

# Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems - A European Study - Results

at <http://www.lbst.de/gm-wtw>

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Presented by Reinhold Wurster  
at WHEC15, Yokohama, 28 June 2004





## Study commissioned by GM

- Well-to-Tank (Fuel) work conducted by L-B-Systemtechnik (LBST) with input from BP, ExxonMobil, Shell and TotalFinaElf
- Tank-to-Wheel (Vehicle) work performed by GM



Considers 14 fuels (88 fuel “pathways”) and 22 conventional and advanced powertrain systems, targeted to 2010 timeframe

# GM Well-to-Wheel Study - Well-to-Tank Pathways Analyzed

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Feedstock



Fuel

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Oil-Based (3)

Gasoline, Diesel, Naphtha

Natural Gas-Based (10)

CNG, Methanol, Fischer-Tropsch Diesel and Naphtha (GTL), Compressed Hydrogen, Liquid Hydrogen

Electricity (7)

Electricity, Compressed Hydrogen, Liquid Hydrogen

Biomass-Based (12)

Compressed Hydrogen, Methanol, Ethanol, Hydrocarbon Liquids, CMG, Bio-ester, ETBE, MTBE

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Total pathways examined:

32 [+ 56 variants]

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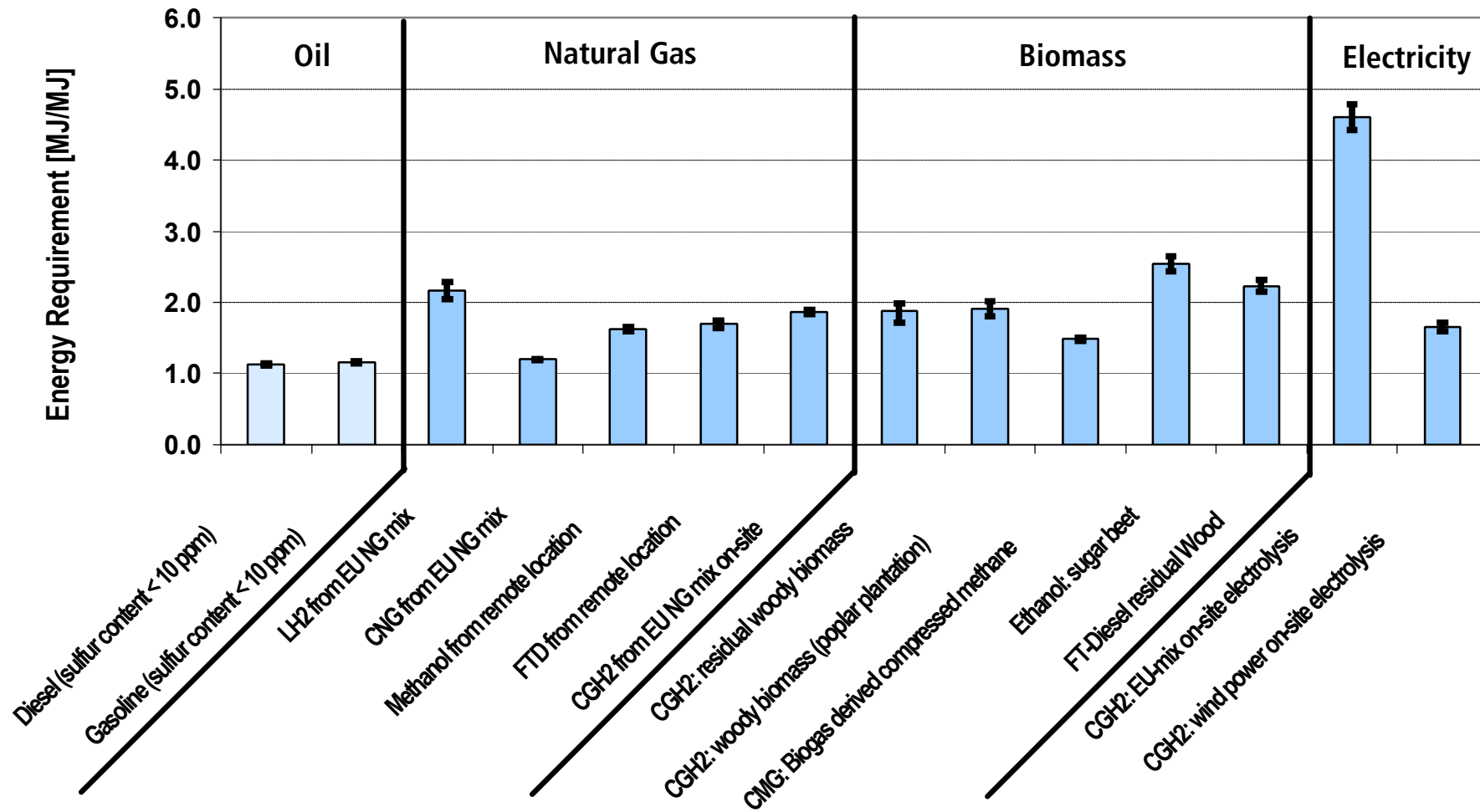


