TNO innovation for life

THE INDUSTRIAL TRANSFORMATION

CONSEQUENCES FOR STORAGE AND TRANSPORT

REINIER GRIMBERGEN

PRINCIPAL CONSULTANT, TNO

VUCA

MY AMBITION FOR TODAY

Volatility	→	Vision
Uncertainty	→	Understanding
Complexity	→	Clarity
Ambiguity	→	Agility

INDUSTRIAL TRANSFORMATION

MAIN DRIVERS AND CHALLENGES

DRIVER: EU GREEN DEAL

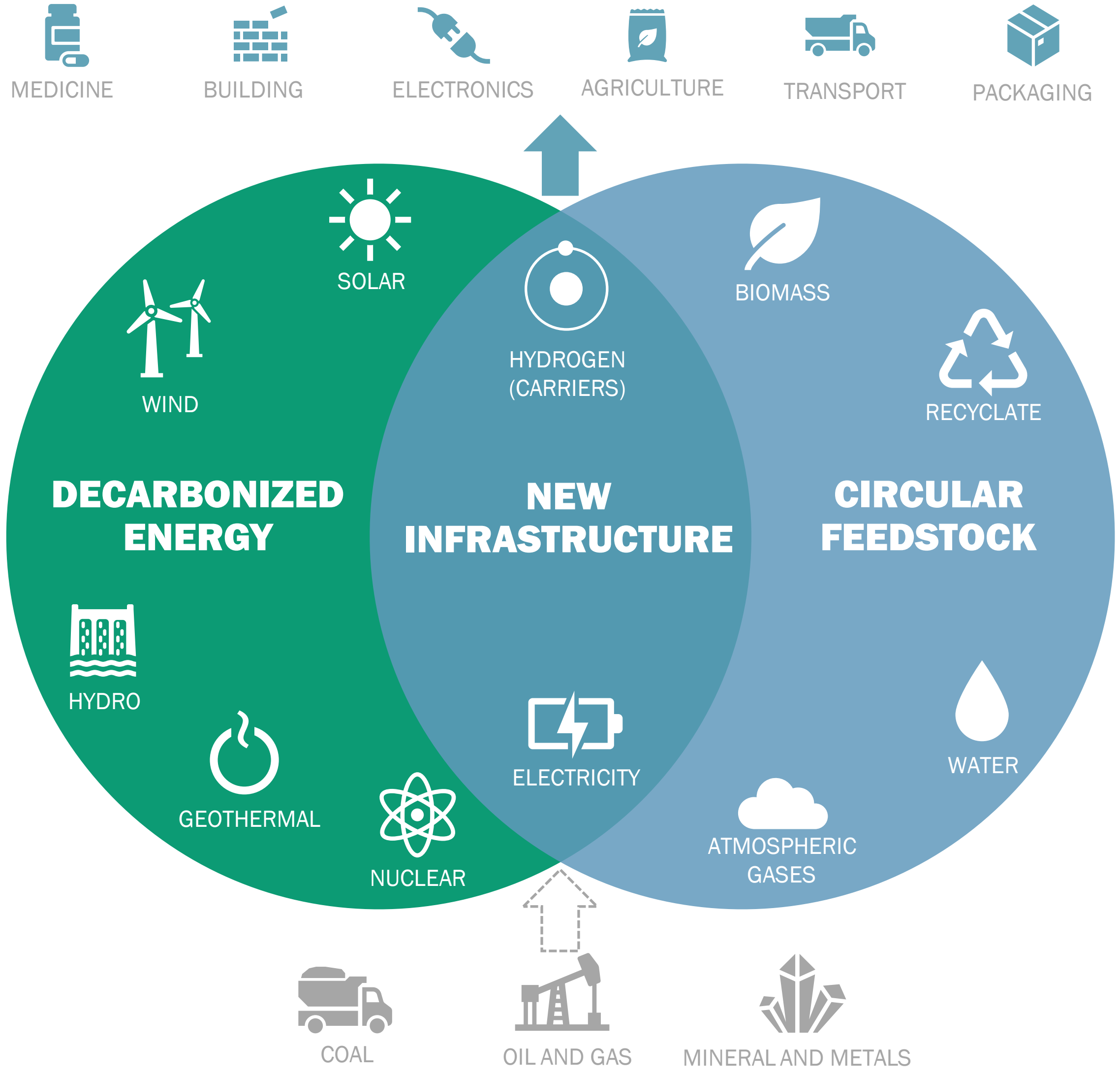
- Fit for 55 Package
- Chemicals Strategy for Sustainability (CSS)
- Circular economy

MAIN TECHNICAL CHALLENGES

- **Energy transition:** access to low-emission electricity and direct electrification
- **Feedstock transition:** access to circular carbon and minerals/metals
- **New feedstock induced products:** oxygenated products from CO_2 and biomass
- **Infrastructure for transport & storage:** energy, hydrogen, biomass, waste and CO_2

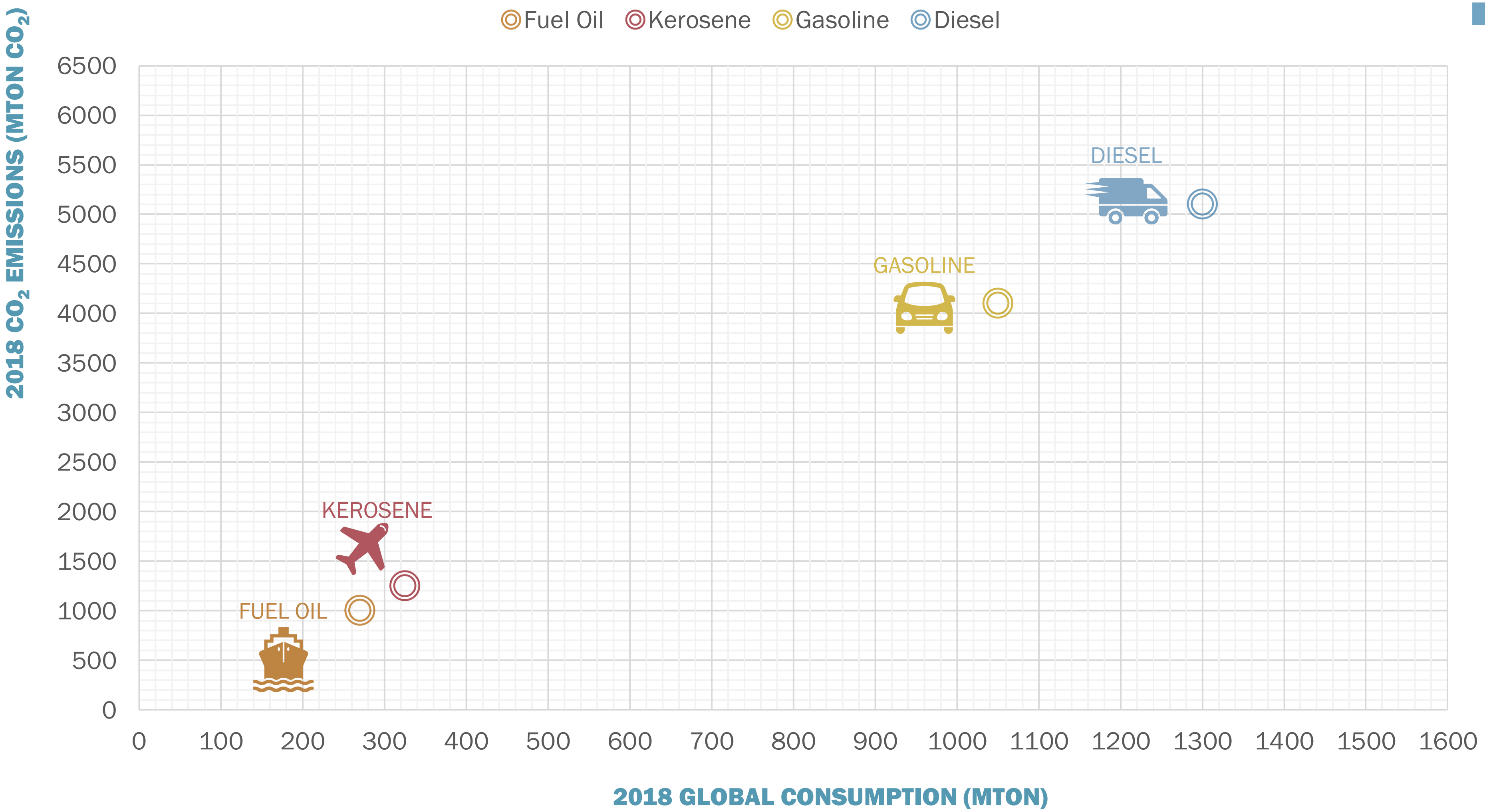
OTHER CHALLENGES

- **Communication and Societal acceptance:** regain trust
- **Human capital:** education and training
- **Financing:** funding the transformation
- **Digitization and AI:** facilitate and accelerate the transformation



