5th JCAP conference

Tokyo, February 2007

Life cycle (“Well-to-Wheels”) assessment of alternative fuels and powertrains in the European context

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Content

- A short introduction to CONCAWE
- The Joint European “Well-to-Wheels” study
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- Major pathways: Energy and GHG balance
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  - Future biofuels
  - Hydrogen
- Cost of CO_2 avoidance
- Potential volumes
- Optimum use of land resources
- Biofuels implementation issues in Europe

The Oil Companies' European association for health, safety and environment in refining and distribution

- Non-profit, European association founded in 1963, capable of carrying out quality research on environmental, health and safety issues related to the downstream oil industry
- Currently 31 member companies representing about 97% of refining capacity in EU-25
- Main areas of activity
  - Automotive Emissions and Fuels Quality
  - Air Quality
  - Water/Soil Quality and Waste
  - Oil Pipelines
  - Safety
  - Refinery technology and infrastructure
  - Health Science
  - Petroleum Products
  - Risk Assessment
  - Implementation of REACH & GHS
- Secretariat based in Brussels
- More details at www.concawe.org

The JEC WTW Study: Background and Objectives

- Joint study between CONCAWE and

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

EUCAR
EUROPEAN COUNCIL FOR AUTOMOTIVE R&D

- Version 1 in December 2003, version 2 in Mai 2006
- Objectives
  - Well-to-wheels energy use and GHG emissions assessment
    - Wide range of automotive fuels and powertrains
    - Relevant to Europe in 2010 and beyond.
  - Consider the viability of each fuel pathway
  - Estimate the associated macro-economic costs.
  - Have the outcome accepted as a reference by all relevant stakeholders.

    ⇨ Focus on 2010-2015

The report is available on-line at: http://ies.jrc.cec.eu/WTW

The JEC WTW Study: Methodology

- Two main principles
- **Marginal impact**
  - Starting from the "Business-as-usual" scenario, consider "marginal" impact of introduction of alternative fuels
- **Allocation** of energy consumption and GHG emissions **based on** realistic **substitution** scenarios
  - All consumptions allocated to alternative fuel being produced
  - Estimation of a debit or credit for each co-product according to their assumed fate

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Well-to-Wheels Pathways

Resource

Crude oil

Coal

Natural Gas

Biomass

Wind

Nuclear

Inc. preliminary views on Carbon Capture and Sequestration

Fuels

Conventional Gasoline/Diesel/ Naphtha

Synthetic Diesel

CNG (inc. biogas)

LPG

MTBE/ETBE

Hydrogen (compressed / liquid)

Methanol

DME

Ethanol

Bio-diesel (inc. FAEE)

Powertrains

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

Compression Ignition:
Diesel, DME, Bio-diesel

Fuel Cell

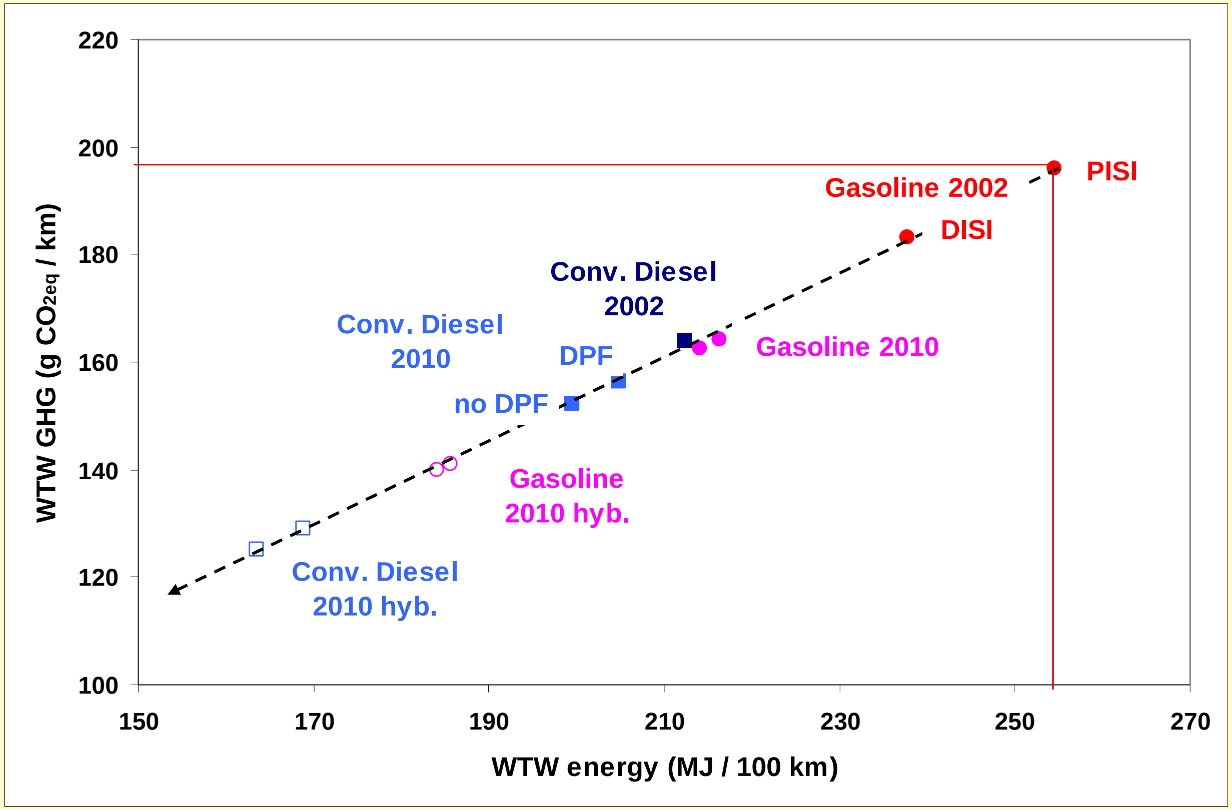
Hybrids: *SI, CI*, FC

Hybrid Fuel Cell + Reformer

Vehicle Assumptions

- Simulation of GHG emissions and energy use calculated for a model vehicle using the ADVISOR freeware
  - Representing the European C-segment (4-seater Sedan)
  - Not fully representative of EU average fleet
  - New European Driving Cycle (NEDC)
- For each fuel, the vehicle platform was adapted to meet minimum performance criteria
  - Speed, acceleration, gradeability etc
  - Criteria reflect European customer expectations
- Compliance with Euro 3/4 was ensured for the 2002 / 2010 case
- Heavy duty vehicles (truck and buses) not considered in this study

The potential of conventional fuels and powertrains



- Continued developments in engine and vehicle technologies will reduce energy use and GHG emissions
  - Spark ignition engines have more potential for improvement than diesel
  - Hybridization can provide further GHG and energy use benefits

CNG and CBG (Biogas)

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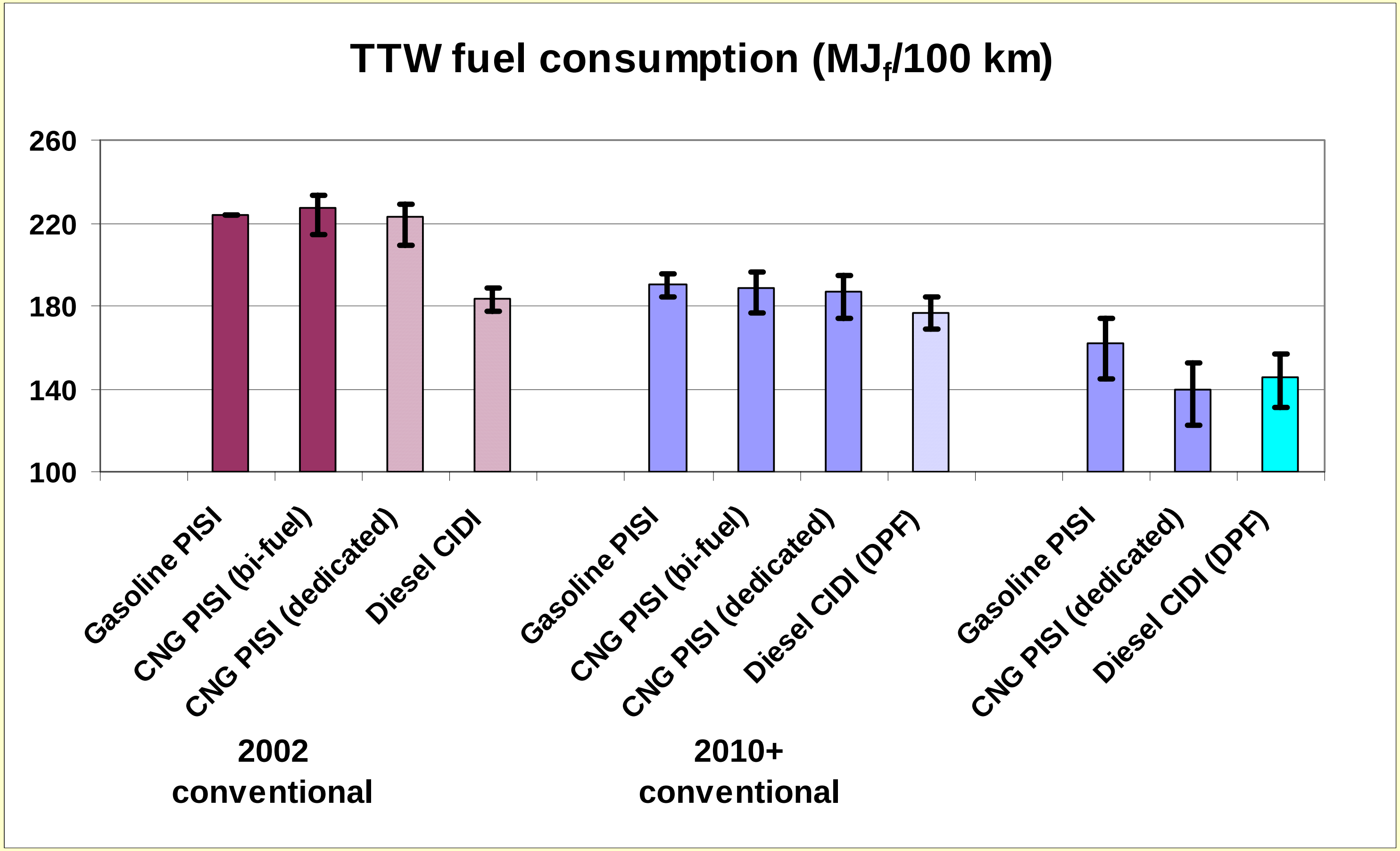
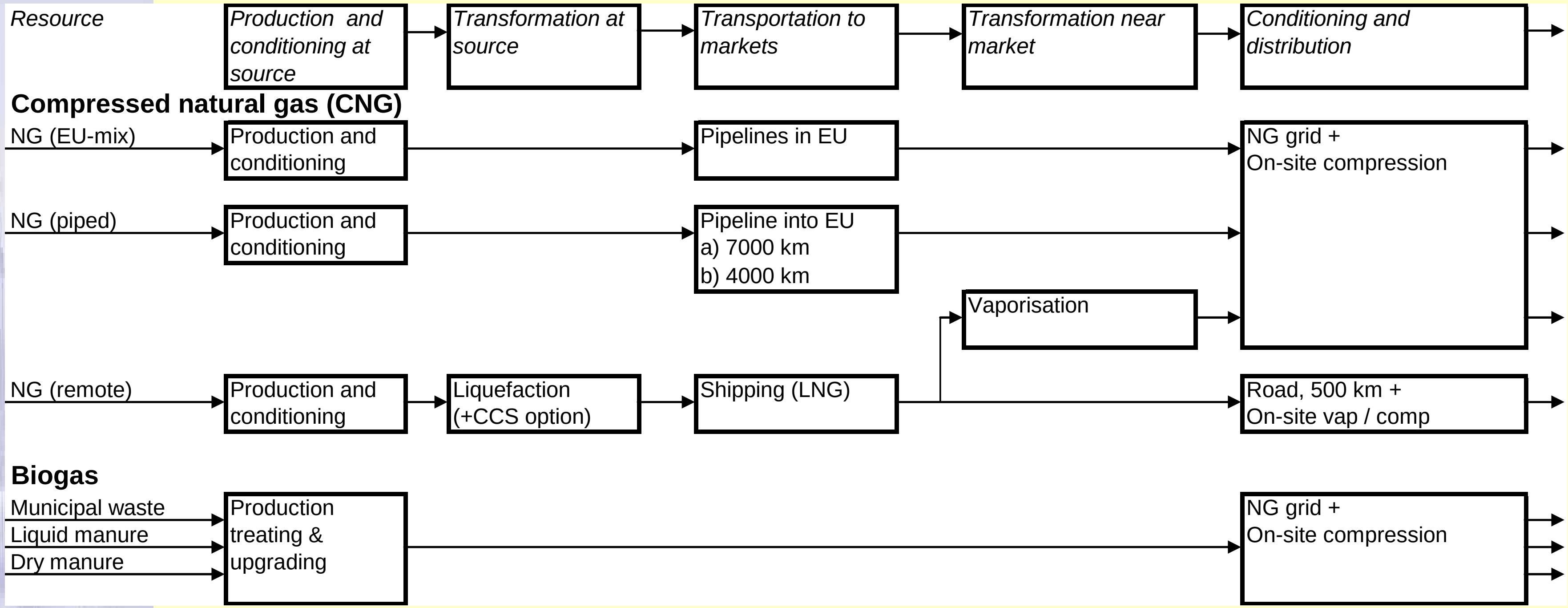
CNG v. liquid fuel engines



- CNG engines are currently slightly less efficient than gasoline engines
- In the future, the improvements on spark ignition engines will bring CNG close to diesel
- Hybridisation is particularly favourable for CNG

