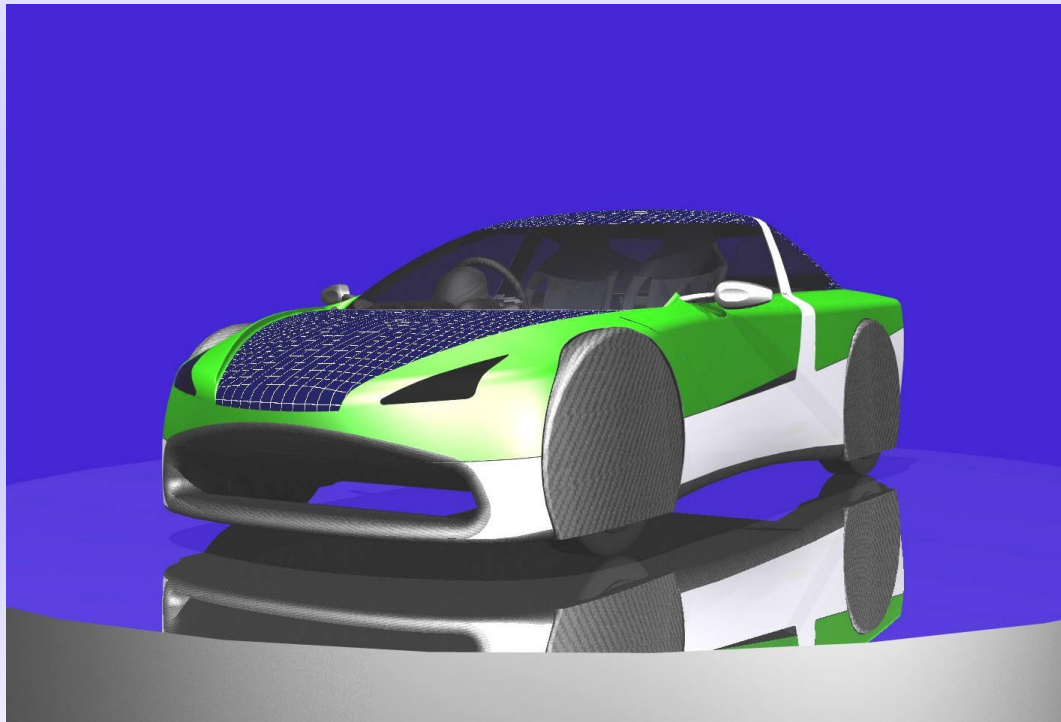


Comparing Future Alternative Fuels and Powertrain Technologies for Vehicles



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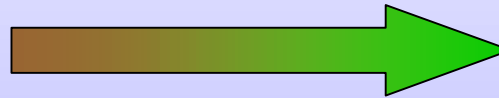
Presentation Overview

- Drivers for sustainable mobility
- Candidate fuels and powertrain technologies
- Comparing the options: **Well-to-Wheels** analysis
- Previous well-to-wheels studies in literature
- Results of a recent well-to-wheels study at UQ to compare future alternative fuels and powertrain technologies for Australian passenger cars
- Conclusions and Future Work

