Just add hydrogen – Making the most out of a limited resource

Workshop IEA Bioenergy Task 33

26. October 2016

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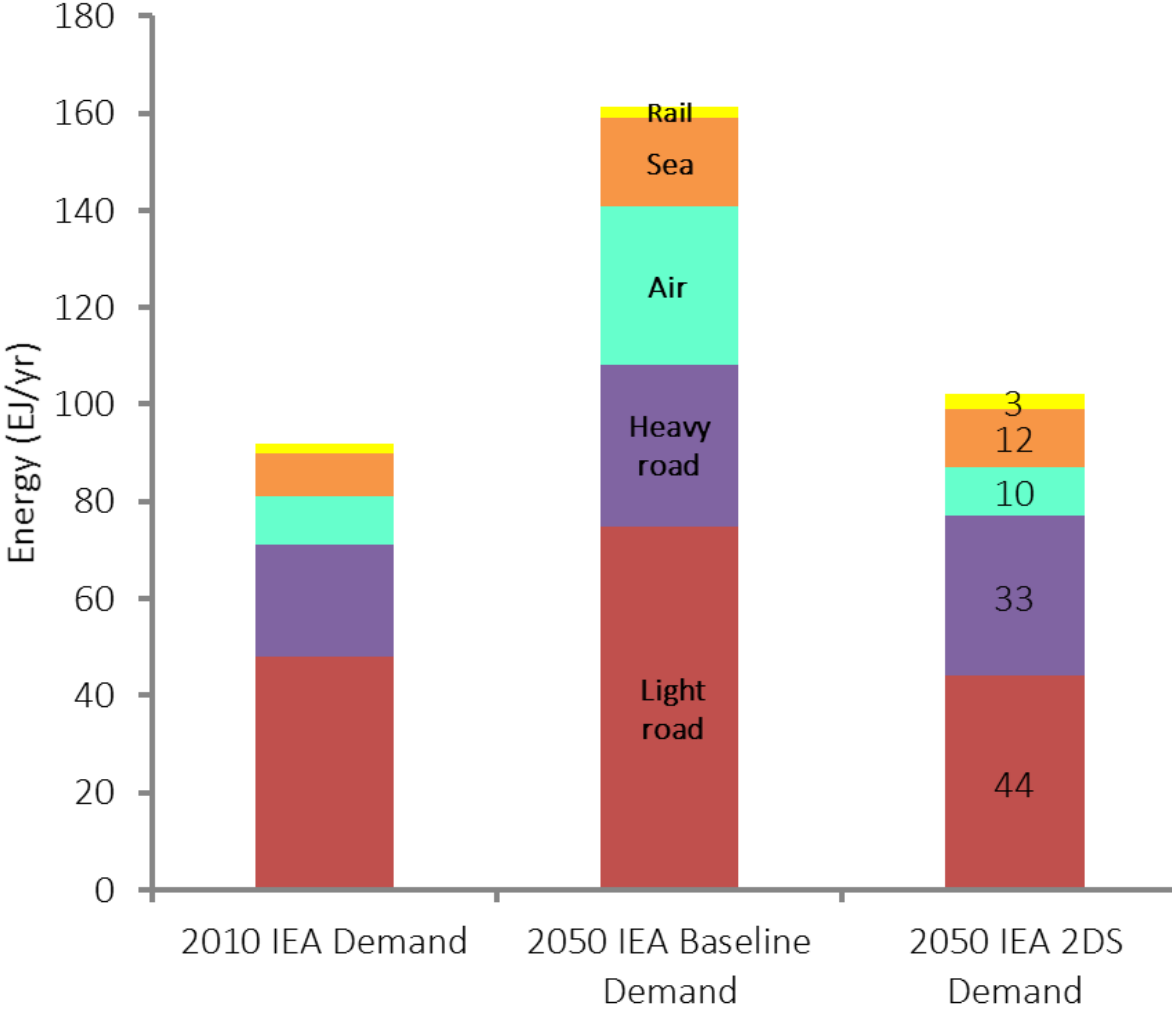
Decarbonisation of transportation

- Possibly the most difficult aspect of climate change mitigation
- Severe lack of attention (electricity, electricity, electricity)

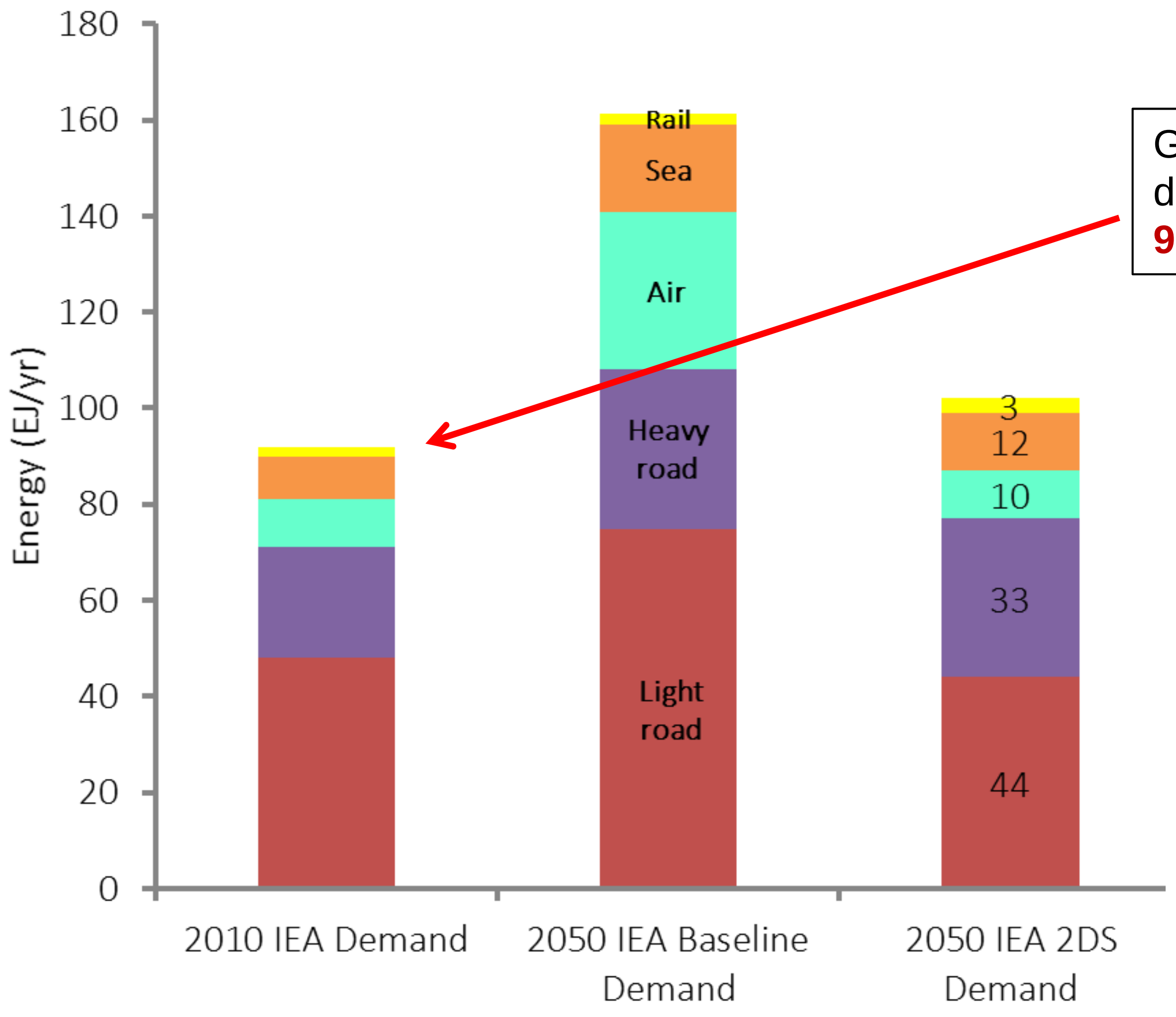
- Many confusing aspects/arguments around the problem.

- This presentation especially motivated by arguments like:
  - ”Electric vehicles will do the job”
  - ”Decarbonisation of fuel important, but only after electricity and heat”
  - ”Sustainable biomass is a scarce resource and therefore cannot do the job”

Global transportation energy demand in 2050

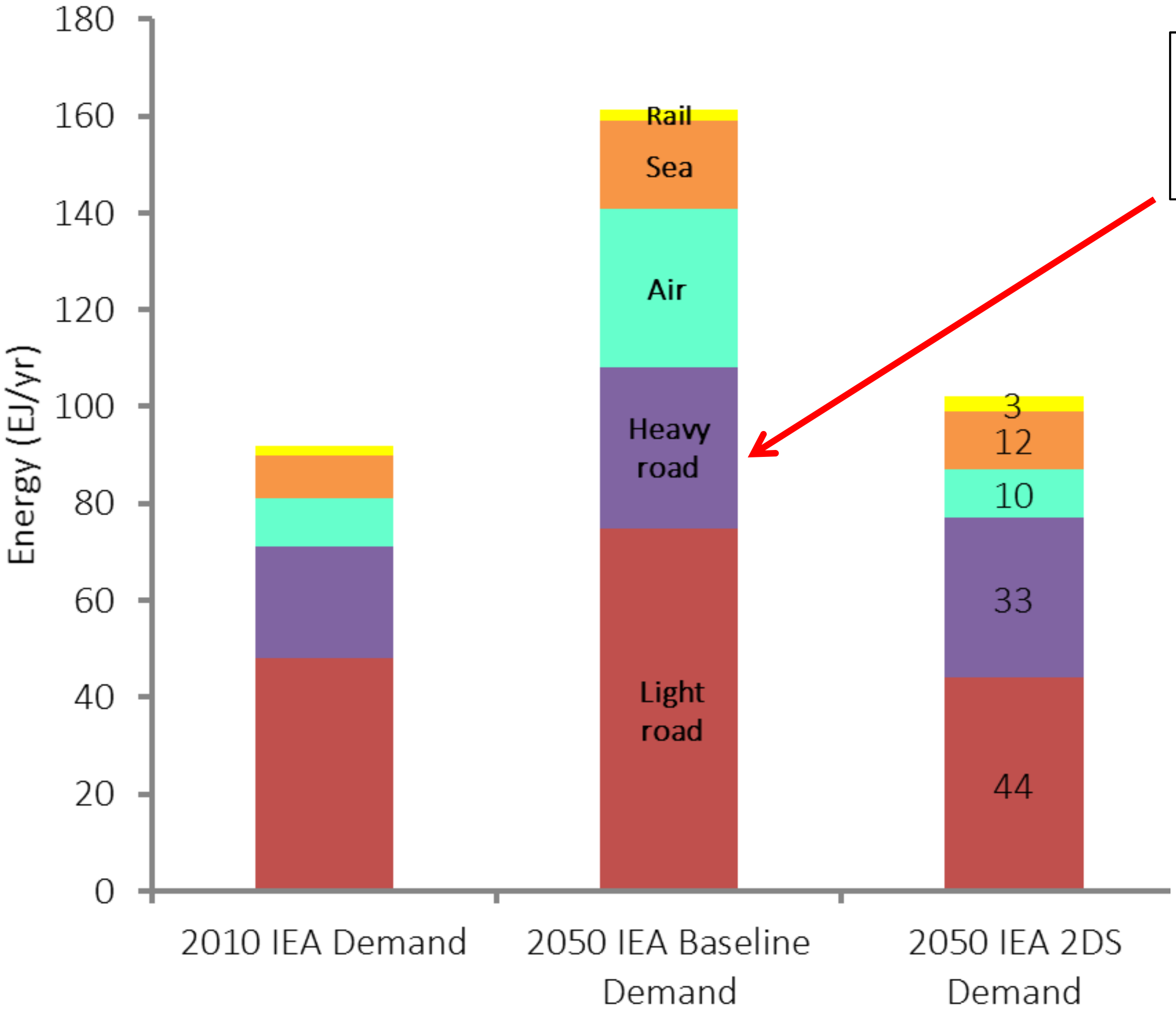


Global transportation energy demand in 2050



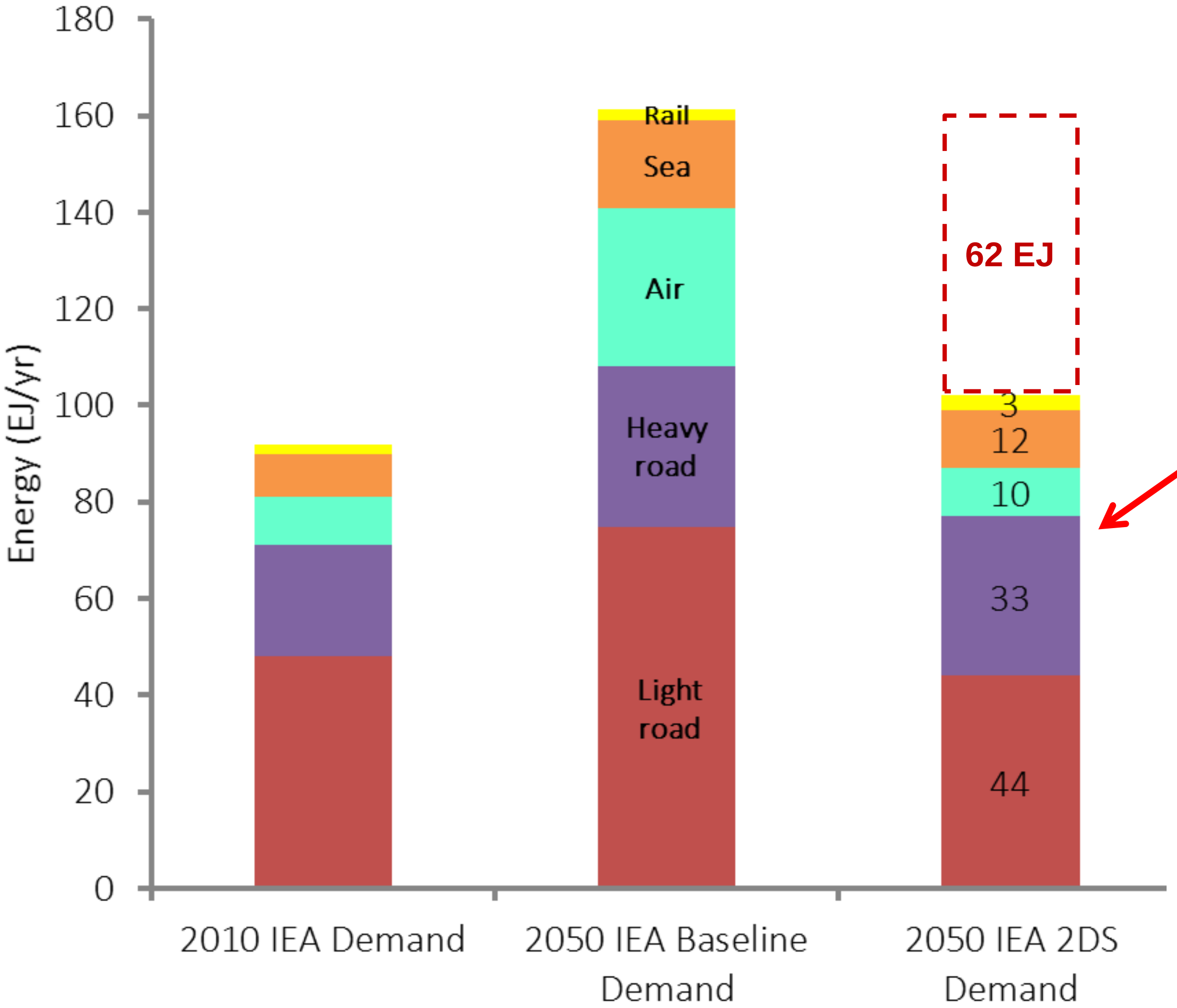
Global transportation energy demand in the reference year 2010
92 EJ/yr

