FACULTY OF ENGINEERING
AND ARCHITECTURE

DEPARTMENT OF FLOW, HEAT AND COMBUSTION MECHANICS
TRANSPORT TECHNOLOGY RESEARCH GROUP

TECHBOOST 2019

Towards climate-friendly road transport

Sebastian Verhelst

GHENT
UNIVERSITY

CLAIMS

GHENT UNIVERSITY

There is no such thing as

“zero emissions”

Basic physics show that a

hydrogen economy

is not feasible

Basic chemistry shows that an

electric economy

is not feasible

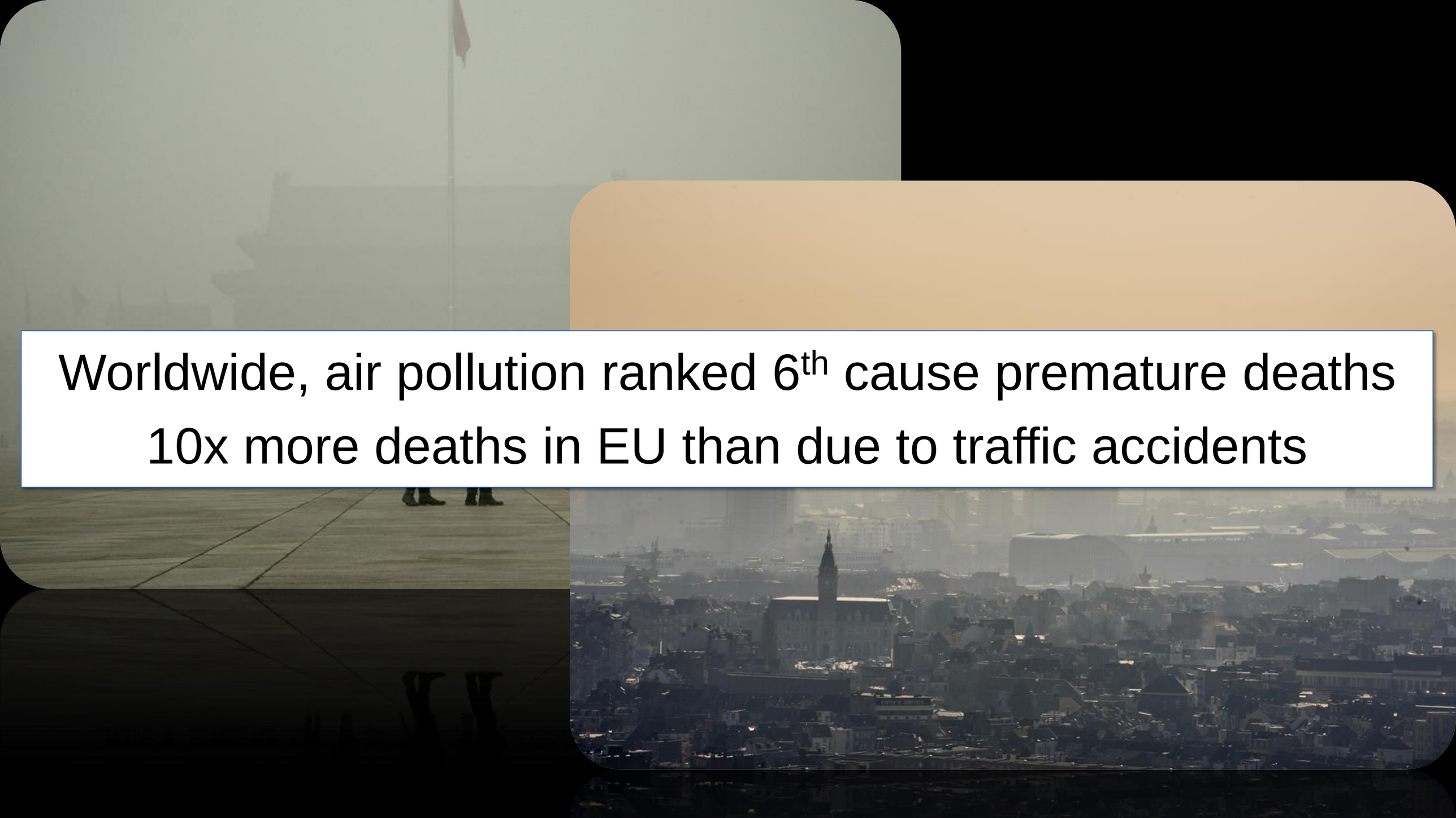
In the long run, we’ll all drive electric... But maybe not as you might think

- Why should internal combustion engines be banned?
- Why should we not ban them?

GHENT UNIVERSITY

WHY DO WE NEED A CHANGE?

GHENT UNIVERSITY



Worldwide, air pollution ranked 6th cause premature deaths

10x more deaths in EU than due to traffic accidents

DOTTING THE I'S AND CROSSING THE T'S

- Burning a hydrocarbon fuel
  - Theoretically: $C_xH_y + O_2 \rightarrow CO_2 + H_2O$
    - So CO_2 is a normal product of combustion and usually a harmless gas
  - Reality: also NO_X, particulate matter (PM), CO, hydrocarbons (unburned or partially burned)
    - These are the pollutant emissions: toxic components
    - Undesired products of combustion, minor species
    - Limited by emission legislation (Euro 4, 5, 6…)

GHENT UNIVERSITY

DIESELGATE

- VW using “defeat devices” on diesel cars
  - Meeting emission limits during testing
  - Emitting many times more out on the road
- Fall-out… not just VW…

CAR magazine Oct 2015

GHENT UNIVERSITY

REAL WORLD NOX EMISSIONS

Mostly “legal”: deficiencies in EU legislation

- Test cycle remote from actual driving conditions
- Many loopholes
- Now new cycle + RDE (Real Driving Emissions)

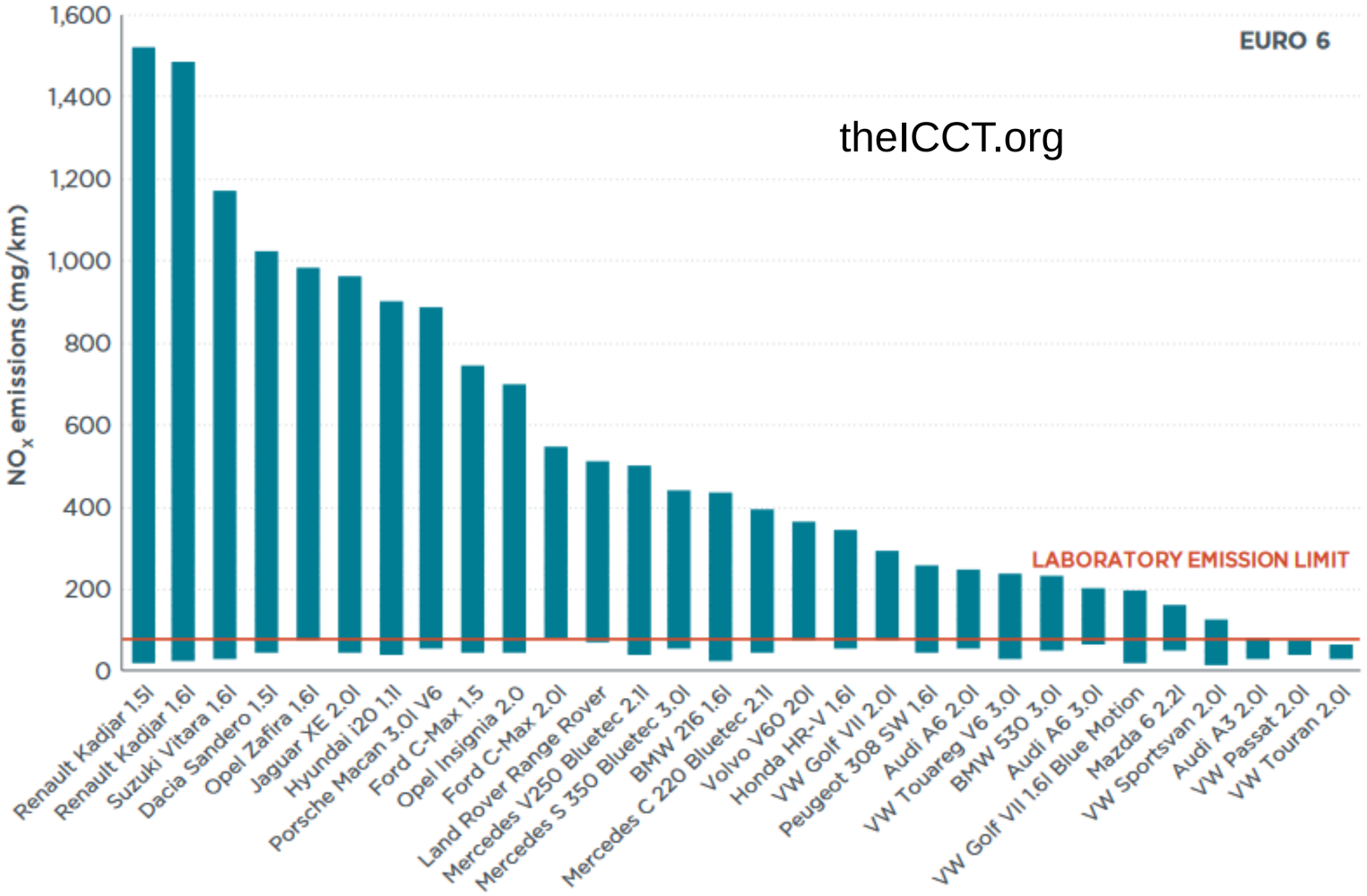
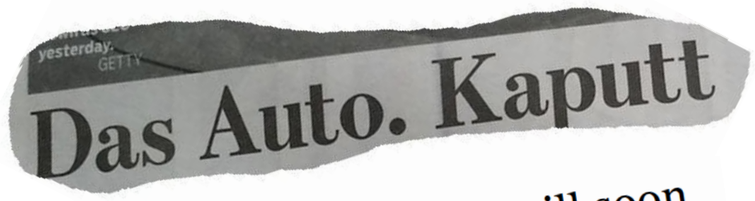


Figure 2. Range of KBA/BMVI test results. Bottom value of each bar corresponds to NEDC laboratory test result, top level of the bar to maximum on-road test result

GHENT UNIVERSITY

SHOULD WE BAN DIESEL CARS?

- Now it gets confusing... Euro 6 can mean multiple things...
  - Legislation has tightened
    (more challenging cycle, testing procedures and RDE)
  - “Euro 6d” or “Euro 6d-TEMP” diesel car:
    clean, also in real life!
    - In fact, cleaner than the dirtiest gasoline cars



Diesel cars 'finished, will soon disappear', EC warns motorists

Diesel is ‘finished’ in Europe amid push for electric cars, EU regulator says

BMW admits mistake in diesel emissions scandal

IANS | May 18, 2018, 09.00 AM IST

GHENT UNIVERSITY

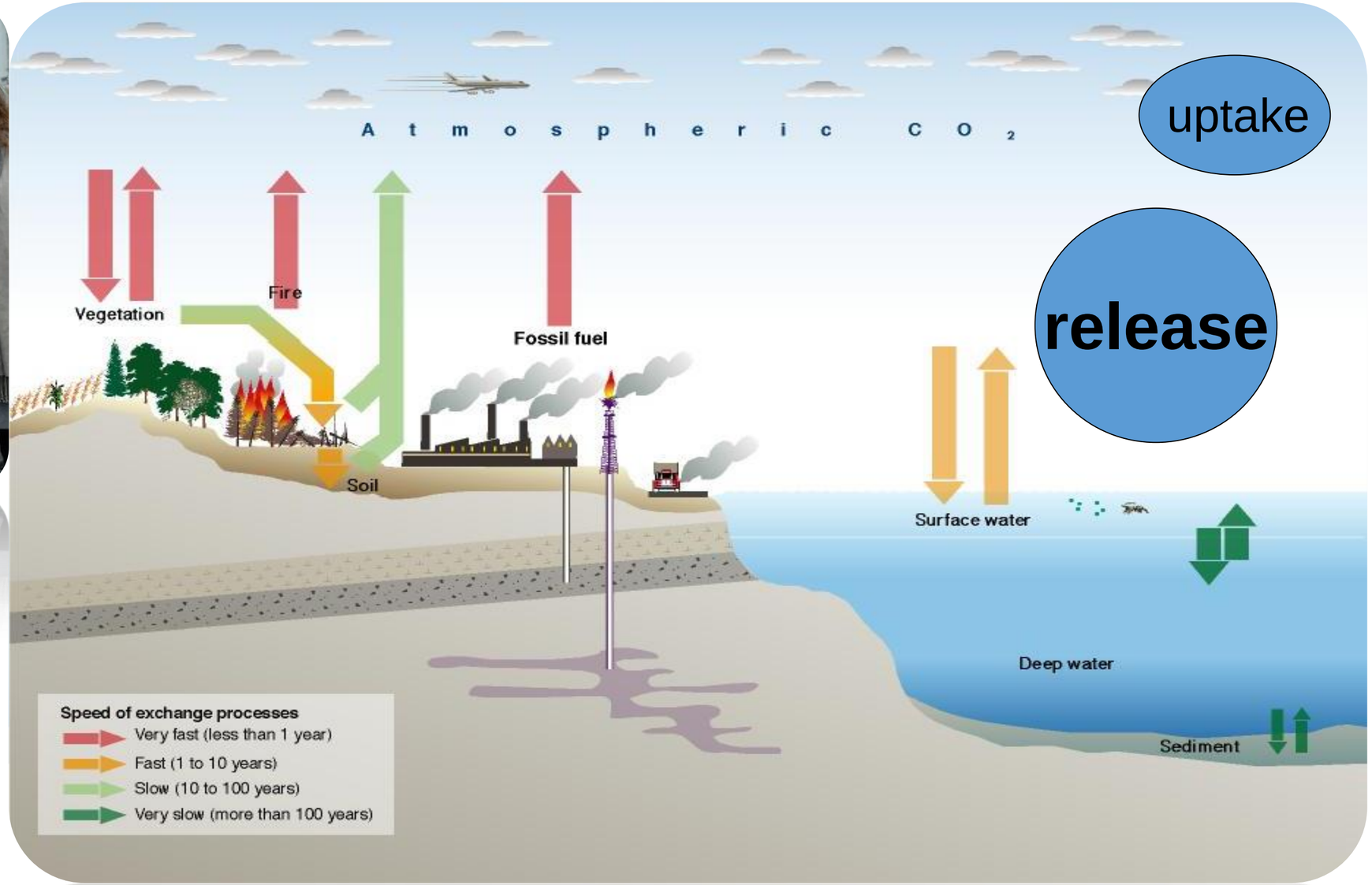
SO CAN WE SOLVE AIR QUALITY PROBLEMS?

- Yes, ultralow emissions are possible, for both gasoline and diesel vehicles

- Vehicles have been demonstrated, driving in congested traffic, with cleaner exhaust than intake!

GHENT UNIVERSITY

BUT… GREENHOUSE GAS EFFECT!



GHENT UNIVERSITY

GLOBAL WARMING

- Consequences: see elsewhere (check IPCC material)

- Solutions:
  1. Reduce primary energy use
  2. Change energy carrier

GHENT UNIVERSITY

REMARK…

Vehicle design

for lowest fuel consumption?

Start with the basics!