Drivers for Sustainable Mobility

Energy Security

Oil-based
propulsion



Non-oil-based
propulsion

Global Warming

Fossil
energy



Renewable
energy

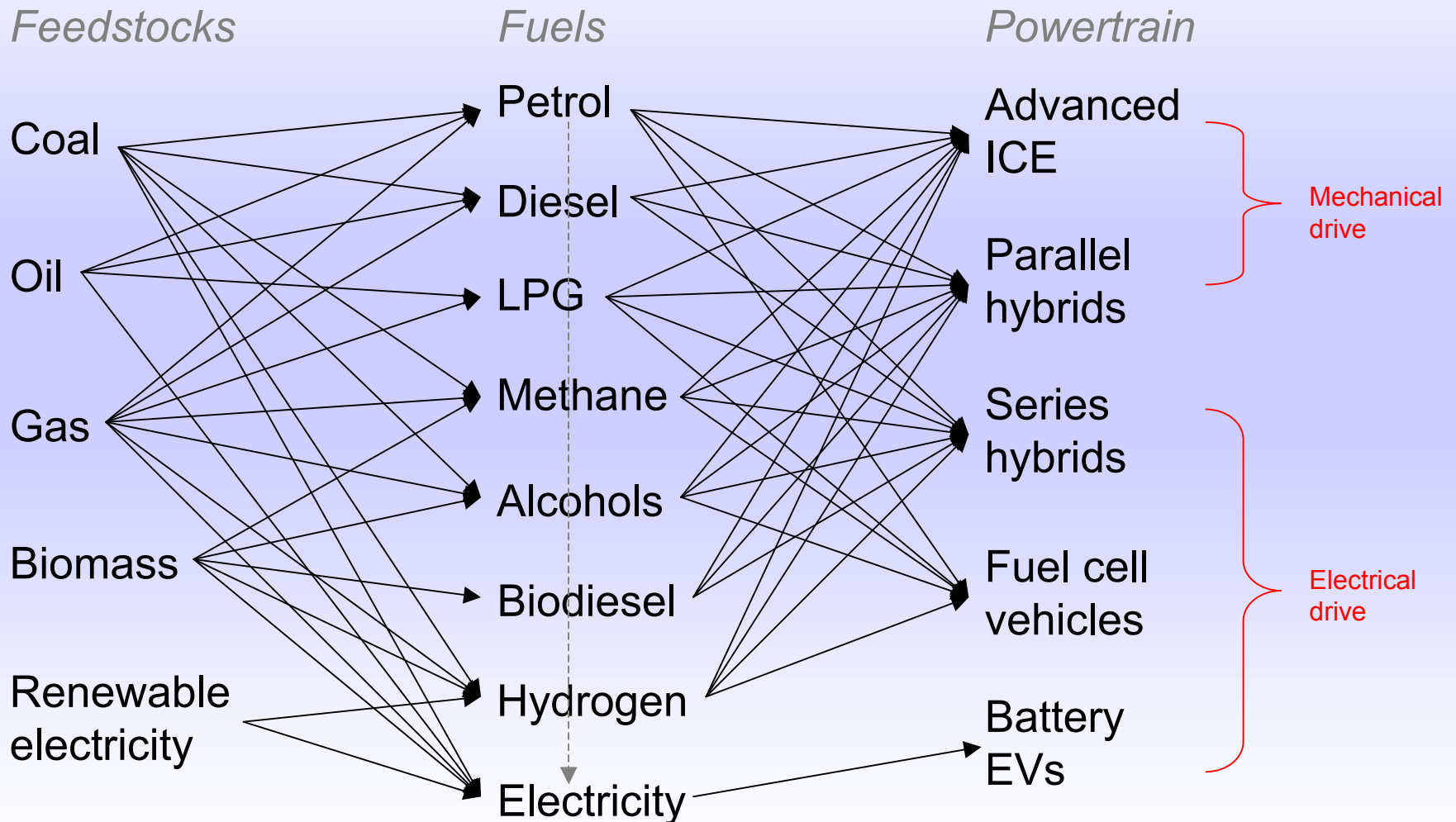
Urban Health

CO, NO_x,
HC, PM
emissions



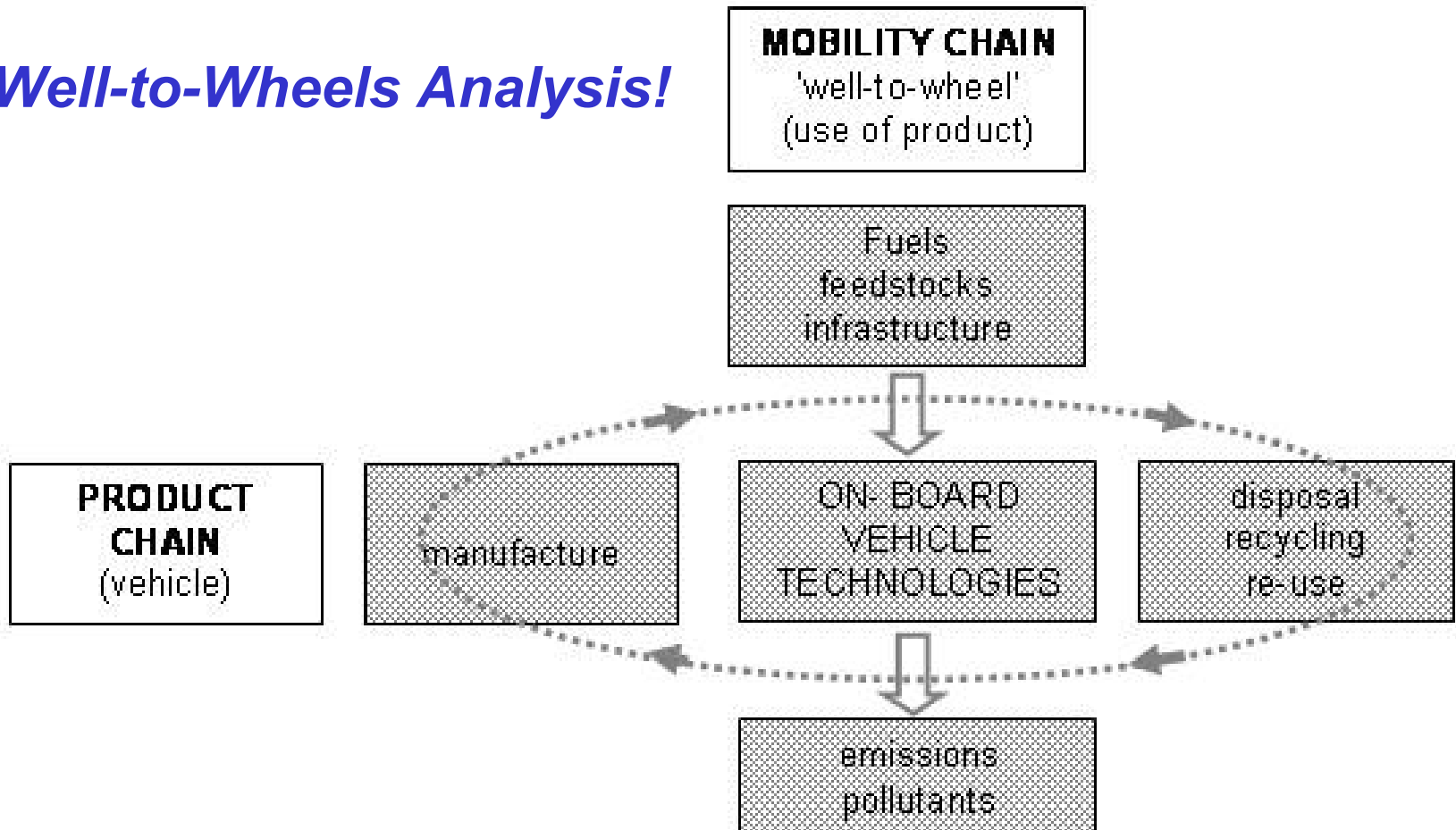
Zero
emissions

Candidate Fuels and Powertrain Technologies



How can we compare the options?

Well-to-Wheels Analysis!



Well-to-Wheels Analysis

Well-to-wheel (WTW) analysis looks consistently across the entire chain and examines all aspects of fuel production and use, including feedstocks, energy consumption, emissions, safety, technology, costs and infrastructure (International Energy Agency, 1999).