Global transportation energy demand in 2050



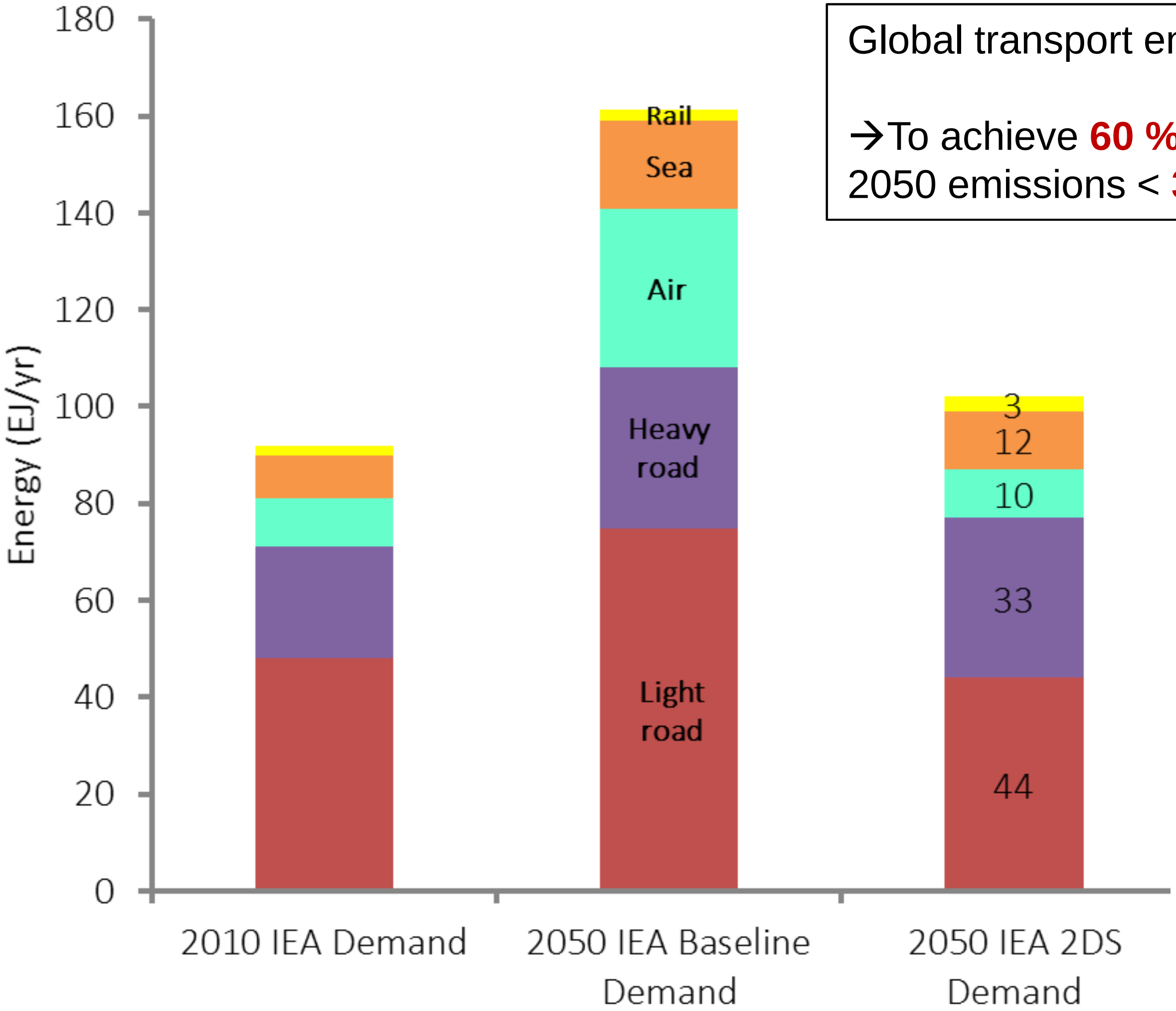
IEA baseline estimate for transportation energy consumption in 2050 is **161 EJ/yr**.

Global transportation energy demand in 2050



IEA estimate for transportation energy demand in 2050 that is consistent with **2°C** scenario is **99 EJ/yr** (2357 Mtoe/a).

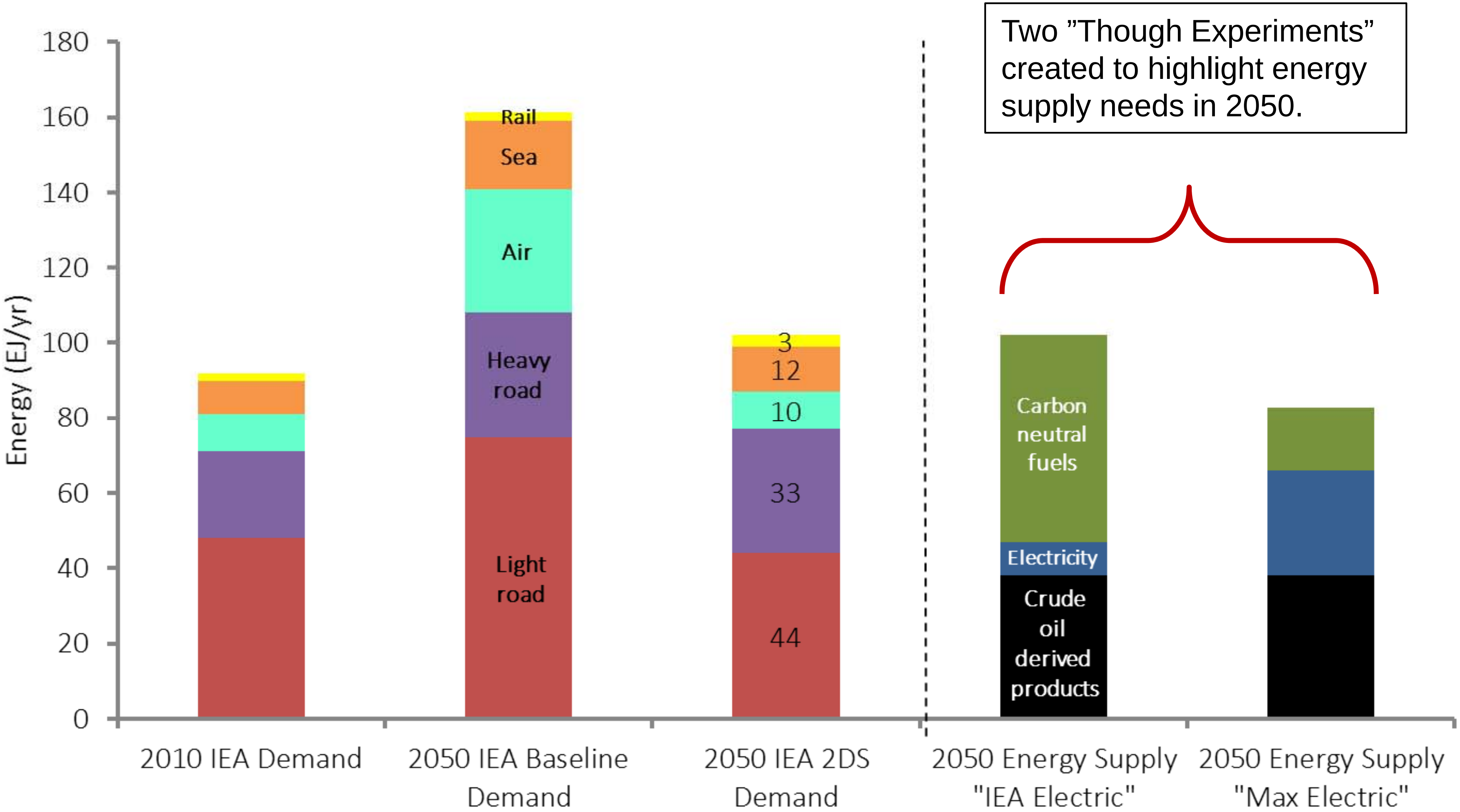
Global transportation energy demand in 2050



Global transport emissions in 2010 were **8** $GtCO_2$-eq/yr.

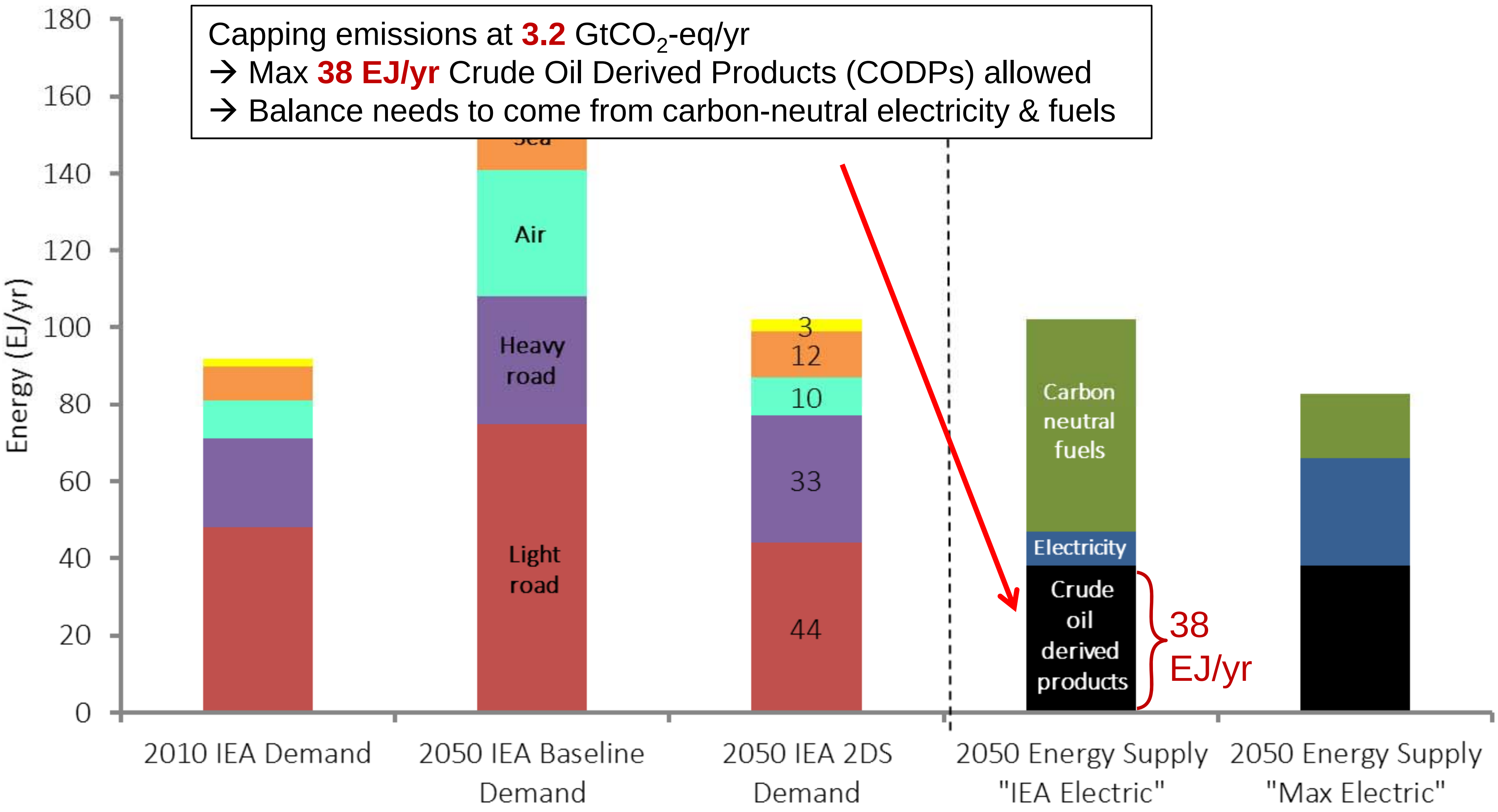
→To achieve **60 %** reduction (relative to 2010),
2050 emissions < **3.2** $GtCO_2$-eq/yr

Global transportation energy thought experiment*



Adapted from GEA, 2012

Global transportation energy thought experiment*



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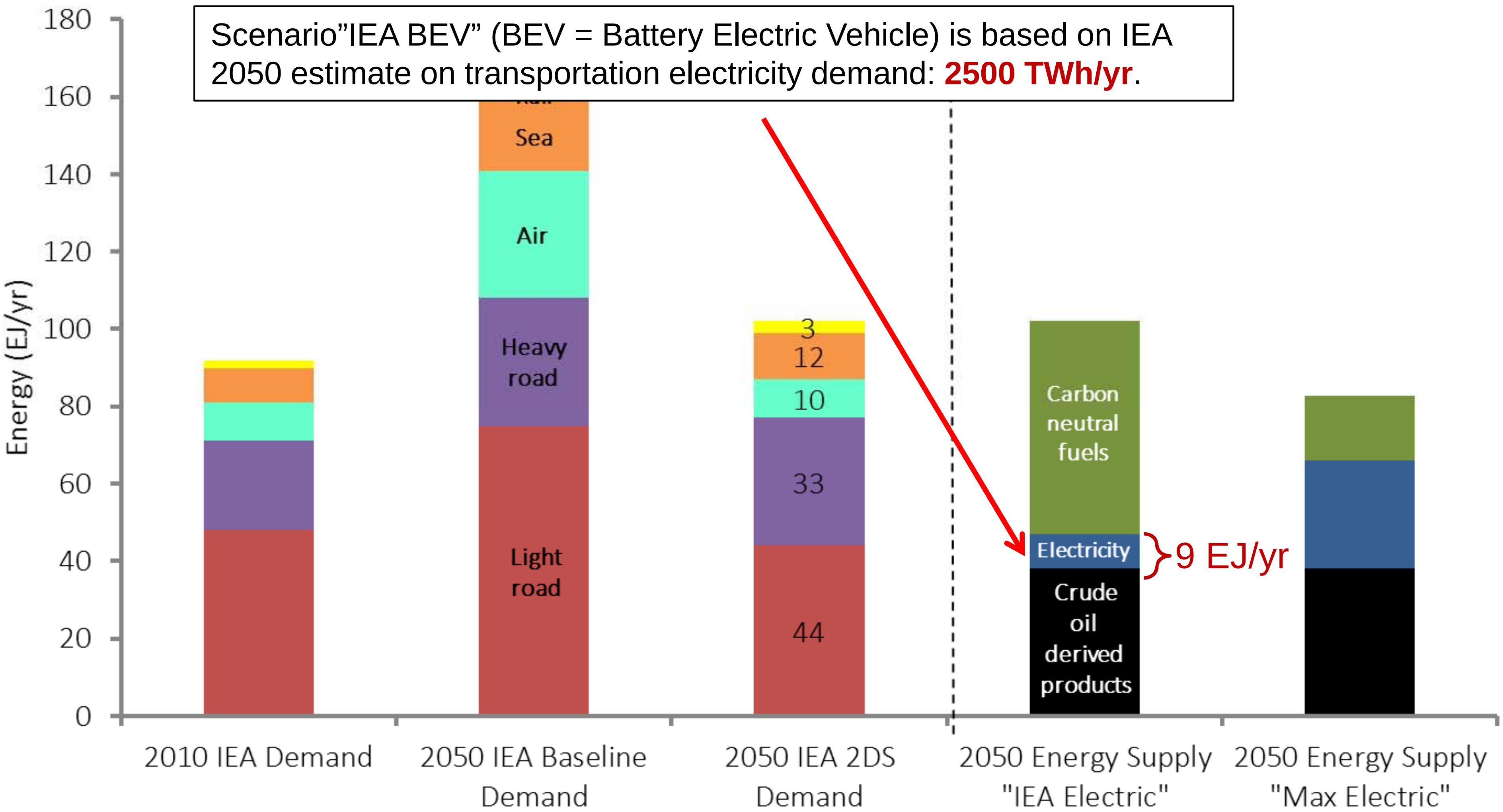
Global transportation energy thought experiment*



