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

A joint initiative of **EUCAR/JRC/CONCAWE**

Preliminary Results for Hydrogen

Summary of Material Presented to the EC Contact Group on Alternative Fuels in May 2003

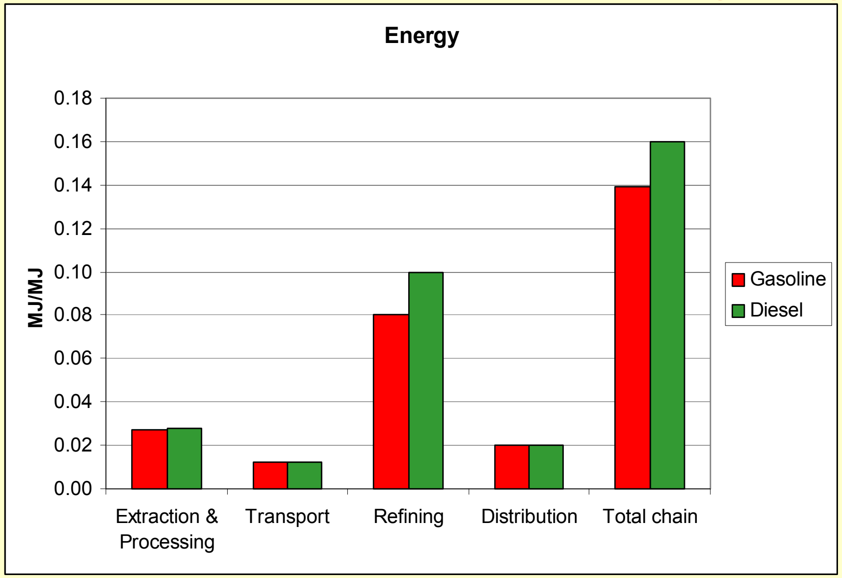
Well-to-Wheels analysis of future fuels and associated automotive powertrains in the European context

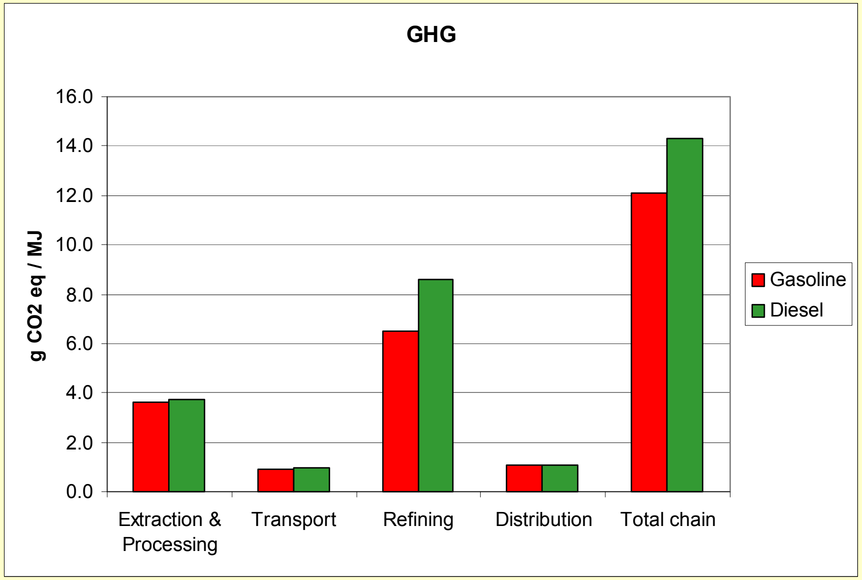
- Partial and preliminary results
  - Conventional fuels/engines
  - Hydrogen powertrains
- Well-to-tank
  - Gasoline and diesel production and distribution
  - Hydrogen pathways
- Tank-to Wheels 2002, assessments 2010
  - Conventional advanced gasoline, diesel, natural gas vehicles
  - Hydrogen vehicles
- Well-to-Wheels integration

WELL-TO-TANK

Well-to-Tank analysis
Conventional oil pathways

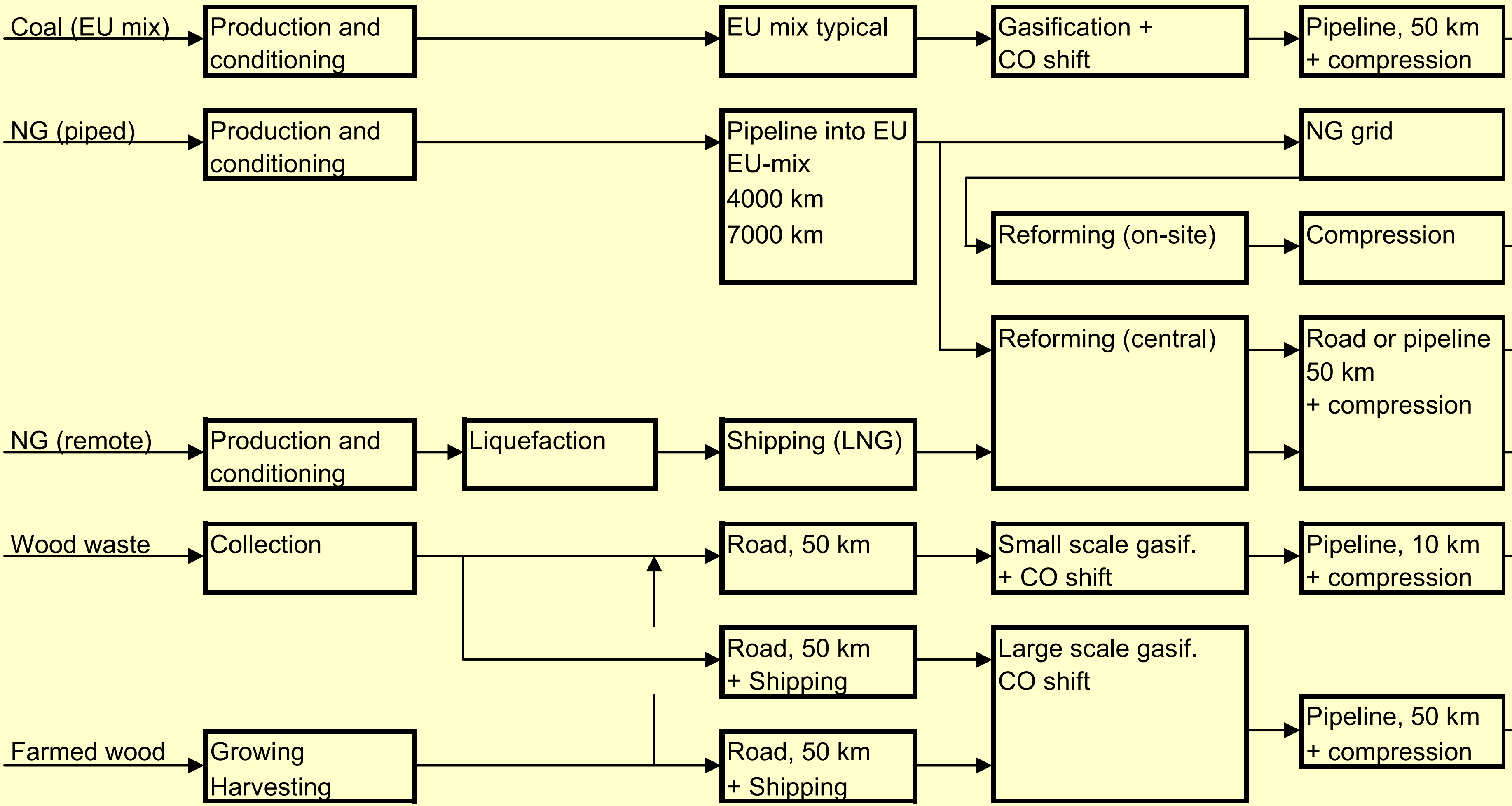
- At the 2010-2020 horizon, alternative fuels will replace some fraction of the current conventional fuels market
  - The energy that can be saved and the GHG emissions that can be avoided therefore pertain to the MARGINAL production of conventional fuels
- Europe is short in diesel and long in gasoline: the “natural” balance between gasoline and middle distillates is stretched
  - **As a result, refinery production of *marginal* diesel is more energy-intensive than that of *marginal* gasoline**





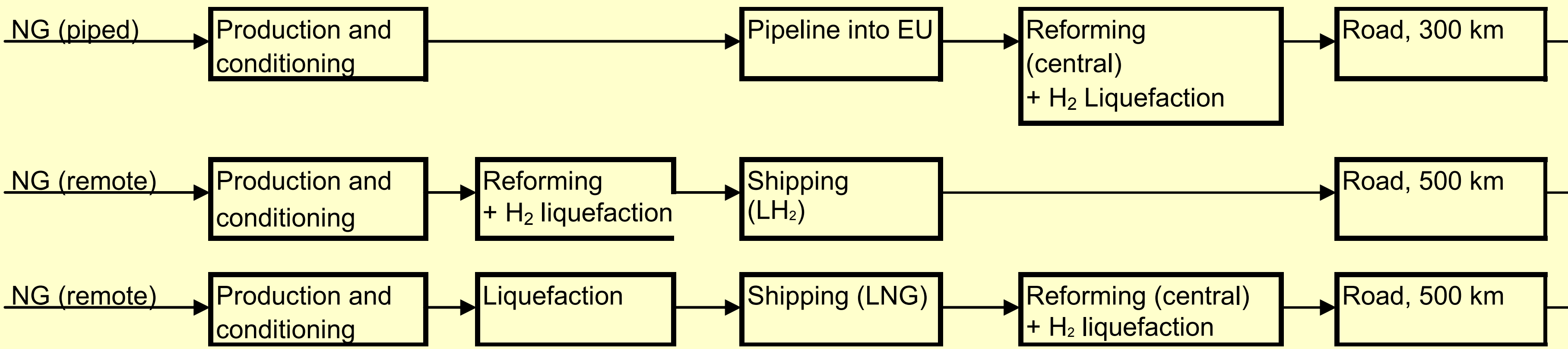
CO_2 on combustion is about 75g/MJ

Compressed hydrogen pathways
(excluding electricity)