The WTW chain is normally considered in two stages

- ***well-to-tank (WTT)***
- ***tank-to-wheels (TTW)***
- fuel storage onboard the vehicle is the mid-way point

Well-to-Wheels Analysis

Well-to-wheels energy consumption:

$$\begin{array}{ccc}
 \text{WTW energy} & \text{Embodied energy in fuel} & \text{Vehicle energy consumption} \\
 \underbrace{\hspace{10em}} & \underbrace{\hspace{10em}} & \underbrace{\hspace{10em}} \\
 (MJ_{WTW} / km) = (MJ_{WTW} / MJ_{TTW}) \times (MJ_{TTW} / km)
 \end{array}$$

Well-to-wheels greenhouse emissions:

$$\begin{array}{ccc}
 \text{WTW GHGs} & \text{Embodied GHGs in fuel} & \text{Vehicle energy consumption} \\
 \underbrace{\hspace{10em}} & \underbrace{\hspace{10em}} & \underbrace{\hspace{10em}} \\
 (gCO_2 - e_{WTW} / km) = [(gCO_2 - e_{WTT} / MJ_{TTW}) + (gCO_2 - e_{TTW} / MJ_{TTW})] \times (MJ_{TTW} / km)
 \end{array}$$

Well-to-Tank (WTT) Stage

Important to define:

- What energy feedstock a fuel is produced from
- What chemical processing occurs in the WTT stage
- How a feedstock and fuel are transported and distributed
- How a fuel is stored onboard the vehicle

Well-to-tank results differ greatly for:

- ***different energy feedstocks*** (e.g. diesel from crude oil vs synthetic diesel from natural gas)
- ***different methods of onboard fuel storage*** (e.g. gaseous hydrogen vs liquid hydrogen)
- ***different geographical locations*** (e.g. Australia vs USA)

Tank-to-Wheel (TTW) Stage

Vehicle energy consumption is an important parameter in the calculation of WTW results.

Vehicle energy consumption is **highly sensitive to**:

- choice of fuel and powertrain technology
- **vehicle platform** (mass and drag)
- **performance requirements** (which determine size and mass of powertrain components)

→ Fuels and powertrain technologies should be compared on the basis of **equivalent platforms and equivalent performance.**

Previous Well-to-Wheels Studies in Literature

CSIRO (Beer et al, 2001):

- Only considered heavy vehicles (trucks, buses...)
- Considered WTW greenhouse gases and regulated emissions – didn't consider WTW energy consumption!
- Didn't consider methanol, electricity or liquid hydrogen fuels
- Didn't consider hybrid-electric or battery-electric powertrains
- Neglected key WTT stages for some fuels (e.g. H₂ compression)
- Tried to account for variations in vehicle energy consumption, but didn't enforce equivalent performance criteria
- Prior to UQ study, was the only published well-to-wheels study relevant to the Australian context

Previous Well-to-Wheels Studies in Literature

Shell (Louis, 2001):

- Considered light-duty vehicles
- Included all fuels and powertrain options
- Relevant to UK context
- Tried to account for variations in vehicle energy consumption but
 - Used vehicle platforms with substantially different mass and drag characteristics
 - Didn't enforce equivalent performance criteria

Previous Well-to-Wheels Studies in Literature

General Motors (Weber et al, 2001)¹ and (Wurster, 2002)²:

- Considered light-duty vehicles
- Relevant to USA¹ and European² contexts
- Didn't include battery-electric powertrains
- Enforced equivalent performance criteria!
- Modelled variations in vehicle energy consumption, but made inconsistent assumptions that seemed to advantage fuel cell powertrains and disadvantage hybrid-electric powertrains and natural gas vehicles

Methodology for UQ Study

WTT stage:

- CSIRO data used to provide relevance to Australian context, also cross-referenced against GM data where necessary

TTW stage:

- A parametric modelling tool (Simpson & Walker, 2003) was developed to:
 - Model variations in energy consumption for different fuels and powertrain technologies
 - Use a consistent vehicle platform
 - Enforce equivalent performance criteria

WTW pathways were compared in terms of full-cycle energy consumption and greenhouse gas emissions (GHGs).

Scope of UQ Study

Feedstocks	Fuels	Powertrains
Black coal Natural gas Crude oil Renewable electricity Biomass	Unleaded petrol (ULP) Diesel Fischer-Tropsch diesel (FTD) Biodiesel Liquefied petroleum gas (LPG) Compressed natural gas (CNG) Liquefied natural gas (LNG) Gaseous hydrogen (GH ₂) Liquid hydrogen (LH ₂) Ethanol (EtOH) Methanol (MeOH) Electricity	ICE hybrid-electric vehicles (HEV) Fuel cell hybrid vehicles (FCHEV) Battery-electric vehicles (BEV)

Vehicle Platform: Holden VY Commodore

<i>Configuration:</i>	4 door sedan
<i>Size (L / W / H):</i>	4868 / 1842 / 1440mm
<i>Curb mass:</i>	1550kg
<i>Drag coefficient (C_D):</i>	0.32
<i>Fuel consumption:</i>	11.0L/100km