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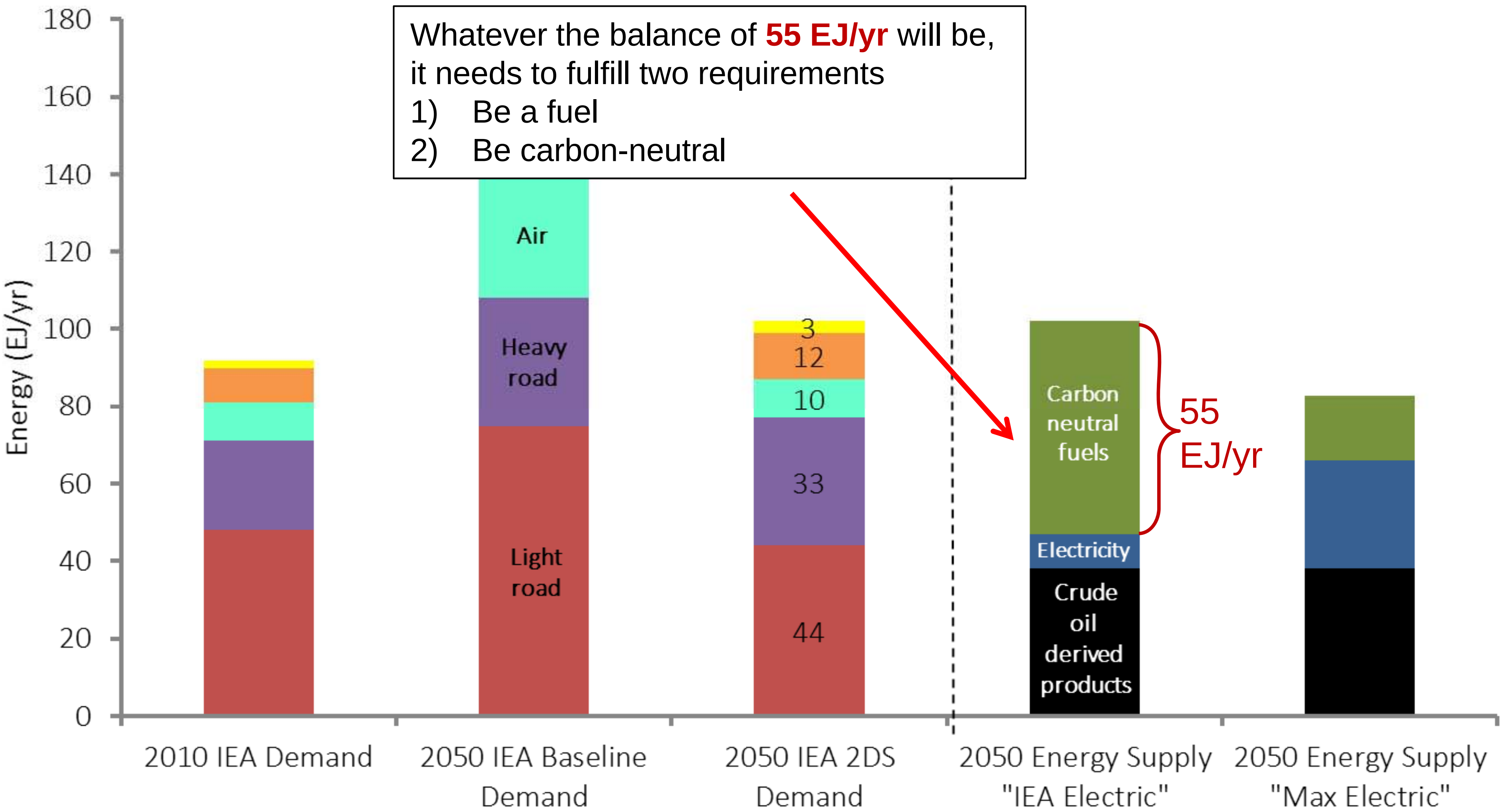

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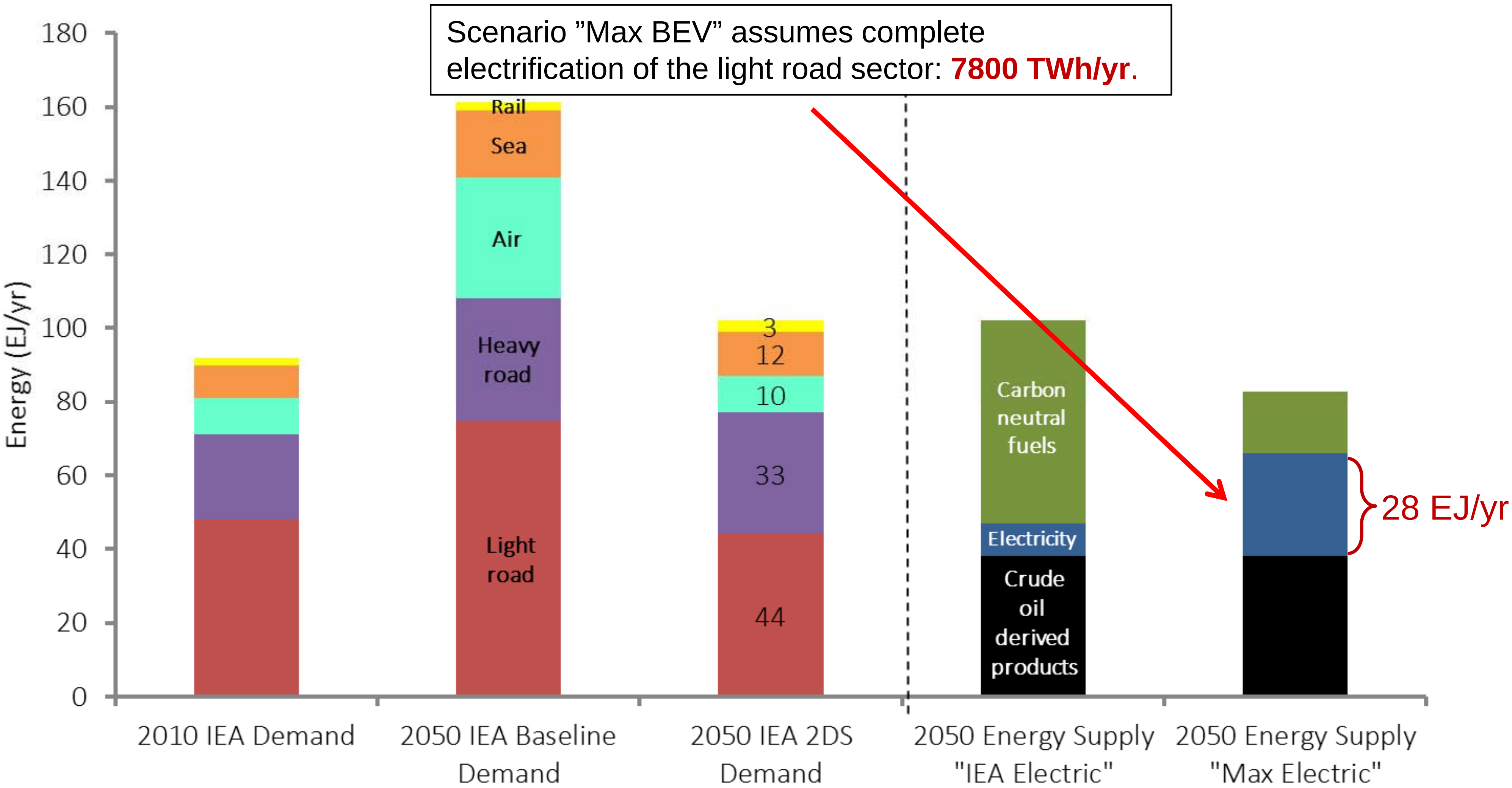

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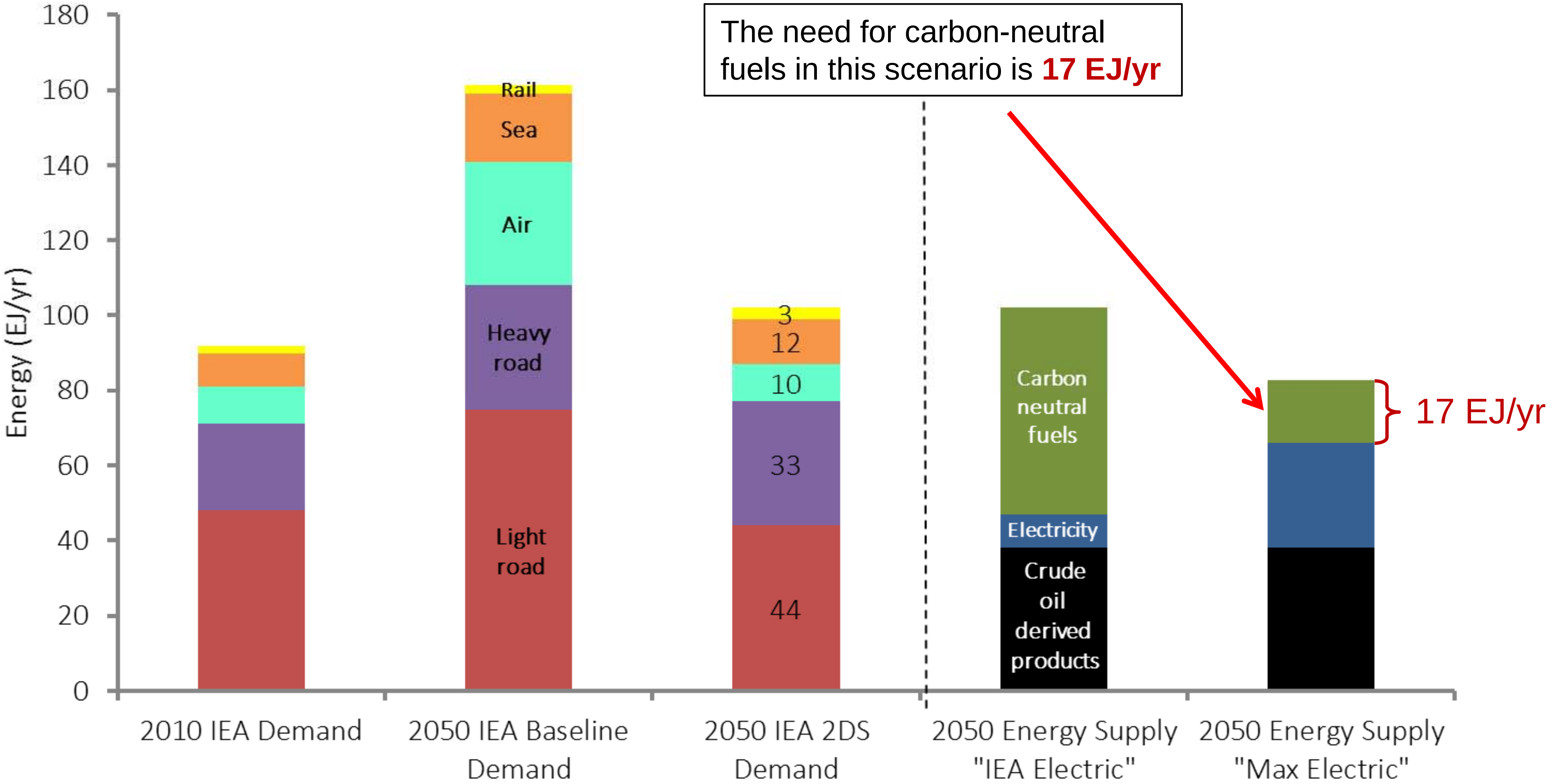

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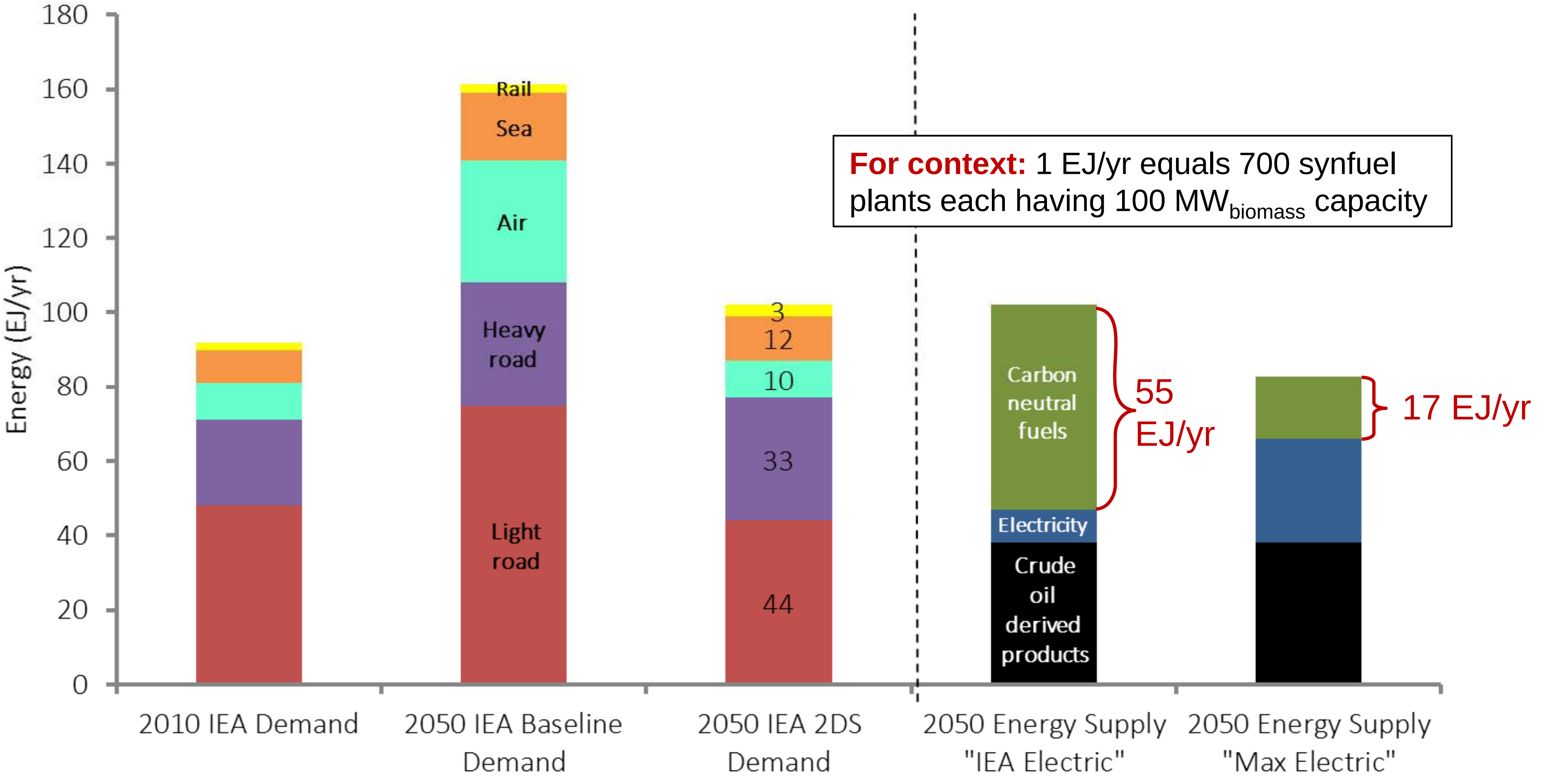


**Adapted from GEA, 2012*

What is the supply potential of sustainable biomass?

- **From AR5 (IPCC, 2014):**
  "…This assessment agrees on a technical bioenergy potential of around 100 EJ (medium evidence, high agreement), and possibly 300 EJ and higher (limited evidence, low agreement)…"

- **From IEA (2011):**
  "…with a sound policy framework in place, it should be possible to provide … 145 EJ of total biomass for biofuels, heat and electricity from residues and wastes, along with sustainably grown energy crops."
  - 80 EJ of biomass assumed for generating heat and power
  - 65 EJ of biomass assumed available for biofuel feedstock

What is the supply potential of sustainable biomass?