- Light
- Low
- Small

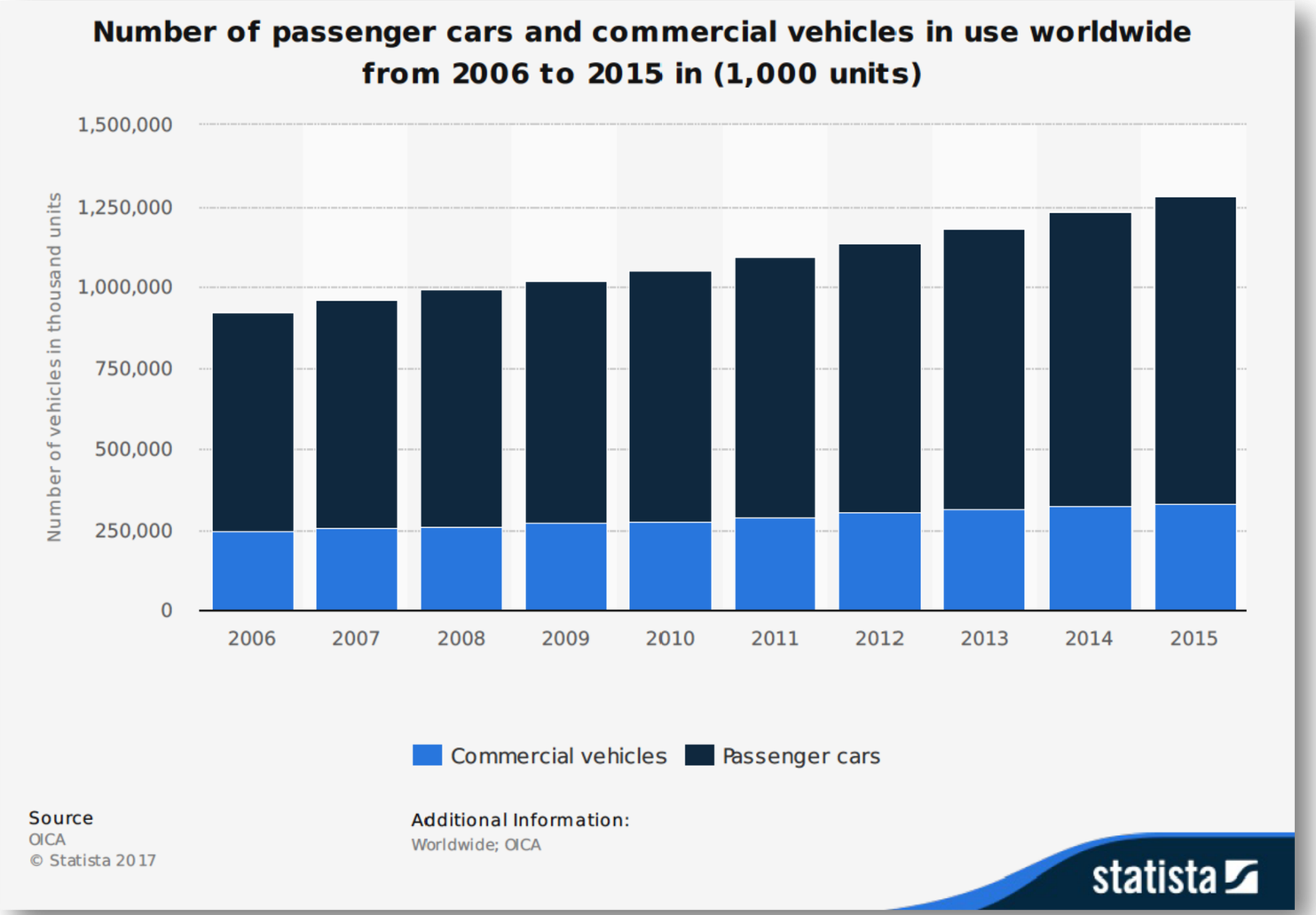
vs.

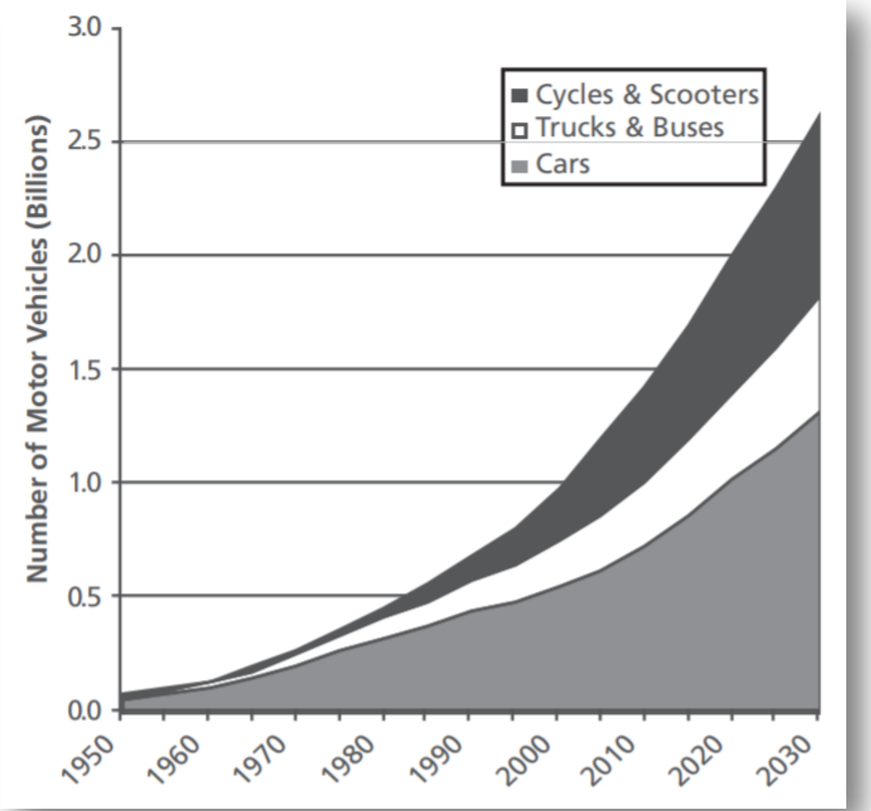
“vehicular obesity”

SUV hype

GHENT UNIVERSITY

VEHICLE GROWTH

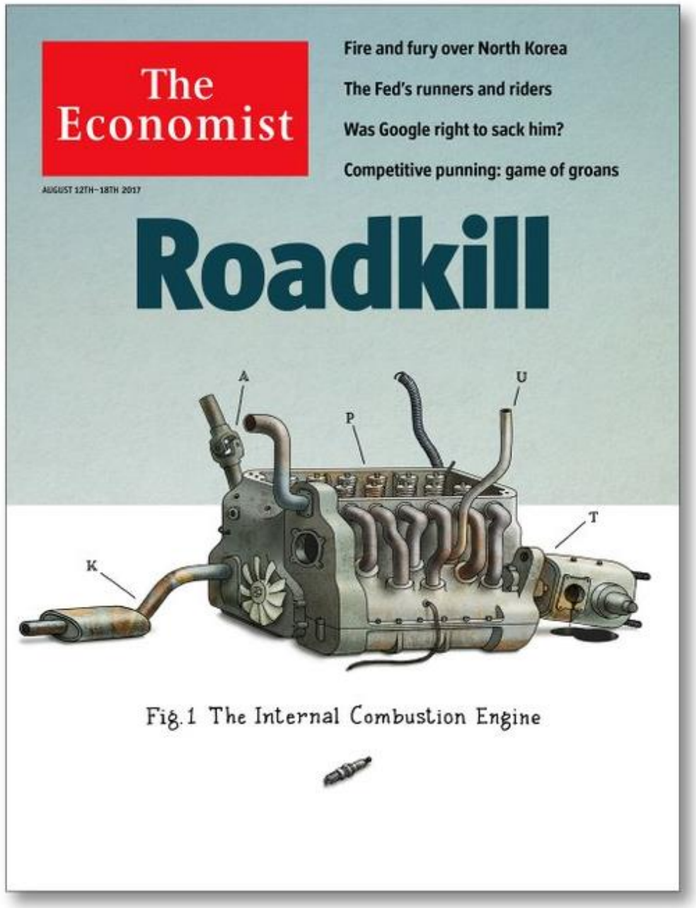




GHENT UNIVERSITY

THINGS NEED TO CHANGE

- Global warming is biggest issue, transportation is big contributor
  - # vehicles ↑ ↑ ↑ + mileage ↑
  - Status quo of real world fuel consumption
    - OEMs using loopholes in legislation; consumer preference for SUVs
- ”ICEs run on fossil fuels and have low η”
  - Hence, ”death of the internal combustion engine” announced (cfr. The Economist)
- Efficiency improvements of the ICE?
  - Incremental?
  - Important increases are costly
    ... while EV prices are decreasing?



GHENT UNIVERSITY

CONTENTS

- Is transport as we know it today, sustainable?
  - Oil reserves, greenhouse gas effect, pollutant emissions, …
- Which alternatives exist?
  - Other fossil fuels
  - Other combustion types
  - Biofuels
  - Fuel cells
  - Battery-electric vehicles
  - …
- How do we pick a winner?
- My own view

GHENT UNIVERSITY

ALTERNATIVES

GHENT UNIVERSITY

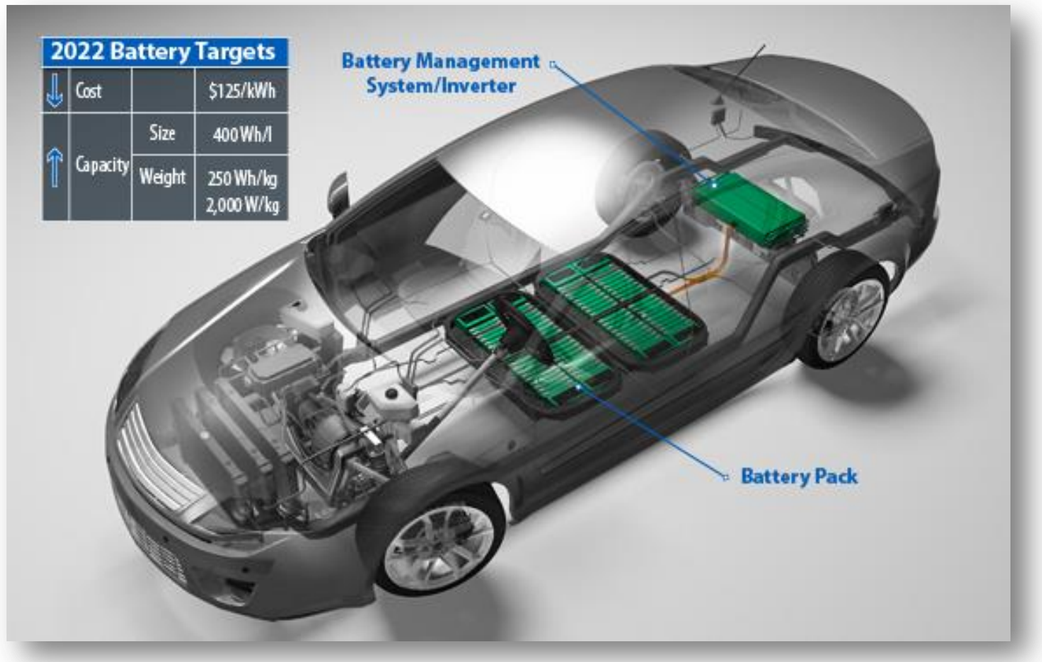
BEV: BATTERY ELECTRIC VEHICLE

Advantages

- Efficiency
- No tailpipe
- Widespread energy carrier

Disadvantages

- It uses a battery
  - Cost
  - Limited driving range
  - Charging time



GHENT UNIVERSITY

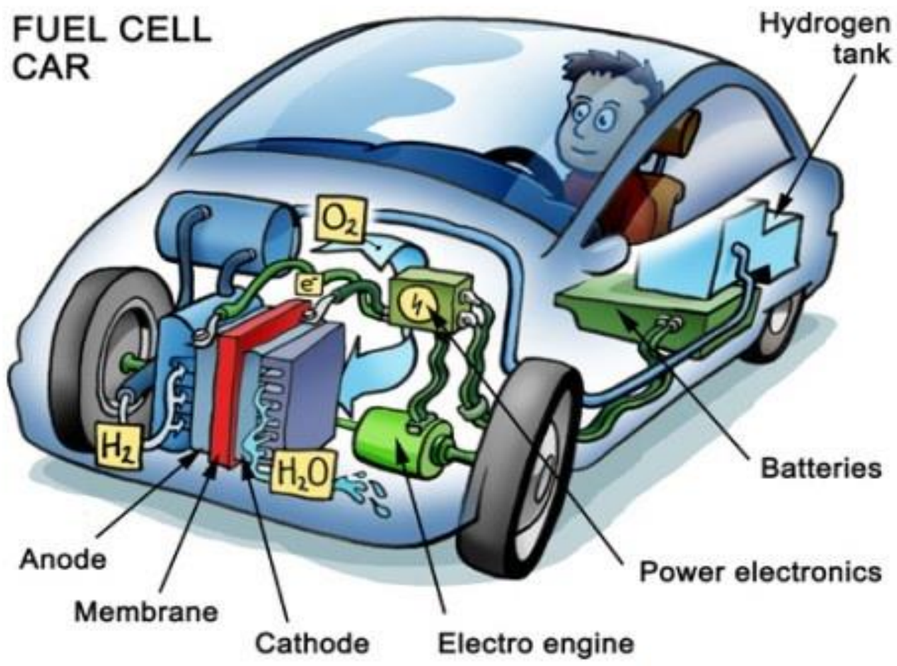
FCV: FUEL CELL VEHICLE

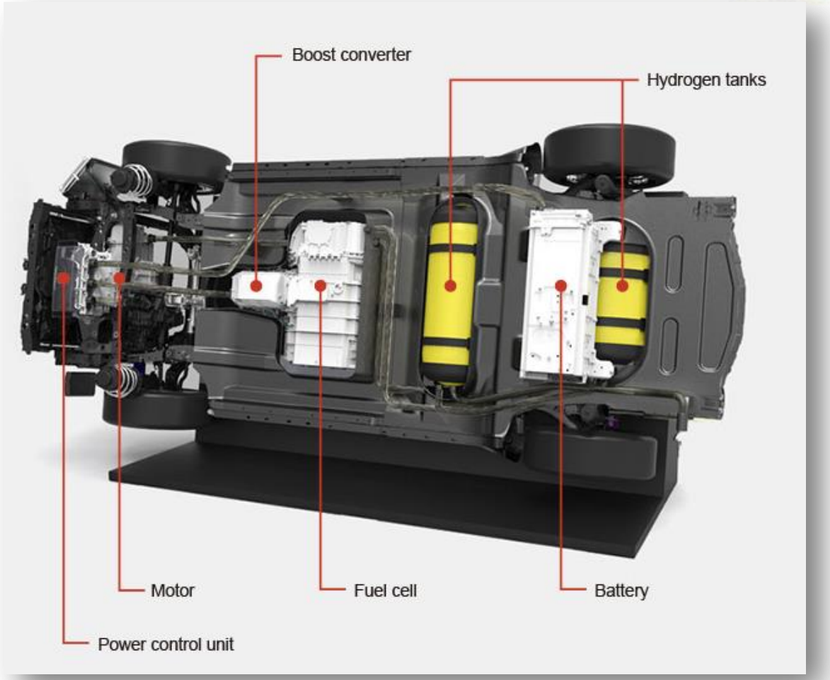
Advantages

- Also electric vehicle, same advantages
- But fuel cell producing electricity from H_2
- High efficiency
  - But lower than BEV
- Filling as convenient as with liquid fuel
  - 5 min for 500 km range

Disadvantages

- It uses hydrogen
  - Infrastructure?
  - Low energy density





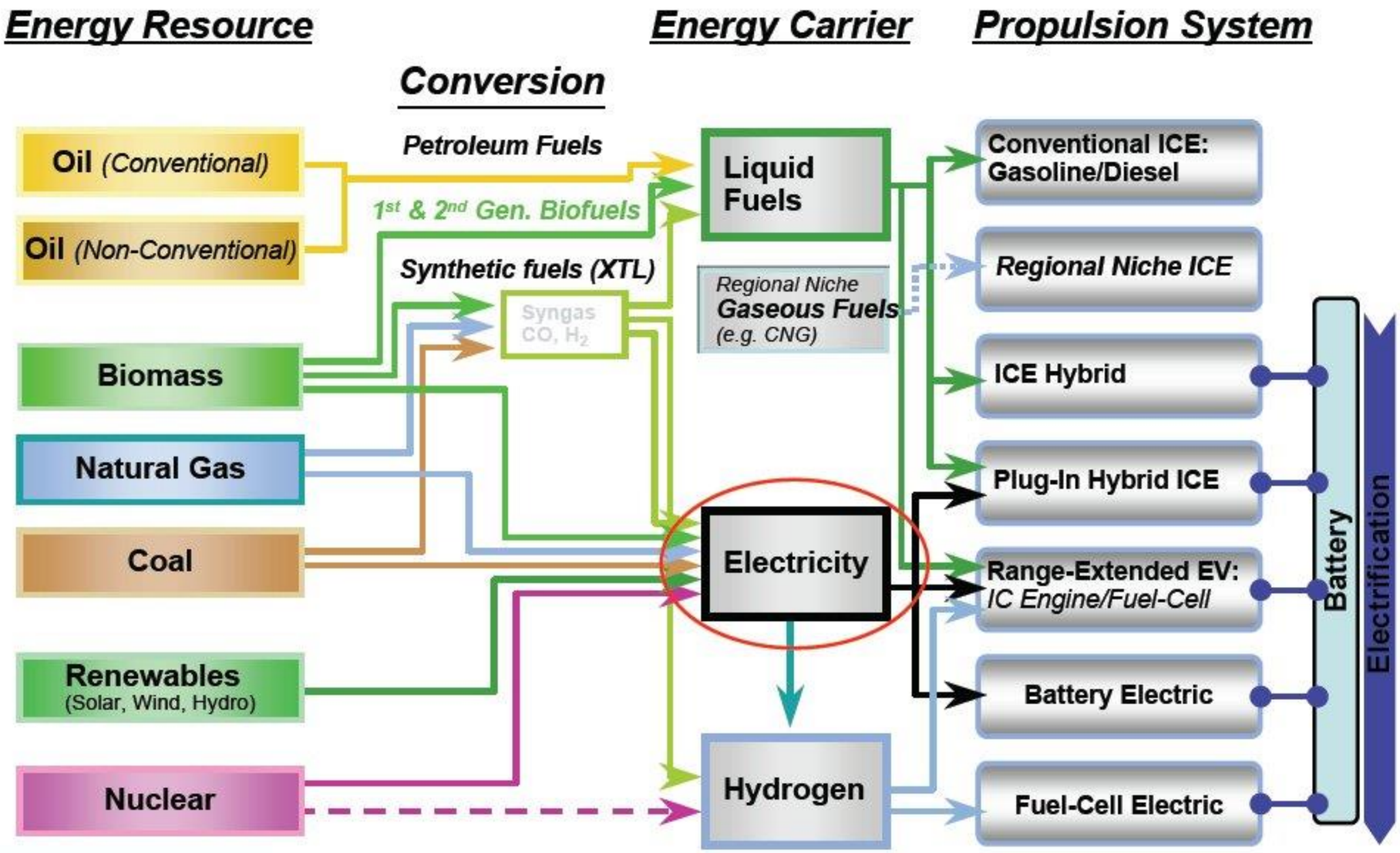
GHENT UNIVERSITY

CRITERIA FOR PICKING AN ALTERNATIVE?