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# Well-to-Tank

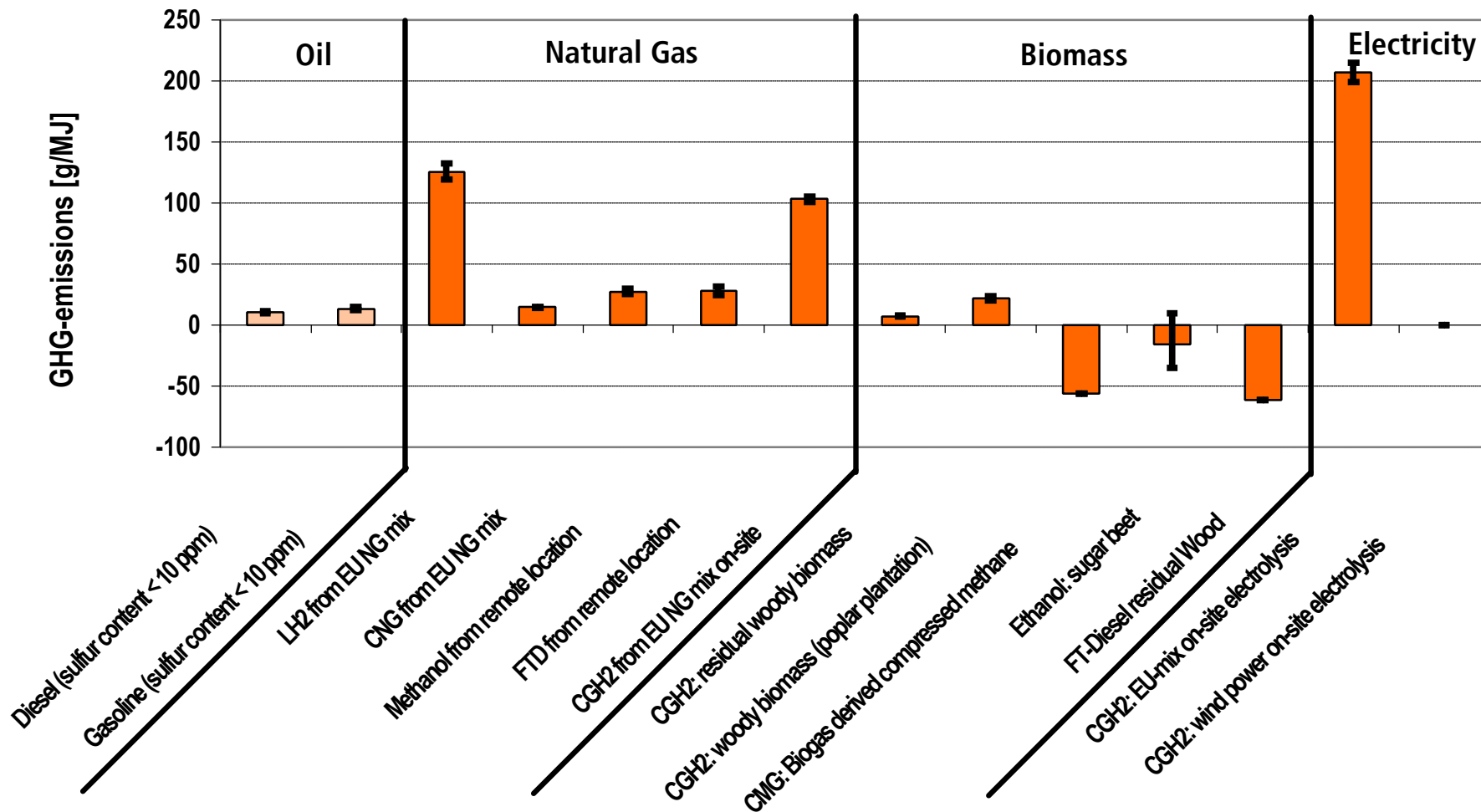
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# Energy Requirements: Well-to-Tank



