Change', 'Peak Everything', and the 'Precautionary Principle', require sustainable energy solutions - even while expectations and demands are rising worldwide. For sustainable heat, they are largely Passive Houses and District Heating, and for sustainable electricity, largely Wind Turbines, and now a sustainable transportation solution is needed – preferably synergistic with these.

Of road transport CO_2 emissions, Light Duty Vehicles such as cars account for about 70%. [10] In the EU, these have been the subject of the ACEA voluntary agreement (and related agreements with Japanese and Korean producers) with the target of 140gCO_2/km by 2008. [11] This will not be met, so a mandatory target maximum of 120 gCO_2/km on the New European Driving Cycle (NEDC), with 130 achieved by the vehicle and the rest by other measures including biofuels, has been proposed for 2012. [12] However vehicle numbers and distance traveled are still increasing and values much below about 100 gCO_2/km on the NEDC would be very hard to achieve with conventional oil-based fuels. The VW Polo BlueMotion (Diesel) is 99 and the current (2004) Toyota Prius (Hybrid) is 104, while the lowest conventional gasoline car is the Daihatsu Sirion 1.0 eco top with 118. These are 4/5 seat family cars as opposed to 2-seat cars, like the Smart or the VW '1-litre' prototype, and two of them are Japanese, both from the Toyota Group. Furthermore, the two lowest values are for 'higher cost vehicles' – one a Diesel and the other a Gasoline-Electric Hybrid.

Heavy duty vehicles such as trucks and buses account for about 30% of road transport fuel and CO_2 emissions. [13] The need to regulate their emissions has now been recognised. [14] All road transport vehicles are mature products in highly competitive markets. On oil-based fuels, they are probably within say 30% of their minimum CO_2 emissions. This is simply due to inevitable resistances to motion, such as aerodynamic drag, rolling resistance etc. Hence for road transport vehicles to achieve zero CO_2 emissions would require fully renewable biofuels and synthetic fuels.

However, the CO_2 emissions of aircraft and big ships on international journeys are excluded from Kyoto 1. Yet as a Danish example, AP Moeller-Maerske, the largest container shipper in the world, says that it's fleet of container ships releases as much CO_2 as the entire country of Denmark. [15] All aircraft and ships already keep full accounts of refuelling and usage of these 'bunker' fuels. Moreover most are kerosene (Avtur) or diesel fuels of known carbon intensity. For each journey segment, such emissions could be allocated simply as one half to the departure country and the other to the arrival country, regardless of the 'flag' of the aircraft or ship. However, they too are mature products in highly competitive markets and, on oil-based fuels, are probably within say 30% of their minimum CO_2 emissions. Again this is due to inevitable resistances to motion, although for aircraft and ships, the mechanisms are different. Hence these too could only achieve zero CO_2 emissions with fully renewable biofuels and synthetic fuels.

1.4 Biofuels Targets

The ambitious biofuels policies of BR, the EU, and the US are tacit recognition of the desire to reduce GHG emissions while retaining liquid fuels and internal combustion engines.

For Brazil, the 'Plan Alcool' started in 1975. By April 2008, ethanol from sugar cane supplied about 50% of the (SI) motor fuel, and – allowing for diesel - about 18% overall. [16] It is also exported on a large and increasing scale.

EU policy has been that biofuels should amount to 5.75% by energy of the road transport fuels by 2010. [17] However, this will not be achieved so the European Commission has now switched from a voluntary to a mandatory directive and from specifying input to specifying outcome. The proposed Fuel Quality Directive specifies that the lifecycle GHG emissions of transport fuels be reduced by 1% per year from 2010 to 2020. [18] The first generation biofuels, bio-ethanol and RME biodiesel, are based on food crops containing sugar and starch and vegetable oils. They offer carbon reductions of 30 to 65%, and are limited in supply because of food-fuel competition. In the USA, about 40% of the corn (maize) crop is used to produce only 1 mbpd of ethanol or about 0.66 mbpd oil equivalent (about 5% of motor fuels). [19] This is leading to a rising chorus against such biofuels. [20] In the European case, 5.75% of first generation biofuels would give GHG savings of about 5.75% x 30% = 1.7% to 5.75% x 65% = 3.7%. Even if the transport fuel demand remained unchanged, this would be sufficient for only about 2 to 4 years of GHG reductions – less than half that required for the new strategy.

Second generation biofuels are based not on food crops but on wastes and woody biomass. A certain amount would be available from agricultural and forestry residues and municipal waste, but more would require additional feedstock, from energy crops such as miscanthus or willow. Even so, production would still be constrained by land area, water and nutrients and by carbon released by land use change for energy crops. These issues are causing increasing concern. [21] [22] [23] In particular, the EC Joint Research Centre Institute for Environment and Sustainability (JRC-IES) has found that a change from grassland to arable biofuels crops causes a one-off, but large, release of soil carbon. Hence, even though the biofuel may reduce GHG emissions, the overall GHG 'payback time' is 20 to 300 years. [24] **(See Fig. 4).**

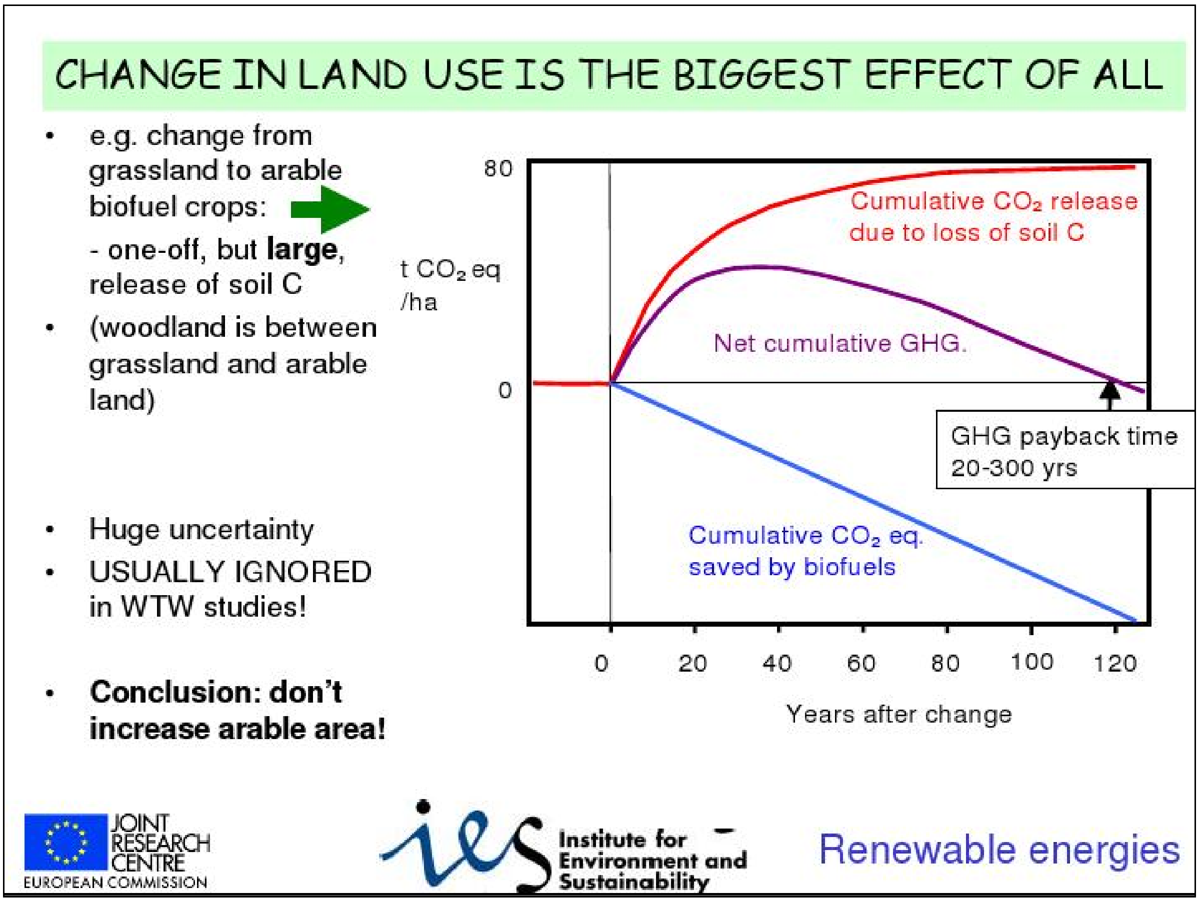


Fig. 4.

Therefore any expansion of biofuels would have to avoid such soil carbon releases, especially by displacement. For example, increased energy crops at home should not lead to land use change – even deforestation – abroad. [25] [26] It seems that the only prudent policy would be use only forestry, agricultural, and municipal wastes as feedstock for biofuels. Yet the EU ambition is that biofuels supply over 30% of the transport fuel demand. [27]

The Netherlands initiated a five-year 'Sustainable Technology Development' programme at the heart of Government in about 1995, and it continues with a dissemination phase. [28] Among the many reports and studies that have informed the programme, one looked at biomass in the Dutch energy infrastructure in 2030. [29] For the Netherlands, a target was assumed of 60% replacement of transportation fuels by 2030 – though 40% was considered more practical. However, in view of the high population density, this assumed significant imports of biomass. This study lead directly to the founding of BioMCN to make bio-methanol, based on biomass and other 'green' renewable feedstocks. Industrial-scale production is scheduled to start in 2009, with an initial capacity of 200,000 tonnes per year and scope for expansion to 800,000 t/yr. [30]

The US DOE plan for 60 billion gallons of ethanol by 2030 is in line with the target of up to 30% of current transport oil consumption. [31] This would require about 1 billion tonnes of biomass per year, compared with the indigenous potential of 1.3 billion tonnes. [32] In practice this would be constrained by the logistics of harvesting and delivery to processing plants.

1.5 Biomass Limits

Some countries could produce considerable amounts of biofuels from indigenous feedstocks, such as Brazil from sugar cane, Sweden from wood and wood wastes, and Denmark from straw. However, most developed countries have biomass limits, due to land, water and nutrients, of only about 10-30% of present transport fuel demand. For Denmark – after 30% fuel saving – the biomass limit would be only about 40%. [33] So for the current demand, it would be only 28%. For Germany, assuming that the production of Biomass-to-Liquid (BtL) fuel (FT diesel or kerosene) was 42% efficient, the total biomass potential would allow a substitution of 21% to 38% of the transport fuel consumption for 2030 (based on energy content). [34]

One way to overcome national biomass limits would be to import bioethanol, as do SEKAB of Sweden, or biomass, as planned by Bio MCN of the Netherlands. However, to increase energy security, countries with high population densities and therefore large import requirements, like the Netherlands and the UK, would need to invest in supply chains. This could be in biomass to ethanol plants in the supplier countries, since it makes more sense to ship not biomass but ethanol. An alternative, which would be more secure, would be to import the biomass feedstock for processing plants in the importing country. Then the only investment needed in the supplier country would be a pelletizing plant, since this greatly increases the energy density and enables automatic handling in standard dry cargo ships, as used for coal, minerals and grain etc. However, all such supplies would need to be properly managed for sustainability, avoiding food-fuel and other conflicts and abuses. [35] Moreover, since they would not be fully indigenous, energy security would remain an issue, while they would still be subject to the world biomass limit.

Testing a sustainable option - here biofuels - for sufficiency amounts to 'backcasting', as used by Mulder and Biesiot. [36] The present world transport fuel demand is about 88 EJ/y. The world biomass potential for 2050 may be as low as 40 EJ/y or as high as 1100 EJ/y. [37] The energy efficiency of methanol production is about 50%, so these would yield such fuel of about 20 to 650 EJ/y, which is 0.2 to 7 times as much. **(See Appendix A).** In reality, the available biomass would be constrained by competition with food crops for land, water, nutrients and farmers, particularly by the carbon released by land use change to arable for energy crops and by the logistics of transporting the biomass. **(See Fig. 4).** [38] It is therefore very unlikely that there would be sufficient available biomass for biofuels alone to meet the world transport fuel demand. Also, the geographic distribution of the biomass would differ greatly from that of the fuel demand, so energy security would remain an issue. However, national, regional and world energy policy has not yet recognised that fully renewable synthetic fuels (of some kind) will be needed for the transport sector to meet the challenges of energy security and climate change. Nor has it identified and quantified how they could be produced.

1.6 Pre-CAST

Oil-based fuels are being increasingly reserved for transport. Even so, transport energy demands much bigger than today's would not be possible using only 'conventional' oil, which is near to peak production. Moreover it will soon drop down the 'energy cliff', to the 'point of futility', where the energy cost of extracting it would equal that in the oil produced. **(See Fig. 3)**. By definition, most sources of 'unconventional oil' would already be nearer this point. [39] [40] [41] Hence, with supply declining and transport demand and GHG emissions still growing, the need for a sustainable transportation solution is urgent.

Two impediments to achieving sustainable transportation have been the preference of the oil majors for 'unconventional' oil and Coal-to-Liquids and the continued advocacy of the so-called 'Hydrogen Economy', and a transition to hydrogen and fuel cell vehicles (FCVs). However, the chemistry and physics shows that hydrogen and fuel cell vehicles are not the answer. [42] Moreover, to replace the worldwide motor vehicle fleet, which is fast approaching one billion, would be far too costly. At say $ 50,000 for each vehicle, the cost could be around $ 50 trillion. Even spread over say 15 years, this would be an unprecedented 'spend rate', which would have to be matched by a comparable 'saving rate' from disposable income. Furthermore, hydrogen fuel cells would be quite impractical for heavy duty vehicles, which account for about 30% of the demand for road transport fuels.

Replacement of the existing fuel production plants (refineries) would also be hugely costly and leave vast ‘stranded assets’. The world - whether oil companies or nations - cannot afford to write off the present fuel infrastructure, much less invest in an all-new one for hydrogen. This could cost a trillion dollars for the USA alone [43] and would have to run alongside for a transition period which may be 38 years or more. [44] Also, with two fuel infrastructures serving only one vehicle market, both would earn reduced rates of return.

