FACULTY OF ENGINEERING
AND ARCHITECTURE

DEPARTMENT OF ELECTROMECHANICAL, SYSTEMS AND METAL ENGINEERING
SUSTAINABLE THERMO-FLUID ENERGY SYSTEMS

FUELS FOR CLEAN SHIPPING

Sebastian Verhelst

20/3/2023

GHENT
UNIVERSITY


LNG
H_2
???
NH_3
HVO
MeOH
???
DME
RME

YOUR SPEAKER

- Prof. Sebastian Verhelst
  - PhD in hydrogen engines, 2005, Ghent University
  - Full Professor at Ghent University (BE) and Associate Prof. at Lund University (SE)
  - Supervising 10 researchers, 2 working on hydrogen as engine fuel, 3 on biofuels, and 5 on methanol
  - Expertise: internal combustion engines, on alternative/ renewable fuels: methanol (since 2009), ethanol, hydrogen (since 1999), straight vegetable oils, animal fats, biodiesel, alcohol blends, ...
  - Increased focus on marine applications since 2015
    - EU H2020 projects FASTWATER (ongoing, coordinator), LeanShips (WP leader)
    - Collaboration with Belgian medium speed engine manufacturer

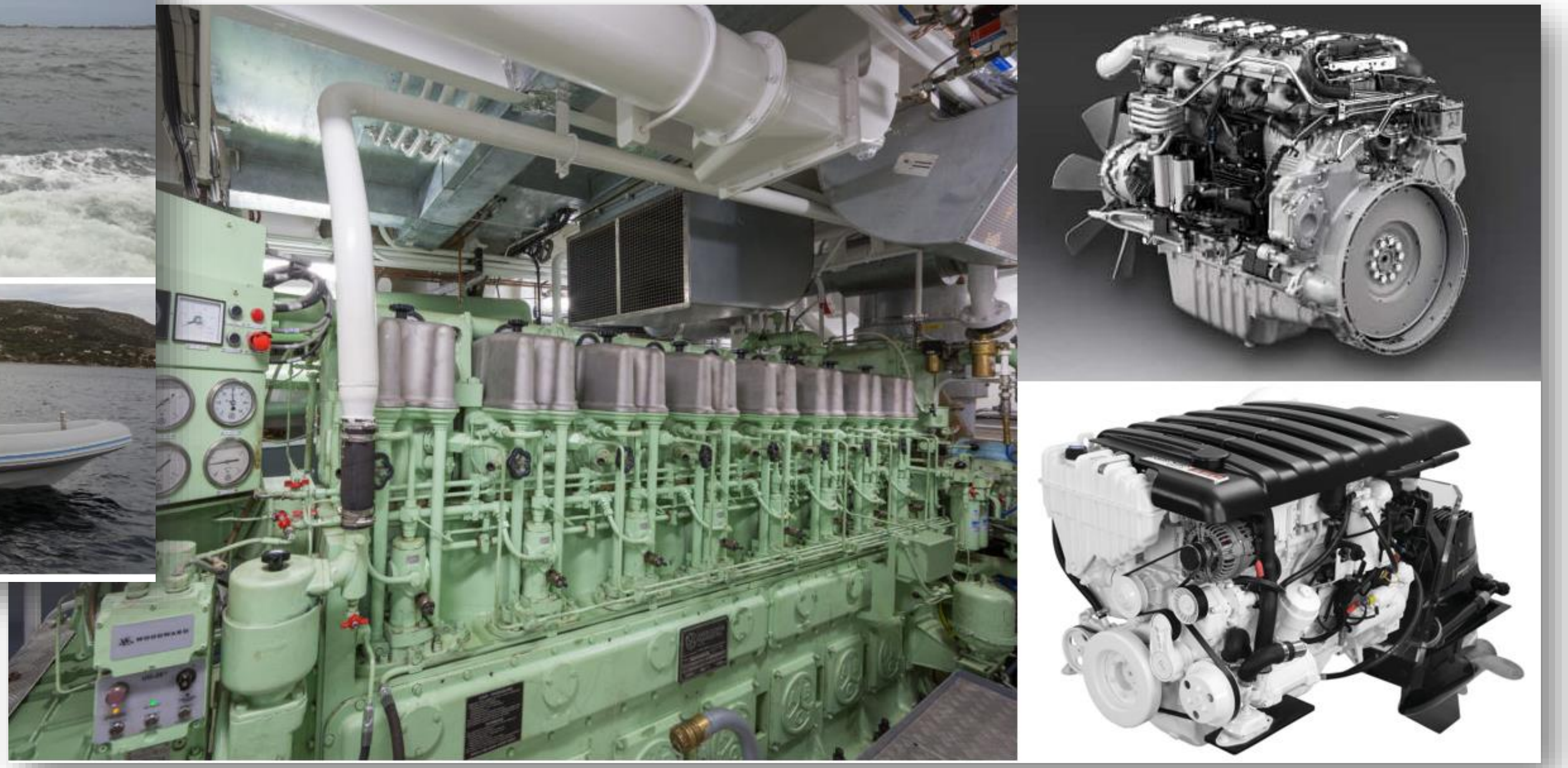
GHENT UNIVERSITY

LUND UNIVERSITY

FASTWATER

FAST Track to Clean and Carbon-Neutral WATERborne Transport

June 2020 – May 2024
The project has received funding from the European's Horizon 2020 research and innovation programme (Contract No.:860251)
fastwater.eu



ANGLO BELGIAN CORPORATION We power your future
HEINZMANN
methanex the power of agility
BALance Technology Consulting
SUPER TOYS BOATS · ENGINES · PWC · ATV
MEYER WERFT PAPENBURG 1795
SWEDISH MARITIME ADMINISTRATION
GHENT UNIVERSITY
LUND UNIVERSITY
SSPA
ScandiNAOS AB
Lloyd's Register
Port of Antwerp

APPROACH OF TODAY

- Rather than bombard you with a plethora of studies and data: provide you with a set of tools and insights
  - Start from the right basis
    - Base criteria for judging an alternative
  - Structured approach for comparing options
    - Production / distribution&infrastructure / use
    - Won't focus on the (engine) technology

      but actually our main expertise
  - Do this in an objective way – no commercial interests!

GHENT UNIVERSITY

START FROM THE BASICS

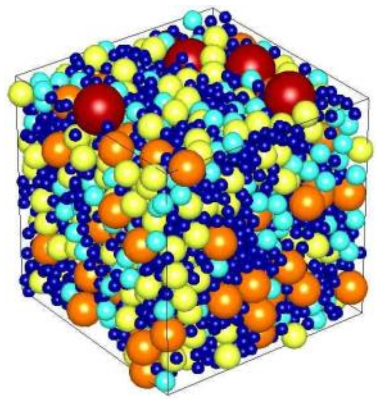
GHENT UNIVERSITY

WHY ARE WE HERE?