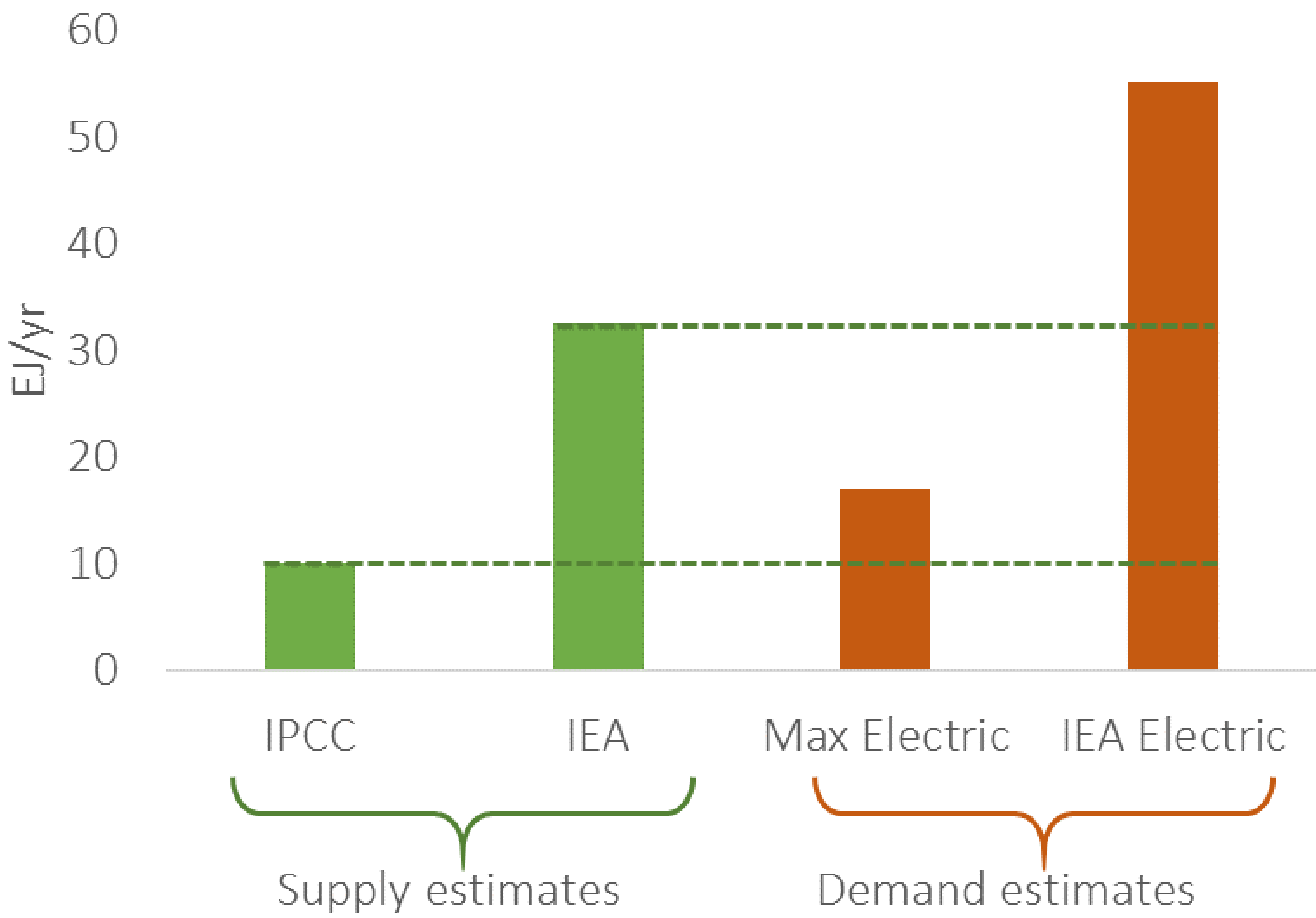
Assuming 80 EJ for heat and power and 50 % overall BTL efficiency

Supply potential estimate based on

- IPCC data = 10 EJ
- IEA data ~ 30 EJ

Demand of CNF

- Max Electric = 17 EJ/yr
- IEA Electric = 55 EJ/yr



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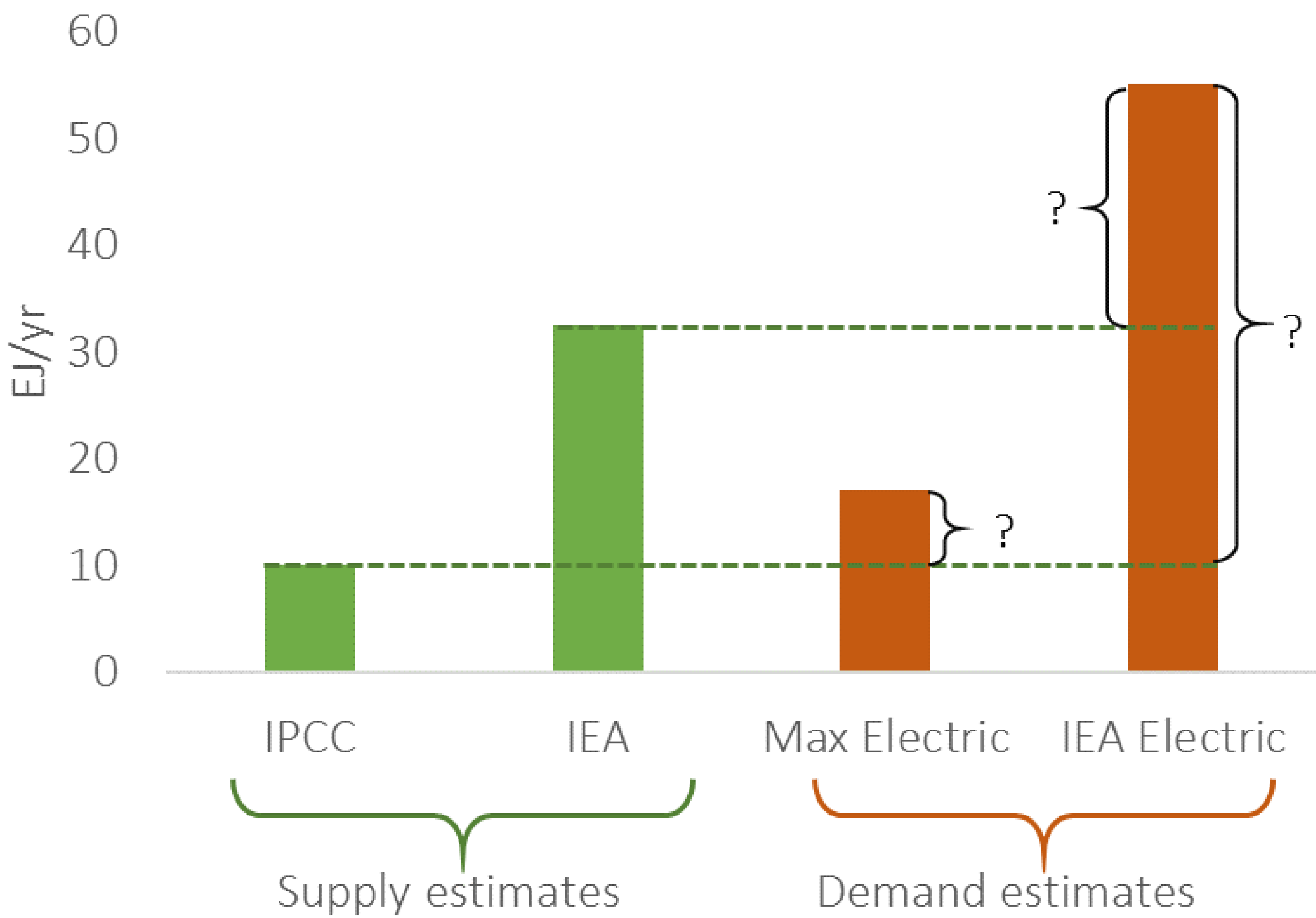
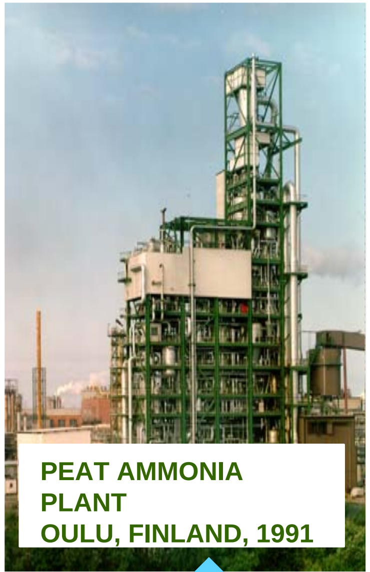


Biomass gasification for advanced biofuels

Long experience of medium-to-large scale thermochemical biorefineries


PEAT AMMONIA PLANT
OULU, FINLAND, 1991


NSE BIOFUELS DEMO, VARKAUS, FINLAND, 2011


PILOT PLANT AT VTT BIORUUKKI, ESPOO, 2016

1985 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030

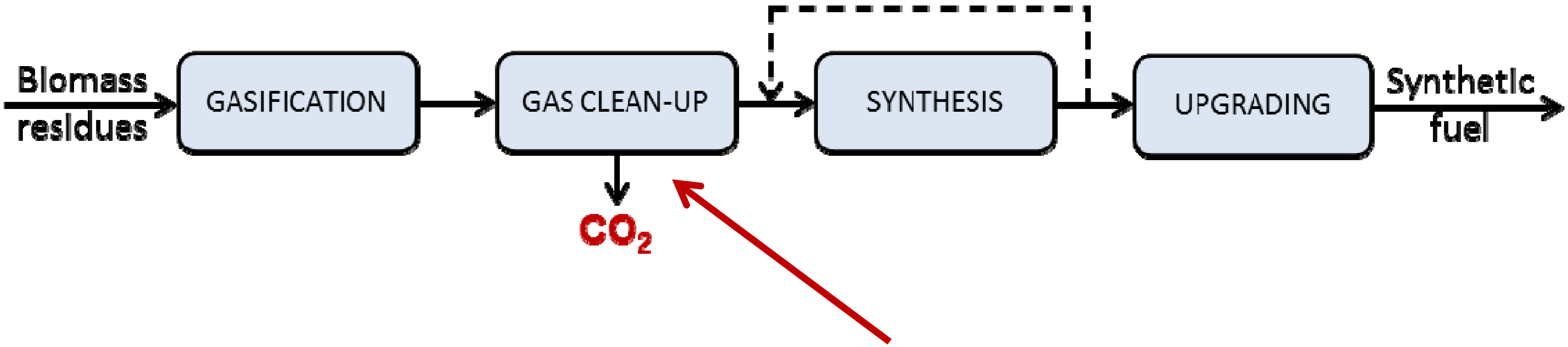
HYDROGEN FOR AMMONIA (140 MW)
- o Coal gasification applied to peat
- o R&D support by VTT

SYNGAS FOR FT-DIESEL
- o Large-scale O_2-blown gasifier
- o Innovative hot gas cleaning
- o Technology from Finland
- o R&D and IPR support from VTT
- o Large-scale plants > 300 MW

NEW PROCESS FOR SMALLER SCALE
- o Simpler process and lower capex
- o Wide feedstock basis, target scale 30-150 MW
- o Biofuels, SNG, hydrogen, bio-chemicals
- o Process development at VTT in 2016-18
- o Industrial demonstration in 2019-20

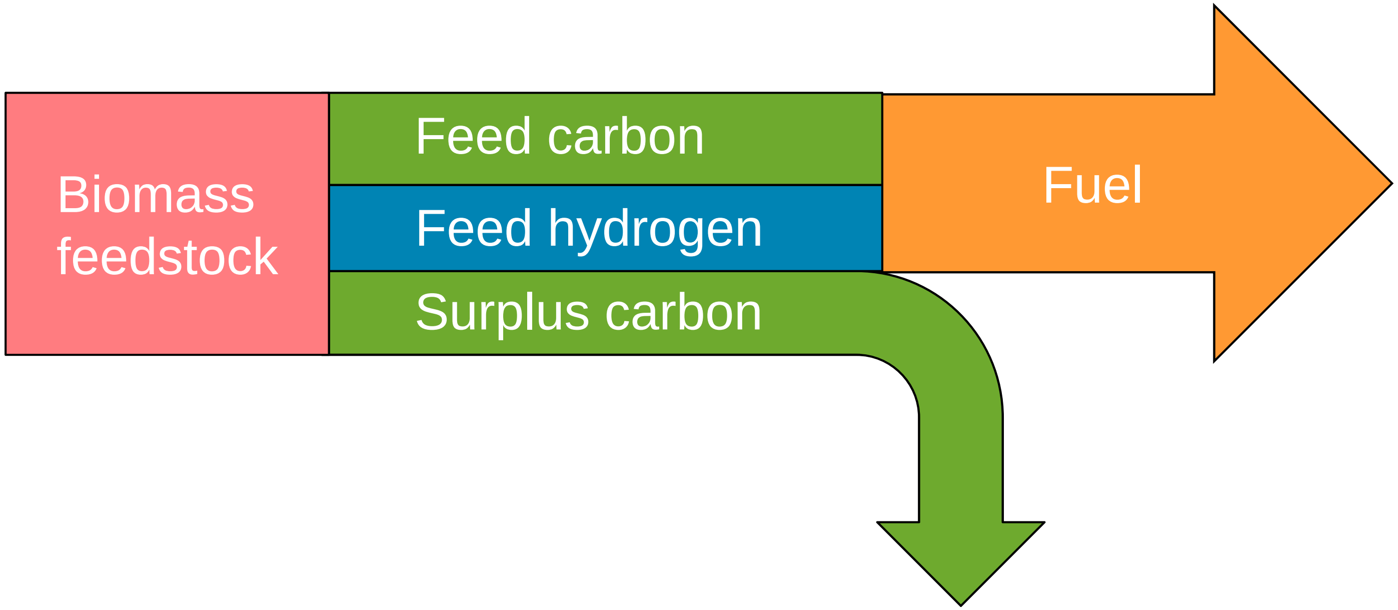
Biomass can be converted to synfuels with an efficiency in the range of 50 – 60 % (LHV), depending on the process configuration and end-product.

If by-product heat from the process is also utilised, additional 20 – 30 %-point improvement can be attained, leading to ~ 80 % overall efficiency

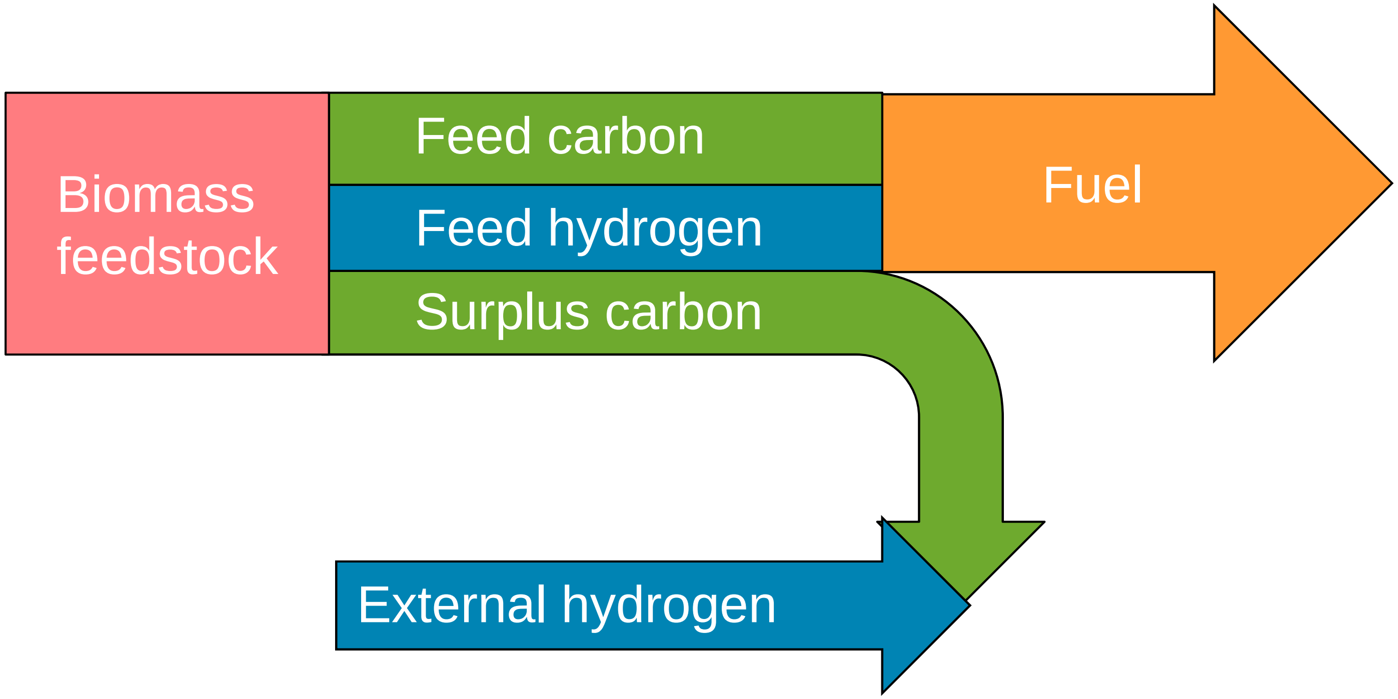


Despite the high energy efficiency, **more than half** of feedstock carbon is rejected from the process, as there is not enough hydrogen to convert it into fuels.