LET'S FIRST PUT SOME EMISSIONS INTO PERSPECTIVE

GLOBAL WELL-TO-WHEEL GHG EMISSIONS OF FUELS



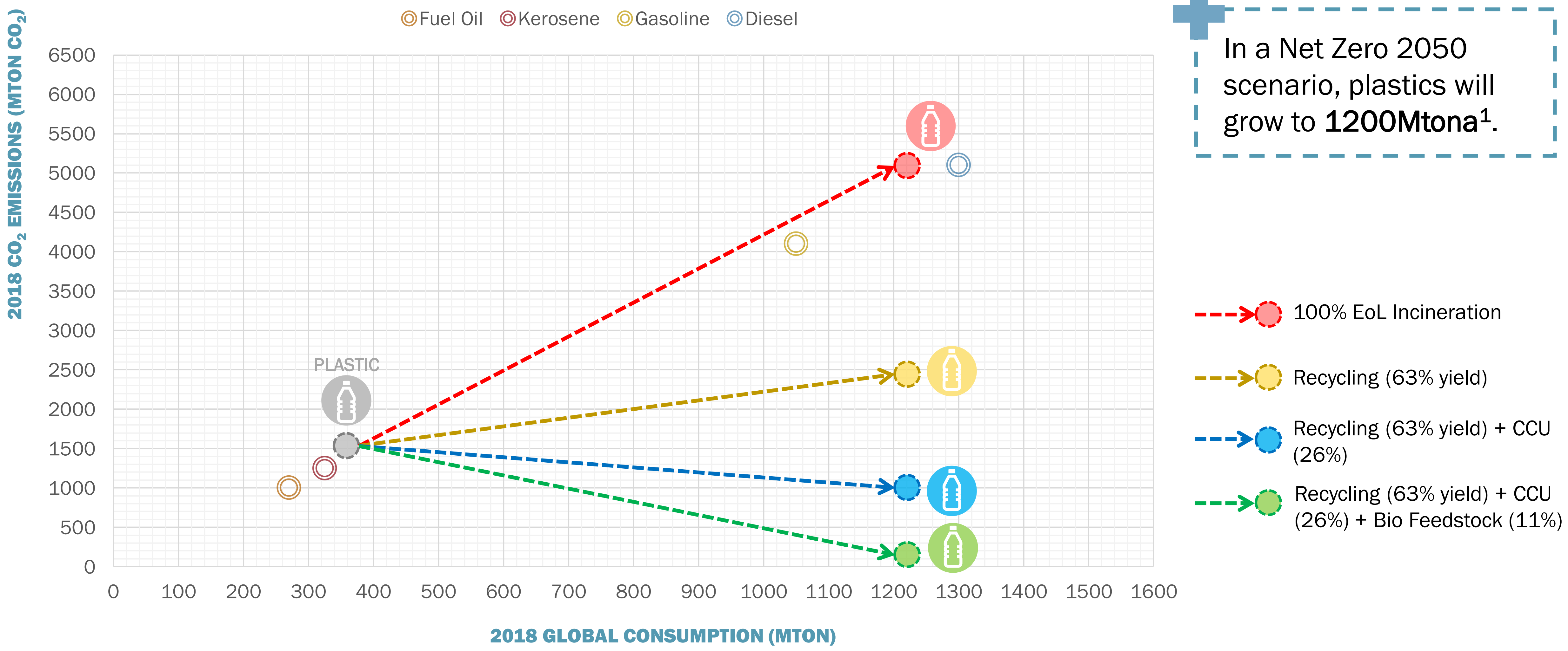
Fuels **volume** and well-to-wheel **emissions** are estimates from TNO analysis[1].

DIESEL	**3.70** tonCO_2/ton
GASOLINE	**3.85** tonCO_2/ton
KEROSENE	**3.90** tonCO_2/ton
FUEL OIL	**3.92** tonCO_2/ton

[1] Personal analysis based on public data and 2050 fuels data derived from Irena Global Energy Transformation Report 2018

LET'S FIRST PUT SOME EMISSIONS INTO PERSPECTIVE

GLOBAL GHG EMISSIONS OF PLASTICS 2018 TO 2050



In a Net Zero 2050 scenario, plastics will grow to **1200Mtona**[1].

[1]Plastics 2050 volumes and scenarios taken from Nova Paper #12, Nova Institut.