Thus the world is at a crossroads and the decision can be delayed no longer. To the left lies 'Unconventional Oil' and 'Coal-to-Liquids', with increased GHG emissions and no sustainable future, and to the right lies the 'Hydrogen Economy', which is unaffordable, incomplete, and with no defined destination. Straight ahead lies 'Biofuels', which has a barrier at the Biomass Limit. **(See Fig. 5).**

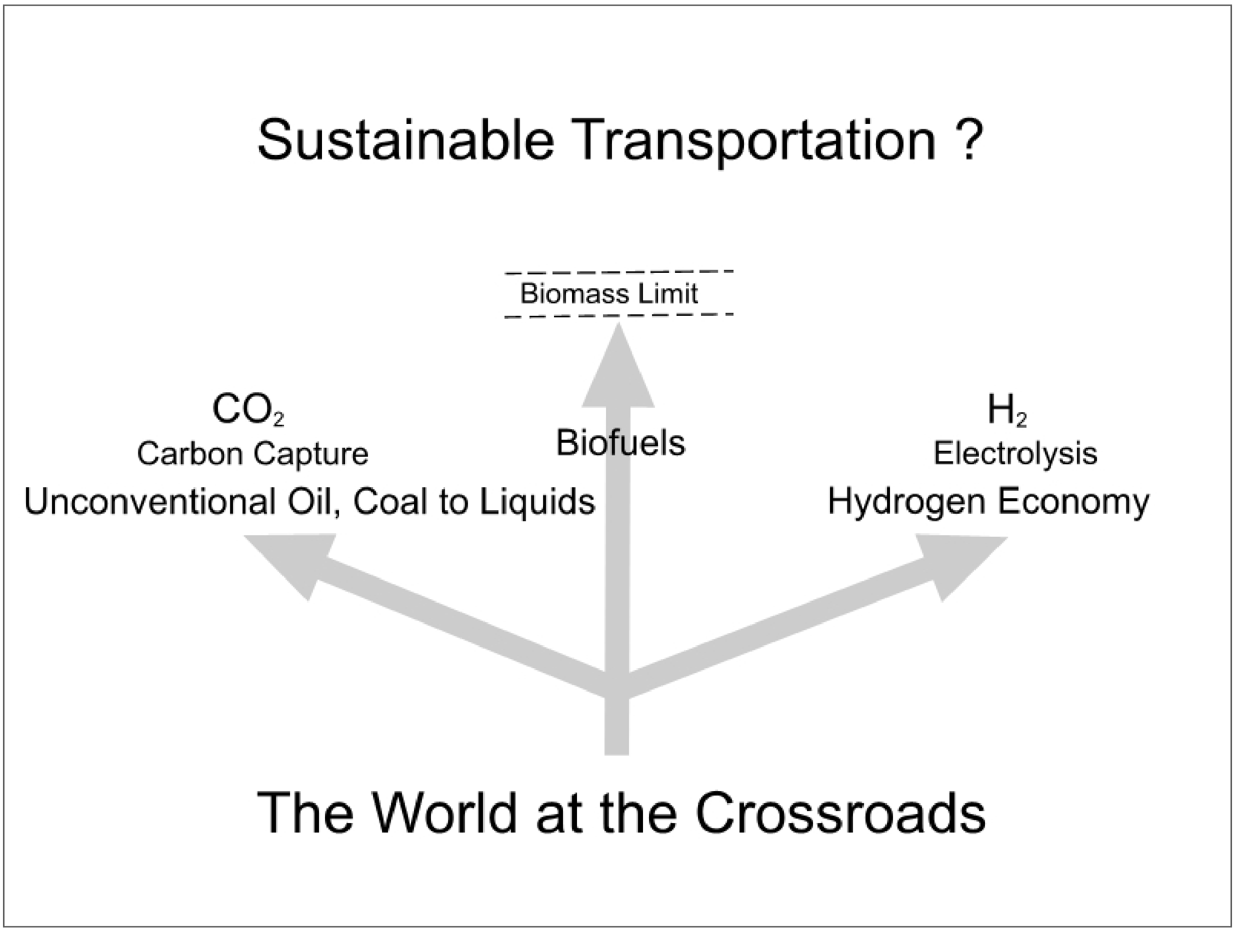


Fig. 5.

Hence if no other choice was made, the road to 'Unconventional Oil' and 'Coal-to-Liquids' would be taken. However, with the help of renewable carbon (biomass and captured CO_2) and electrolytic hydrogen made with renewable electricity – most notably from wind turbines - the Biomass Limit barrier could be overcome by going to Synthetic Fuels, so reaching the present level of demand and more. Moreover all fuels would be based on renewable sources – biomass, CO_2 and renewable electricity – thus ensuring sustainability. Although synthetic fuels by themselves could be sufficient for energy security and sustainability, biofuels could contribute partially – and even wholly in some countries. This is the 'CAST' solution. **(See Fig. 6).**

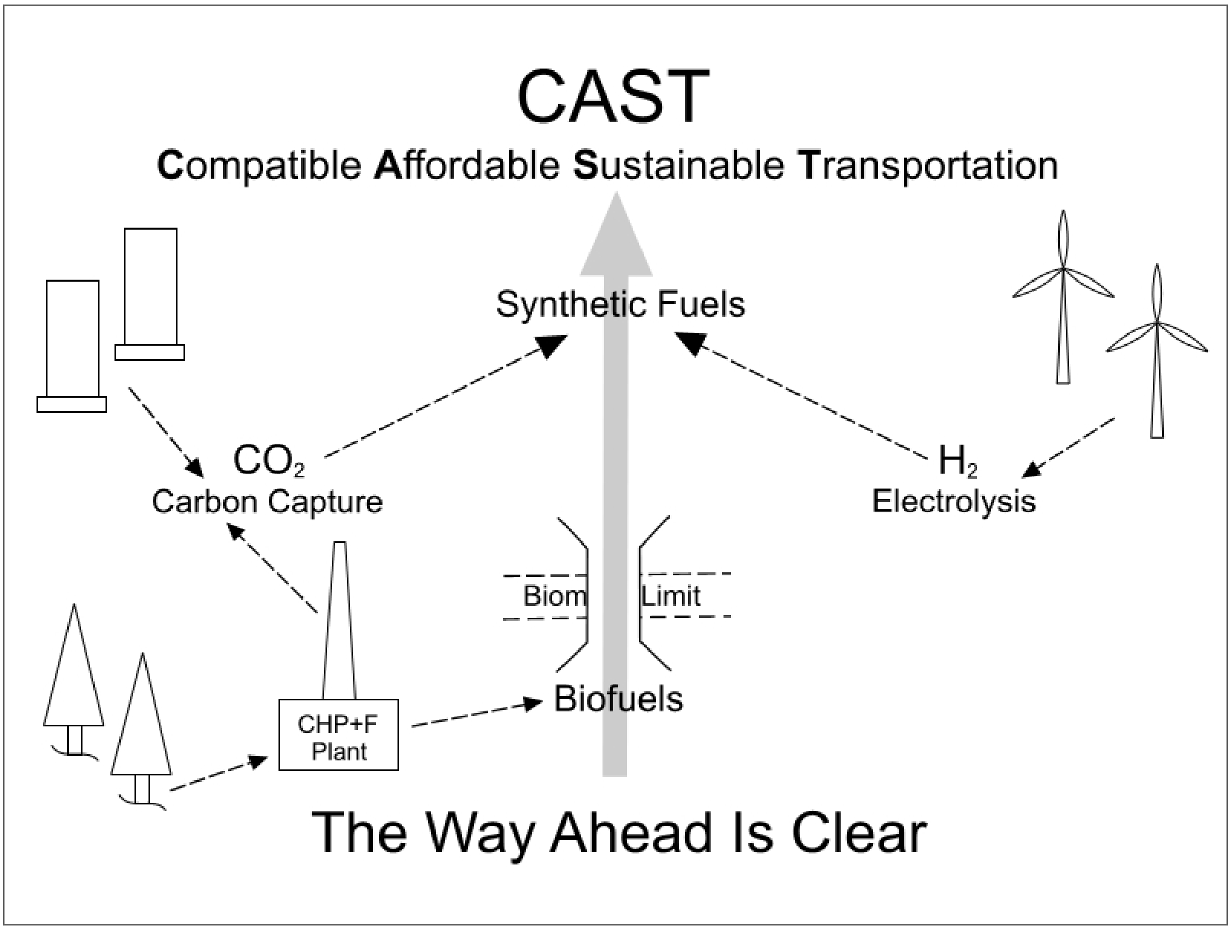


Fig. 6.

2 CAST – Compatible Affordable Sustainable Transportation

2.1 Compatible and Complete

The CAST proposal allows free choice of feedstock, allowing variation, and of process, allowing innovation. Only four sustainable fuels are specified: sustainable kerosene and diesel; sustainable ethanol and methanol. The fuel mix could vary, both from country to country and over time. The four fuels cover all types of transport vehicles: aircraft, ships, trains, buses, trucks and cars. Synthetic kerosene for aircraft and synthetic diesel for big ships, trains and trucks would give the same payloads and ranges. Ships, trains and trucks could also use the (cheaper) alcohols with minor losses of payload or range. Aircraft and big ships are extremely costly and may have lifetimes of 40 years. Hence their owners have a vital interest in a transition to sustainable fuels – to enable their continued operation. With the CAST proposal including sustainable synthetic kerosene and diesel, international air and marine transport could be brought within Kyoto 2.

With a determined effort, lead off by announcing CAST at COP 15, it should be possible to complete such a sustainable transportation solution by 2050, when Denmark's oil would be just about exhausted. [45] Moreover, since the CAST solution depends more on engineering and chemistry and less on biomass and biology, the transition could be accelerated with less risk of 'unintended consequences'. This may well be needed, because action on energy security and climate change is now extremely urgent. Indeed according to Hansen et al, the current atmospheric CO_2 of 385 ppm, leading inevitably to a peak of 450 or more, already exceeds the limit of at most 350 stabilised that they believe necessary. [46]

2.2 Compatible: Keep Liquid Fuels

The world has adopted just a few liquid transport fuels – gasoline, kerosene, and diesel – all derived from oil. [47] Most liquid fuels are compounds of Carbon, Hydrogen and sometimes Oxygen. CHO liquids are easy to produce, and have high energy densities. They can be transported by pipelines and by sea and road tankers, stored in low cost tanks, and dispensed by self-service. Also, the alcohols methanol and ethanol can at least equal the vehicle (TTW) energy efficiency of diesel and gasoline while giving scope for vehicle engines of increased specific power and efficiency and reduced size and weight. Moreover, methanol and ethanol can mix with gasoline, enabling Flexible Fuel Vehicles (FFVs) with a single fuel tank. This would be invaluable for future energy security, especially throughout the transition to fully sustainable fuels.

2.2.1 Gasoline, Kerosene and Diesel

To avoid major losses of payload and/or range, jet aircraft would need synthetic kerosene. This would have the same gravimetric and volumetric energy density as existing oil-based kerosene (Avtur). It would also be needed for maximum compatibility with existing jet engines, which would take perhaps 10 years to 're-qualify' on any new fuel. Both aircraft and engine designs are long-lived, up to 40 years. For similar reasons, big ships would also need synthetic kerosene (for gas turbines) and diesel (for Diesel engines). Hence these traffics must bear the premium of about 1.2 to 1.4 x in feedstock and energy used for production compared with those for alcohol fuels. [48] [49]

For road vehicles, synthetic diesel might be needed to ease the transition, as might synthetic gasoline. Therefore, despite the feedstock and energy penalties, converting methanol to gasoline has been considered. [50] However when running on E85, E100, M85 and M100, flex-fuel, total-flex, tri-flex and dedicated vehicles have higher performance and fuel energy efficiency. Moreover, alcohol-optimized SI engines have achieved CI (Diesel) engine levels of energy efficiency. [51] Hence compared with Diesel engines, the lesser weight and cost of such SI engines should more than offset the somewhat greater weight and volume of the methanol fuel tank. Therefore, to avoid the additional feedstock and energy use for their production, any synthetic gasoline and diesel for road vehicles should be replaced by alcohol fuels as soon as possible.

2.2.2 Ethanol and Methanol

For most road vehicles, energy per unit mass and volume as high as oil-based fuels is much less important. Because road vehicles account for the major part (by energy) of all transport fuels consumed, the sustainable fuels should be chosen for both efficient production and efficient conversion in internal combustion engines (ICEs). In particular, light duty vehicles such as cars account for some 70% of road transport fuel (by energy). [52] For these, maximum payload and range are less important than fuel production and use efficiency – and hence operating cost. Therefore to avoid the higher feedstock and energy use when producing synthetic diesel or gasoline, ethanol and methanol are preferable.

Where ample biomass is available – e.g. in tropical countries able to grow sugar cane - ethanol is the obvious choice. Conversely, in developed countries, where the indigenous biofuel potential may be only 10% or less, allothermal conversion of biomass to biofuels and more particularly, fully synthetic fuels would be required. [53] Methanol has the highest carbon efficiency of liquid fuels, and hence gives the maximum yield from a given amount of biomass. [54] Also, when synthesised from carbon dioxide, methanol uses the least hydrogen. [55] Hence methanol is preferable not only to synthetic diesel and gasoline but also to ethanol. Methanol was used successfully in a wide variety of dedicated and flex-fuel cars and dedicated trucks in the 1990s. [56] It is in use as M15, M85 and M100 on a rapidly increasing scale in China, with 2.71 million tonnes in 2007. [57] Moreover, proposed Coal-to-Liquids (methanol) plants could replace 1 mbpd of oil – 10% - by 2013. [58] [59] Although such methanol is far from renewable, it is prompting the use of M15 in existing vehicles and the development and production of vehicles able to use M85 and M100.

2.3 Compatible: Keep Internal Combustion Engines

The world has adopted and invested in just two types of engines to use the liquid fuels – piston-type internal combustion engines (ICEs) for cars, vans, buses, trucks, trains, and ships, and gas turbines for some ships and most aircraft. Moreover both have very high power densities (in kW/kg and kW/m3) and good energy efficiencies. Furthermore, they still have considerable development potential. Yet they contain few scarce materials, which also means that the embedded energy is very low, and are very inexpensive (e.g. in $/kW). For aircraft, ships, trucks and buses, which are still expensive but run around 50% of the time, this is highly desirable but for cars, which are much more numerous yet run only about 5% of the time, it is essential. [60] In addition, there are huge investments of energy, materials and money in the plant to manufacture such vehicles. The auto makers are either all but bankrupt (GM, Ford, Chrysler) or fully stretched and cannot afford to write off present plants, never mind invest in new ones. Premature replacement of the existing vehicle plants and fleets would be hugely costly and leave vast 'stranded assets'.