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# GHG Emissions (CO<sub>2</sub> Equivalent): Well-to-Tank



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## Tank-to-Wheel

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## GM Well-to-Wheel Study

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### European Tank-to-Wheel Analysis (Vehicle Pathways)

- Baseline vehicle: Opel Zafira
- Duty cycle: European Driving Cycle (EDC)
- All vehicle concepts modeled to meet same set of European customer performance requirements
- Technologies targeted for the 2010 time frame
  - Advanced IC engine and transmission technologies
  - Advanced vehicle level technologies
  - Hybrid system technologies
  - Fuel processor and fuel cell systems in hybrid and non-hybrid architectures



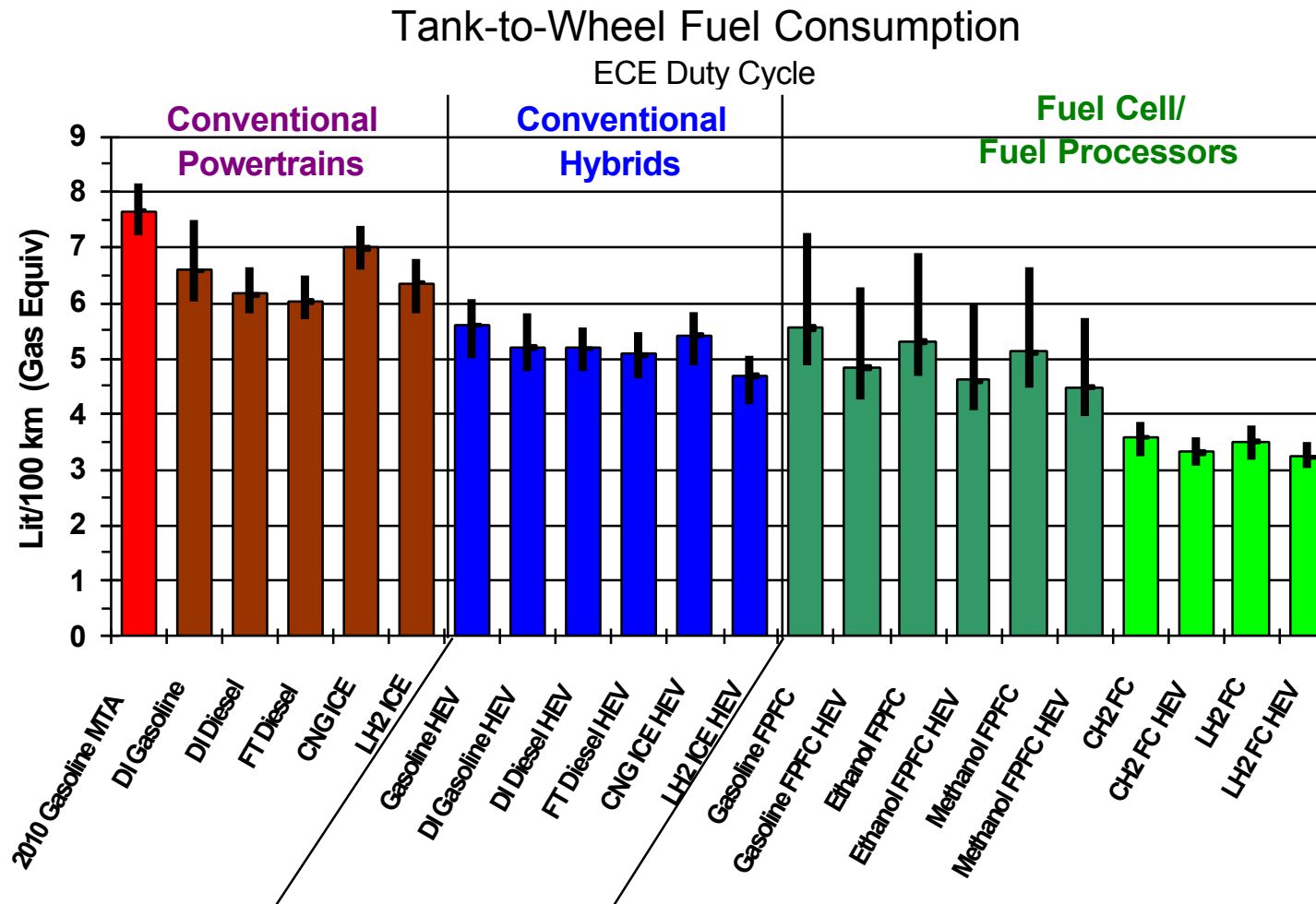
# GM Well-to-Wheel Study - Powertrains



	IC Engine	IC Engine Hybrid	Fuel Cell Non-Hybrid	Fuel Cell Hybrid
Gasoline	X	X	X	X
+Advanced Powertrain				
Diesel	X	X		
FT Diesel	X	X		
CNG	X	X		
Methanol			X	X
Ethanol (E100)			X	X
Hydrogen	X	X	X	X

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# GM Well-to-Wheel Study - TTW Fuel Consumption



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## Well-to-Wheel

Remark:

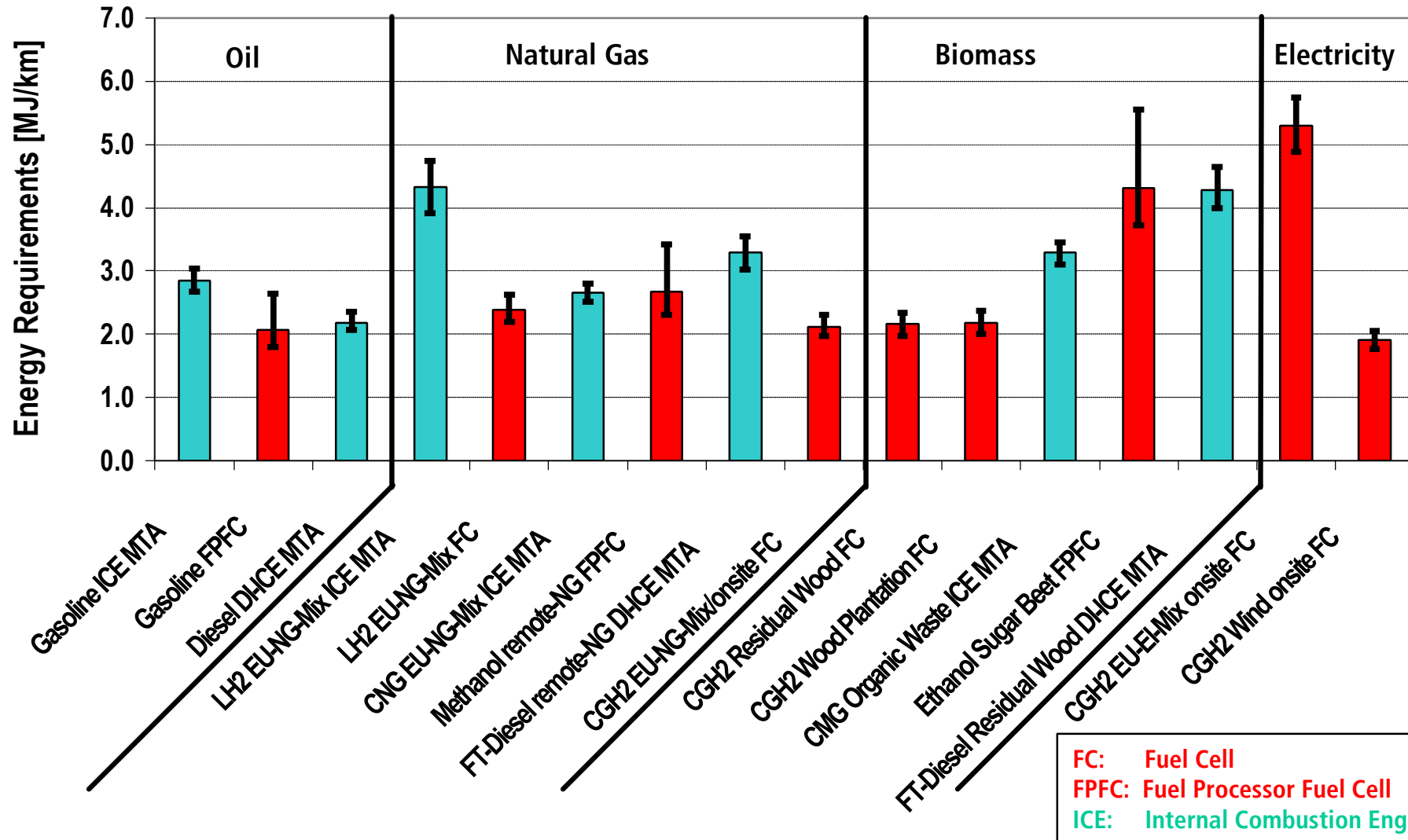
(no energy requirements for manufacturing  
have been considered in this study)