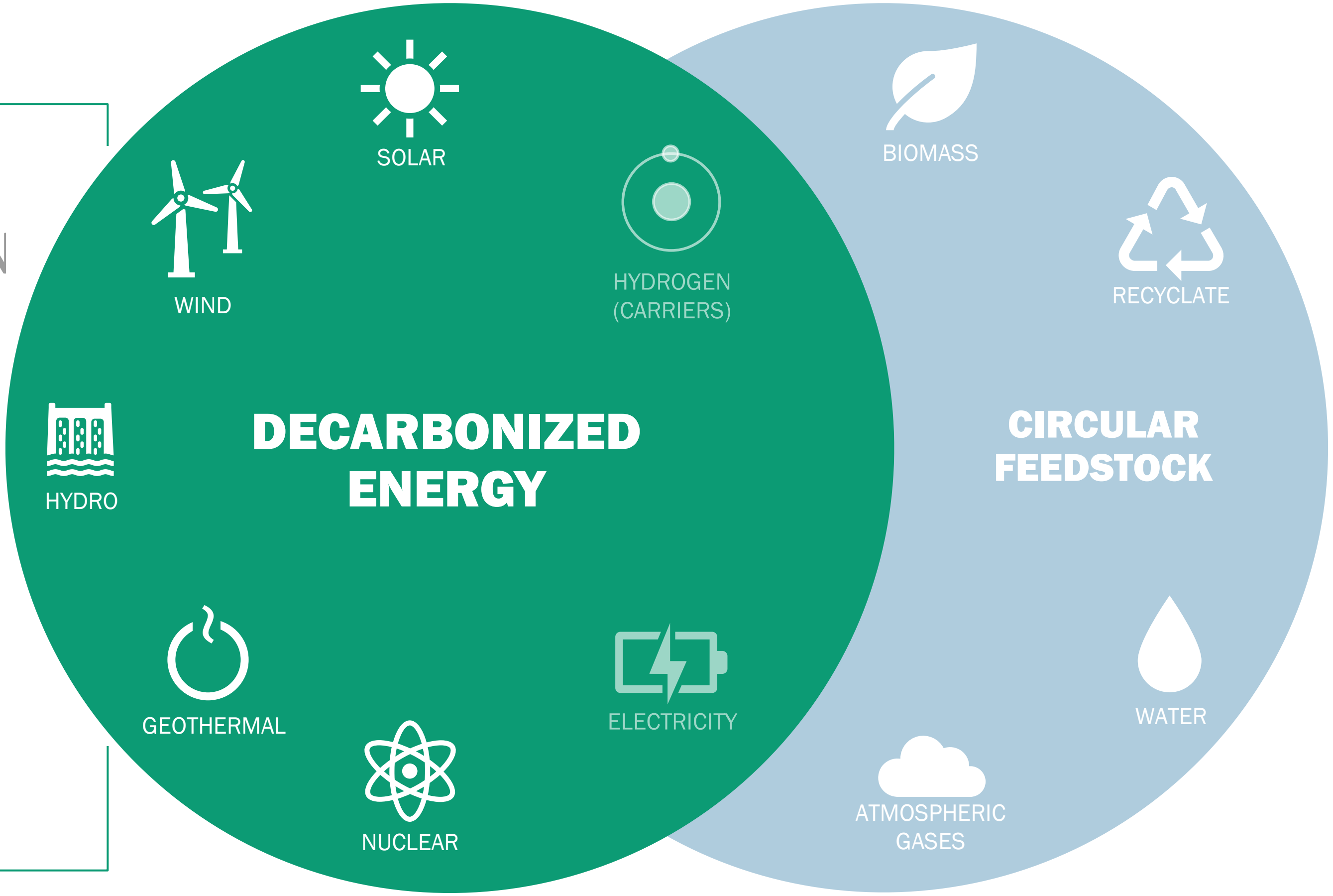
INDUSTRIAL TRANSFORMATION

A 2050 VISION FOR THE EUROPEAN PROCESS INDUSTRY

ENERGY TRANSITION

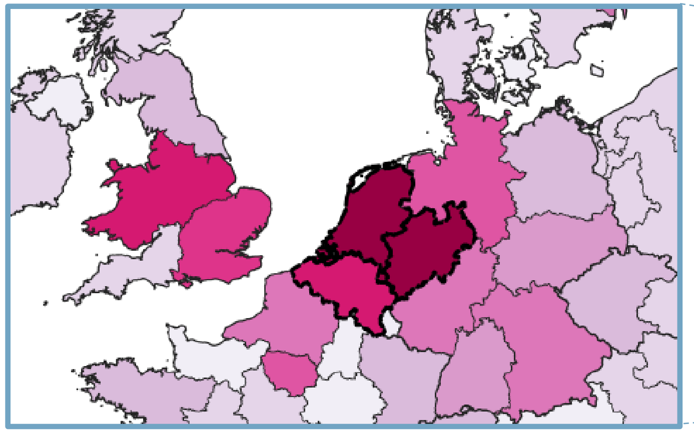
DECARBONIZATION BY ELECTRIFICATION

The goals of the national governments and the European Union are clear: a 55% reduction in carbon emissions (compared with 1990) by 2030 and zero carbon emissions by 2050. That means a very steep drop in emissions over the next years, impacting the industrial electricity and heat systems. Electrification and renewable energy supply are key challenges ahead.