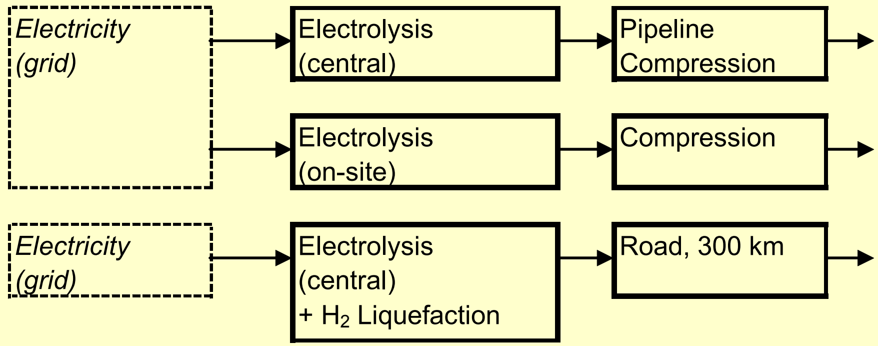


Prelimina

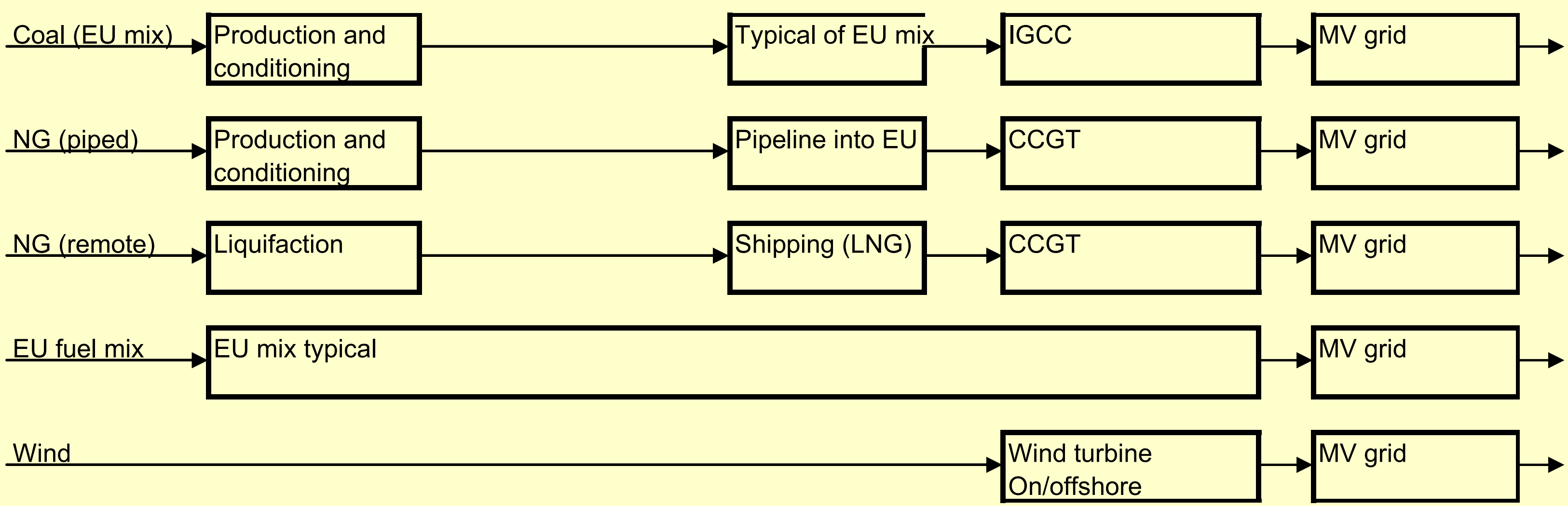
Liquefied hydrogen pathways
(excluding electricity)



Electricity to hydrogen pathways



Electricity production pathways



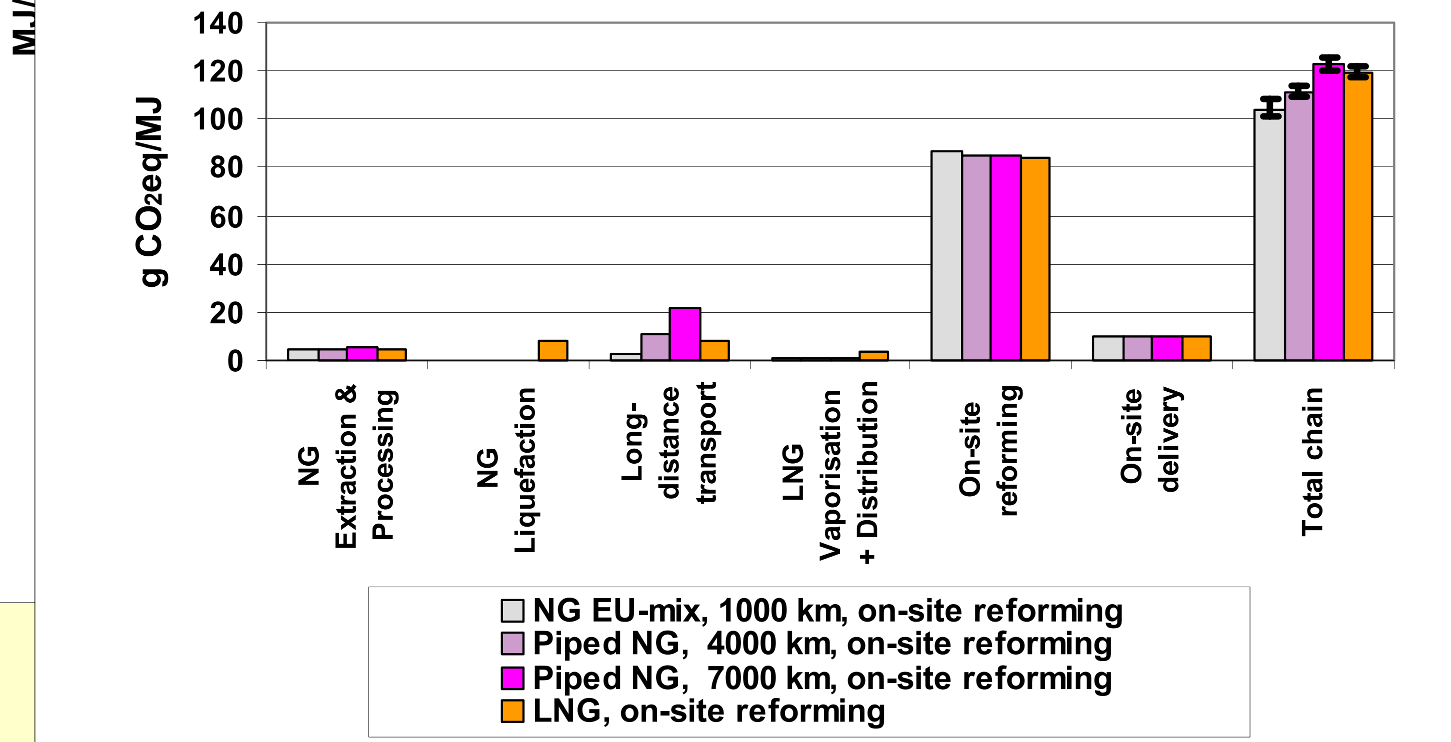
Compressed Hydrogen

Compressed hydrogen from on-site NG reforming

Reforming energy is the main element

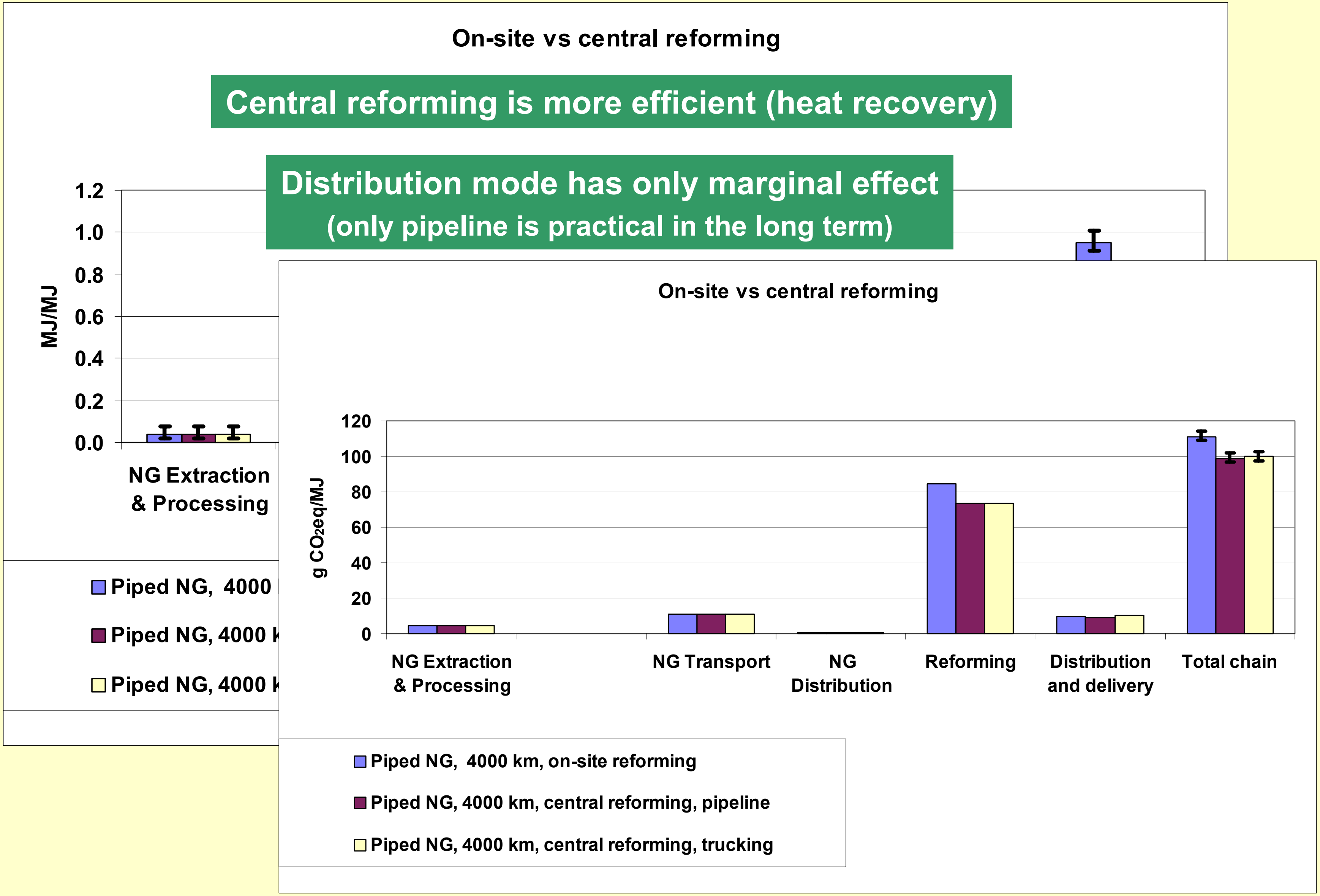
Compressed hydrogen from on-site NG reforming

GHG from reforming is major contribution (because of decarbonisation)