- We want to set out the path to sustainable shipping
- That means: aiming, **long-term**, for a chain
  energy source – energy carrier – energy converter that is

- **Sustainable**
  - Source: solar, wind, bio, …
  - Closed cycle for energy carrier and converter materials

- **Scalable**
  - Use abundantly available resources
  - Also implies affordable



- **Storable**
  - High energy and power density: need range & payload

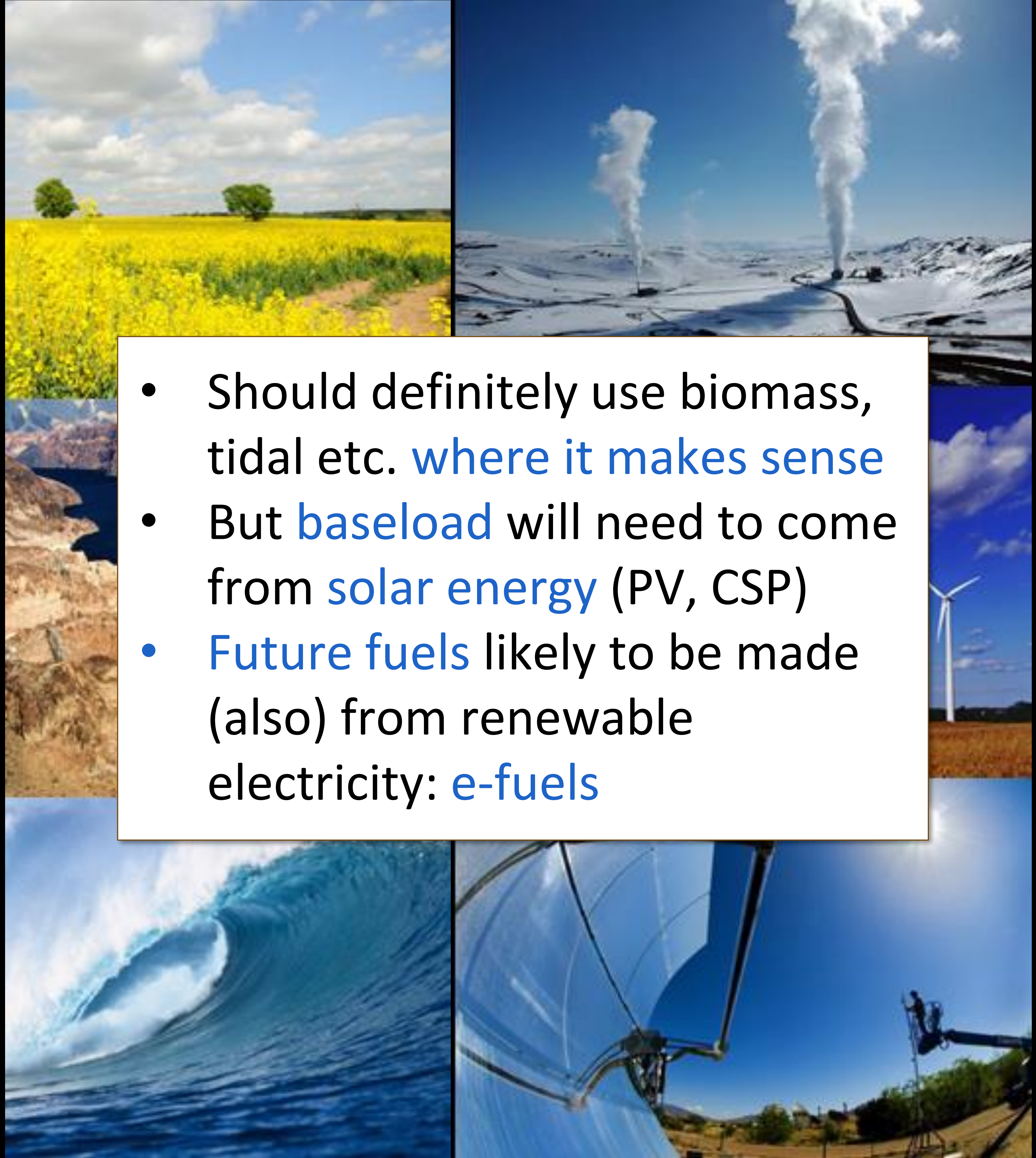
My "Triple S" criteria for assessing any option

GHENT UNIVERSITY

7 TW

7 TW

14 TW



- Should definitely use biomass, tidal etc. where it makes sense
- But baseload will need to come from solar energy (PV, CSP)
- Future fuels likely to be made (also) from renewable electricity: e-fuels

44 TW

72 TW

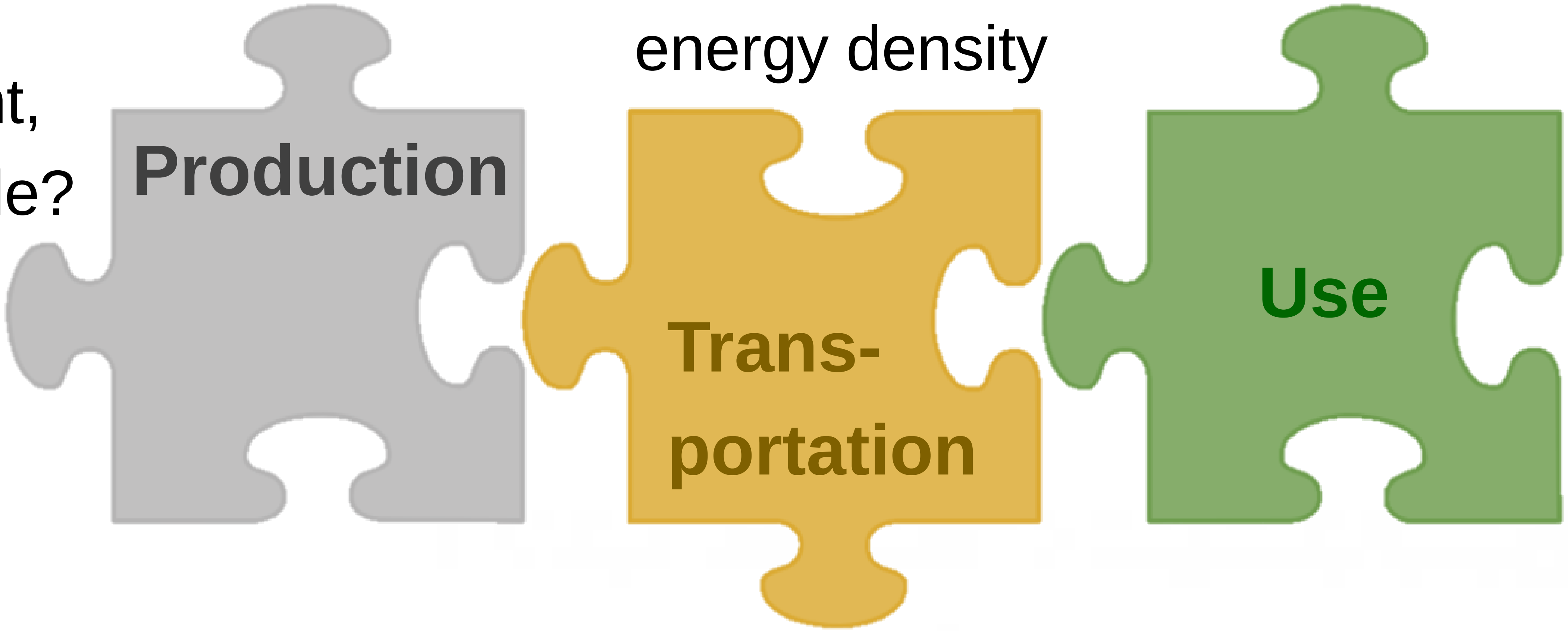
85.000 TW

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

WHICH FUELS?