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# Energy Requirements: Well-to-Wheel



Vehicle: Opel Zafira

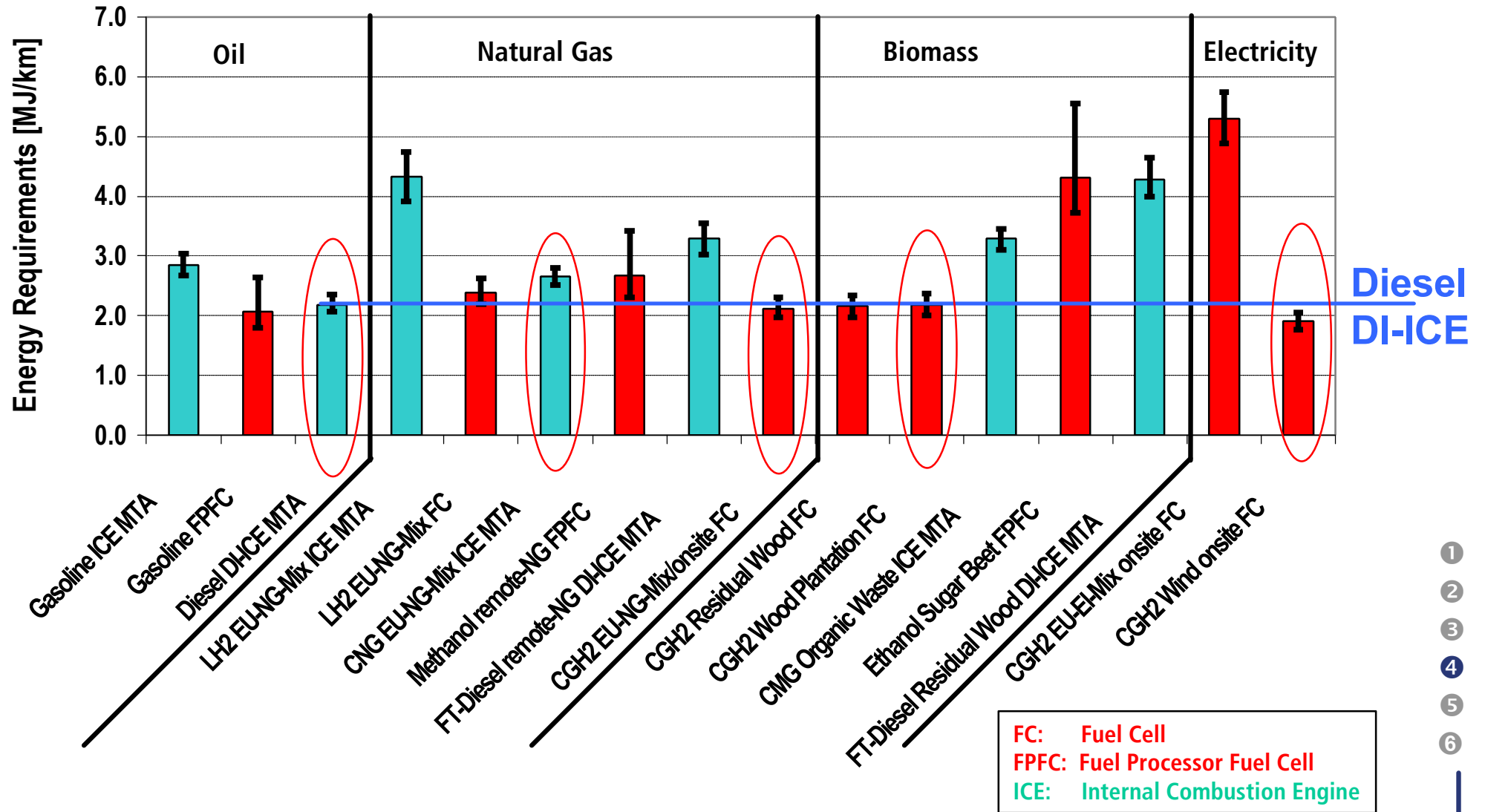


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# Energy Requirements: Well-to-Wheel