Liquid biofuels and synthetic fuels for transport would address both the energy security and climate change challenges. Yet they are highly compatible with the existing vehicles, so avoiding the energy and money costs of premature replacement of the vehicle fleets and manufacturing plants.

2.3.1 Compression Ignition Engines

The peak energy efficiency of CI (Diesel) engines of truck and bus sizes on diesel fuel is up to 44%. [61] [62] Moreover because such engines are unthrottled, the efficiency remains high even at the low loads typical of urban driving, giving excellent fuel economy. Similar CI engines may also use methanol and ethanol even though they have high Octane Numbers and hence low Cetane Numbers. Ignition may be achieved either by a glow-plug or spark plug, or by a very high compression ratio (e.g. 28 to 1), together with the addition of an ignition improver (typically 5%) to the fuel.

2.3.1.1 MAN engines for M100

MAN developed 'spark-assisted' CI (Diesel) engines for buses running on methanol (M100) in the 1990s. When so doing, the energy efficiency of a transit bus was measured on a test track as equal to that with a Diesel engine running on diesel fuel. [63] These engines are particularly significant because methanol is the easiest sustainable fuel to produce and no ignition improver was needed, so reducing the fuel cost. Moreover, such engines could almost certainly use ethanol (E100) if required. **(See Fig. 7).**

2.3.1.2 Scania engines for ED95

For CI engines with very high compression ratios, diesel levels of energy efficiency have already been achieved using ethanol plus an ignition improver, known as ED95. [64] Scania has supplied such CI engines dedicated to using ED95 in buses for 17 years, with 600 in service. The latest have a peak thermal efficiency on ethanol (ED95) of 43%, compared with that on diesel of 44%. [65] The series production of ethanol-fuelled buses and trucks from Scania and trucks from Volvo is due in 2010. [66] Hence for trucks and buses there should be no need to persist with synthetic diesel which would incur feedstock and energy losses. Ethanol has a higher energy density than methanol, so for some trucks seeking higher payload and range, this may be worth the somewhat higher cost. There will always be some ethanol obtained from biomass by fermentation, especially in tropical countries. However, such ethanol will always be subject to biomass limits.

2.3.2 Spark Ignition Engines

SI (Otto or gasoline) engines are usually used in Light Duty Vehicles (LDVs) such as cars and light vans. For such engines the average energy efficiency on the New European Driving Cycle (NEDC) is about 18%. [67] However, on alcohol fuels, even current engines have higher energy efficiency. For example, the fuel economy of a VW 1.6 l TotalFlex car on E100 is 5% above that on E22. [68]

For SI engines, a crucial parameter of the fuel is 'knock resistance', usually expressed as the Octane Number. However the value for iso-Octane, taken as 100, is not the limit. Higher values are offered by ethanol and methanol at about 106. This and their other attributes (latent heat of evaporation, flame speed etc) allow higher compression ratios than with gasoline, and hence higher energy efficiency. Moreover, such fuels may be used in modified engines with little or no throttling, so that the efficiency remains high at the low loads typical of urban driving. [69] Optimization of engines for alcohol fuels should bring considerable gains in energy efficiency and hence fuel economy.

2.3.2.1 Flex-Fuel engines for E0-85

Flex-fuel engines are fitted in Flex-Fuel Vehicles (FFVs) in production for markets where ethanol fuel (E85) is available. This includes the USA, Sweden and is starting in the Netherlands, France and the UK. However, due to the development effort required, a small range of engines is fitted in a larger range of vehicles. **(See Appendix B).** Compared to that for ethanol, the volumetric energy density of methanol is 0.75. So based on fuel flow, it is likely that vehicles designed for E85 could also use M55, and those designed for E100 could also use M75. This could speed the transition to sustainable methanol fuel. **(See Fig. 7)**

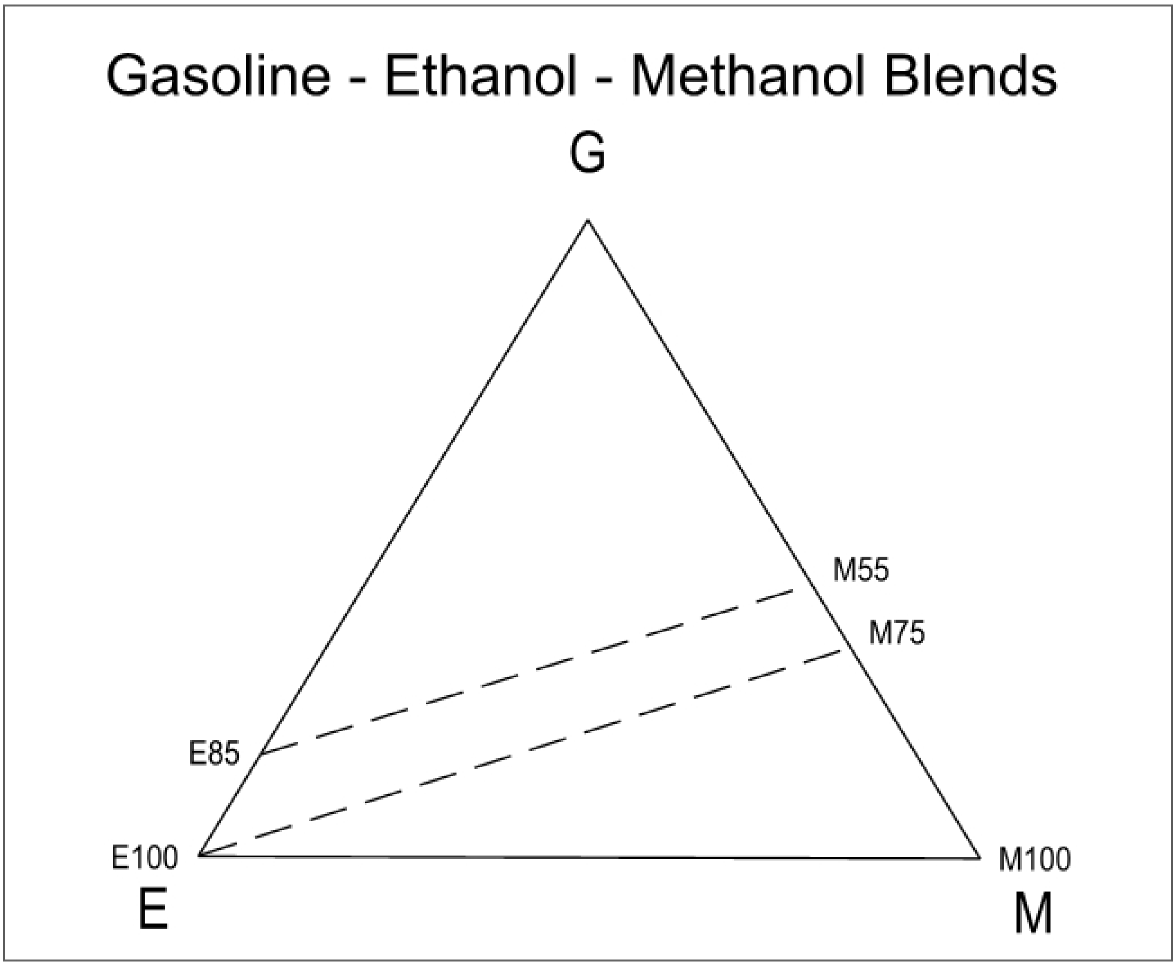


Fig. 7.

2.3.2.2 Total-flex engines for E0-100

Total-flex cars in Brazil can use E0-100. However, they are usually run on E100, which is cheaper per kilometre than gasoline (E0) or gasohol (E22) – the lowest blend usually sold in Brazil. Such total-flex cars avoid the need for blends of 15% gasoline (23% in winter) by having a small starter tank for gasoline. [70] This also allows the use of hydrated alcohol, which is cheaper to produce.

2.3.2.3 Brusstar engines for E10-100 and M100

At the US EPA, Brusstar has developed high efficiency SI engines using E100 and M100, and E10-100. With E100 and M100, the engines have achieved peak thermal efficiencies of up to 42% and high efficiencies at part load due to unthrottled operation, with high levels of Exhaust Gas Recirculation (EGR). [71] Being downsized and turbo-charged and optimized for methanol and ethanol, they could be typical of the engines of a sustainable transport future. Brusstar has also studied such engines with gasoline/ethanol blends from E100 down to E10, which is today's oxygenated gasoline. [72] Hence the Brusstar engine is total-flex, which would ease the transition to fully sustainable fuels. [73]

2.3.2.4 Lotus Tri-flex engines for E0-100 and M0-100

Lotus has developed SI engines using E0-100 (total-flex) in an Exige 265E and E0-100 and M0-100 (tri-flex) in an Exige 270E. The latter runs well on any blend of Gasoline, Ethanol, and Methanol. [74] Such tri-flex engines would be ready for the transition from gasoline to alcohol. Being designed for any GEM blend including M100, they could also use E100 in other places (countries) and times. **(See Fig. 7).** The additional cost of tri-flex over flex-fuel or total-flex engines would be negligible.

2.4 Affordable Fuels and Vehicles

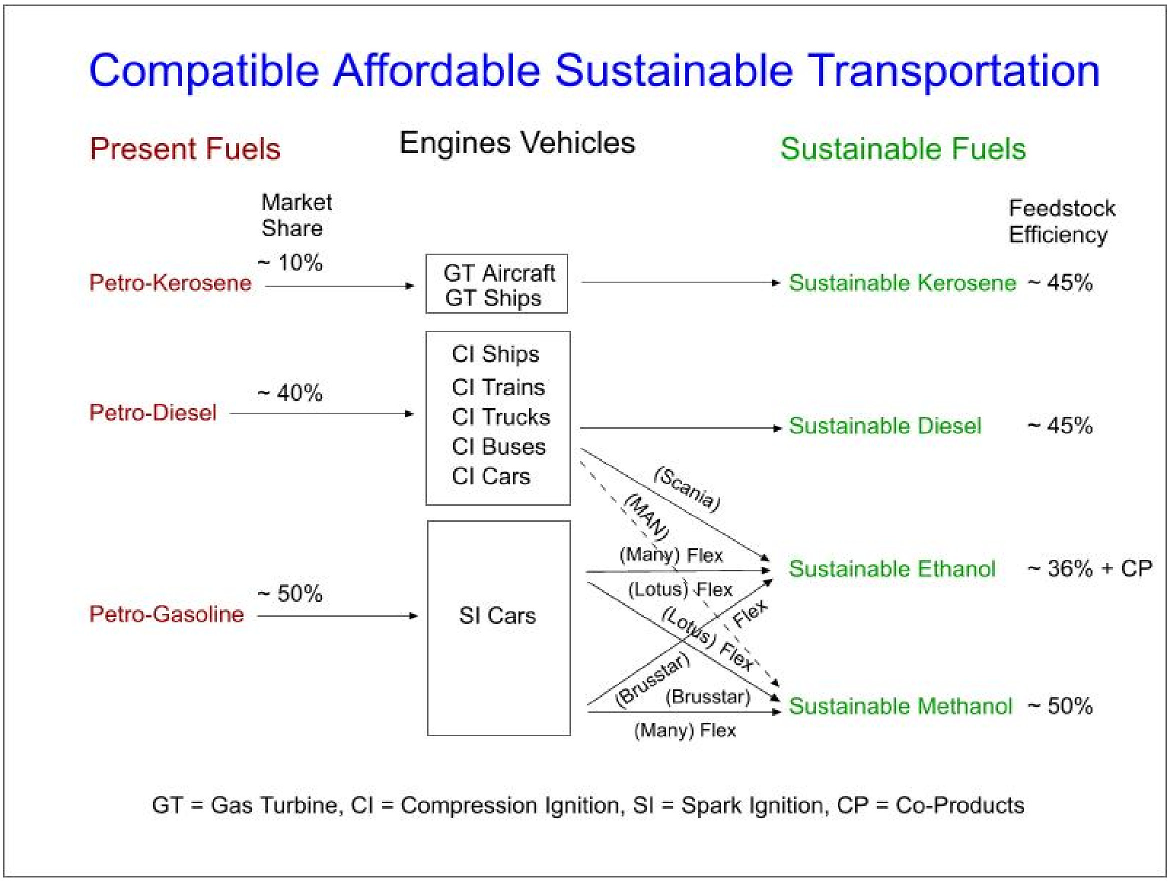
Most light duty vehicles are bought by private individuals, using higher-cost capital, and run only about 5% of the time. [75] Also, while LDVs may have lifetimes of 15 years, they are very rarely kept all that time by the original buyers. This means that buyers are progressively less likely to invest in higher cost vehicles, ranging from Diesels, HEVs, PHEVs, BEVs up to FCVs. This is particularly so for FCVs, which would probably be by far the most expensive. Moreover, it would be hugely expensive for governments to offer incentives to private individuals to buy PHEVs, BEVs, and FCVs. Also, such higher-cost vehicles would give poor energy returns for the additional energy invested and very high money costs of any carbon/GHG savings. In addition, the power and fuel companies would have to make investments in electricity generation, transmission and distribution for these fairly peaky, low-diversity, loads (for PHEVs and BEVs) or in an all-new hydrogen supply chain (for FCVs). Moreover, electricity from national grids or nets would be used when charging PHEVs and BEVs, and might well be used to generate hydrogen for FCVs. In most countries, such electricity is likely to be carbon-intensive for at least several decades.

For a fast and complete transition to fuel security and zero GHG emissions, road transport vehicles able to use 100% sustainable fuels would have to sell very well and gain 100% market shares. Moreover, for affordable dedicated and tri-flex vehicles based on ICEs, it could be done without serious material shortages, since the powertrains are based on common materials. There would be no unreasonable demands for Platinum Group Metals, as required for hydrogen FCVs.