Compressed Hydrogen

Prelimina

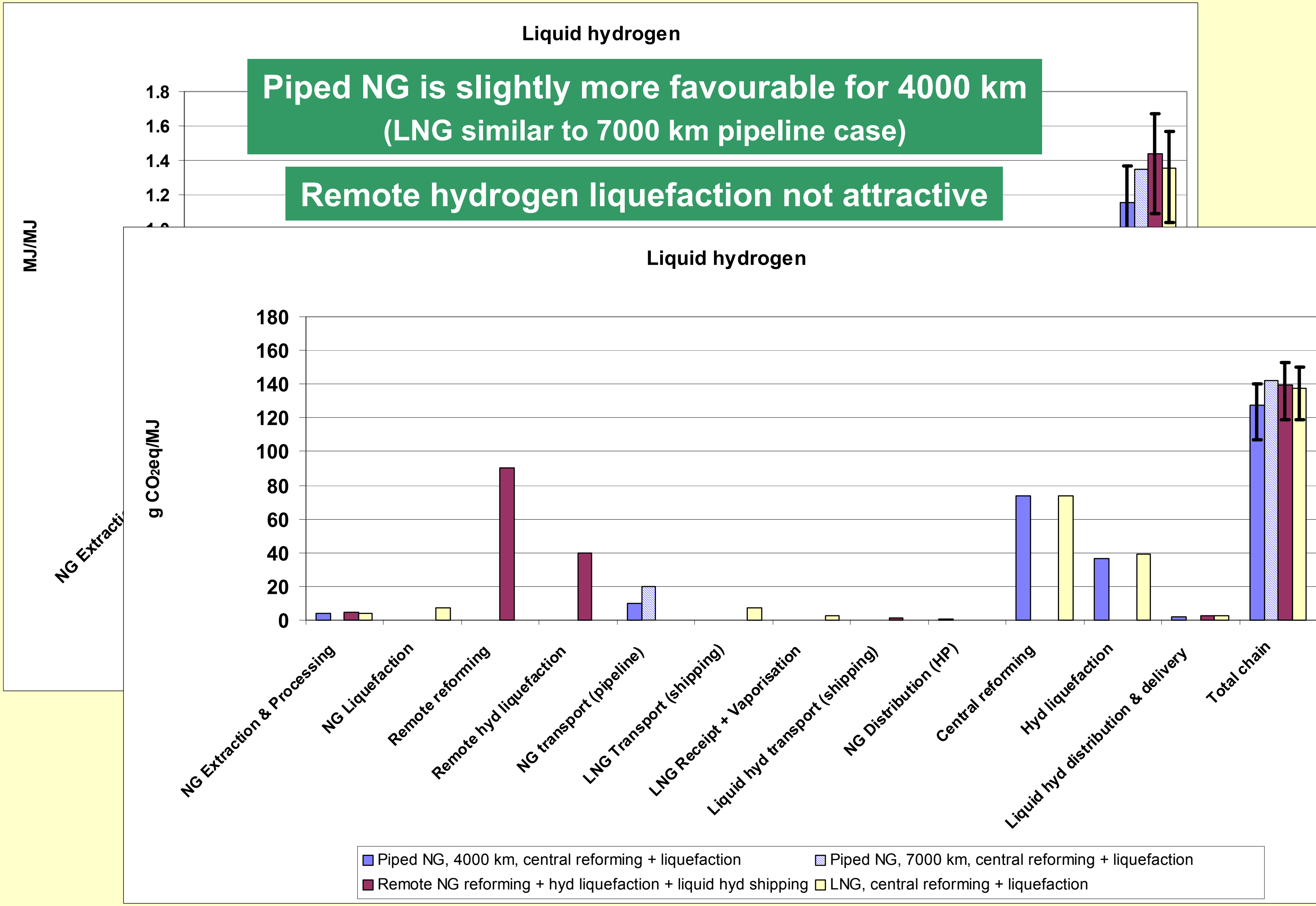


Liquid Hydrogen

Prelimina

Piped NG is slightly more favourable for 4000 km
(LNG similar to 7000 km pipeline case)

Remote hydrogen liquefaction not attractive



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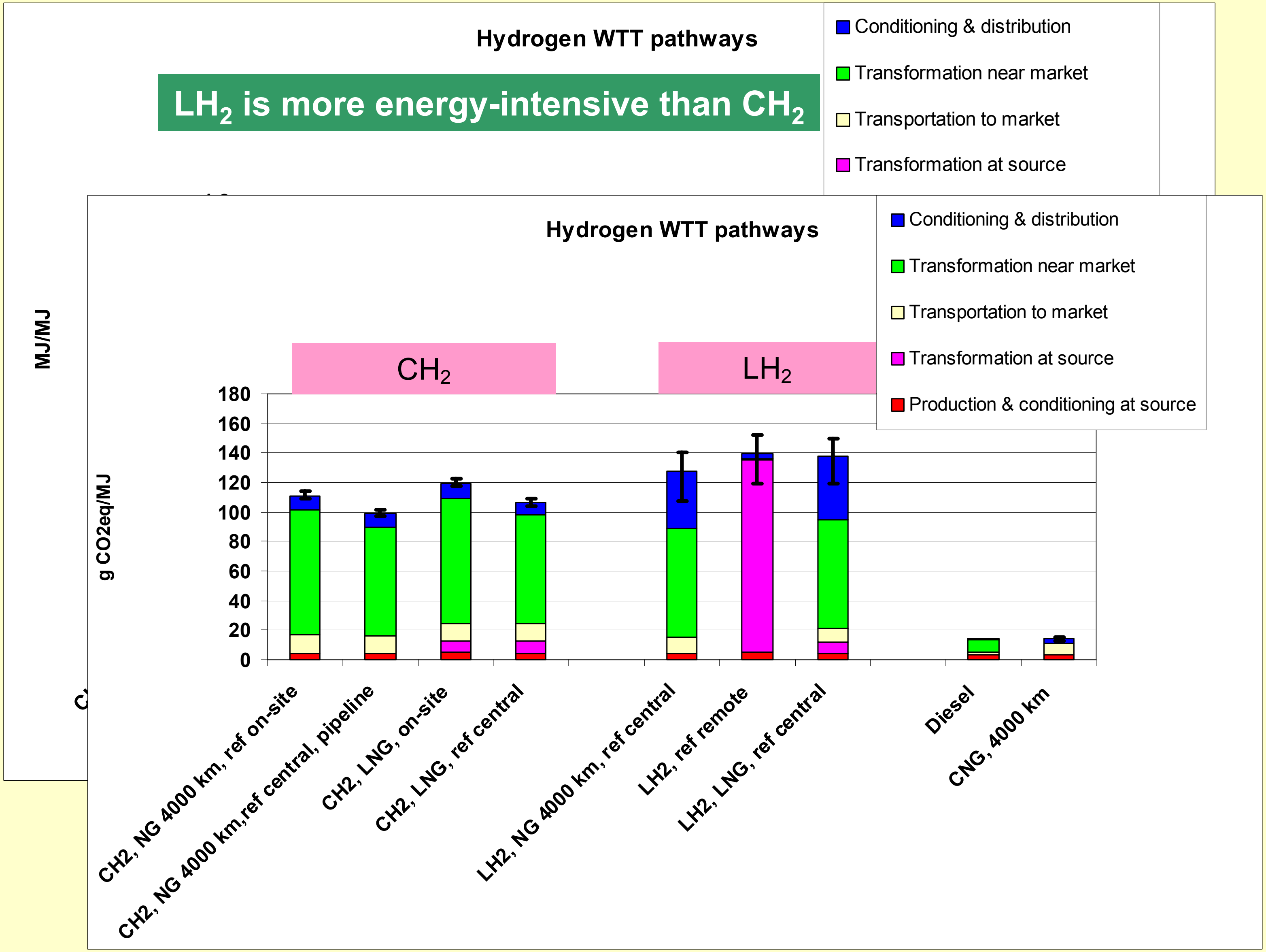
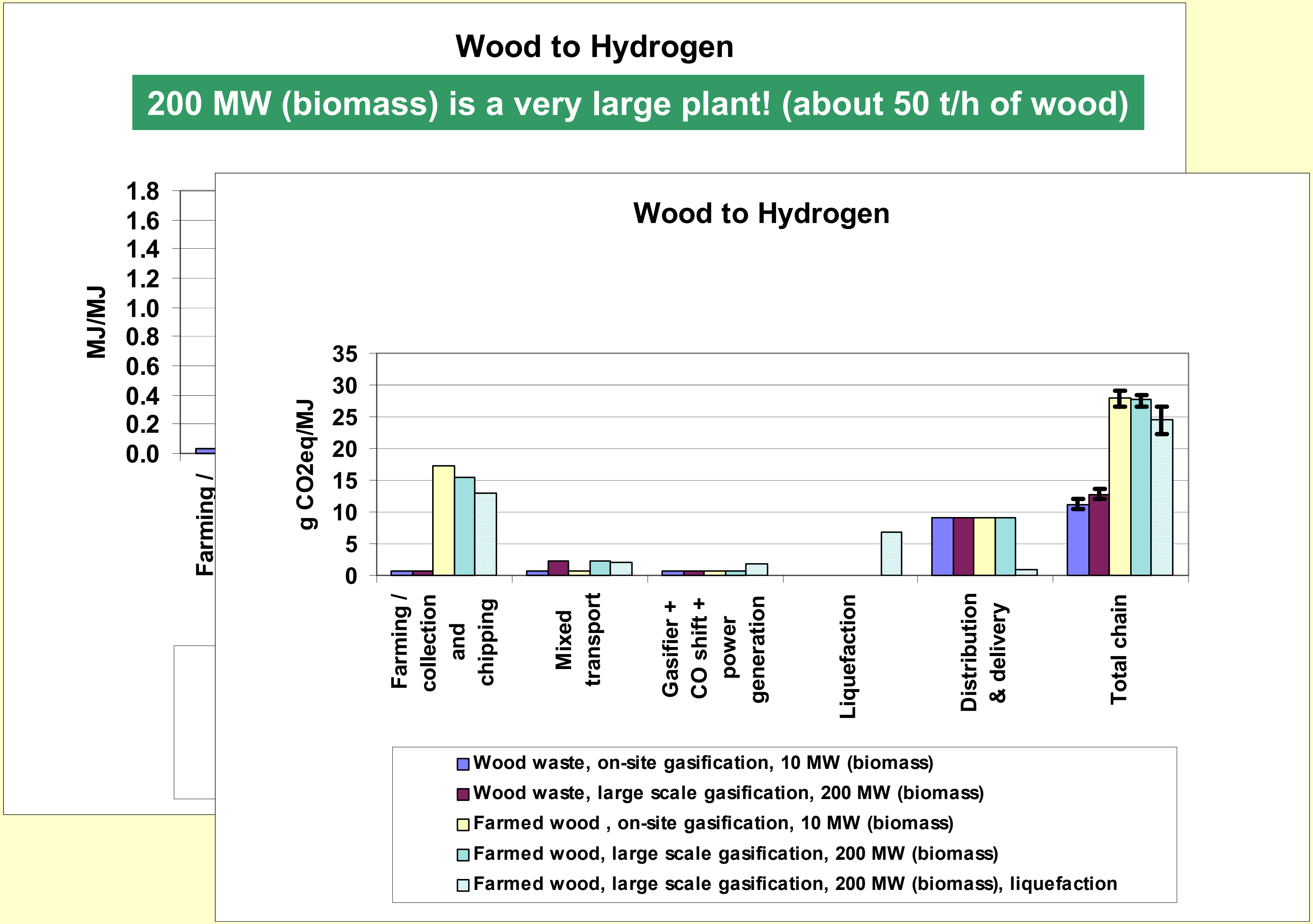
Summary