Vehicle: Opel Zafira

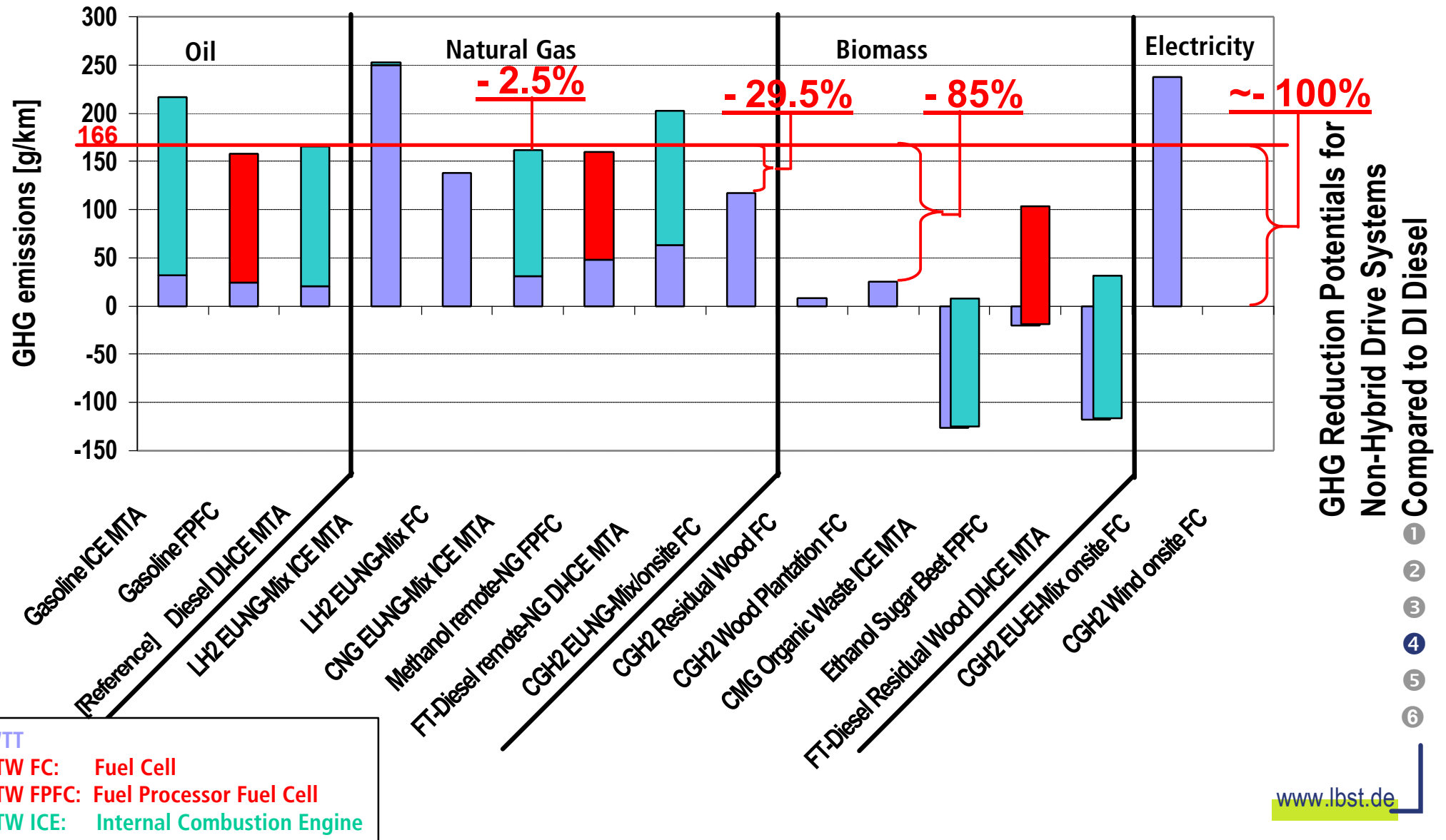


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# GHG Emissions (CO<sub>2</sub> Equivalent): Split into WTT and WTW



Vehicle: Opel Zafira



**WTT**  
 TTW FC: Fuel Cell  
 TTW FPFC: Fuel Processor Fuel Cell  
 TTW ICE: Internal Combustion Engine

GHG Reduction Potentials for  
 Non-Hybrid Drive Systems  
 Compared to DI Diesel

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## Some Conclusions from the GM Study

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## GM Well-to-Wheel Study - Key Findings of WTW Analyses

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- Energy consumption and GHG emissions must be assessed on a full WTW basis for a meaningful assessment of the competing fuel-vehicle pathways
- Clear advantage for hybrid ICE vehicles with Otto-cycle engines (gasoline, CNG, hydrogen) with regard to energy consumption
- Clear advantage for FCVs in GHG emissions and fuel economy
- Hydrogen has the highest feedstock flexibility of all fuels
- Best biomass derived fuel is hydrogen
- Renewable energy derived hydrogen is the superior fuel pathway, regarding GHG emissions

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## GM Well-to-Wheel Study - Key Findings of WTW Analyses (2)

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- NG-derived hybridized CGH<sub>2</sub> FCV is 25% better in GHG emissions than the hybridized CNG vehicle
- NG-derived CGH<sub>2</sub> FCV is almost 30% better in GHG emissions than CNG vehicle
- ICE vehicles fueled with liquid hydrogen from natural gas offer zero vehicle GHG emissions, but result in higher WTW GHG emissions than either conventional gasoline or diesel ICE vehicles