Performance Targets

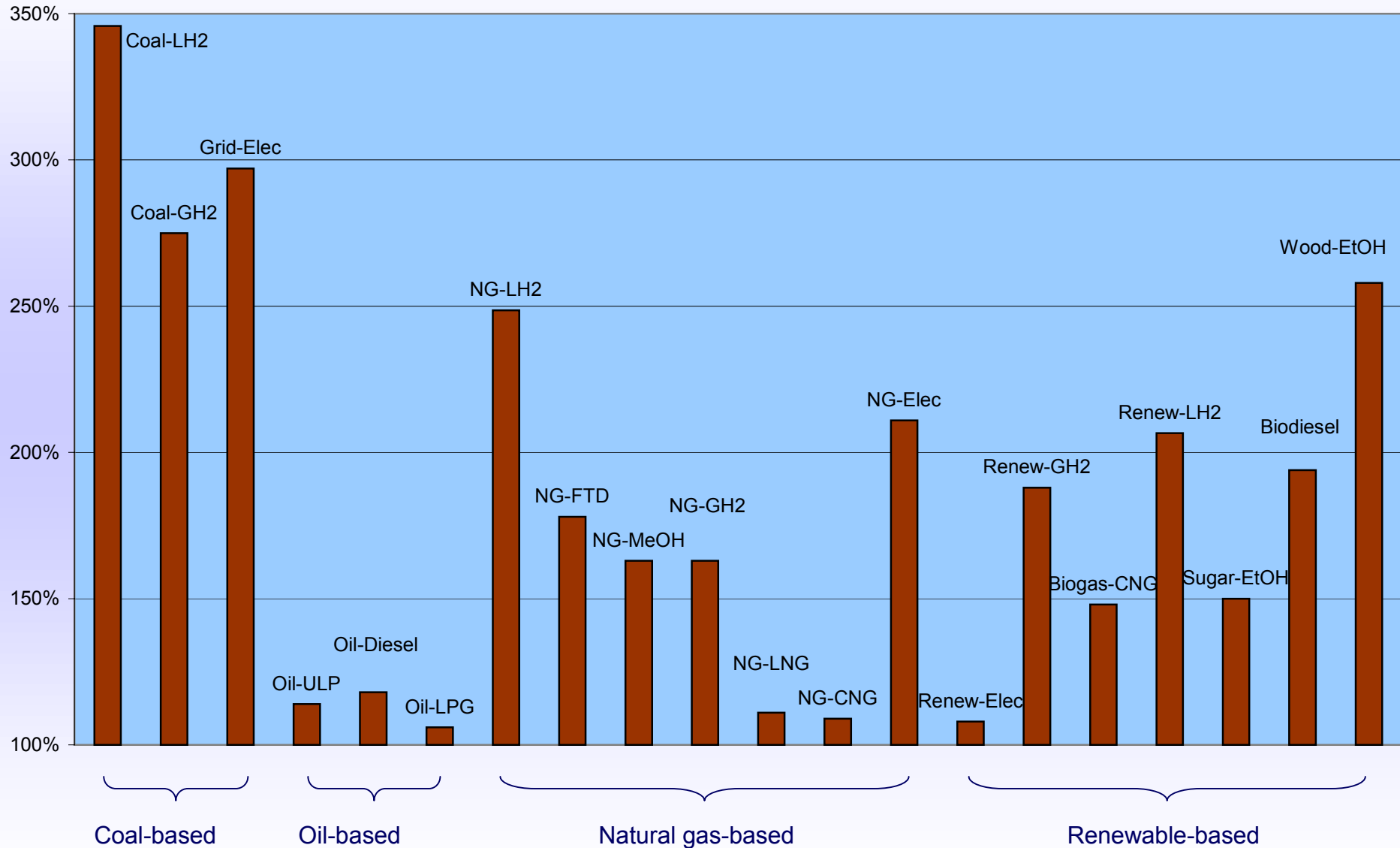
Top speed	180kph
Acceleration time (0-100kph)	9.0 s
Continuous gradability	6.5% @ 100kph
Maximum driving range	500km

All of the simulated vehicles in this study were designed to meet these criteria!

