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

Jean-François Larivé, CONCAWE
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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

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
Well-to-Wheels Pathways

**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, H₂
- Compression Ignition: Diesel, DME, Bio-diesel
- Fuel Cell
- Hybrids: SI, CI, FC
- Hybrid Fuel Cell + Reformer

**Resource**
- Crude oil
- Coal
- Natural Gas
- Biomass
- Wind
- Nuclear

Inc. preliminary views on Carbon Capture and Sequestration
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
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)
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.

**TTW fuel consumption (MJ/100 km)**

- 2002 conventional
- 2010+ conventional

- CNG PISI
- CNG PISI (bi-fuel)
- Diesel CIDI
- Gasoline PISI
- CNG PISI (dedicated)
- Diesel CIDI (DPF)
- Gasoline PISI (dedicated)
- Diesel CIDI (DPF)
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CNG & CBG: WTT pathways

Compressed natural gas (CNG)

NG (EU-mix)
- Production and conditioning
- Transformation at source
- Pipelines in EU
- NG grid + On-site compression

NG (piped)
- Production and conditioning
- Pipeline into EU
  - a) 7000 km
  - b) 4000 km
- Vaporisation

NG (remote)
- Production and conditioning
- Liquefaction (+CCS option)
- Shipping (LNG)
- Road, 500 km + On-site vap / comp

Biogas

Municipal waste
- Production treating & upgrading
- NG grid + On-site compression

Liquid manure

Dry manure

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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
CNG: WTW Energy and GHG balance

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

- 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
Conventional ethanol and bio-diesel pathways

Ethanol

**Resource Production and conditioning at source**
- *Sugar beet*
  - Growing
  - Harvesting
  - Road
  - Fermentation + distillation
  - Pulp
  - Animal feed
  - Electricity
- *Wheat*
  - Growing
  - Harvesting
  - Road
  - Fermentation + distillation
  - Wheat straw as fuel (option 4)
  - DDGS
  - Animal feed
  - Electricity
- *Sugar cane (Brazil)*
  - Growing
  - Harvesting
  - Fermentation + distillation
  - Road, 150 km + Shipping
  - Road, 2x150 km

FAME/FAEE

**Production and conditioning at source**
- *Rape seed*
  - Growing
  - Harvesting
  - Road
  - Pressing
  - Esterification
  - Road, 2x150 km
- *Sunflower seed*
  - Growing
  - Harvesting
  - Road
  - Pressing
  - Esterification
  - Road, 2x150 km
- *NG (remote)*
  - Production and conditioning
  - Methanol
  - Shipping and transport
  - Methanol
  - Road, 2x150 km
- *Rape seed*
  - Growing
  - Harvesting
  - Road
  - Pressing
  - Esterification
  - Road, 2x150 km
- *Wheat*
  - Growing
  - Harvesting
  - Road
  - Ethanol
  - Esterification
  - Road, 2x150 km
How much fossil energy and GHG do ethanol and bio-diesel save?

Answer: some, a lot or none at all
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?

-40%  -20%  0%  20%  40%  60%  80%  100%  120%

WTW Fossil energy savings  WTW GHG emissions savings

Conv. Boiler  NG GT+CHP  Lignite CHP  Straw CHP  NG GT+CHP  Sugar cane  RME: glycerine as chemical  RME: glycerine as animal feed

DDGS to animal feed  DDGS to heat & power

Wheat grain  Ethanol  Bio-diesel

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?

-40%  -20%  0%  20%  40%  60%  80%  100%  120%
Conv. Boiler NG GT+CHP Lignite CHP Straw CHP NG GT+CHP Sugar cane RME: glycerine as chemical RME: glycerine as animal feed

DDGS to animal feed
DDGS to heat & power
Wheat grain Ethanol Bio-diesel

- RME can deliver 50% GHG savings
- The magnitude of N₂O emissions is a major issue (depends on soil type and framing practices)
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
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$_2$O 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$_2$O 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
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
## Syn-diesel and DME pathways