With their ability to set tax rates differentially as between oil-based and sustainable fuels, governments could greatly influence which fuels are used by the national vehicle fleet, and so help to meet the national and international GHG reduction targets. However, power, heat and fuel companies are closer to the resource depletion and climate change challenges. They would probably be paying – and hence seeking to minimise - carbon/CO_2 taxes. As large scale professional and informed operators, they would make very sure that they invested in, and operated, their plant to best effect. With their high availability and low cost of capital, they should be ready to make investments in plant for producing sustainable liquid fuels, bio- and synthetic, that run 80 to 90% of the time. Moreover, wind turbines and fuel production plant may last 25 years or more, giving ample time to repay the investment and earn a return. So fuel companies are best placed to deliver most of the sustainable transportation solution. Furthermore, governments would not be dealing with individual voters, but only a few competing companies.

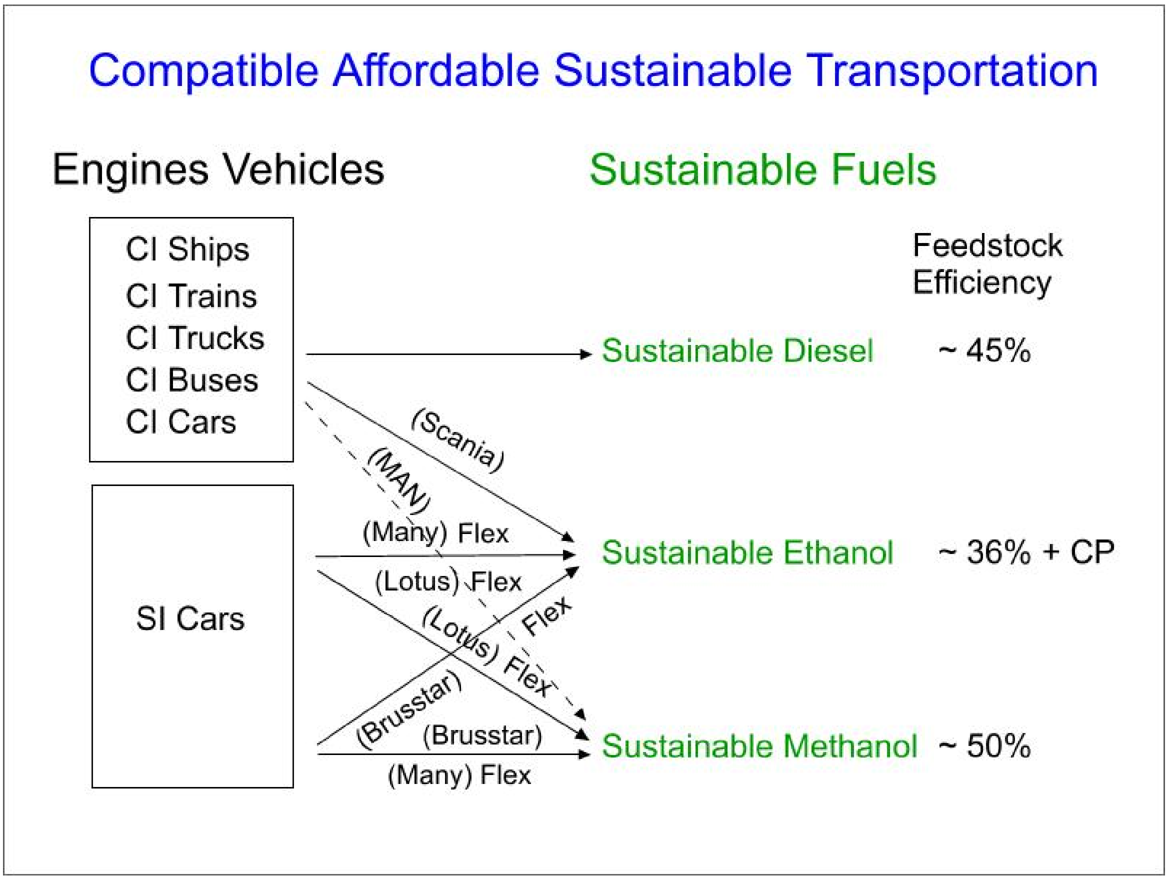
2.4.1 Choice of Sustainable Fuels

It might be thought that the energy efficiency of fuel production (WTT), vehicle use (TTW) and overall Well-to-Wheel (WTW) is crucial. However, this is only true with fossil fuels, which give rise to GHG emissions, and not with fully renewable fuels which are sufficient, and thus sustainable. Hence the proposed Compatible Affordable Sustainable Transportation (CAST) solution is based on kerosene, diesel, ethanol, and methanol, produced as advanced biofuels and synthetic liquid fuels, based on renewable sources. Moreover all four fuels are highly compatible with the existing fuel infrastructure and vehicle fleet and enable easy transitions. **(See Fig. 8) (See Fig. 9)**



Compatible Affordable Sustainable Transportation
Present Fuels
Engines Vehicles
Sustainable Fuels
Market Share
Feedstock Efficiency
Petro-Kerosene
~ 10%
GT Aircraft
GT Ships
Sustainable Kerosene ~ 45%
Petro-Diesel
~ 40%
CI Ships
CI Trains
CI Trucks
CI Buses
CI Cars
Sustainable Diesel ~ 45%
(Scania)
(MAN)
(Many) Flex
Sustainable Ethanol ~ 36% + CP
Petro-Gasoline
~ 50%
SI Cars
(Lotus) Flex
(Lotus) Flex
Flex
(Brusstar)
(Brusstar)
Sustainable Methanol ~ 50%
(Many) Flex
GT = Gas Turbine, CI = Compression Ignition, SI = Spark Ignition, CP = Co-Products

Fig. 8.



Compatible Affordable Sustainable Transportation
Engines Vehicles
Sustainable Fuels
Feedstock Efficiency
CI Ships
CI Trains
CI Trucks
CI Buses
CI Cars
Sustainable Diesel ~ 45%
(Scania)
(MAN)
(Many) Flex
Sustainable Ethanol ~ 36% + CP
SI Cars
(Lotus) Flex
(Lotus) Flex
Flex
(Brusstar)
(Brusstar)
Sustainable Methanol ~ 50%
(Many) Flex

Fig. 9.

Furthermore, the same fuels should be adopted worldwide. Both fuel and vehicle suppliers could then make the investments in both plants and products necessary for the rapid and complete transition required by resource depletion and climate change. [76]

Thus the proposed CAST solution is very similar to the present – liquid fuels and ICEs - but because of resource depletion and climate change, a transition is needed to renewable fuels and compatible vehicles, which alone are sustainable. The synthetic fuel solution has been published by Bossel, Eliasson and Taylor [77] and as alcohols by Pearson and Turner. [78]

2.5 Producing the Sustainable Fuels

Kerosene would be for aircraft and diesel for ships and some trucks, even though they have feedstock and energy efficiencies 1.2 – 1.4 x lower than methanol. Ethanol and methanol are well suited to road transport, both light duty vehicles (cars) and heavy duty vehicles (buses and trucks). Ethanol (E100) is likely to remain the dominant sustainable road transport fuel in Brazil and similar tropical countries - in Latin America and Africa etc. - well-suited to growing sugar cane and in sufficient quantities to meet demand. However, most developed countries are likely to evolve to – or adopt from the start – methanol (M100). This is the easiest to produce both from limited biomass by gasification, and to synthesise from captured CO_2 and hydrogen made with renewable electricity. Moreover, while ethanol is usually made by fermentation, the synthesis process used for methanol would probably be more predictable in output and quality. **(See Fig. 10).**

Sustainable Transport Biofuel and Synthetic Fuel Production Pathways

<table>
<tr><th>Carbon Source</th><th>Hydrogen Source</th><th>Process</th><th>Product</th></tr>
<tr><td>Biomass C6 sugars (Food)</td><td rowspan="3">Biomass</td><td rowspan="2">Fermentation</td><td>Ethanol</td></tr>
<tr><td>Biomass C5 sugars (Cellulosic)</td><td>Ethanol</td></tr>
<tr><td>Biomass Lignin (Autothermal)</td><td rowspan="4">Gasification and Catalytic Synthesis</td><td>Methanol</td></tr>
<tr><td>Biomass (Allothermal)</td><td rowspan="3">Electrolytic Hydrogen from Wind Electricity</td><td>Methanol</td></tr>
<tr><td>CO2 from Fluegas</td><td>Methanol</td></tr>
<tr><td>CO2 from Air</td><td>Methanol</td></tr>
<tr><td>Biomass (Allothermal)</td><td rowspan="3">Electrolytic Hydrogen from Wind Electricity</td><td rowspan="3">Gasification and Fischer-Tropsch Synthesis</td><td>Diesel/Kerosene</td></tr>
<tr><td>CO2 from Fluegas</td><td>Diesel/Kerosene</td></tr>
<tr><td>CO2 from Air</td><td>Diesel/Kerosene</td></tr>
</table>

Fig. 10.

2.5.1 Carbon Sources: Biomass

As well as carbon, biomass contains some hydrogen, which must be present in the synthesis gases required to produce fuels such as methanol and synthetic diesel and kerosene. In an autothermal process, compared with using captured CO_2, this saves some energy but much of the carbon is wasted. [79] However, in an allothermal process, more hydrogen is added, so that all the carbon is used and the fuel yield increased by about 100%. [80]

The cost and collection of biomass is always an issue, as also is uniformity and cleanliness. Cost may be addressed by using forestry and agricultural wastes, such as straw. Even a half of the world straw harvest amounts to over 1 billion tonnes a year. [81] Collection may be addressed by using industrial and municipal waste. About 300 kg of methanol can be produced from each tonne of Municipal Solid Waste. [82] This is increasingly well sorted, due to the need to reduce landfill. This addresses uniformity and cleanliness, although the requirements of a gasification process are much lower than those of a fermentation process.

2.5.2 Carbon Sources: CO_2 Streams

Methanol and other sustainable fuels, such as synthetic gasoline, may be produced from CO_2. [83] For their methanol production process, DONG Energy envisage capturing CO_2 from the IBUS ethanol process. [84] [85] [86]

Methanol could also be synthesised from CO_2 captured from fluegas, with hydrogen from renewable electricity. The CO_2 could be captured from the fluegas of plants fuelled by coal and biomass, as in the CASTOR project. [87] Ample CO_2 could be captured while fossil fuel was still being burnt, and this may be a long transition. This would have the advantage of raising the potential synthetic fuel production while the world comes to terms with declining oil production. However, CO_2 captured from power station fluegas may result in a loss of electricity efficiency of around 5 to 10% points. [88] This implies a CO_2 emission cost, so methanol synthesised from such CO_2 would give a carbon reduction of only about 50%. [89]

To eliminate the carbon emissions from heat and power generation, fossil fuels must eventually be displaced by biomass and other renewables. For example, CHP plants may burn biomass, as is increasingly the case in DK, SE and NL. Then the captured CO_2 would incur a small heat and power output cost and hence a money cost, but no CO_2 emission cost. With such CO_2 and electrolytic hydrogen produced from renewable electricity, synthetic fuels could offer carbon reductions of up to 100%. However, the production of fuels synthesised from CO_2 captured from the fluegas of plants burning only biomass would still be constrained by biomass limits.

2.5.3 Carbon Sources: CO_2 from air

Sustainable fuels such as synthetic methanol could also be produced from CO_2 captured from the air. [90] [91] [92] This is essentially unlimited and for most developed countries such fuels would be needed for at least 70 to 90% of the transport demand. Moreover they would be free from the constraints of land area, water and nutrients and also carbon-neutral. They would also be fully indigenous, thus offering security of supply. Furthermore, such air capture, if followed by sequestration, could also be used to reduce the atmospheric CO_2 concentration, as suggested by Hansen et al. [93]

2.5.4 Hydrogen from Wind Electricity

The hydrogen needed for producing allothermal biofuels and synthetic fuels must be carbon free to be sustainable. Making it from biomass would waste the carbon that is needed for liquid fuels. Therefore it should be produced from renewable electricity. To produce the renewable electricity for very large amounts of synthetic methanol, a source with a high Energy Return on Energy Invested (EROI) is essential. Large wind turbines of 1 MWe and above have values of about 30 or more. [94] Unlike hydro-electricity, wind electricity is available in all countries worldwide. Hence it can be indigenous without requiring much land, especially if the wind farms are offshore. Most countries have coastlines and the offshore wind resource is huge. [95] [96] Indeed, the wind resource is huge right across the world.

Testing a sustainable option - here wind-based synthetic fuel - for sufficiency amounts to 'backcasting', as used by Mulder and Biesiot. [97] Hoogwijk has estimated that the global wind power at 'turbine' height is about 11 TW onshore, and – including offshore – about 15.3 TW. [98] Archer and Jacobson have estimated that the wind power – at 6.9 m/s or more at 80 m height – is about 72 TW. If only about 20% of this could be captured, it would be 14.4 TW. [99] With an energy efficiency from global wind power at 'turbine' height via electrolytic hydrogen and CO_2 captured from the air of 40%, that in the synthetic methanol could be about 6 to 29 TW. **(See Appendix C).** The present (2006) world transport oil-based fuel demand is about 2.8 TW. So the present world transport fuel demand and more could be met as fully sustainable synthetic methanol entirely with wind electricity.