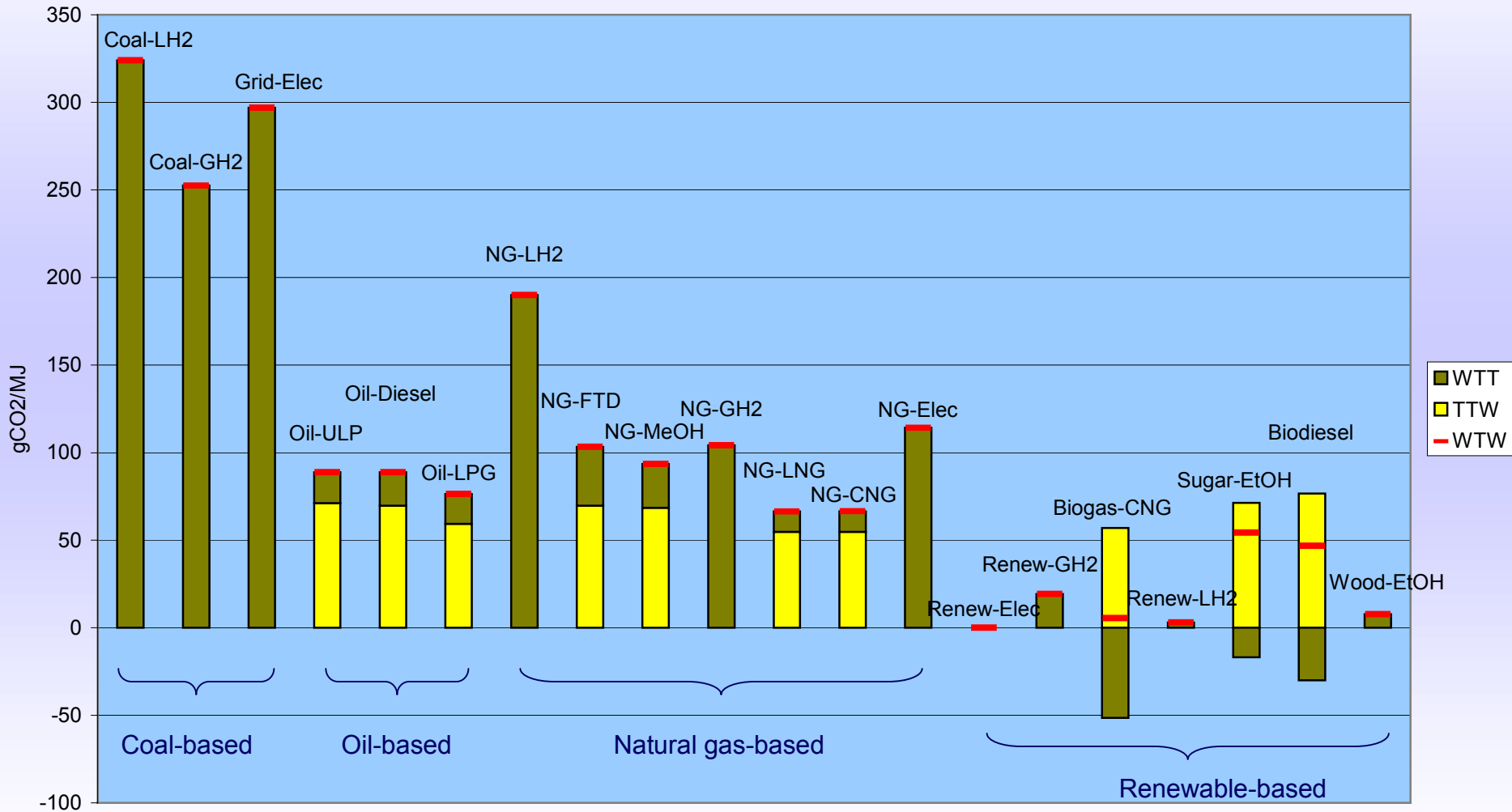
Well-to-Tank (WTT) Stage

A total of 20 WTT pathways were considered for 12 fuels...

Embodied energy for various fuels



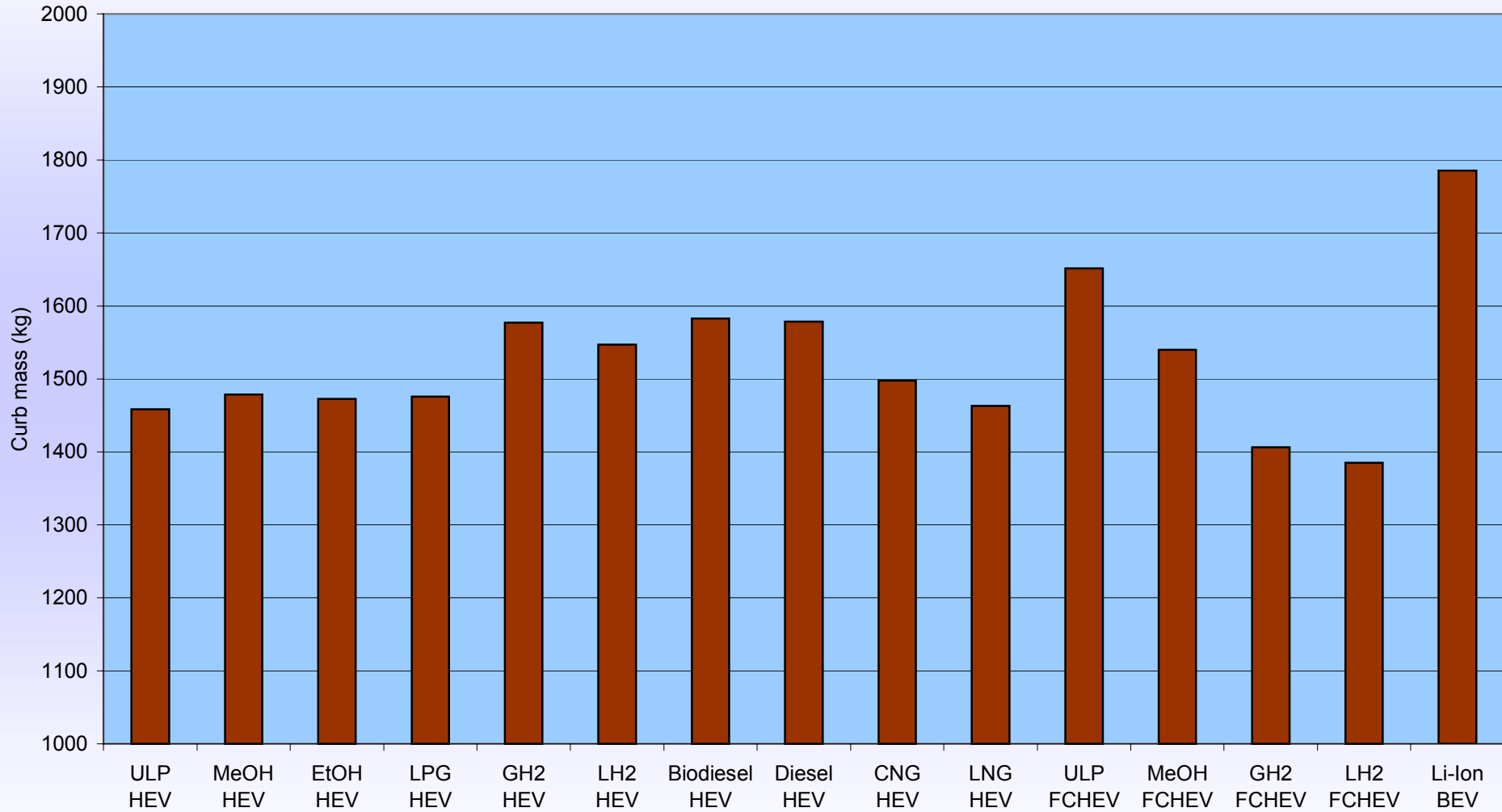
Exbodied greenhouse gas emissions for various fuels