<table>
<thead>
<tr>
<th>Resource</th>
<th>Production and conditioning</th>
<th>Transformation at source</th>
<th>Transportation to markets</th>
<th>Transformation near market</th>
<th>Conditioning and distribution</th>
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<tbody>
<tr>
<td><strong>Syn diesel</strong></td>
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</tr>
<tr>
<td>NG (piped)</td>
<td>Production and conditioning</td>
<td>Pipeline into EU</td>
<td>GTL plant</td>
<td>As for refinery fuels</td>
<td></td>
</tr>
<tr>
<td>NG (remote)</td>
<td>Production and conditioning</td>
<td>GTL plant (+CCS option)</td>
<td>Shipping</td>
<td>As for refinery fuels or</td>
<td>Mixed land transport, 500 km</td>
</tr>
<tr>
<td>Coal</td>
<td>Production and conditioning</td>
<td>Shipping</td>
<td>CTL plant (+CCS option)</td>
<td>As for refinery fuels</td>
<td></td>
</tr>
<tr>
<td>Waste wood</td>
<td>Collection</td>
<td>Road, 50 km + Shipping (800 km)</td>
<td>200 MW gasifier</td>
<td>FT plant</td>
<td></td>
</tr>
<tr>
<td><strong>Methanol / DME</strong></td>
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<tr>
<td>Coal (EU mix)</td>
<td>Production and conditioning</td>
<td>Shipping</td>
<td>Gasification MeOH/DME synthesis</td>
<td>Mixed land transport 500 km</td>
<td></td>
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<td>Mixed land transport 500 km</td>
<td></td>
</tr>
<tr>
<td>Waste wood</td>
<td>Collection</td>
<td>Road, 50 km + Shipping</td>
<td>200 MW gasifier MeOH/DME synthesis</td>
<td>Road, 150 km</td>
<td></td>
</tr>
<tr>
<td>Waste/Farmed wood</td>
<td>Growing Harvesting</td>
<td>Road</td>
<td>BL gasifier + MeOH/DME synthesis</td>
<td>Road, 150 km</td>
<td></td>
</tr>
<tr>
<td>Waste wood via Black liquor</td>
<td>Collection</td>
<td>Road</td>
<td>Wate wood boiler</td>
<td></td>
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</tr>
</tbody>
</table>
Biomass to Syn-diesel and DME: Energy and GHG balance

WTW Fossil energy savings

WTW GHG emissions savings

- RME: glycerine as animal feed
- Syn-diesel: farmed wood
- DME: farmed wood
Syn-diesel and DME from fossil and biomass sources: Total energy and GHG balance

Waste wood via BL
Farmed wood
Coal
Remote NG
Waste wood via BL (BTL)
Farmed wood (BTL)
Coal (CTL)
NG Remote (GTL)
CNG bi-fuel (LNG)
Conv. diesel DICI+DPF

WTW energy

2010+ vehicles

WTW GHG

MJ / 100 km

DME
DICI

DME
DICI+DPF

0 100 200 300 400 500

0 100 200 300 400
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
If hydrogen is produced from NG, GHG emissions savings are only achieved with fuel cell vehicles.
Liquid hydrogen is less energy efficient than compressed hydrogen
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

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

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JCAP conference, Tokyo February 2007
Impact of hydrogen production route

Hydrogen production via electrolysis

Electrolysis is less energy efficient than direct hydrogen production

Electrolysis is less energy efficient than direct hydrogen production

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

**Vehicle CO₂ emissions**
- Average new
- Average fleet

**Biofuels penetration**
- Ethanol (conv)
- Biodiesel
- Ethanol (adv)
- BTL

**WTW CO₂ emissions from passenger cars**
- BAU
- Biofuels
- Biofuels + Vehicles
Improved vehicle efficiency is likely to be a non-regret route

The cost of vehicle efficiency improvements is compensated by fuel savings
Cost v. potential for CO₂ avoidance

Liquid fuels, CNG

Oil @ 50 €/bbl

% CO₂ avoided compared to conventional fuel case

€ spent / t fossil fuel substituted

-200% -150% -100% -50% 0% 50% 100% 150%

EtOH ex cellulose

BTL diesel

EtOH (wheat or sugar beet)

Bio-diesel

CNG

GTL diesel

CTL diesel

BTL diesel (black liquor)

BTL diesel

GTL diesel

CNG

EtOH (wheat or sugar beet)

Bio-diesel

CNG

GTL diesel

CTL diesel

BTL diesel (black liquor)
Cost v. potential for CO₂ avoidance

Hydrogen

Oil @ 50 €/bbl

€ spent / t fossil fuel substituted

% CO₂ avoided compared to conventional fuel case

-200% -150% -100% -50% 0% 50% 100% 150%

Hydrogen

ex NG, FC

Hydrogen

ex NG, ICE

EtOH

(wheat or sugar beet)

Bio-diesel

BTL diesel

CNG

GTL diesel

CTL diesel

EtOH ex cellulose

Oil or wind

Nuclear or wind

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
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 CO₂ avoidance with biomass

Oil @ 50 €/bbl

- Conventional biofuels
- Max ethanol
- Max Syn-diesel
- Max DME
- Max hydrogen (ICE)
- Max hydrogen (FC)
Land use efficiency

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

- If CO₂ 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