The traditional conversion route is therefore **hydrogen constrained**.


Biomass
feedstock
Feed carbon
Feed hydrogen
Surplus carbon
Fuel

By adding hydrogen from external source (enhancement), the **surplus carbon** could be hydrogenated to fuel as well.



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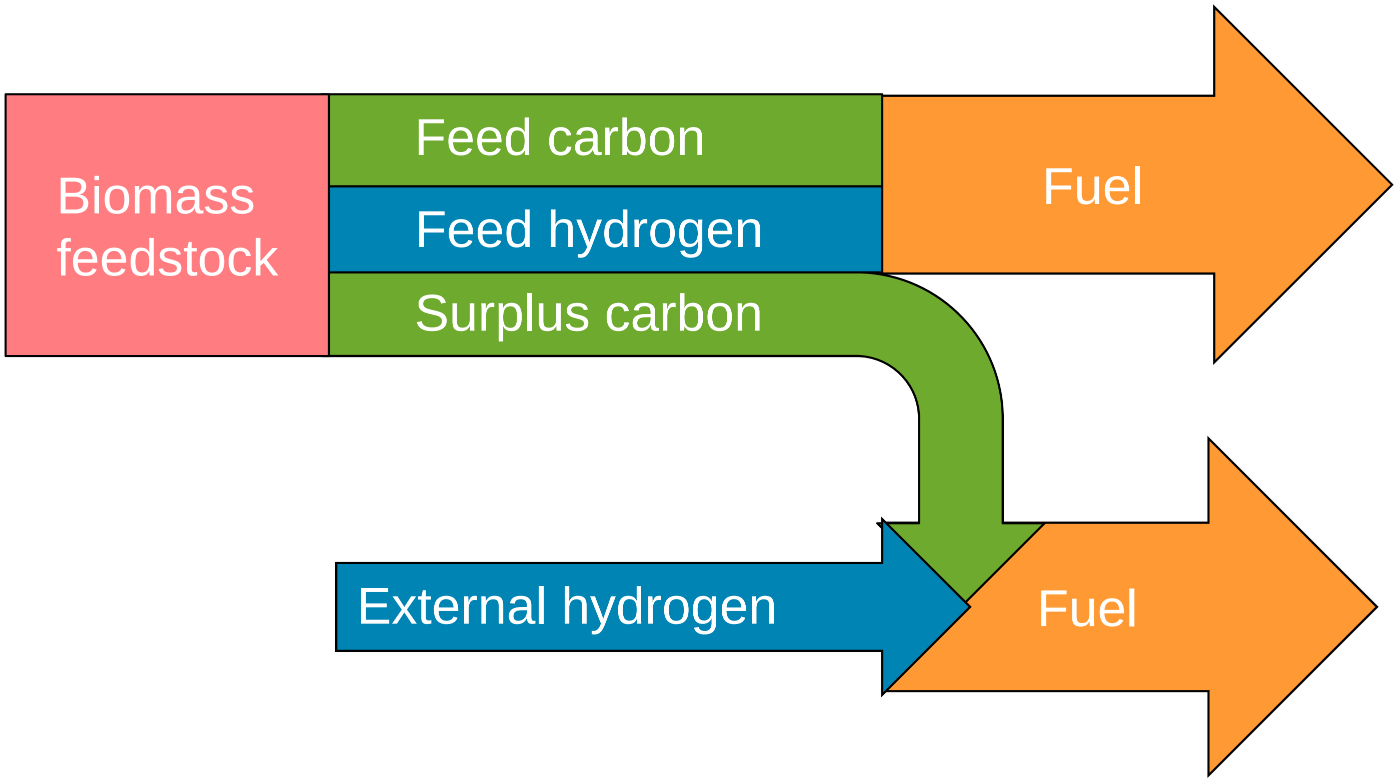
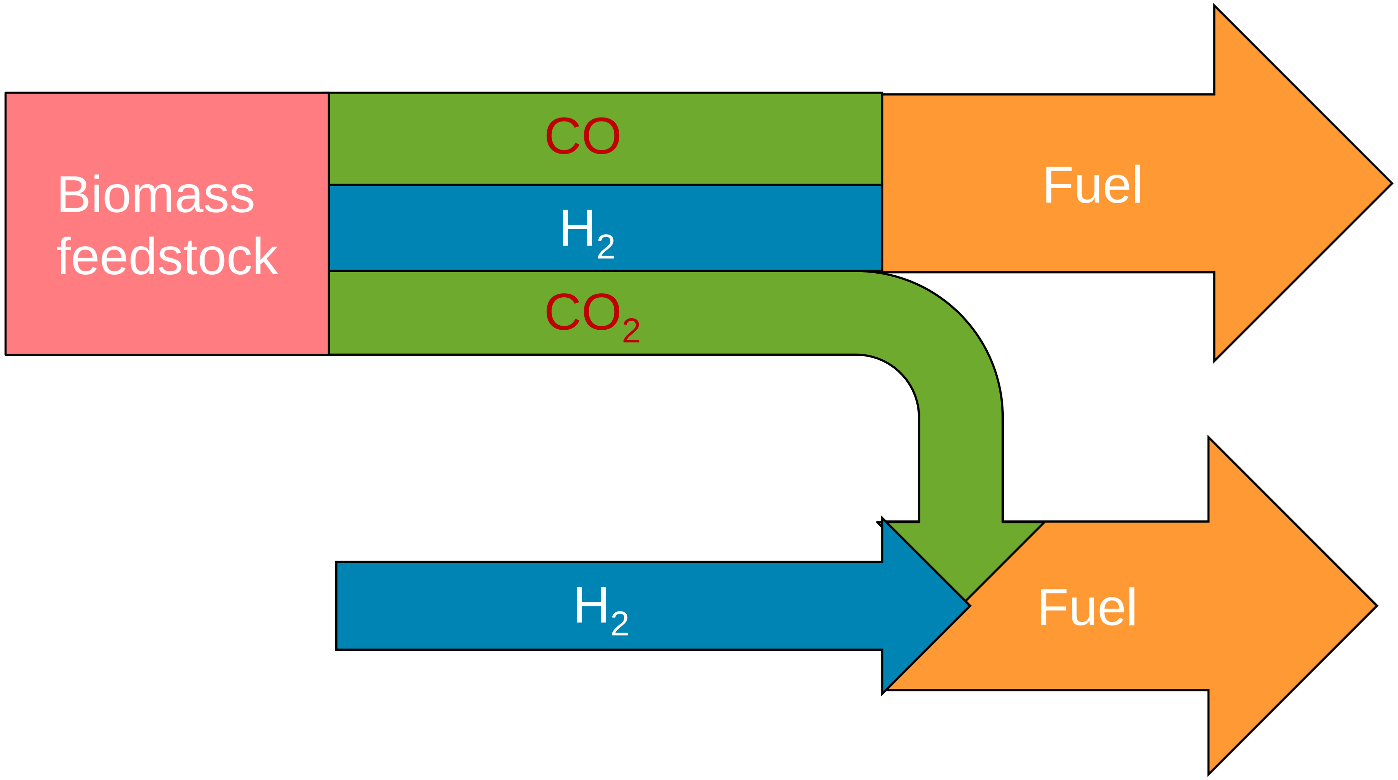
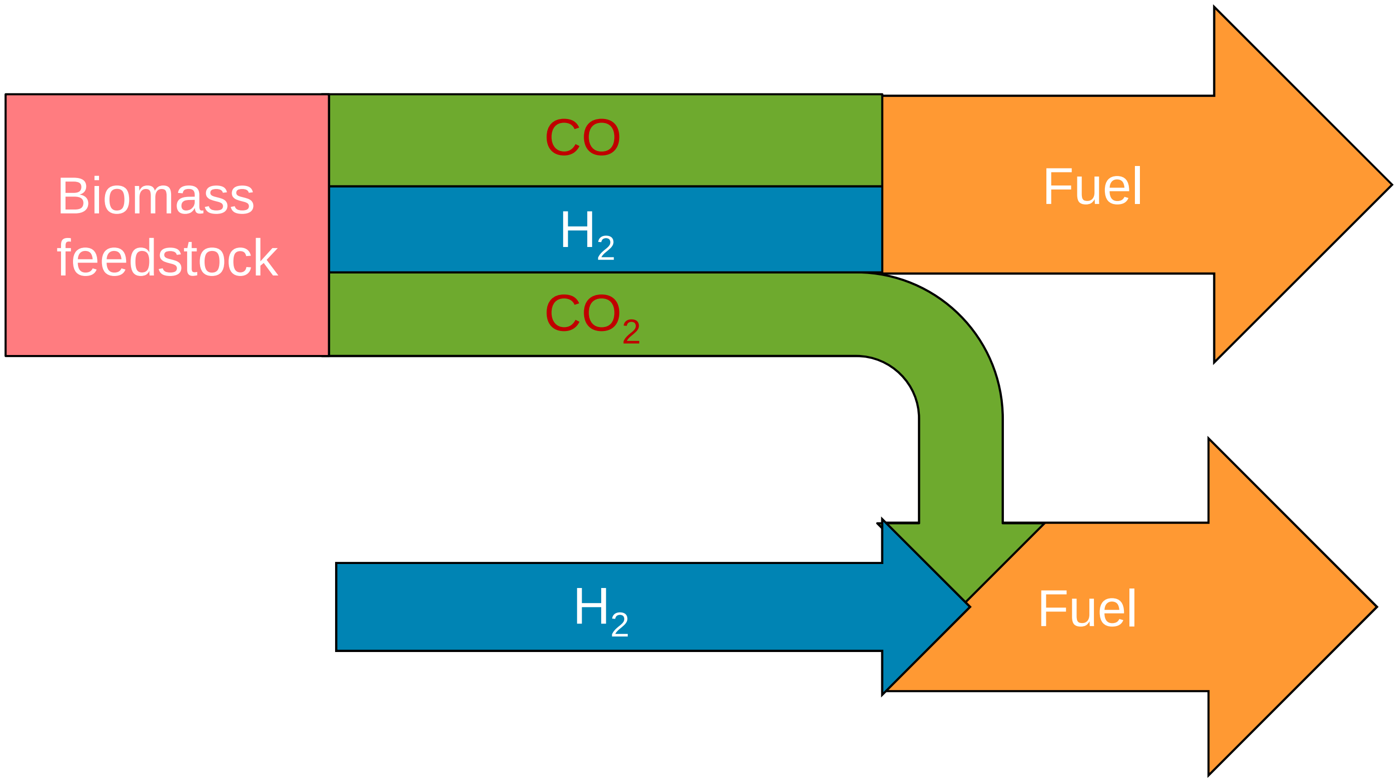


But the surplus carbon is in the form of **CO_2** instead of CO!

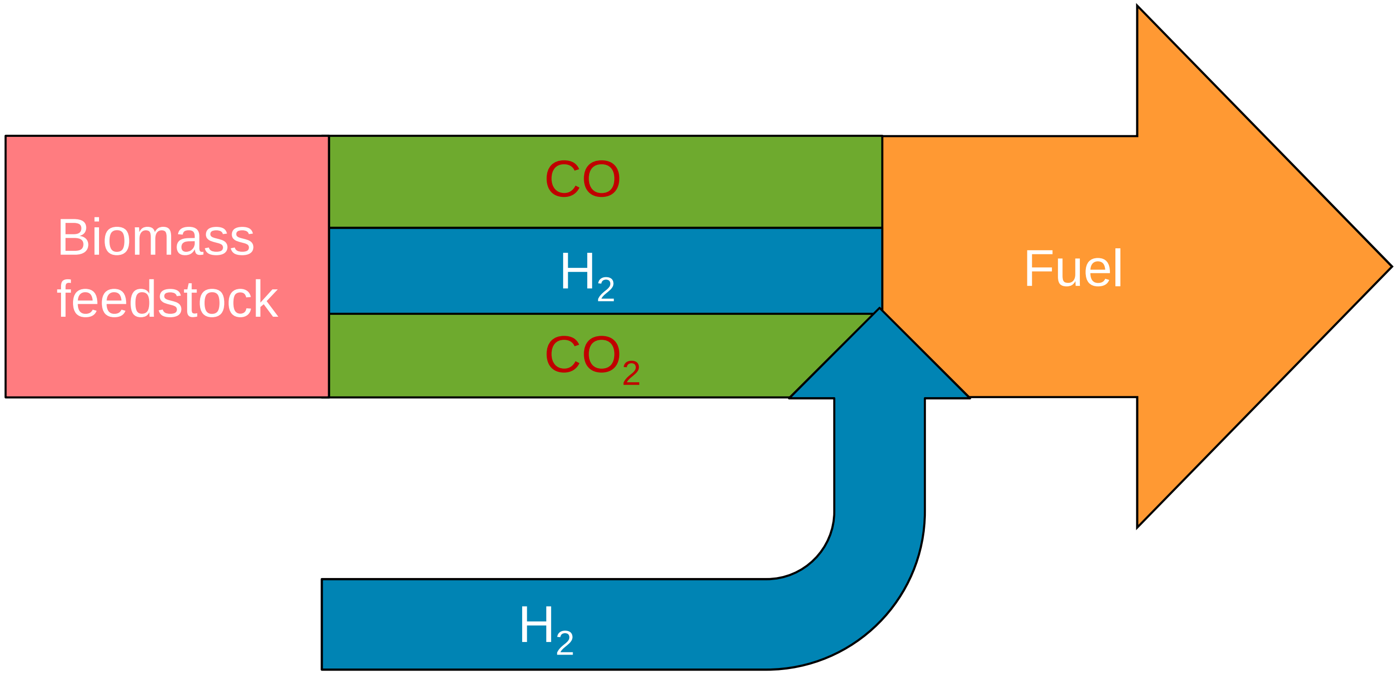


Implications:

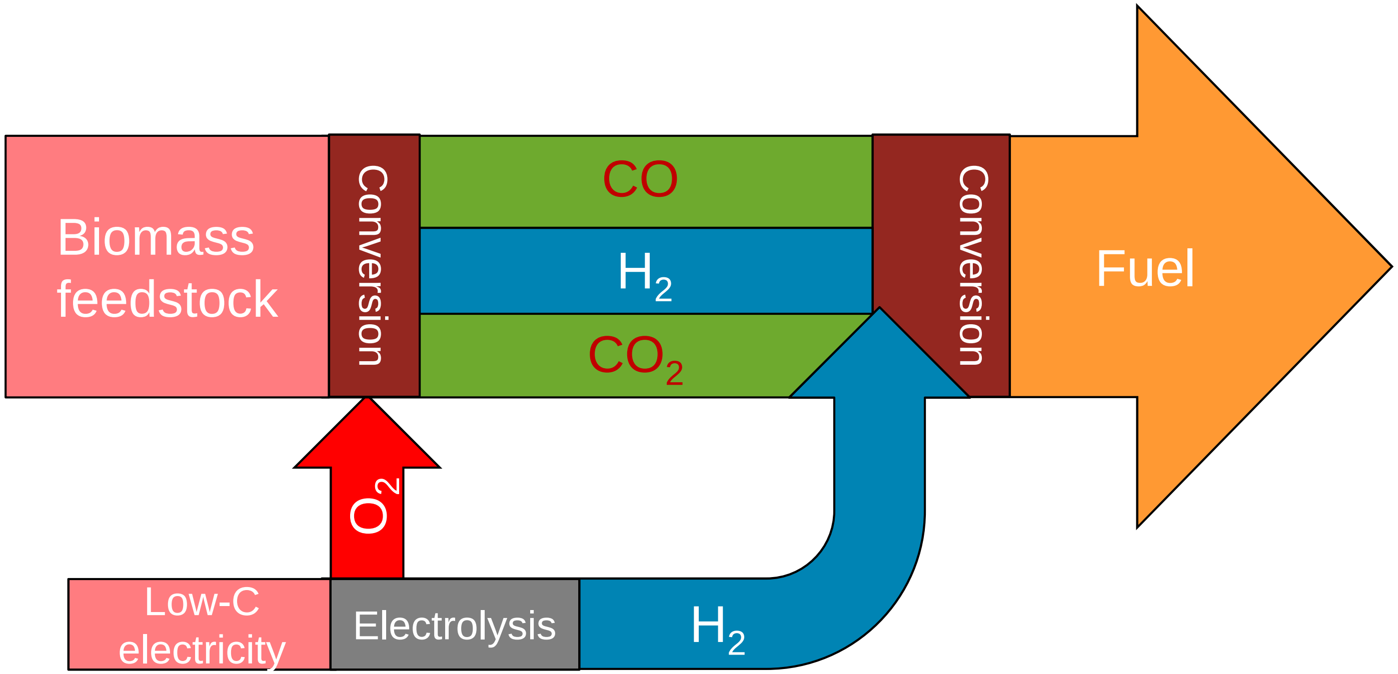
- Only methane and methanol have reaction routes via CO_2
- More H_2 is required to produce one mole of fuel from CO_2 than from CO
- CO_2 has higher activation energy than CO
- Byproduct water from CO_2 hydrogenation inhibits methanol catalysts



Despite challenges related to CO_2 hydrogenation, the potential increase in fuel output is significant.



The process is not sensitive to the source of hydrogen, but production from water via electrolysis using low-carbon electricity is considered in this presentation



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Hydrogen enhancement potential of synthetic biofuels manufacture in the European context: A techno-economic assessment

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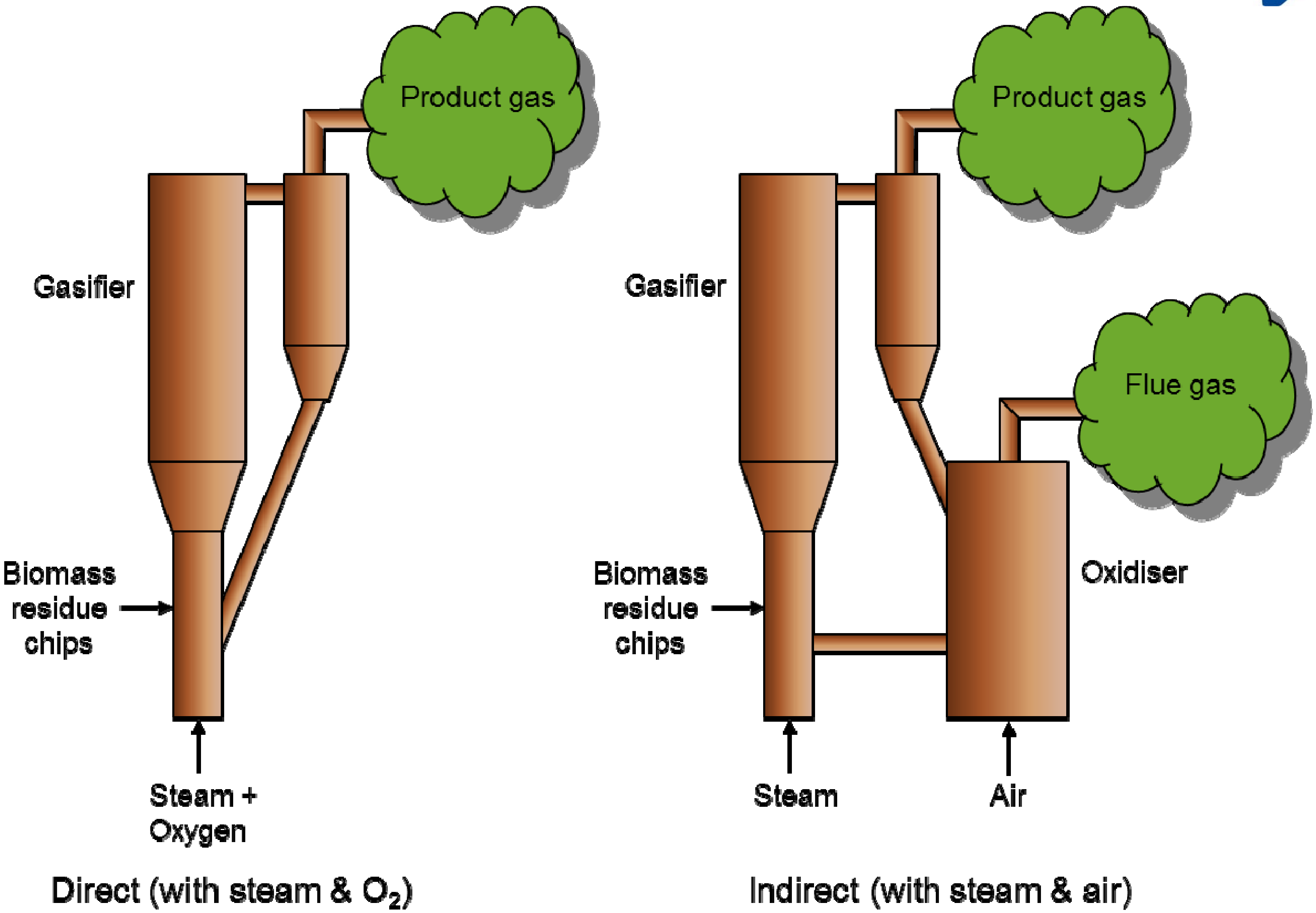
ABSTRACT

Potential to increase biofuels output from a gasification-based biorefinery using external hydrogen supply (enhancement) was investigated. Up to 2.6 or 3.1-fold increase in biofuel output could be attained for gasoline or methane production over reference plant configurations, respectively. Such enhanced process designs become economically attractive over non-enhanced designs when the average cost of low-carbon hydrogen falls below 2.2–2.8 €/kg, depending on the process configuration. If all sustainably available wastes and residues in the European Union (197 Mt/a) were collected and converted only to biofuels, using maximal hydrogen enhancement, the daily production would amount to 1.8–2.8 million oil equivalent barrels. This total supply of hydrogen enhanced biofuels could displace up to 41–63 per cent of the EU (European Union)'s road transport fuel demand in 2030, again depending on the choice of process design.

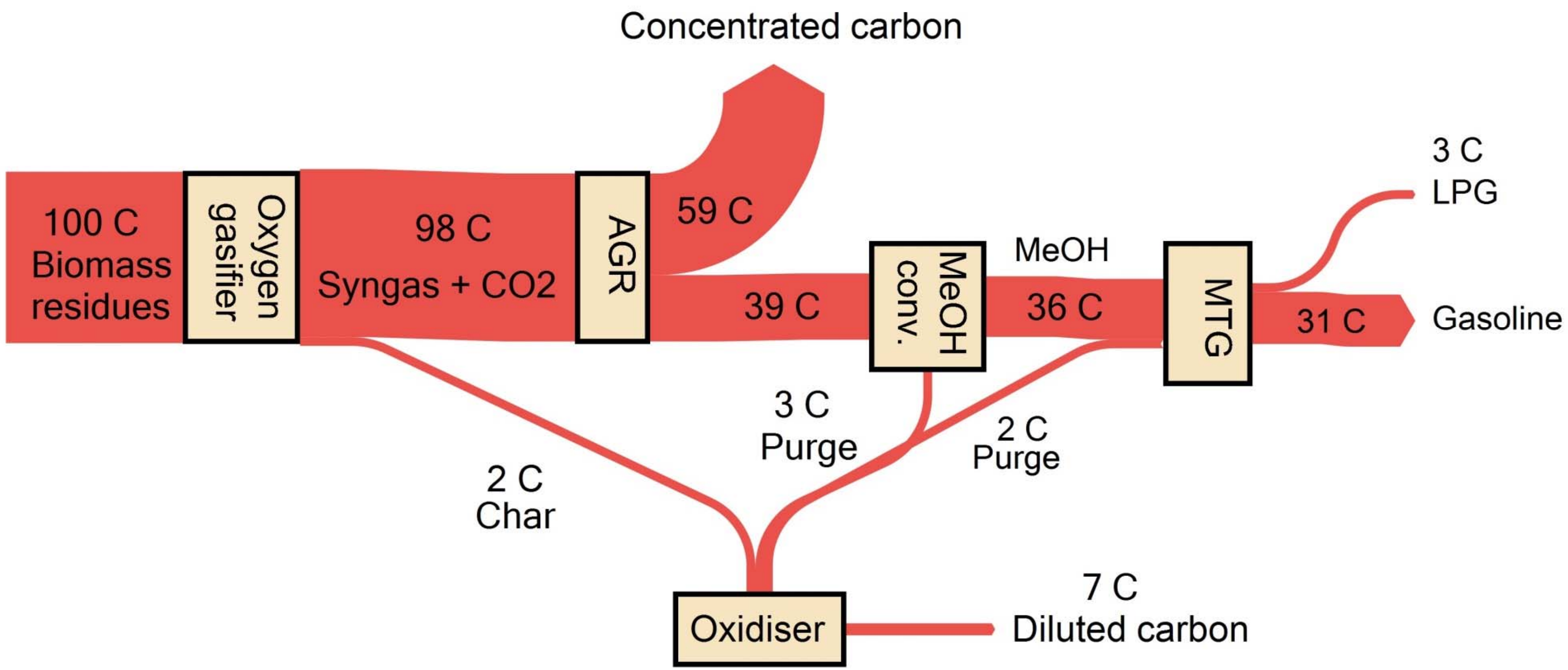
Table 2
Summary of examined plant configurations.

Configurations	Gasifier type	Stoichiometry adjusted by	CO_2 removal	Electrolyser	ASU[a]	End product
OG	O_2	Sour shift	Yes		Yes	Gasoline
OG+	O_2	H_2 addition		Yes		Gasoline
OM	O_2	Sour shift	Yes		Yes	Methane
OM+	O_2	H_2 addition		Yes		Methane
SG	Steam	Gasifier	Yes		Yes	Gasoline
SG+	Steam	H_2 addition		Yes		Gasoline
SM	Steam	Gasifier	Yes		Yes	Methane
SM+	Steam	H_2 addition		Yes		Methane

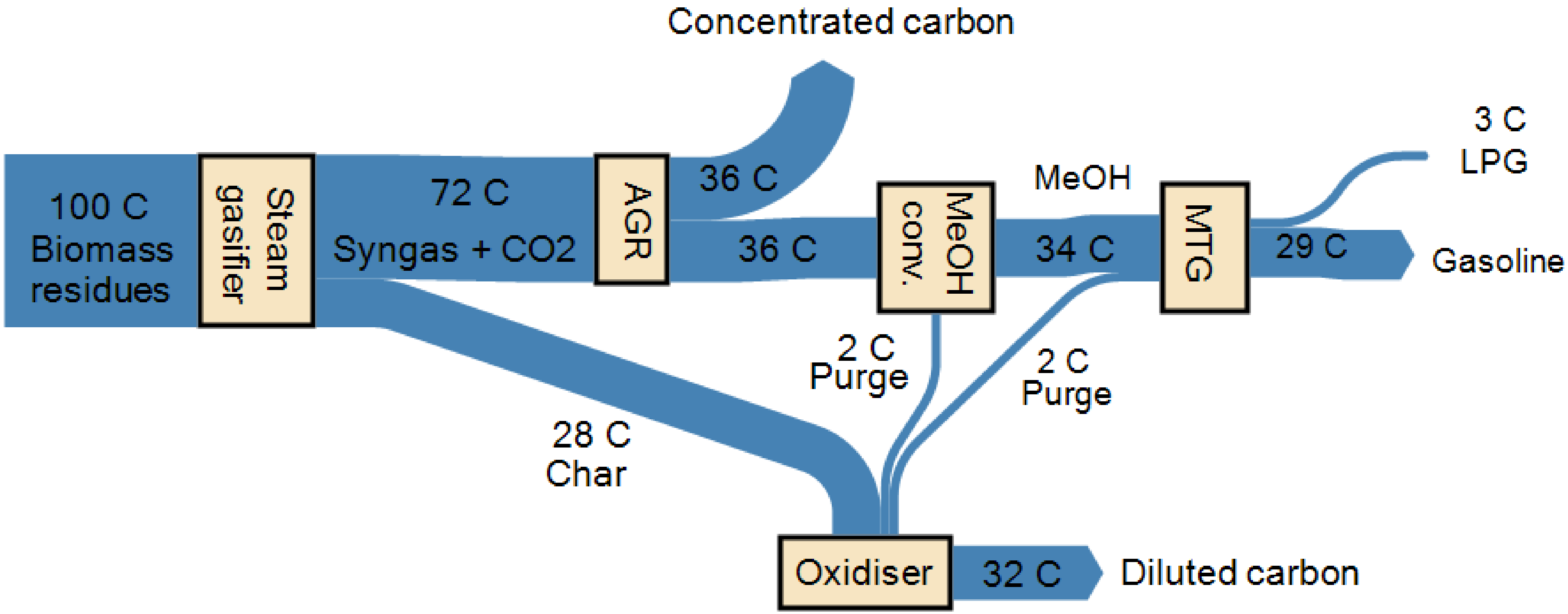
[a] ASU = cryogenic Air Separation Unit.