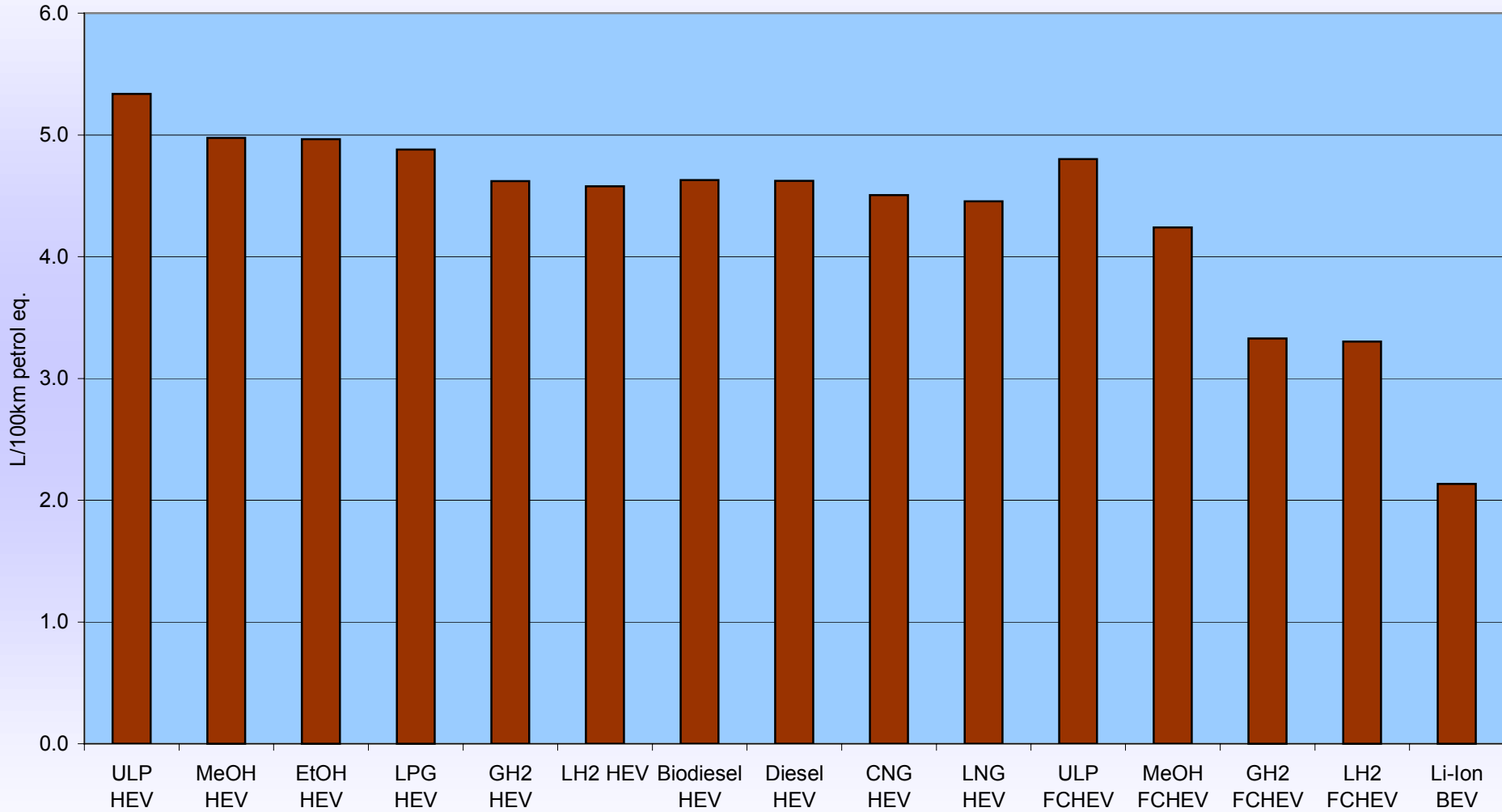
Tank-to-Wheel (TTW) Stage

Based on the Holden VY Commodore platform, a total of 15 TTW powertrains were considered for the 12 fuels...