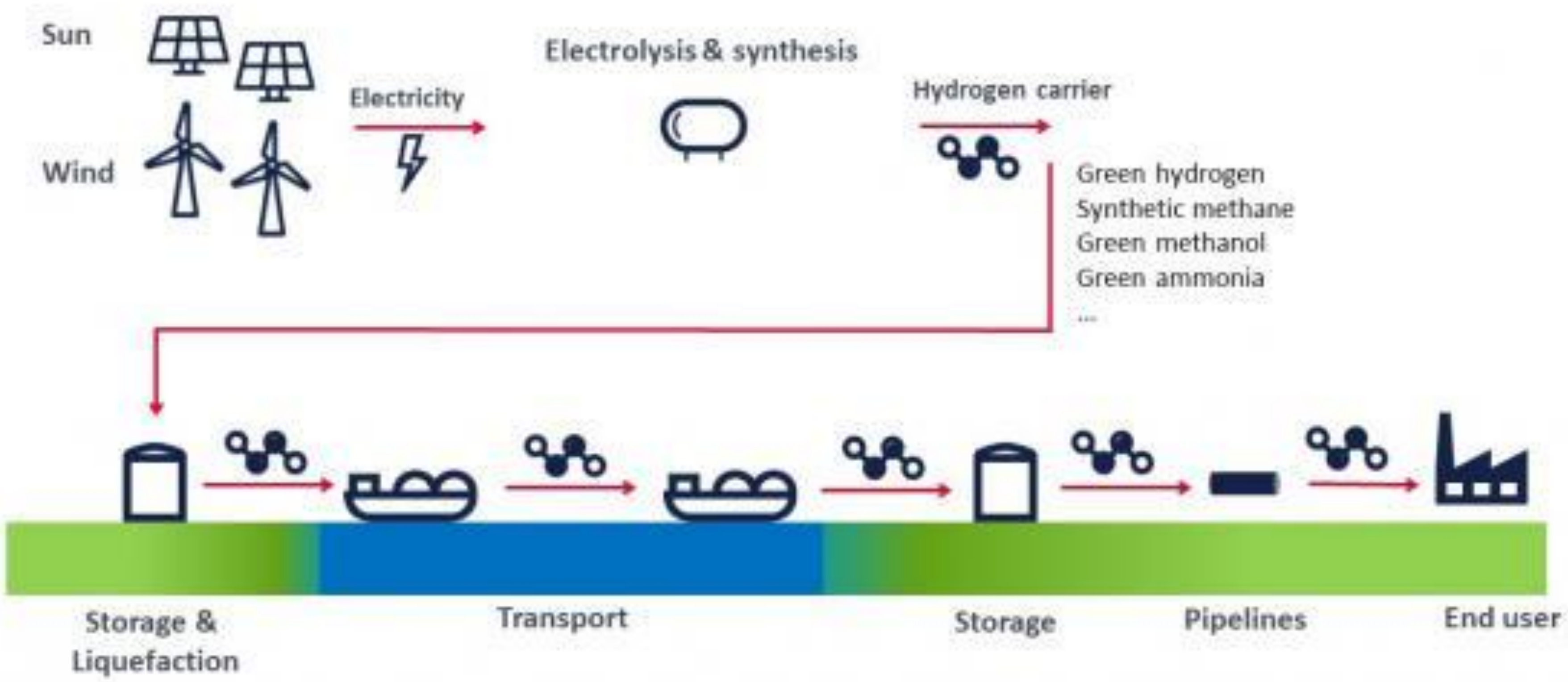
how efficient,
how scalable?

from production location
to point of use:
energy density



energy density,
how efficient,
how clean?

Need to look at all parts of the energy carriers' "life"