The renewable electricity should also be low in cost. If the electrolysers making the hydrogen were variable, they would make ideal loads, especially on systems with considerable variable generation, such as wind farms. On all electric power markets, the price varies markedly over the day and year. [100] When surplus to the local demand, electricity often has a very low price. Moreover, with more and more wind farm capacity being added, and often exceeding the usual electricity demand, ever more 'surplus' electricity would be available for electrolysing hydrogen and hence synthesising methanol. However, to ensure that the electrolysers had a reasonable load factor of say 70%, they would usually be sized for less than the peak output of wind electricity. The remaining less frequent 'surplus' wind electricity could be stored in Pumped Storage, used for District Heating, or sold for export. **(See Fig. 11)** [101]

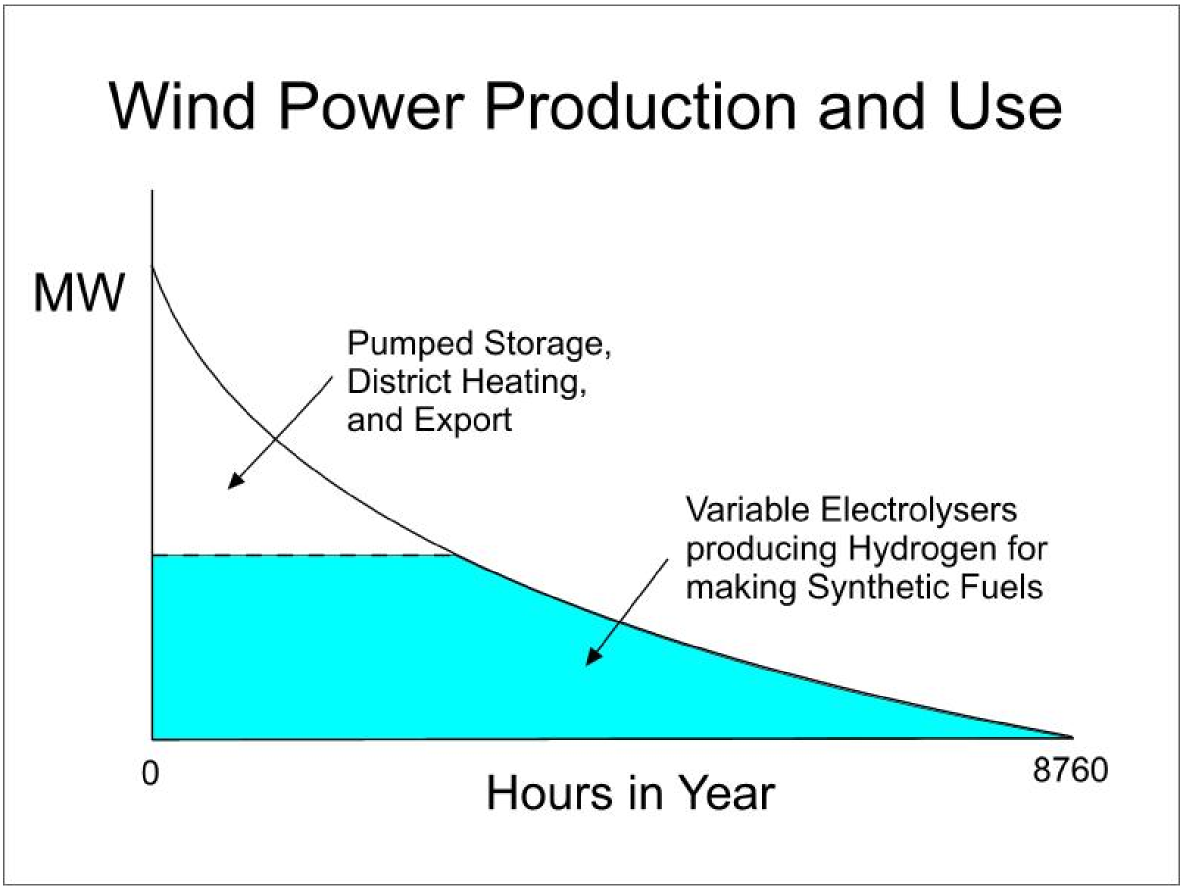


Fig. 11.

2.5.5 Combined Production of Heat, Power and Fuel

The energy efficiency (WTT) of producing synthetic methanol with CO_2 from air might be about 50% (LHV basis). [102] However, combined production of heat, power and fuel in CHP+F plants fueled by coal and biomass would allow process integration, with the low temperature reject heat having access to District Heating (DH) networks – for use in buildings and some industrial processes. As well as enabling CO_2 capture from the fluegas, such plants would house the electrolysers producing hydrogen (and oxygen for some processes) from low-cost 'surplus' wind electricity. Indeed, the electricity flowing into the fuel production plants would be so large that the reject heat would probably be able to meet the entire national demand for DH. However, the electricity input and fuel production could be distributed between CHP stations to suit their local heat loads. Denmark has the advantage of extensive DH coverage, reaching some 60% of buildings. This integration could apply to processes using both fermentation (ethanol), and gasification (methanol, possibly ethanol, synthetic diesel and kerosene). [103] All biomass could be used as a carbon source for fuel synthesis, either directly – so saving some hydrogen and thus energy - or indirectly, via fluegas. Hence the CHP+F plants could maximise the energetic and feedstock efficiency of the finite biomass resource, yet also produce enough synthetic fuels from CO_2 captured from fluegas and from atmospheric air, to meet the full transport fuel demand. **(See Fig. 12).** Such integration gives a very high degree of synergy and is also foreseen in the Danish Society of Engineers Energy Plan 2030. [104]. In engineering terms, it would maximise the 'Second Law' (of thermodynamics) or 'exergetic' efficiency, which is quite different from the 'First Law' or energetic efficiency. [105]

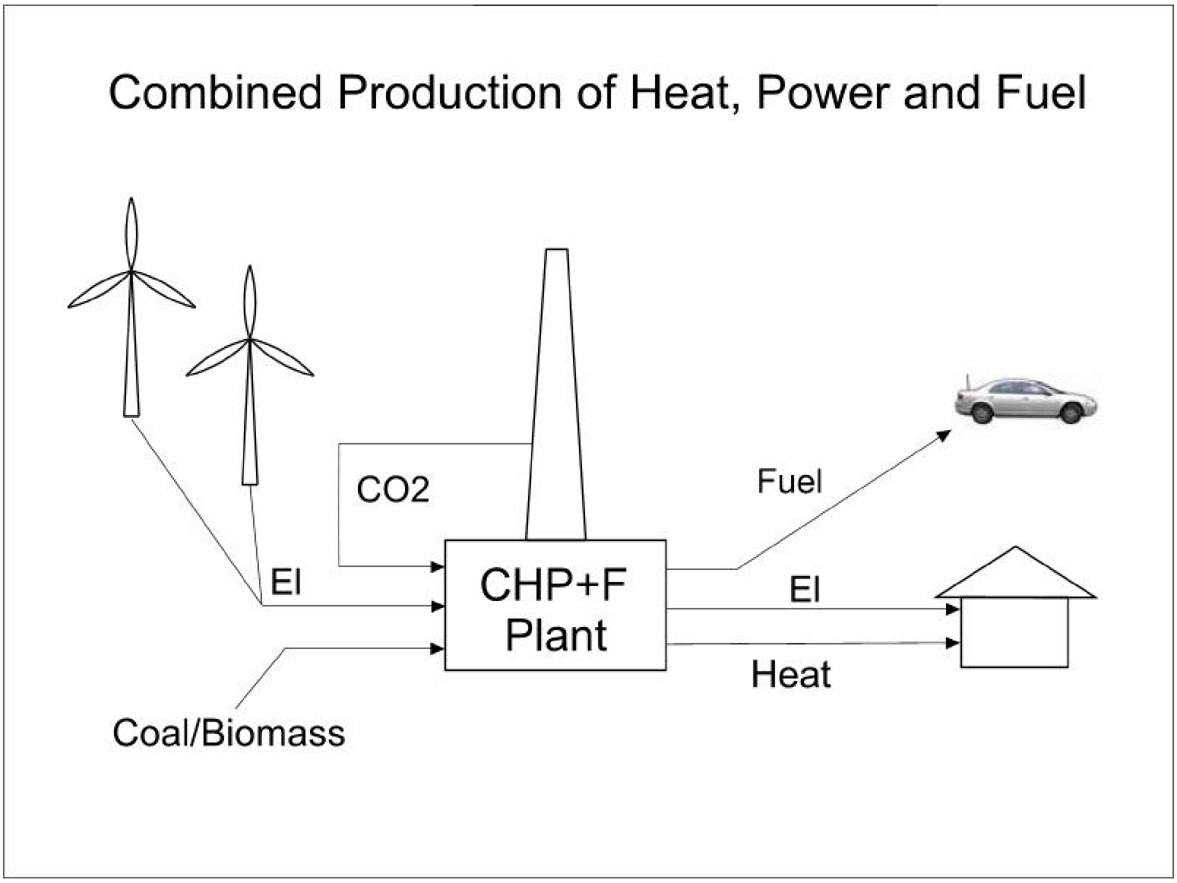


Fig. 12.

2.6 Transition to Sustainable Transportation

Sustainable transport still requires transitions for both fuels and vehicles. However with CAST, they would be incremental and not require the premature replacement of the fuel and vehicle production infrastructures. Any transition would take time to eliminate the consumption of oil-based fuels and thus the GHG emissions. Moreover, the required sustainable fuel capacity would depend partly on progress with the development of the sustainable fuel-vehicle combinations for increased overall fuel and vehicle (WTW) energy efficiency.

2.6.1 Transition to Sustainable Fuels

For developed countries, first generation biofuels would be phased out and indigenous second generation biofuels could rise to at most 10 to 30%. Hence imported biomass/biofuel and/or indigenous synthetic fuels would have to supply at least 70 to 90%. **(See Fig. 13).** Developing countries could continue with – or adopt – first generation biofuels such as bioethanol. For tropical countries, where sugar cane may be grown, this could even exceed the local fuel demand and be exported. Thus ethanol or methanol may be available in different countries and at different times. However, the additional cost of tri-flex capability would be negligible, so enabling the vehicle makers to supply one version to suit all markets.

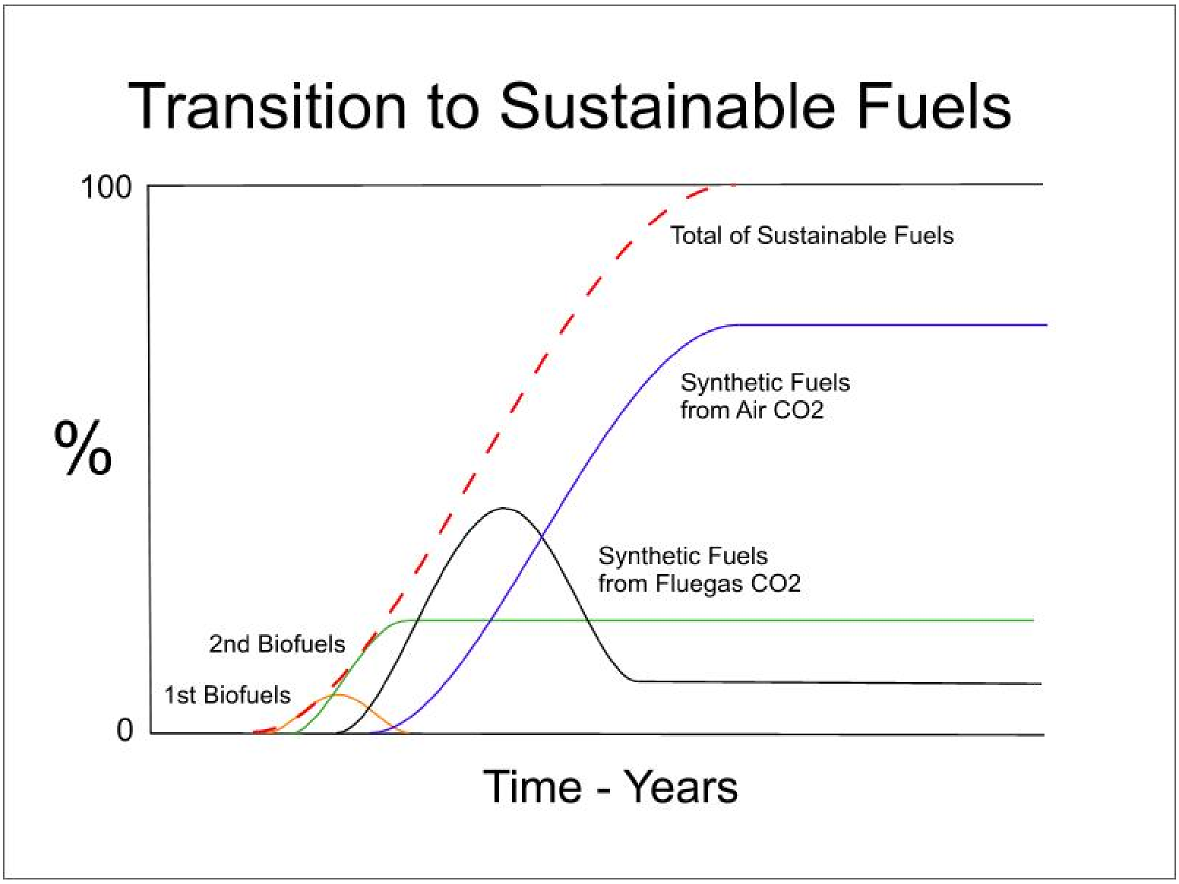


Fig. 13.

2.6.2 Transition of Vehicle Fleets

Since E100 and M100 contain no (petro-) gasoline, they would be fully sustainable fuels. At the start of the transition, there should be a mandatory switch of all new sales to tri-flex vehicles, able to use both such fuels, or dedicated vehicles, able to use one or other such fuel. Tri-flex vehicles (3FVs) could be sold before 100% alcohol fuels became universally available and continue to use oil-based fuels. Then as the sustainable fuel supply was increased, they would enable the transition to be accelerated. Moreover tri-flex engines could evolve over time from basically gasoline designs with compromised performance on alcohol, to those more optimized for alcohol, but retaining acceptable performance on gasoline. When alcohol fuels became universally available, new vehicle engines could be further optimised for such fuels. Provided that the requirement was allowed for in the original design, existing engines could be optimised after manufacture by upgrading the software of the Engine Control Units (ECUs).

By supplying dedicated vehicles, the fuel transition could be accelerated permanently. These would use only sustainable fuels, such as E100 or M100, so the engines could be fully optimized for such fuels. However, such vehicles would be limited initially to 'captive fleets' such as buses and municipal vehicles, where refuelling takes place at the depot. In such cases, the supply of alcohol fuels should be guaranteed, as should the prices (relative to oil-based fuels), by government subsidies or taxes. The buyers of such fleets - often local governments – could not be expected to carry such risks or financial penalties. In addition, the fuel transition could be accelerated temporarily, since the existing SI ICEVs could accept 'low blends' of alcohol. This is already being done in Brazil (E22), the USA (E10) and Sweden (E5). However, gasoline should be supplied until all 'mainstream' gasoline-only vehicles had been withdrawn from service. In practice, the rising cost of oil-based fuels may cause them to be withdrawn from service early, unless alcohol conversion kits were available, as in Brazil. Gasoline would probably continue to be available in small quantities (and at high prices) for the relatively few 'classic' cars.