CNG & CBG: WTT pathways



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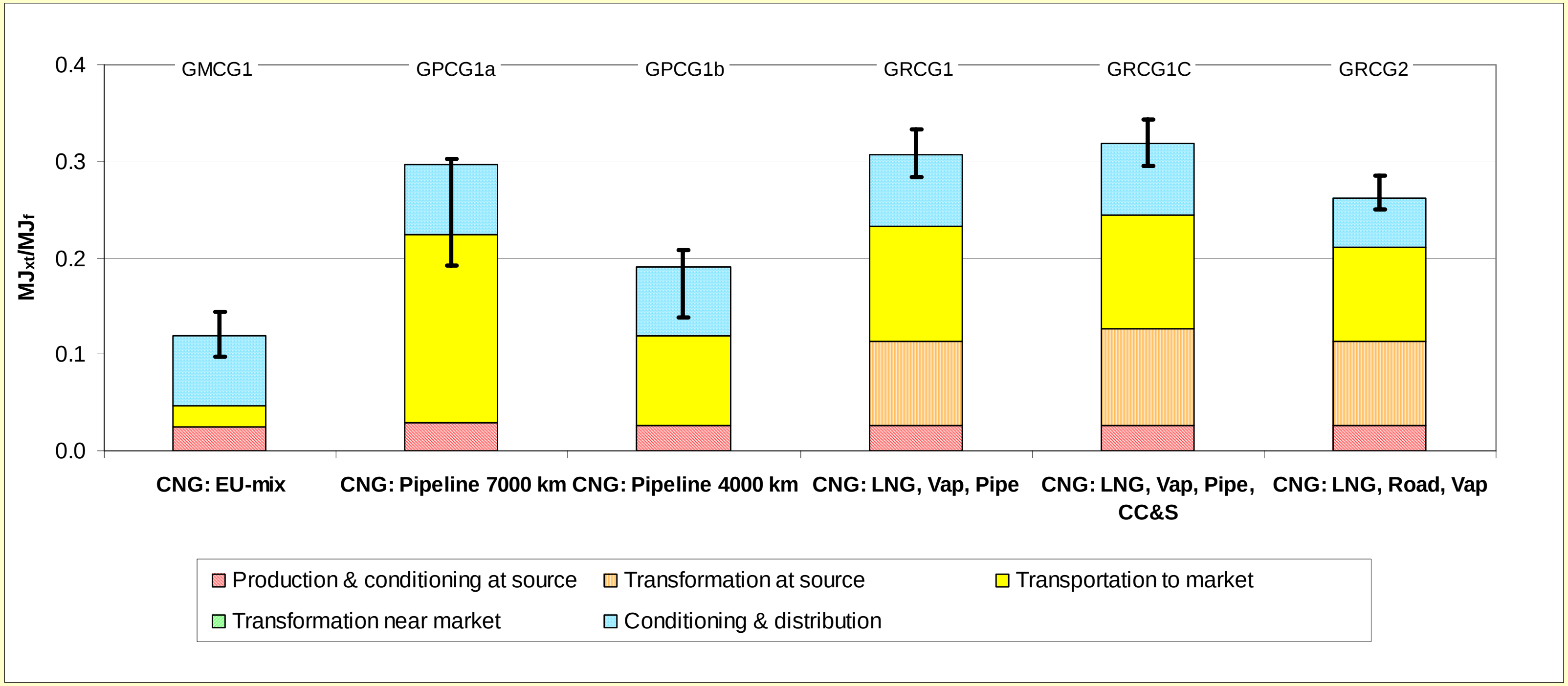
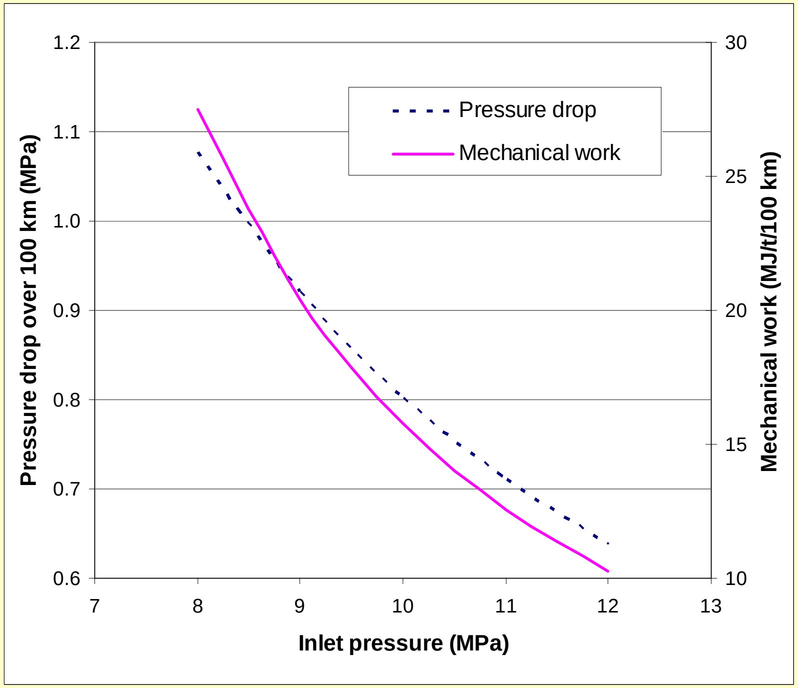
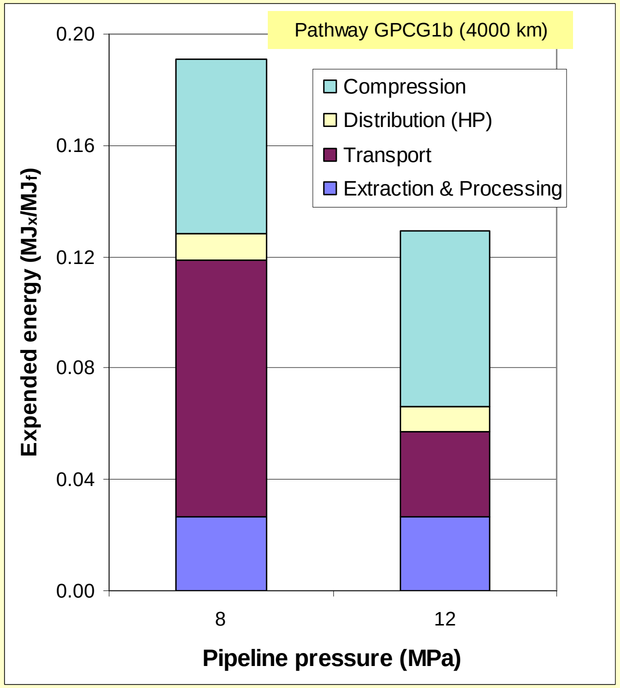
CNG: WTT energy



- The origin of the natural gas and the supply pathway are critical to the overall WTW energy use (and GHG emissions)
  - Longer supply routes become more prevalent in the future

CNG: impact of transport pressure





- Energy to transport NG through pipeline may decrease because of higher pressure pipelines
  - Our base case assumes 8 MPa, error bars include 12 MPa case
  - Future new lines may operate at up to 15 MPa
  - Global impact will be limited because of existing infrastructure

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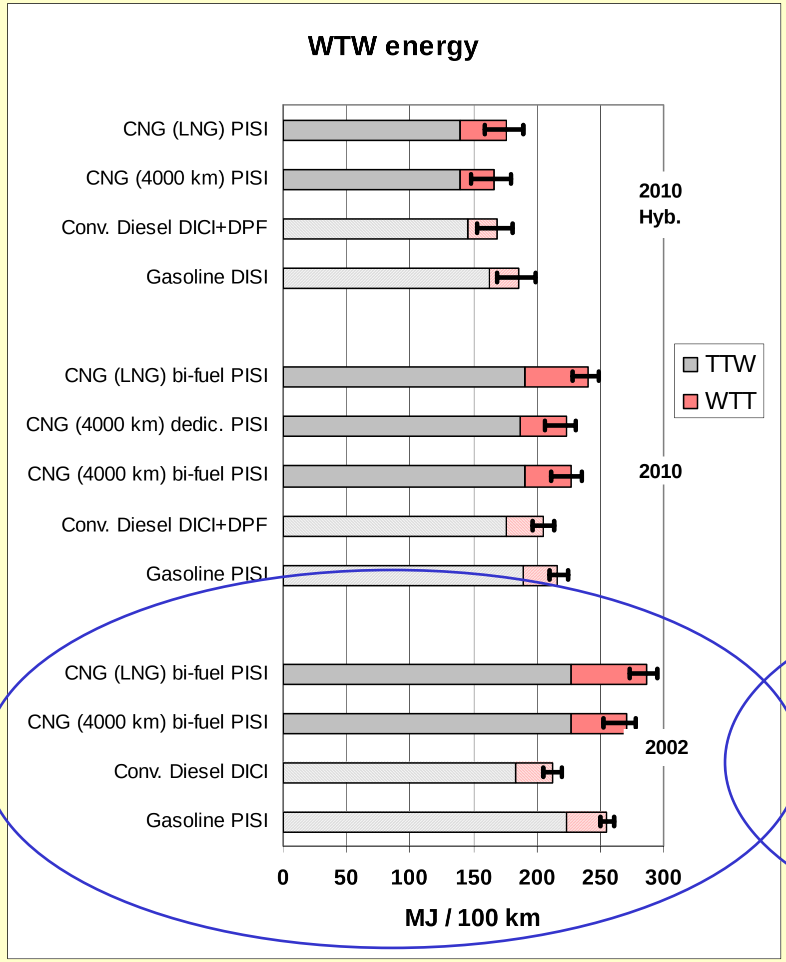
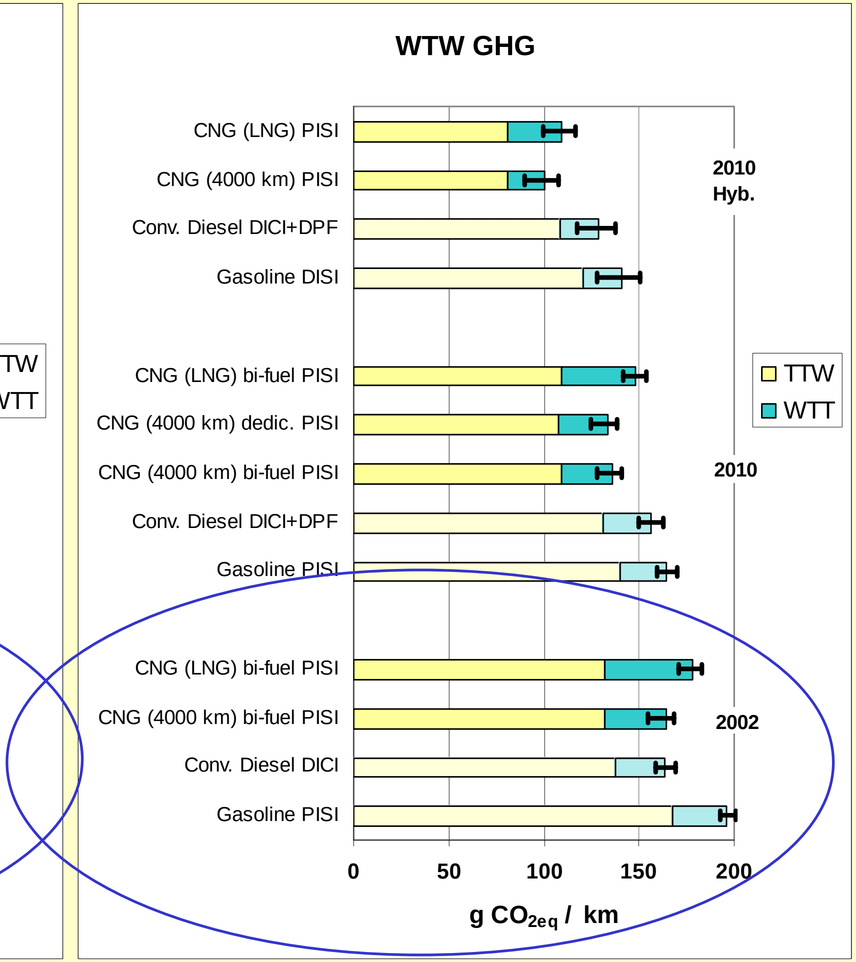
CNG: WTW Energy and GHG balance



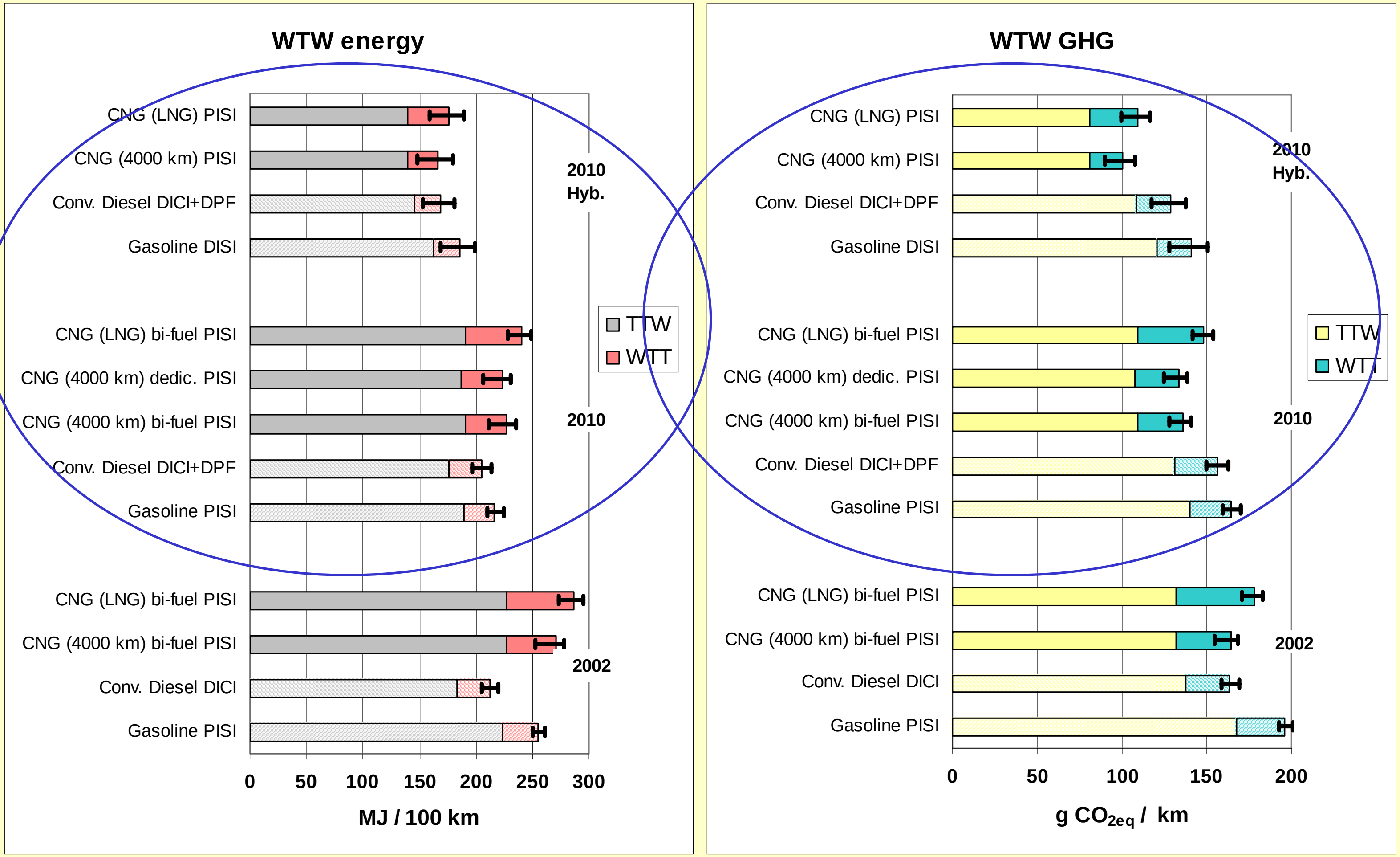


Today ⇨

- More energy than for conventional liquid fuels
- GHG between lower than gasoline, approaching diesel in the best case

CNG: WTW Energy and GHG balance

2010+ ⇨



- Greater engine efficiency gains predicted for CNG vehicles, especially noticeable with hybridization
  - WTW energy use remains higher than for conventional fuels except in the case of hybrids
  - WTW GHG emissions lower than those of diesel
  - Dedicated CNG vehicles perform only marginally better than bi-fuel vehicles

CNG: Summary

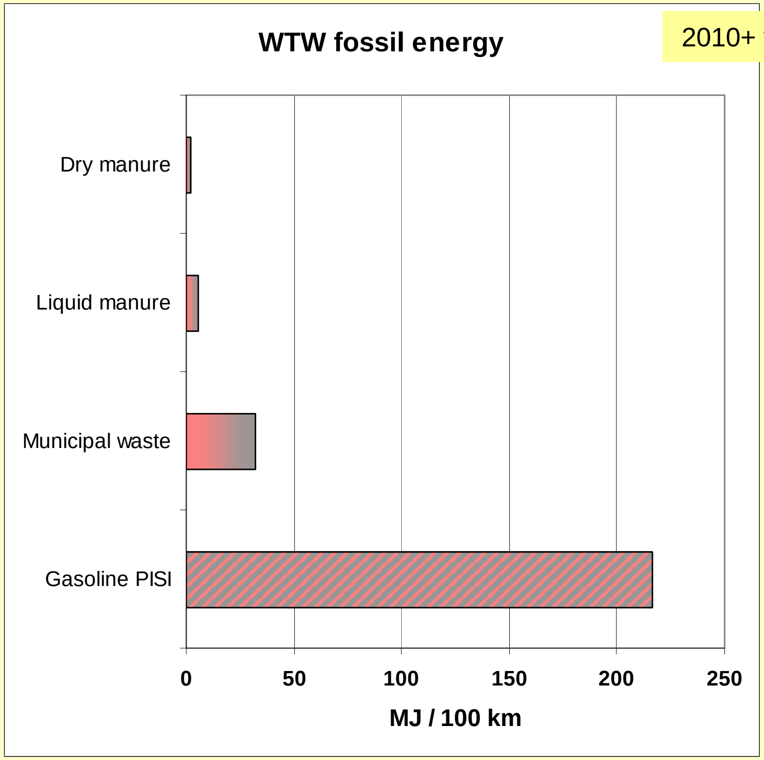
- Today the WTW GHG emissions for CNG lie between gasoline and diesel, approaching diesel in the best case

