Well-to-Wheels analysis of future automotive fuels and powertrains in the European context

A joint study by

EUCAR / JRC / CONCAWE

Summary of Results

Heinz Hass, FORD
Jean-François Larivé, CONCAWE
Vincent Mahieu, JRC/IES

Outline

- Objectives
- Pathways
- Vehicle Assumptions
- Overall results: WTW energy/GHG, costs
- Specific results
  - Conventional liquid fuels
  - CNG
  - Alternative liquid fuels
  - DME
  - Hydrogen
- Potential for conventional fuel substitution and CO_2 avoidance
- Conclusions

Study Objectives

- Establish, in a transparent and objective manner, a consensual well-to-wheels energy use and GHG emissions assessment of a wide range of automotive fuels and powertrains relevant to Europe in 2010 and beyond.
- Consider the viability of each fuel pathway and estimate the associated macro-economic costs.
- Have the outcome accepted as a reference by all relevant stakeholders.

Well-to-Wheels Pathways

Resource

Crude oil

Coal

Natural Gas

Biomass

Wind

Nuclear

Fuels

Conventional Gasoline/Diesel/Naphtha

Synthetic Diesel (F-T)

CNG

Hydrogen (compressed / liquid)

Methanol

DME

Ethanol

FAME

Powertrains

Spark Ignition*:*
Gasoline, CNG, Ethanol, H_2

Compression Ignition:
Diesel, DME, FAME

Fuel Cell

Hybrids:
SI, CI, FC

Hybrid Fuel Cell + Reformer

Well-to-Tank Matrix

Resource \ Fuel		Gasoline, Diesel, Naphtha (2010 quality)	CNG	Hydrogen (comp., liquid)	Synthetic diesel (Fischer-Tropsch)	DME	Ethanol	FAME	Methanol	Electricity
Crude oil		X								
Coal				X					X	X
Natural gas	Piped		X	X	X	X			X	X
	Remote		X	X	X	X			X	X
Biomass	Woody waste			X	X	X	X		X	
	Farmed wood			X	X	X	X		X	X
	Sugar beet						X			
	Wheat						X			
	Rapeseed							X		
	Sunflower							X		
Wind										X
Nuclear										X
Electricity				X						

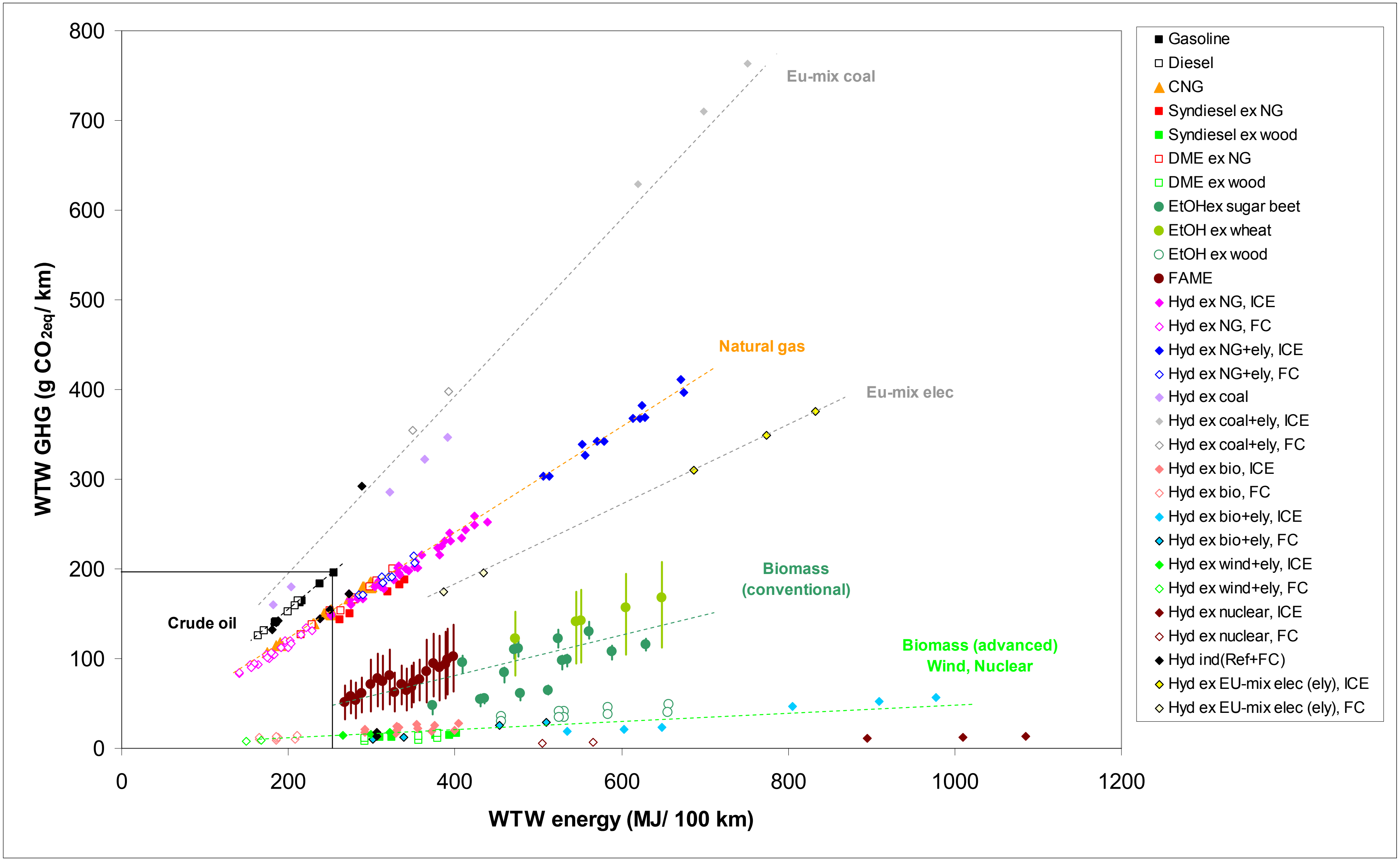
Tank-to-Wheels Matrix

X: 2002-2010 X: 2010 only	PISI	DISI	DICI	Hyb. SI	Hyb. DICI	FC	Hyb. FC
Gasoline	X	X		X			X
Diesel			X		X		X
CNG (dedicated)	X			X			
Diesel 95% / FAME 5%			X		X		X
Gasoline 95% / EtOH 5%	X	X		X			
Methanol							X
FAME			X		X		
DME			X		X		
F-T Diesel			X		X		
Naphtha							X
Hydrogen, compressed	X			X		X	X
Hydrogen, liquid	X			X		X	X

Vehicle Assumptions

- The simulations of GHG emissions and energy use were based on a model vehicle representing the European C-segment and on the New European Driving Cycle (NEDC). The model vehicle results are not representative of the EU fleet
- When necessary, the vehicle platform was adapted to ensure that each fuel and powertrain combination met a set of minimum performance criteria (speed, acceleration, gradability etc). The criteria reflect European customer expectations
- Compliance with Euro III / IV was ensured for the 2002 / 2010 case
- No assumptions were made with respect to availability and market share of the vehicle technology options proposed for 2010 and beyond
- Heavy duty vehicles (truck and busses) were not considered in the study

Overall Results – GHG Emissions vs. Energy Use



Overall Results – GHG Emissions vs. Energy Use

- Chart shows WTW GHG emissions versus total WTW energy input:
  - Energy includes renewable energy, GHG emissions reflects fossil fuel use
  - Performance of current Gasoline ICE is highlighted
  - Data points cluster on lines representing the energy source material
  - Wide spread along each line according to the fuel pathway and vehicle option considered
- Large variations in N_2O emissions influence GHG emissions from conventional biomass fuels
- Advanced biomass fuels, together with wind and nuclear offer largest GHG emission reductions

General Observations: WTW

❑ A Well-to-Wheels analysis is the essential basis to assess the impact of future fuel and powertrain options.

- Both fuel production pathway and powertrain efficiency are key to assessing GHG emissions and energy use.
- A common methodology and data-set have been developed, providing a basis for the evaluation of pathways. Data can be updated as technologies evolve.

➢ *Results must further be evaluated in the context of volume potential, feasibility, practicality, costs of the fuels pathways investigated.*

General observations and the main conclusions are presented using the following scheme:

❑ Points pertaining to energy use and GHG emissions are in normal font and with a square bullet.

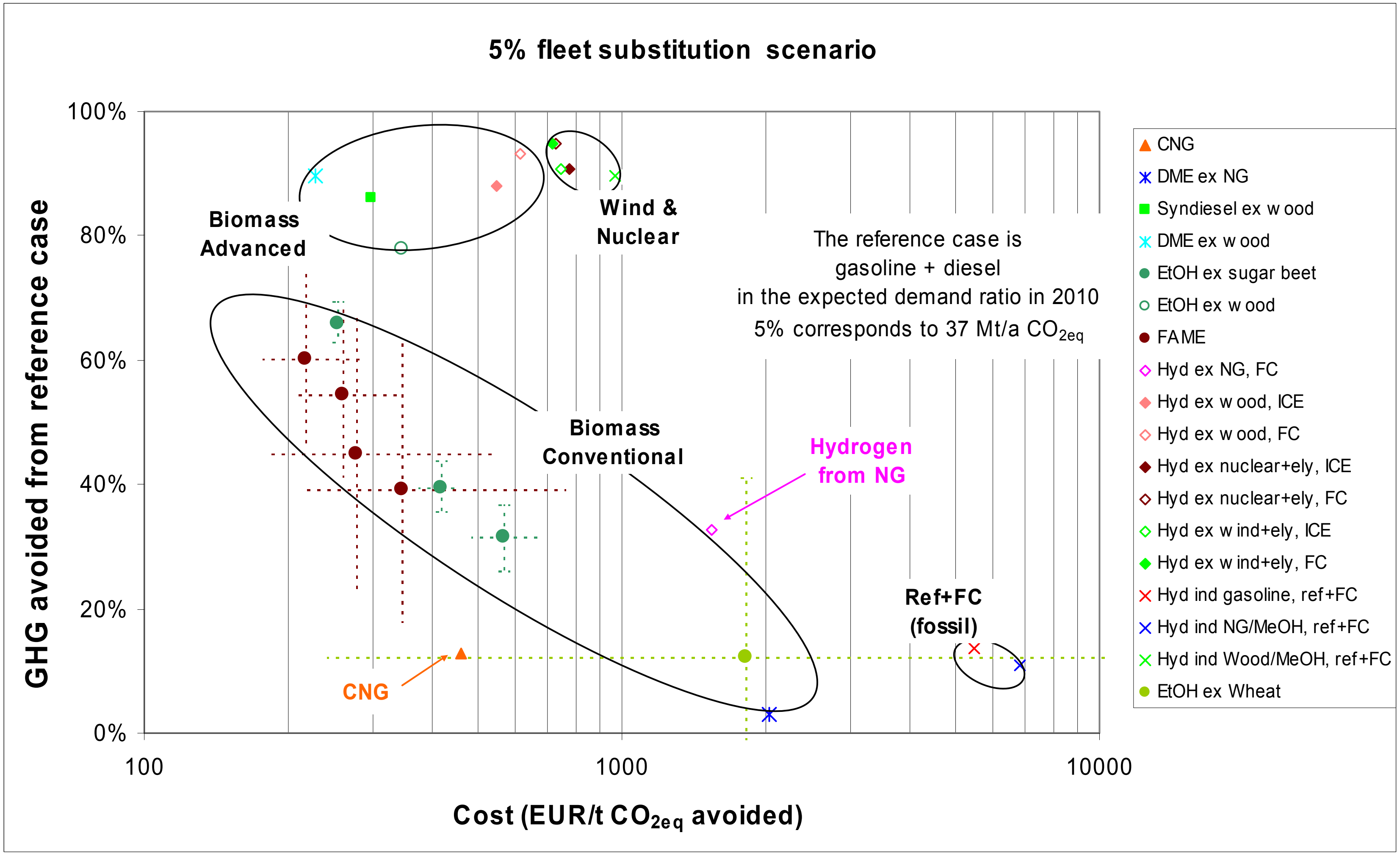
➢ *Additional points involving feasibility, availability and costs are in italic and with an arrow bullet.*