Of present road vehicles, many cars have SI engines and trucks, buses, vans and the remaining cars have CI engines. While oil-based fuels are supplied, to minimise the refining losses, the 'barrel-split' should be maintained. [106] Since petroleum normally yields roughly equal amounts of gasoline and diesel, during the transition they should be about equally displaced by renewable fuels. Gasoline could be displaced by ethanol or methanol in 3FVs, while diesel could be displaced by synthetic diesel in CI (Diesel) engines in heavy-duty vehicles, trucks and buses. However, use of the (lower-cost) alcohol fuels would require suitable CI engines. These could be Scania (CI with very high compression ratio), which use ED95, or MAN (CI with spark-assist), which use M100. [107] Both have demonstrated TTW energy efficiencies comparable with those on fossil diesel. [108] [109] Moreover the Scania engines could probably use some methanol, (at least M75), and the MAN engines probably ethanol (E100). **(See Fig. 7).** At the end of the transition, the whole 'mainstream' (non-'classic') fleet would have to be using fully sustainable fuels – preferably E100 or M100. **(See Fig. 14).**

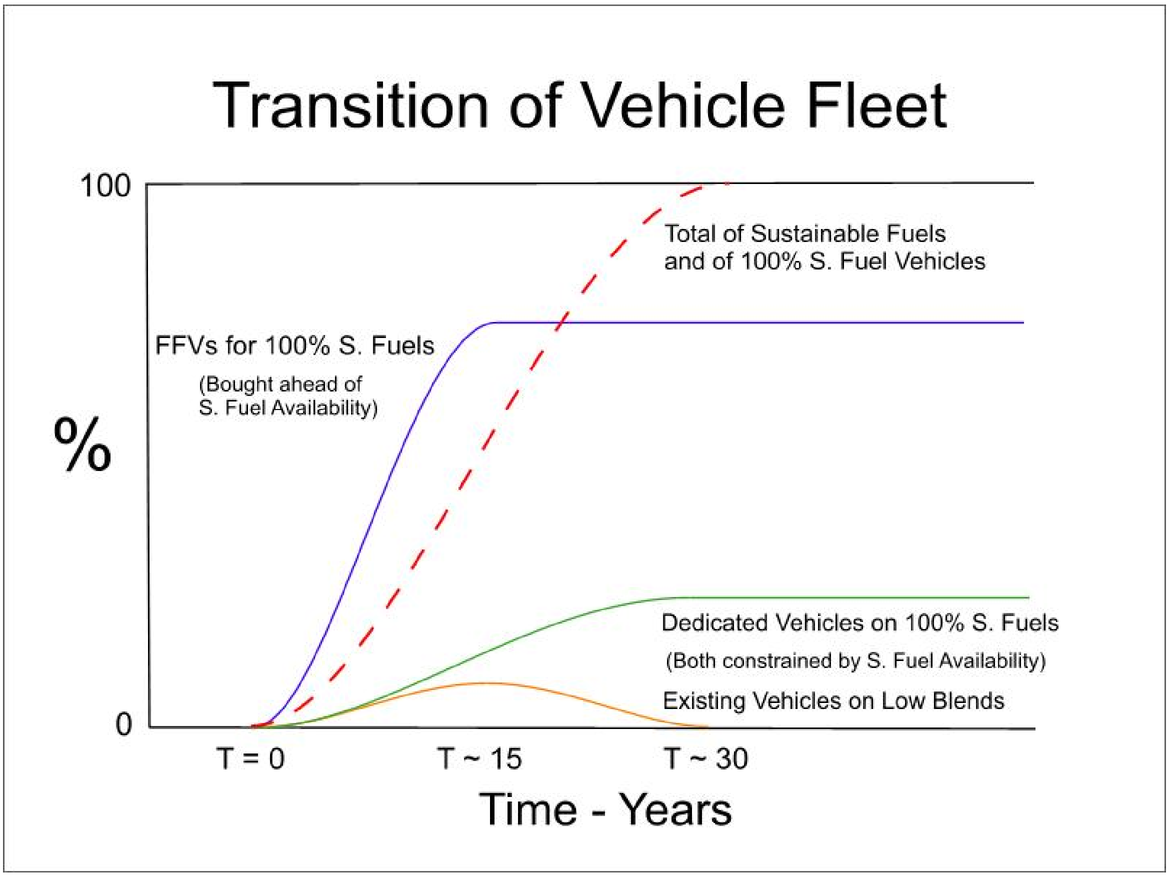


Fig. 14.

2.6.3 Transition Times

The turnover time of the light duty vehicle (LDV) fleet may be about 15 years. So SI LDVs (cars and vans) could be replaced with tri-flex vehicles able to use E100 and M100, and CI LDVs (some cars and vans) with dedicated vehicles able to use A100 (E100 or M100), over about 15 years. Heavy Duty Vehicles (buses and trucks), most of which have CI engines, could also be replaced with A100 dedicated vehicles, but may have lifetimes of up to 30 years. The rate of vehicle sales and market penetration also affects the transition time. Even with ample availability of sustainable fuels, the speed of transition away from oil-based fuels would be constrained by the capabilities of the road vehicle fleet. [110] According to a major US study, a build up taking 10 years would give a transition time of about 30 years, and of 20 years about 30 to 38 years. [111]

For aircraft and ships to retain their full payload and range, the sustainable fuels would be synthetic versions of the present kerosene and diesel. Hence the capabilities of these vehicles would not constrain the transition time. However, the time to build a new plant for aircraft, ships or road vehicles may be up to a decade. All such companies are very heavily invested in existing plants, with engine lines, body lines etc. that cost roughly a billion dollars each and run for 20 years - albeit with updating. The last thing they want is 'stranded assets'. Hence to ease the transition, the sustainable vehicle fleets should be compatible with such plants.

Conversely, the time to build a new fuel plant may be at most one or two years, and they probably earn their return in say five years. Therefore the transition time would dictate the build-up of sustainable fuel plant capacity, to avoid it standing idle. Hence the transition to sustainable transport fuels and vehicles with zero GHG emissions would take at least 30 years. This is independent of the fuel and vehicle technologies.

3 CONCAST - Building the Consensus for CAST

District Heating networks and Combined Heat and Power plants and wind turbines could be adopted by any country 'unilaterally'. However, transport vehicles travel and need refuelling worldwide. Passenger transport makes services and leisure available worldwide. Freight transport makes trade goods - including fuels and vehicles - available worldwide. Hence any Sustainable Transportation solution could only succeed if adopted worldwide. A Compatible and Affordable solution such as CAST would make this far more likely.

The CAST proposal defines a complete worldwide sustainable transportation solution. After the validity of the CAST proposal has been checked, it should be shown to other parties. This would be to seek to build a consensus for the CAST solution, along with the concepts of mandatory vehicle requirements and a mandatory GHG emissions limit timeline for the transport sector. All new vehicles would be required to be dedicated (initially for captive fleets) or tri-flex, capable of using 100% sustainable fuels, to enable the CAST transition, while the transport GHG timeline might form part of 'Kyoto 2'. Such a consensus would ensure that existing plants and vehicle investments earn their planned returns and would greatly reduce the risks when investing in new production plants and vehicles. These factors would encourage such investments - so easing fuel supplies and reducing GHG emissions. This would be essential for gaining the co-operation of the sustainable fuel suppliers, both existing oil companies and new players.

Building the consensus for CAST – CONCAST - should begin with the EU countries that have started towards sustainable transportation – DK, SE, DE, & NL. Within these countries, potential allies include DONG Energy of Denmark (ethanol and methanol), SEKAB of Sweden (ethanol), CHOREN of Germany (synthetic kerosene and diesel) and Bio MCN of the Netherlands (methanol). Then could come the American countries that have started towards sustainable transportation – US and BR (ethanol). These could be followed by Eastern countries that are just starting towards sustainable transportation – CN (methanol) and JP – and then the rest, including FR and UK (some ethanol). **(See Fig. 15)**

Fig. 15.

3.1 Quote 1:

'It is not so much the legislation itself, but the decisiveness to really do something'.
'So the focus is not so much on biofuels, but on the concept of sustainable transportation'.
'Cost-competitiveness has so many unknowns….. And as oil reserves are depleting, it will only be a matter of time'.

Per Carstedt, CEO of SEKAB, October 2007. [112]

This refers to the Swedish Government plan to be 'Off Oil by 2020'. [113]

3.2 Quote 2:

'Flexifuel has considerable potential in larger models too. That is why we plan to continuously expand the implementation of this technology over the coming years. Biofuel standardization and guidelines for sustainable production within the EU would make the fuel's development even smoother'.

Lex Kerssemakers, Senior VP, Volvo Cars, July 2007. [114]

This shows that vehicle makers want sustainable transport fuels – in order to stay in business.

4 Delivering Sustainable Transportation

4.1 Demand Reduction

The demand for transport should be reduced by e.g. 'tele-commuting' - using broadband for working from home – and switching to transport modes with lower energy intensities - train, tram, bus, bicycle and foot. For planning the mix of public and private transport, it is essential to know the nature of the sustainable road transport solution. The CAST proposal for road transport is mainly alcohol fuelled Internal Combustion Engine Vehicles (ICEVs). This would define the (relatively high) cost of operating private transport – cars - and so increase the demand for public transport – buses, trams and trains. Also, the (relatively high) cost of operating trucks would encourage a modal shift from trucks to trains. This would reduce the energy required per tonne-km and enable the use of electric traction via overhead wires, as opposed to batteries or fuel cells.

Increased public transport should reduce the usage time factor of private cars and their fuel usage. Moreover, since public transport would mainly displace urban driving, it would - in the case of low-cost ICEVs - eliminate their least efficient operation. However - in the case of FCVs – it would eliminate their most efficient operation, so further reducing the case for private buyers investing in such higher cost vehicles. Nevertheless, trains and buses would still need fuel and there would still be substantial fuel demands from car and truck transport.

4.2 Supply Side: Actual and Proposed Legislation

California, 2007. AB32. This requires a 'Full fuel cycle' CO_2 reduction of 10% from 2010 to 2020. [115]

USA, 2007. Energy Independence and Security Act. This requires that renewable fuels be increased to 36 billion gallons by 2022. [116]

UK, 2008. Proposed Low Carbon Transport Fuel Obligation, mandating the reduction in carbon intensity of the fuel mix and covering all fuels. [117]

EU, 2008. Proposed Fuel Quality Directive. This requires that road transport fuel GHG emissions be reduced by 1% per year from 2010 to 2020. [118]

4.3 Supply Side: Policy Measures for CAST

The policy measures must be mandatory; Voluntary measures do not work. [119]

The CAST proposal for sustainable transportation, with energy security and zero GHG emissions, and the shortest possible transition time of 30 years, implies a GHG reduction rate of over 3% per year. This should be mandated in future policy, since a rate of 1% per year, giving a transition time of 100 years, would certainly not meet the energy security and climate change challenges.

4.4 Supply Side: Paying for the Sustainable Fuel Chain

The oil companies do not guarantee to meet their customers' demands for fuels, particularly at fixed prices. Rather do they let them compete and bid up the prices. Effective substitute liquid fuels could set their own prices, since until they arrived in quantity, those of ever-scarcer oil-based fuels would continue to rise. [120] However to be available soon enough and on a sufficient scale, the sustainable transportation solution must be driven forwards. Success is essential, since the costs – both monetary and environmental – of failure would be very high indeed. [121]

The oil used in 2007 was 31 billion barrels, which at an average price of $72.39/bbl is $ 2.5 trillion. The average price for 2008 will probably be over $ 100/bbl. Assuming this – an increase of $27.61/bbl – the increment would be $ 0.86 trillion, for a total of $3.36 trillion. [122] Hence the oil companies are making very large profits. [123] [124] Yet they are contributing almost nothing to GHG reduction or sustainability. They should be required to do much more on both scores. Therefore national governments could require the oil/energy companies to pay for the sustainable fuel chains as a cost of doing business in their countries and the high profits thus directed to delivering a Sustainable Transportation solution. Moreover, in order to be deliverable, it must also be Compatible and Affordable – as is the CAST proposal – and acceptable worldwide.

The oil companies should welcome the CAST proposal, and a mandatory CO_2/GHG reduction timeline, since it would reduce uncertainty, and hence risk. Indeed, they would probably be greatly relieved not to have to keep on pushing the frontier of oil exploration and production. This would incur ever higher cost and risk for drilling 'wildcats' and ever-diminishing returns in oil for sale. **(See Fig. 16).** [125] Instead, they – and their customers - would have a sustainable future. There should no competition between the different sustainable fuels, as each would have their own market sector. Moreover, the total market - by replacing all oil-based transport fuels - would be huge, so there would be more than enough business opportunities for all.