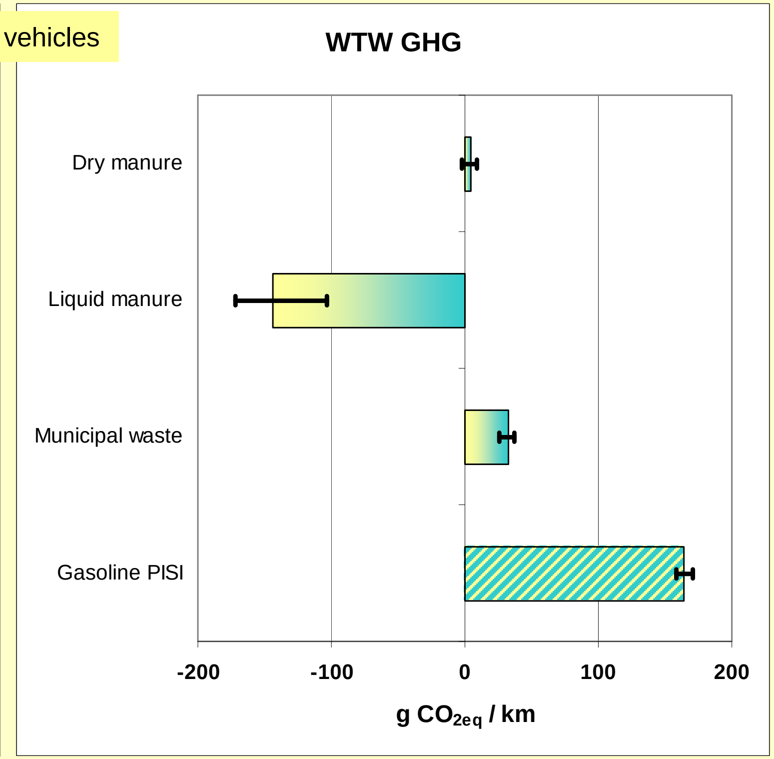
- Beyond 2010, greater engine efficiency gains are predicted for CNG vehicles, especially noticeable with hybridization
  - WTW GHG emissions become lower than those of diesel
  - WTW energy use remains higher than for conventional fuels except in the case of hybrids
  - Dedicated CNG vehicles perform only marginally better than bi-fuel vehicles

- The origin of the natural gas and the supply pathway are critical to the overall WTW energy use and GHG emissions
  - Longer supply routes become more prevalent in the future
  - Energy to transport NG through pipeline may decrease because of higher pressure pipelines

Compressed Biogas (CBG)

2010+ vehicles





- Biogas from waste has a favourable GHG balance
- Using wet manure in this way stops methane emissions to atmosphere, the result of intensive livestock rearing rather than an intrinsic quality of biogas
- Alternative use for electricity production also needs to be considered

Conventional Biofuels

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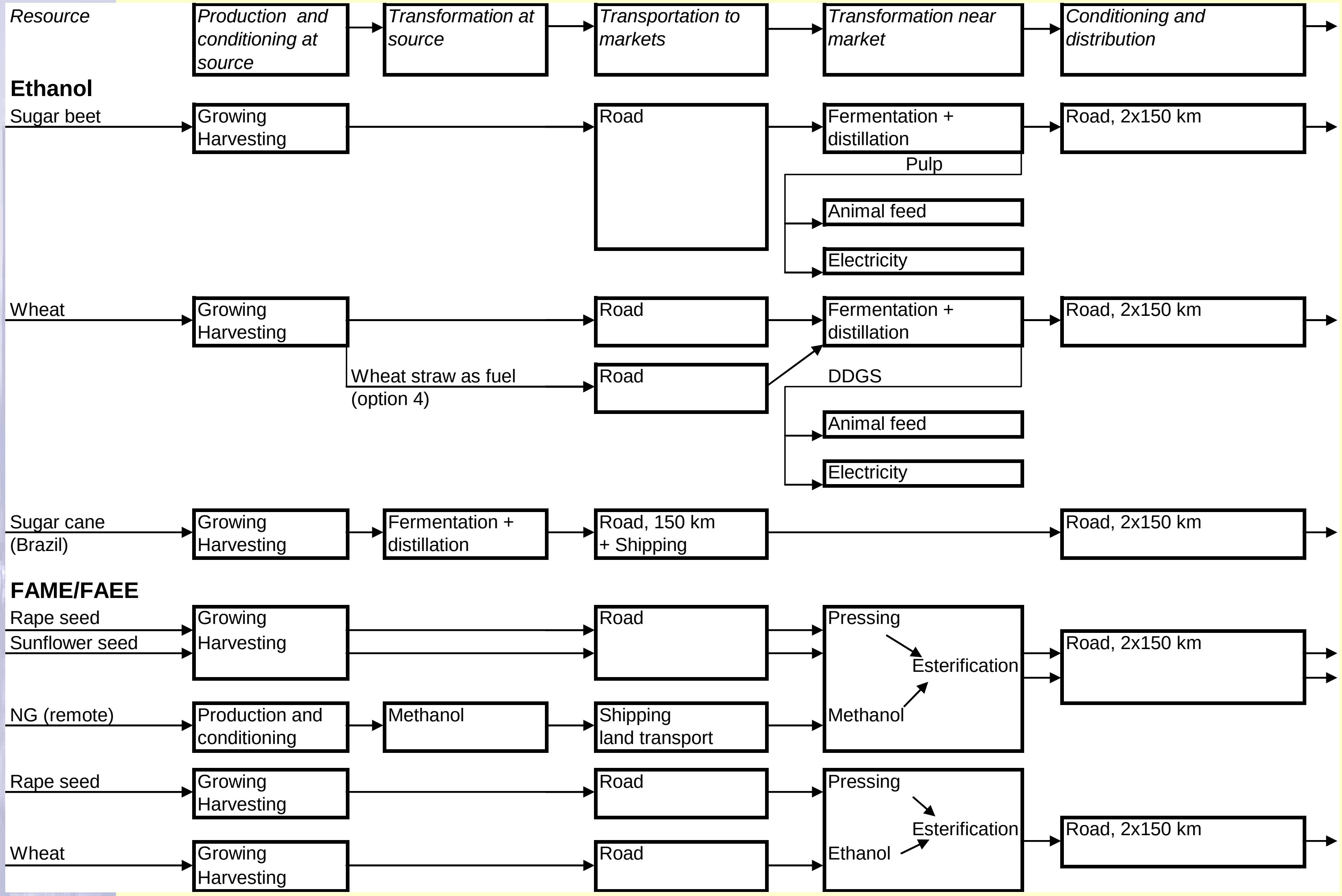
Conventional ethanol and bio-diesel pathways

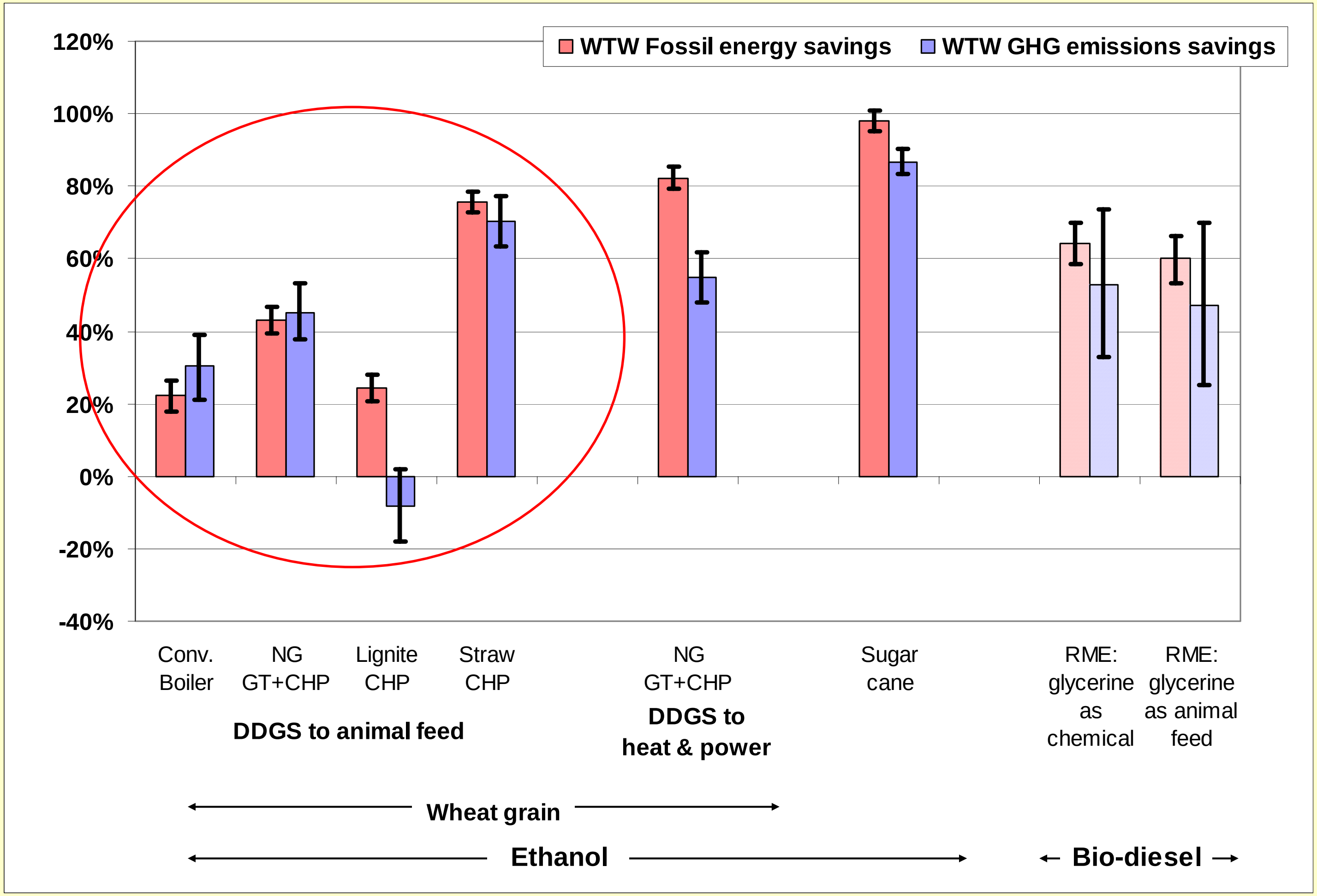


How much fossil energy and GHG do ethanol and bio-diesel save?

Answer: some, a lot or none at all

How much fossil energy and GHG do ethanol and bio-diesel save?

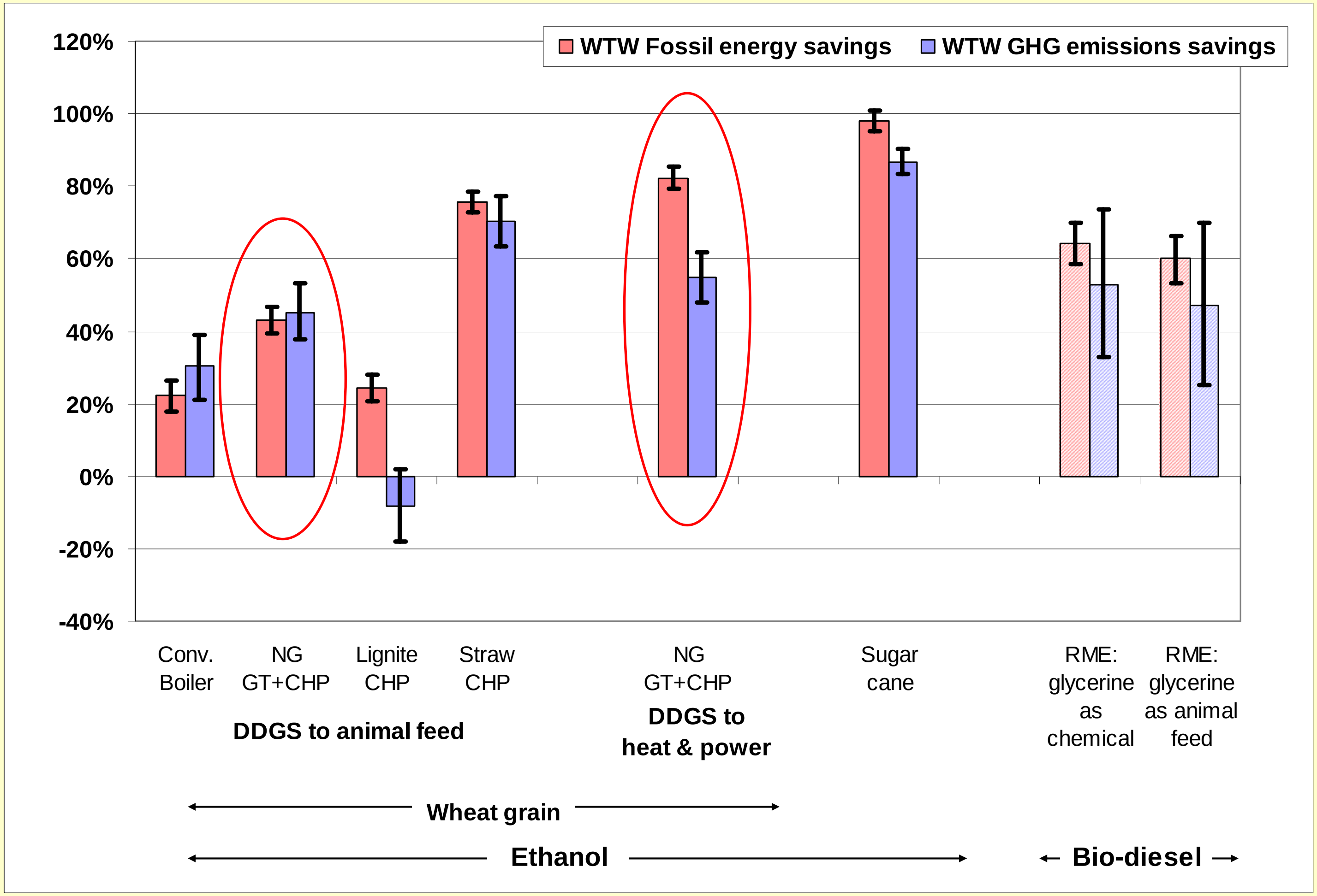
What energy is used and how?



- With the same feedstock and the same production process, the type of power plant and energy carrier used can make or break ethanol

How much fossil energy and GHG do ethanol and bio-diesel save?