Overall Results – Costs of CO_2 avoided

The cost estimates in this study are based on the following assumptions:

- In a business as usual scenario - 5% of the conventional EU-25 fleet (marginal diesel and gasoline) will emit ca 37 Mt CO_{2eq}/a in 2010 (280 M vehicles, fleet average consumption 137 g CO_2/km, 16000 km/a average mileage, 140 Mt/a of gasoline and 60 Mt/a of diesel)
- If this portion of the EU transportation demand were hypothetically to be replaced by alternative fuels and powertrain technologies, the GHG savings vs. incremental costs would be as indicated
- CO_2 avoided costs are calculated from incremental capital and operating costs for fuel pathway and vehicle

Overall Results – Costs of CO_2 avoided



General Observations: Costs

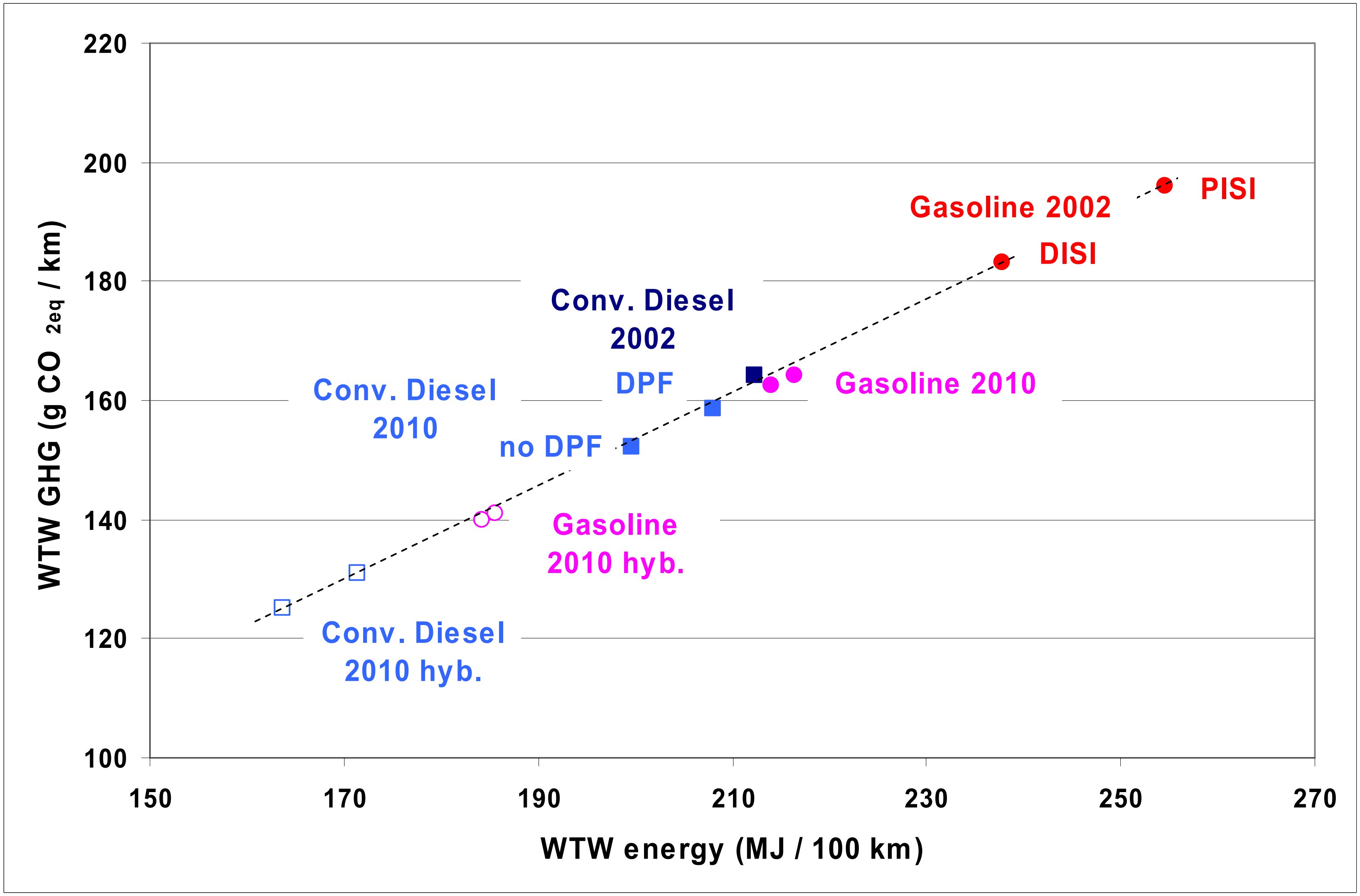
- *A shift to renewable / low carbon sources is currently costly*
  - *However, high cost does not always result in high GHG emission reductions*
  - *At comparable costs GHG savings can be considerably different and vice versa*
- *In a 5% replacement scenario significant GHG emission reductions can be achieved by using fuels from biomass at a cost of 200-300 €/ton CO_2 avoided*

Specific Results: WTW

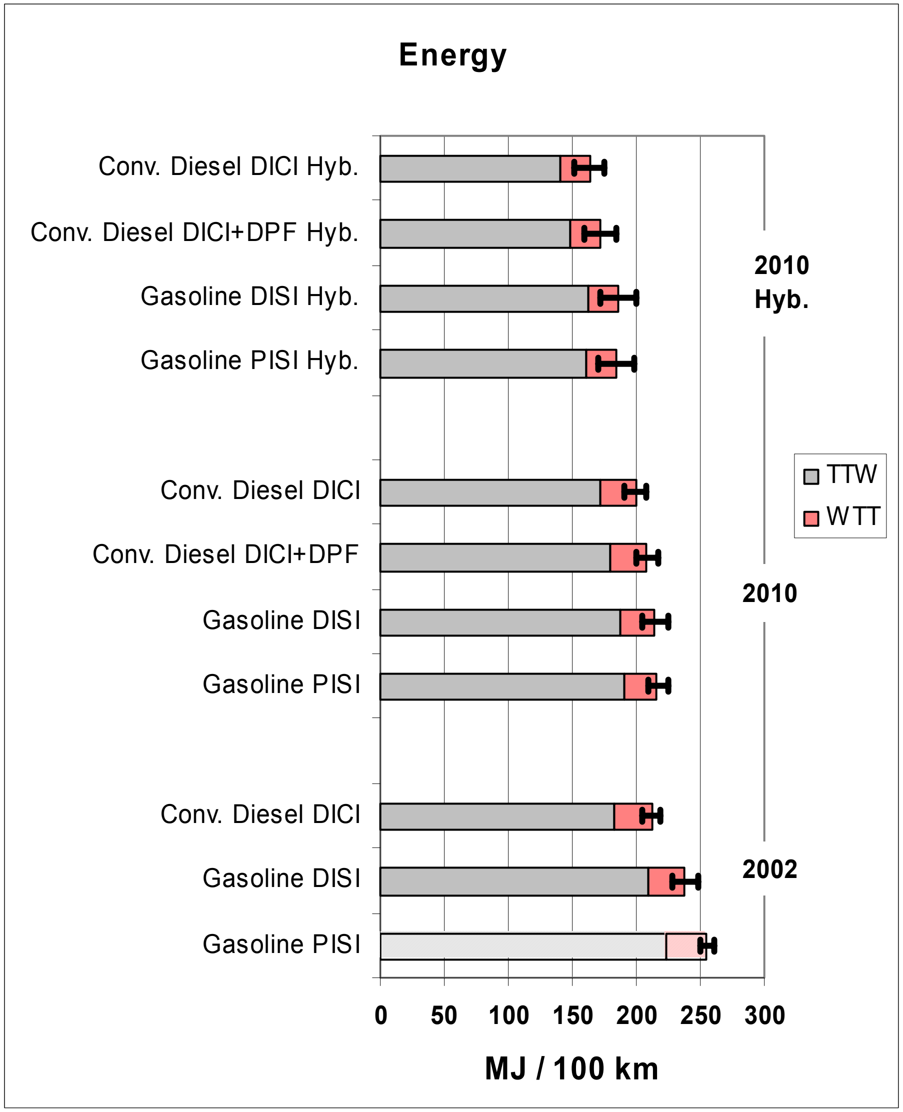
The results are reviewed in detail for the following fuels and a range of applicable powertrains :