- How do you judge the suitability of an alternative?
  - “well-to-wheel” energy use, CO_2 emission, …
  - “life cycle” energy use, CO_2 emission, …
  - “total cost of ownership” TCO
    (purchase price – resale value + costs of use)
  - Driving range
  - Safety
  - Ease of use
  - …

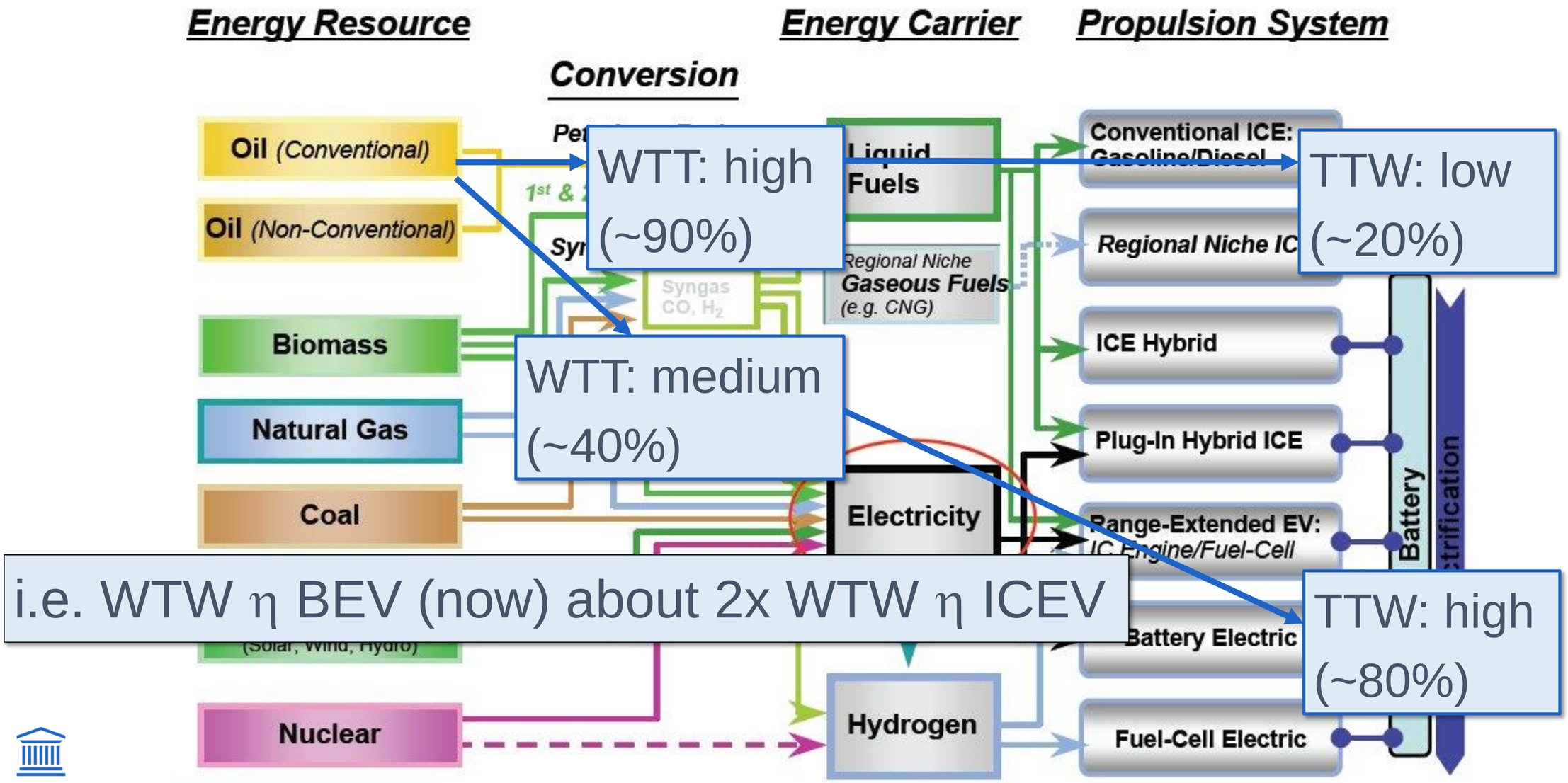
GHENT UNIVERSITY

WELL-TO-WHEEL (WTW)



GHENT UNIVERSITY

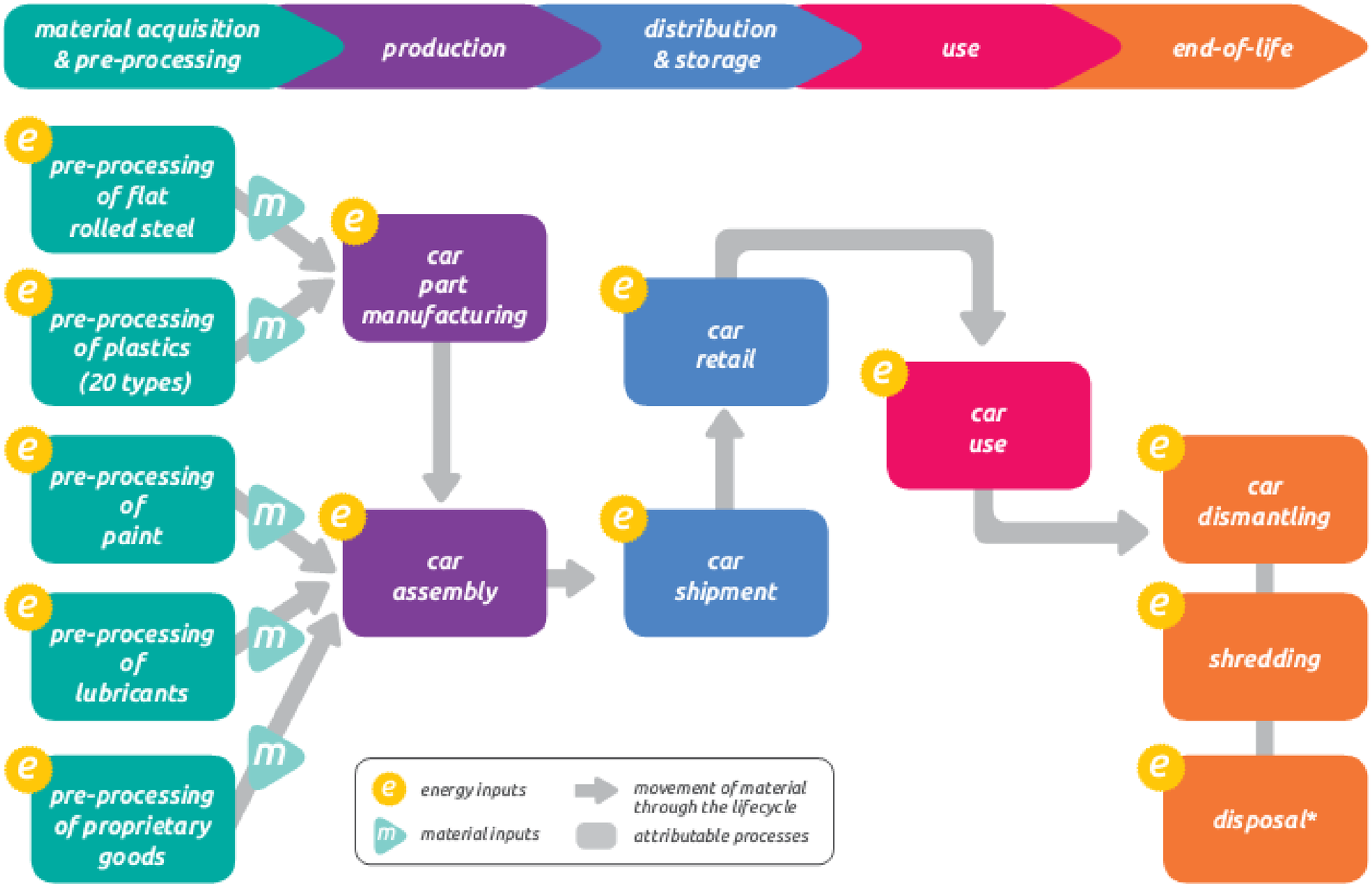
WELL-TO-WHEEL (WTW)



GHENT UNIVERSITY

LCA

Life Cycle Analysis



GHENT UNIVERSITY

LCA – LIFE CYCLE ANALYSIS

Green credentials

Average lifecycle for car in US midwest

	Tesla Model S P100D (battery-electric vehicle)	BMW 7 Series 750i xDrive (internal combustion engine)	Mitsubishi Mirage (internal combustion engine)
Production emissions (kg CO_2 equivalent)	12,204	8,190	4,752
Use emissions - 270,000km (kg CO_2 eq)	48,600	95,310	46,980
End of life emissions (excluding battery, kg CO_2 eq)	311	351	159
Lifecycle emissions total - 270,000km (kg CO_2 eq)	61,115	103,851	51,891
Lifecycle emissions per km - intensity (g CO_2 eq/km)	226	385	192

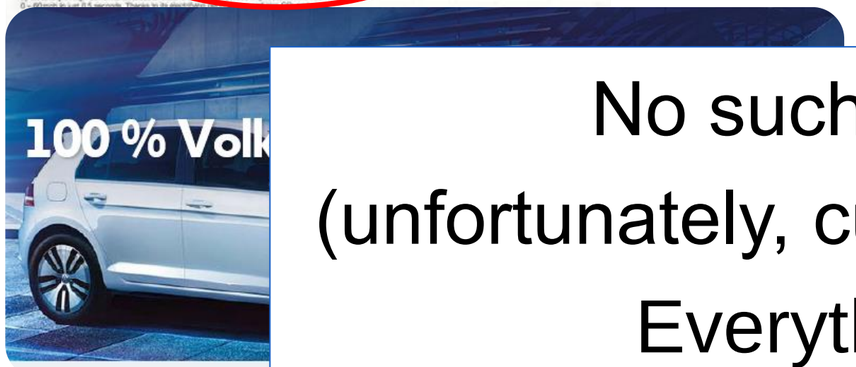
All data are based on vehicles driven in the US midwest

Source: Trancik Lab, MIT

© FT

GHENT UNIVERSITY

ADVERTISING: THE NEXT SCAM?



No such thing as “zero emissions”!

(unfortunately, current legislation works that way…)

Everything we do has an impact

ENERGY DENSITY?

Batteries

- 85 kWh Li-ion battery: 540 kg
- = energy contents of 7.4 kg gasoline
- Or factor 76 difference in energy content
- Partly compensated by higher efficiency of electric drive (x 4)

Hydrogen

- In liquid form (-253°C): 6 x mass of gasoline for same energy (incl. storage)
- Compressed (700 bar): 5 x

GHENT UNIVERSITY

PICK A WINNER…

Technology/ fuel	Climate	Air quality	Purchase cost	Cost of use	…
Gasoline	👎👎	👍	👍	👎	
Diesel	👎	👎👎	👎	👍	
LPG, CNG	👎	👍	👎	👍👍	
engine					
Hydrogen fuel cell	👍👍*	👍👍👍	👎👎👎	👎👎👎	
Battery-electric	👍👍👍*	👍👍👍	👎👎👎	👍👍👍	
…					

Hence the cliché “There is no silver bullet”

Or my version: the law of conservation of misery

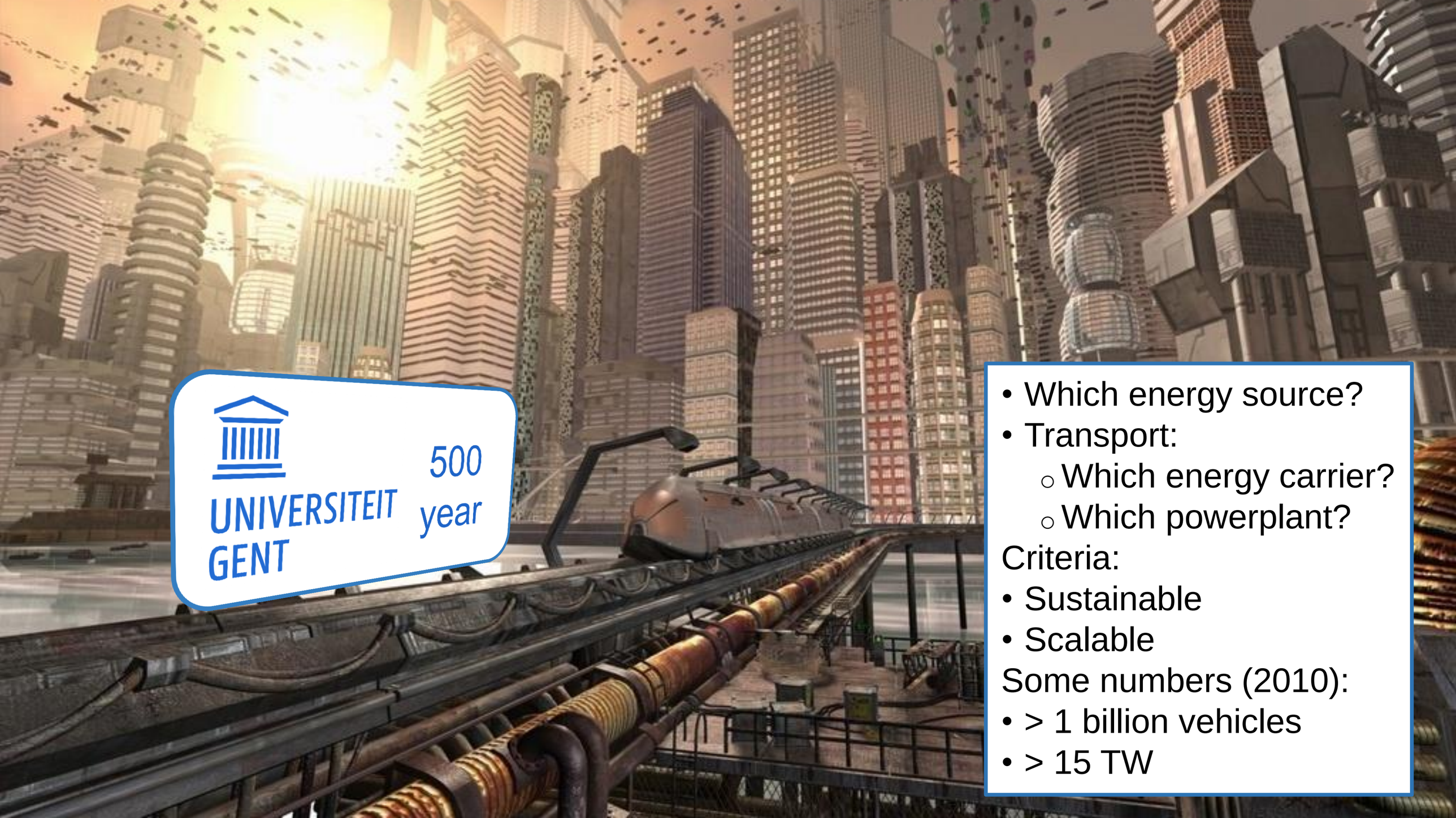
*:dependent on production!

GHENT UNIVERSITY

“Prediction is very difficult,
especially if it is about the future”
– Niels Bohr

MY VISION…

GHENT UNIVERSITY



UNIVERSITEIT GENT 500 year

- Which energy source?
- Transport:
  - Which energy carrier?
  - Which powerplant?