GHENT
UNIVERSITY

PRODUCING FUELS

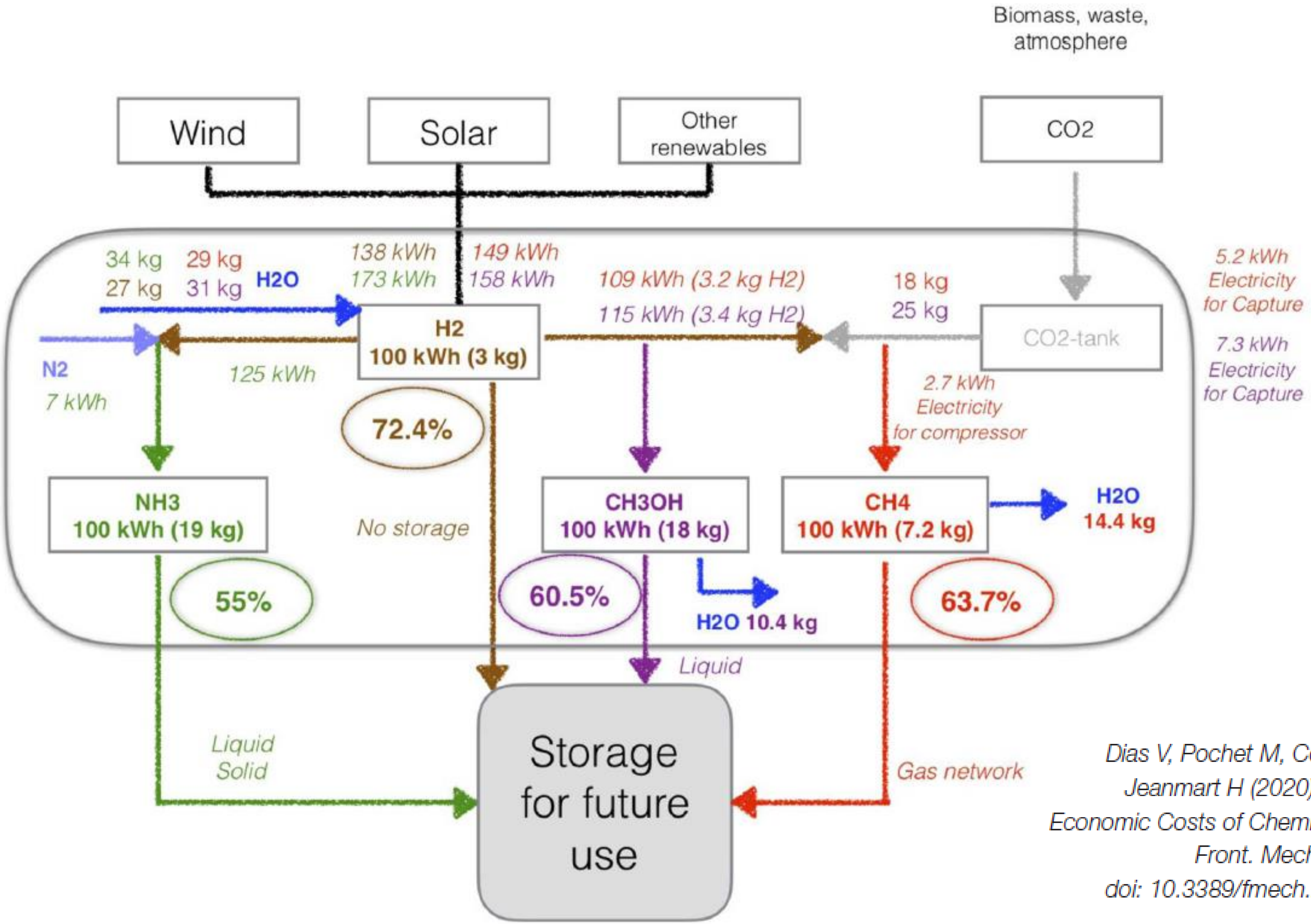
GHENT UNIVERSITY

WHICH FUELS?

- If we need to synthesize fuels, let’s make what we want
  - Sufficient energy density
  - Preferably simple molecules
    - **Production is more efficient → Well-to-tank (WTT) part of the equation**
- Scalable? Needs 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 240K or 8.6 bar)
  - Methanol (MeOH), CH_3OH (liquid)
  - Dimethylether (DME), CH_3OCH_3 (liquid at 5.3 bar)
  - …

GHENT UNIVERSITY

TO CARBON OR NOT TO CARBON?



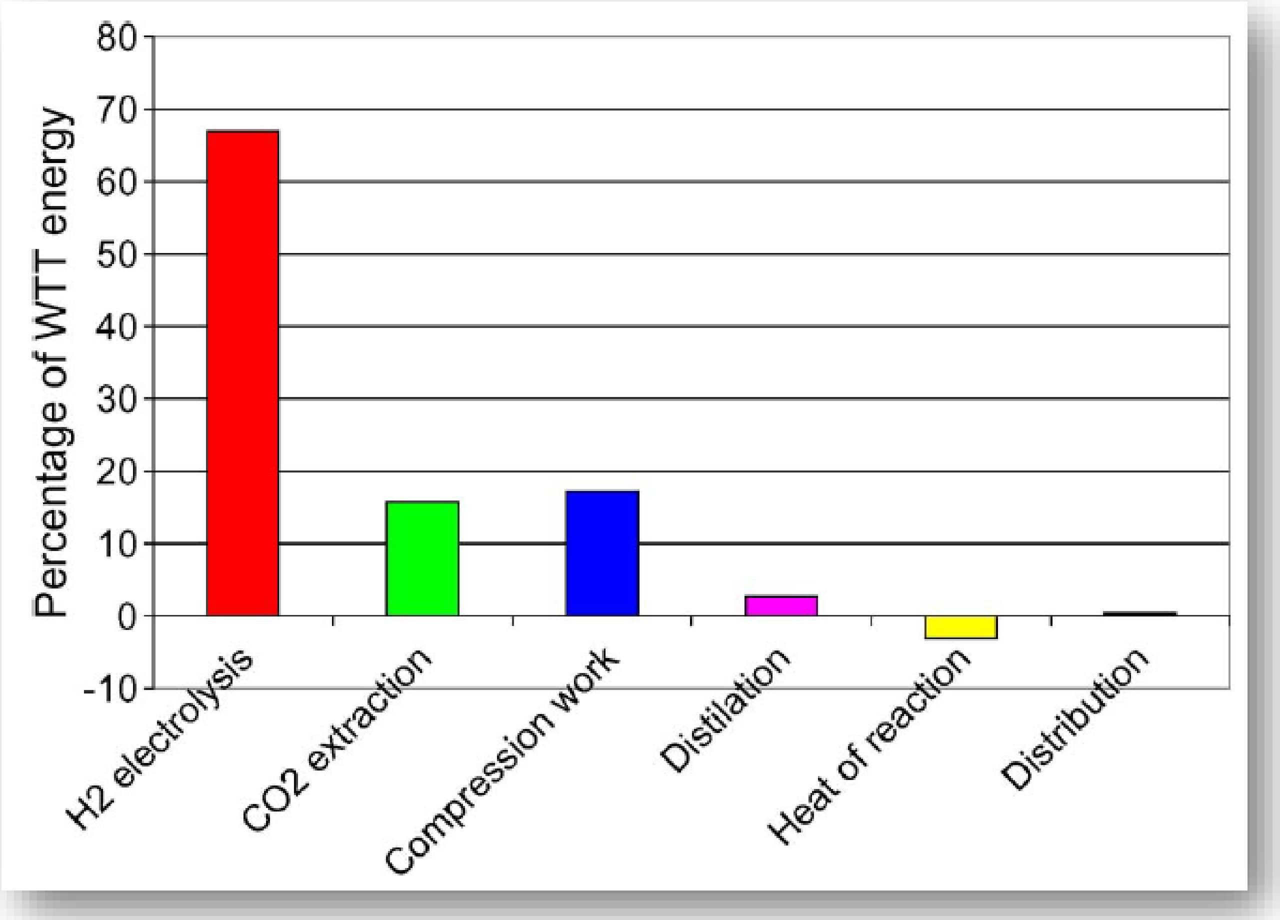
Dias V, Pochet M, Contino F and Jeanmart H (2020) Energy and Economic Costs of Chemical Storage. Front. Mech. Eng. 6:21. doi: 10.3389/fmech.2020.00021

GHENT UNIVERSIT

PRODUCTION EFFICIENCIES?

- Some surprises
  - Carbon capture does not come for free, but it's producing hydrogen that is the biggest energy chunk
  - Example: methanol production
  - Splitting nitrogen is also energy intensive
  - Thus, there are differences (and there is a range of numbers in literature), but they're not miles apart
  - Obviously the future price of carbon is a major uncertainty today