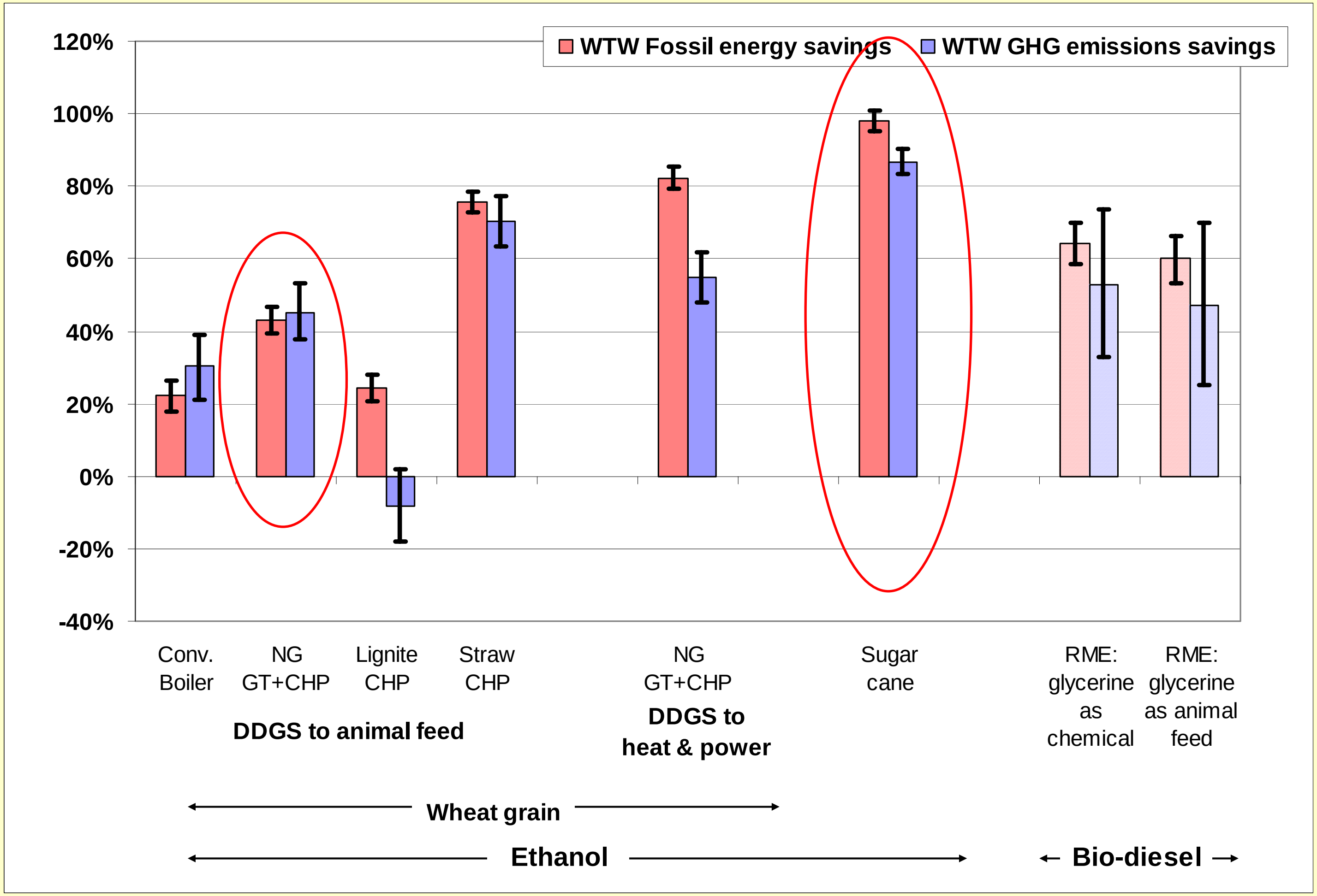
What happens to the by-products?



- Using by-products for energy gives of course more savings but is it likely to happen?

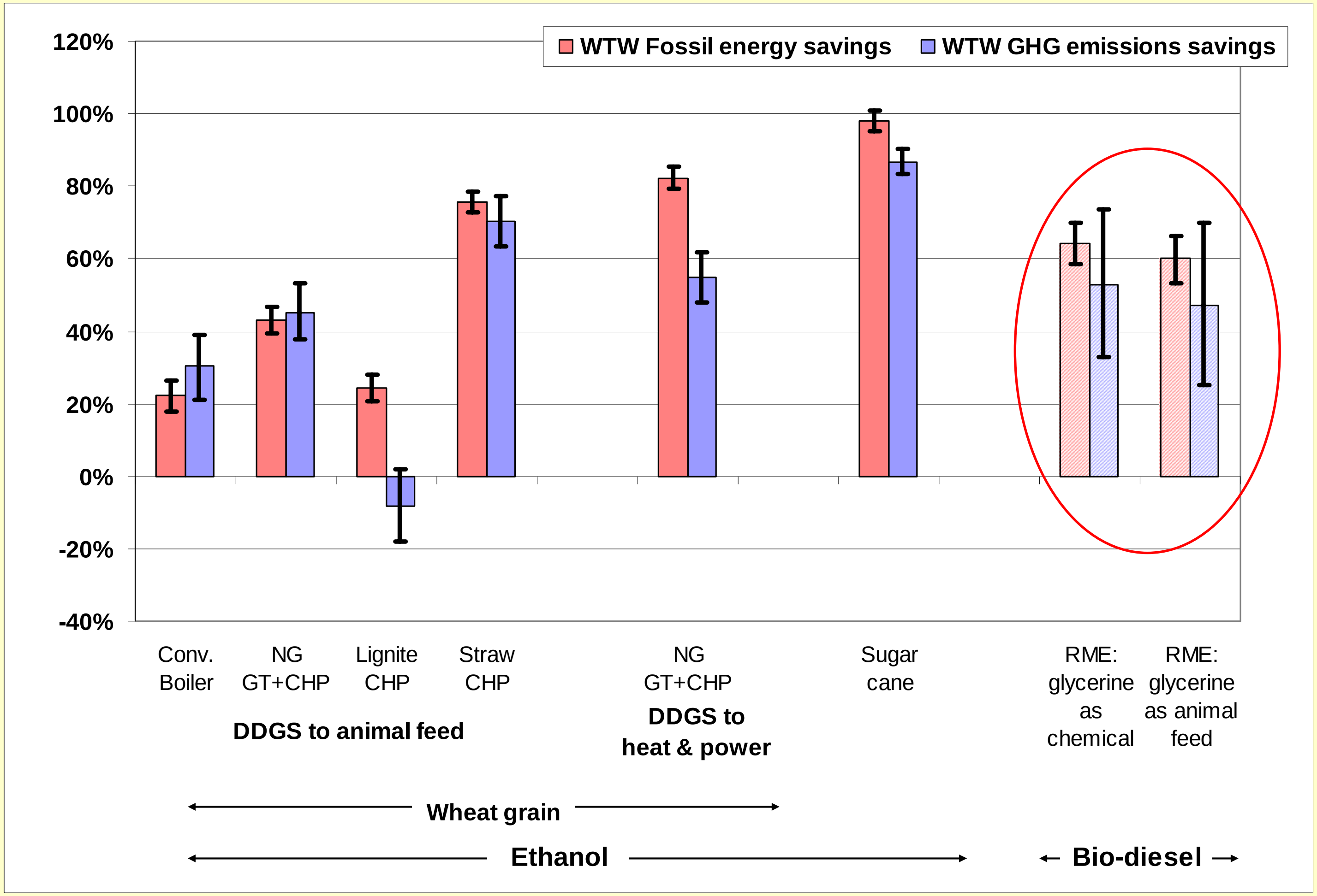
How much fossil energy and GHG do ethanol and bio-diesel save?

What is done elsewhere?



- Ethanol from sugar cane saves over twice as much fossil energy and GHG than the most likely EU pathway

How much fossil energy and GHG do ethanol and bio-diesel save?



- RME can deliver 50%GHG savings
  - The magnitude of N_2O emissions is a major issue (depends on soil type and framing practices)

Bio-fuels: fossil and total energy

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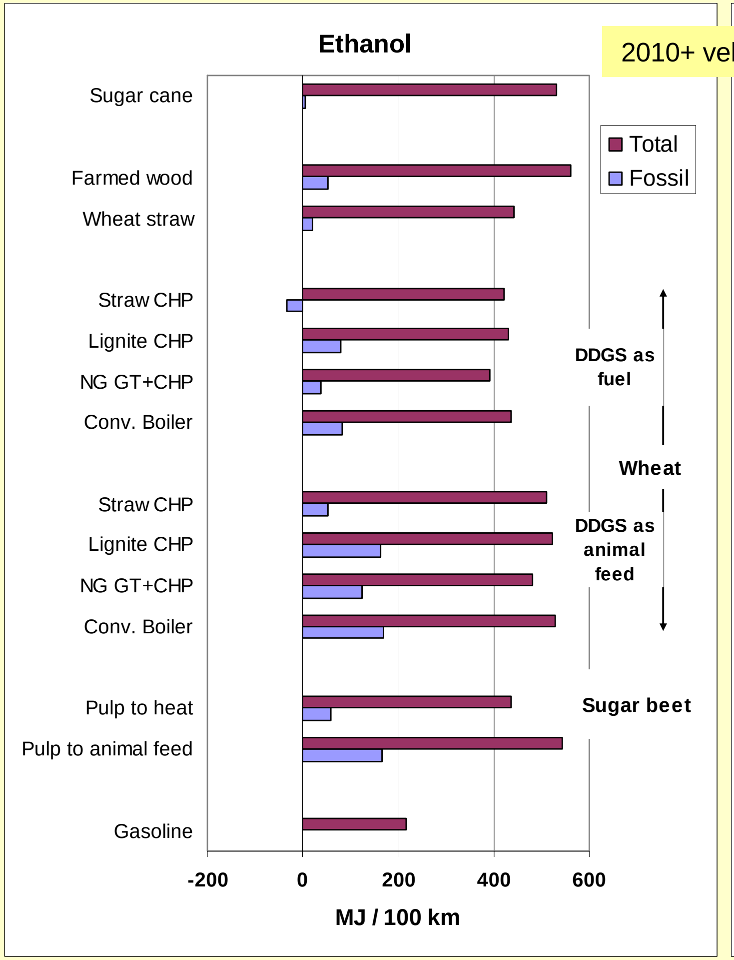

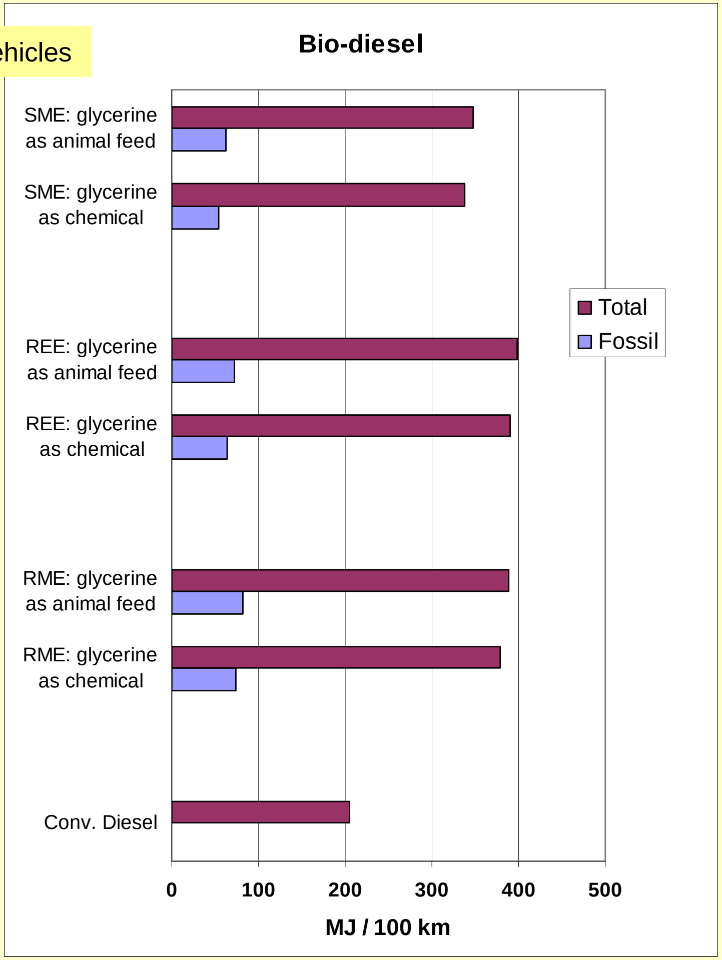

- The conversion of biomass into conventional bio-fuels is not energy-efficient
  - Ethanol and bio-diesel require more bio-energy than the fossil energy they save

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Conventional ethanol and bio-diesel: Summary

- Conventional production of ethanol as practiced in Europe gives modest fossil energy/GHG savings compared with gasoline
  - Existing European pathways can be improved by use of co-generation and/or use of by-products for heat
  - Choice of crop and field N_2O emissions play a critical part
- Ethanol production is energy-intensive:
  - The production process (o/a use of CHP) and the energy source are critical
  - Using (brown) coal could result in increased GHG emissions even with CHP!
  - Using straw as fuel would obviously yield the best GHG balance
- Use of by-products for energy yields lowest GHG emissions. Economics are likely to favour other uses, at least short term:
  - Sugar beet pulp
  - Wheat DDGS
- Sugar cane uses very little fossil energy (transport only)
- Bio-diesel saves fossil energy and GHG compared to conventional diesel
  - Field N_2O emissions play a big part in the GHG balance and are responsible for the large uncertainty
  - Use of glycerine has a relatively small impact
  - Sunflower is more favourable than rape
  - The fossil energy and GHG balance can be further improved if the seedcake can be used as an energy source

Ethanol from cellulose

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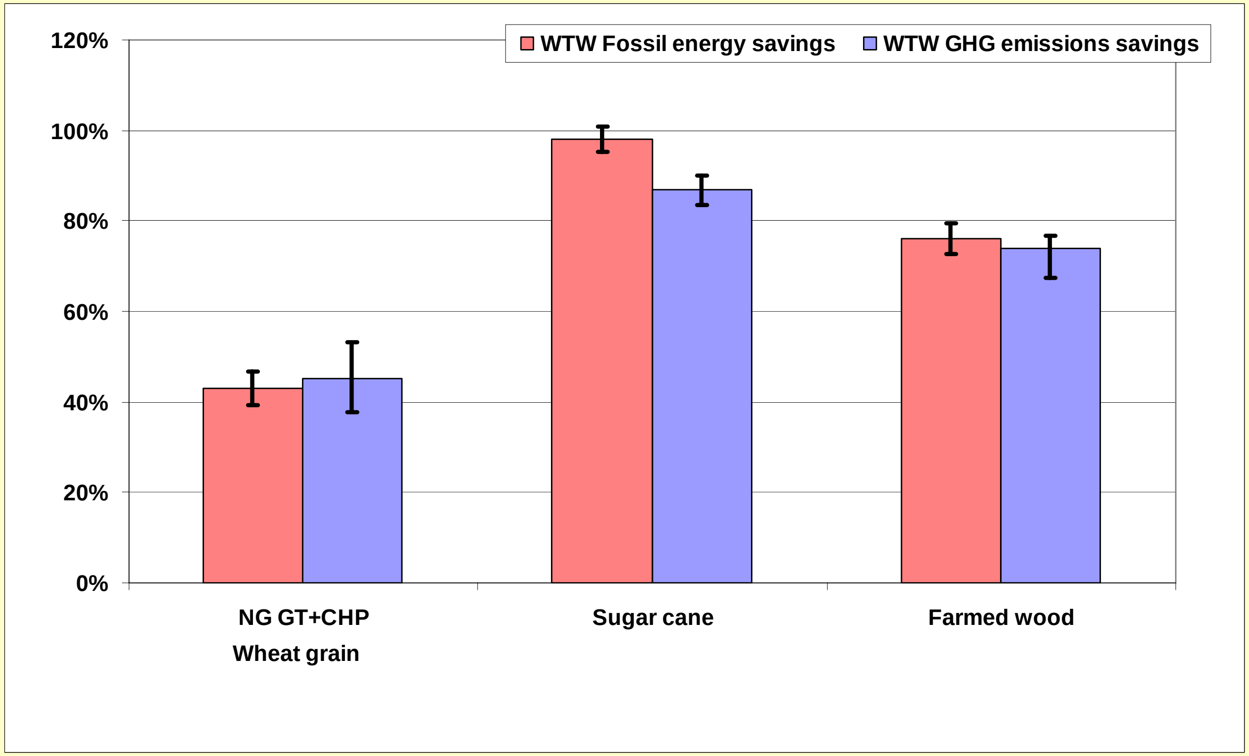
Cellulose to Ethanol pathways