Criteria:

- Sustainable
- Scalable

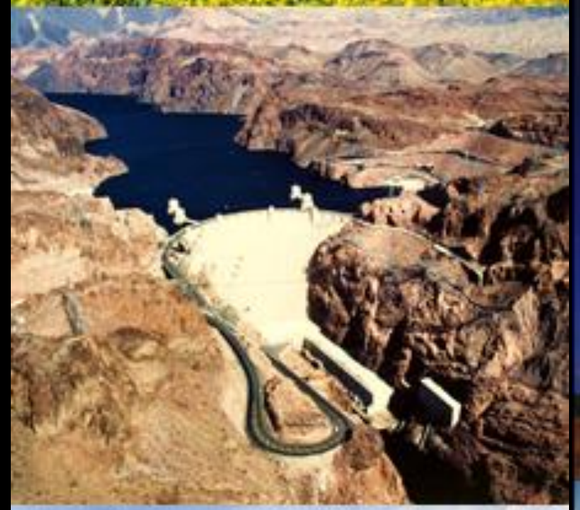
Some numbers (2010):

- > 1 billion vehicles
- > 15 TW

7 TW

44 TW

7 TW

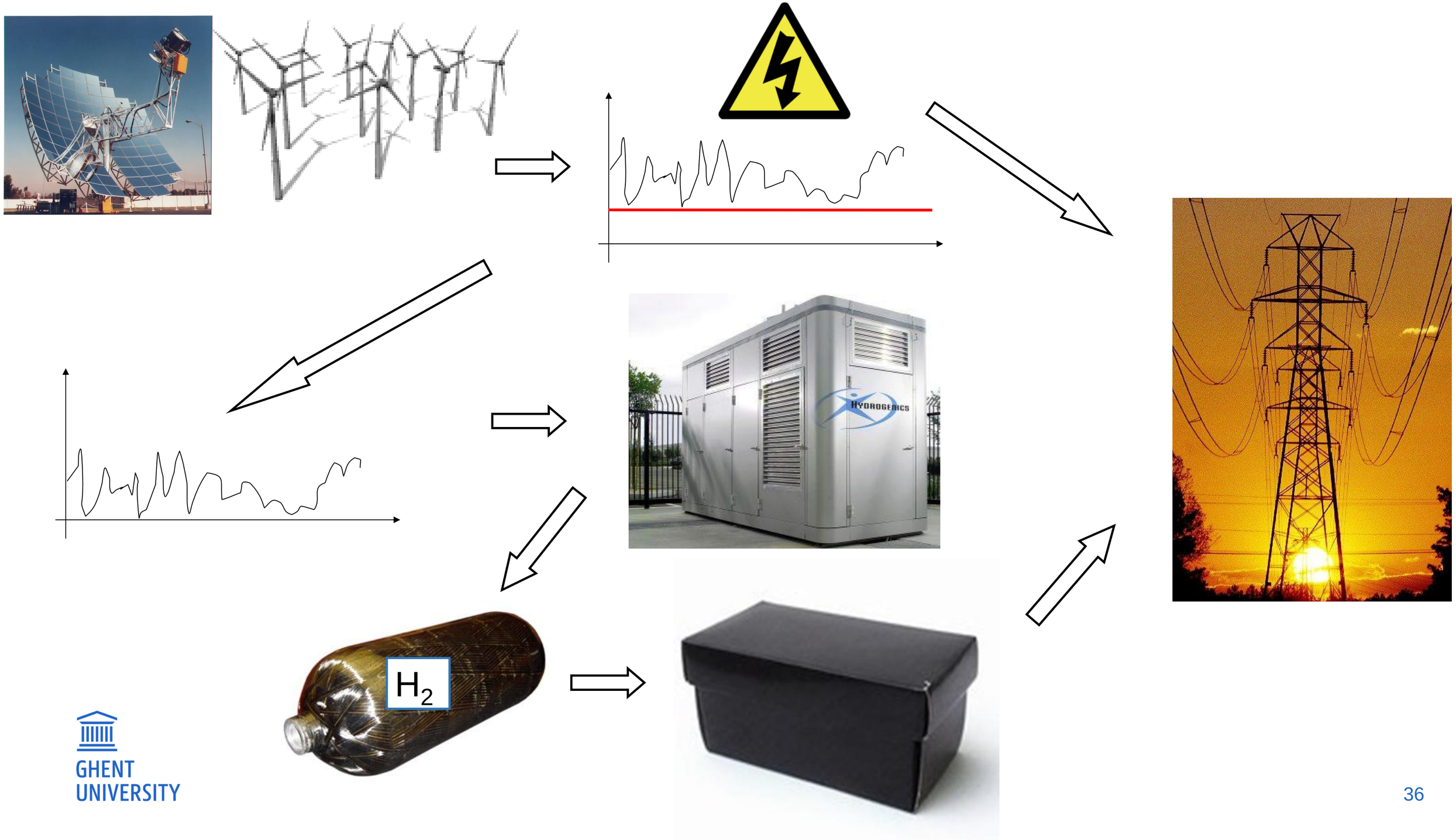


72 TW

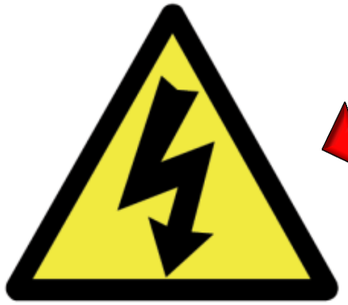
14 TW

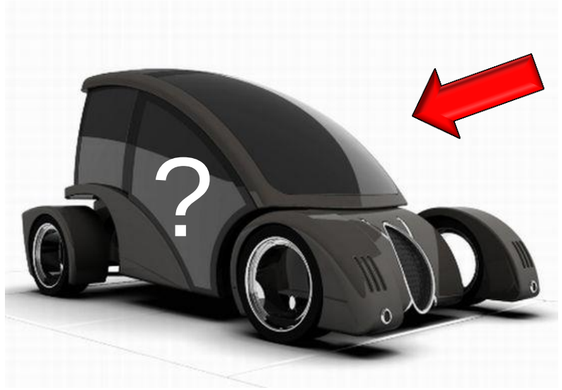
85.000 TW

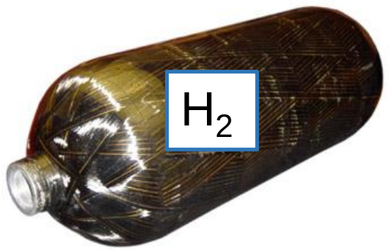
D. Abbott, “Keeping the energy debate clean: How do we supply the world’s energy needs?” Proc. IEEE 98(1):42–66

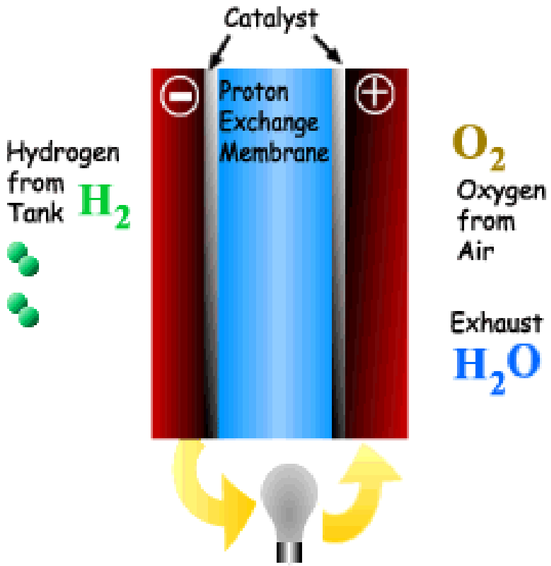


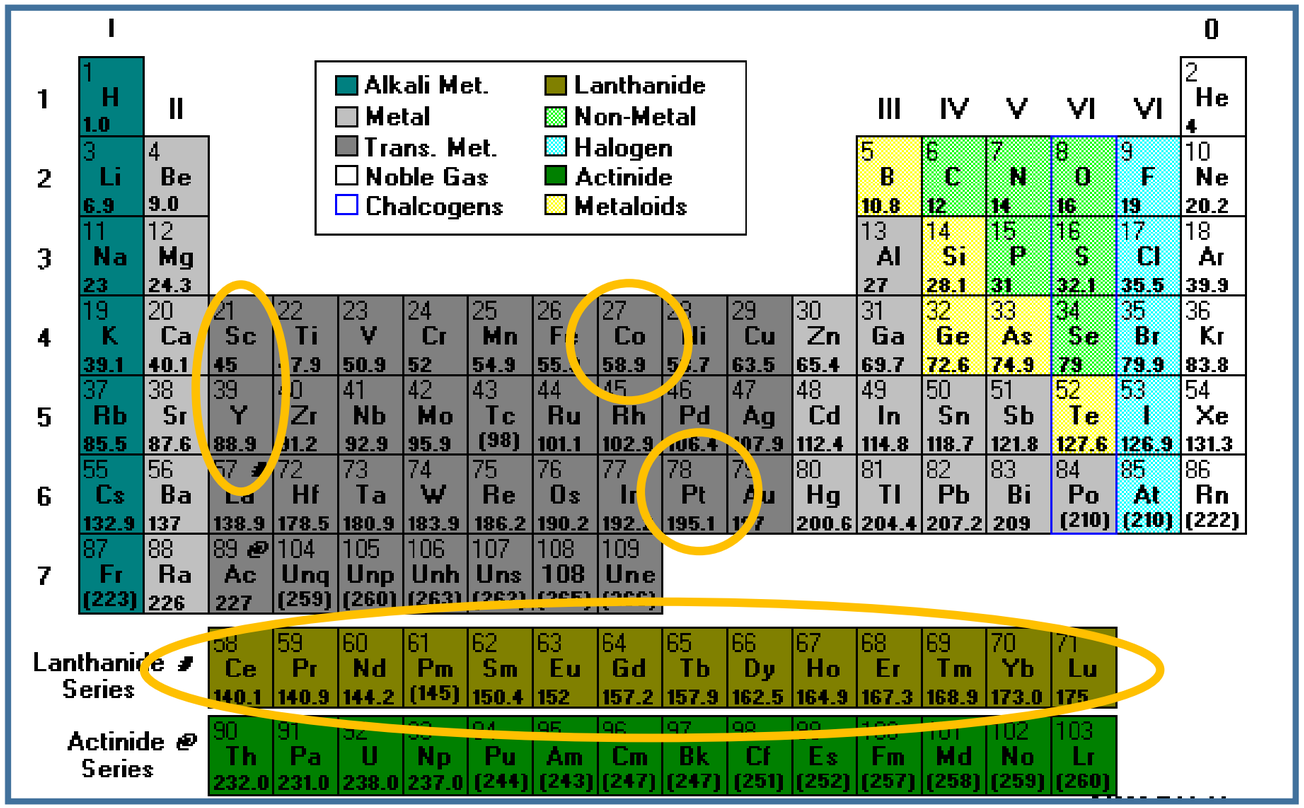
GHENT UNIVERSITY











GHENT UNIVERSITY

Bloomberg

Hyperdrive

Threat of Cobalt Shock Is a Top Risk for Electric Vehicles

By David Stringer and Martin Ritchie

May 21, 2018, 2:00 PM GMT+2 *Updated on May 22, 2018, 4:11 AM GMT+2*

- Key EV metal is facing shortages in early 2020s, BNEF says
- Recycling, battery chemistry shift can help reduce reliance

Modern-day slavery in focus
Global development

Modern-day slavery in focus is supported by

HUMANITY UNITED

About this content

Siddharth Kara

Fri 12 Oct 2018 09.00 BST

4,998

Is your phone tainted by the misery of the 35,000 children in Congo's mines?

My field research shows that children as young as six are among those risking their lives amid toxic dust to mine cobalt for the world's big electronics firms

GHENT UNIVERSITY

MASSIVE SCIENCE

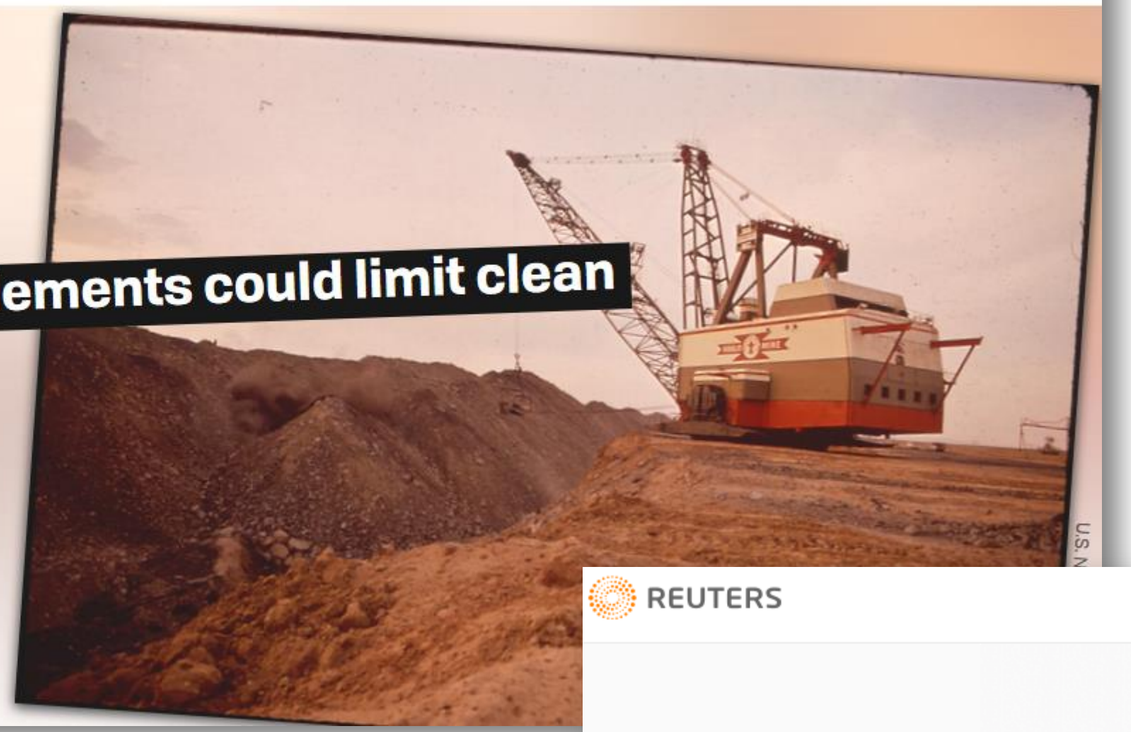
Stories Consortium About Shop Search SUPER MASSIVE SUPPORT US SIGN IN

Shortages of rare earth elements could limit clean energy development

We've started searching for rare earth elements in some unlikely places

Laura Mast
Environmental Engineering
Georgia Institute of Technology

October 5, 2018



REUTERS

Business Markets World Politics TV More

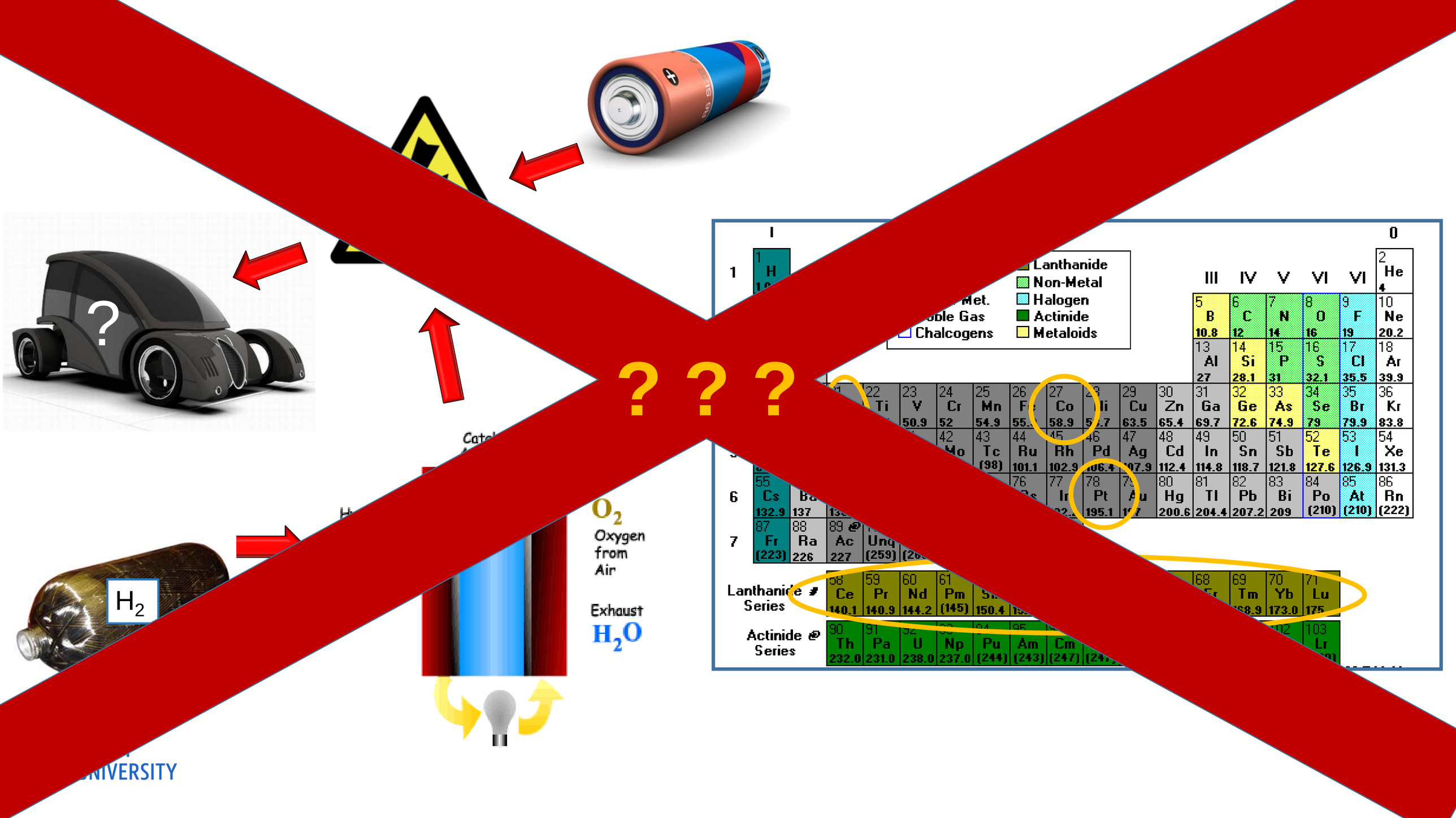
TECHNOLOGY NEWS MARCH 9, 2018 / 12:03 PM / A YEAR AGO