Preliminary



Wood-to-Hydrogen pathways



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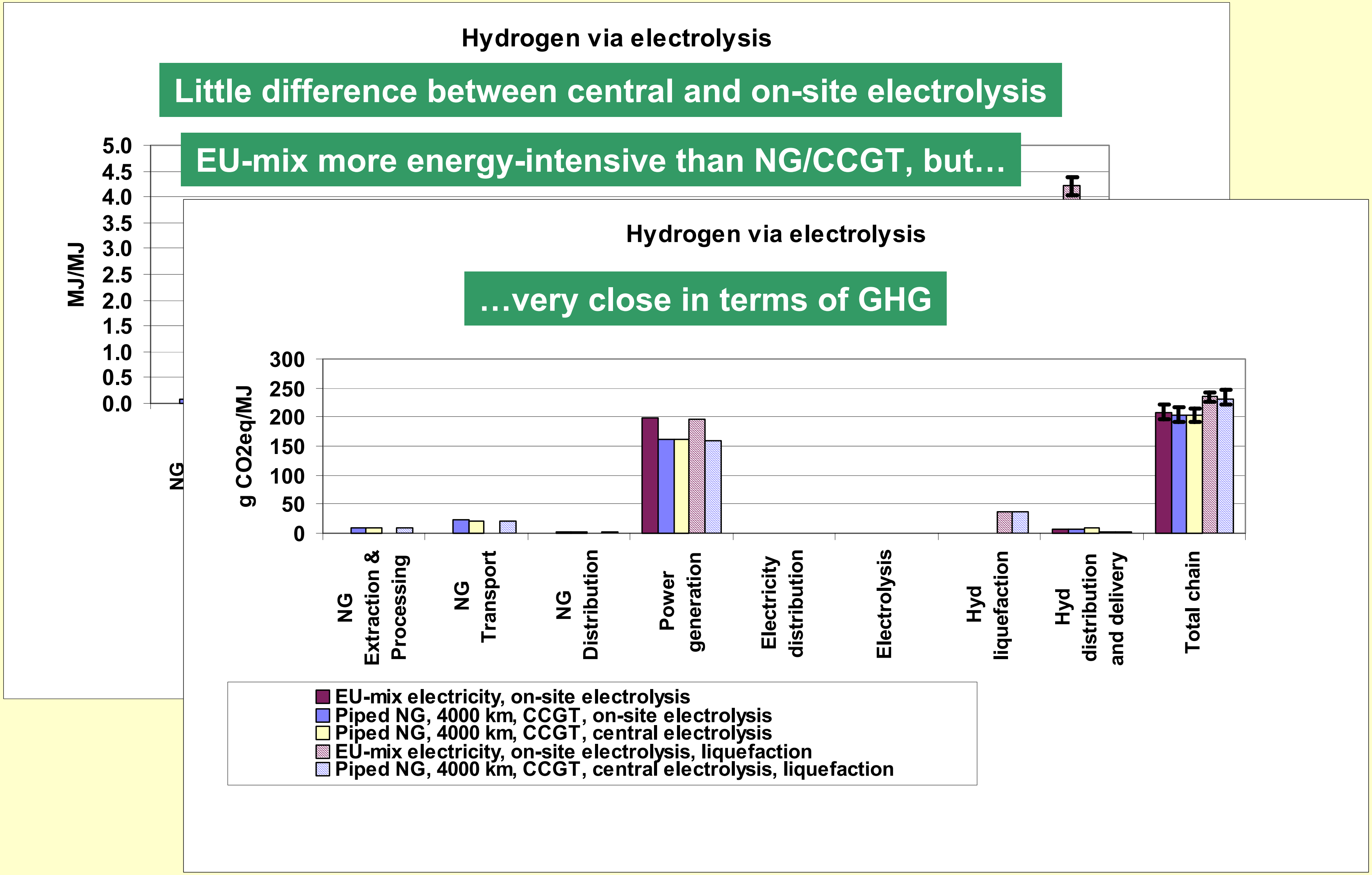
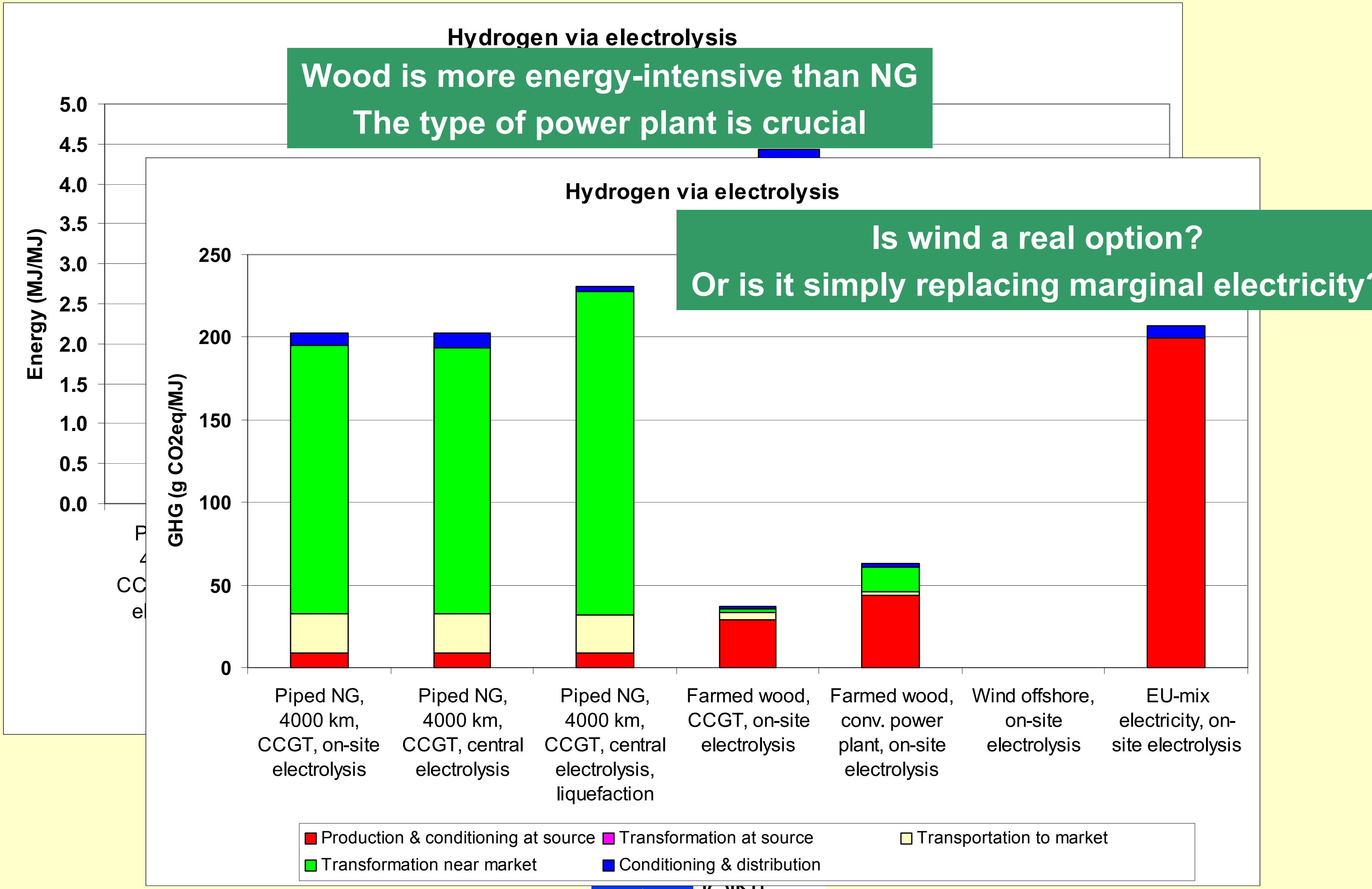
Hydrogen via electrolysis pathways



Hydrogen via electrolysis pathways



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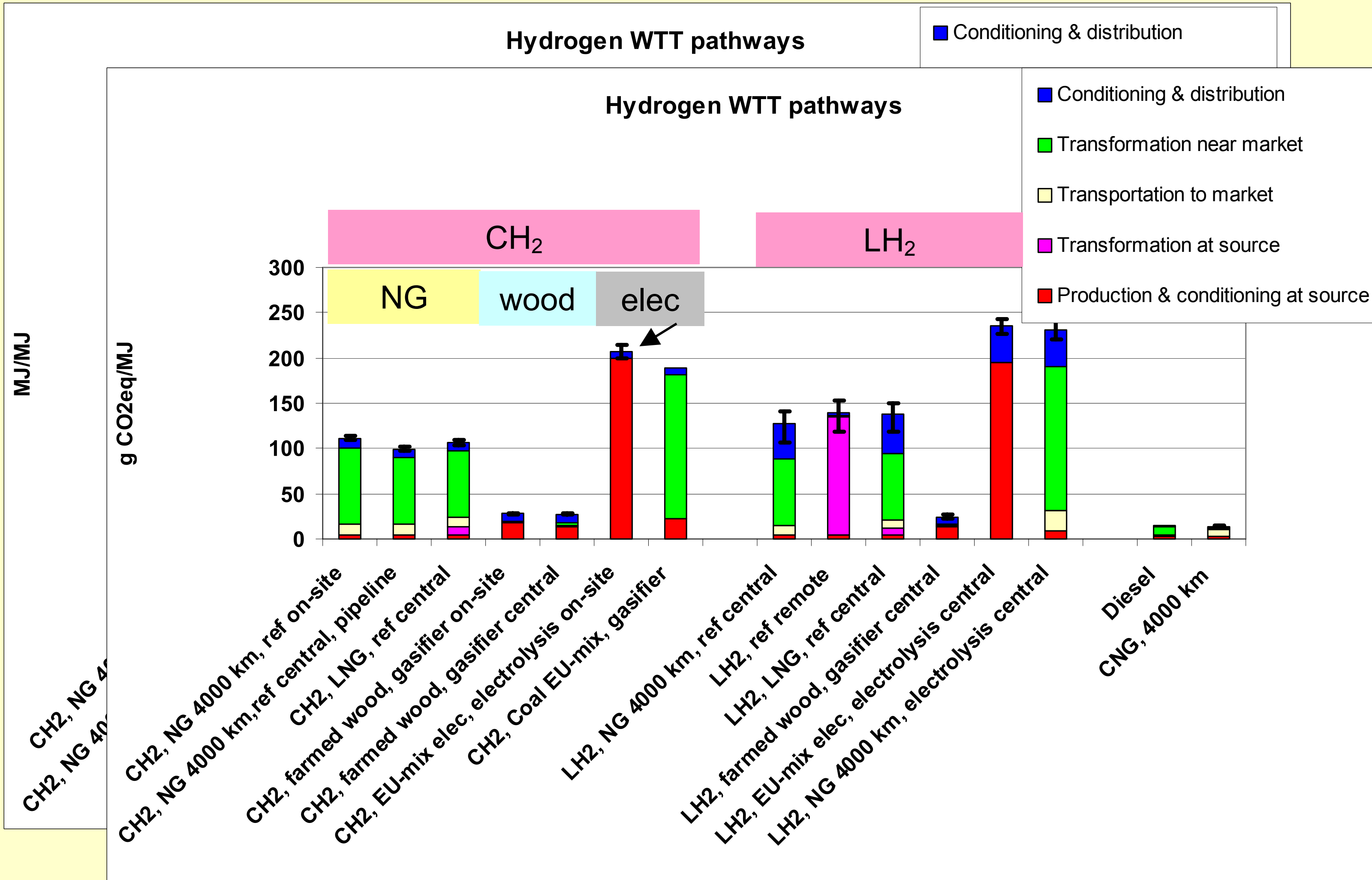
Summary



Electrolysis must be the "last resort"
unless an uncontroversial renewable energy source can be used

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WTT Conclusions

- LH_2 is more energy and GHG intensive than CH_2
- Central reforming requires somewhat less energy than on-site
- Electrolysis is very energy-intensive and can only be justified if genuinely renewable electricity is available