Resource	*Production and conditioning at source*	*Transformation at source*	*Transportation to markets*	*Transformation near market*	*Conditioning and distribution*
Ethanol					
Wheat straw	Collection		Road	Hydrolysis + fermentation + dist.	Road, 2x150 km
Waste/Farmed wood	Collection		Road	Hydrolysis + fermentation + dist.	Road, 2x150 km

Ethanol from cellulose



- Cellulose-to-Ethanol processes will offer a practical way of using the whole plant
  - Higher fossil energy and GHG savings
  - Wider choice of crops
  - More ethanol per hectare
- The technology is still in development
  - Plants are relatively cheap and can re-use part of conventional ethanol plants
  - Availability and cost of enzymes is a major issue

Syn-diesel and DME

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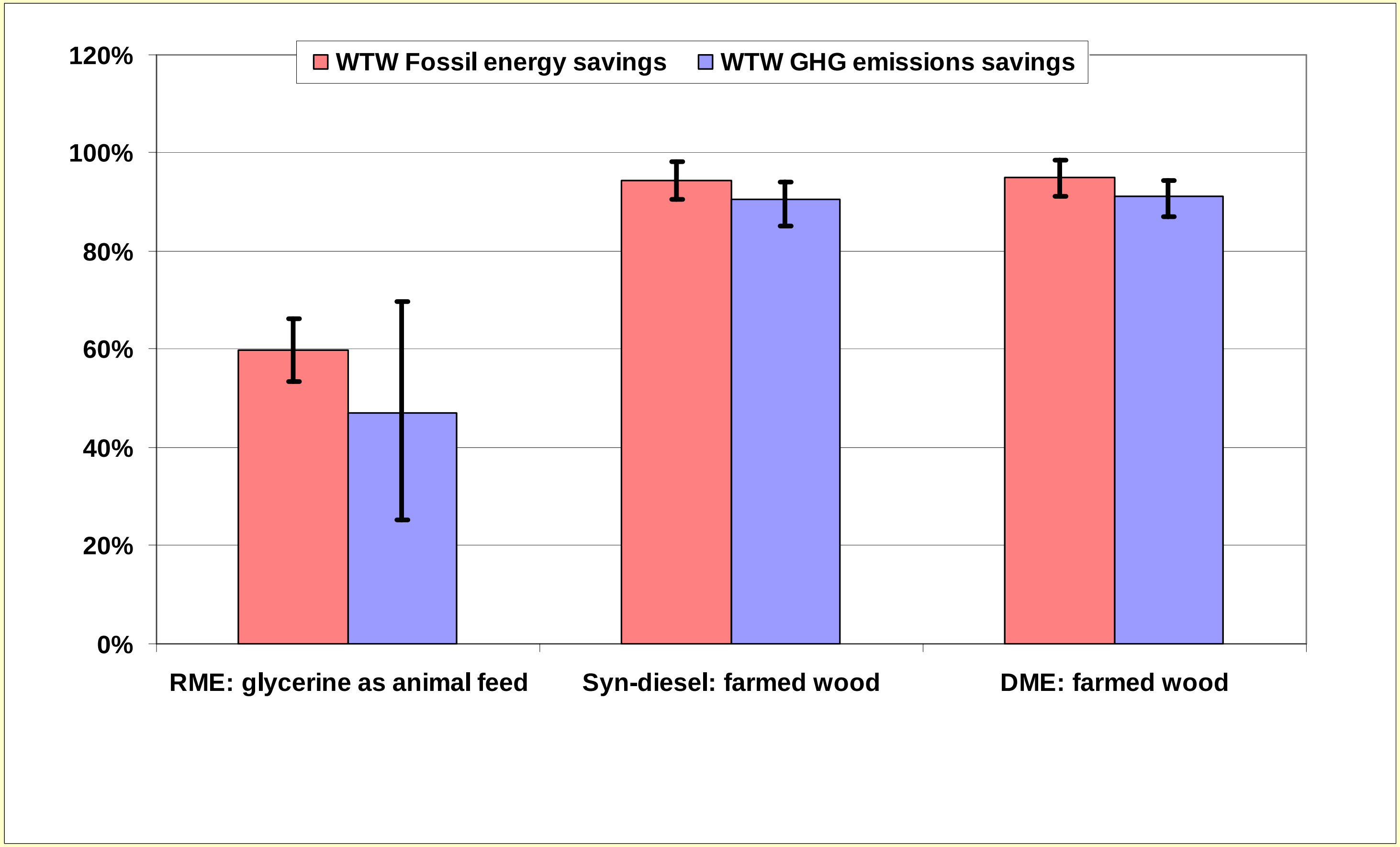
Syn-diesel and DME pathways

Resource	*Production and conditioning at source*	*Transformation at source*	*Transportation to markets*	*Transformation near market*	*Conditioning and distribution*
Syn diesel					
NG (piped)	Production and conditioning		Pipeline into EU	GTL plant	As for refinery fuels
NG (remote)	Production and conditioning	GTL plant (+CCS option)	Shipping		As for refinery fuels or Mixed land transport, 500 km
Coal	Production and conditioning		Shipping	CTL plant (+CCS option)	As for refinery fuels
Waste wood	Collection		Road, 50 km + Shipping (800 km)	200 MW gasifier FT plant	
Methanol / DME					
Coal (EU mix)	Production and conditioning		Shipping	Gasification MeOH/DME synthesis	Mixed land transport 500 km
NG (piped)	Production and conditioning		Pipeline into EU	Methanol/DME synthesis	Mixed land transport 500 km
NG (remote)	Production and conditioning	Methanol/DME syn (+CCS option)	Shipping		Mixed land transport 500 km
Waste wood	Collection		Road, 50 km + Shipping	200 MW gasifier methanol/DME synthesis	Road, 150 km
Waste/Farmed wood	Growing Harvesting		Road	(200 MW gasifier methanol/DME synthesis)	(Road, 150 km)
Waste wood via Black liquor	Collection		Road	BL gasifier + MeOH/DME syntesis Wate wood boiler	Road, 150 km

Biomass to Syn-diesel and DME: Energy and GHG balance



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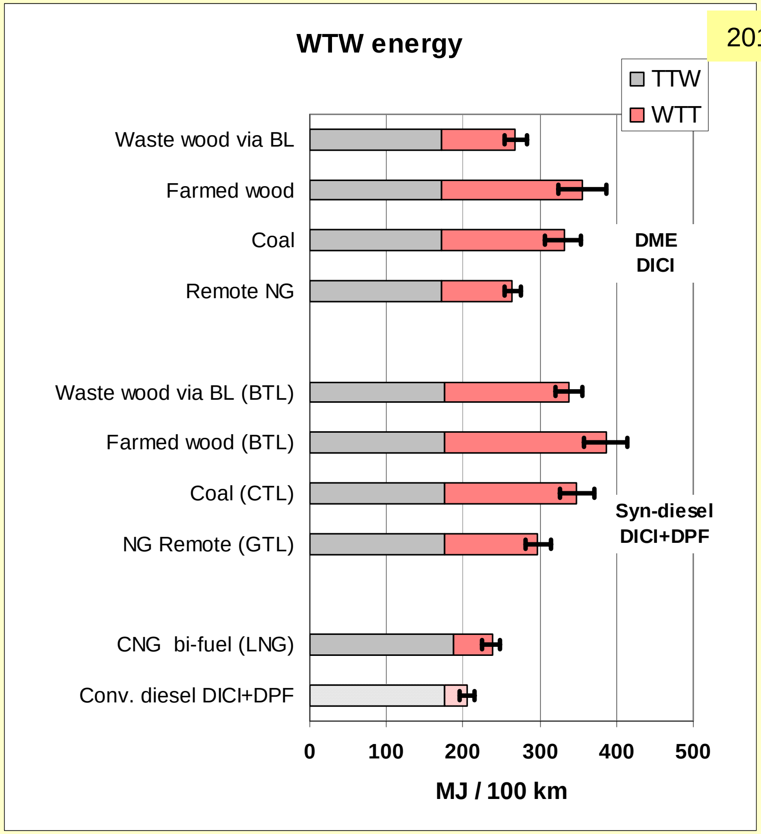
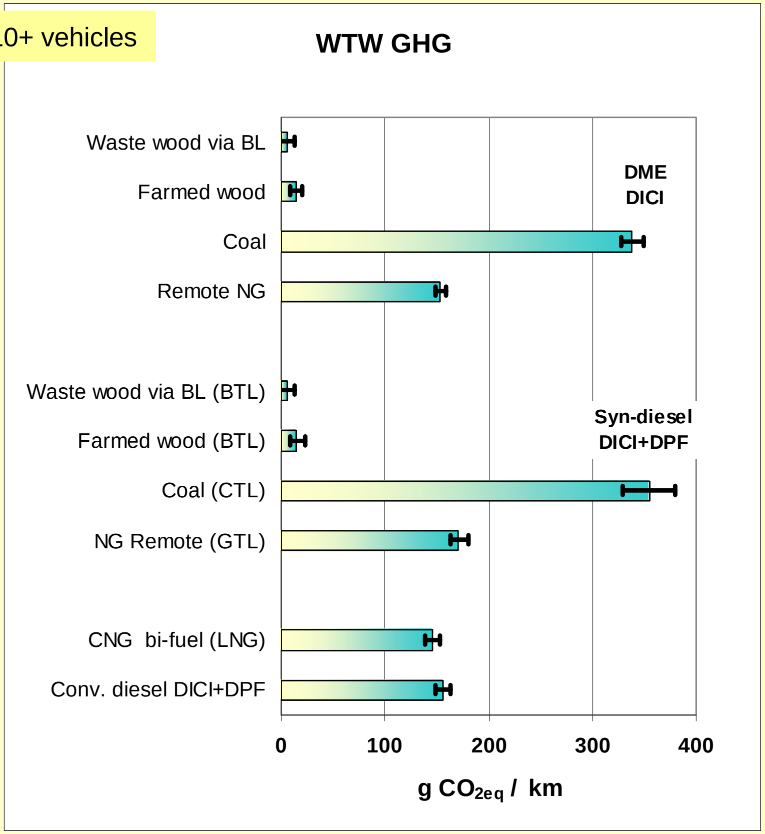
Syn-diesel and DME from fossil and biomass sources: Total energy and GHG balance

2010+ vehicles





Synthetic diesel and DME from fossil sources

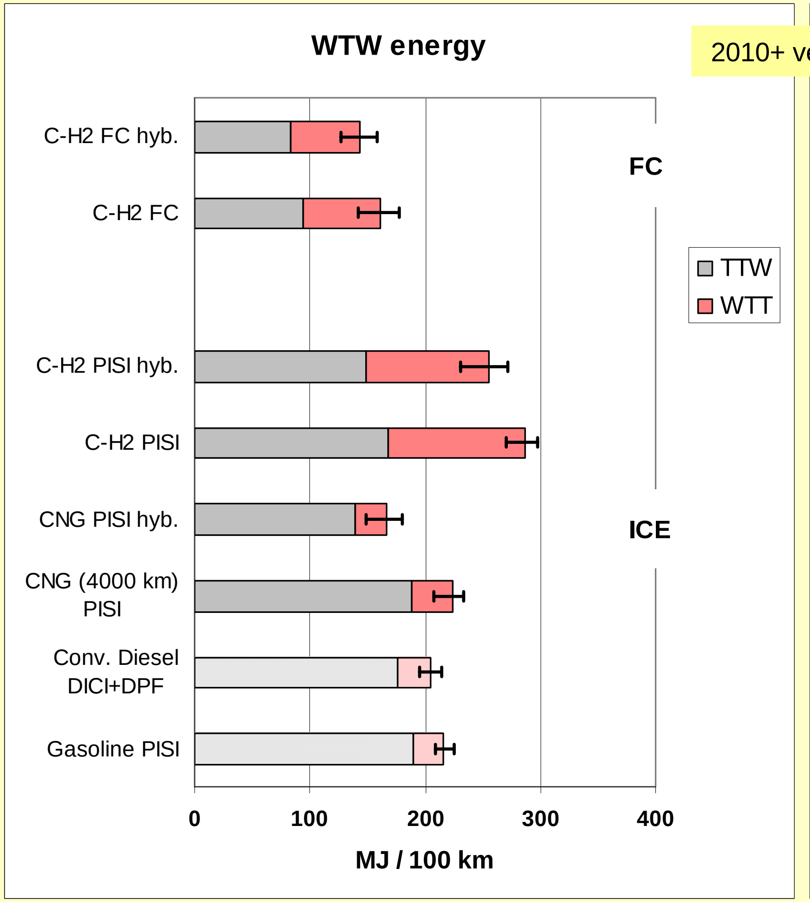
- Diesel synthesis requires more energy than conventional diesel refining from crude oil
- GHG emissions from syn-diesel from NG (GTL) are slightly higher than those of conventional diesel, syn-diesel from coal (CTL) produces considerably more GHG
- CNG from LNG is more energy and GHG efficient than GTL diesel or DME from remote gas

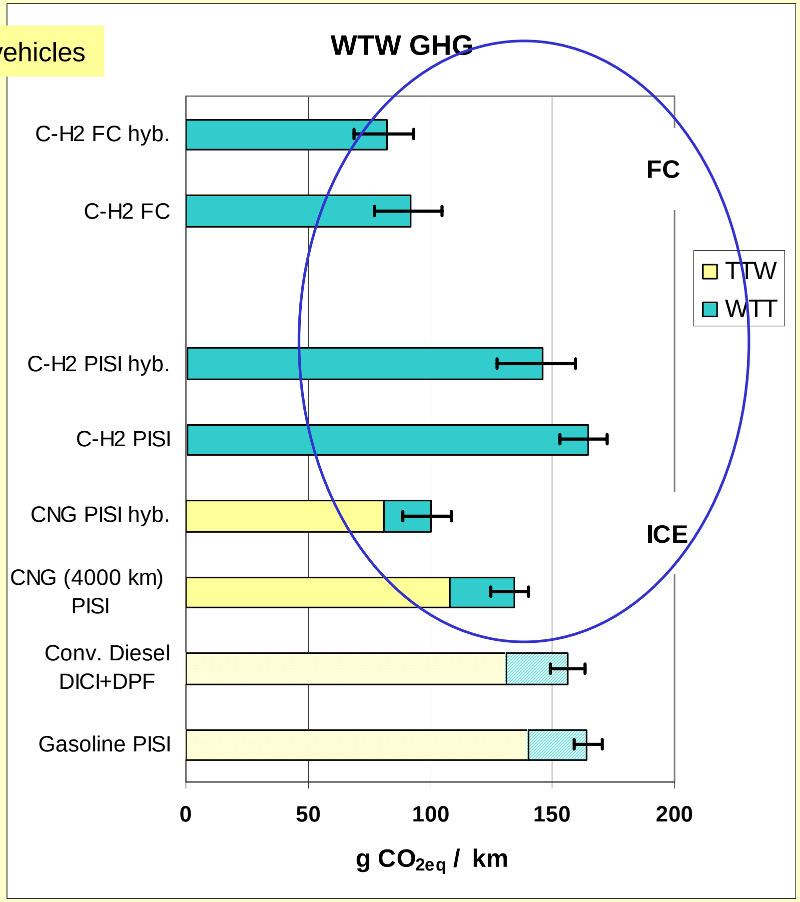
Biomass to Syn-diesel and DME: Main issues