Methanol synthesis



PIEEE 100(2):440-460

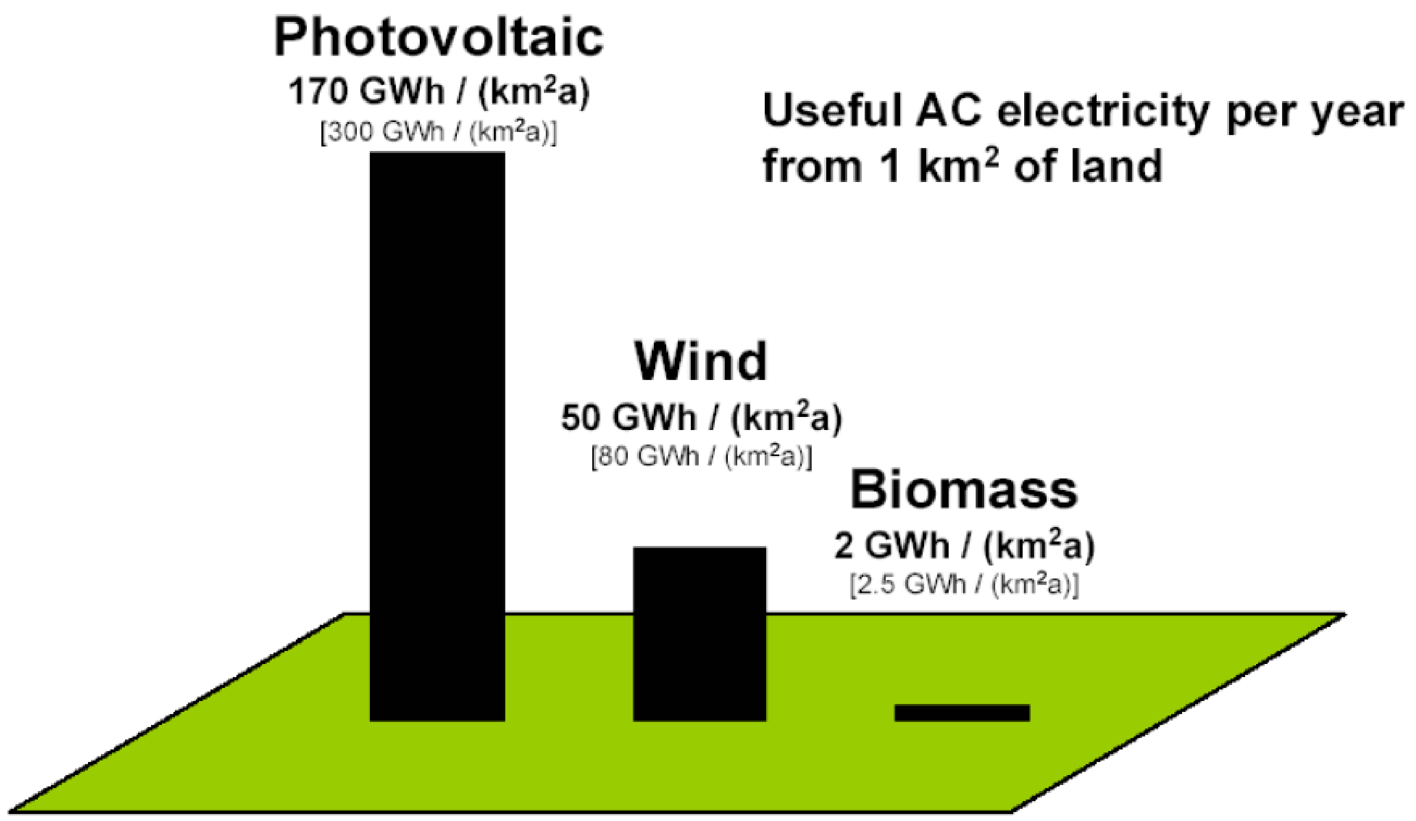
GHENT UNIVERSITY

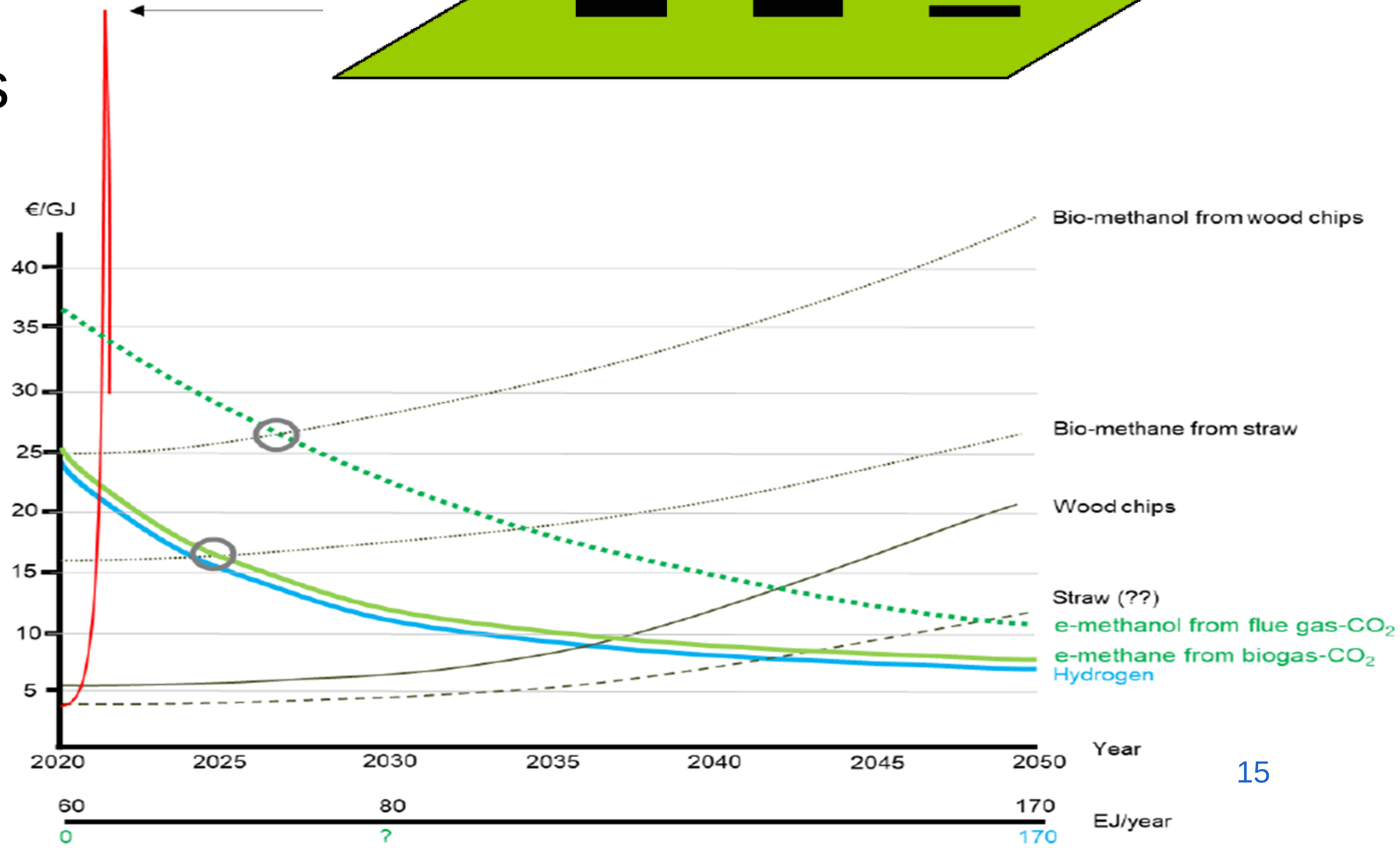
KEY POINTS, PRODUCTION

H_2	– Essential building block – energy and molecule – "primary fuel" – so production obviously most efficient
NH_3	– No carbon needed – Top 5 chemicals worldwide – mature product
CH_4	– Carbon needed, $4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$ – Main component of natural gas, vast infrastructure – Uncertainty on competition for sustainable carbon (chemical industry, aviation), hence on price. CCU and DAC just getting started – Legislative framework hindering through focus on tailpipe emissions (road) – Marine: legislation of well-to-wake GHG emissions
MeOH	– Carbon needed, $3H_2 + CO_2 \rightarrow CH_3OH + H_2O$ – Top 5 chemicals worldwide – mature product – MTO attractive route for sustainable chemistry (MTO: methanol-to-olefins)

WHAT ABOUT BIOFUELS?