TANK-TO-WHEELS

Gasoline, Diesel, Natural gas, Hydrogen
2002 - 2010

Tank-to-Wheels study:
Gasoline, Diesel, Natural gas, Hydrogen

- For the purpose of this study, **a “virtual” vehicle** was created, figurable as a VW Golf 1.6 l gasoline (most popular segment of the market)
- The results **do not** represent a fleet average

- The Fuels / powertrains considered here are :
  - Technologies 2002 are purely Internal Combust. Engines (I.C.E.)
  - Technologies assessed for 2010 include : I.C.E. & Fuel Cells

- The engine technologies and fuels investigated do not imply any assumptions with regard to their potential market share

ICE hybrid vehicles will be included later

Tank-to-Wheels study
Performance & Emissions

- All technologies fulfil at least minimal customer performance criteria
  - For bi-fuel (gasoline-CNG) the vehicle performance decay (12% torque down-shift) is accepted. A dedicated CNG engine, upsized at 2 l. to fulfil the required performances is simulated.
  - The H_2 I.C. engine is simulated as extrapolated from single cylinder present studies : 1.3 liter, already turbo-charged to meet the performances.
- "Vehicle / Fuel" combinations comply with emissions regulations
  - **The 2002 vehicles comply with Euro III**
  - **The 2010 vehicles comply with EU IV**
- Direct Injection for gaseous fuels is not simulated as still at the level of research with open issues to be adressed (energy penalty or limited range)

Prelimina

Tank-to-Wheels study

Fuels & adapted technologies for comparable performance

	gasoline		diesel	Fuel cell
Engine Type	PISI	SIDI	CIDI	F.C.
Gasoline	1.6 lit.	1.6 lit.		
Diesel			1.9 lit.	
CNG (Bi Fuels)	1.6 lit.*			
CNG (dedicated)	2.0 lit.			
CGH2	1.3 lit. TC			75 kW
LH2	1.3 lit. TC			75 kW

* Reduced performance

Objective is to compare vehicles at same level of technology

PISI : Port Injection Spark Ignition
SIDI : Spark Ignition Direct Injection
CIDI : Compression Ignition Direct Injection (Common Rail)
F.C. : Fuel Cells (Direct Hydrogen)

Tank-to-Wheels study

Comments : state of the art 2002

- H2 ICE : Energy efficiency results from simulation are better than gasoline reference :
- Reason:

  - The S.I. H2 engine model is, already in 2002, simulated as *downsized and turbo charged (DSTC)*, while the reference gasoline engine is not.

  - The gasoline ICE will include the same technology in the 2010 version (and therefore be more energy efficient)
  - The benefit of DSTC will not be accounted twice for H2 in 2010

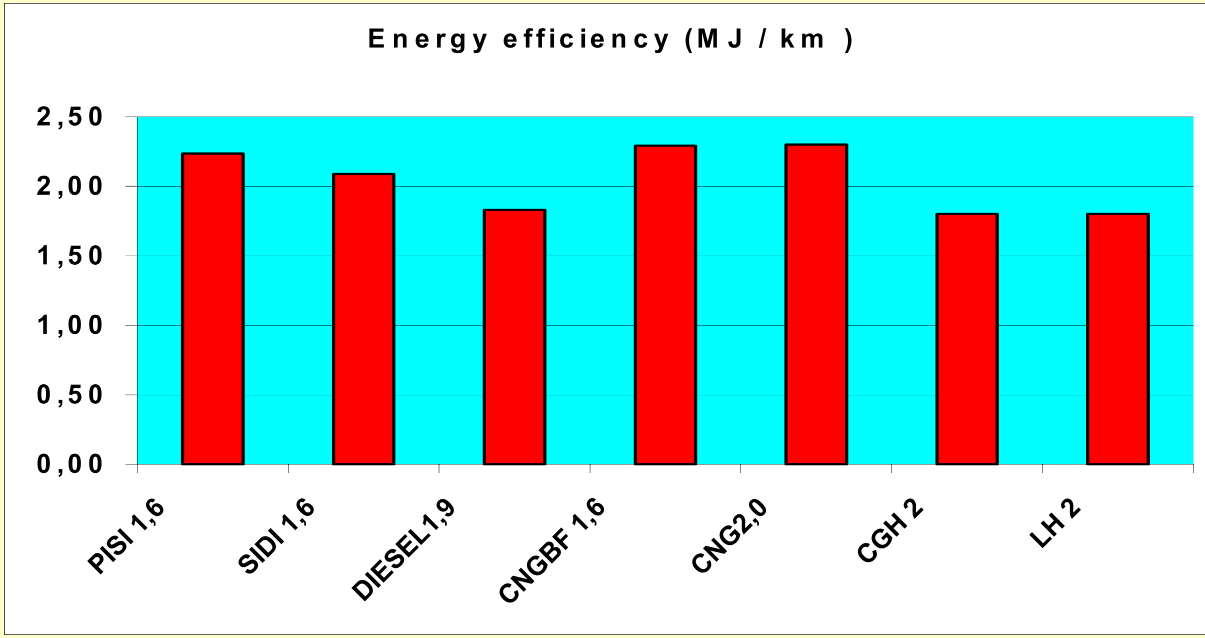
No GHG are emitted by the H2 powertrain, except the NOx contribution

Tank-to-Wheels study
Compared Energy Efficiency

gasoline diesel CNG bi-fuel CNG dedicated

Cold start on NEDC	PISI 1,6	SIDI 1,6	DIESEL1,9	CNGBF 1,6	CNG2,0	CGH2	LH2
CO_2 (g/km)	166,2	155,3	135	129	130	0	0
ENERGY EFF. (MJ/100km)	**223,5**	**209**	**183**	**229**	**230**	**180**	**180**
MASS Consump. (kg/100km)	5,21	4,87	4,26	5,08	5,1	1,50	1,50
FUEL Consump. (l /100km)	6,95	6,49	5,1	7,12	7,15	5,60	5,60
Other G.H.G. (g/km)							
Methane (g/kmCO_2 eq.)	0,84	0,84	0,25	3,36	3,36		
N_2O (g/km CO_2 eq	0,93	0,93	3,1	0,93	0,93	0,93	0,93
GHG global g/km	168,0	157,0	137,9	133,3	133,8	0,9	0,9

ICE engines STATE of the ART 2002



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Tank-to-Wheels study
Compared G.H.G. emissions

Cold start on NEDC	PISI 1,6	SIDI 1,6	DIESEL1,9	CNGBF 1,6	CNG2,0	CGH2	LH2
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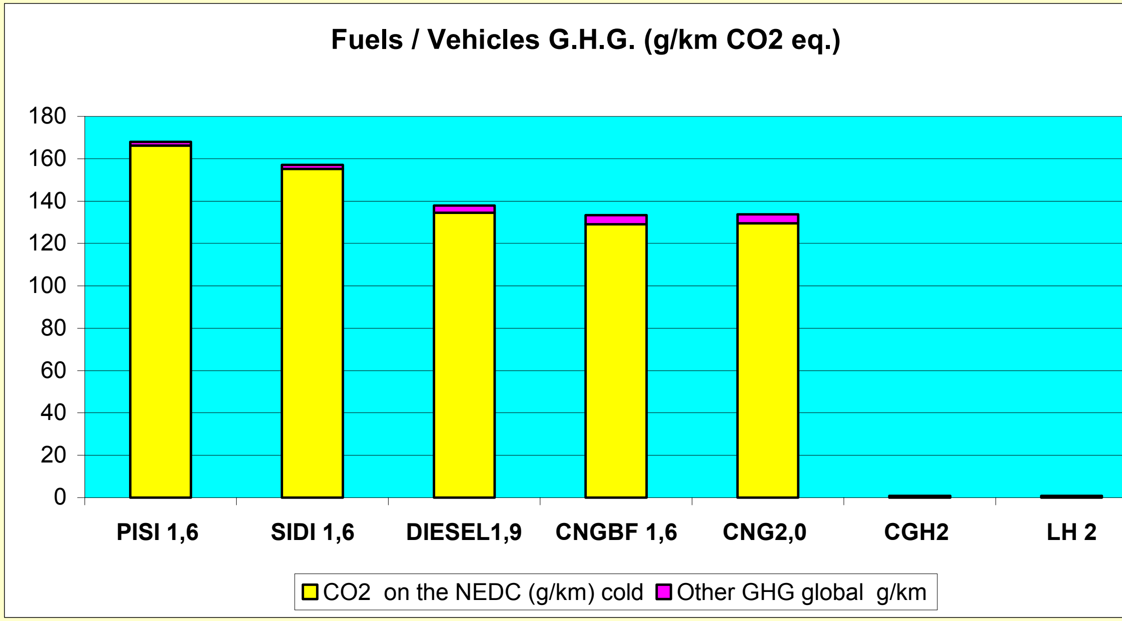
ICE engines
STATE of the ART 2002



Tank-to-Wheels study

Evolutions 2002 - 2010

- From present State of the Art until 2010, Fuel efficiency evolutions should occur, depending on:
  - the maturity of the technology
  - the specific possibilities and constraints of the fuel

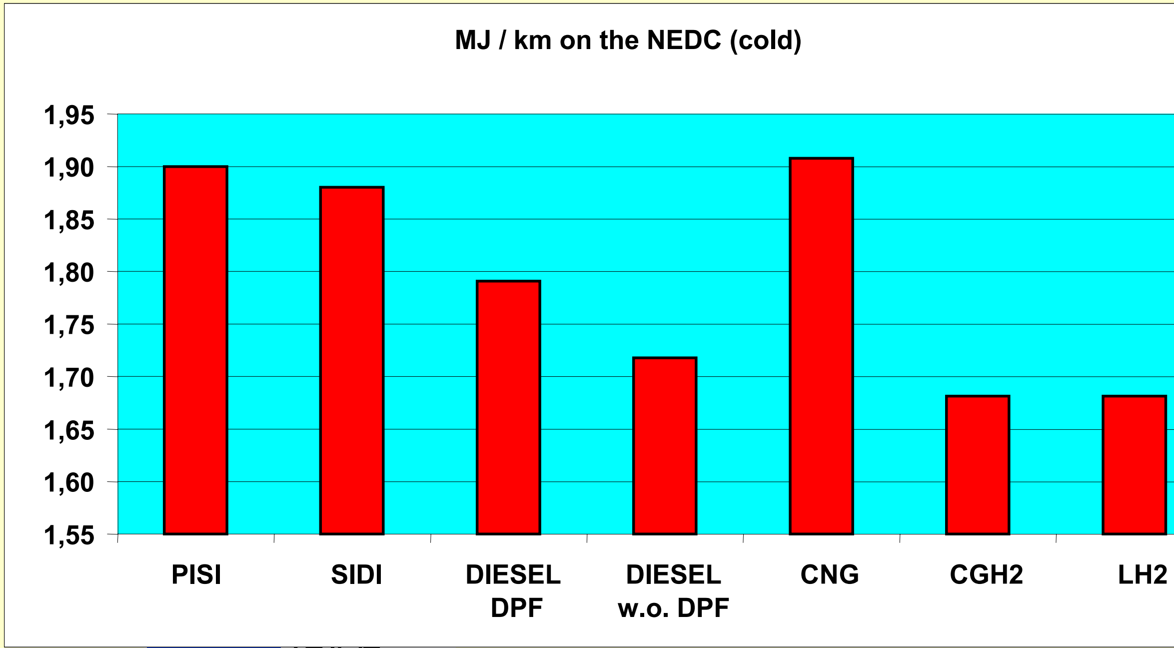
- Car manufacturers globally converge towards assumptions :
  - Port injection S.I. : + 15 % (includ. Downsizing Turbo Charged)
  - Direct injection S.I. : + 10 %
  - Diesel : + 6 % (or 2 %, only, under Particle Trap)
  - Hydrogen I.C.E. : + 6 % (D.S.T.C. already accounted as 2002)