- Methanol reformer based FCVs have no real advantage over advanced diesel vehicles, have slight advantages over gasoline ICE vehicles, no advantages over gasoline onboard reforming vehicles

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- Hydrogen from traditional electric grid mix shows no advantages at all
- Advantage of switching to GTL (FT diesel) is non-existent
- Biomass pathways depending on given situation differ widely in GHG emissions
- The differences are mainly attributable to N<sub>2</sub>O emissions which depend on type of soil, nitrogen fertilizer input and climatic conditions which vary widely in different regions of Europe
- Carbon release (CO<sub>2</sub> emissions) caused by land use change was not considered (but may have a significant influence)

## Websites of L-B-Systemtechnik

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L-B-Systemtechnik Website:  
[www.lbst.de](http://www.lbst.de)

Information on hydrogen and fuel cells:  
[www.HyWeb.de](http://www.HyWeb.de)

Information on fossile energy resources:  
[www.energiekrise.de](http://www.energiekrise.de)

Hydrogen and fuel-cell vehicle overview:  
[www.h2cars.de](http://www.h2cars.de)

Information on fuel cells:  
[www.innovation-brennstoffzelle.de](http://www.innovation-brennstoffzelle.de)

Information on hydrogen projects:  
[www.h2guide.de](http://www.h2guide.de)

European Integrated Hydrogen Project:  
[www.eihp.org](http://www.eihp.org)

**EIHP**

HyNet - The European Thematic Network on  
Hydrogen:  
[www.HyNet.info](http://www.HyNet.info)



HyWays - The Development and Detailed  
Evaluation of a Harmonised “European  
Hydrogen Energy Roadmap”  
[www.HyWays.de](http://www.HyWays.de)

**HyWays**

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