Product gas
Gasifier
Biomass residue chips
Steam + Oxygen
Direct (with steam & O_2)
Product gas
Gasifier
Flue gas
Oxidiser
Biomass residue chips
Steam
Air
Indirect (with steam & air)

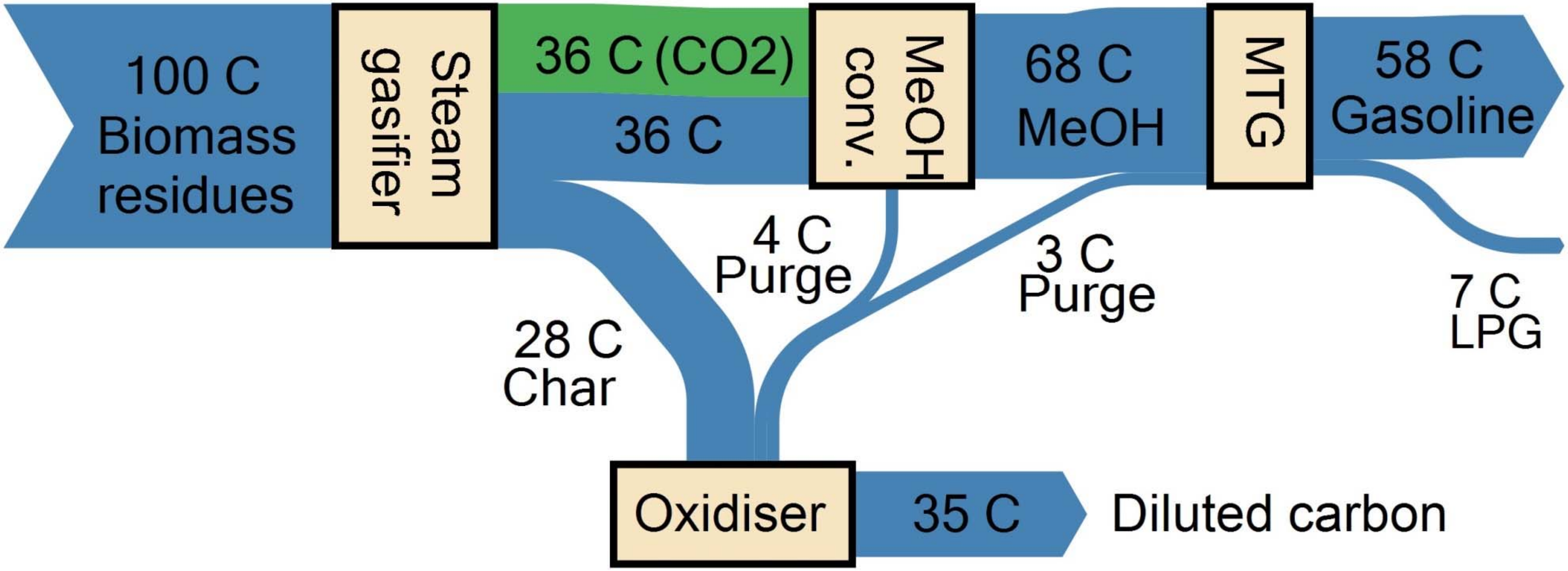
Gasoline via **oxygen** gasification (carbon flows)



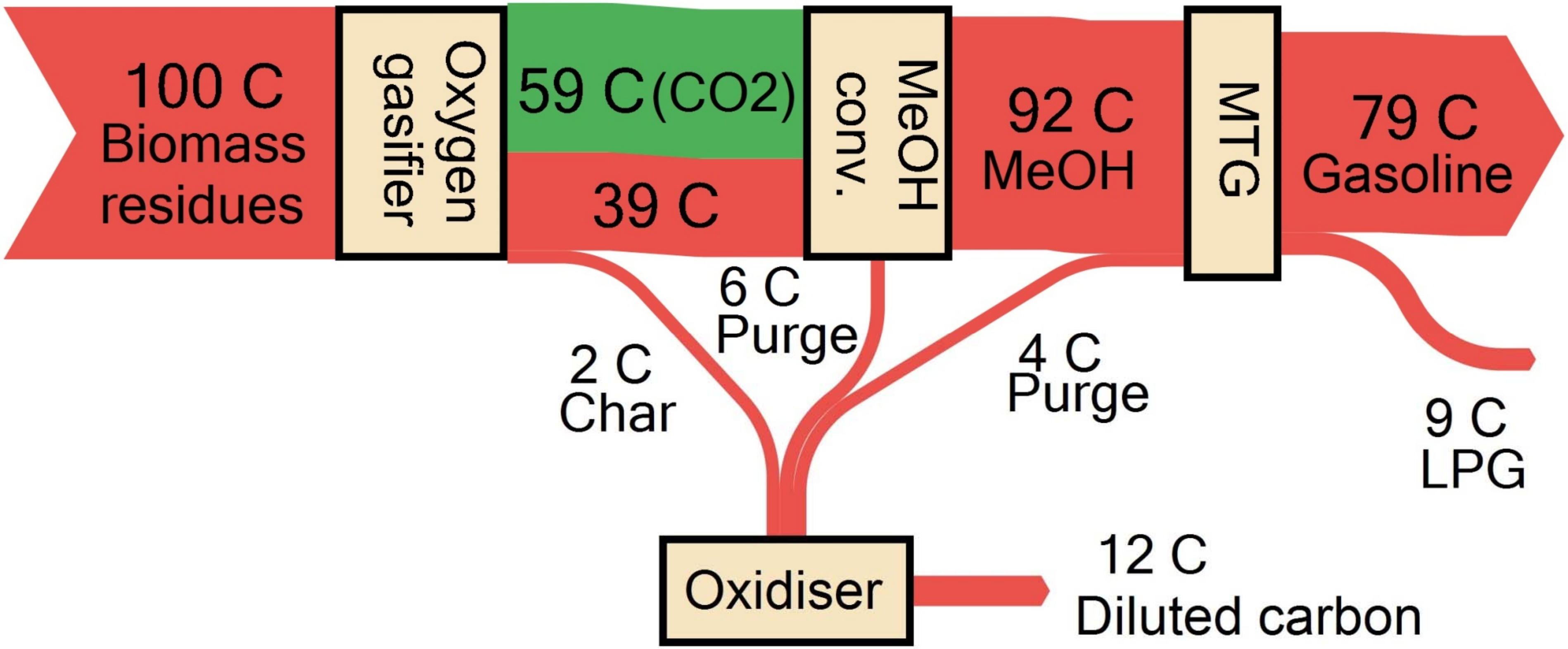
Gasoline via **steam** gasification



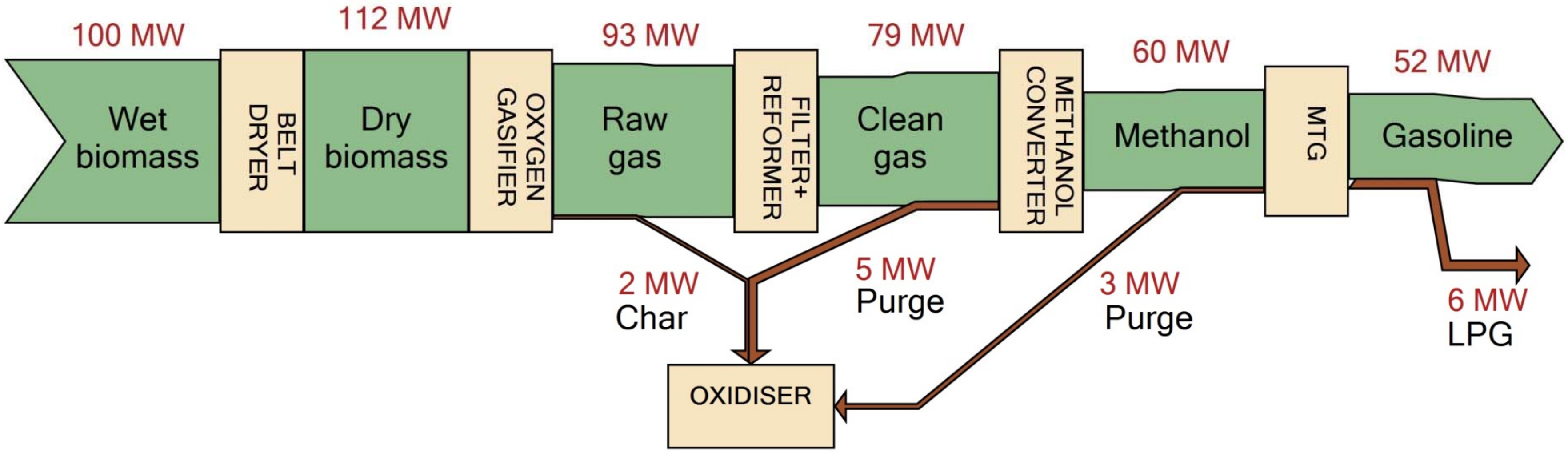
Gasoline via **enhanced steam** gasification



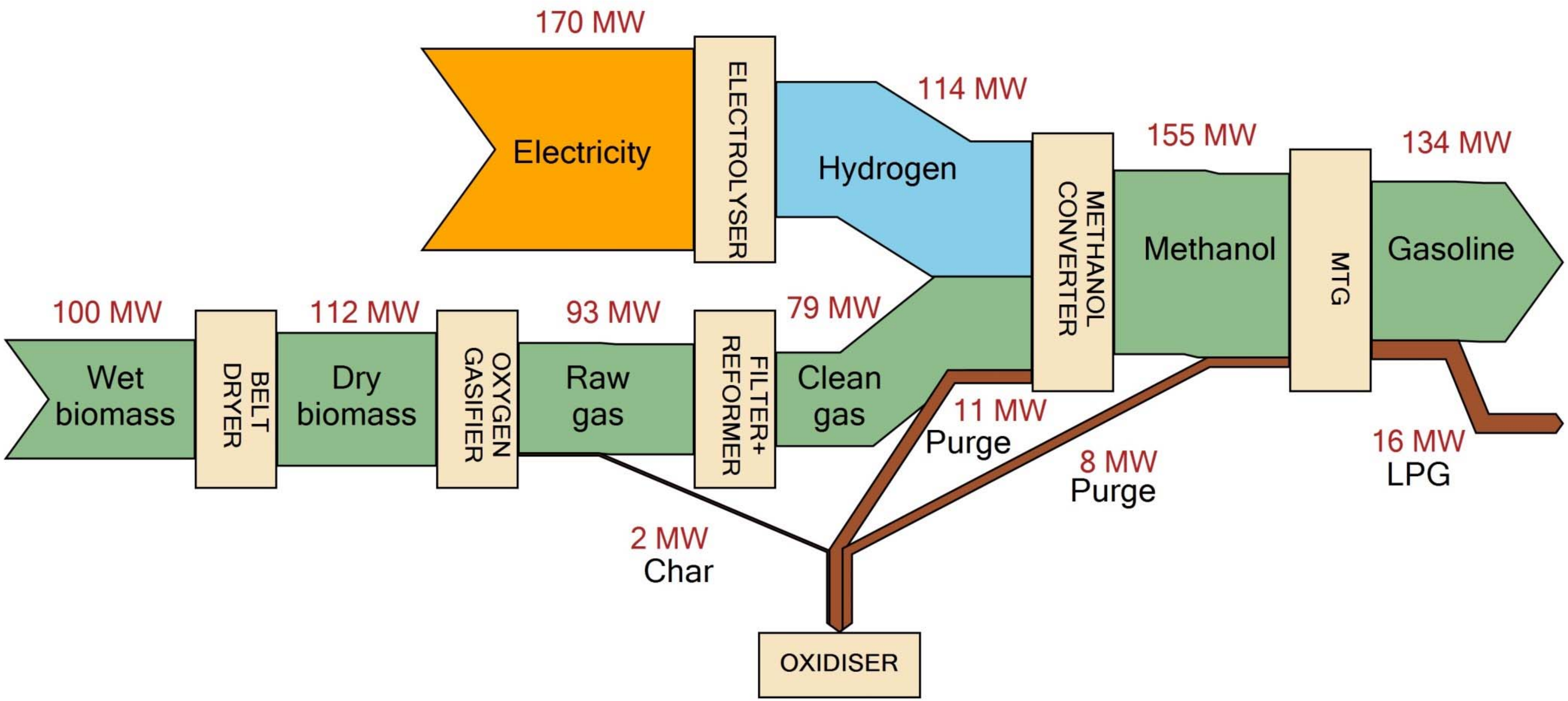
Gasoline via **enhanced oxygen** gasification



Gasoline via **oxygen** gasification (energy)



Gasoline via **enhanced oxygen** gasification (energy)



SUMMARY

When the maximally enhanced by an external H2 source, following increases in fuel output can be observed:

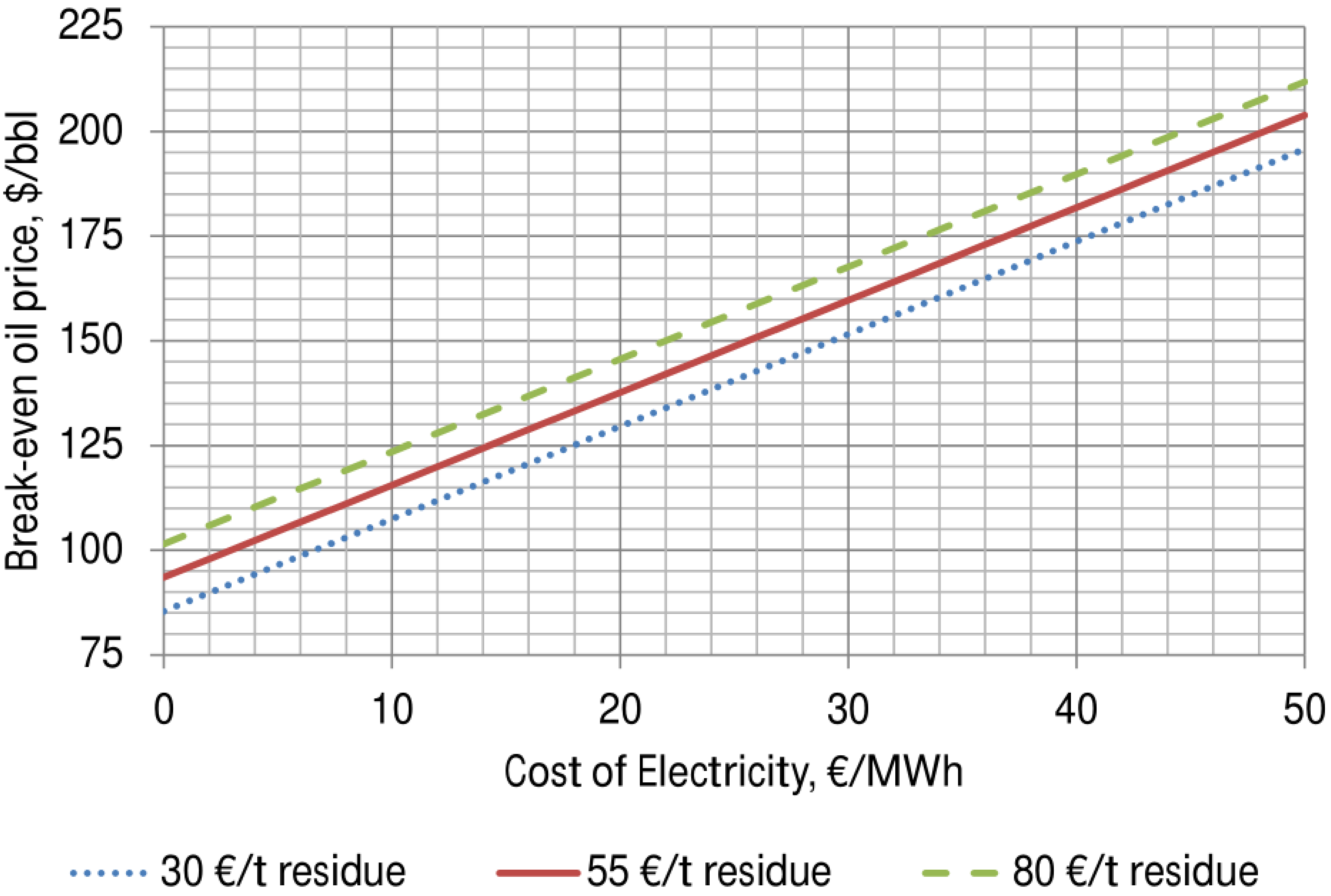
- **2.2-fold** (methane) or **1.9-fold** (gasoline) for steam gasification;
- **3.1-fold** (methane) or **2.6-fold** (gasoline) for oxygen gasification.