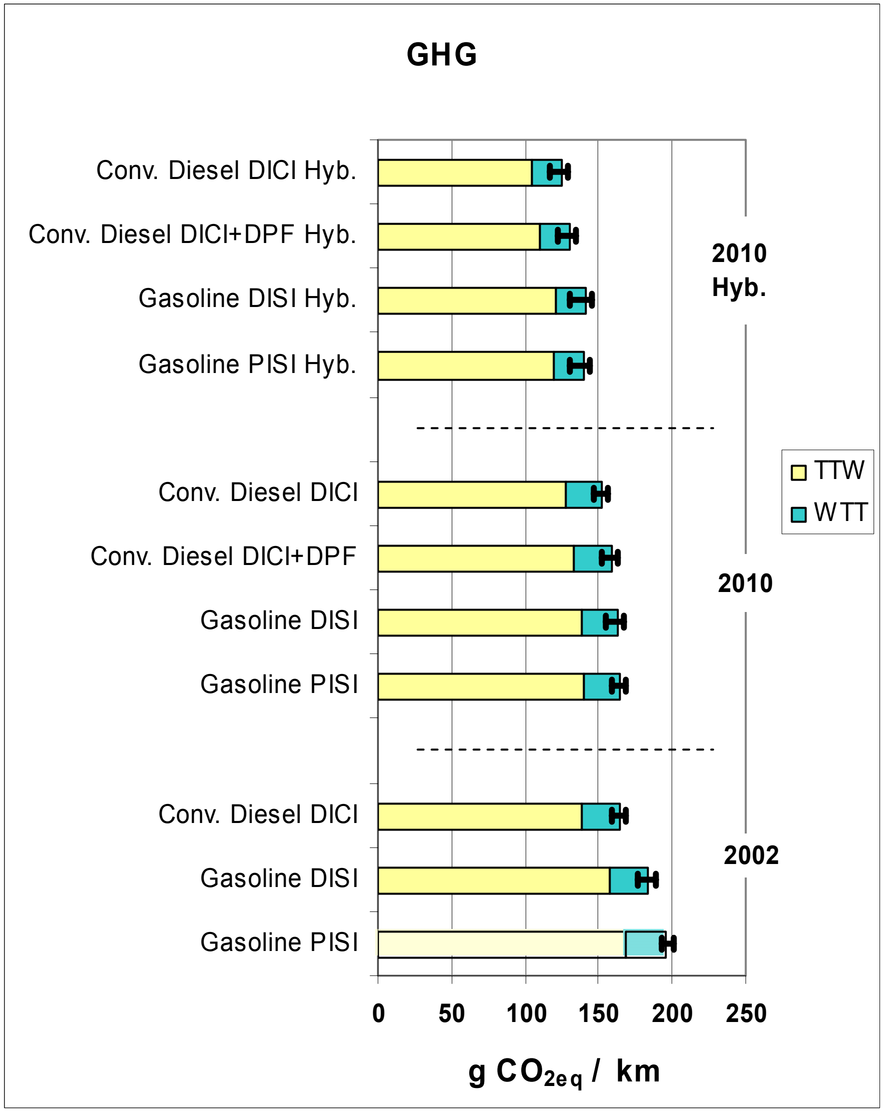
- Liquid fuels from crude oil
- Compressed natural gas
- Alternative liquid fuels (including biomass sources)
- Di-methyl ether (DME)
- Hydrogen

Conventional Fuels from Crude Oil



Conventional Fuels from Crude Oil



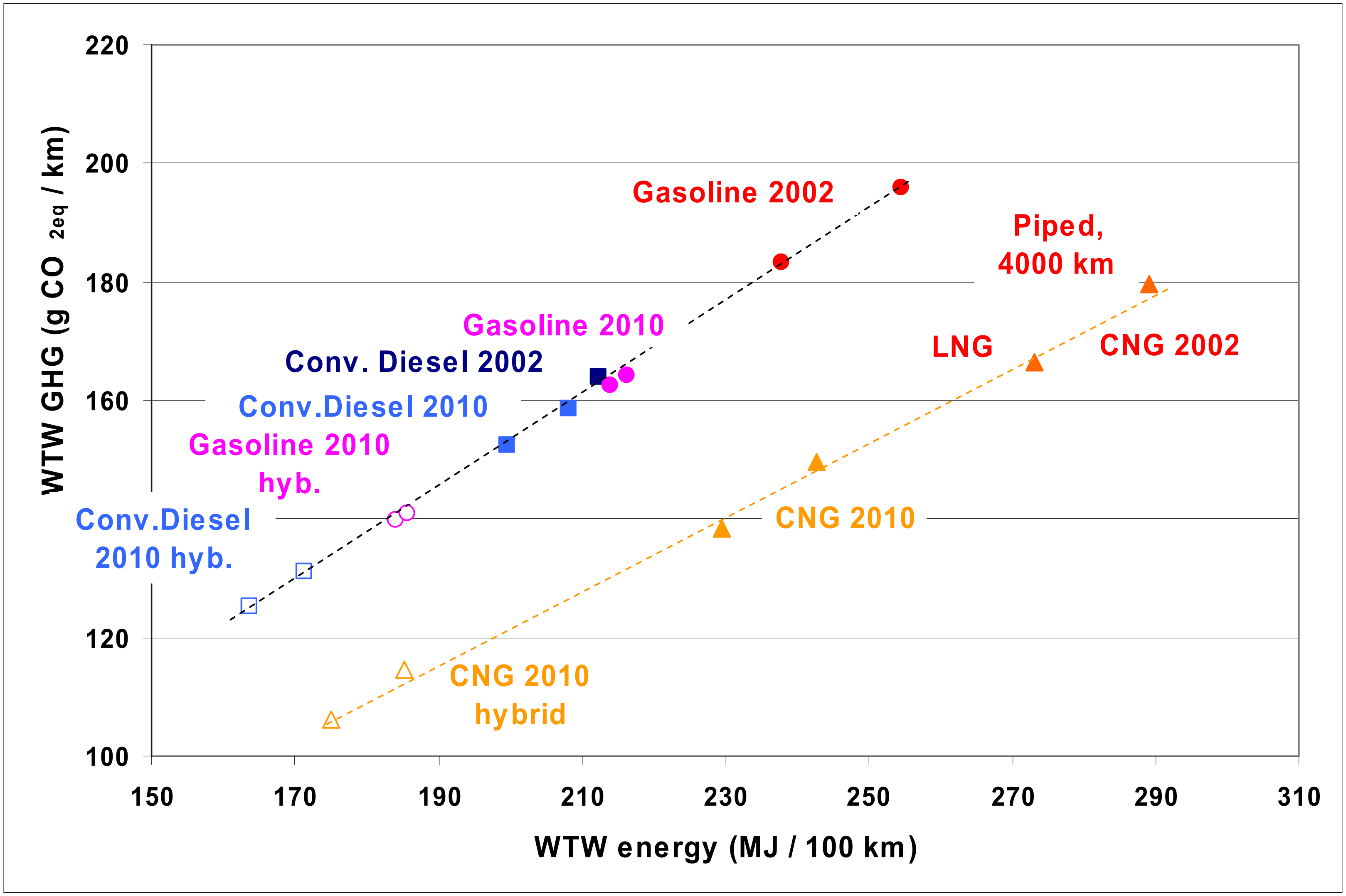


Conventional Fuels / Vehicle Technologies

- Developments in engine and vehicle technologies will continue to contribute to the reduction of energy use and GHG emissions:
  - In the timeframe 2002 to 2010, higher energy efficiency improvements are predicted for the gasoline and CNG engine technology (PISI) than for the diesel engine technology
  - Hybridization of the conventional engine technologies can provide further GHG emission and energy use benefits

➢ *Hybridisation technologies would increase the complexity and cost of the vehicles*

Compressed Natural Gas (CNG)