Vehicle curb mass for various fuel + powertrain combinations



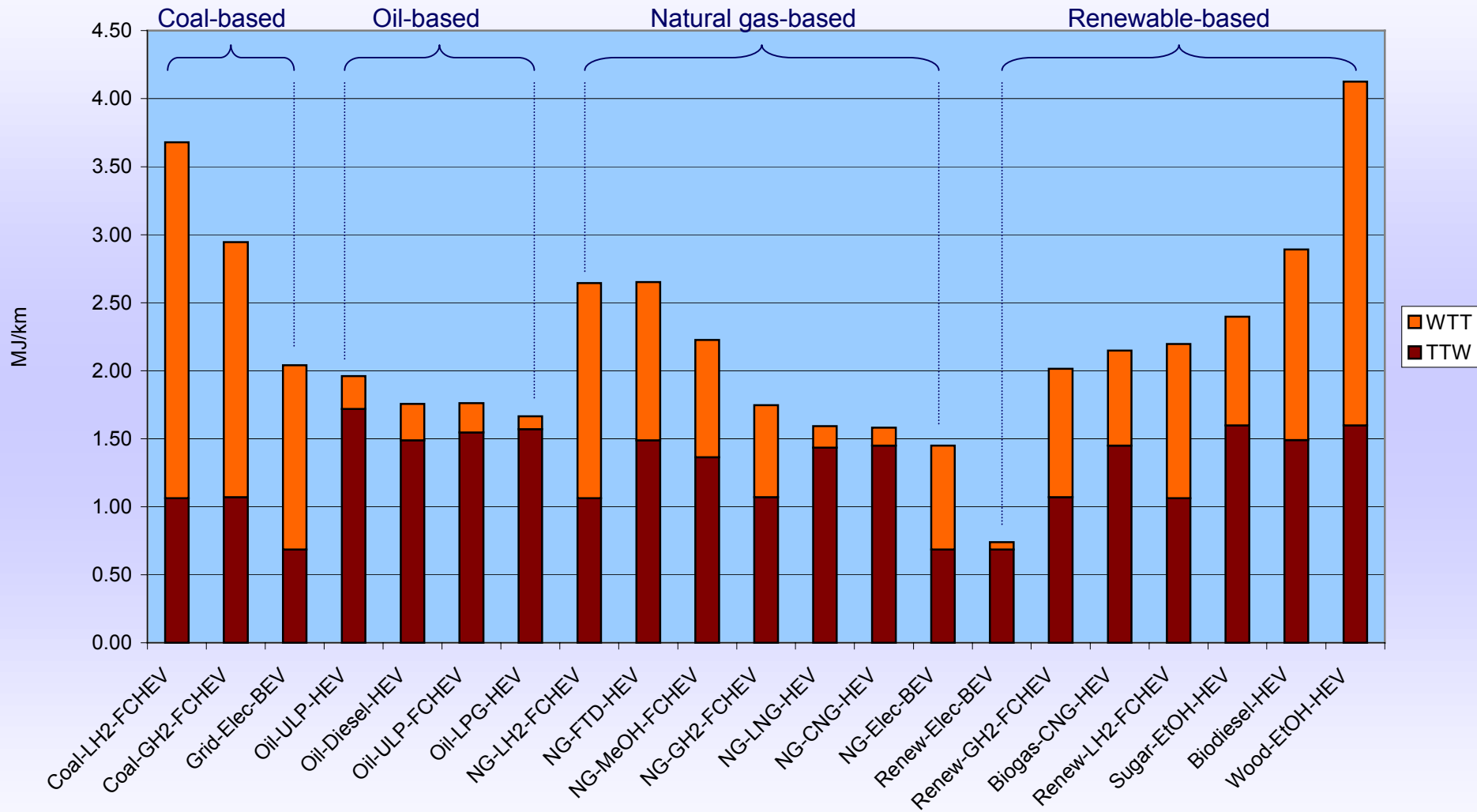
Vehicle Energy Consumption for Various Fuel + Powertrain Combinations



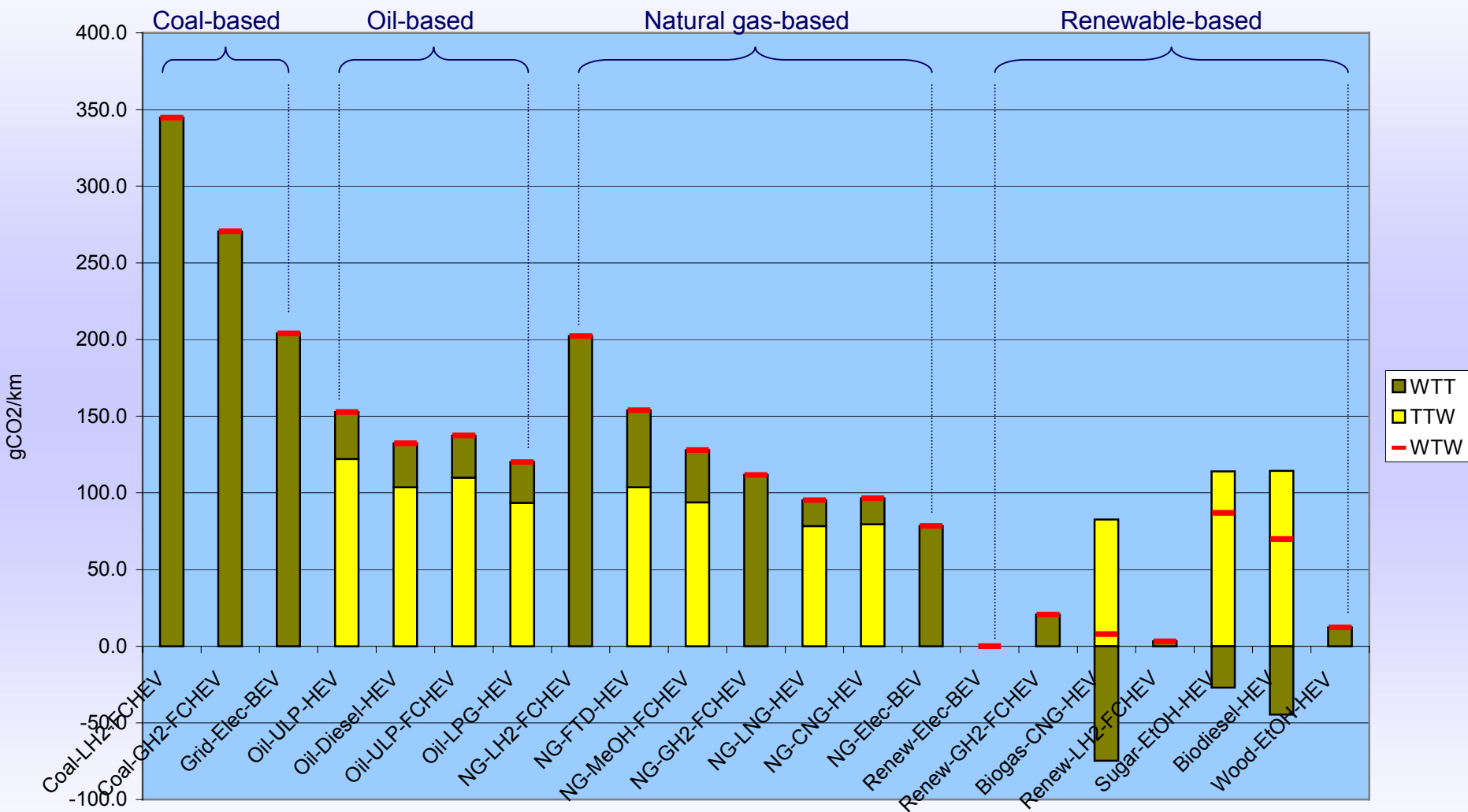
Well-to-Wheel (WTW) Results

For each fuel, the most-efficient powertrain technology was selected and used to calculate WTW results for the 20 WTT pathways.