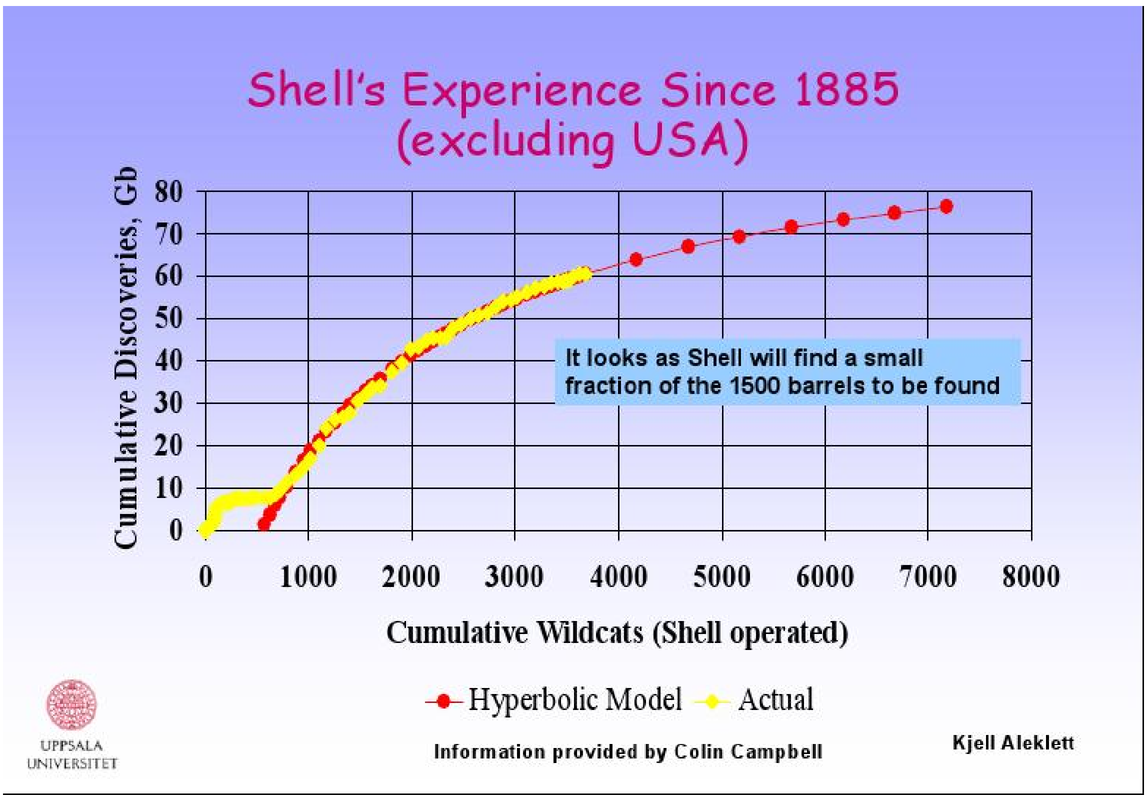


Fig. 16.

4.4 Supply Side: Building the Sustainable Fuel Chain

Building the sustainable fuel chain would make use of much of the existing competence and recent R&D investment in carbon (CO_2) capture and the electrolytic production of hydrogen. It would also harness the expertise in the catalytic production of methanol, and the capacity to design and build CHP plants, including biomass handling and combustion, and wind turbines that Denmark possesses in very high degree. Indeed, the CAST solution offers the prospect of such business worldwide and on a huge scale.

4.5 Supply Side: DONG Energy

The CAST and CONCAST proposals offer a sustainable transportation solution for all vehicles worldwide. They were inspired by the 'VEnzin Vision', which was proposed by DONG Energy. [126] This envisages fermentation of the cellulose and hemi-cellulose content of biomass to ethanol and the use of the lignin, via gasification, to produce methanol. DONG also own power and CHP stations fuelled by coal and biomass. The CHP stations would allow process integration with fuel production and access to District Heating as a profitable market for the low temperature reject heat.

DONG lead the CASTOR project on CO_2 capture from fluegas. [127] They also have probably the world's largest proportion of wind electricity, hence considerable 'surplus' low-cost renewable electricity for producing electrolytic hydrogen (and oxygen for some processes). [128] They are thus extremely well placed to explore production pathways for methanol: biomass (lignin) gasification autothermal, biomass (lignin) gasification allothermal with hydrogen, CO_2 capture from fluegas with hydrogen and CO_2 capture from atmospheric air with hydrogen. [129] Hence DONG could maximise the energetic and feedstock efficiency of the finite biomass resource, and also produce synthetic methanol and other sustainable fuels from CO_2 captured from fluegas and from atmospheric air to meet the full Danish transportation fuels demand.

DONG Energy could benefit from expertise in modelling the operation of wind farms and electrolysers from DTU-Risø. [130] They could also access expertise on the catalytic synthesis of methanol from Topsoe, a notable supplier of such plant. [131]

By moving into sustainable liquid transport fuels, as they have started to with IBUS and Inbicon, DONG Energy could secure all their existing businesses against the challenges of resource depletion and climate change. Thus they would have – based on biomass, CO_2 and wind - sustainable sources of heat, electricity and transport fuels, and could enjoy - with Denmark - a sustainable future.

5 The Climate Change Summit

The solution to sustainable transportation must be chosen now, because of the downside risks to energy security and climate change, and the 30 years or more required for the full transition. The consequences of just drifting into the use of Unconventional Oil and Coal to Liquids while waiting for hydrogen - which may never happen - would be huge.

The next UN Climate Change Summit – COP 15 - will be held in Copenhagen from 30 November to 11 December 2009. During the year beforehand, the Danish Government could examine the CAST proposal for a sustainable transportation solution as a response to the challenges of energy security and climate change. It could also promote a worldwide consultation to build a consensus for such a solution – CONCAST. Due to the conjunction of competences and timing set out above, there will never be a better opportunity. If the CAST proposal is found to be valid and to command such a consensus, then it could become the subject of a major signing ceremony at the Summit. Since CAST includes the aviation and marine sectors omitted from Kyoto 1, Denmark could announce - as part of 'Kyoto 2' - a sustainable solution for the whole transport sector.

5.1 Demonstrations and Exhibits

DONG Energy has been granted funding to help complete the bioethanol demonstration plant at Kalundborg beforehand. [132] Also Denmark plans to show the use of biofuels at COP 15. Most of the VIP cars will be fuelled with second generation biofuel from DONG Energy. However a wider range of vehicles running on each of the sustainable road fuels – synthetic diesel, ethanol and methanol - could show the way ahead for road transport, and indeed for all transport worldwide - CAST.

There are many different models of E85 flex-fuel cars available in Europe and the USA and many different E100 total-flex cars available in Brazil. **(See Appendix B).** Hence it would be easy to have several such vehicles present to demonstrate the use of ethanol. Also Lotus could provide the Exige 270E Tri-Fuel (tri-flex) to demonstrate the use of methanol. In addition, they could adapt an existing E85 flex-fuel or E100 total-flex family car to E/M0-100 tri-flex capability. (See the Vehicle Hardware Proposal below).

Also ED95 buses from Scania and ED95 trucks from Scania and Volvo could be present along with 'standard' Diesel trucks, buses and cars. Pumps dispensing say synthetic diesel, ED95, E85, E100 and M100 should be set up on the demonstration circuit. This would show that the fuels and vehicles are both highly compatible with the existing infrastructures. Moreover, it would show that sustainable fuels will soon be much more widely available.

There could also be exhibits on their sustainable fuels developments from DONG Energy, SEKAB, CHOREN, and BioMCN.

Brusstar and colleagues at the US EPA have done pioneering work on alcohol engines. The US EPA has also done invaluable work on Transportation, Air Quality, CO_2 and GHG emissions and the methanol toxicity issue. Hence it should be possible to arrange a major EPA presence at the Summit.

Appendix A: Biomass-based methanol versus the present world transport fuel demand

Biomass-Based Methanol Potential

The world biomass production potential for 2050 might be from 40 to 1100 EJ/y. [133]

The energy efficiency of synthetic methanol production from biomass is about 50%. [134]

(The fuel production WTT efficiency would be further considered in the proposed Fuel Report. See below).

Hence the biomass-based methanol potential might be 40 x 0.5 to 1100 x 0.5 = 20 to 650 EJ/y.

Present World Transport Fuel Demand

From the IEA Key World Energy Statistics 2008, the world consumption of petroleum products in the transport sector for 2006 was 2105 Mtoe. Using the conversion factor of 1 Mtoe = 4.1868 x 10^4 TJ, this is 88.13 EJ/y = 2.8 TW. [135]

The effect of any difference in vehicle TTW efficiency when using methanol is ignored, since it will probably be higher than with gasoline. (See above, Section 2.3.2).

(The vehicle TTW efficiency would be further considered in the proposed Vehicle Report. See below).

Hence the present (2006) world oil-based transport fuel demand is about 88 EJ/y = 2.8 TW.

Biomass-based methanol versus the present world transport fuel demand

Compared with the present (2006) world oil-based transport fuel demand of 88 EJ/y, the biomass-based methanol potential might be from 20 to 650 EJ/y, which is about 0.2 to 7 times as much.

Appendix B: Flex-fuel and Total-flex Vehicles

Flex-fuel Vehicles (gasoline/E85) available in Europe 2008. [136]

Audi	A3	1.6	Peugeot	407	2.0	Volvo	C30	1.8
	A4	2.0 TFsi	Renault	Twingo			S40	1.8
Ford	Focus	1.8		Clio			V50	1.8
	C Max	1.8		Megane	1.6		V70	2.0, 2.5t
	Mondeo	2.0		Laguna	1.6		S80	2.0, 2.5t
	S Max	2.0	Saab	9-3	1.8t, 2.0t	VW	Golf	1.6
	Galaxy	2.0		9-5	2.0t, 2.3t		Golf Plus	1,6
Mazda	5	2.0	Seat	Altea	1.6		Jetta	1.6
	6	2.0		Leon	1.6		Variant	1.6
Peugeot	308	2.0	Skoda	Octavia	1.6		Caddy	1.6

This amounts to about 10 different engines.

Additional E85 flex-fuel engines are available on the US market. [137] Although their range is still small, GM has promised to increase the number of flex-fuel models offered for sale.

Many E100 total-flex engines and vehicles are available on the Brazilian market. Ethanol from sugar cane currently accounts for about 50% of SI (gasoline-type) engine vehicle fuel. It is blended with gasoline (E22) and also sold 'neat' (E100). Therefore total-flex (E0-100) has become standard on almost all new cars. The market is relatively large and fast-growing, and all the larger international car makers are present. VW, GM, Ford and Renault already offer such vehicles. Honda already sells flex-fuel Civics and Fits, and Toyota has introduced the Corolla Flex and the Corolla Fielder Flex. [138]

Appendix C: Wind-based Methanol versus Present World Fuel Demand

Wind Resources

Hoogwijk estimated the global technical wind electricity potential at 'turbine' heights as 96 PWh/y; about six times the world electricity production in 2001. However, this was based only on onshore sites. Including offshore sites to 50 m water depth could increase this by about 40% to 96 x 1.4 = 134 PWh/y. = 15.3 TW. [139]

Archer & Jacobson evaluated the global wind electricity potential at 'turbine' heights, including offshore. For locations with mean annual wind speeds of 6.9 m/s at 80 m, it was found to be about 72 TW (~54,000 Mtoe) for the year 2000. Even if only about 20% of this could be captured, it could easily satisfy 100% of the world's energy demand for all purposes (6995-10177 Mtoe) and over seven times the world's electricity needs. (1.6-1.8 TW). 72 TW x 0.2 = 14.4 TW. [140]

A ratio of about 5 to 1 in the two values for global wind power at 'turbine' heights deserves further investigation. Meanwhile the Hoogwijk value and the Archer and Jacobson '20% capture' value are within 7%.

Process Efficiencies

High Voltage Direct Current (HVDC) transmission would probably give the highest transmission efficiencies of electricity from the wind turbines to the fuel synthesis plants. This is assumed to be 100%.

The electrical efficiency of conventional electrolysers is about 70% to 80%. [141]

(If the global wind power at 'turbine' height was ample, then the electrolysers could be 'sized' to increase their load factor. **(See Fig. 11)**. However, to maximise the fuel produced, the electrolysers would be 'sized' for maximum wind power output, so that the load factor equaled that of the wind turbines).

For hydrogen with CO_2 captured from air, the energy efficiency of synthesising methanol (LHV basis) may be about 38% with potential for over 44%, [142] 35-37% [143] or 50%. [144]

Assuming a value for large electrolysis plant of 80% and a value for a mature synthesis process of 50%, the fuel energy efficiency would be about 40%.

(For the synthesis of methanol from electrolytic hydrogen and a stream of CO_2 from a fermentation process, Henriksen et al gave the fuel energy efficiency – including that of the electrolysers - as 60%. [145] Moreover, compared with fluegas from fossil-fired plant, such CO_2 would not incur a carbon overhead. However, although well worth exploiting, this would be a limited resource).

(The fuel production WTT efficiency would be further considered in the proposed Fuel Report and Time Report. See below).
The potential production of synthetic methanol from wind energy could be 40% x about 14.4, 15.3 to 72 = 6 to 29 TW of fuel.

Present World Transport Fuel Demand

This is taken as about 88 EJ/y = 2.8 TW. **(See Appendix A).**

The effect of any difference in vehicle TTW efficiency when using methanol is ignored, since it will probably be higher than with gasoline. (See above, Section 2.3.2).

(The vehicle TTW efficiency would be further considered in the proposed Vehicle Report. See below).

Any contribution from biofuels has been omitted.

Hence the present (2006) world oil-based transport fuel demand to be met from wind energy is 2.8 TW.

Wind-based methanol versus present world transport fuel demand

Values for the potential production of synthetic methanol from wind energy of 6 to 29 TW and a present (2006) world oil-based transport fuel demand of 2.8 TW show that the latter could be met entirely with wind-based methanol.

Appendix D: Sustainable Transportation Status

All data is for motor fuels and vehicles only, excluding air and sea transport.

EU targets: 5.75% biofuel (by energy but not GHG) by 2005 (advisory) and 10% (hopefully by GHG) by 2020, 20% by 2030 (mandatory).

1st Gen. Biodiesel is ignored as unsustainable.

FT diesel (and synthetic gasoline) could be used in existing fleet. However these have lower energy and feedstock efficiencies, hence the emphasis on 'High Blends' - E85 and M85 and finally E100 and M100.

Denmark

Biofuel Target: 40% implied by DONG Energy table, after 30% transport energy saving.

Biofuel Suppliers: DONG Energy. Kalundborg to produce 18 million l/y E in 2009.

High Blend Vehicle sales: None

High Blend Vehicle market share: None.

High Blend Vehicle fleet penetration: None.

Sustainable Fuel sales: None.

Sweden

Biofuel Target: 40-50% by 2020 in PM's 'Oil Report'.
100% implied by SEKAB with E imports from Brazil and Africa.
Biofuel Suppliers: SEKAB (E) and CHEMREC AB (M). Production of 150 million l/y E in 2008, + 300 million l/y E in 2009.
High Blend Vehicle sales: E85 FFVs rising fast.