Overall carbon conversions for enhanced configurations:

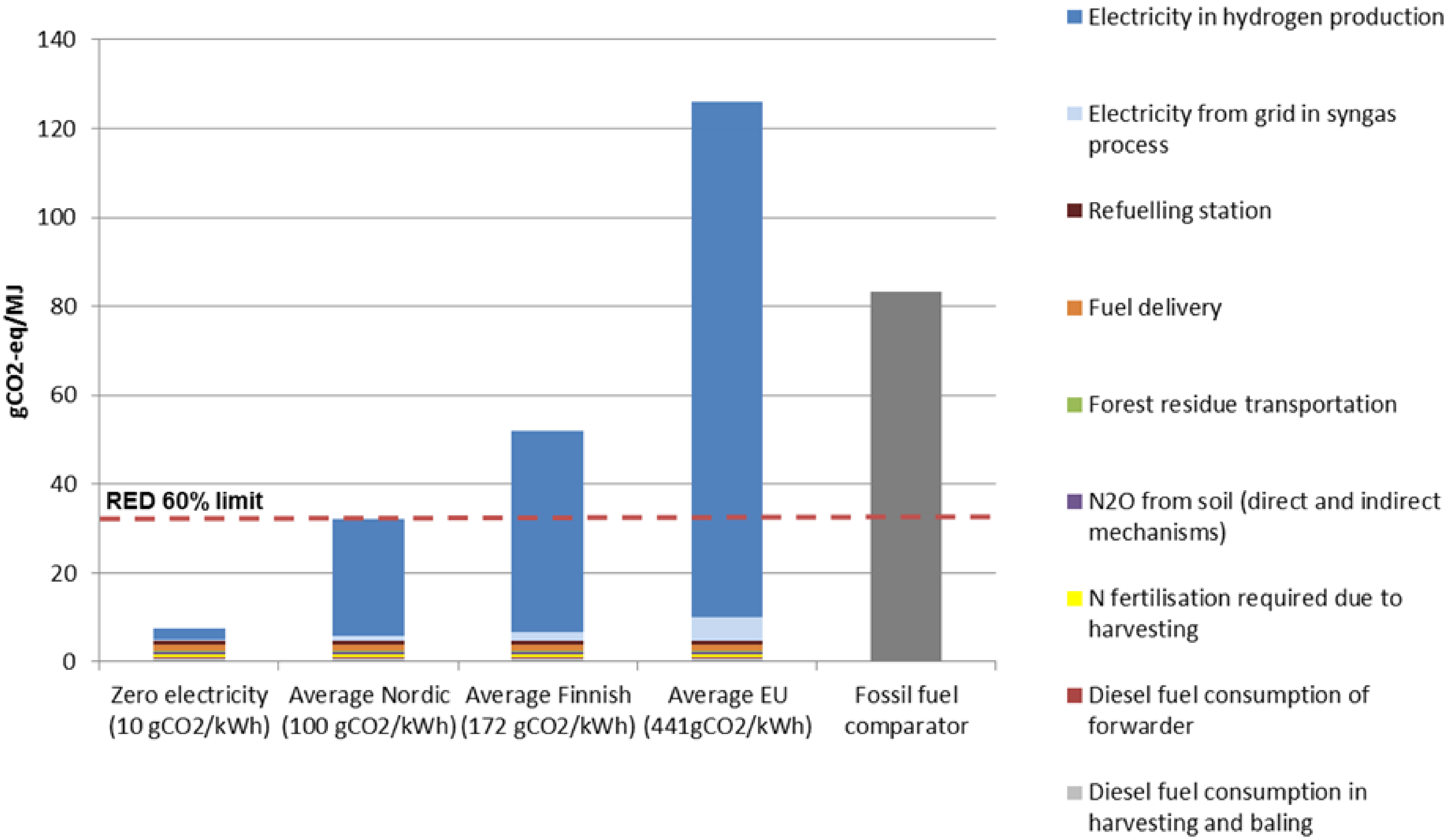
- **67.0%** (methane) and **58.4%** (gasoline) for steam gasification;
- **98.0%** (methane) and **79.4%** (gasoline) for oxygen gasification.

Econ. feasible over base case when low-GHG H2 cost lower than

- 2.2 €/kg (methane) and 2.7 €/kg (gasoline) for steam gasification;
- 2.4 €/kg (methane) and 2.8 €/kg (gasoline) for oxygen gasification.

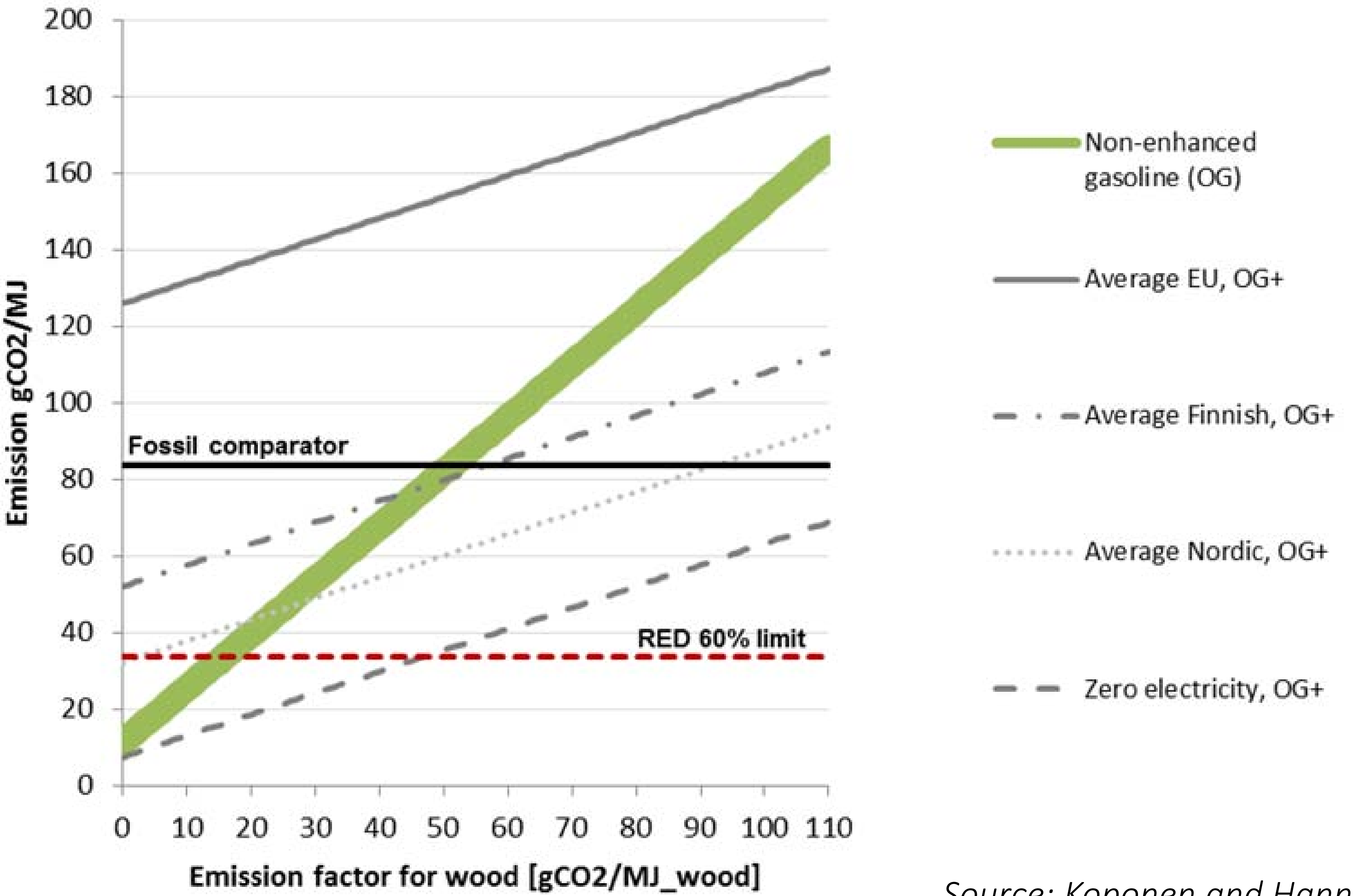

225
200
175
150
125
100
75
Break-even oil price, $/bbl
0
10
20
30
40
50
Cost of Electricity, €/MWh
30 €/t residue
55 €/t residue
80 €/t residue

GHG emission balances for H2 enhanced synthetic biofuels



Source: Koponen and Hannula (2016)

GHG emission balances for H2 enhanced synthetic biofuels



Source: Koponen and Hannula (2016)

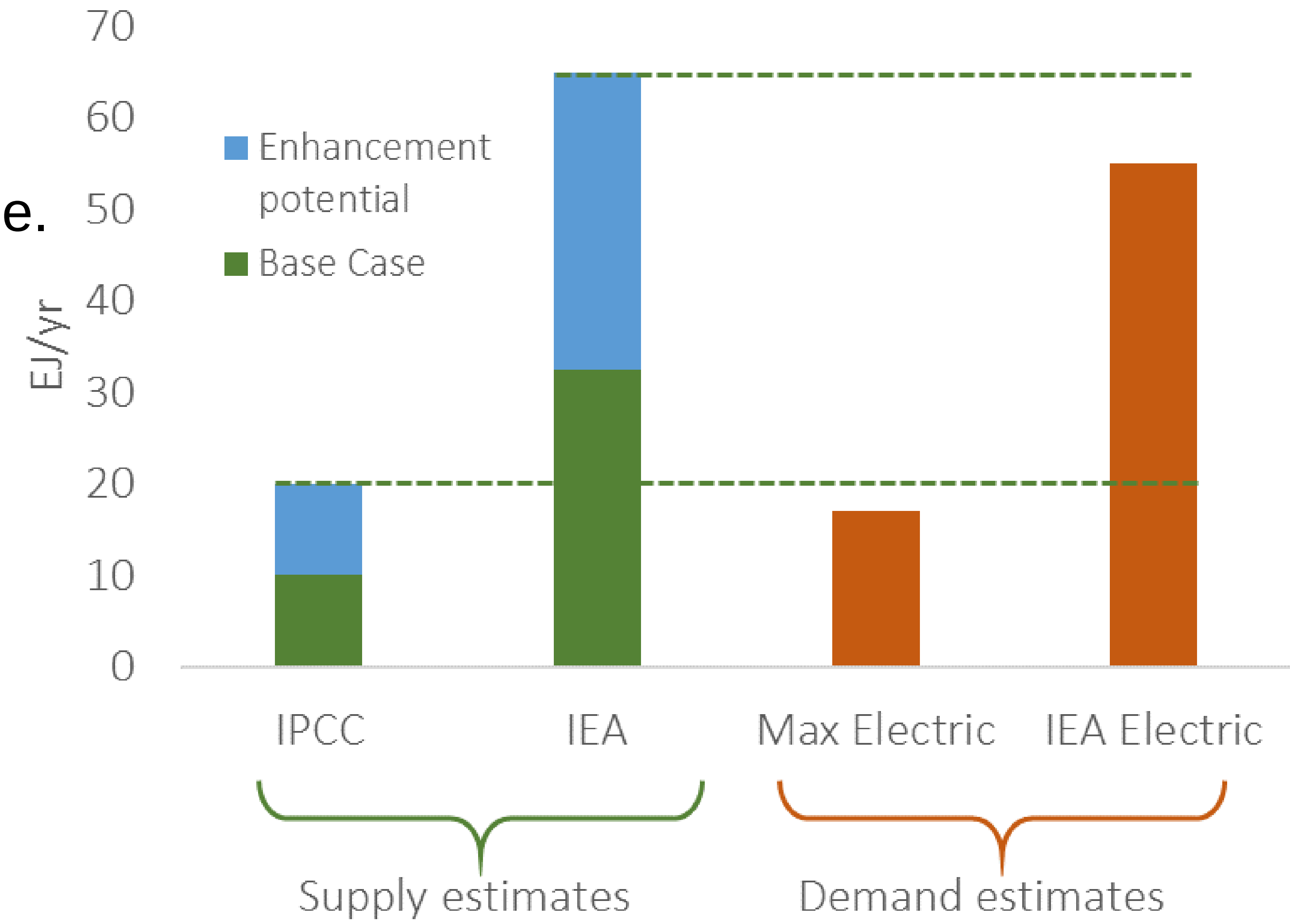
Take-home messages 1/2

- Manufacture of synthetic biofuels makes for an efficient use of biomass, provided that close attention is paid to heat integration issues.
- Still, less than half of biomass carbon utilised in fuel production
  - Renewable and sustainable carbon a scarce resource globally

    → Both the use of biomass (energy efficiency) **and** land (resource efficiency) for bioenergy purposes should be as efficient as possible.
  - This aspect not often discussed in relation to bioenergy.

Take-home messages 2/2

- Significant increase in biofuel output could be attained via H2 enhancement
- However, to ensure deep emission savings, electricity needs to come from a *very* low carbon source: Significant impact presumes that electric grids are first largely decarbonised
- Costs also a major issue.
- H2 enhanced biofuels still the least-cost solution for large scale decarbonisation of the hydrocarbon supply system?



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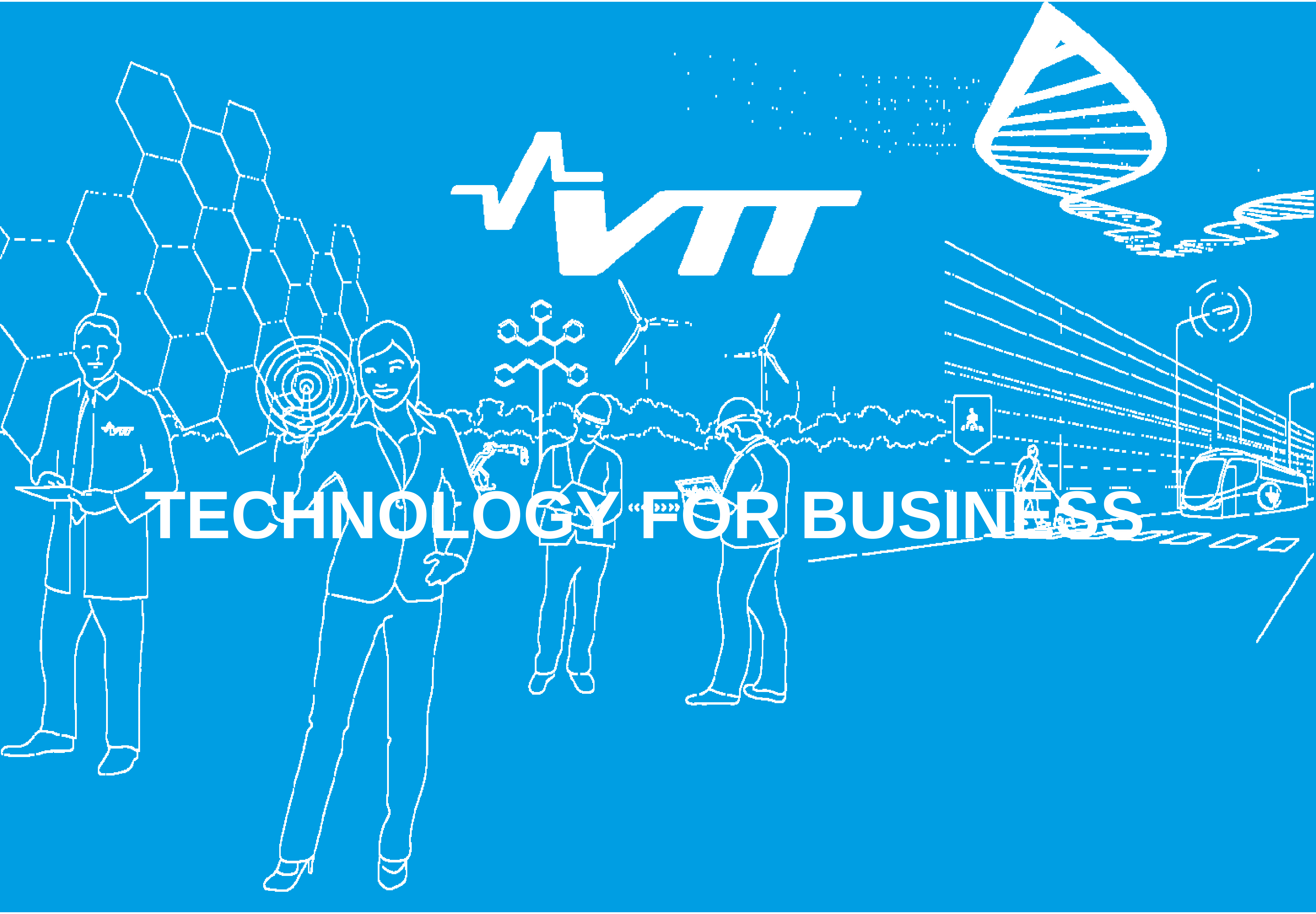
- Koponen, K. and Hannula I. (to be submitted), **2016**. *GHG emission balances for hydrogen enhanced synthetic biofuels from solid biomass.*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