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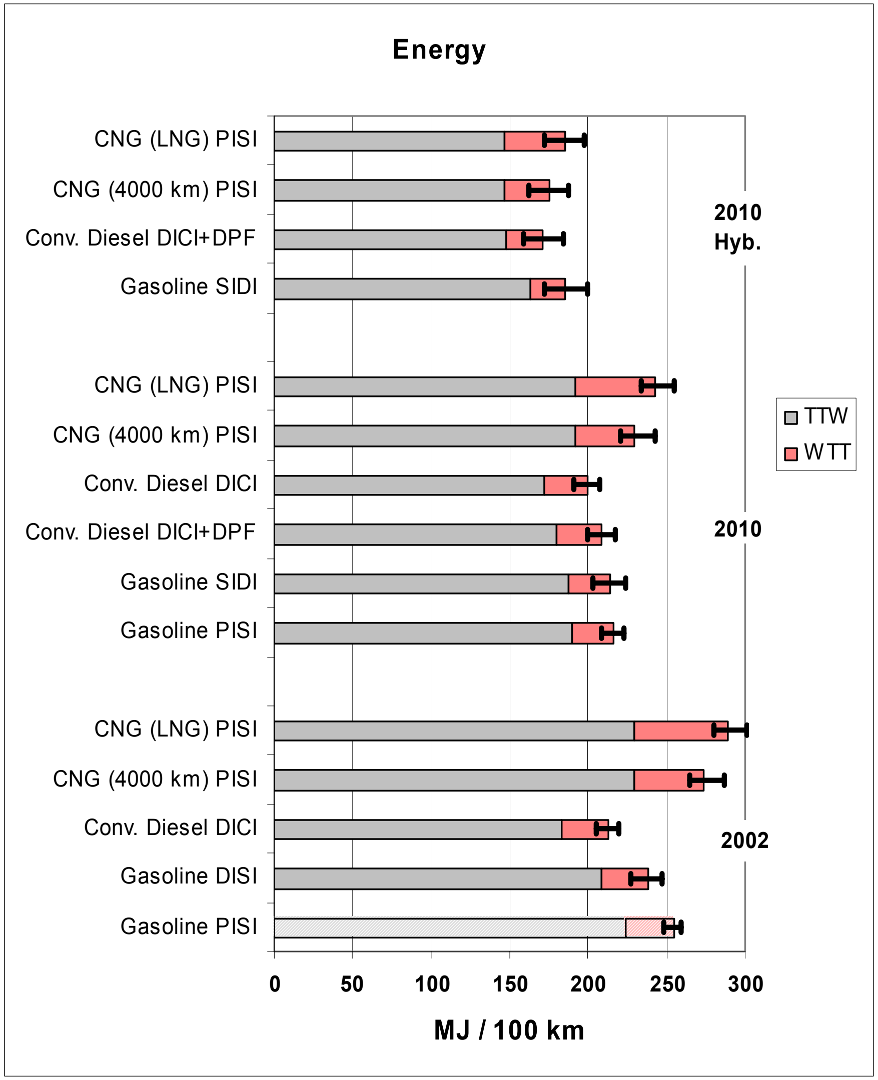
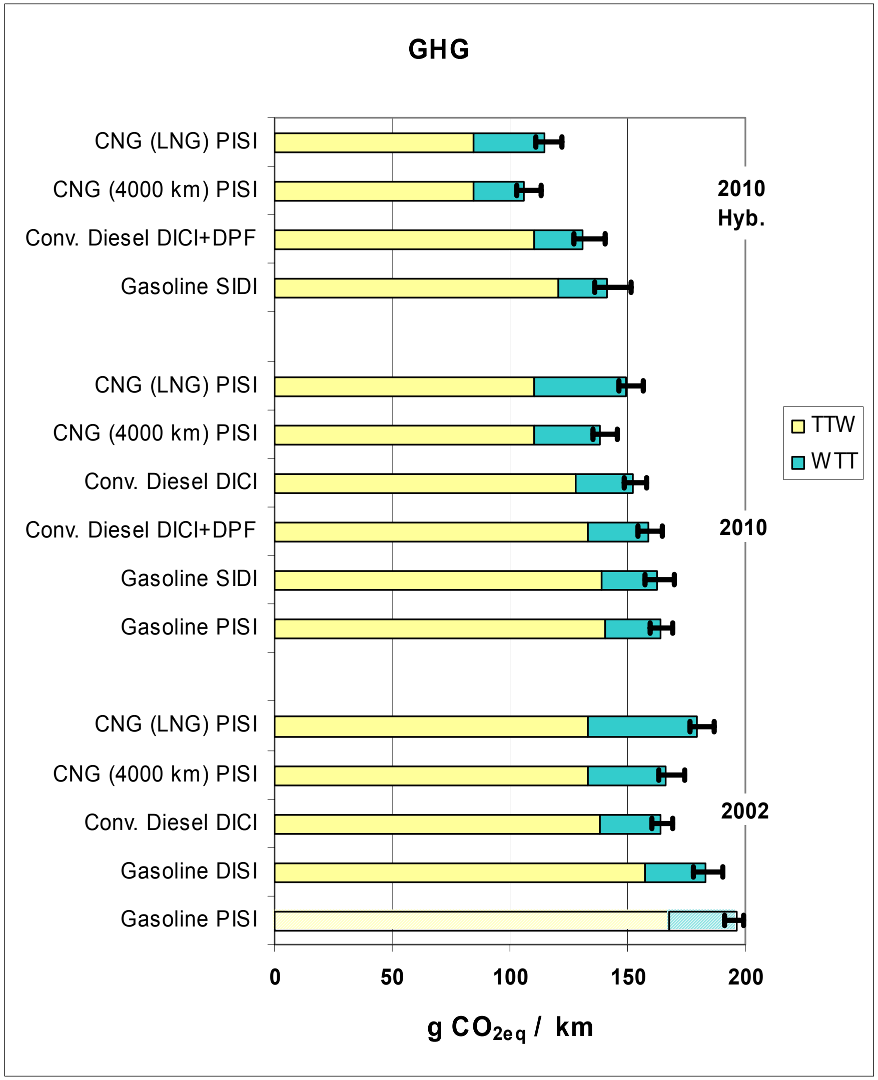
Compressed Natural Gas (CNG)

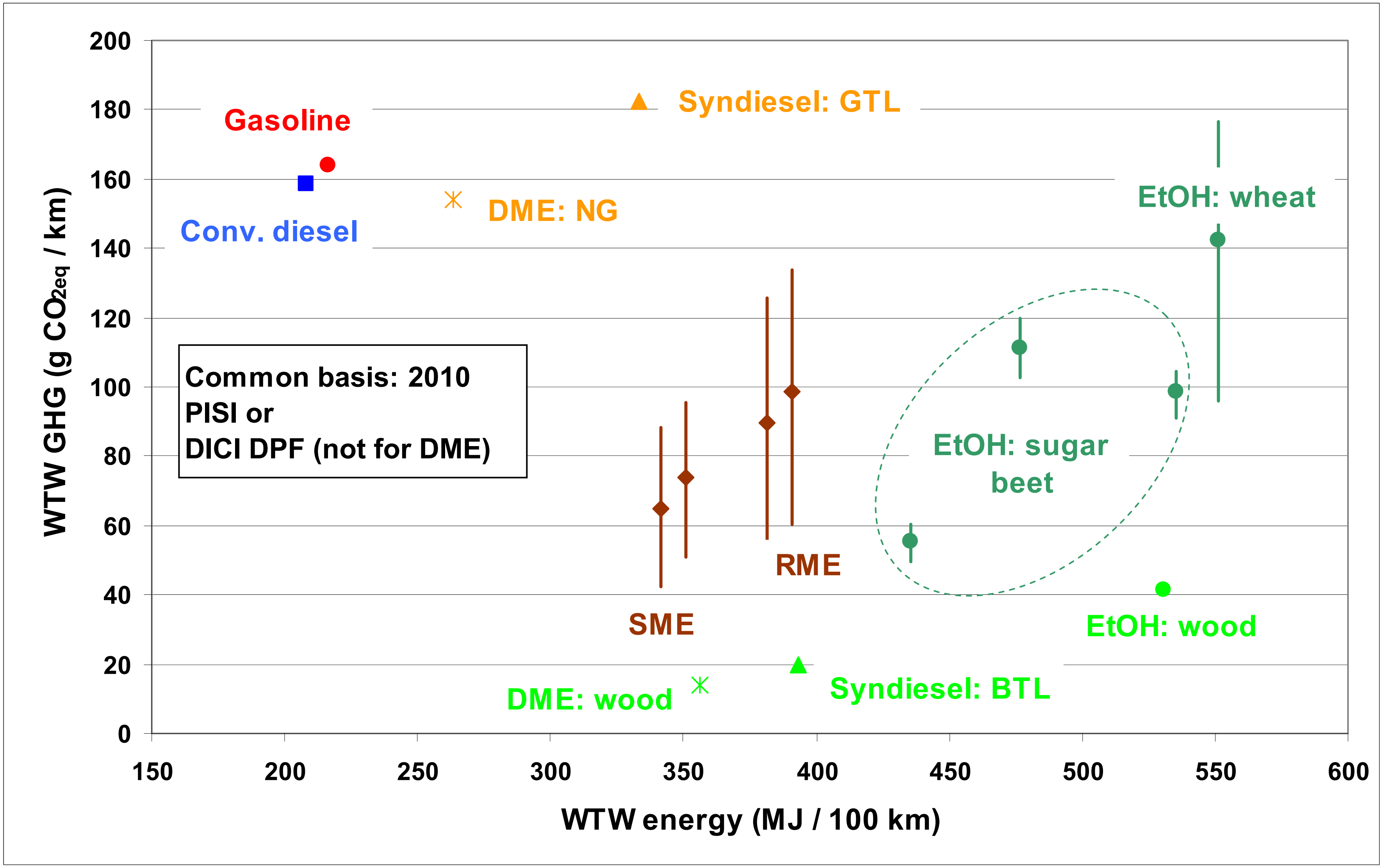




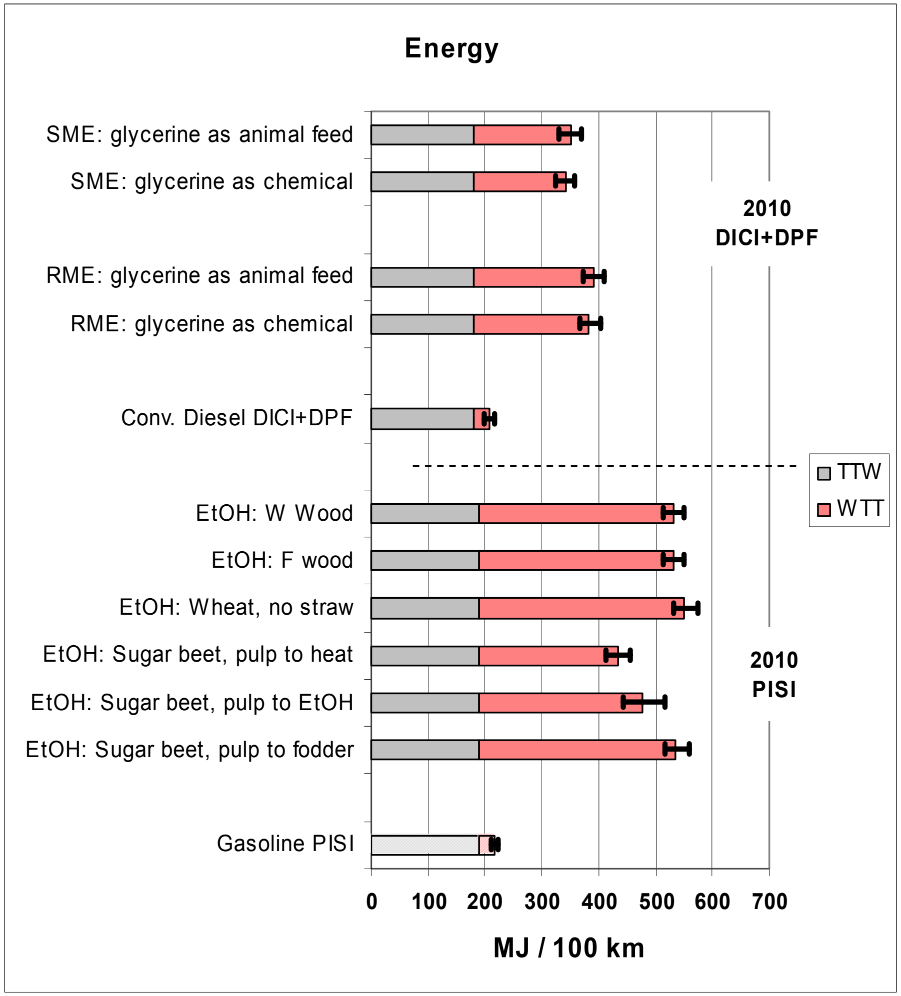
Compressed Natural Gas (CNG): key points