  - Nat. Gas & H2 : + 1 % supplementary for optimal air - gas mixture

			DPF	w/o DPF		
	PISI	SIDI	DIESEL	DIESEL	CNGI	H2
2010 improvement	15	10	2	6	16	7

Tank-to-Wheels study
Compared Energy Efficiency

	Gasoline		DPF	w/o DPF			
Cold start N.E.D.C.	**PISI**	**SIDI**	**DIESEL**	**DIESEL**	**CNG**	**CGH2**	**LH2**
CO2 (g/km)	**140**	**138**	**131**	**126**	**107**	**0**	**0**
ENERGY EFF. (MJ/100km)	190,0	188,0	179,1	171,8	190,8	168,1	168,1
MASS Consump. (kg/100km)	4,43	4,38	4,17	4,00	4,23	1,40	1,40
Cons. NEDC (l/100km) 2010	5,91	5,84	4,99	4,79	5,93	5,22	5,22
Other G.H.G. (g/km)							
Methane (g/kmCO2 eq.)	0,42	0,42	0,21	0,21	0,84		
N2O (g/km CO2 eq	0,5	0,5	1,55	1,55	0,5	0,5	0,5
GHG global g/km	**140,5**	**138,9**	**133,0**	**127,6**	**108,8**	**0,5**	**0,5**



Tank-to-Wheels study
Compared G.H.G. emissions

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CO_2 (g/km)	**140**	**138**	**131**	**126**	**107**	**0**	**0**
ENERGY EFF. (MJ/100km)	190	188	179	172	191	168	168
MASS Consump. (kg/100km)	4.43	4.38	4.17	4.00	4.23	1.40	1.40
Cons. NEDC (l/100km) 2010	5.91	5.84	4.99	4.79	5.93	5.22	5.22
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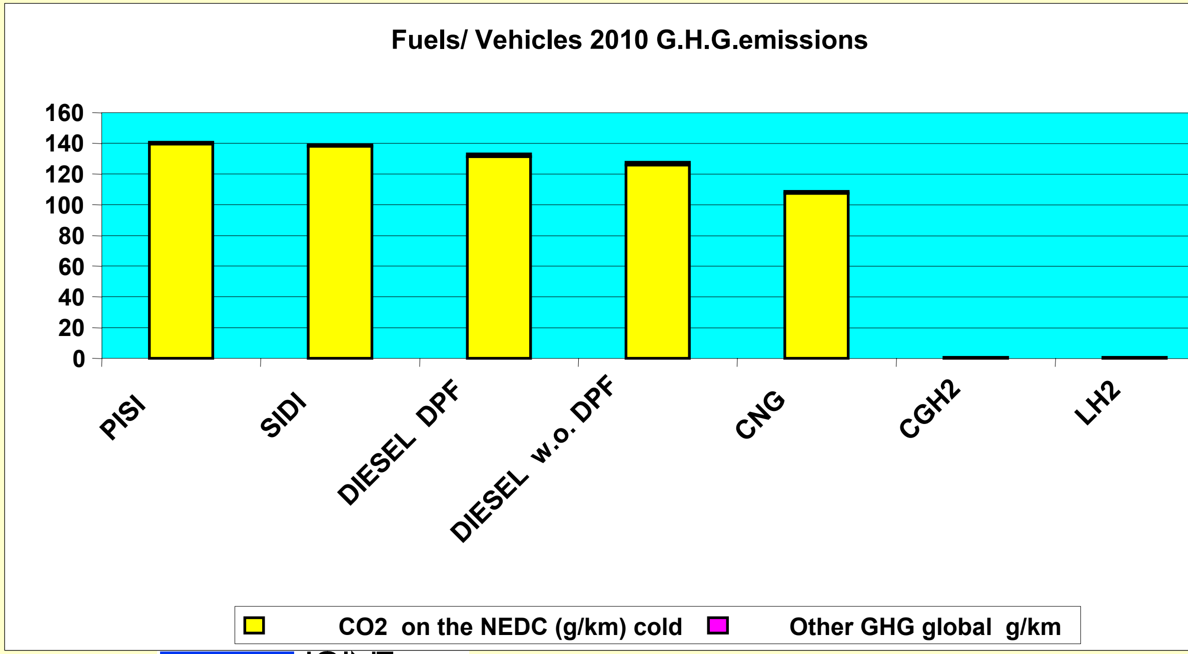
N_2O (g/km CO_2 eq	0.5	0.5	1.55	1.55	0.5	0.5	0.5
GHG global g/km	**140.5**	**138.9**	**133.0**	**127.6**	**108.8**	**0.5**	**0.5**

Forecast 2010 I.C.E.s'



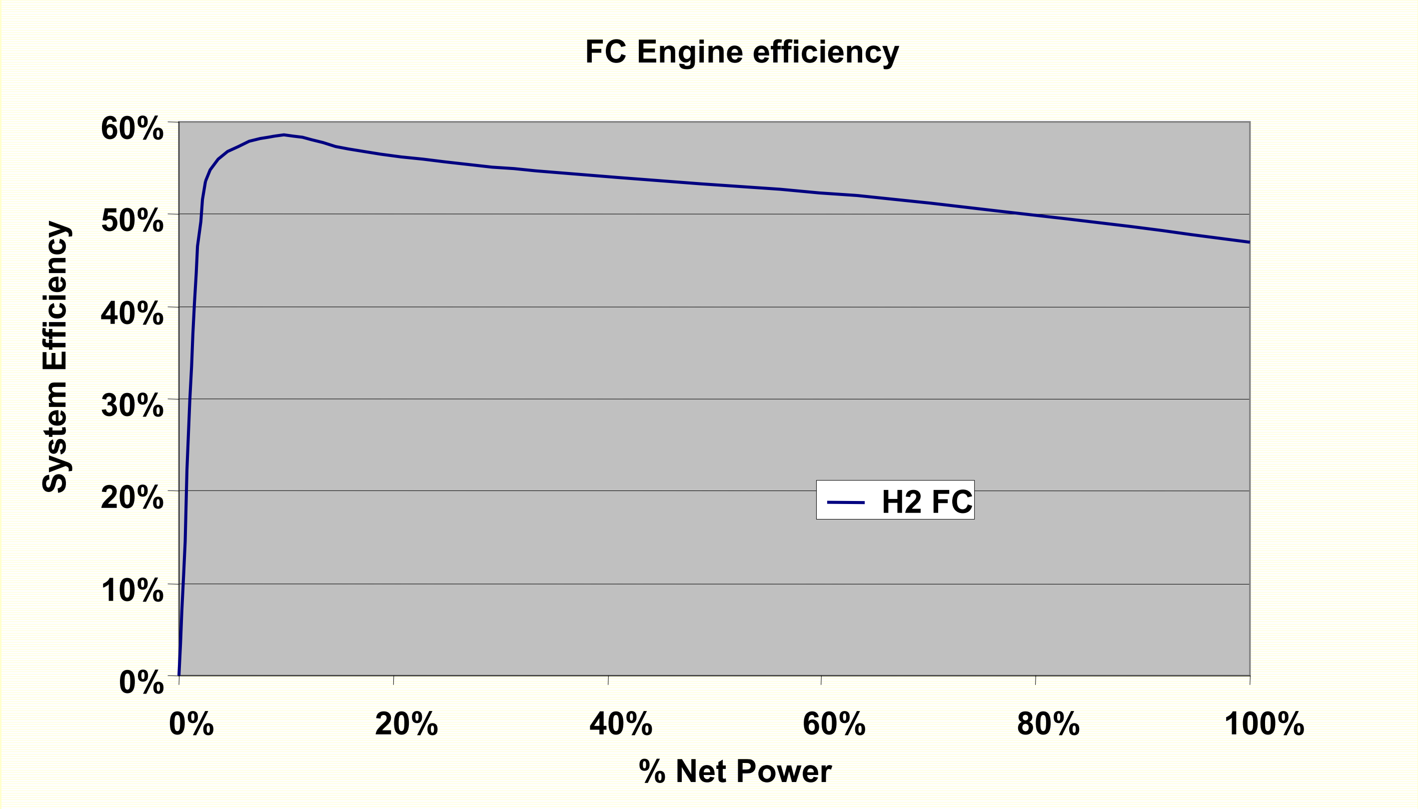
Tank-to-Wheels study

Comments : assessments 2010

- Hydrogen Fuel Cells : Stack : 80 kW, 200 kg — Elect. Motor : 75 kW, 73 kg
- Non Hybrid : Fuel : 4.7 kg — Pressure Tank : 69 kg (CryoTank : 57 kg)
- Hybrid : Fuel : 4.2 kg — Pressure Tank : 56 kg
  Batteries : 20 kg — (CryoTank : 51 kg)
  "Battery Electric" range : 20 km
- Gasoline vehicles : Cycle test weight class : 1250 kg
  Diesel, Nat.Gas, H2 vehicles : Cycle test weight class : 1360 kg
  H2 Fuel Cells vehicles : Cycle test weight class : 1470 kg

Tank-to-Wheels study

Comments : assessments 2010



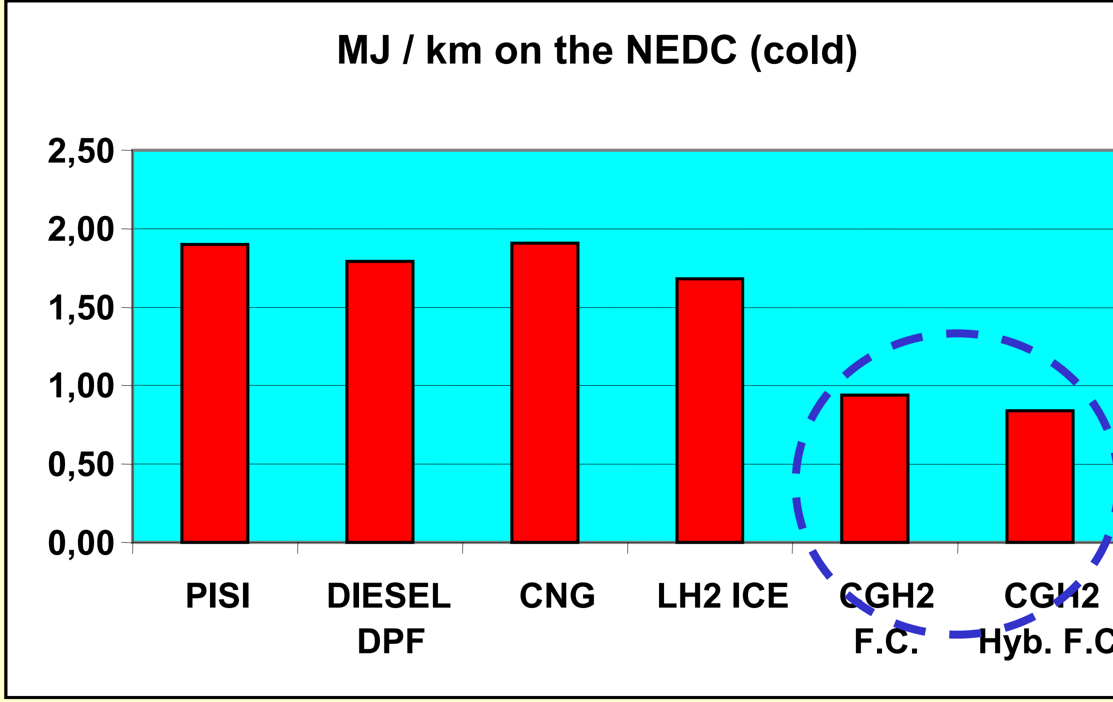
The Fuel Cell system efficiency maps, implemented in code Advisor, are an average distribution . (Sources : G.M. Opel, European program FUERO, Daimler Chrysler)