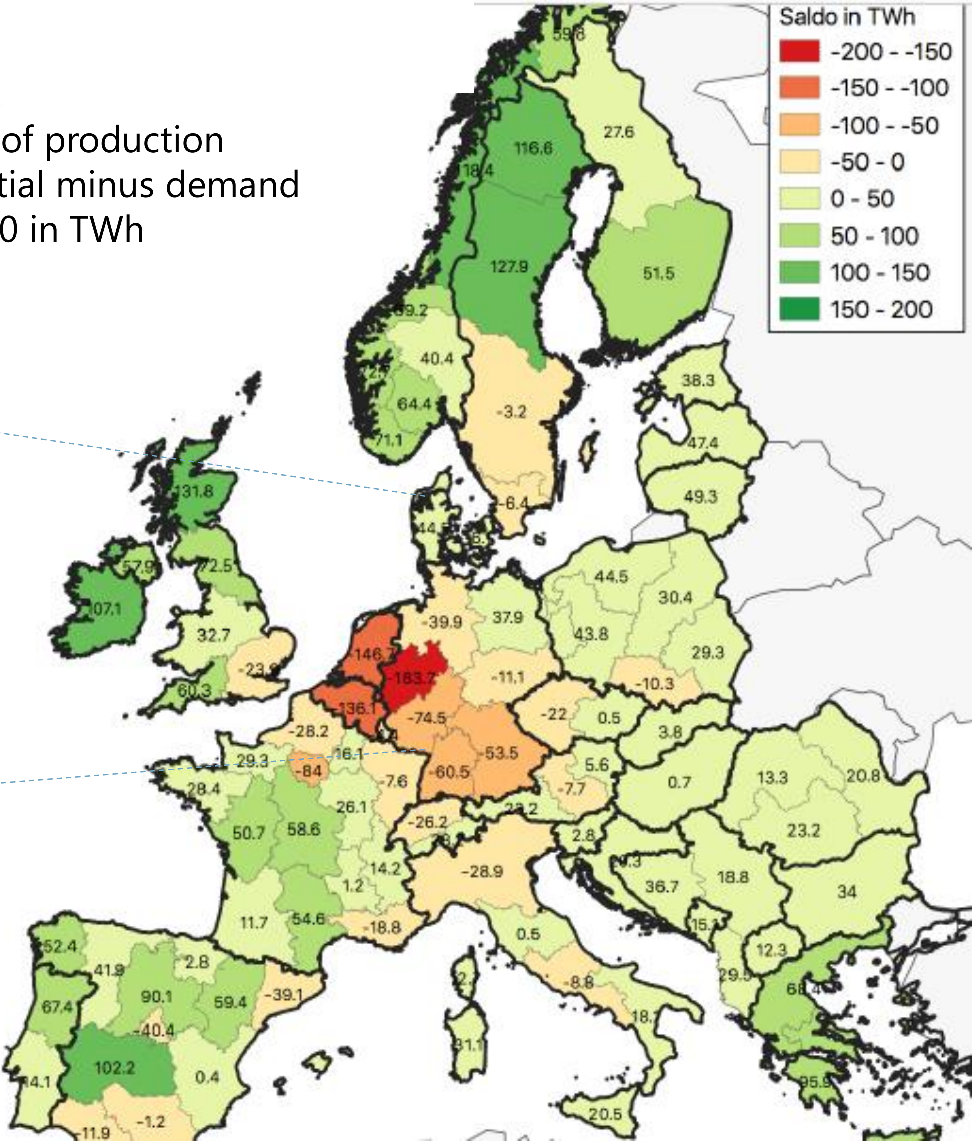


ARRRA CLUSTER'S RENEWABLE ELECTRICITY PRODUCTION POTENTIAL IS INSUFFICIENT TO MEET DEMAND

Saldo of production potential minus demand in 2050 in TWh



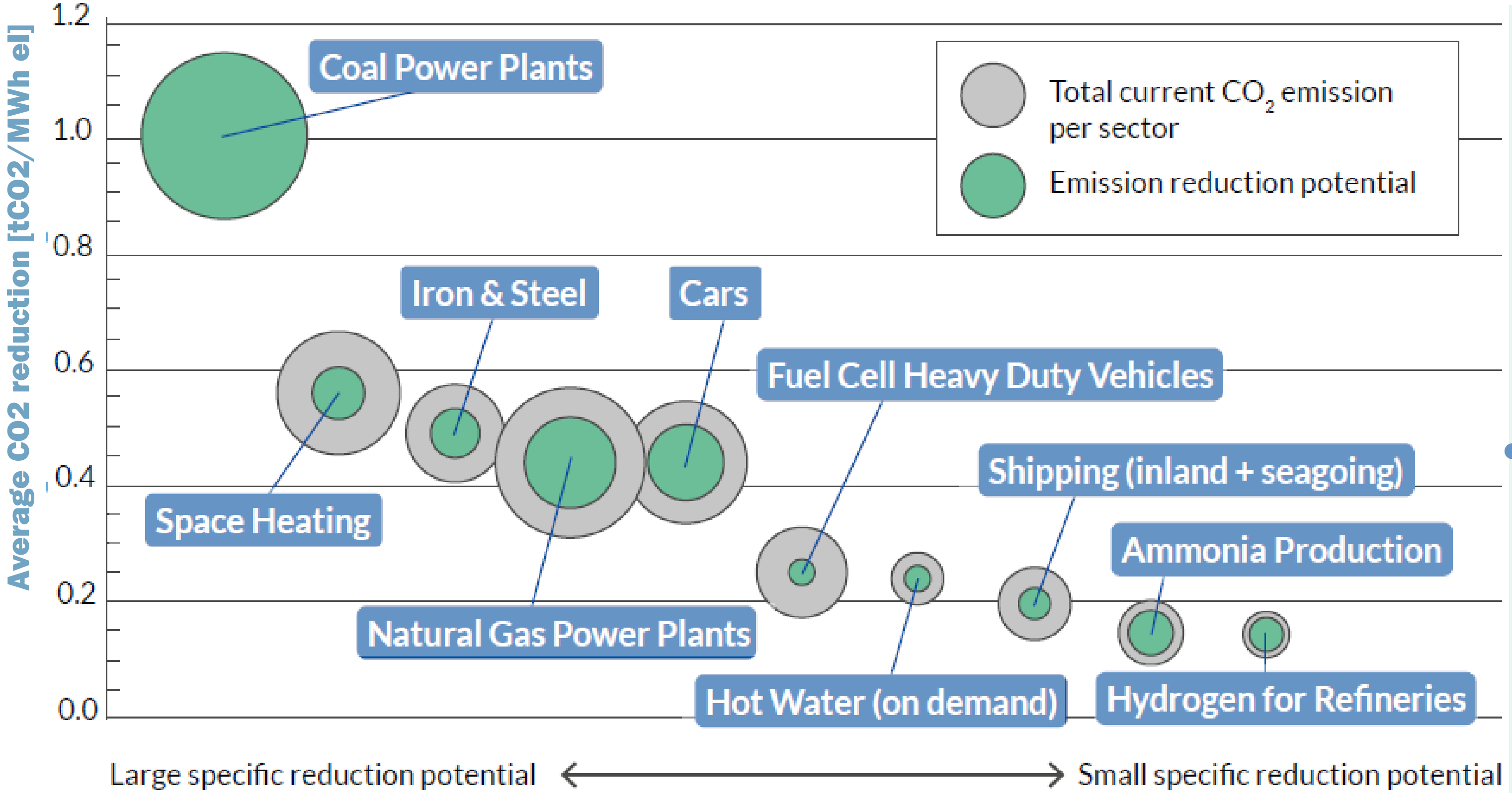
Electricity demand incl. electricity for hydrogen and decarbonisation



Source: Wuppertal institute 2020

ELECTRIFICATION DECARBONIZATION PRIORITY

2030 CO_2 reduction potential of the different options for the Netherlands (bubble sizes are correlated with the Mton/CO_2/year values)



		Coal PPs	Space heating	Iron & Steel	NG PPs	Cars	HDVs	Hot water	Shipping	Ammonia	Refinery Hydrogen	Total
2018 CO_2 emissions	[Mton CO_2/y]	35.0	18.9	12.5	28.4	18.6	10.2	3.5	7.0	5.4	2.9	142.4
2030 percentage	[% 'green']	100.0	20.0	25.0	40.0	40.0	10.0	33.0	20.0	50.0	50.0	48.0
2030 reduction potential	[Mton CO_2/y]	35.0	3.8	3.1	11.4	7.4	1.0	1.2	1.4	2.7	1.4	68.4
Power demand in 2030	[TWh/y]	35.0	6.7	6.4	25.8	16.9	4.1	4.9	7.1	18.2	10.0	135.2

MERIT ORDER OF ELECTRIFICATION

1. FOSSIL POWER GENERATION
2. SPACE HEATING (HEAT PUMPS)
3. IRON & STEEL (H-DRI)
4. PASSENGER VEHICLES (BEV)

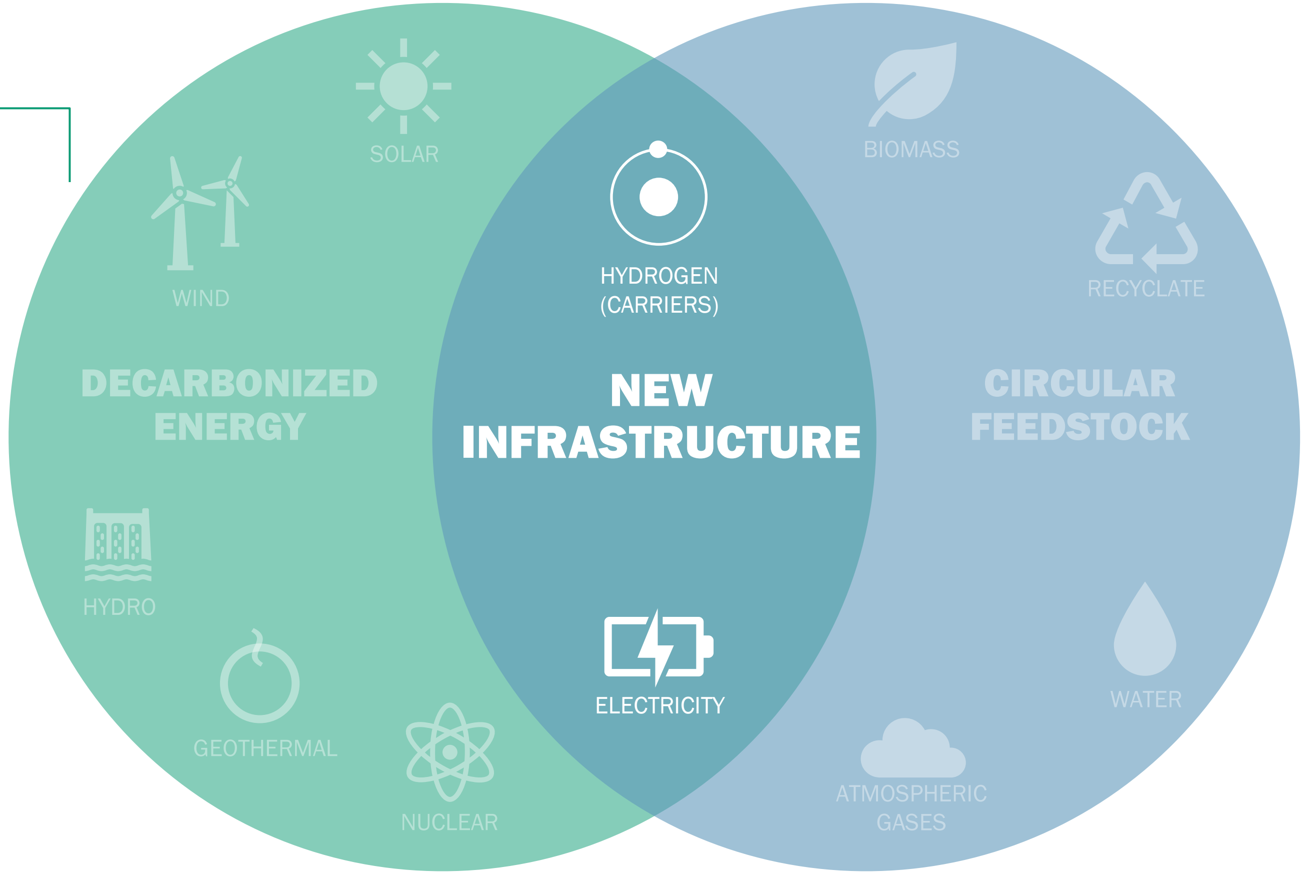
48% reduction emission in 2030 requires **135 TWh/yr (15.5 GW)** green electricity.