Platinum's fuel-cell car bonanza proves elusive

Jan Harvey 6 MIN READ

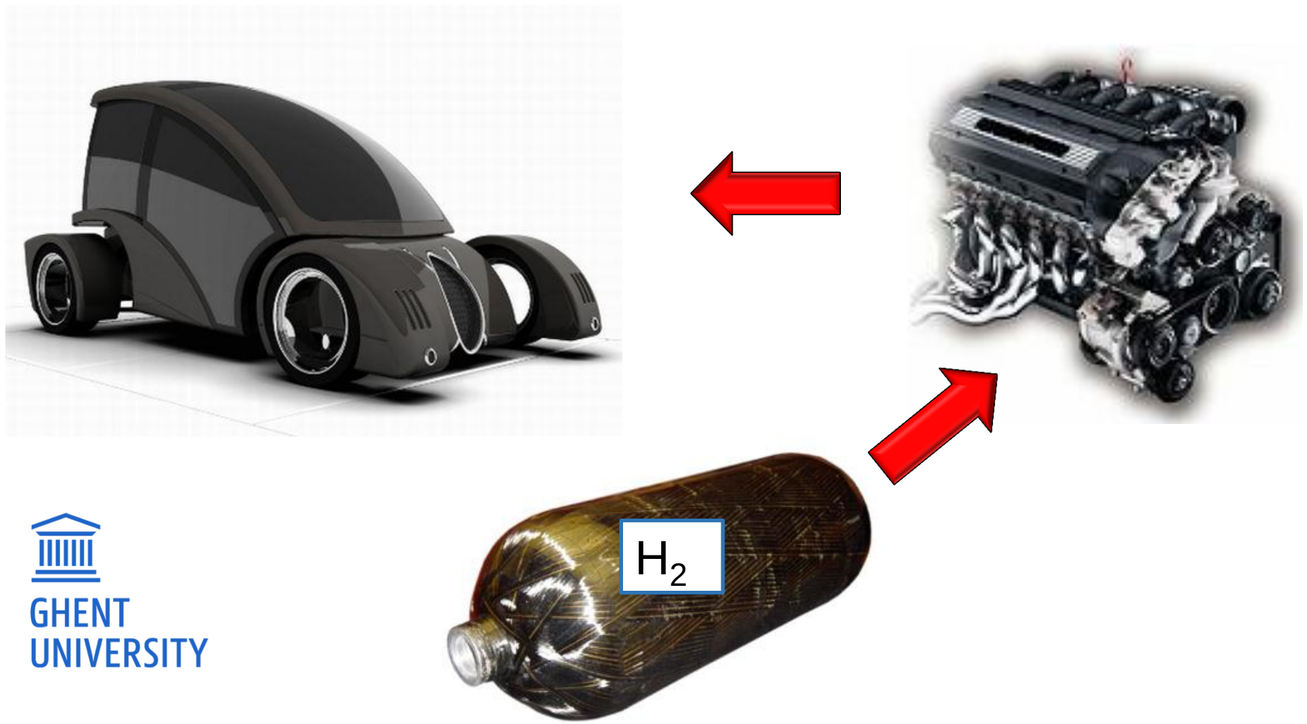
At spot prices, the 30-60 grams of the metal it can take to power a mid-range fuel-cell car may cost more than $1,800. The amount needed for a diesel autocatalyst, in comparison, is worth just over $200 at the top end.

GHENT UNIVERSITY


? ? ?
?
H_2
O_2
Oxygen from Air
Exhaust
H_2O
Lanthanide
Non-Metal
Halogen
Actinide
Metaloids
Chalcogens
Lanthanide Series
Actinide Series

INTERNAL COMBUSTION ENGINE

- Sustainable if it runs on a renewable fuel
- Scalable as it is produced from abundantly available, recyclable materials

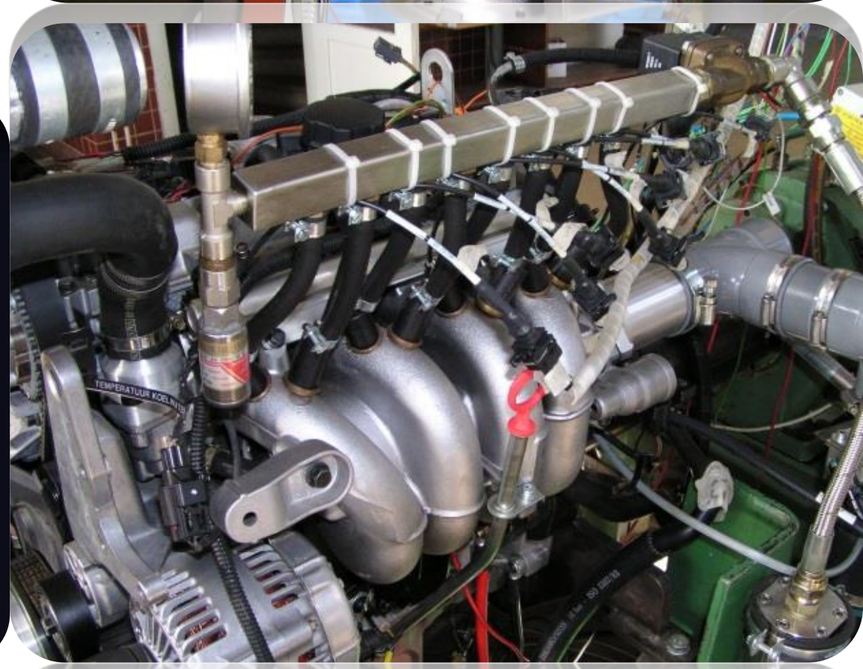


GHENT UNIVERSITY

THE H_2-FUELED ICE

- Investigated thoroughly at UGent
- Specific power > gasoline engines
- Engine efficiency > diesel engines
- Ultralow emissions

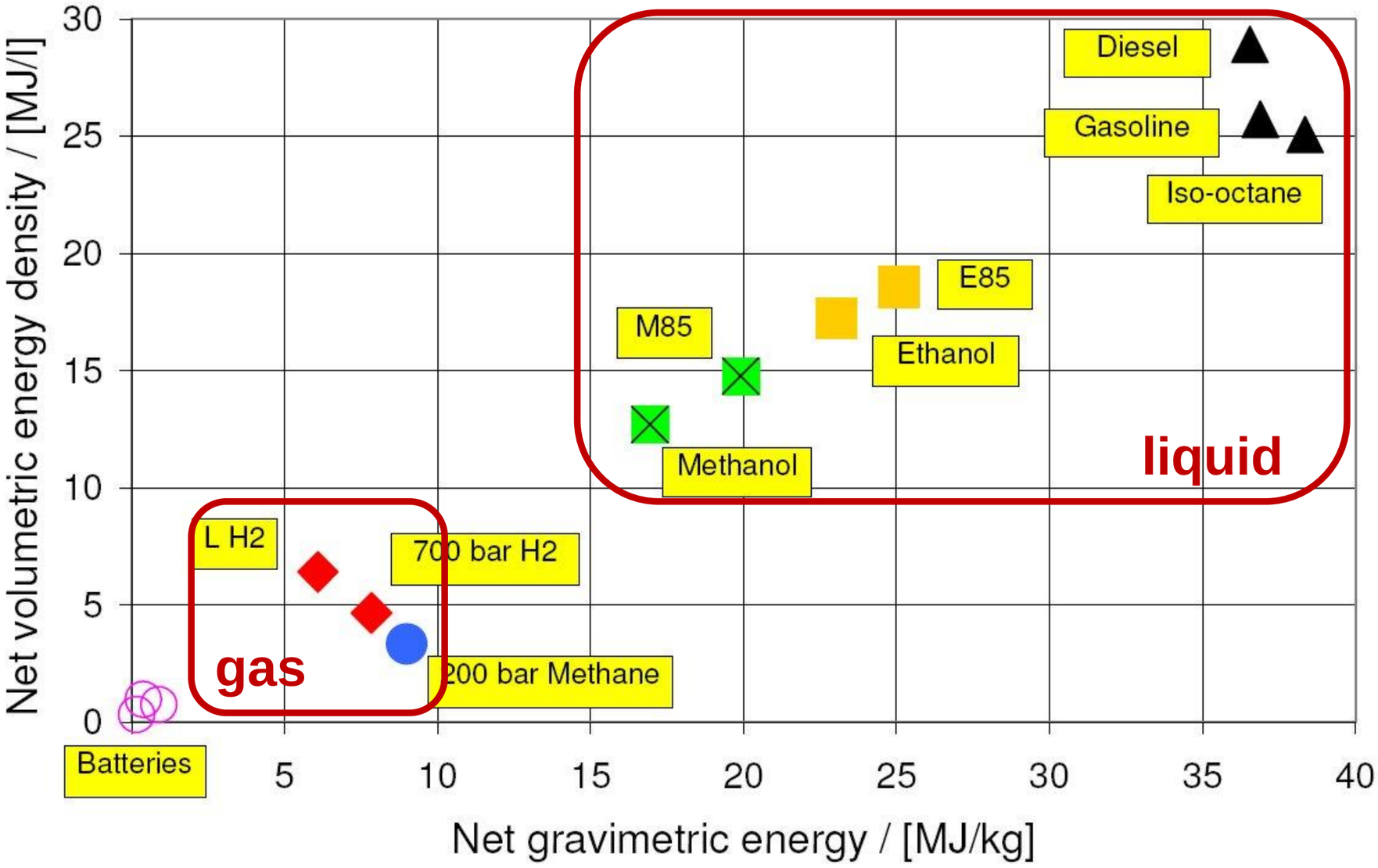
BUT...



Progr Energy Comb Sci 35:490

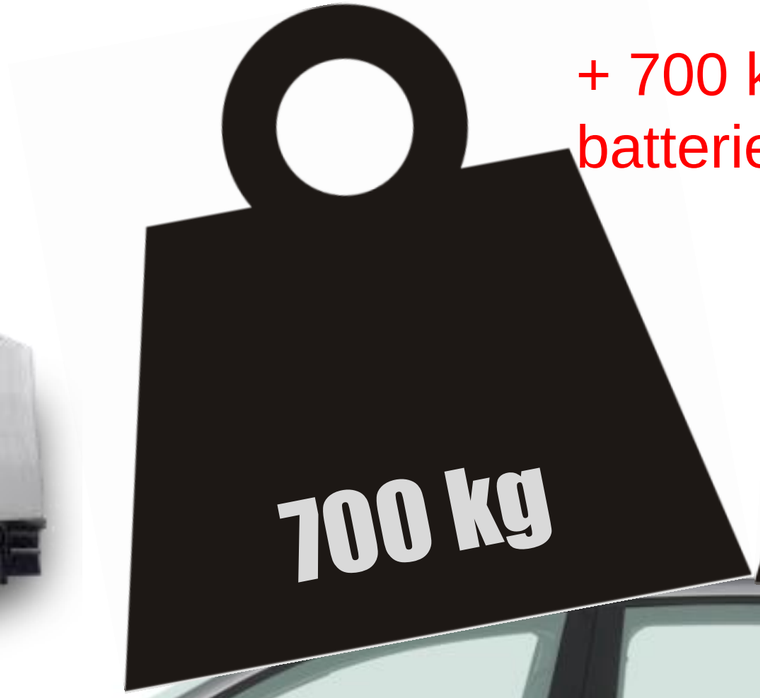
GHENT UNIVERSITY

ENERGY DENSITY IS CRUCIAL!



GHENT UNIVERSITY

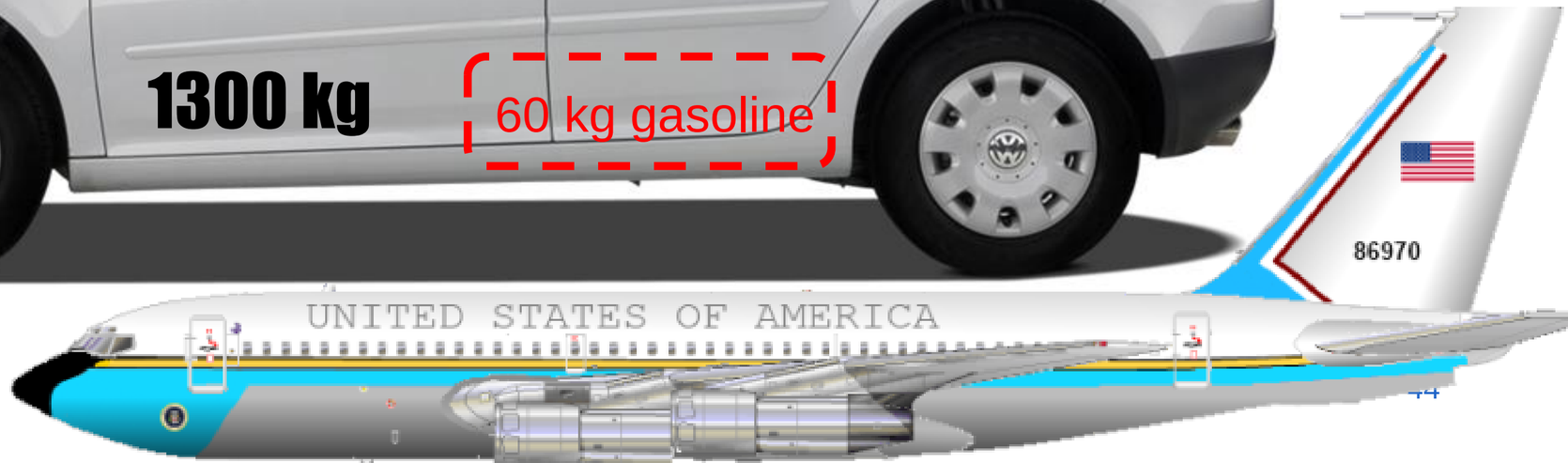
VISUALLY…



+ 700 kg batteries

+ 100 kg hydrogen

+ 40 kg alcohol



GHENT UNIVERSITY

LIQUIDS: DISTRIBUTION & STORAGE EASIER

€ 250

€ 2.500

€ 25.000

Scalability also means affordability!

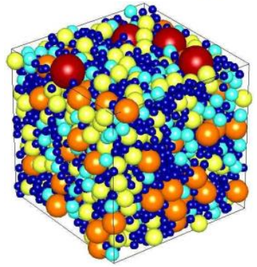
GHENT UNIVERSITY

ENERGY CARRIER AND DRIVE?