Tank-to-Wheels study

Compared Energy Efficiency

Cold start N.E.D.C.	PISI	DIESEL	CNG	LH2 ICE	CGH2 F.C.	CGH2 Hyb. F.C.
CO2 (g/km)	**140**	**131**	**107**	**0**	**0**	**0**
ENERGY EFF. (MJ/100km)	190	179	191	168	94	84
MASS Consump. (kg/100km)	4,43	4,17	4,23	1,40	0,78	0,70
Cons. NEDC (l/100km) 2010	5,91	4,99	5,93	5,22	2,92	2,60
Other G.H.G. (g/km)						
Methane (g/kmCO2 eq.)	0,42	0,21	0,84			
N2O (g/km CO2 eq	0,5	1,55	0,5	0,5		
GHG global g/km	**140,5**	**133,0**	**108,8**	**0,5**	**0,0**	**0,0**

Forecast 2010
Direct H2 Fuel Cells



Tank-to-Wheels study
Compared G.H.G. emissions

Cold start N.E.D.C.	PISI	DIESEL	CNG	LH2 ICE	CGH2 F.C.	CGH2 Hyb. F.C.
CO2 (g/km)	**140**	**131**	**107**	**0**	**0**	**0**
ENERGY EFF. (MJ/100km)	190,0	179,1	190,8	168,1	94,0	84,0
MASS Consump. (kg/100km)	4,43	4,17	4,23	1,40	0,78	0,70
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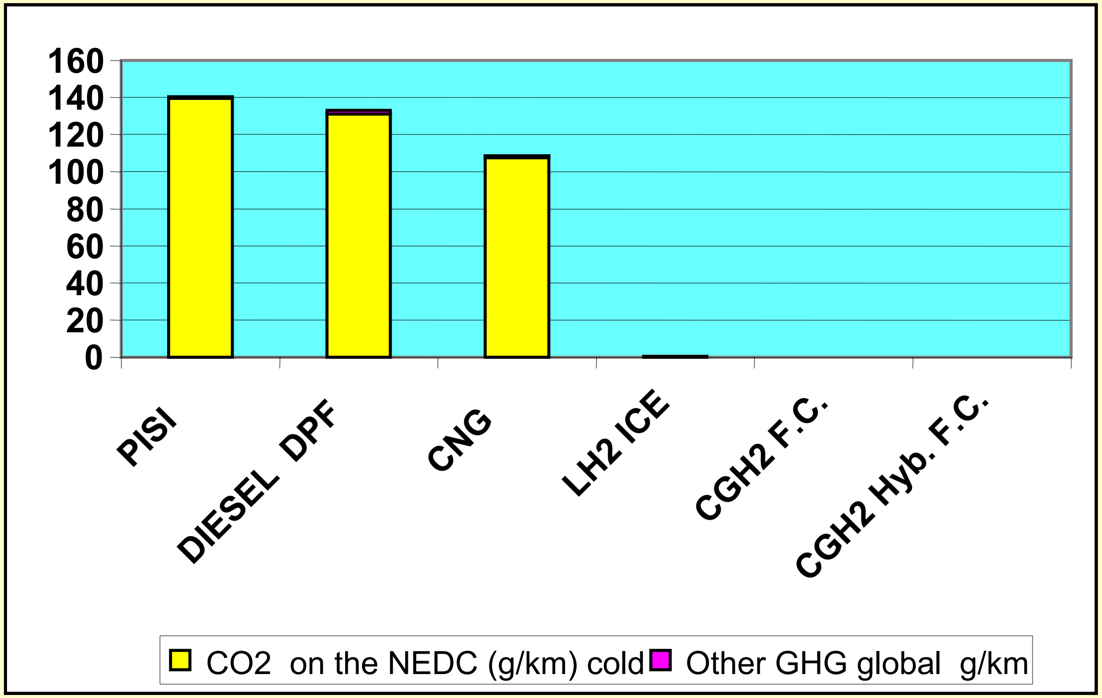
Forecast 2010
Direct H2 Fuel Cells



WELL-TO-WHEELS

Well-to-Wheels analysis SELECTED PATHWAYS

The following WTW integration aims at comparing:

2002 / 2010 technologies

Gasoline, Diesel, NG Conventionals and H_2 ICE, Direct & Hybrid FC

Fuelled by

- Diesel & Gasoline Fossil Fuel
- CNG 4000 km

for Conventionals

Compressed H2

- CH_2,NG 4000 km, on-site reforming
- CH_2 and LH_2, NG 4000 km, central reforming
- CH_2, LNG, central reforming
- CH2, farmed wood, gasifier on-site
- CH2, farmed wood, gasifier central
- CH_2, EU-mix electricity, electrolysis on-site
- CH2, EU-mix coal, gasifier central

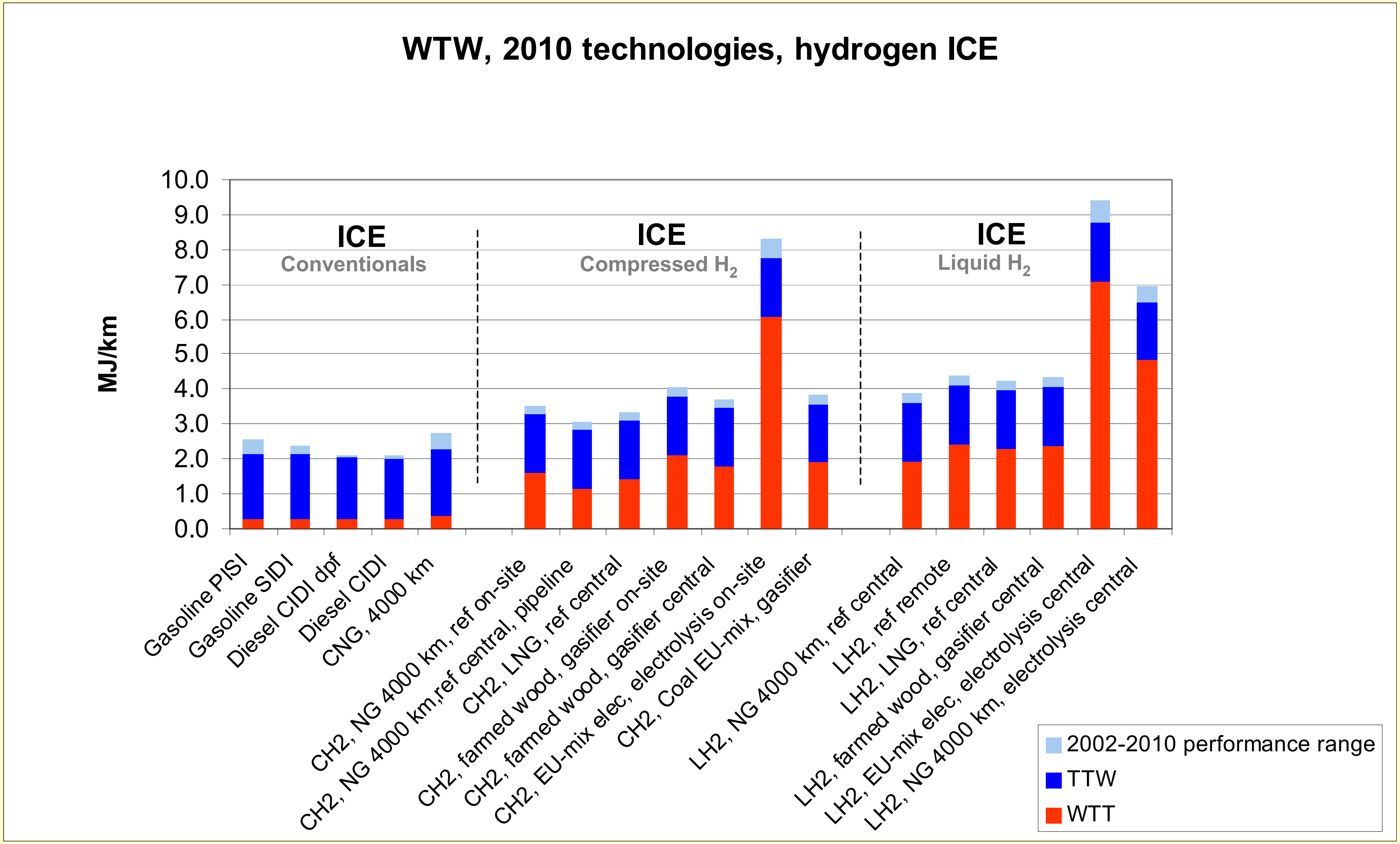
Liquid H2

- LH_2, NG 4000 km, central reforming
- LH2, remote reforming
- LH_2, LNG, central reforming
- LH2, farmed wood, gasifier central
- LH_2, EU-mix electricity, electrolysis central
- LH2, NG 4000 km, CCGT, electrolysis cen