INDUSTRIAL TRANSFORMATION

A 2050 VISION FOR THE EUROPEAN PROCESS INDUSTRY

NEW INFRASTRUCTURE

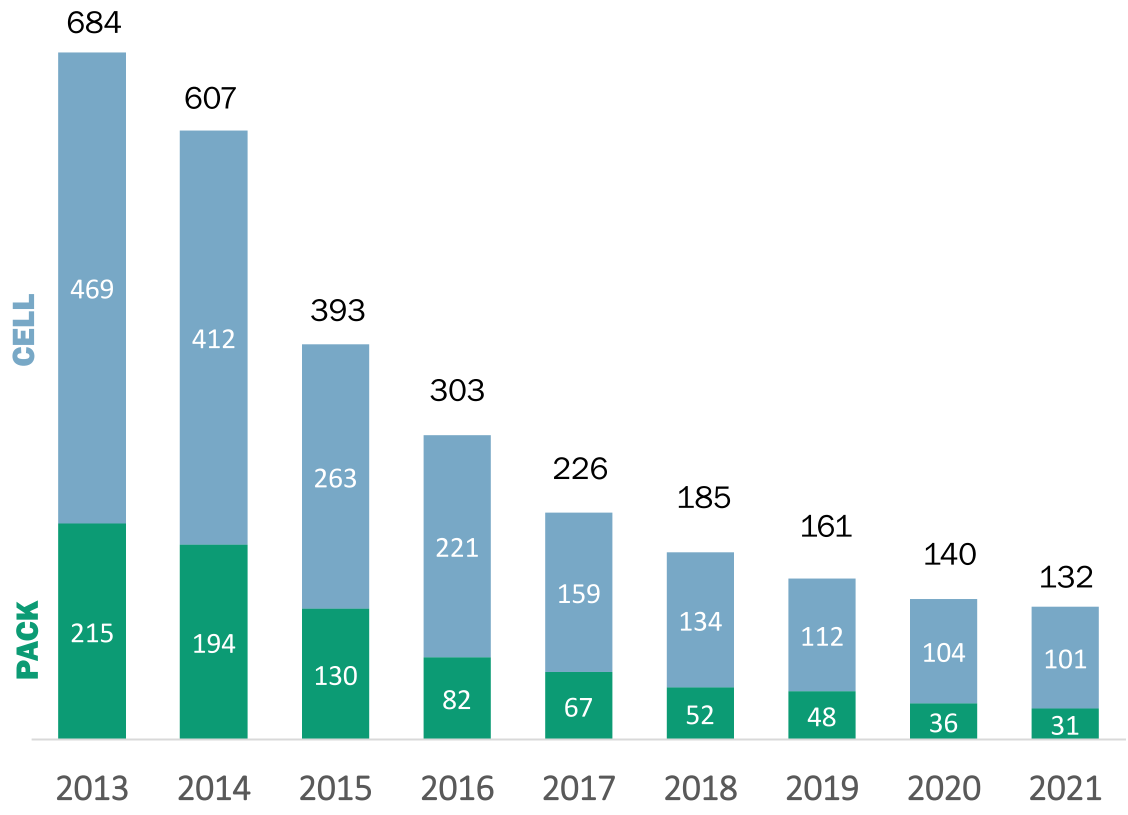
ELECTRICITY AND
HYDROGEN (CARRIERS)



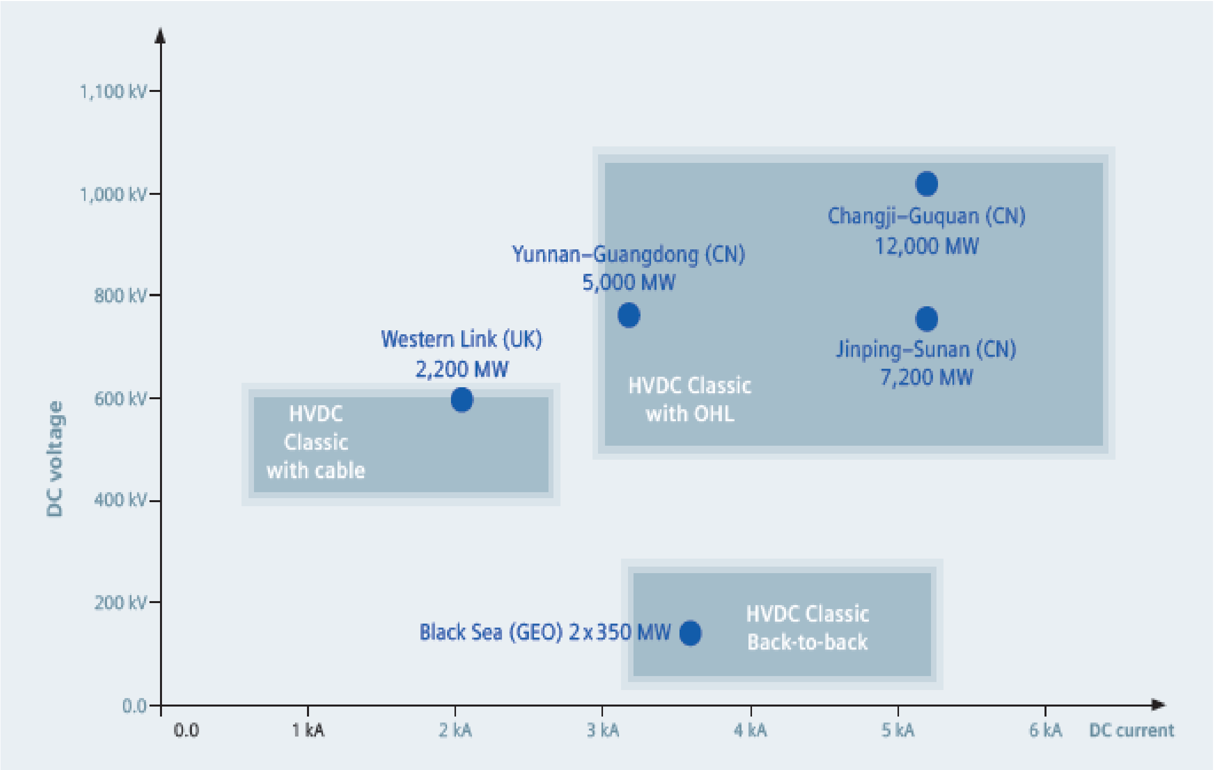
ELECTRICITY: SHORT TERM STORAGE AND TRANSPORT