Must be:

- Sustainable
  - Closed cycle for energy carrier and powertrain materials

- Scalable
  - Use abundantly available resources
  - Affordable



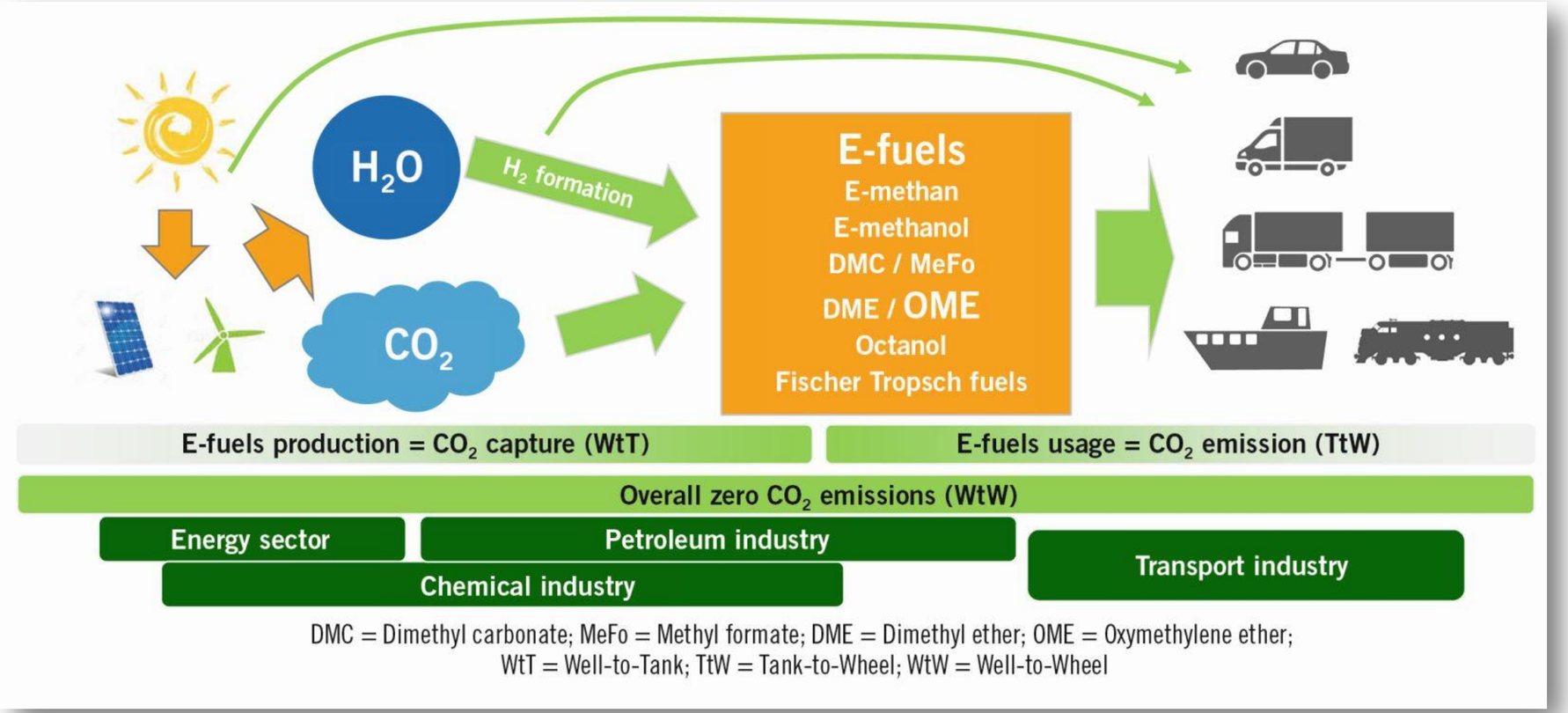
- Storable
  - High energy and power density

→ Need for renewable, **liquid** fuels

GHENT UNIVERSITY

RENEWABLE FUELS

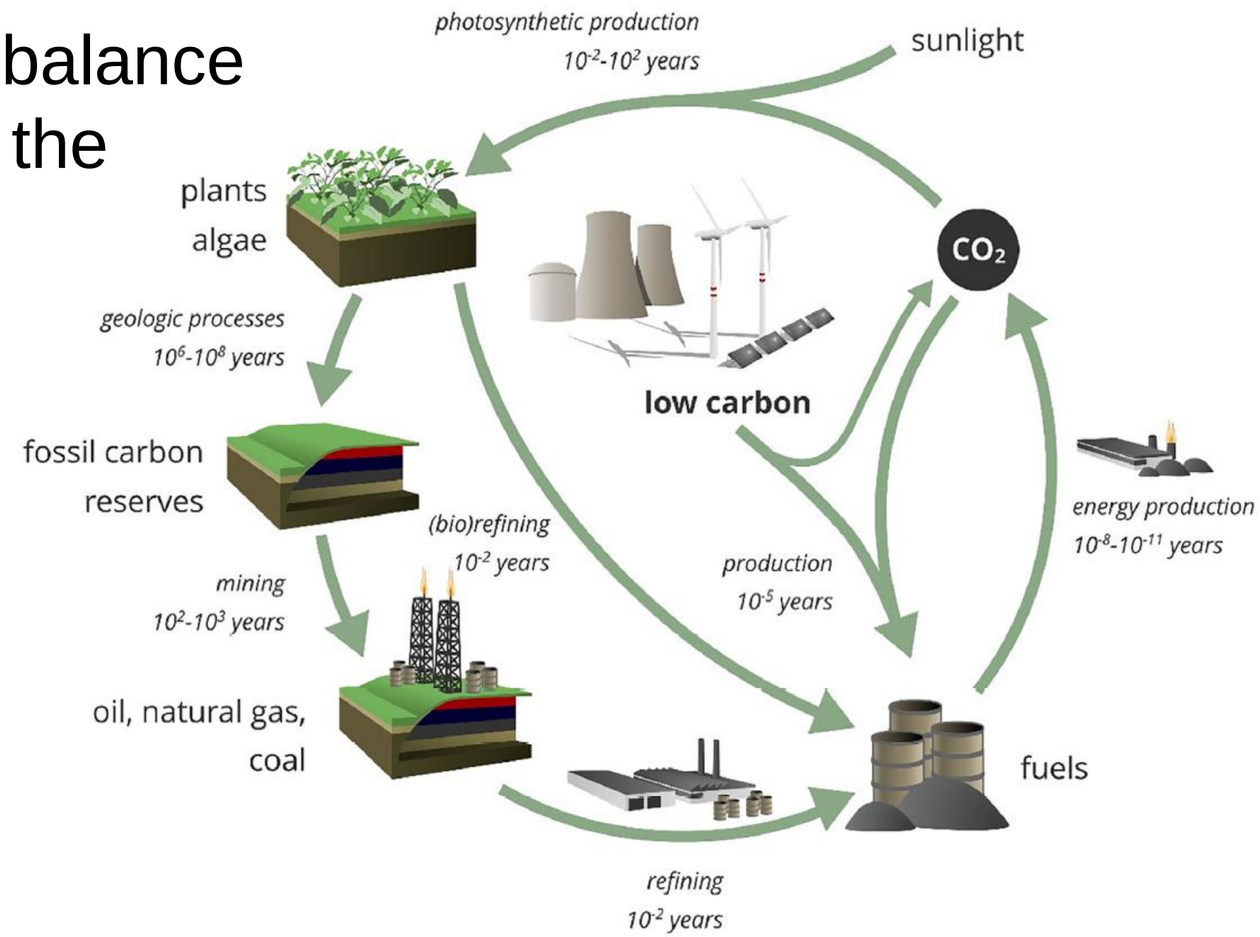
- Solar fuels, e-fuels, “liquid electricity”, …
- Making sustainable energy storable



GHENT UNIVERSITY

WHICH FUELS?

- Fuels containing carbon outperform others in terms of energy densities
- Note carbon in itself is not a problem
  - the whole biosphere works on it!
- But: we need to restore the carbon balance
  → close the carbon cycle, increase the speed at which carbon is captured
  - Can't rely on fossilization, can't rely on biomass: too slow
  - Must use chemistry, driven by renewable energy, to capture carbon

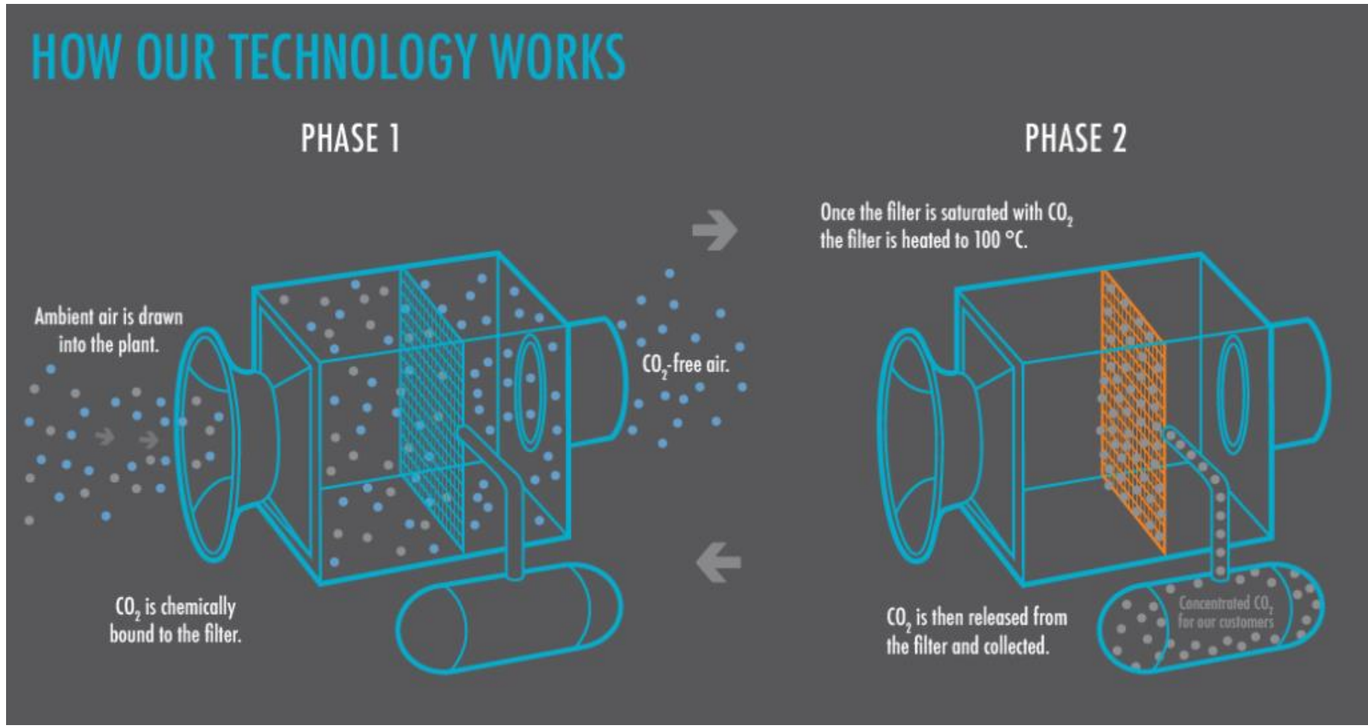


ChemSusChem 10:1039

GHENT UNIVERSITY

CO_2 CAPTURE

- Capturing carbon to make fuels
  - Start with main point sources: e.g. 50% of CO_2 emitted from 220 major sources in Flanders
  - Use carbon from other sources: biomass & waste
  - Ultimately: direct air capture
  - Carbon capture & use (CCU)



GHENT UNIVERSITY

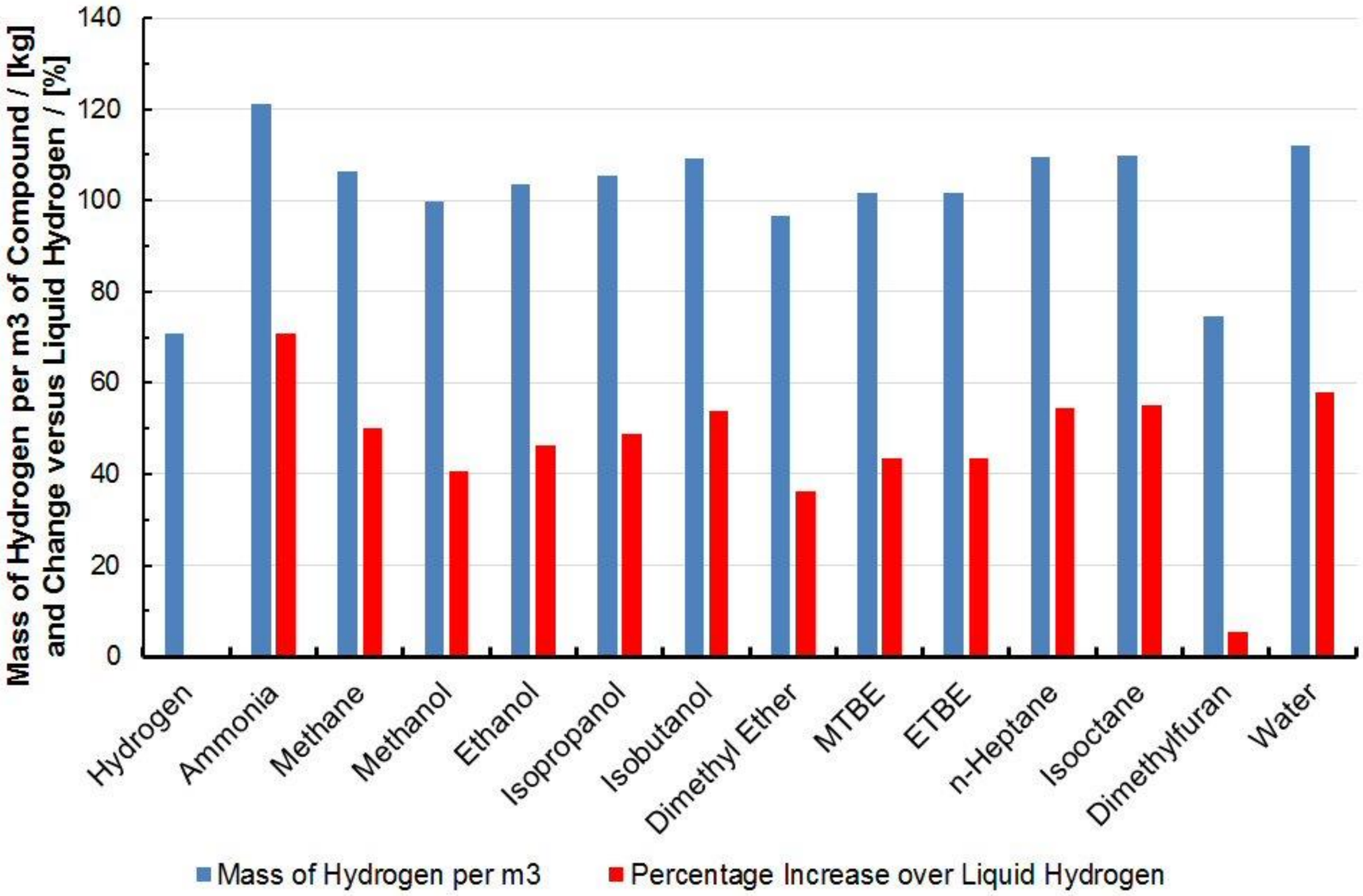
WHICH FUELS?

- Now that we need to synthesize fuels, let's make what we want
  - Sufficient energy density & preferably simple molecules
    - Production is more efficient (WTT)
    - Conversion (TTW) can be controlled more easily (η, emissions)
- Abundantly available building blocks: C, H, O, N, …
- Thus, most simple fuels:
  - Hydrogen, H_2 (at p_{atm}, liquid at 20K)
  - Methane, CH_4 (at p_{atm}, liquid at 91K)
  - Ammonia, NH_3 (at T_{atm}, liquid at 8.6 bar)
  - Methanol, CH_3OH (liquid)
  - Dimethylether (DME), CH_3OCH_3 (liquid at 5.3 bar)
  - …

RENEWABLE LIQUID FUELS

GHENT UNIVERSITY

H_2: VERY BAD AT STORING HYDROGEN



GHENT UNIVERSITY

H_2 STORAGE: ENERGY IMPLICATIONS

- Making hydrogen liquid, or compressing it to 700 bar, takes as much energy as making e.g.methanol from it
  - Between 10% (CH_2) and 30% (LH_2) of the heating value

- E.g. methanol is using CO_2 to carry H_2 more efficiently!