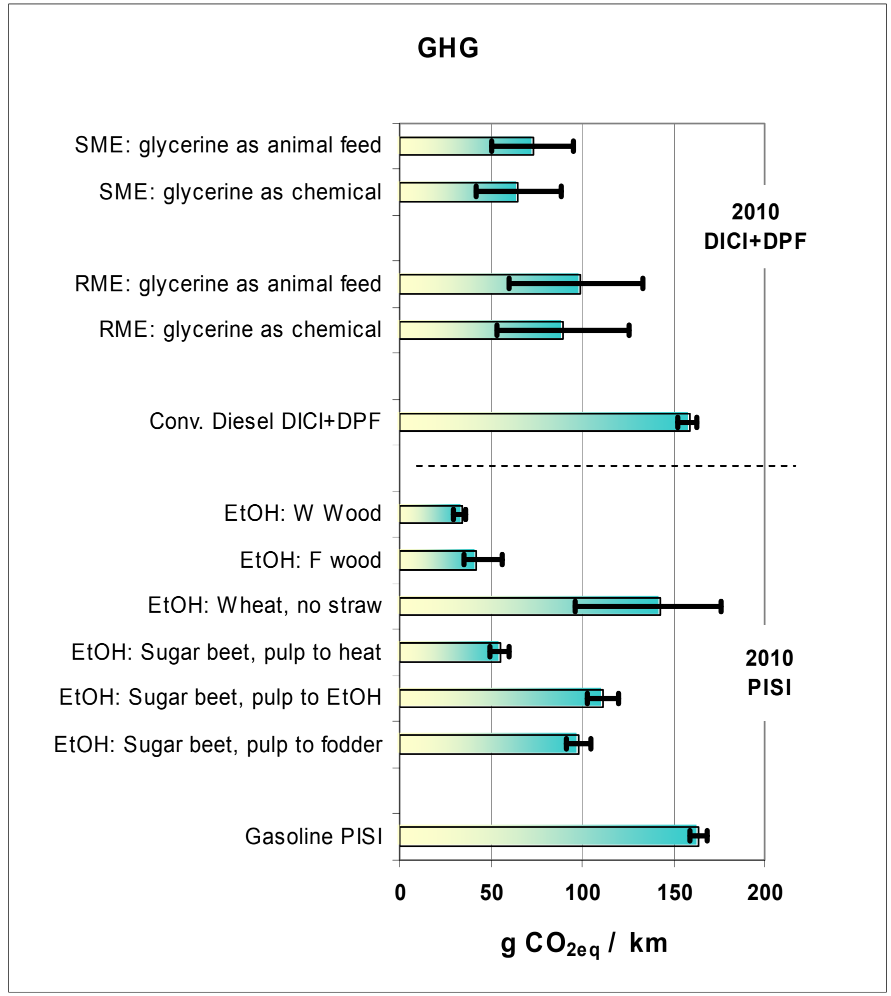
- The origin of the natural gas and the supply pathway are critical to the overall WTW energy use and GHG emissions
- Today the WTW GHG emissions for CNG lie between gasoline and diesel, approaching diesel in the best case
- Beyond 2010, greater engine efficiency gains are predicted for CNG vehicles, especially with hybridization
  - WTW GHG emissions becomes better than those of diesel
  - WTW energy use remains higher than for conventional fuels
- The cost of CO_2 avoided is relatively high as CNG requires specific vehicles and a dedicated distribution and refueling infrastructure
  - Targeted application in fleet markets may be more effective than widespread use in personal cars

Alternative Liquid Fuels

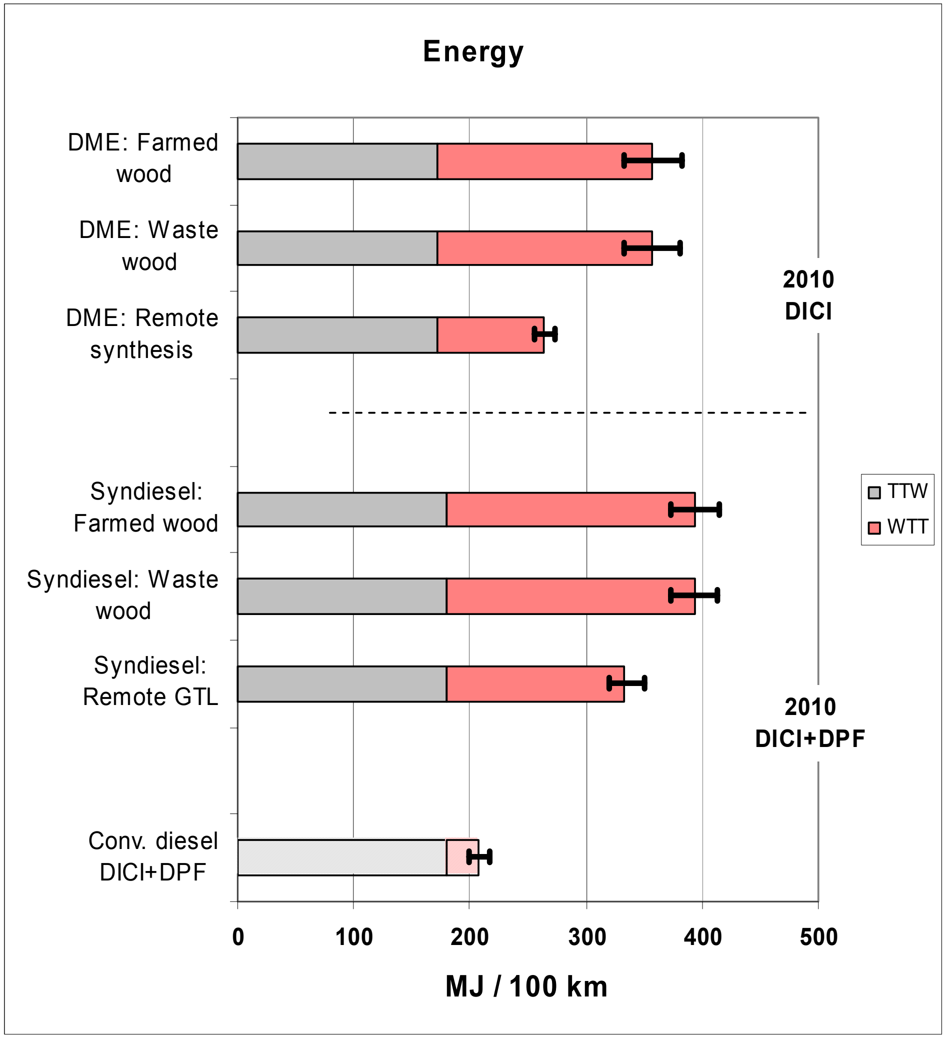


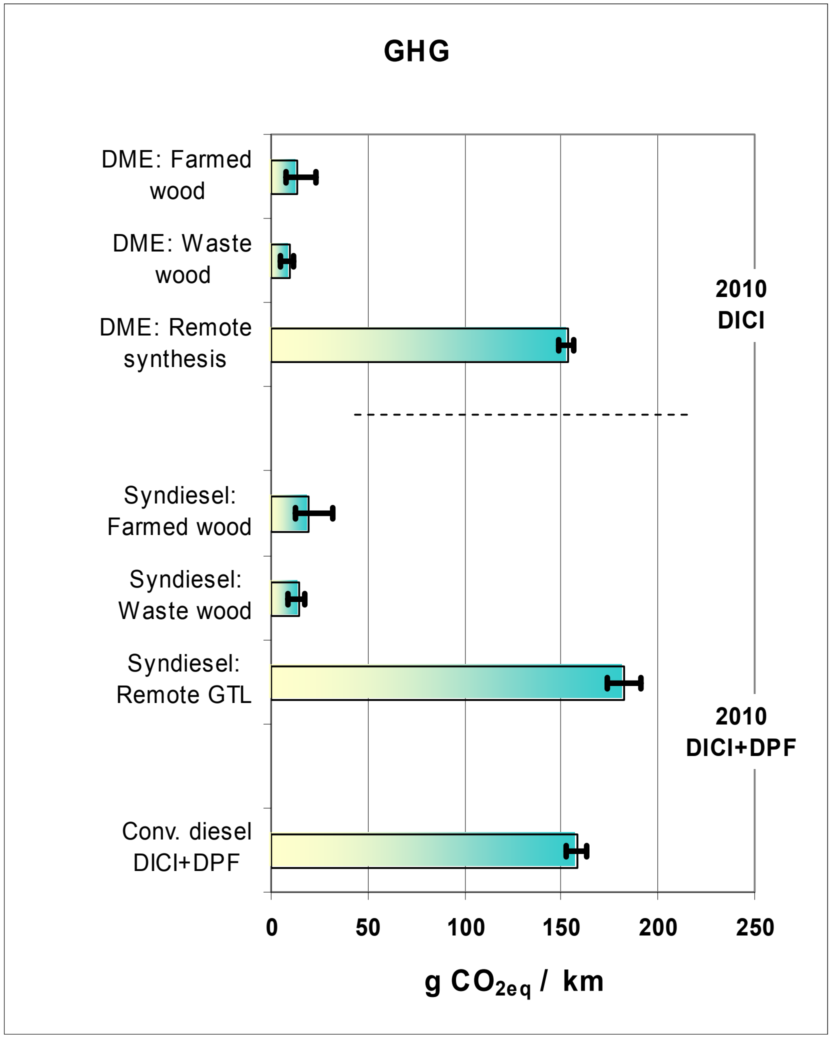
Alternative Liquid Fuels: Conventional Biofuels





Alternative Liquid Fuels: Syndiesel





Alternative Liquid Fuels: key points (1)

- A number of routes are available to produce alternative liquid fuels that can be used neat or in blends with conventional fuels in the existing infrastructure and vehicles
- Conventionally produced bio-fuels such as ethanol and FAME provide some GHG benefits but are energy intensive compared to conventional crude oil-based fuels
  - The GHG balance of conventional biofuels is particularly uncertain because of N_2O emissions
- *Potential volumes of ethanol and FAME are limited. The cost/benefit depends of the specific pathway, by-product usage and N_2O emissions*

Alternative Liquid Fuels: key points (2)