VOLUME-WEIGHTED AVERAGE PACK AND CELL PRICE SPLIT

Real2021 $/kWh



Source: BloombergNEF



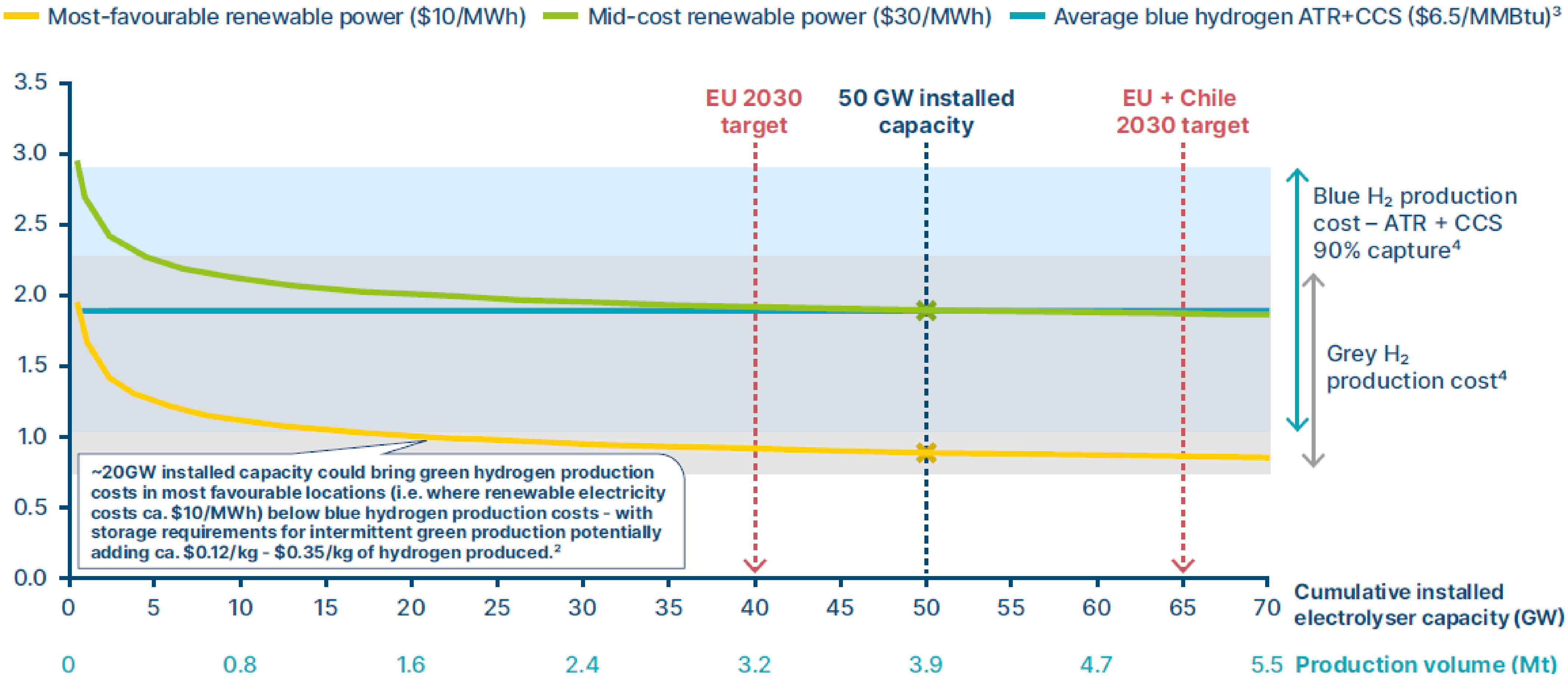
Source: Siemens HVDC technology

LOW EMISSION ELECTRICITY WILL GRADUALLY REPLACE OIL AND GAS AS AN ENERGY VECTOR

GREEN HYDROGEN COST EXPECTED TO DECREASE TO <$2/KG

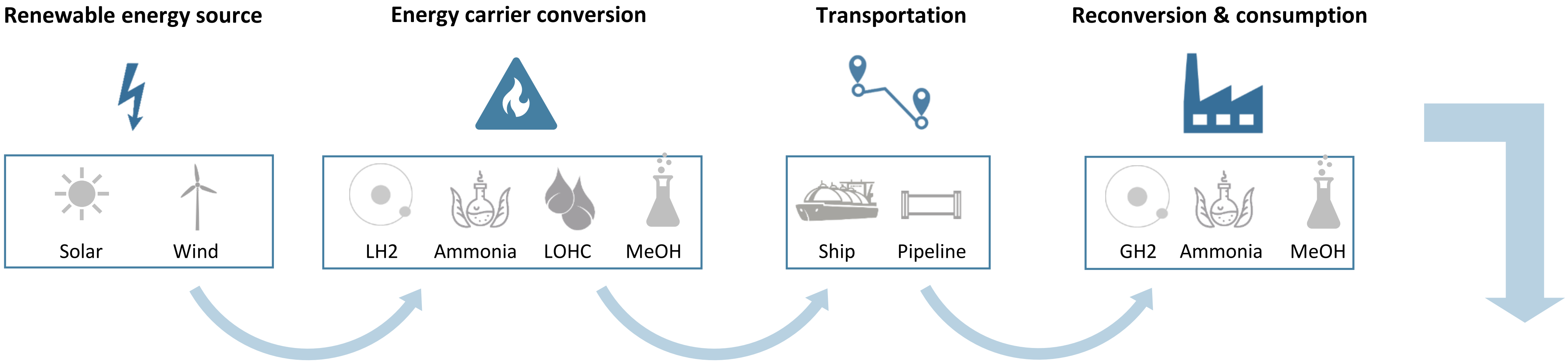
AT 50GW INSTALLED CAPACITY, MAKING IT COST COMPETITIVE WITH BLUE HYDROGEN

Green hydrogen production costs[1] (excluding storage costs[2], 2020s)
$/kg

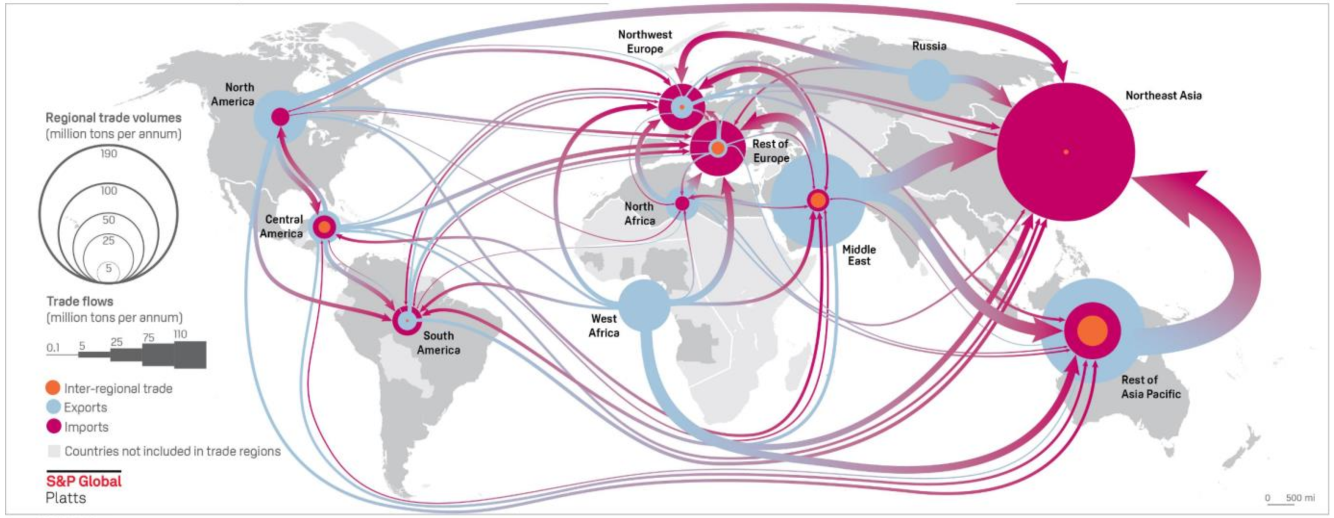


Source: Energy Transition Commission, Making Hydrogen possible, accelerating clean hydrogen in an electrified economy