- The BTL (or DME) route offers high renewability
  - It uses bio-energy to fuel the conversion process
  - It is, however, not energy-efficient
- DME can be produced at somewhat lower energy use and GHG emissions than syn-diesel
  - Use of DME as automotive fuel would require modified vehicles and infrastructure similar to LPG
- A wide range of biomass sources can potentially be used
  - How flexible a given plant could be remains to be seen in view of specific problems related to different types of biomass
- BTL plants will be sophisticated and costly
  - Scale will be an issue: compromise between cost and feasibility of feedstock transportation and economies of scale in the processing plant
  - The "black liquor" route offers higher wood conversion efficiency although the scope for practical applications will be determined by the specific circumstances of the pulp and paper industry

Hydrogen

Hydrogen from NG : ICE and Fuel Cell





- If hydrogen is produced from NG, GHG emissions savings are only achieved with fuel cell vehicles

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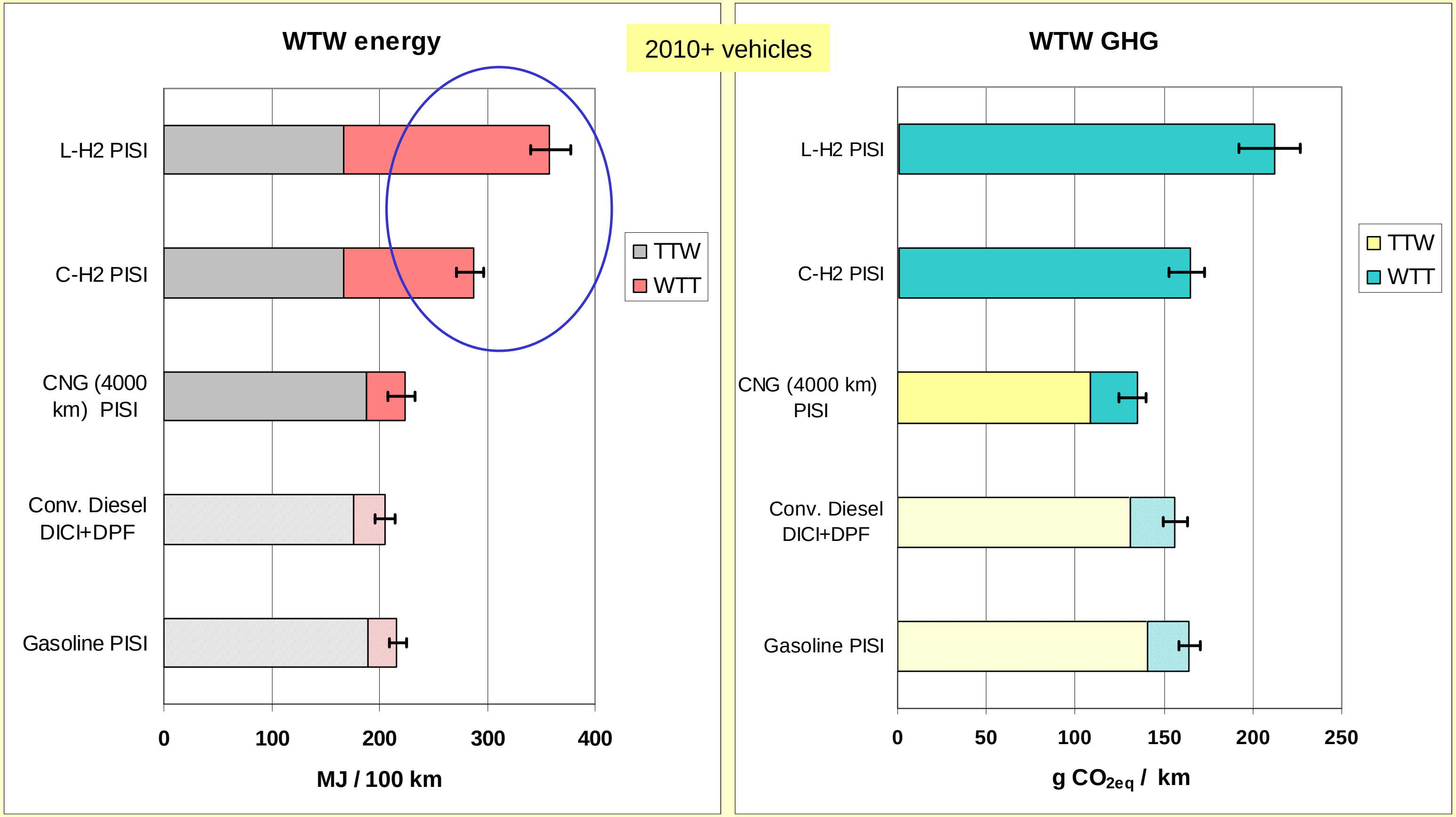
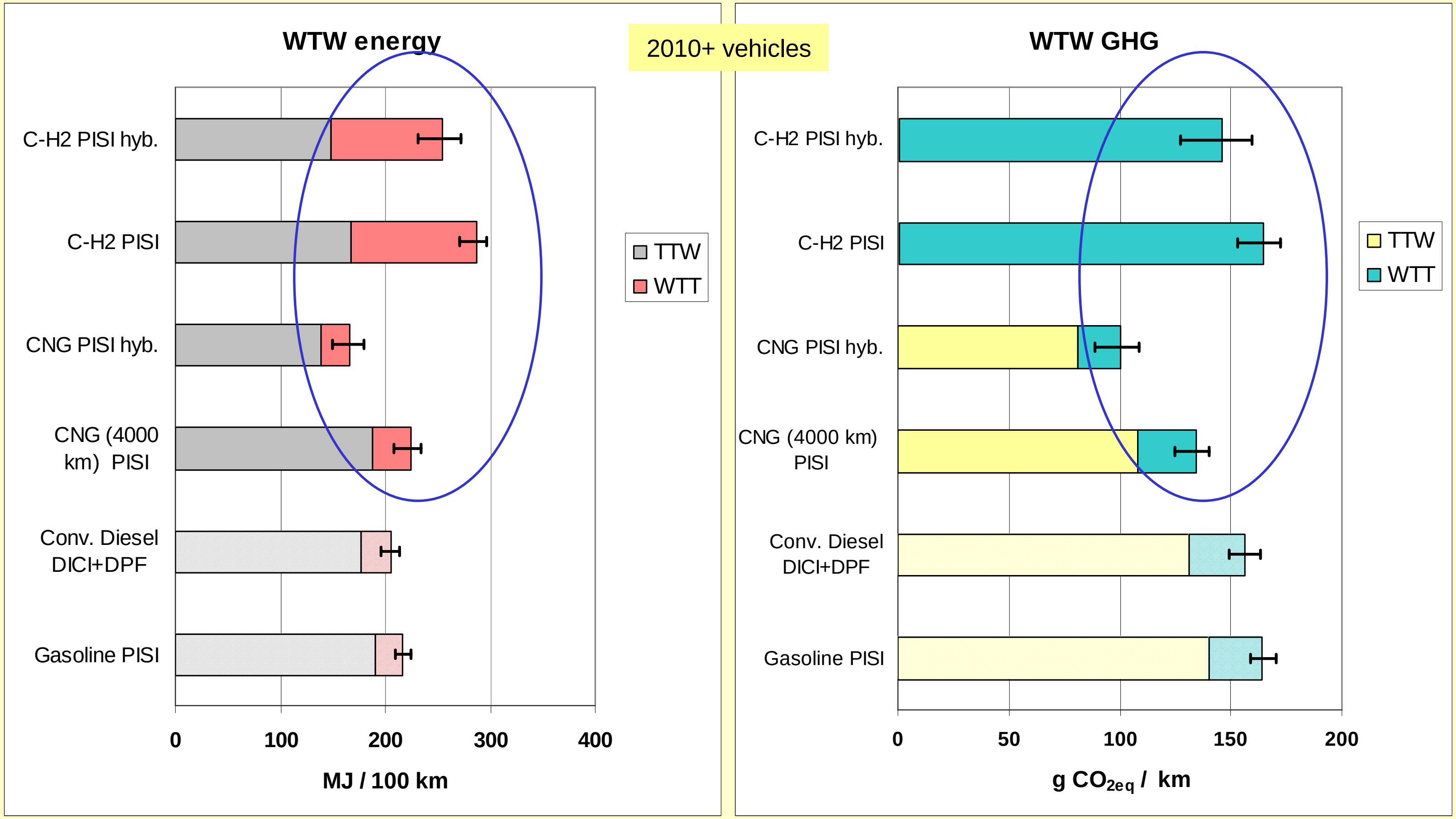
Hydrogen from NG : Compressed v. Liquid



- Liquid hydrogen is less energy efficient than compressed hydrogen

Hydrogen from NG : hydrogen v. CNG ICE

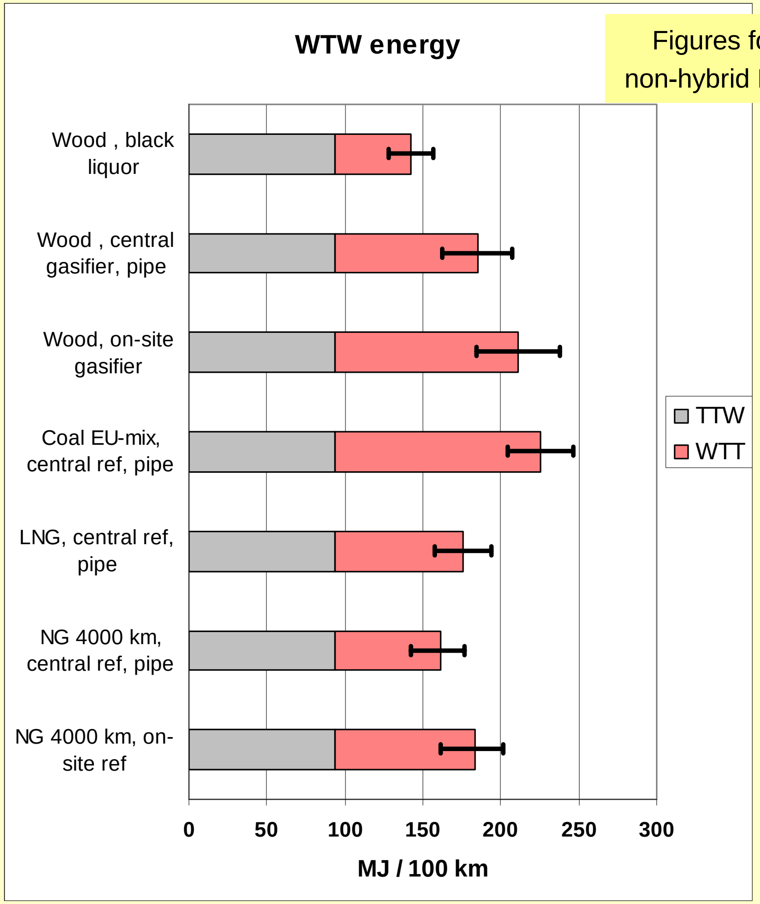


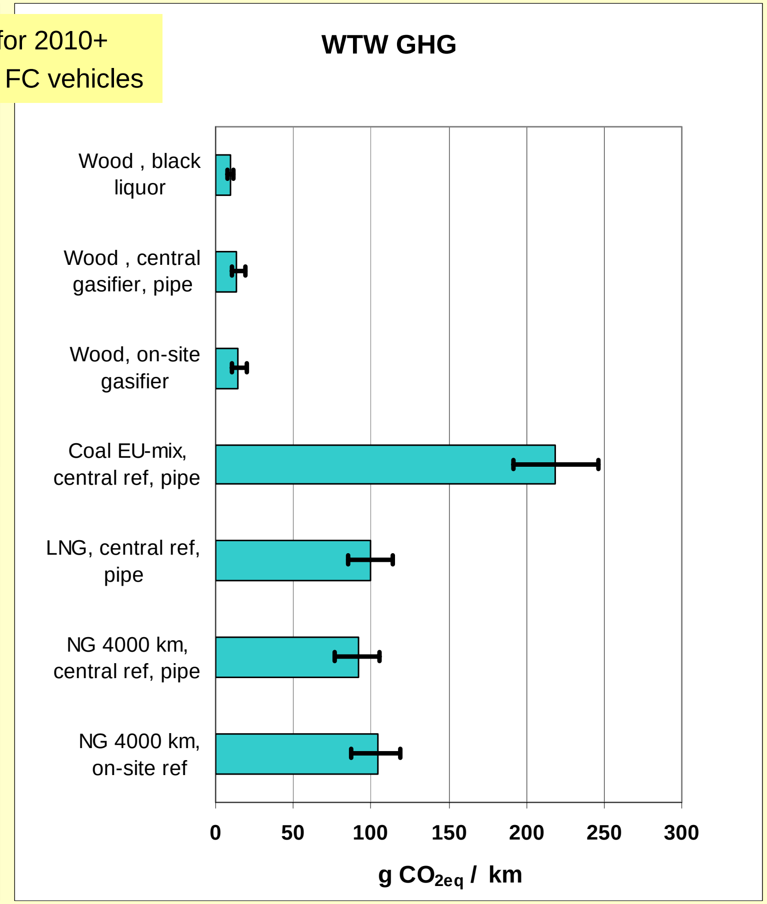
- For ICE vehicles, direct use of NG as CNG is more energy/GHG efficient than hydrogen

Impact of hydrogen production route

Direct hydrogen production via reforming

Figures for 2010+ non-hybrid FC vehicles

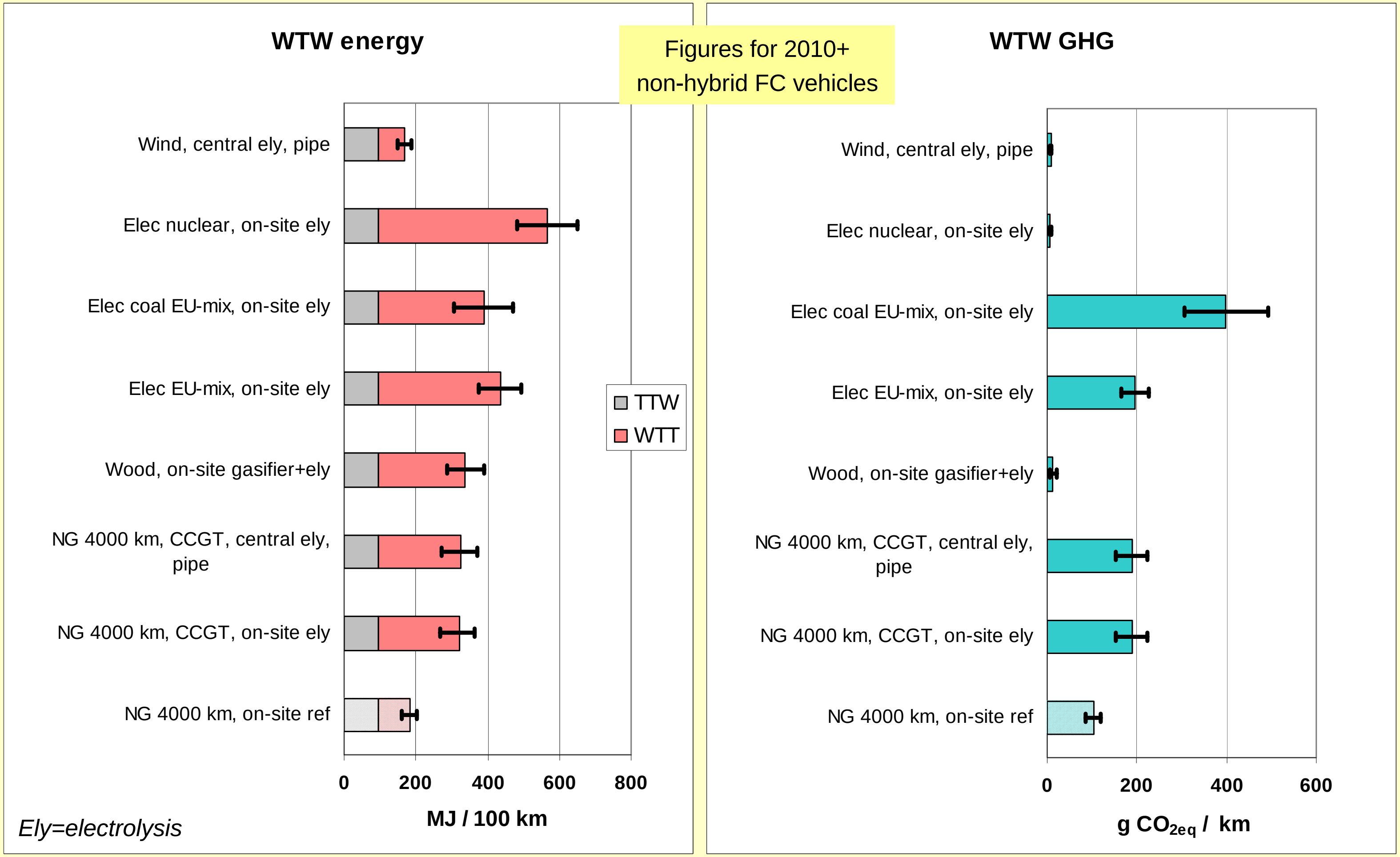




- Only hydrogen from renewables gives low GHG
  - But comparison with other renewables uses is required