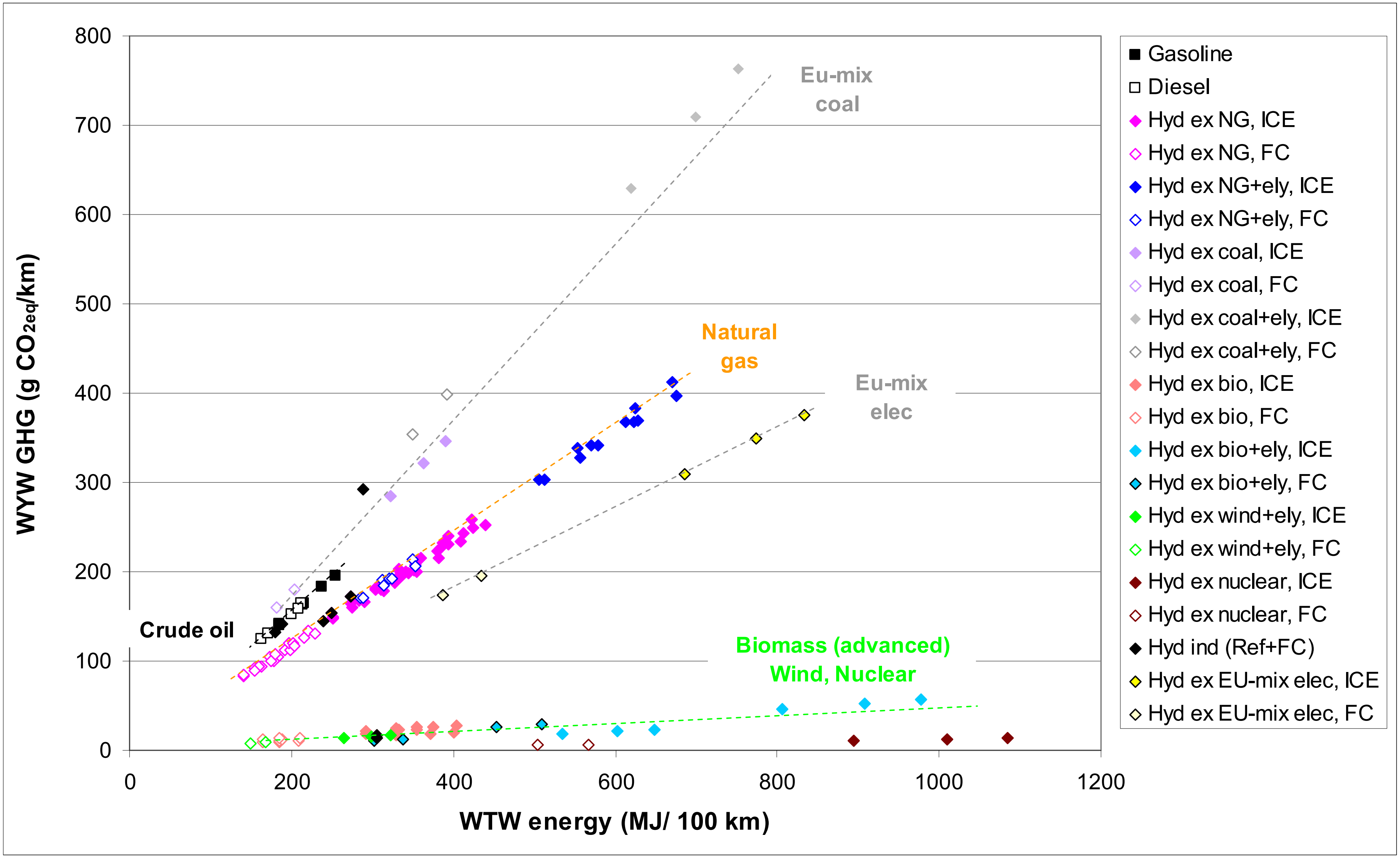
- GTL processes enable high quality diesel fuel to be produced from natural gas. However, the WTW GHG emissions are higher than for conventional diesel fuel
- *Only limited GTL volumes can be expected to be available by 2010 and beyond*
- New processes are being developed to produce synthetic fuels from biomass (BTL) with lower overall GHG emissions, though still high energy use
- *BTL processes have the potential to save substantially more GHG emissions than current bio-fuel options at comparable cost*
  - *Issues such as land and biomass resources, material collection, plant size, efficiency and costs, may limit the application of these processes*

Di-Methyl Ether (DME)

- DME can be produced from natural gas or biomass at lower energy use and GHG emissions than other GTL or BTL fuels

- *Implementation costs would be much higher as DME would require specifically designed engines and a dedicated distribution and refuelling infrastructure*

Hydrogen



WYW GHG (g CO2eq/km)
WTW energy (MJ/ 100 km)
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
Eu-mix
coal
Natural
gas
Eu-mix
elec
Crude oil
Biomass (advanced)
Wind, Nuclear
Gasoline
Diesel
Hyd ex NG, ICE
Hyd ex NG, FC
Hyd ex NG+ely, ICE
Hyd ex NG+ely, FC
Hyd ex coal, ICE
Hyd ex coal, FC
Hyd ex coal+ely, ICE
Hyd ex coal+ely, FC
Hyd ex bio, ICE
Hyd ex bio, FC
Hyd ex bio+ely, ICE
Hyd ex bio+ely, FC
Hyd ex wind+ely, ICE
Hyd ex wind+ely, FC
Hyd ex nuclear, ICE
Hyd ex nuclear, FC
Hyd ind (Ref+FC)
Hyd ex EU-mix elec, ICE
Hyd ex EU-mix elec, FC

Hydrogen: key points (1)

- Many potential production routes exist and the results are critically dependent on the pathway selected.
- If hydrogen is produced from natural gas:
  - WTW GHG emissions savings can only be achieved if hydrogen is used with fuel cell vehicles
  - The WTW energy use / GHG emissions are higher for hydrogen ICE vehicles than for conventional fuels and CNG vehicles
- *In the short term, natural gas is the only viable and cheapest source of large scale hydrogen. WTW GHG emissions savings can only be achieved if hydrogen is used in fuel cell vehicles albeit at high costs*
- *Hydrogen ICE vehicles will be available in the near-term at a lower cost than fuel cells. Their use would increase GHG emissions as long as hydrogen is produced from natural gas*

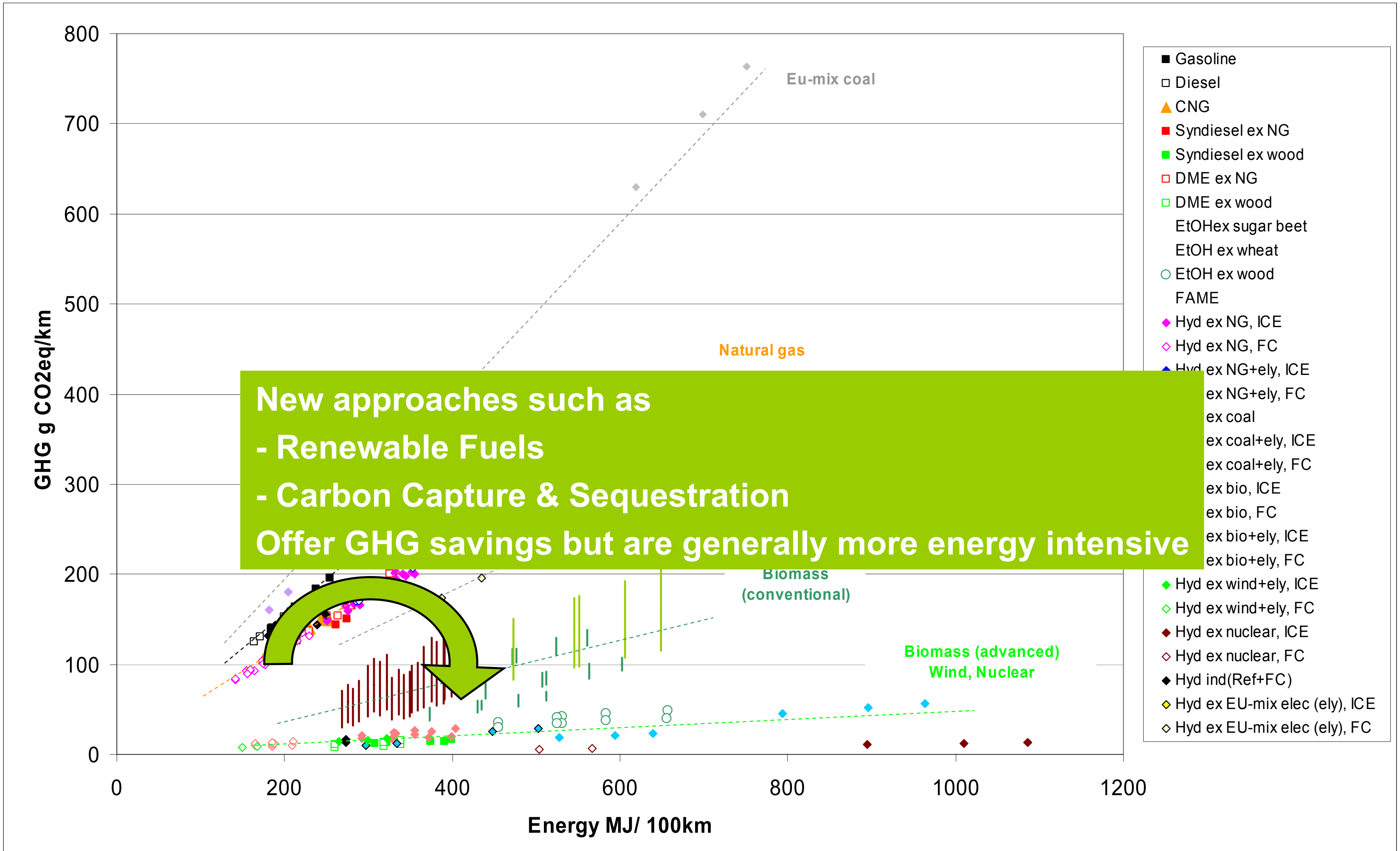
Hydrogen: key points (2)

- Electrolysis using EU mix electricity results in higher GHG emissions than producing hydrogen directly from NG
- Hydrogen from non-fossil sources (biomass, wind, nuclear) offers low overall GHG emissions
- *Renewable sources have a limited potential for the foreseeable future and are at present expensive*
- *More efficient use of renewables may be achieved through direct use as electricity rather than road fuels application*

Hydrogen: key points (3)

- Indirect hydrogen through on-board reformers offers little GHG benefit compared to advanced conventional powertrains or hybrids
  - *On-board reforming could offer the opportunity to establish fuel cell vehicle technology with the existing fuel distribution infrastructure*
  - *Large scale central hydrogen production (from coal or gas) offers the potential for CO_2 capture and sequestration*
  - *The technical challenges in distribution, storage and use of hydrogen lead to high costs. Also the cost, availability, complexity and customer acceptance of vehicle technology utilizing hydrogen technology should not be underestimated.*