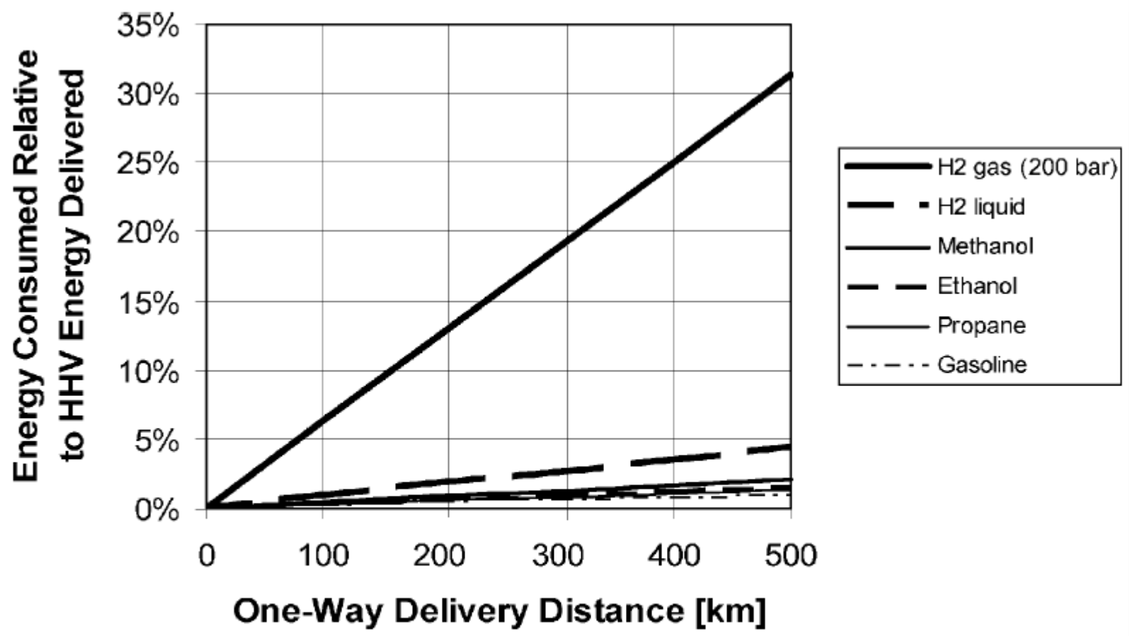
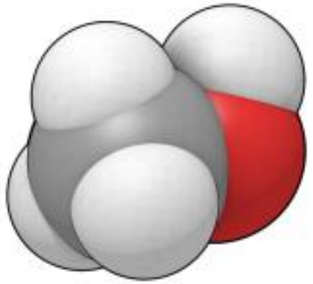


Fig. 6. ***Energy needed for the road delivery of fuels relative to their HHV energy content.***

PIEEE 94:1826

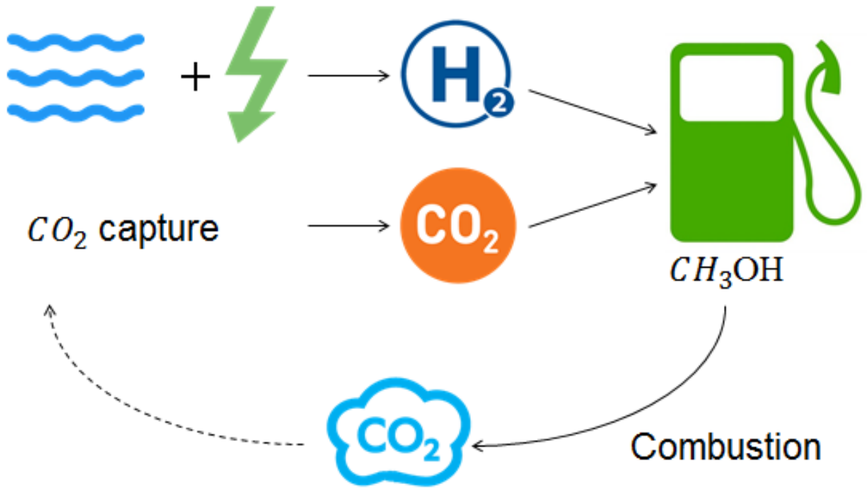
GHENT UNIVERSITY

CASE: METHANOL



- Can be produced in different ways
  - Biomass, fossil fuels
  - *Synthesize using renewable energy:*
    $H_2 + CO/CO_2 \rightarrow CH_3OH$
- Liquid
  - Cheap tanks, cheap distribution
  - *Evolution* of infrastructure possible

→ Has been a focus for UGent since 2009

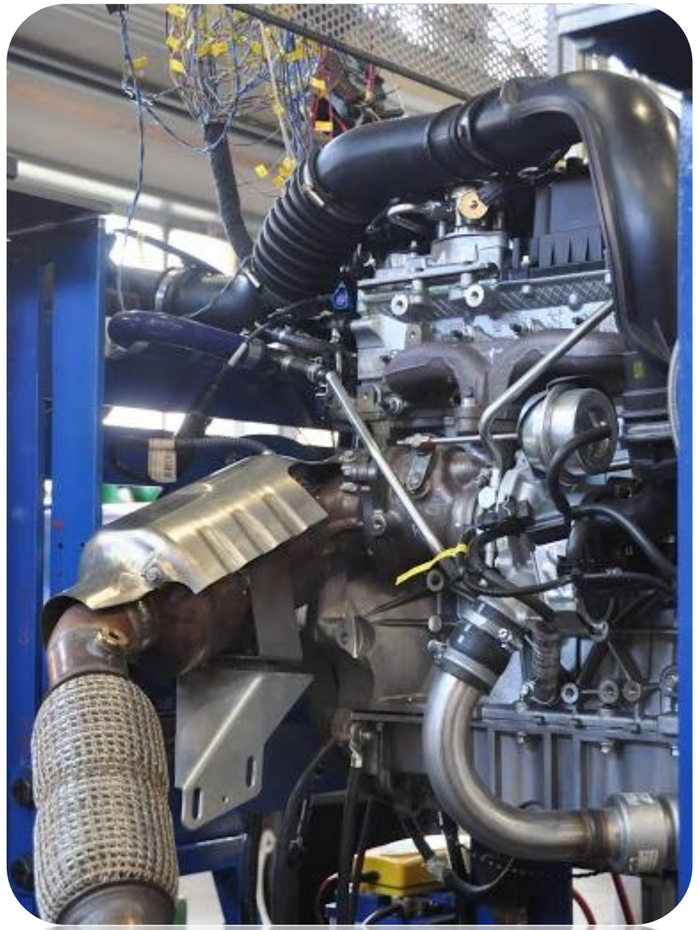


GHENT UNIVERSITY

UGent RESEARCH INTO **METHANOL**

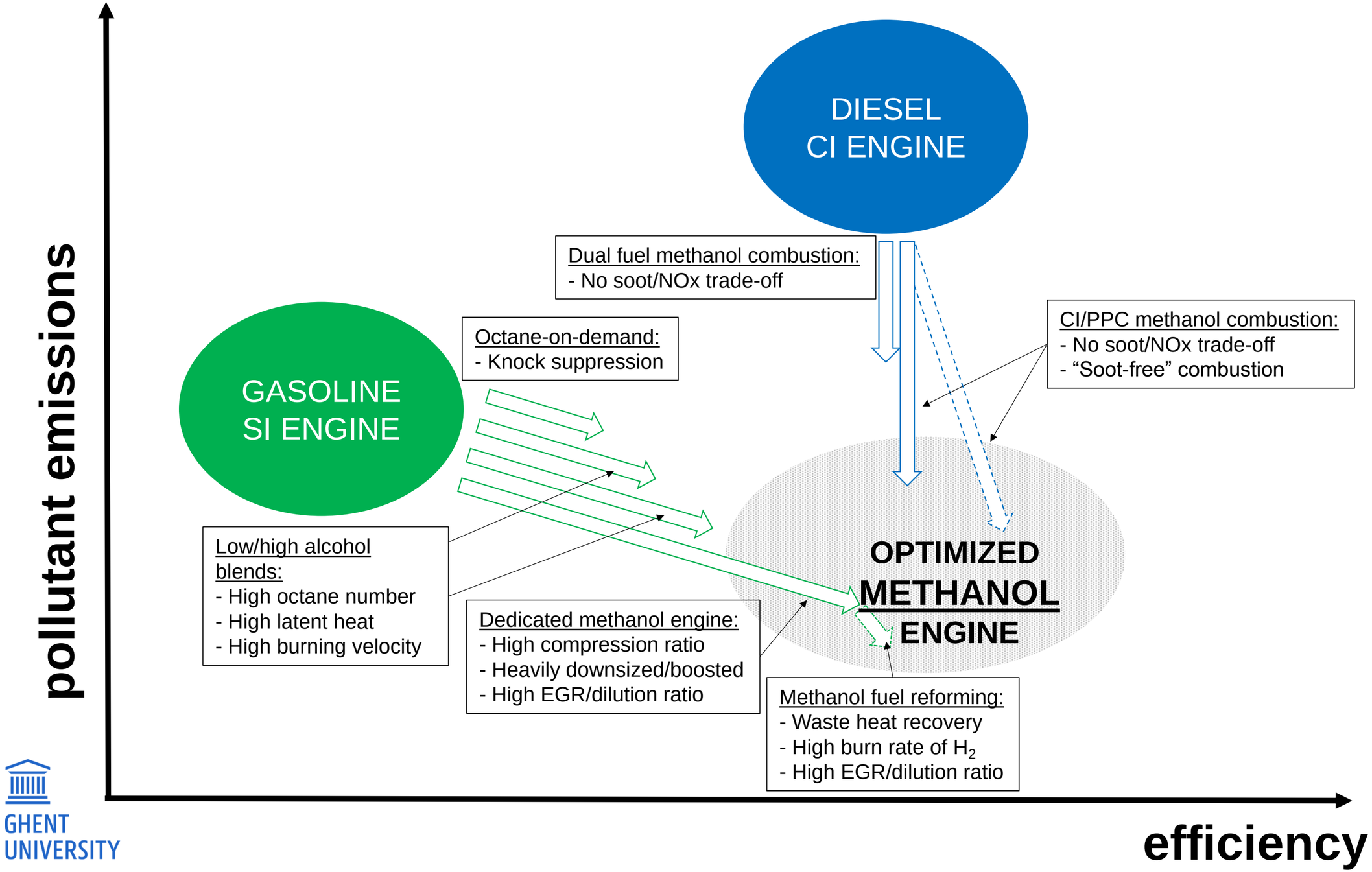
- Converted engines on test bench
- Conclusion from extensive set of measurements:
  - Power density > gasoline
  - Efficiency > diesel
  - And emissions can be lower than both!