Impact of hydrogen production route

Hydrogen production via electrolysis



- Electrolysis is less energy efficient than direct hydrogen production

Hydrogen: main points

- There are many ways to produce hydrogen from fossil, biomass and other renewable sources
- If hydrogen is produced from NG, GHG emissions savings are only achieved with fuel cell vehicles
  - For ICE vehicles, direct use of NG as CNG is more energy/GHG efficient than hydrogen
- Liquid hydrogen is less energy efficient than compressed hydrogen
- Only hydrogen from renewable sources gives low GHG
  - But comparison with other renewables uses is required
- Electrolysis is less energy efficient than direct hydrogen production

Potential for CO_2 avoidance
Cost and Availability

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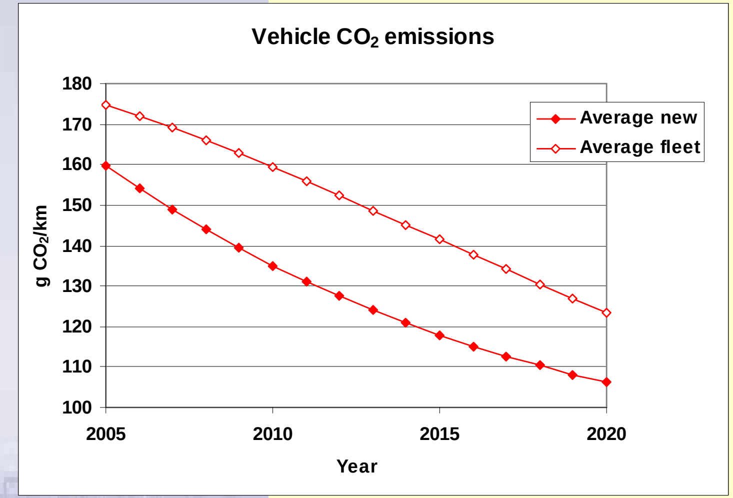
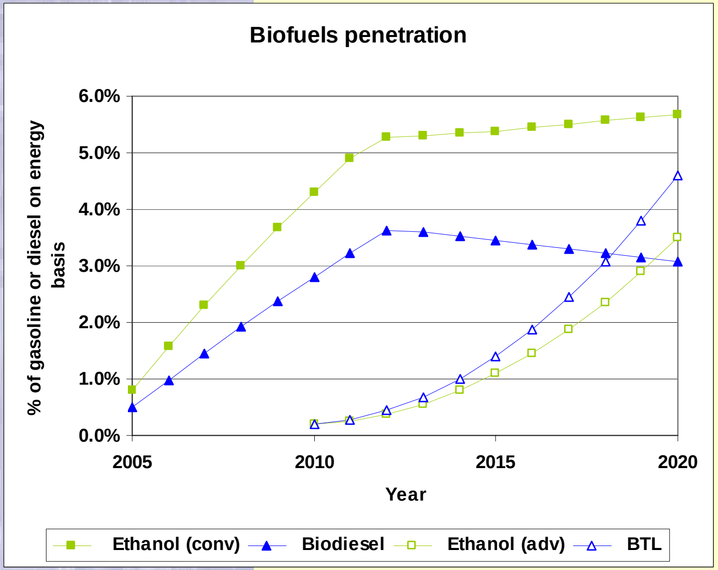
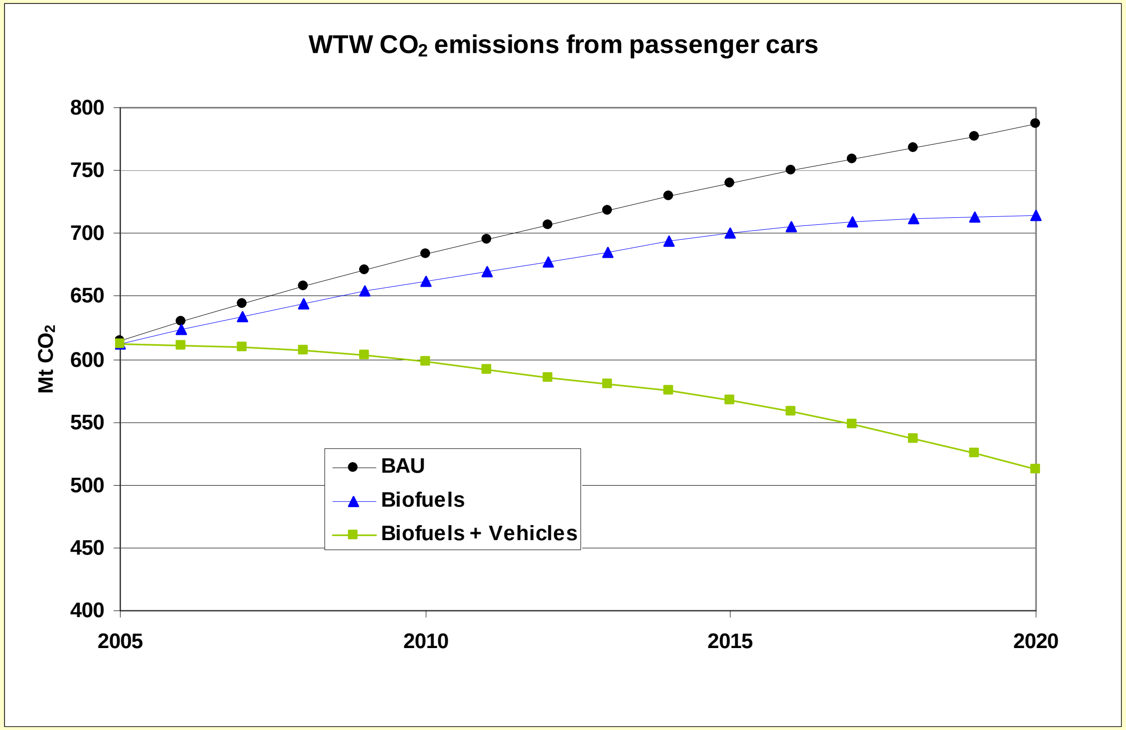
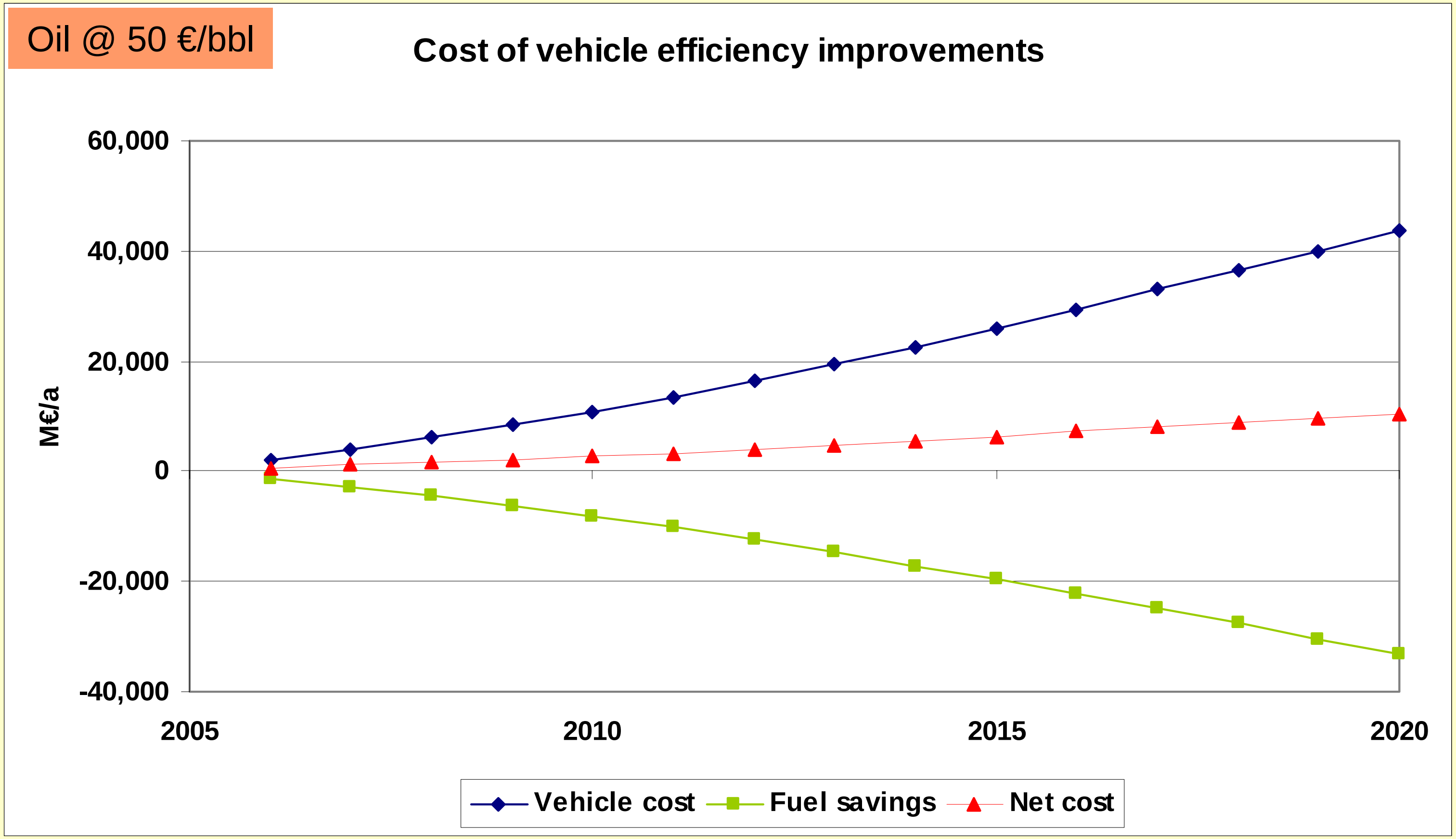
Improved vehicle efficiency is likely to be a non-regret route







Improved vehicle efficiency is likely to be a non-regret route



- The cost of vehicle efficiency improvements is compensated by fuel savings

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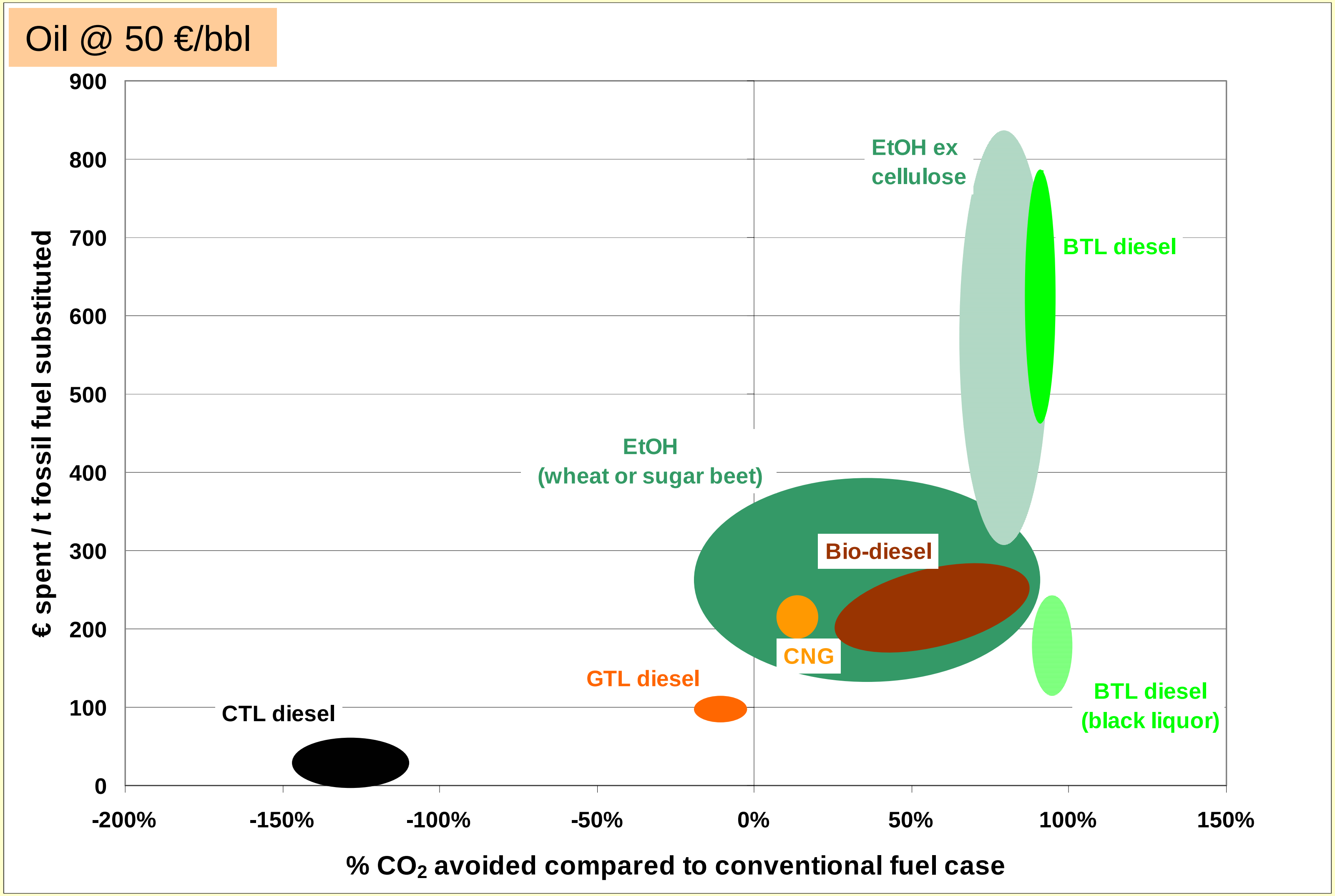
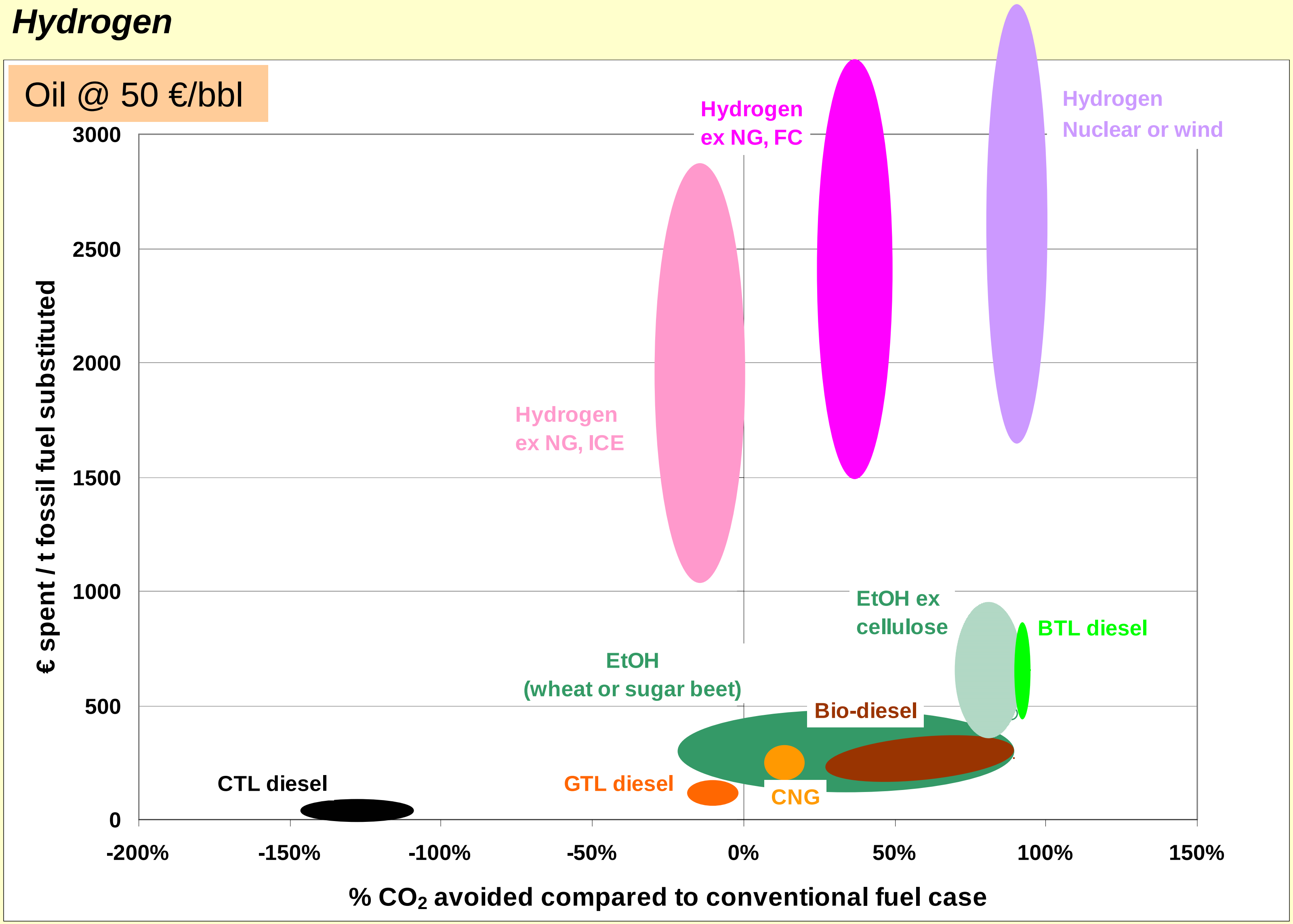
Cost v. potential for CO_2 avoidance