Overall Results – GHG Emissions vs. Energy Use



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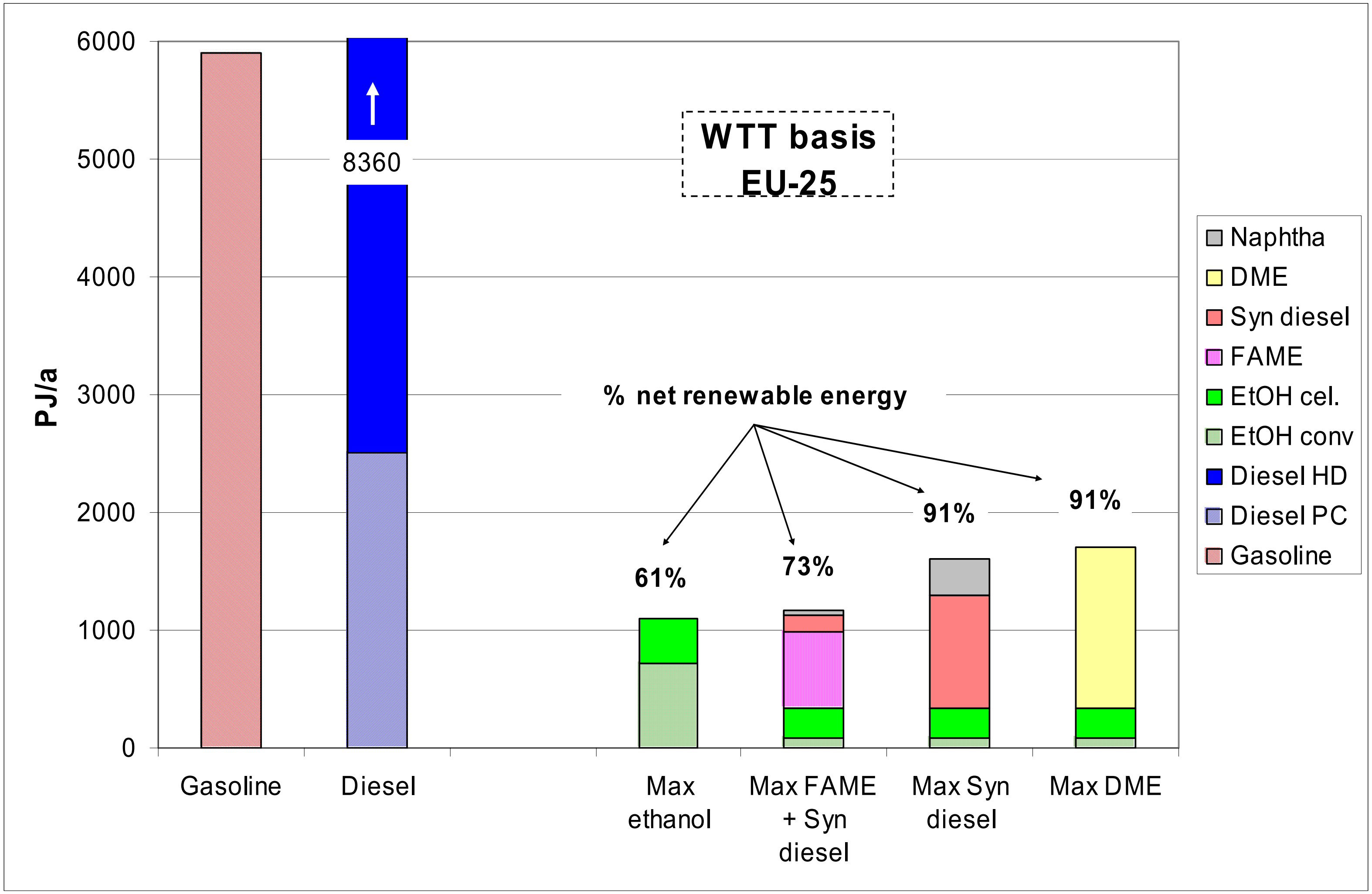
Alternative use of primary energy resources - Biomass

Where could the biomass come from?

Source		Crop		Fuel
Agricultural Surplus land	⇨	Sugar beet + Wheat grain Or Oil seeds Or Wood	⇨	Ethanol + Ethanol Or FAME Or Syn diesel(*) Or DME
Set asides	⇨	Wheat grain Or Oil seeds Or Wood	⇨	Ethanol Or FAME Or Syn diesel Or DME
Forestry residues	⇨	Wood waste	⇨	Ethanol Syn diesel Or DME
Agricultural wastes	⇨	Straw	⇨	Ethanol

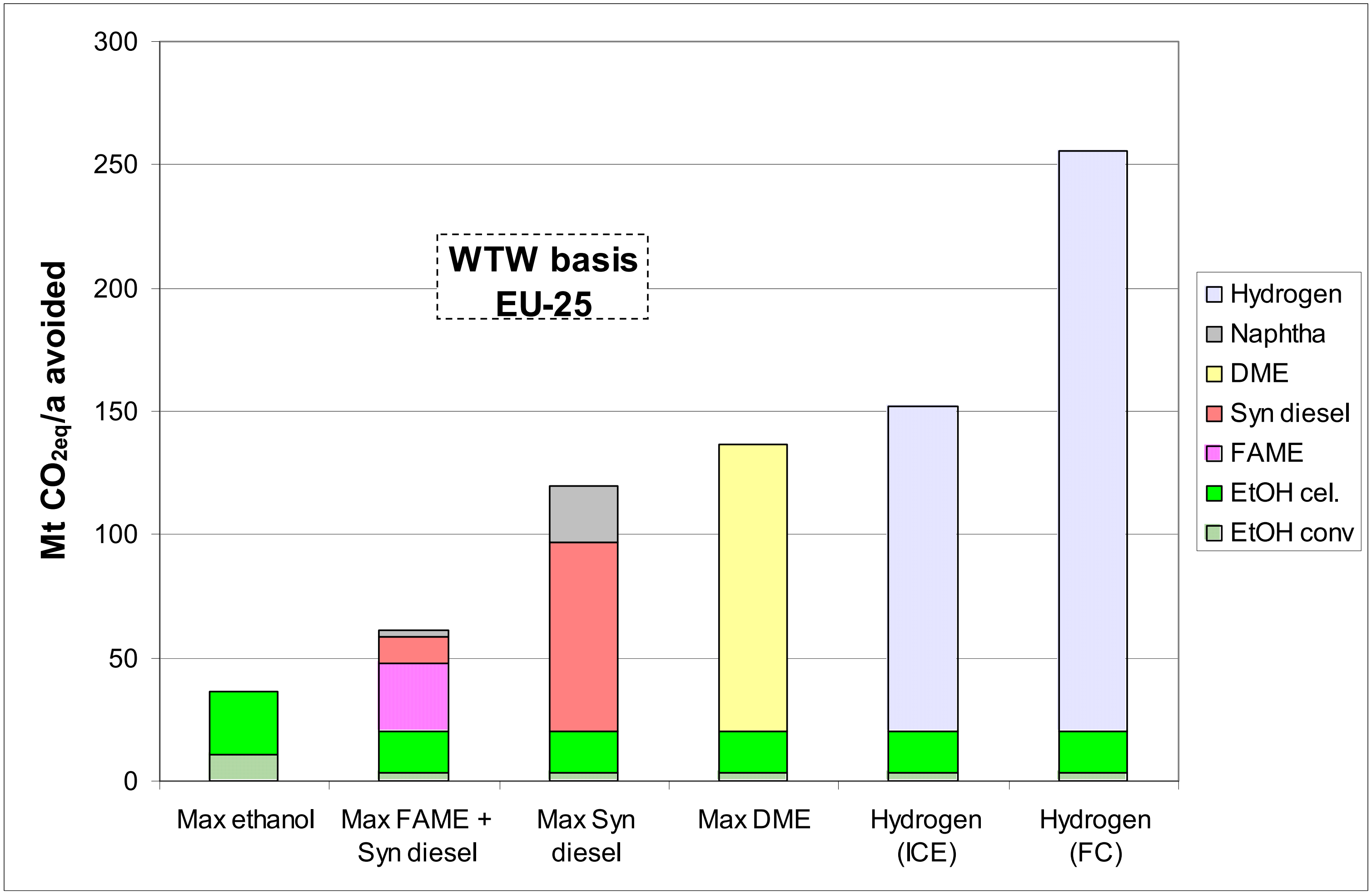
Alternative use of primary energy resources - Biomass

Potential for conventional fuels substitution with biomass-derived fuels



Alternative use of primary energy resources - Biomass

Potential for CO_2 avoidance with biomass-derived fuels



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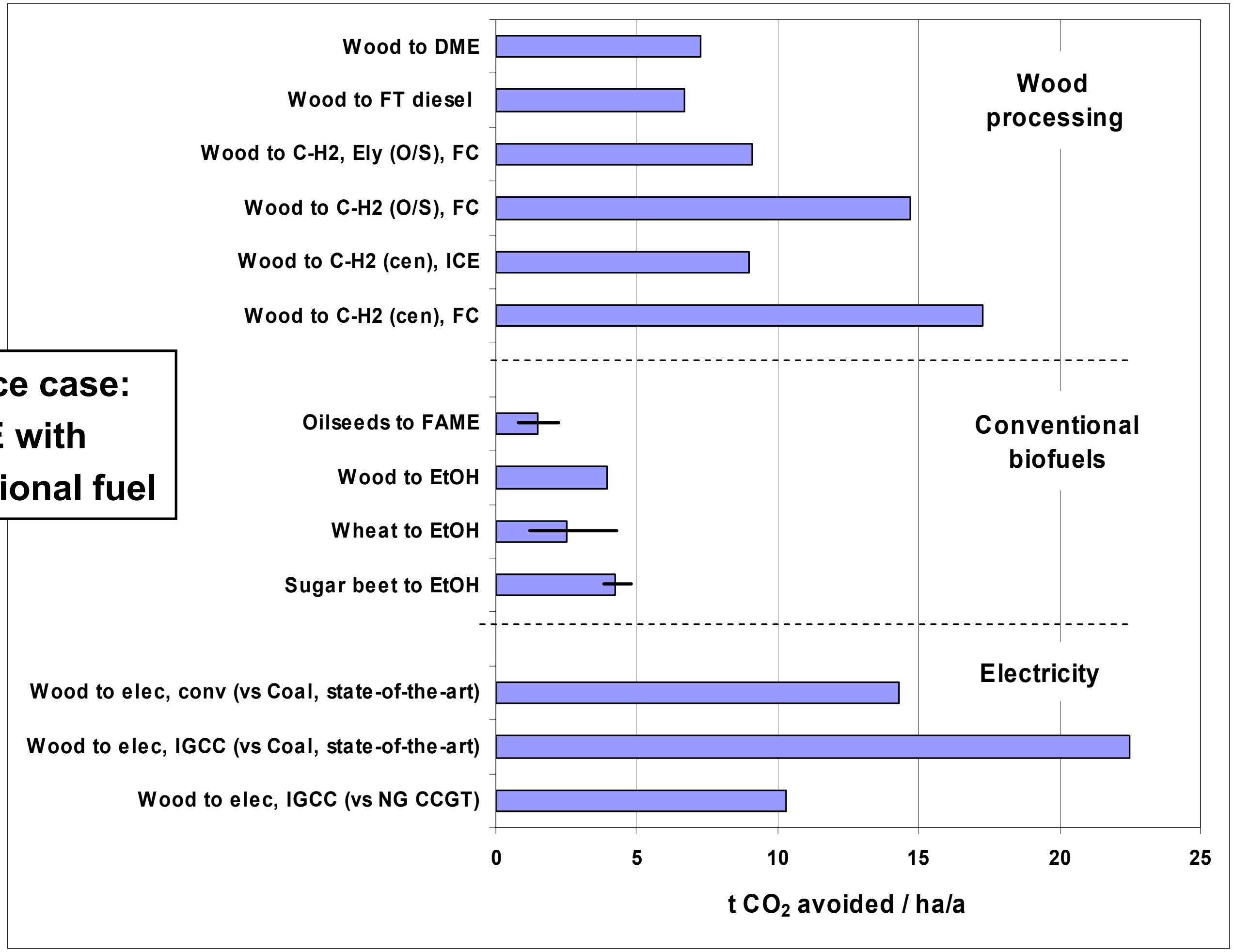
Alternative use of primary energy resources - Biomass