- Short-term, clearly biodiesel (RME), HVO etc. are the most interesting options
  - “drop-in” solutions: same engine, same tanks
- Long term, the expectation is that e-fuels take over
  - No “biomass limit”: more scalable
  - Hence, likely to become cheaper





GHENT UNIVERSITY

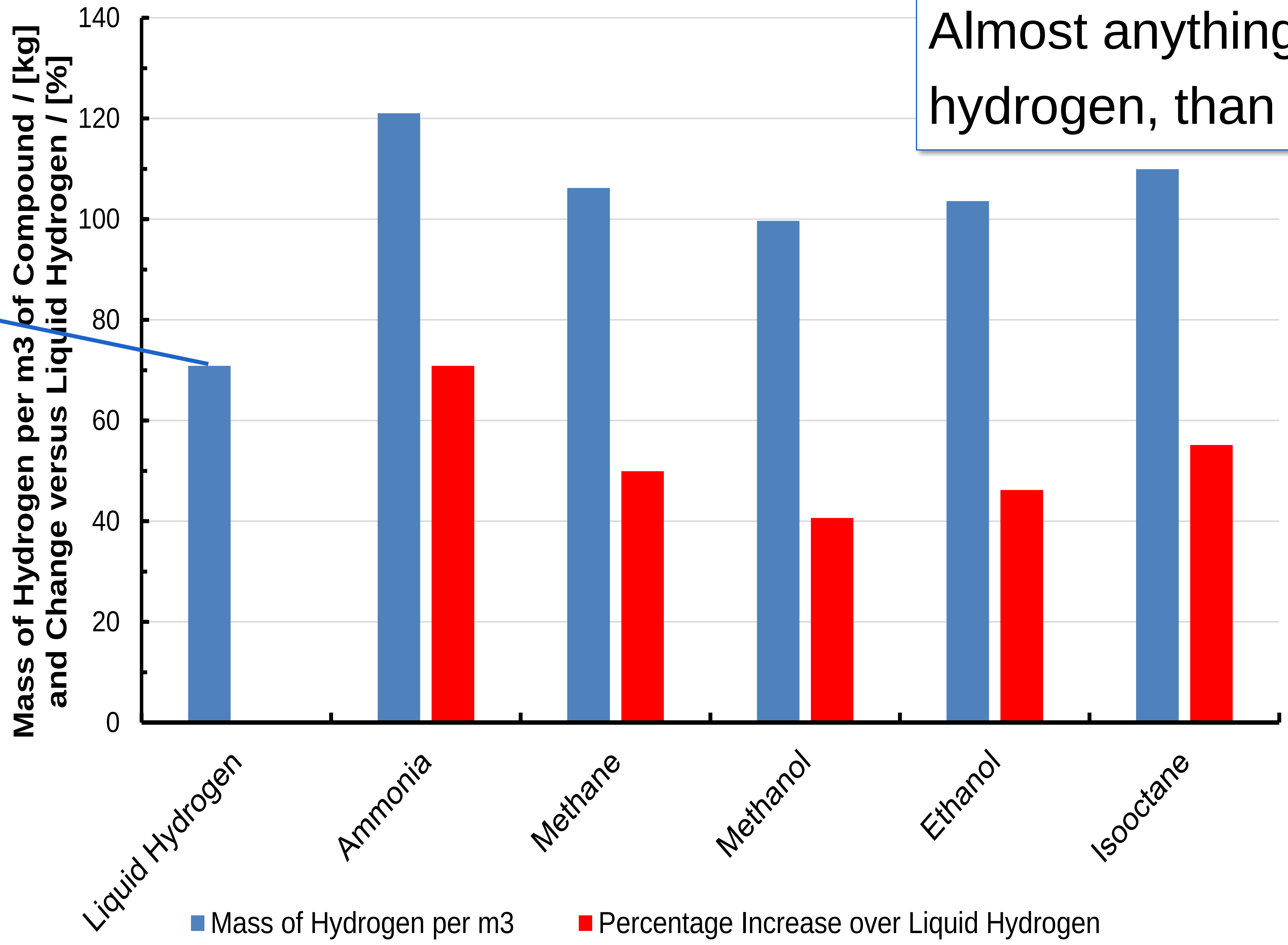
DISTRIBUTING, STORING AND BUNKERING FUELS:

FUEL INFRASTRUCTURE

HYDROGEN OR A HYDROGEN VECTOR?

Almost anything is better at storing hydrogen, than hydrogen itself!

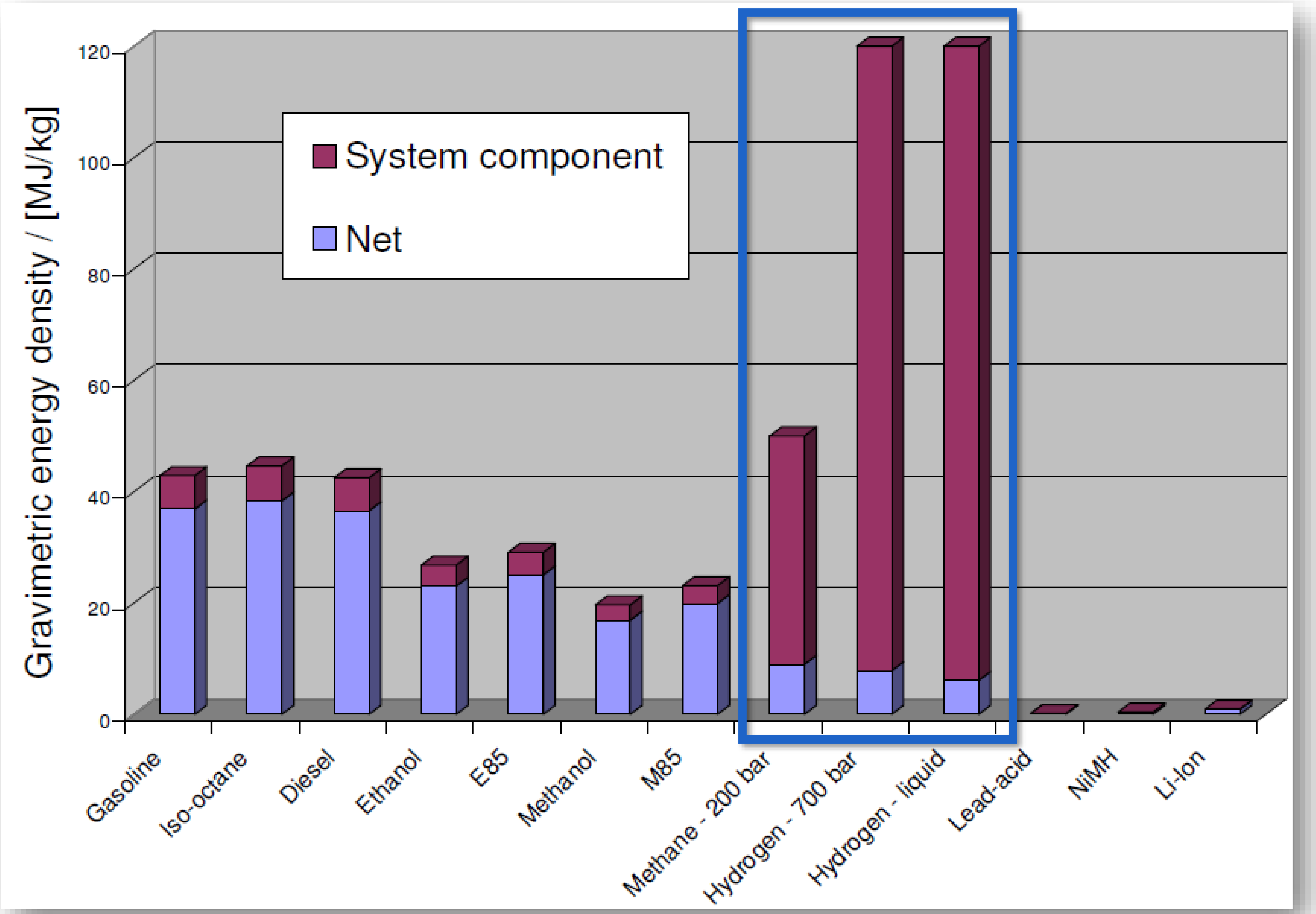
70kg/m³
The density of styrofoam!