High Blend Vehicle market share: E85 FFVs 20% in early 2008. 30% expected in 2009.

High Blend Vehicle fleet penetration: Some E85 FFVs. 700+ ED95 buses.

Sustainable Fuel sales: > 1000 E85 pumps. All G is E5, some E85 and a little ED95, so far met by imported E.

Germany

Biofuel Target: 21-38 % in 2030 implied by Dena BtL study.

Biofuel Suppliers: Choren with 18 million l/y FT diesel from mid-08. Schwedt plant for 250 million l/y FT diesel due in 2012.
High Blend Vehicle sales: None.

High Blend Vehicle market share: None.

High Blend Vehicle fleet penetration: None.

Sustainable Fuel sales: Some FT diesel from Choren.

Netherlands

Biofuel Target: 40-60% by 2030 in PGG Report to Government. Based largely on imported biomass. [146]

Biofuel Suppliers: BioMCN to make up to 800,000 t/y bio-M. [147]

High Blend Vehicle sales: A few E85 FFVs.

High Blend Vehicle market share: None ?

High Blend Vehicle fleet penetration: None ?

Sustainable Fuel sales: Tiny. Tamoil to install 19 E85 pumps in 2008. [148]

USA

Biofuel Target: 30% by 2030 from DOE. Most new E to be cellulosic. [149]

Biofuel Suppliers: Many. All E from corn. 24.6 bn l in 2007.

High Blend Vehicle sales: Some E85 FFVs. Due to be 50% by 2012.

High Blend Vehicle market share: Some.

High Blend Vehicle fleet penetration: 6 million E85 FFVs.

Sustainable Fuel sales: All gasoline now E10. A little E85.

Brazil

Biofuel Target: 100% ?

Biofuel Suppliers: Many. All E from sugar-cane. 19 bn l in 2007. Much exported.

High Blend Vehicle sales: Almost all SI are E100 FFVs.

High Blend Vehicle market share: Almost all SI are E100 FFVs.

High Blend Vehicle fleet penetration: Already millions of E100 FFVs.

Sustainable Fuel sales: All gasoline E22. Much E100. ~ 40% E in all.

China

Biofuel Target: ?

Biofuel Suppliers: Several. E from sorghum etc. M from coal. Plans for more. [150] Produced 1.8 bn l E in 2007.

High Blend Vehicle sales: Some E85 FFVs in one province.

High Blend Vehicle market share: Some

High Blend Vehicle fleet penetration: Slight.

Sustainable Fuel sales: Some E85. Some M85 and M100 buses and taxis in Shanxi province. [151] [152]

Japan

Biofuel Target: ?.

Biofuel Suppliers: ?

High Blend Vehicle sales: None ?.

High Blend Vehicle market share: None ?

High Blend Vehicle fleet penetration: None ?.

Sustainable Fuel sales: None ?

France

Biofuel Target: ? Based on E85 ?

Biofuel Suppliers: ?

High Blend Vehicle sales: A few Renault, Peugeot FFVs.

High Blend Vehicle market share: None ?

High Blend Vehicle fleet penetration: None ?.

Sustainable Fuel sales: Little ? Some E85 pumps.

UK

Biofuel Target: Study suggests that 100% by 2050 could be 33% domestic, rest imported.

Biofuel Suppliers: British Sugar to produce 70 million l/y E, from beet. Wessex Grain to produce up to 131 million l/y E.
High Blend Vehicle sales: A few Saab, Ford FFVs.

High Blend Vehicle market share: Tiny.

High Blend Vehicle fleet penetration: Almost none

Sustainable Fuel sales: Little ? A few E85 pumps. SEKAB plans to install some ED95 pumps. [153]

Appendix E: CAST Projects and Partners

These are contributions that Lotus Engineering and Taylor could make to CAST and CONCAST. As well as being a prelude to the hardware proposal, they could also be precursors to the technical reports that would be needed to inform and build the consensus.

Fuel Report – Lotus & Taylor

The Biomass Limit may be only 10-30%. For example, DK has, after 30% energy saving, a Biomass Limit (for cellulosic bioethanol) of about 40%. [154] Hence for the present transport fuel demand, it would be 28%.

There are fuel production (WTT) and engine (TTW) options for raising the Biomass Limit. However, at least for developed countries, they are very unlikely to raise it to 100% of the transport fuel demand. Therefore synthetic fuels will also be needed. Therefore it should include the rationale for the fuel and engine choices - both those chosen and those not. It should also include a full quantitative analysis, with the chemistry of ethanol and methanol production along with the process efficiencies and carbon intensities.

Compare processes for methanol synthesis, e.g.
Carbon from biomass, autothermal
Carbon from biomass, allothermal, with hydrogen from 'surplus' wind electricity.
Carbon from fluegas, with hydrogen from 'surplus' wind electricity
Carbon from the air, with hydrogen from 'surplus' wind electricity
The results affect the fuel plant capital cost, the feedstock efficiency and thus the Biomass Limit.

The process considered for Well-to-Tank analysis is that producing methanol from CO_2 captured from air and electrolytic hydrogen from renewable electricity, such as wind turbines. Most developed countries have low biomass limits, and may use even less, so such synthetic fuels are likely to account for at least 70 to 90% of the transport fuel demand. However, while carbon from biomass and CO_2 captured from 'biomass' fluegas have much lower limits, the energy and money costs of both capital plant and feedstock may be cheaper.

Vehicle Report – Lotus & Taylor

This would cover the performance and efficiency of each powertrain and the NEDC fuel consumption and hence the corresponding well-to-wheel efficiencies and CO_2 for each demonstrator vehicle on specific fuel mixes. The science and technology of fuels and IC engines is understood well enough for initial studies to be carried out by mathematical modelling. The process chosen for a first Tank-to-Wheel analysis uses 'neat' methanol (M100) in Spark Ignition (SI) Internal Combustion Engine (ICE) vehicles. This was chosen to represent the situation after the transition from fossil to renewable, sustainable transport fuel.

A separate exercise would compare the fuel and engine options, e.g. synthetic diesel with CI engines, ethanol with Scania-type engines, methanol with MAN-type engines, and ethanol and methanol with SI engines, including Brusstar-type. The data on engines using ethanol and methanol is very limited but mathematical modelling can help. The results affect the fuel plant capital cost, the feedstock efficiency and thus the Biomass Limit.

Fuel + Vehicle Report – Lotus & Taylor

The combination of synthetic methanol fuel and ICE was chosen as representing the major part of a 'CAST' solution for road vehicles. Even with their compatibility and affordability advantages, the embedded (production) and overall WTW energy and GHG emissions over their Life Cycle for such vehicles should be compared with those for a conventional gasoline fuelled ICE vehicle, a Battery Electric Vehicle and a hydrogen Fuel Cell Vehicle. The first is to represent a present-day vehicle and the latter two higher cost vehicles that have been proposed for future transportation. It is important to include the embedded energy, since this largely accounts for the higher money cost, and has to be repaid in lower operating energy and GHG emissions to be justified.

Previous Well-To-Wheel studies, such as CONCAWE, have assumed vehicle performance levels that were very high, with the top speed taken as 180 km/h. [155] If the top speed requirement was kept at 180 km/h and national speed limits are assumed to remain at about 110 km/h (68 mph) or often unlimited, as in Germany, then the driving cycle should better reflect such usage. This might be approximated by the Ecotest (NEDC plus the ADAC highway) cycle. [156]

In the past, family cars had much lower top speeds. The VW Beetle was designed for 100 km/h and the modern equivalent is the Tata Nano. Also crowded roads often have speed limits as low as 65 km/h, to maximise traffic flow. When the post-peak decline in oil production is finally acknowledged, nationwide speed limits may well be cut to 80 km/h, including motorways. This will be particularly likely in the UK where almost no provision has been made for sustainable fuels. Even the USA cut speed limits to 55 mph (90 km/h) in some previous oil crisis.

The performance level of cars and other vehicles affects their energy efficiency and hence fuel economy. If the design top speed is high, the engines will be relatively large and powerful, and the fuel economy will suffer. This is particularly so if measured on the NEDC, which emphasises low speeds. If design top speeds are to remain high, then fuel economy should be measured by the Ecotest (NEDC plus the ADAC highway) cycle. However, it seems far more likely that fuel economy will take preference over top speed, so the design top speed should fall to 140 km/h or even lower. Even with reasonable laden hill-climbing performance, this would enable smaller, less powerful engines, which would give appreciably higher fuel economy.

Vehicle Hardware - Lotus

The full significance of the CAST sustainable transportation solution would be much better understood by journalists, politicians and policymakers if there were vehicles present that could use methanol. For preference, they should be able use gasoline, ethanol and methanol in any mixture. Lotus Engineering have developed a sports car capable of running on any tri-fuel mixture up to G100, E100 and M100: the Lotus Exige 270 Tri-Fuel. [157] [158] However it should be complemented by a high volume family car. One of those already capable of E85 flex-fuel or E100 total-flex could be adapted to tri-flex capability before COP 15. There are about 34 models using about 10 different engines. The smallest seems to be 1.6 l, from VW and Renault. The next smallest is 1.8 l, from Ford/Volvo. **(See Appendix B)**.

After adaptation to tri-fuel capability, the vehicle (TTW) energy efficiency should be measured. This should be combined with the estimated Wind-to-Tank (WTT) efficiency to determine the overall Wind-to-Wheels efficiency and CO_2/GHG emissions.

The adapted vehicle would be supplied for demonstration at COP 15.

Time Report – Taylor, DONG Energy, Risø

The needs of a complete CAST solution should be explored by modelling the dynamics of the electricity-fuel system, on a daily to one-year timescale.

The fuel and vehicle transition has major implications for their suppliers, public policy and economics. The needs of a the shortest transtion should be explored by modelling the dynamics of the fuel production plants and vehicle fleets, on a one-year to several decades timescale.

CONCAST Activities – Lotus & Taylor

Second generation biofuels and synthetic fuels could be produced with biomass, captured CO_2 and hydrogen from renewable electricity - all with CO_2 savings of 85 to 90 % or more. They could include kerosene, diesel, gasoline, ethanol and methanol. However since ethanol and methanol offer higher production and use efficiency, gasoline should be phased out as soon as the road vehicle fleet allows, leaving just the CAST proposal of synthetic kerosene and diesel, and ethanol and methanol to cover all forms of transport.

Report on sustainable transportation in DK, SE, DE, NL etc. for the 'consensus'.

Establish the scope for global adoption of the CAST proposal for Sustainable Fuels and Vehicles.

Work with the Danish energy industry and the Danish Government on 'building the consensus'.

The Danish Government would understand that such sustainable transport fuels would complement DH from CHP fuelled with waste and biomass and electricity from wind turbines. (They also lead in all of these). Hence the period leading up to the Summit should be used to build a consensus for this sustainable transport fuel solution. This could include Denmark, Sweden, Germany, Netherlands, Brazil, USA, France and UK, in which such sustainable fuels and vehicles have made progress. This could enable Denmark and the other 'consensus' countries at the Summit to propose the adoption of these solutions for the 'Kyoto 2' era.

Appendix F: Presentations

Constituencies that should support the consensus for CAST include:

For bio- and synthetic fuels generally - energy security, climate change, carbon capture, wind turbines and electrolysers.

For bio- and synthetic methanol specifically – Topsoe, BioMCN, MAN Ferrostaal, and coal-to-methanol.

For bio- and synthetic ethanol specifically – Topsoe, DONG Energy and Inbicon, SEKAB and Taurus Energy AB.

For bio- and synthetic FT diesel and kerosene specifically – Choren, VW, and Daimler.

The sequence of presentations could be:

Charles Nielsen, Head of R&D, DONG Energy, DK.

He was responsible for the 'VEnzin Vision' and the resulting IBUS and Inbicon ethanol and methanol developments.

Per Carstedt, CEO of SEKAB, SE.

He founded the Bioalcohol Fuel Foundation (BAFF) that successfully promoted the use of ethanol and flex-fuel (E85) cars in Sweden. [159] He is now CEO of SEKAB, the supplier of most of the fuel ethanol in Sweden. [160]

The SEKAB web site has a link to the Sustainable Ethanol Initiative. [161] This is almost certainly due to Per Carstedt and is exactly what is needed - especially as part of the consensus. This could be the template for part of the endorsement at COP 15. The SEKAB ethanol fuels comply with the Nordic 'Swan' scheme. [162]

A consensus for CAST would support the Swedish 'Off oil by 2020' policy and the strategy of bioethanol from the Swedish forests as well as from sugar-cane in Brazil and Africa.

Tom Blades, CEO of Choren, DE.

Choren produce SunFuel. [163] VW and Daimler were partners and are now minority shareholders. In view of the long German history in this field, it is no surprise that they use a BtL process and an FT stage, to produce (via methanol) gasoline and 'clean' diesel. [164] [165] Choren has recently opened a Beta plant in Freiberg. [166] The first 'Sigma' plant for 250 million l/y of BtL fuel will be in Schwedt, next to a petro-chemical complex. [167]

The VW 'fuels and powertrains strategy' has already found favour with the German government and the EU. Moreover, they mention the energy efficiency of the processes, which is a real mark of confidence. They realise that the fuel infrastructure and vehicle fleet transitions prevent any early adoption of hydrogen and FCVs. [168]

The Choren processes could also produce synthetic aviation kerosene, which is another of the CAST fuels.

Rob Voncken CEO of BioMCN, NL.

Billions are to be invested in a bioenergy centre in Delfzijl. The pilot plant for about 20,000 t/y started successfully in March 2008. The construction of the first production line for 200,000 t/y started in Summer 2008. The production capacity is to be increased considerably over the next few years, to 800,000 tonnes of biomethanol a year, making it the largest biomethanol plant in the world. [169]

Kjell Bergstrom, CEO of Saab/GM Powertrain, SE. Saab have developed the BioPower range of engines and cars. These are FFVs which demonstrate the advantages of alcohols (here E85) as fuels.

Giuliano Grassi at EUBIA would be able to advise on biofuels strategy - especially in the EC arena.

Nakao Onoda at IEA has worked in relevant ministries in Japan and devised the world's first regulation for heavy duty vehicle CO_2 emissions. [170] He would be able to advise on the formulation of regulations.

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