Liquid fuels, CNG



Cost v. potential for CO_2 avoidance

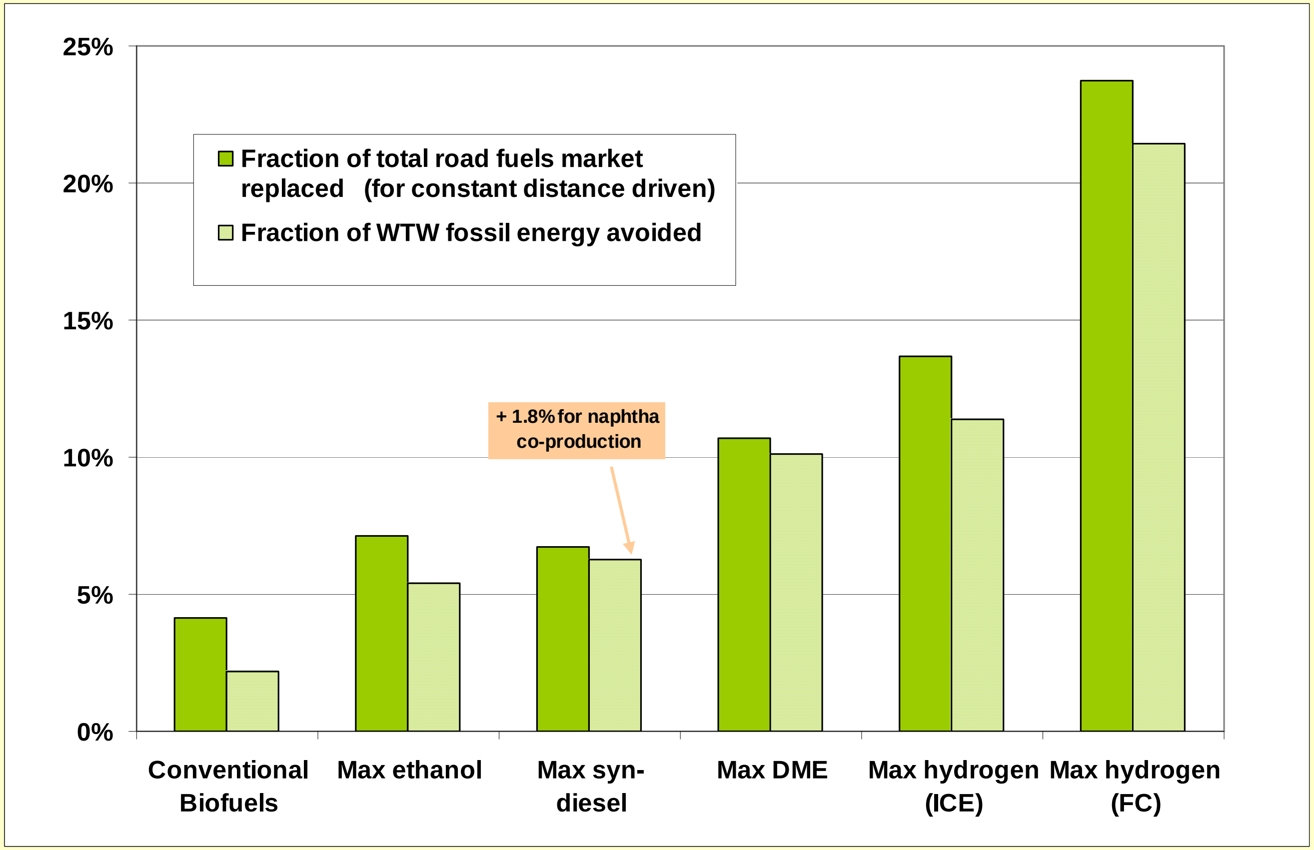
Hydrogen



Potential of EU biomass for road fuels production

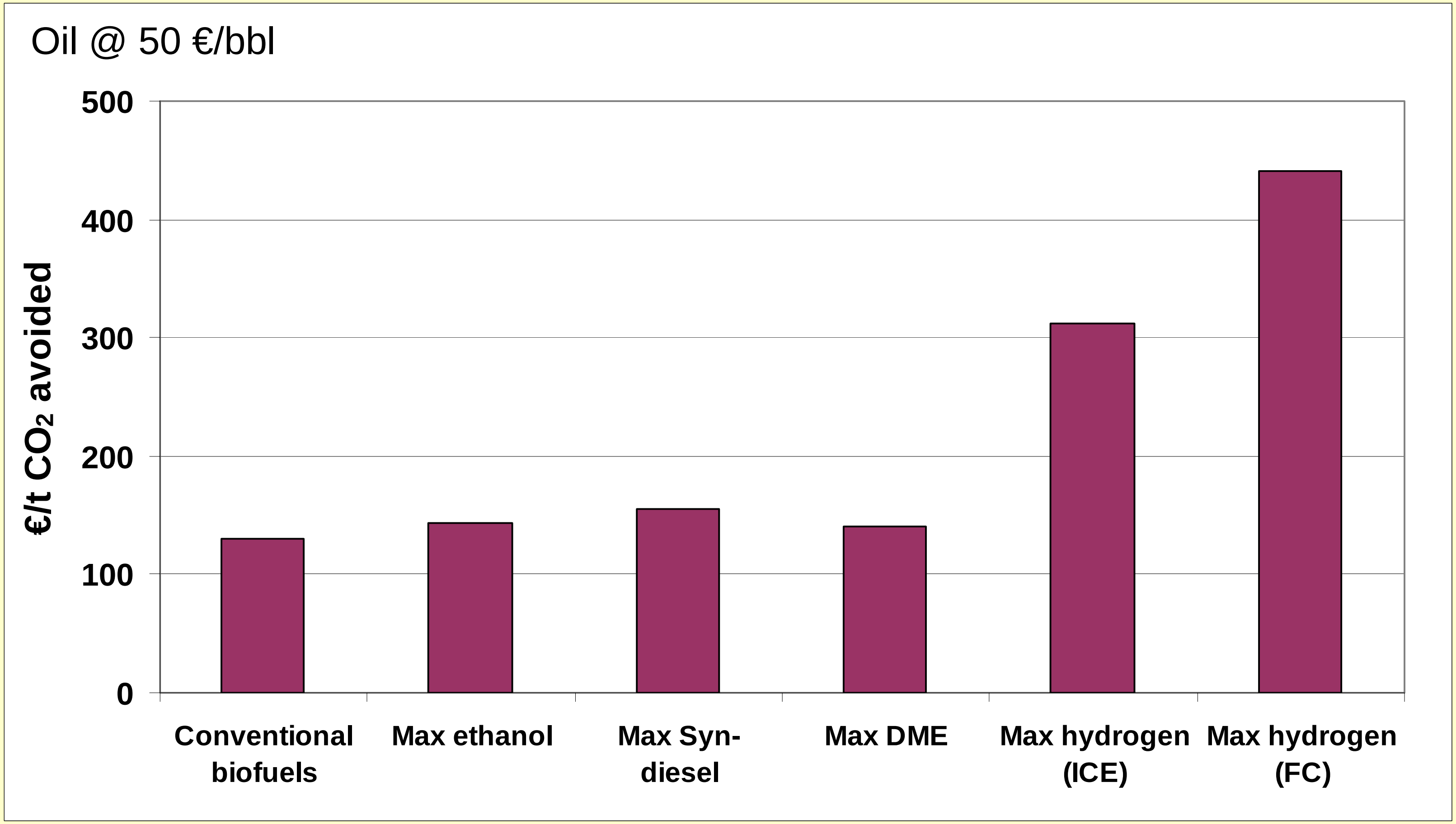
- Agricultural land
  - Set-asides
  - Land released by reduction of sugar production
  - Yield improvements
  - Account for actual yields in each area rather than EU-wide “standard “ value
  - No change of use of pastures and meadows
- Waste
  - Wood
  - Manure and organic waste (for biogas)
  - Including consideration of other uses and practicality/economics of collection

Potential of EU biomass for road fuels production

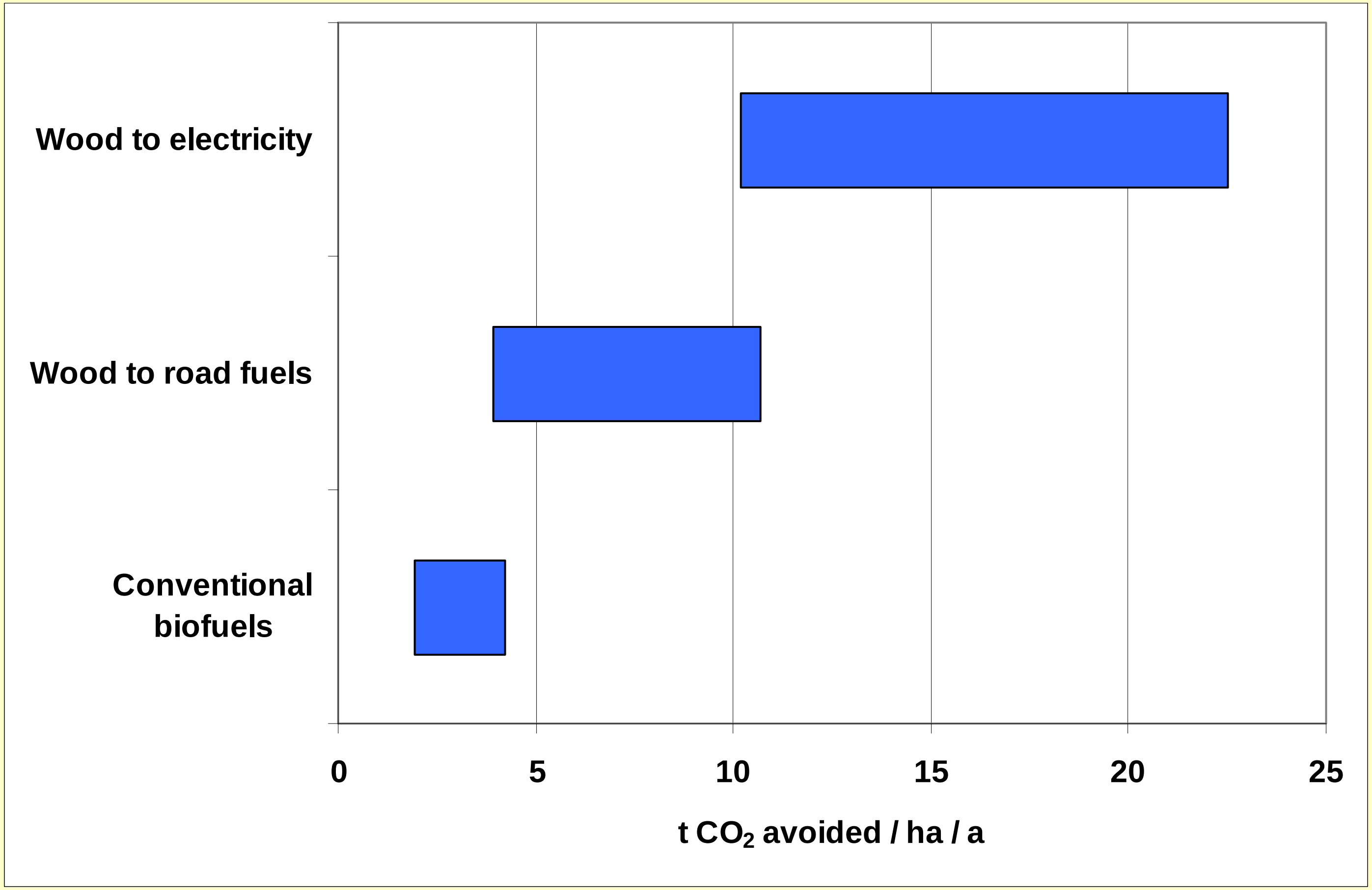


- There is a limited potential for first generation biofuels
- More advanced routes that dedicate all biomass to fuel production are more promising
- Even in the highly favourable case of hydrogen + fuel cells, biomass could only account for about 25% of the total EU-25 road transport fuel market

Cost of CO_2 avoidance with biomass



Land use efficiency



Bars show the GHG savings each year, per hectare of land

- If CO_2 emissions reduction is the main objective, biomass should be used to produce electricity

Biofuels implementation issues in Europe

- Quality
  - Ethanol blends vapour pressure
  - Oxidation stability of bio-diesel from different sources
    - Importance of quality standard EN14214
    - Limitation on vegetable oil sources
    - Specific issue for long-term storage in e.g. strategic stocks
- Multiplicity of grades developing in different EU Member States
  - E5/E10/E85
  - B5/B10/B30/B100
- How to incentivise the “right” biofuels
  - Certification issues
- Potentially more ethanol available than bio-diesel
  - Worsens already existing imbalance between gasoline and middle distillates demand