Progr Energ Comb Sci 70:43

GHENT UNIVERSITY

DON'T FORGET STORAGE SYSTEM!



Big impact for gases

GHENT UNIVERSITY

FUEL INFRASTRUCTURE

- Ease, and thus cost,
  of distributing, storing and bunkering fuels:
  very strongly linked with energy density

- Energy density also affects use,
  so more on this in next section...

GHENT UNIVERSITY

USING FUELS

GHENT UNIVERSITY

USING FUELS - CONSIDERATIONS

(this piece of the puzzle missing in most studies!)

- Conversion efficiency (fuel to power)
- Pollutant emissions: GWP, air quality
- On-board storage
- Safety
- TRL of energy converter
- ...

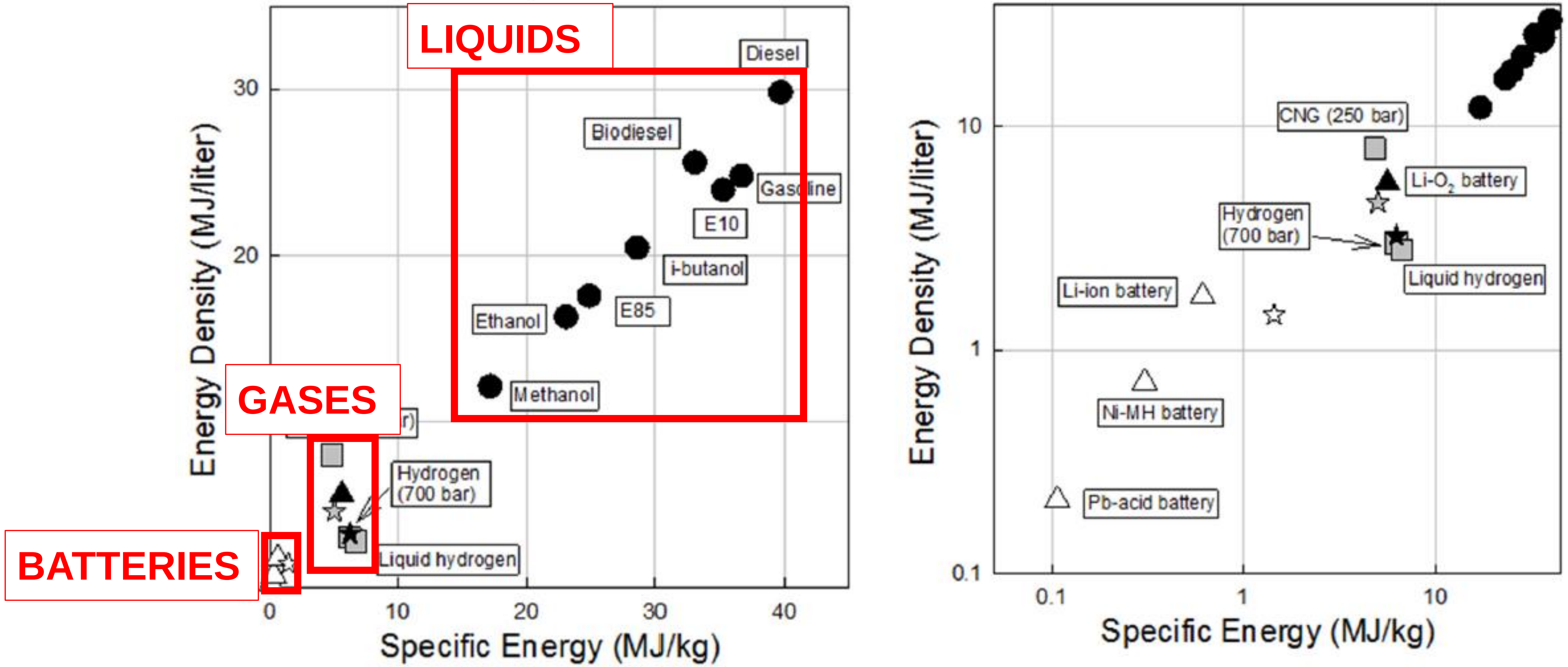
GHENT UNIVERSITY

AGAIN: KEEP IT SIMPLE

- Conversion (end-use) can be controlled more easily with simple fuel molecules
  - Better trade-off between efficiency and emissions
  - Or no trade-off at all
    - H_2, ammonia, methanol, DME: no soot!
- Is tank-to-wake (TTW) part
  of the well-to-wake (WTW) equation
- Also holds for on-board storage: liquid fuel greatly simplifies ship design and increases range&payload

GHENT UNIVERSITY

NET ENERGY DENSITY AND SPECIFIC ENERGY FOR SELECTED ENERGY CARRIERS



Volume and weight are important for shipping:

– Weight → draught → resistance (+ port limits)
– Volume → competition with cargo (money maker)