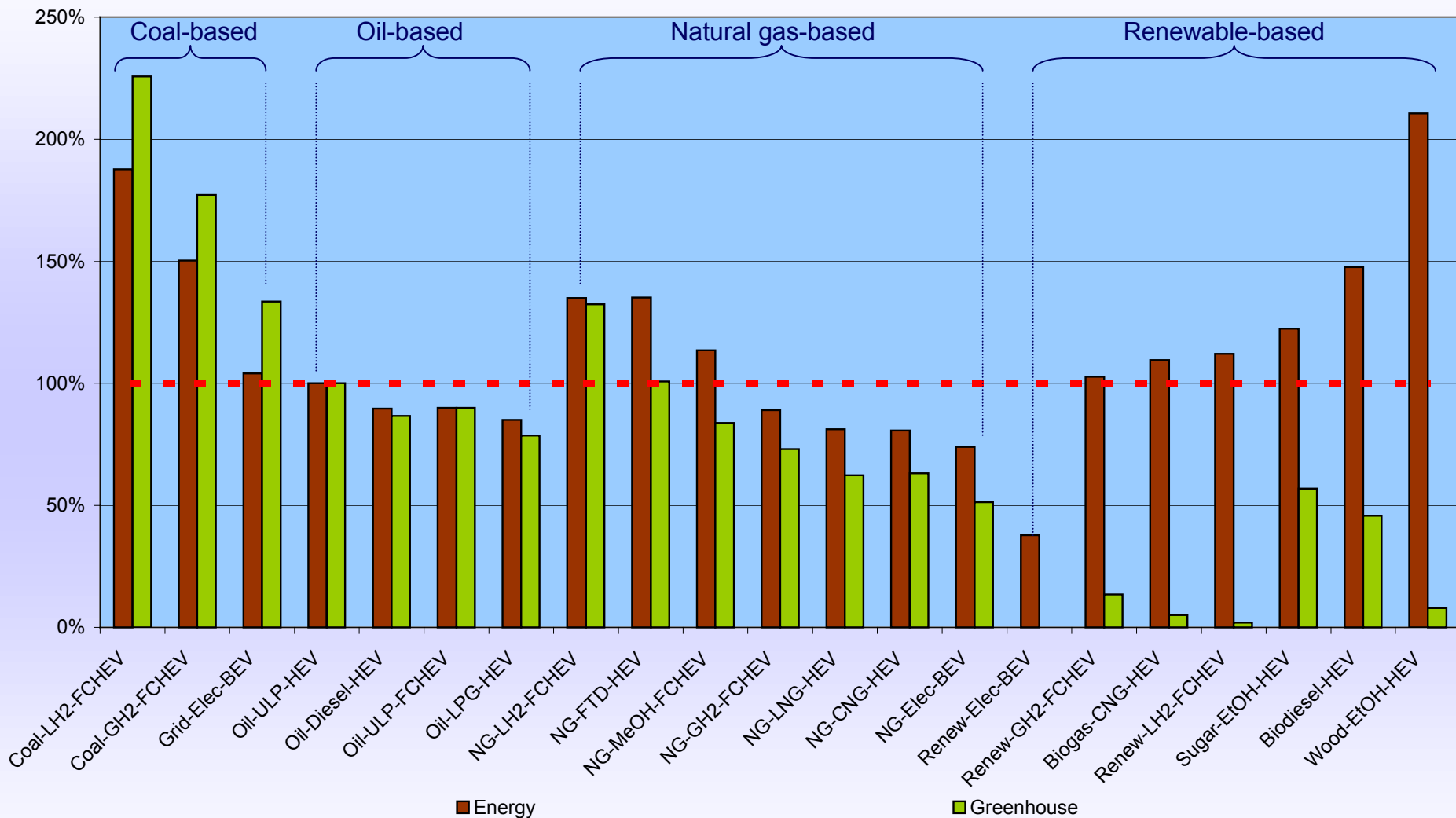
Well to Wheel Energy Consumption



Well to Wheel Greenhouse Emissions



Relative Well-to-Wheels Results



WTW Study Conclusions

1. Direct utilisation of fuels is best, avoiding unnecessary energy conversion steps
2. Coal pathways have extremely high WTW energy and GHGs!
3. Biofuels have large embodied energy and therefore may not be a practical choice for reducing greenhouse emissions from transport.
4. Hydrogen fuel suffers a major disadvantage because of point 1.
5. Natural gas seems to be a promising transitional energy feedstock for automotive fuels, based on its versatility in use and low WTW energy and GHGs.
6. BEVs are by far the most efficient powertrain technology and provide the lowest WTW energy consumption and greenhouse gas emissions for a given feedstock

What about Urban Emissions?

Urban emissions were not considered in this study, however:

- Present-day HEVs are achieving negligible emissions of pollutants (e.g. Toyota Prius)
- Reformer-based fuel cell systems can do even better
- Direct hydrogen fuel cells and battery-powered systems can achieve zero tailpipe emissions

Upstream (well-to-tank) emissions of air pollutants for various fuel pathways needs further study...

Future work

- Repeat for different platforms and performance targets (e.g. 4x4 wagon) to examine sensitivity of results
- Publish this study in international journals
- Use WTW results to conduct a study of mitigation costs for GHG emissions from the transport sector
- Focused research on promising technologies

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- T. Weber et al (2001) Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – North American Analysis, General Motors Corporation, Detroit.
- R. Wurster et al (2002) Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study, L-B-Systemtechnik GmbH, Ottobrunn.

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