for ICE, Direct & Hybrid FC

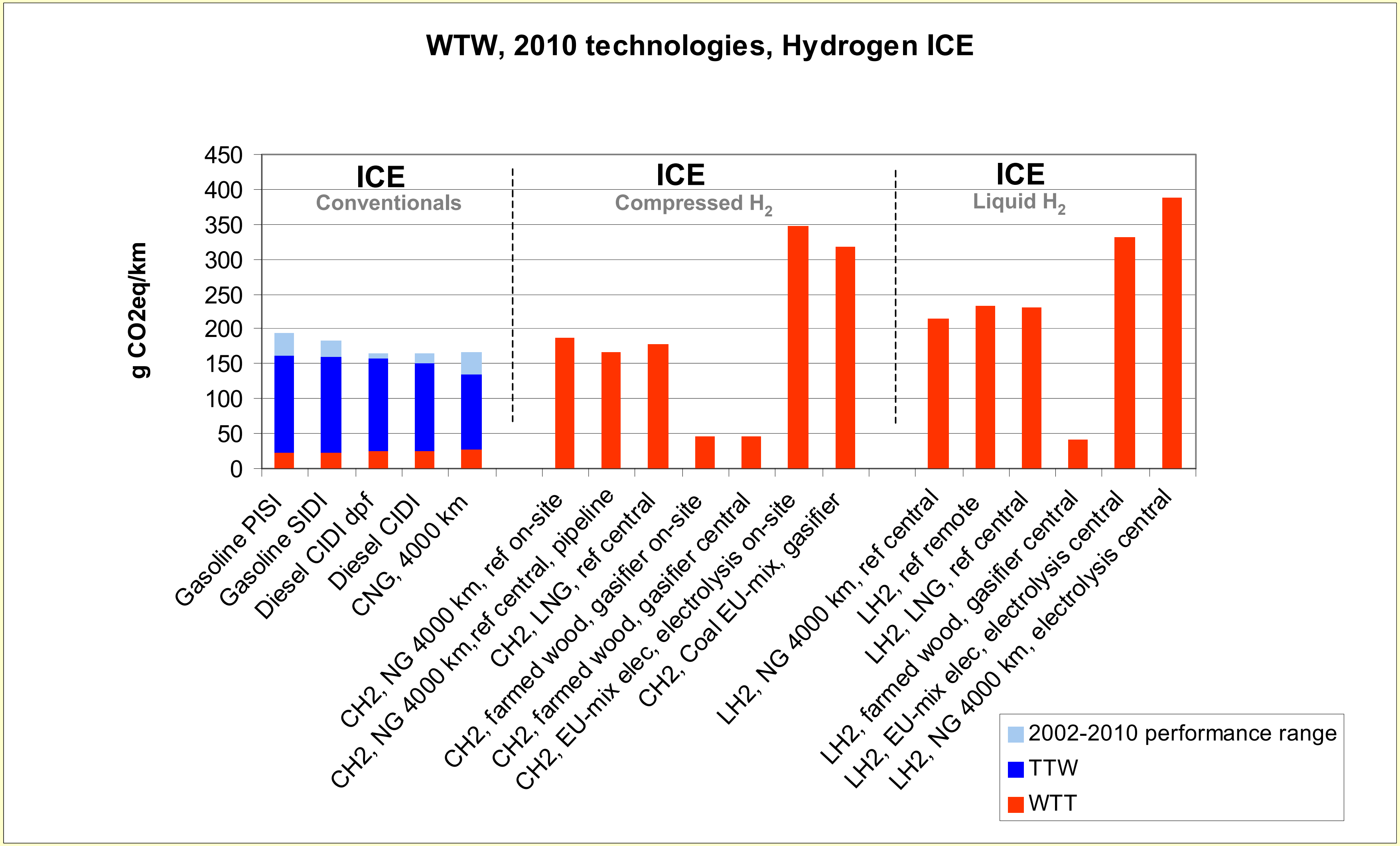
Well-to-Wheels analysis
ICE H2 vs conventional pathways

Prelimina



Well-to-Wheels analysis
ICE H_2 vs conventional pathways

Prelimina



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Well-to-Wheels assessment
Fuels / Vehicles assumptions 2010
Remarks for ICE

Global Primary Energy Intensity: for all fossil energy sources, used in ICE:

LH2 > CGH2 > Conventional fuels

Highest energy use --Lowest energy use

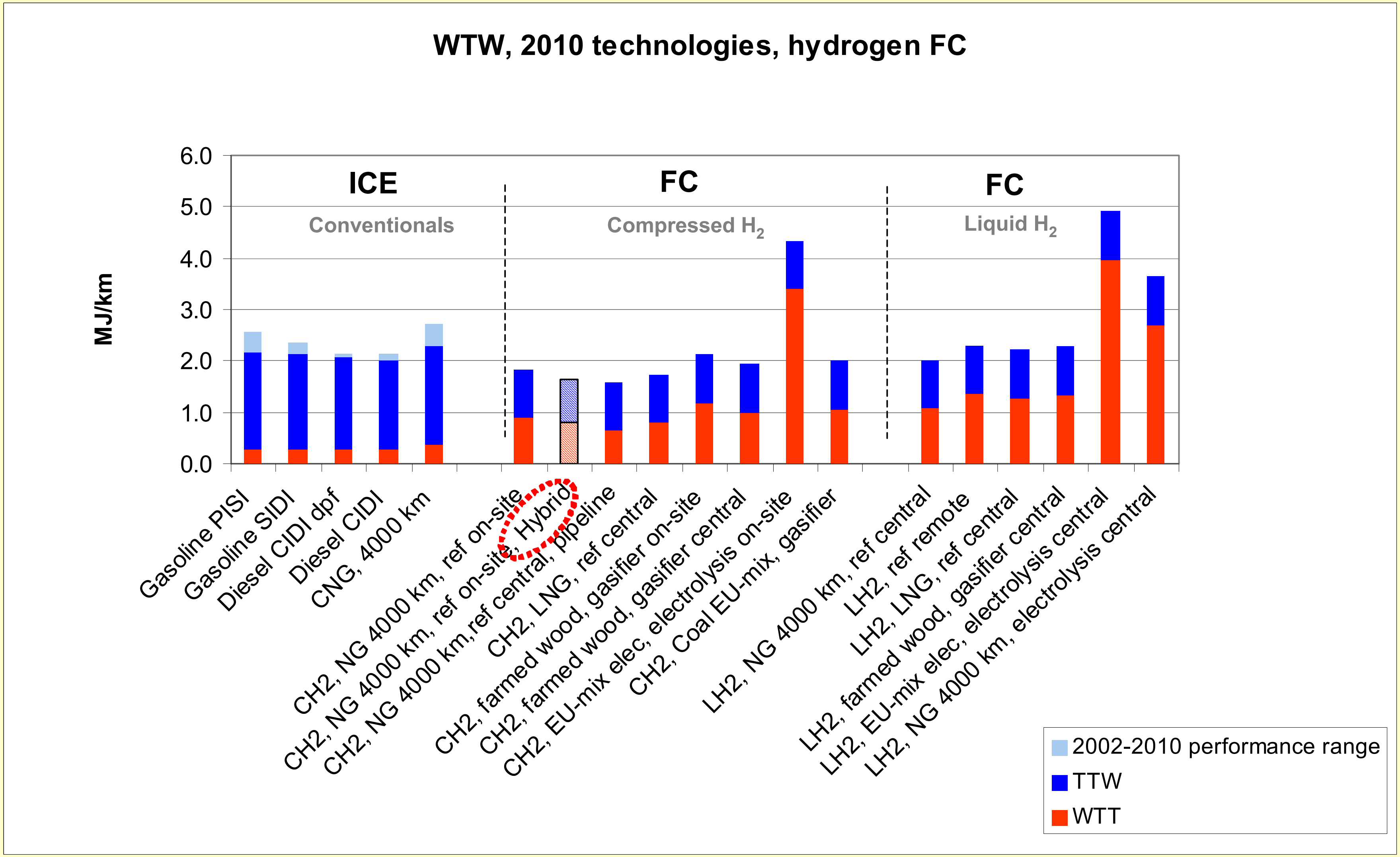
GHG global impact :

- Direct use of NG as CNG better than hydrogen
- Hydrogen ICE more GHG-intensive than conventional engines/fuels
- Electrolysis worst option unless electricity is from renewable source
- Coal could only compete with CO_2 sequestration

Renewable sources obviously give best GHG but…
Are there alternative use for these?

Well-to-Wheels analysis
Fuel Cell vs conventional pathways

Preliminary



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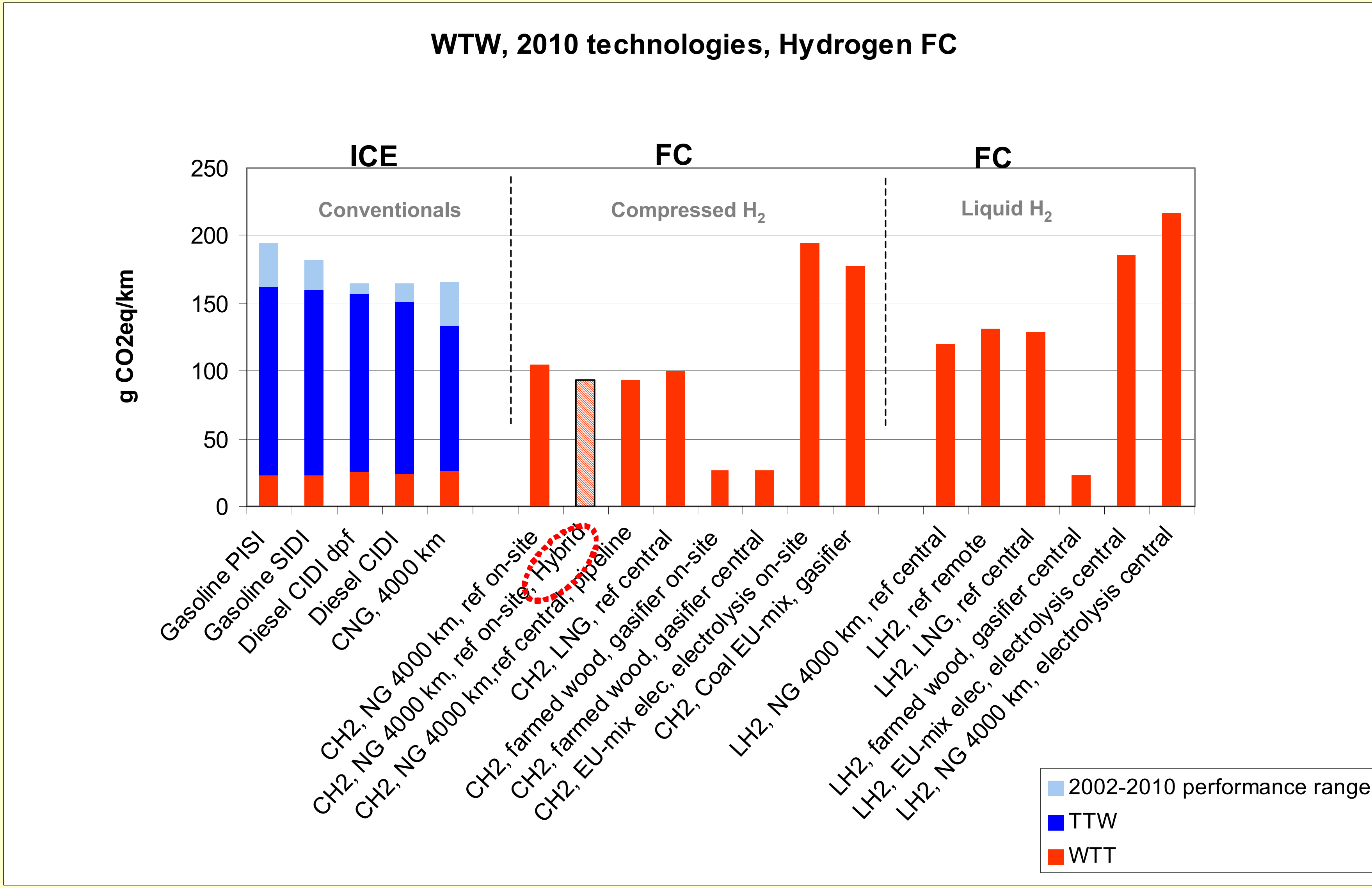
Well-to-Wheels analysis
FC vs conventional pathways

Prelimina



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Well-to-Wheels assessment

Fuels / Vehicles ICE - F.C. 2010

Remarks

Global Primary Energy Intensity: for all fossil sources:

LH_2/FC ~ conventional ICEs > CH_2/FC

Highest energy use ---Lowest energy use

GHG global impact :

- **H_2 Fuel Cells, even with H2 from NG, compare favourably with conventional fuels ICE's**
- **Worst option remains Electrolysis from EU-mix power**

ICE hybrids still to be calculated