GHENT UNIVERSITY

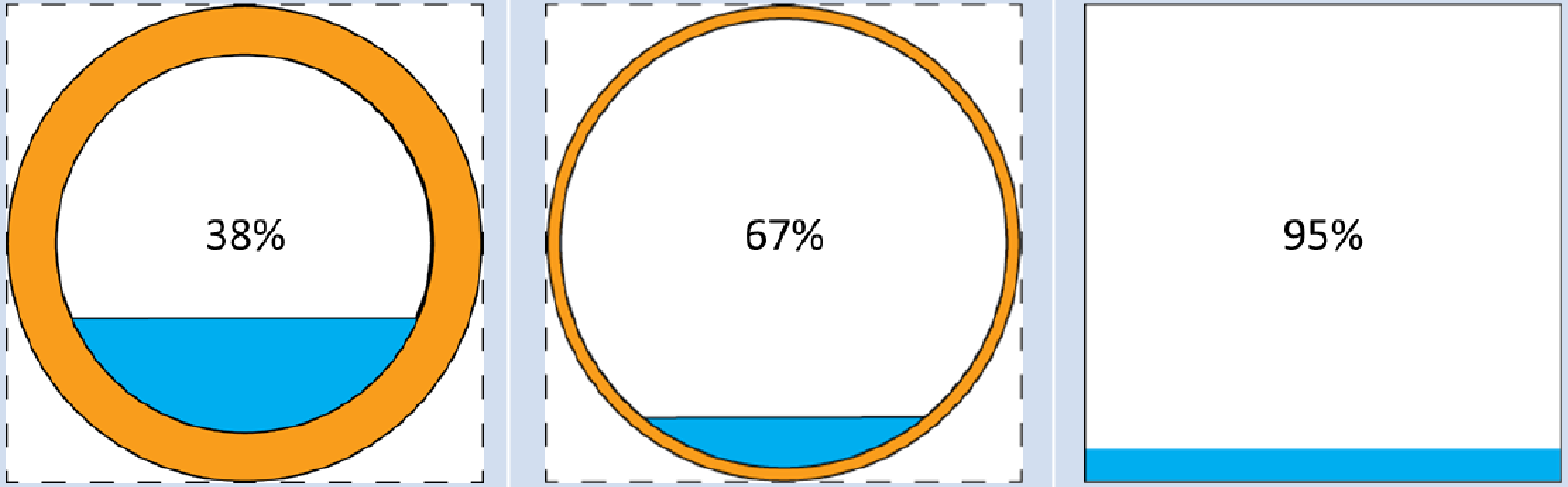
Wallington TJ et al. DOI:10.1021/ed3004269

STORABILITY

ALTERNATIVE FUELS

STORAGE SYSTEM

	LH_2	NH_3	MeOH
State	20 Kelvin, 1 bar	240 Kelvin, 1 bar	298 Kelvin, 1 bar
Shape	Round	Round	Rectangular
Effective volume [%]	38%	67%	95%



HYDROGEN: KEY POINTS FOR USE

- "Compatible" with EU tailpipe-focused legislation
- But, see before: very low energy density – makes storage difficult, inefficient and thus costly
- Can be converted to (motive) power with high efficiency and ultralow emissions
  - Only NO_X and H_2 to consider
    - NO_X: can be controlled relatively easily
    - GWP of H_2: 11±5

GHENT UNIVERSITY

GWP OF H_2

- GWP 11 ±5
  - Indirect GHG
- But outcry bit exaggerated?
  - H_2 infra much more leak-tight anyway: expensive product
  - But important for retrofitting leaky natural gas pipelines!
  - And important for LH_2 tankers
    (“boil-off up to 13% of cargo”!)

Hydrogen ‘twice as powerful a greenhouse gas as previously thought’: UK government study

Report highlights importance of preventing leakage from future H2 infrastructure

AMMONIA: KEY POINTS FOR USE

- Question marks concerning use
  - Extremely toxic, to human and marine life
  - Gas at atmospheric conditions – liquefy for transport (-33^oC)
    → safety and cost implications
  - Oxides of nitrogen emissions can be very high
    - Including N_2O: very potent greenhouse gas (GWP 265)
    - We have no idea yet how to deal with them (aftertreatment can increase emissions!)
  - Very difficult to burn
    - Basically needs hydrogen – but converting (part of) ammonia into hydrogen is difficult!
    - Basically only viable in dual fuel approach in largest ship engines
  - Very low TRL

METHANOL: KEY POINTS

- Attractive looking at entire chain + use as molecule
  - USP is: simplest hydrogen carrier that is liquid at atmospheric conditions – makes ship design, storage, transportation and distribution much easier (and therefore cheaper) – liquids needed for some applications
  - Easy to use, with high efficiency and ultralow emissions
  - Harmless to marine life
  - Methanol-fuelled ships commercially available (dozens sailing soon)

METHANE: KEY POINTS

- Relatively attractive looking at entire chain
  - LNG industry, natural gas grid, existing appliances
  - Still a gas, so still challenges in transport and storage
- However, increasing concerns on methane release before, and at point of use
  - Potent greenhouse gas: GWP 28 (100y) - 84 (20y)

QUO VADIS INTERNAL COMBUSTION ENGINES?

- Can run on all e-fuels, is sustainable and scalable
  - Need to get rid of fossil fuels, not of ICEs!
  - Commercial for CH_4, some for MeOH, work in progress for H_2, initial R&D for NH_3
- Higher efficiency the more highly loaded they are
  - Versus Fuel Cell (FC): efficiency drops with load
- Higher efficiency the bigger they are
  - HD: >45%; biggest engines >50% - i.e. competitive with FC systems!
- Remains most likely prime mover for shipping also long-term
- Most e-fuels enable higher efficiency than current fossil fuels
- Zero-impact emissions possible,
  effect on efficiency depends on the fuel (aftertreatment cost)

TAKE-AWAYS

GHENT UNIVERSITY

KEY MESSAGES

- Hydrogen is an indispensable building block for a renewable energy system and sustainable chemistry
- We will always need to produce molecules
  - Fuel heavy transportation, input for chemistry
  - All plans for green production of H_2, MeOH, NH_3 are valuable!

WHICH FUELS?

- Any choice is only as “clean” as its production method
- No inherent difference between molecules
  - E.g. hydrogen, ammonia, methanol: all mainly produced from natural gas now
  - With sufficient renewable energy sources, all can be produced with *net* zero CO_2 emissions
- Include chemical as well as energy use of molecules, and we’ll always need C, H, O, N, P, S, …

GHENT UNIVERSITY

WHICH FUELS?

- Hydrogen's greatest challenge is its very poor energy density
  - Direct use comes with great losses
- Need hydrogen vectors
  - Can include carbon:
    increased energy density and ease of use outscores increased energy expenditure for fuel production
    - We'll always need carbon!
    - Legislation needs to allow for this: needs to get lifecycle-based to result in the global optimum (no tailpipe focus)
  - Keep things simple
    - Simple molecules → no e-diesel
    - Simple storage → liquid
    - Methanol much more viable as fuel than ammonia

Sebastian VERHELST

Professor of Internal Combustion Engines

SUSTAINABLE THERMO-FLUID
ENERGY SYSTEMS
Transport Technology unit

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

https://www.ugent.be/ea/eemmecs/en/research/stfes

Ghent University
@ugent
sebastian-verhelst-0398959

Thanks for listening!