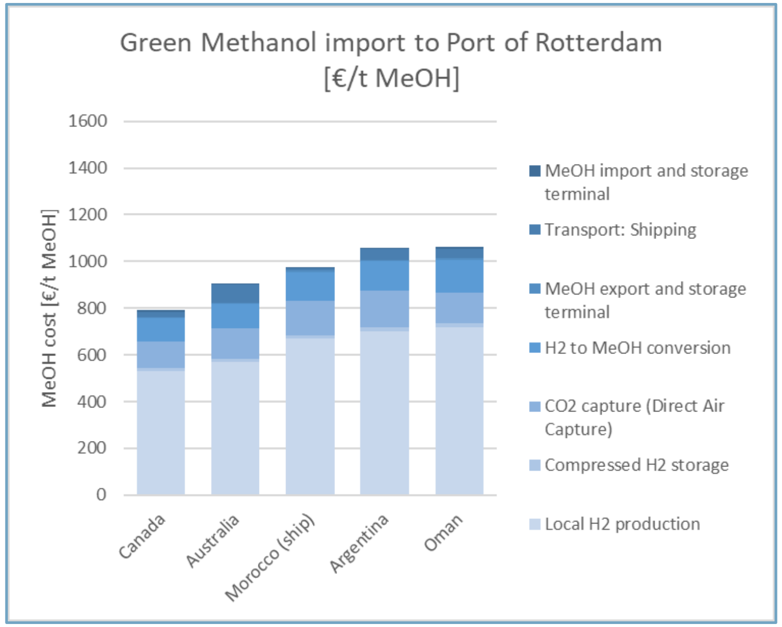
HYDROGEN (CARRIER) IMPORT VALUE CHAINS COST MODEL



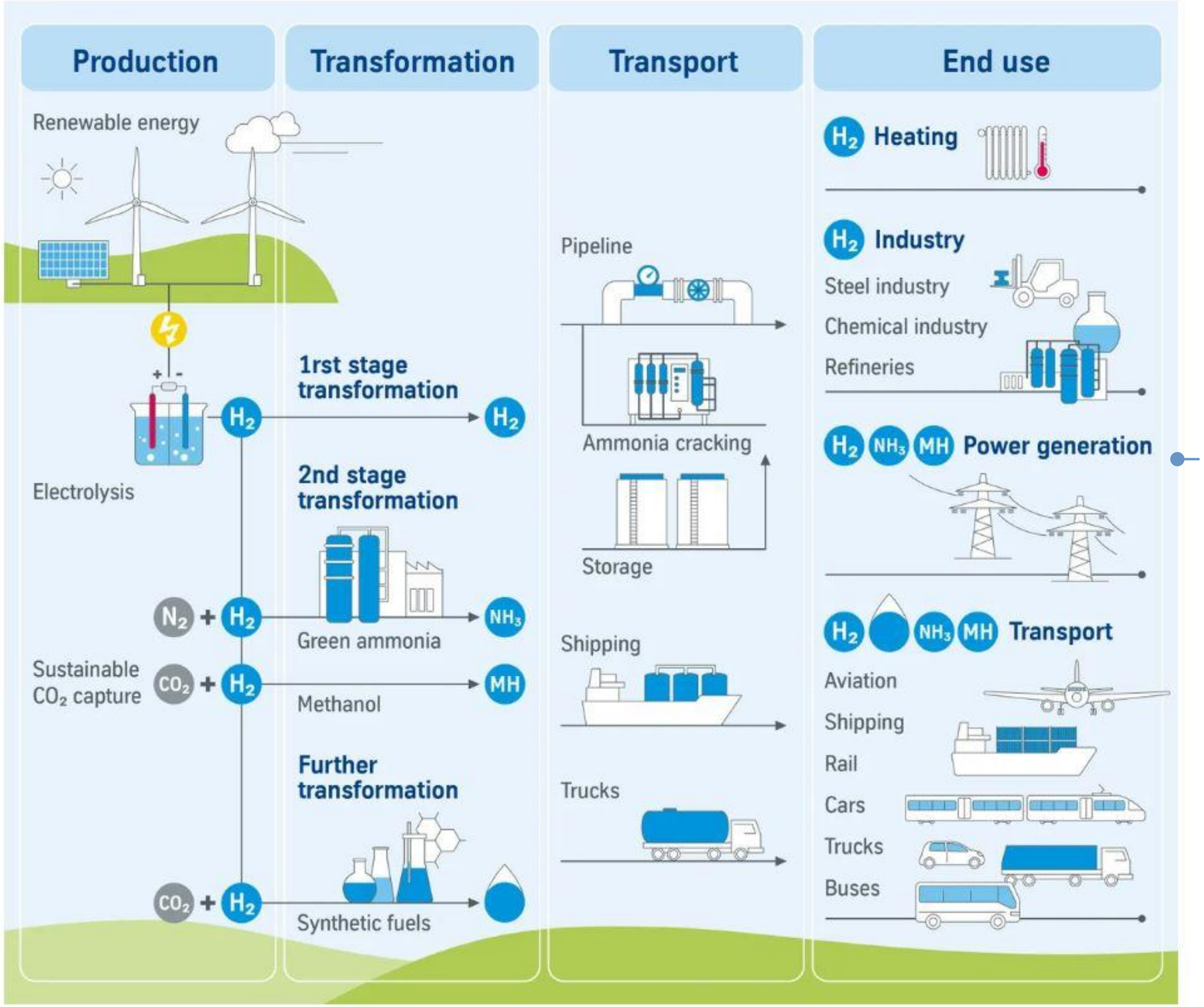
LIQUIFIED NATURAL GAS TRADE FLOW, 2018



Source: S&P Global Platts



HYDROGEN: FOCUS ON LOCAL-FOR-LOCAL PRODUCTION



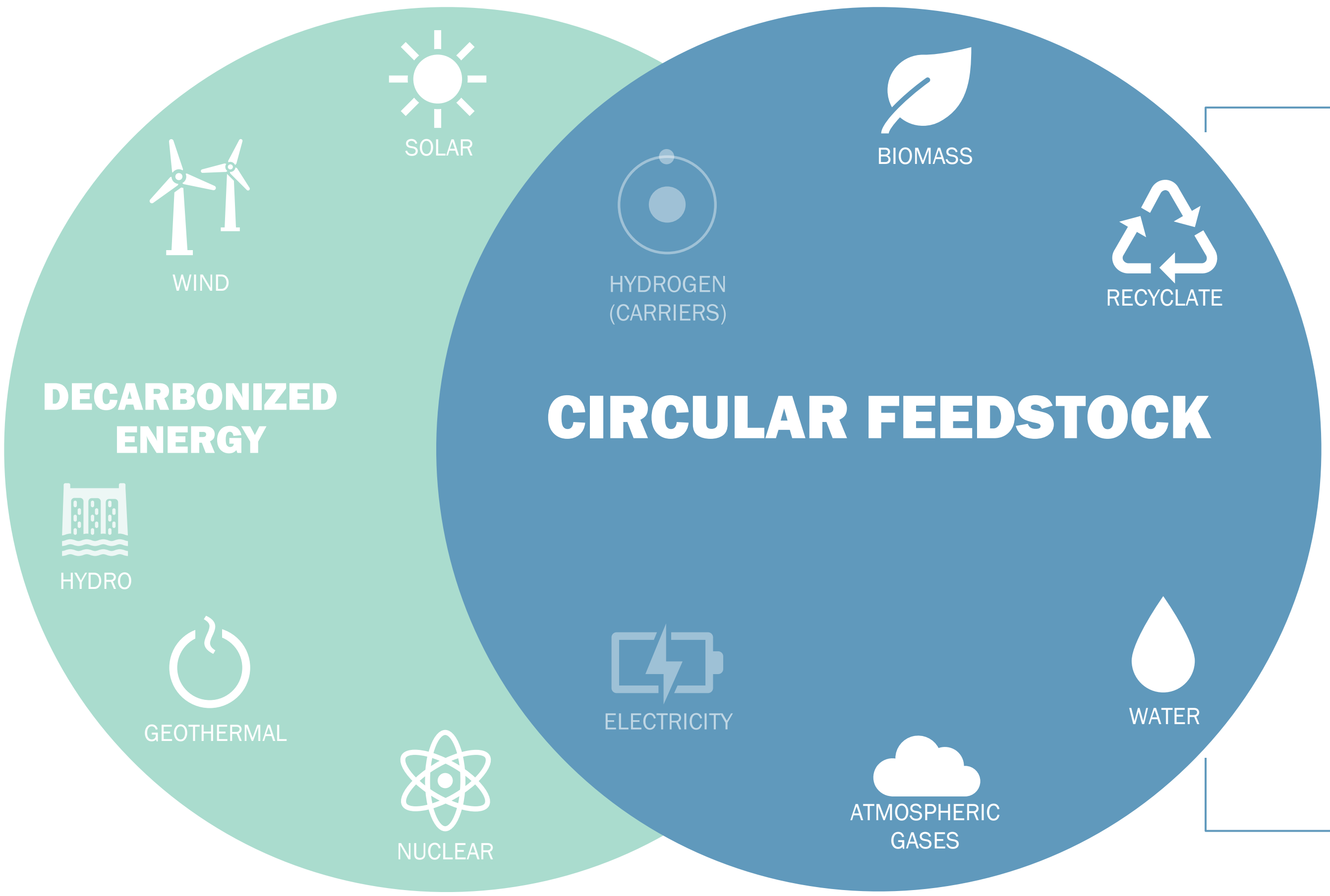
The value chain of green methanol – from production to application in various industries.