LeanShips
Low Energy And
Near to zero emissions Ships

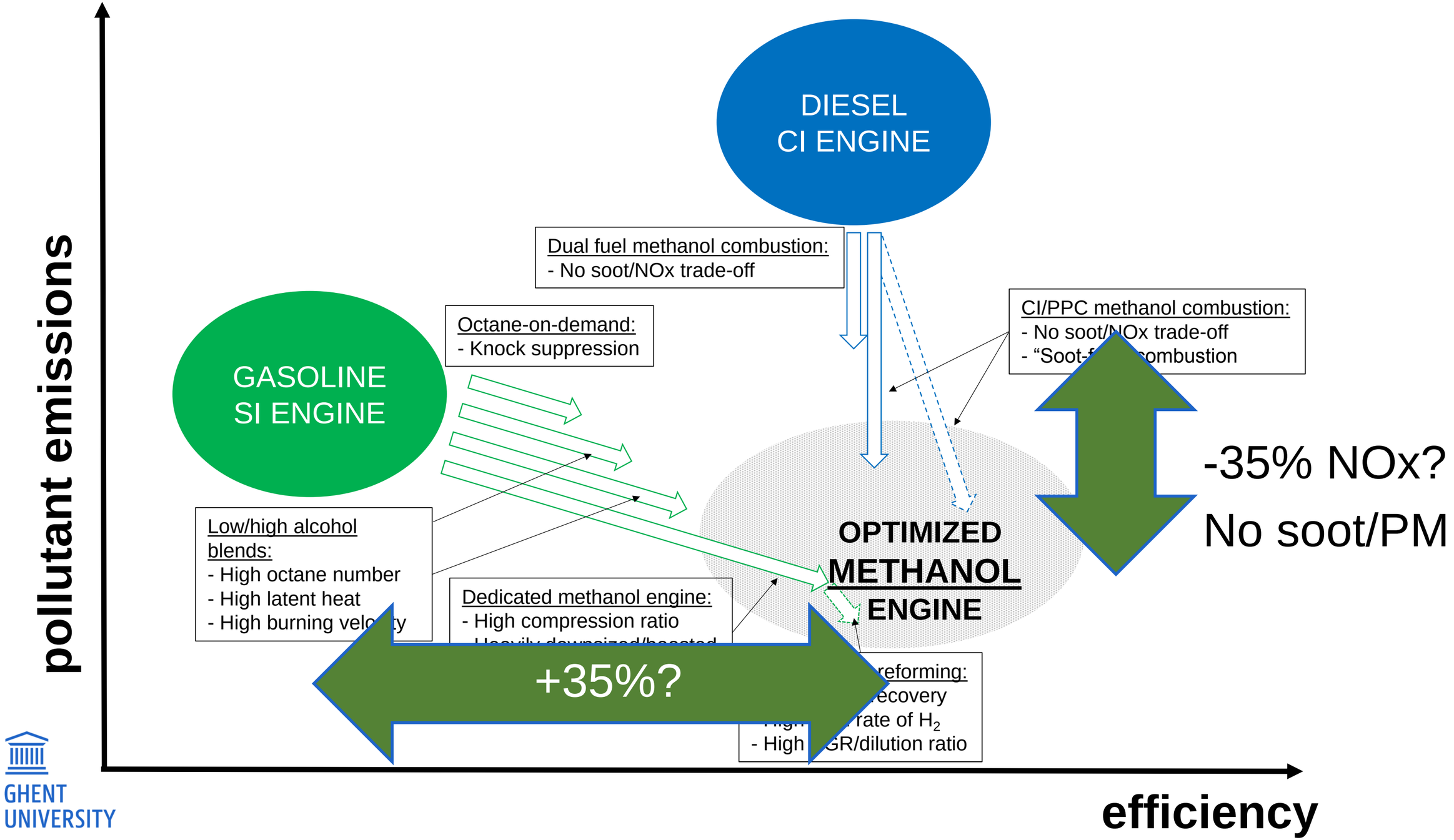


Progr Energ Comb Sci 70:43

GHENT UNIVERSITY

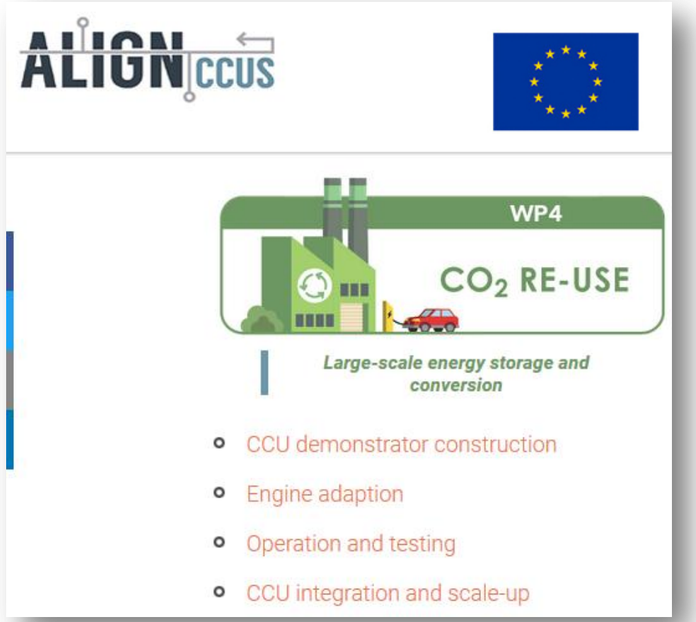


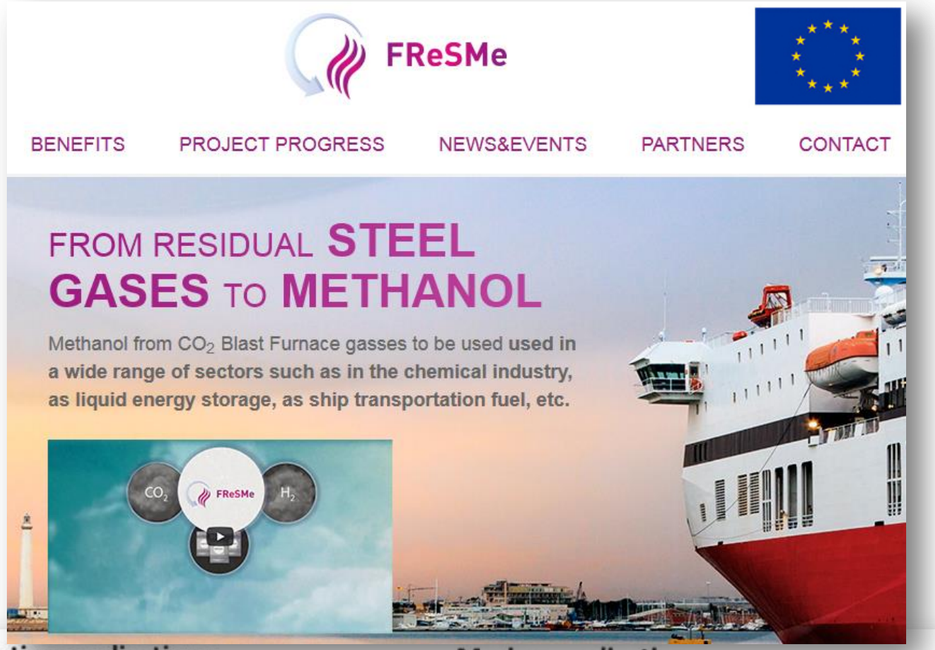
GHENT UNIVERSITY



GHENT UNIVERSITY

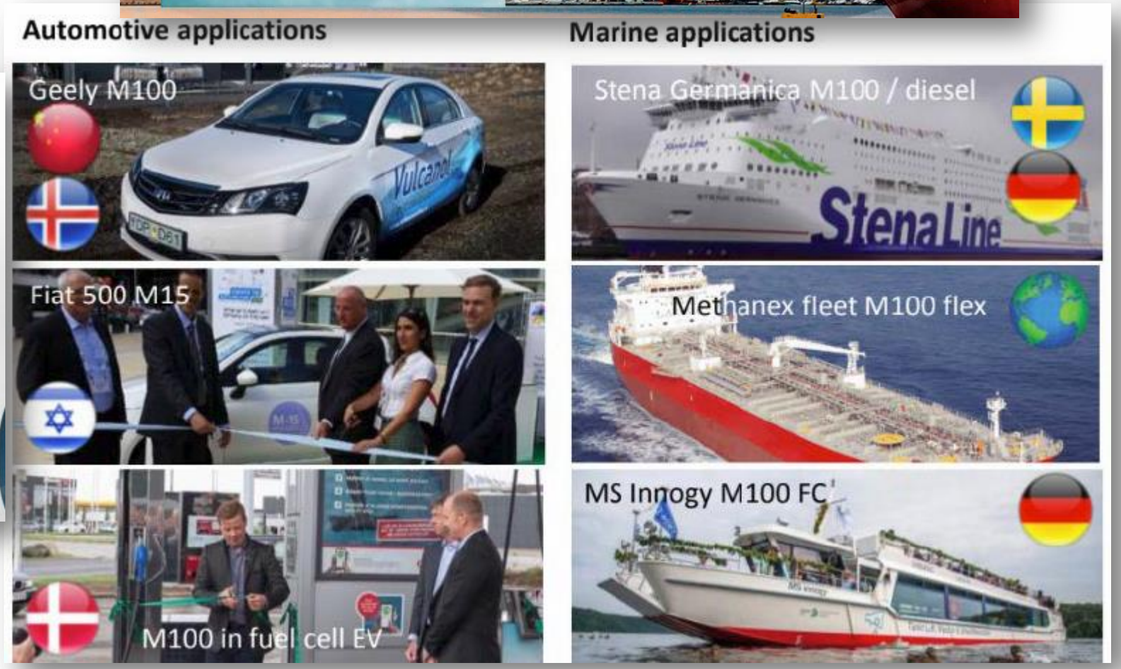
ONGOING PROJECTS





Enerkem – Waste to Methanol

GHENT UNIVERSITY



BioMCN – Biomethane to Biomethanol

FLANDERS

flux50 | Home | Events & News | Innovator zones | Projects | About

What is an innovator zone?

- Energy Harbors
- Microgrids
- Multi-energy Solutions
- Energy Cloud Platforms
- Intelligent Renovation

To help Flemish companies bring innovative and fully-integrated energy proc
services to the international market, Flux50 sets up and coordinates living la
'innovator zones'. These zones reflect the thematic priorities of Flux50. A firs
zone is **Energy Harbors.**

NEWS | ABOUT | PARTNERS | PIPELINES | TRAINING | CONTACT

CAPTURE

CENTRE FOR ADVANCED PROCESS TECHNOLOGY FOR URBAN RESOURCE RECOVERY

OUR INITIATIVE

OUR INFRASTRUCTURE

CO2 TO PRODUCT

Today, Flanders is emitting approximately 65 Mton of carbon dioxide or CO2 per year, half of which is produced by point...

Read more...

WATER 'FIT-FOR-USE'

Industrial water use can account for 25% of the total production cost and up to 57% of the total freshwater consumption...

Read more...

PLASTICS TO RESOURCE

Plastics are a key material within the circular economy. Their diverse composition and processing techniques make them both...

Read more...

GHENT UNIVERSITY | province of East Flanders | Flanders State of the Art | vito vision on technology

Steelanol
Fueling a sustainable future

Home | News | Partners | Contact

Steelanol recycles carbon into sustainable, advanced bio-ethanol

We capture carbon from an industrial source and recycle it, just like we do with glass, paper and plastic.

ArcelorMittal | PRIMETALS TECHNOLOGIES | LanzaTech | E4tech

GHENT UNIVERSITY

FLANDERS

DE TIJD

Nieuws Markten LIVE Netto LOG IN ABO

EU zet reddingsoperatie voor vluchtelingen stop | 'Zweedse bankreus versluisde witwasgeld naar campagneleider Trump' | Bentley | Verre droom

NIEUWS > ONDERNEMEN > MILIEU & ENERGIE

Ook in Gent project voor opvang en hergebruik CO2

27 maart 2019 12:14

Port of Antwerp

ABOUT THE PORT BUSINESS CONNECTIVITY SUSTAINABILITY PORT OF THE FUTURE SERVICES AND INFO

Port of the future

Home > Port of the future > Energy and environment: new solutions for a sustainable future > Transition to a Multi Fuel Port

- Energy and environment: new solutions for a sustainable future
  - Transition to a Multi Fuel Port
- Smart port
- Smart transport en industry 4.0
- Strong together: community building

Transition to a Multi Fuel Port

Antwerp is the fifth-largest bunkering port in the world. It therefore has an important role to play in the transition from fossil fuels to renewable sources of energy for shipping.

Port of Antwerp aims to become a Multi-Fuel Port by 2025, a port where in addition to conventional fuels, alternative, more sustainable fuels can also be made available.Specifically we will achieve this by:

- Including methanol, hydrogen gas and electrical energy in the bunkering market
- Further expanding LNG bunkering (at the moment some 750 tonnes of LNG is bunkered annually in the port of Antwerp)
- Developing conventional bunkering into a fully fledged port service in its own right, with the introduction of a high-quality licensing system and a digitisation path.

DE TIJD

Nieuws Markten LIVE Netto MIJN TIJD ABONNEER

Filip Balcaen koopt IBM-toren in Brussel | Beleggersagenda van donderdag 28 maart | Reynders speelt finale voor topjob bij Raad van Europa | EU zet red vluchteling

NIEUWS > ARCHIEF

Bedrijven in Antwerpse haven gaan CO2 opvangen en hergebruiken

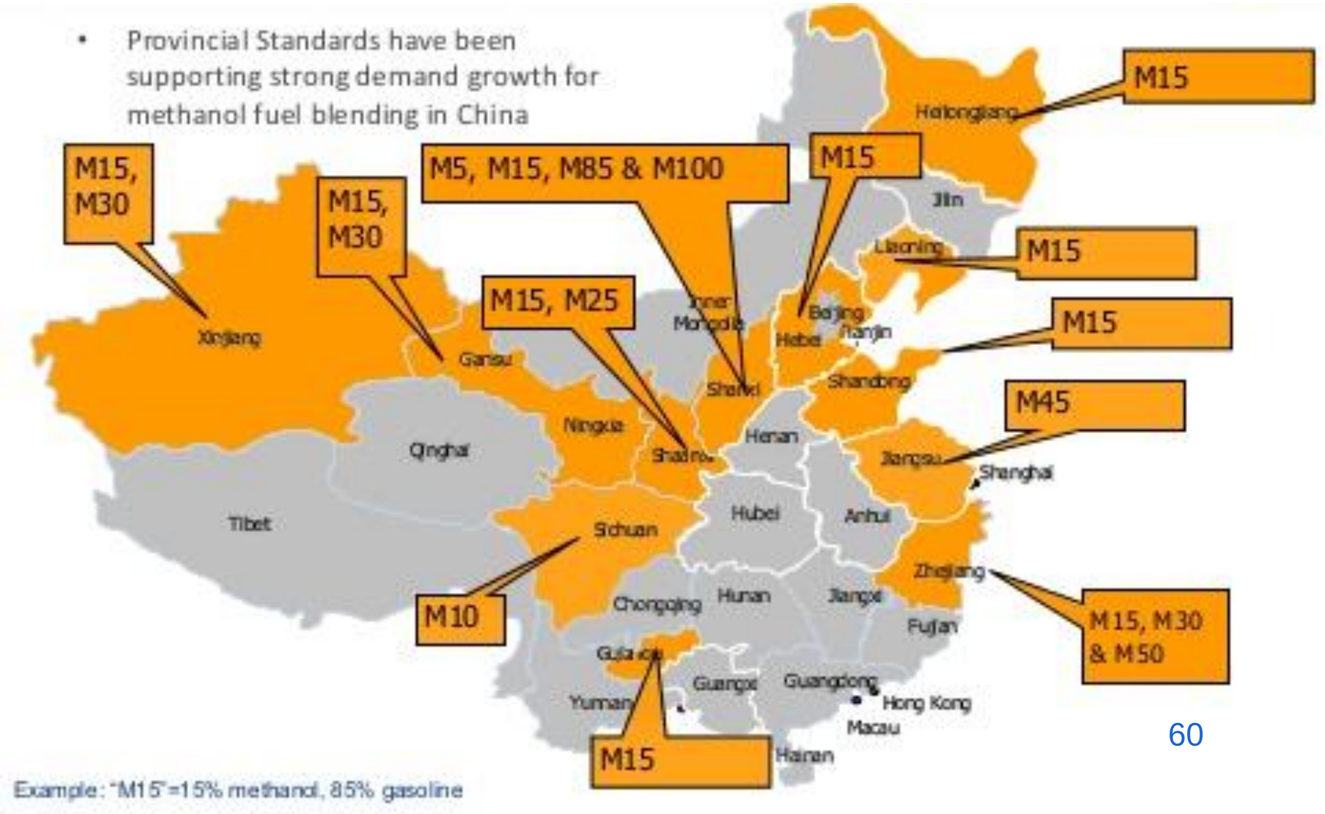
23 maart 2019 00:00

GHENT UNIVERSITY

METHANOL AS A FUEL

- Now: China main methanol fuel market
  - Improving air quality & increasing energy security

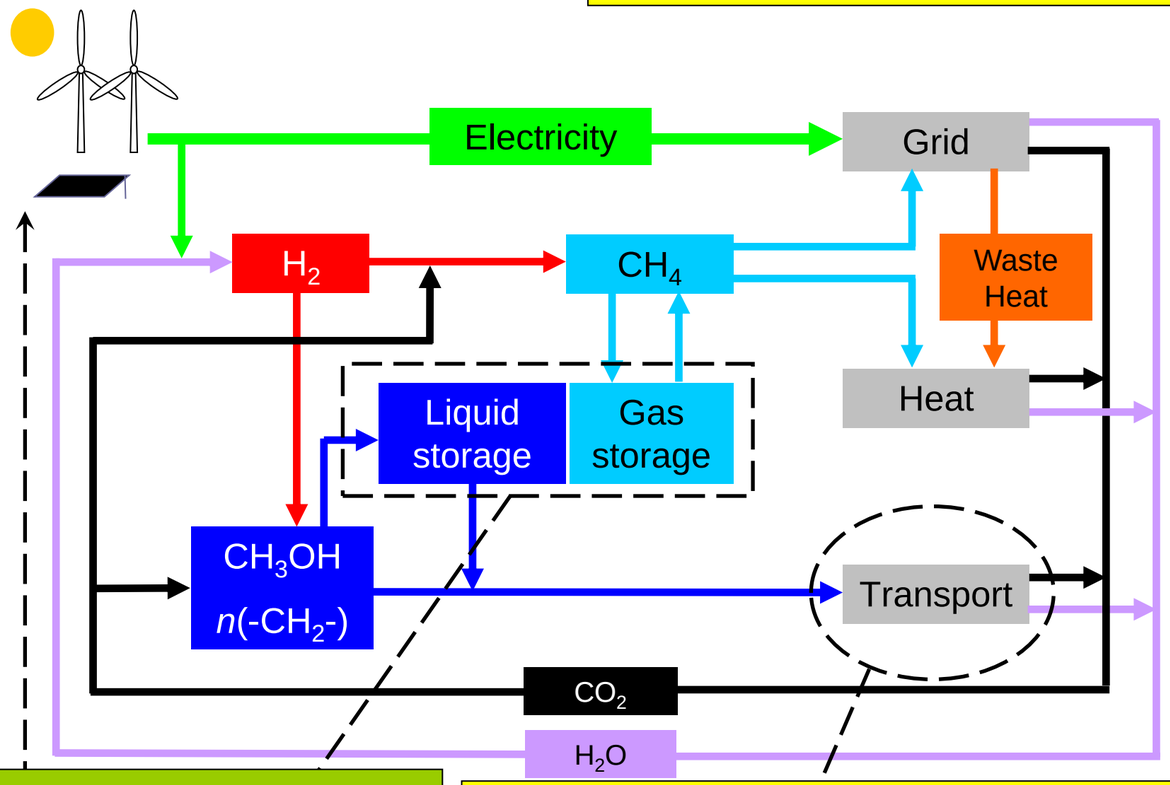
- 2015: 35 billion liters of methanol for energy use



GHENT UNIVERSITY

AN INTEGRATED SYSTEM

"Renewable Power Methane", cfr. E-gas projects;



Massive storage of renewable energy makes investment in it viable

…And this can be brought into play <u>quickly</u> using liquid fuel blends in <u>existing</u> vehicles

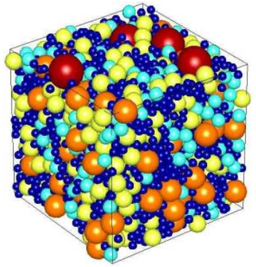
GHENT UNIVERSITY

R. J. Pearson et al. "Energy storage via carbon-neutral fuels made from CO2, water, and renewable energy," Proc. IEEE, vol. 100, no. 2, pp. 440–460, Feb. 2012.

- Why should internal combustion engines be banned?
- Why should we not ban them?

WHY SHOULD INTERNAL COMBUSTION ENGINES BE BANNED?

- Air quality problems can be solved, even on gasoline and diesel
- A combustion engine does not HAVE to run on a fossil fuel
- ICE, with renewable (liquid) (e-)fuel is a solution that is sustainable, scalable and storable



GHENT UNIVERSITY

WHY SHOULD WE **NOT** BAN THE ICE?

- Legislator needs to focus on **impact**
  - Pollutant emissions, greenhouse gases
- NOT on technology!
- ICE or BEV; BEV or FCEV... Irrelevant!

  Each has its merits and can be sustainable

  Each has unanswered questions
- We will likely find different answers for different applications (as is already the case now)

GHENT UNIVERSITY

CLAIMS

There is no such thing as “zero emissions”

Think about tank-to-wheel and vehicle production

Basic physics show that a hydrogen economy is not feasible

H_2 will be an important element, but has severe storage limitations

Basic chemistry shows that an electric economy is not feasible

Electric is best for increasing efficiency… but that’s not the only criterion!

In the long run, we’ll all drive electric...

But maybe not as you might think

Could be on e-fuels, made from sustainable electricity!

GHENT UNIVERSITY

Thank YOU!

&thanks to:

Internally:
my current and previous PhD students (Ramón, Joachim, Jeroen V, Jonas, Louis, Jakob, Thomas, Stijn, Khanh, Roel, Ahmed, Gilles, Haohan, Jeroen D, Erik, Vikram, Menno), thesis students, department colleagues in Ghent and Lund, …

Externally:
Prof. Jamie Turner of University of Bath; Dr. Richard Pearson (formerly Lotus Engineering); KVAB renewable carbon working group: Prof. Johan Martens, Prof. Norbert De Kimpe, Prof. Annemie Bogaerts, Prof. Pierre Jacobs, Prof. Guy Marin, Prof. Korneel Rabaey, Prof. Mark Saeys; Tim Berckmoes, Lieven Vervaeke, Koen Christianen and Luc Mattheeuws of ABC Engines; Pieter Huyskens of Damen Shipyards; Jan-Willem Vissers, Rudi Block and Dr. Tobias Husberg from Volvo Penta; Jorne Beyen from DEME; Christoph Meichelböck from Abeking & Rasmussen; Ben Iosefa, Ayça Yalcin, Yori Robbe and Michel Hamrouni of Methanex; Eelco Dekker and Greg Dolan of the Methanol Institute; Dr. Leslie Bromberg of MIT; Markus Lehne from Balance; Joanne Ellis from SSPA; Prof. Bengt Ramne, Patrik Molander and Joakim Bomanson from Scandinaos; Hubert Kienzler from Heinzmann; Pieter Vandermeeren and Didier Van Osselaer from Port of Antwerp; …

FACULTY OF ENGINEERING
AND ARCHITECTURE

Sebastian VERHELST

Associate Professor of Internal Combustion Engines

DEPT. OF FLOW, HEAT AND
COMBUSTION MECHANICS

E sebastian.verhelst@ugent.be
T +32 9 264 33 06

www.ugent.be/ea/floheacom

Ghent University
@ugent
Ghent University

GHENT
UNIVERSITY