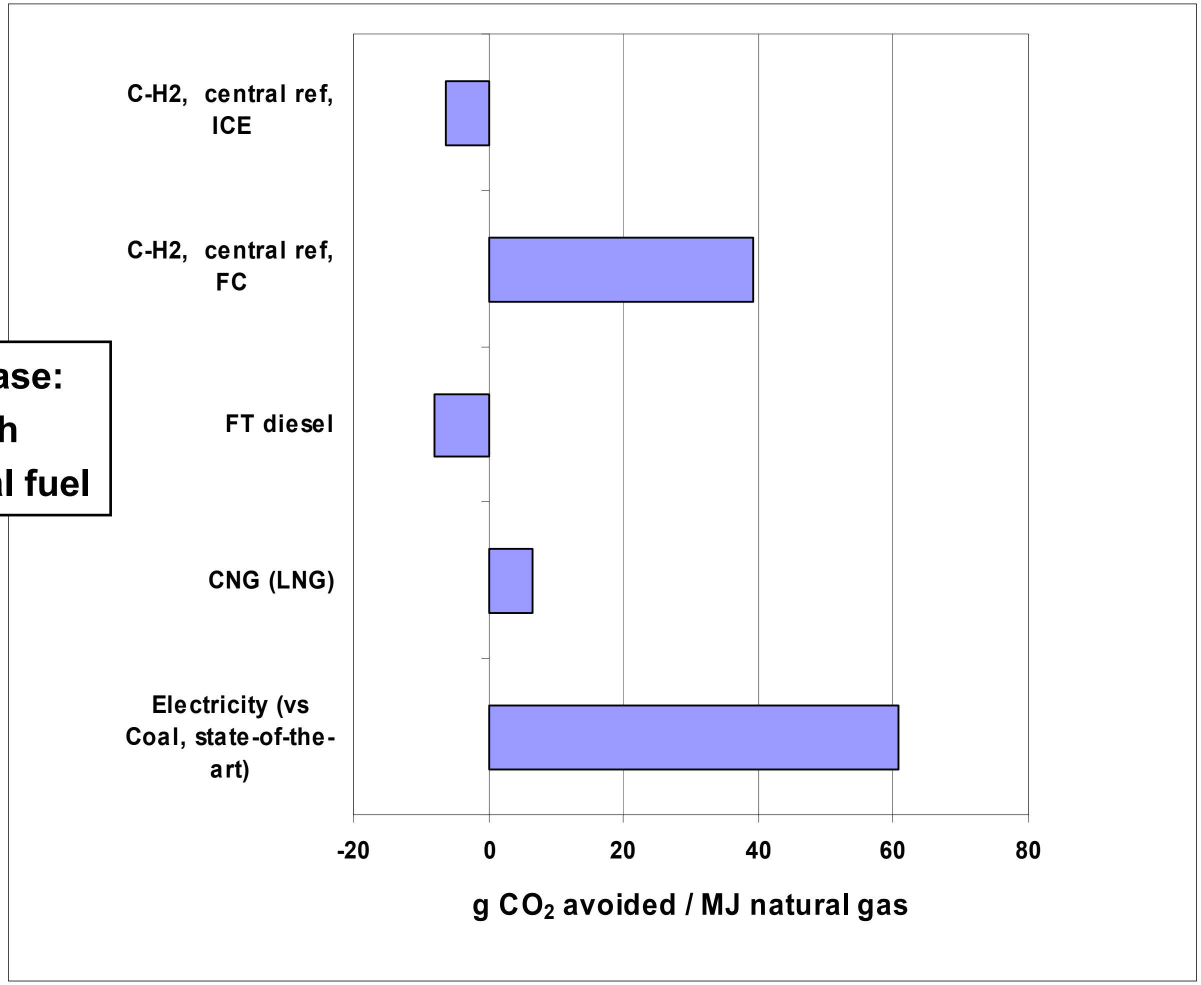
Potential for CO_2 avoidance from 1 ha of land



Reference case:
2010 ICE with
Conventional fuel

Alternative use of primary energy resources – Natural gas

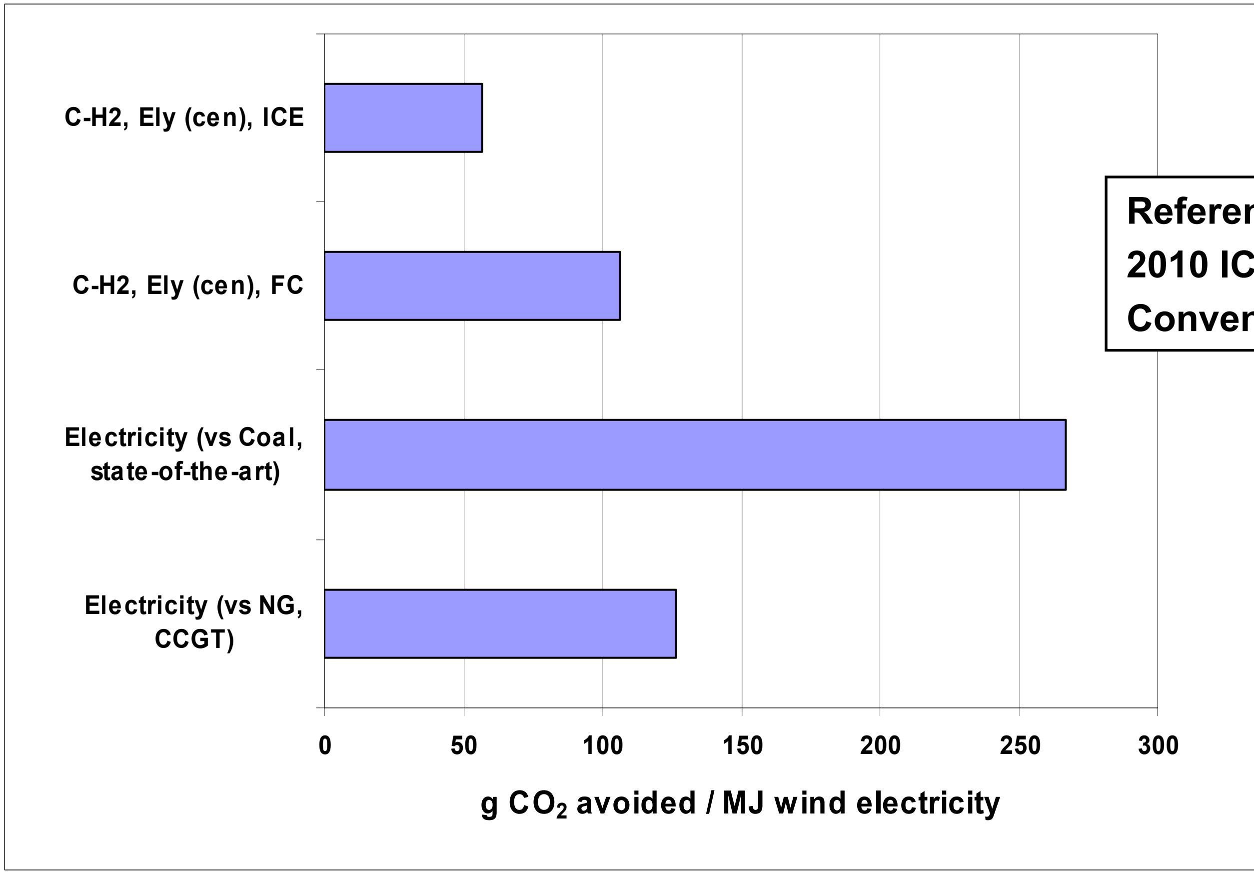
Potential for CO_2 avoidance from 1 MJ extracted gas



Reference case: 2010 ICE with Conventional fuel

Alternative use of primary energy resources - Wind

Potential for CO_2 avoidance from 1 MJ wind electricity



Reference case: 2010 ICE with Conventional fuel

Conclusions

- A shift to renewable/low fossil carbon routes may offers a significant GHG reduction potential but generally requires more energy. The specific pathway is critical
- *No single fuel pathway offers a short term route to high volumes of "low carbon" fuel.*
  - *Contributions from a number of technologies/routes will be needed.*
  - *A wider variety of fuels may be expected in the market*
  - *Blends with conventional fuels and niche applications should be considered if they can produce significant GHG reductions at reasonable cost*
- *Transport applications may not maximize the GHG reduction potential of renewable energies*
- *Optimum use of renewable energy sources such as biomass and wind requires consideration of the overall energy demand including stationary applications*

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The study report is available on the WEB:

http://ies.jrc.cec.eu.int/Download/eh

For questions / inquiries / requests / notes

to the consortium,

please use the centralised mail address:

infoWTW@jrc.it