MAIN TAKEAWAYS FROM THE HYDROGEN VALUE CHAIN

1. **Local-for-Local** production fits linear scaling characteristic of electrolysis.
2. **Avoid hydrogen transport** and storage as much as possible due to inefficiency (costs) and safety risks.
3. Transport and storage of hydrogen in the form of methanol and ammonia is **proven technology**.

INDUSTRIAL TRANSFORMATION

A 2050 VISION FOR THE EUROPEAN PROCESS INDUSTRY



FEEDSTOCK TRANSITION

FROM FOSSIL TO CIRCULAR FEEDSTOCK

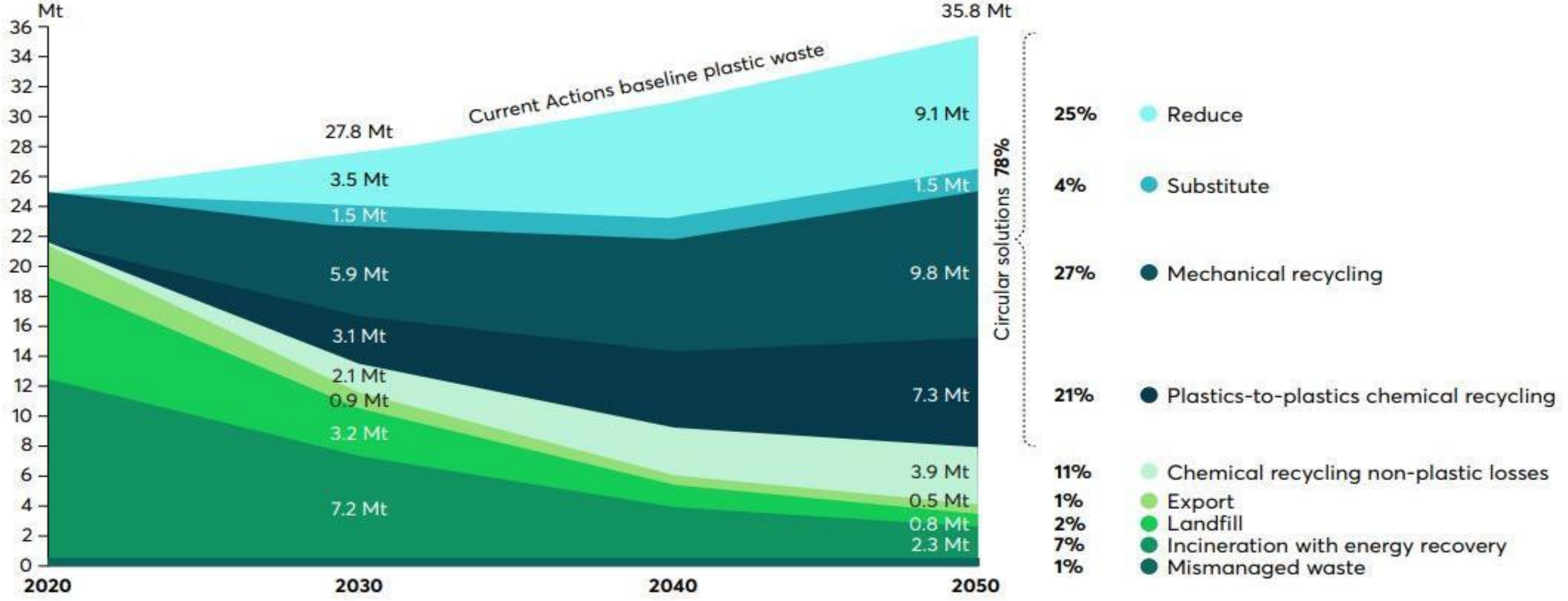
The prospect of material shortages and the sustainable concerns raised by the use of fossil feedstock forces the industry to unite and take action. New technologies, supply chains and infrastructure are needed for sourcing renewable feedstock. At the same time, more collaboration and symbioses are required for closing the circularity loop of materials.

CIRCULAR FEEDSTOCKS

PLASTICS RECYCLING

By 2050, the plastics system could achieve **78% circularity** with 30% of waste avoided through reduction and substitution and 48% being recycled, leaving 9% in landfills and incinerators.

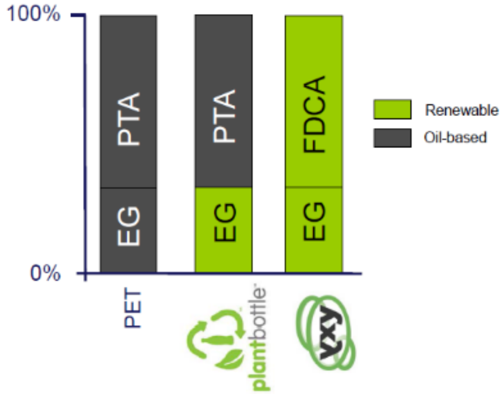
PHYSICAL FATE OF PLASTIC WASTE FROM PACKAGING, HOUSEHOLD GOODS, AUTOMOTIVE AND CONSTRUCTION 2020-2050 (Mt)



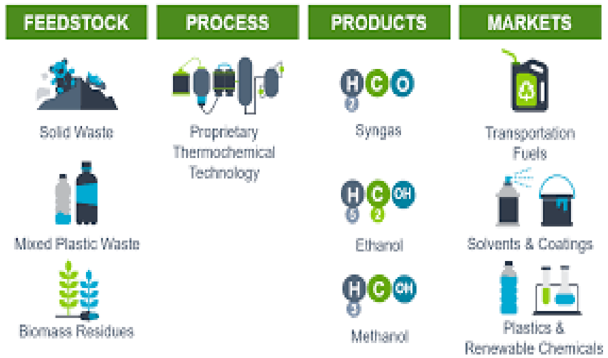
Source: "ReShaping Plastics" model

CIRCULAR FEEDSTOCKS

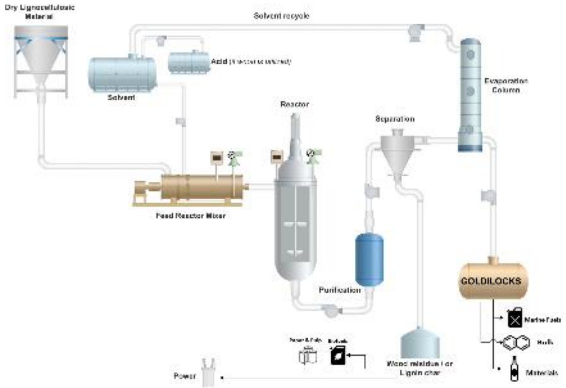
BIO-FEEDSTOCKS



SUGAR (CHEMOCAT)



BIOMASS GASIFICATION



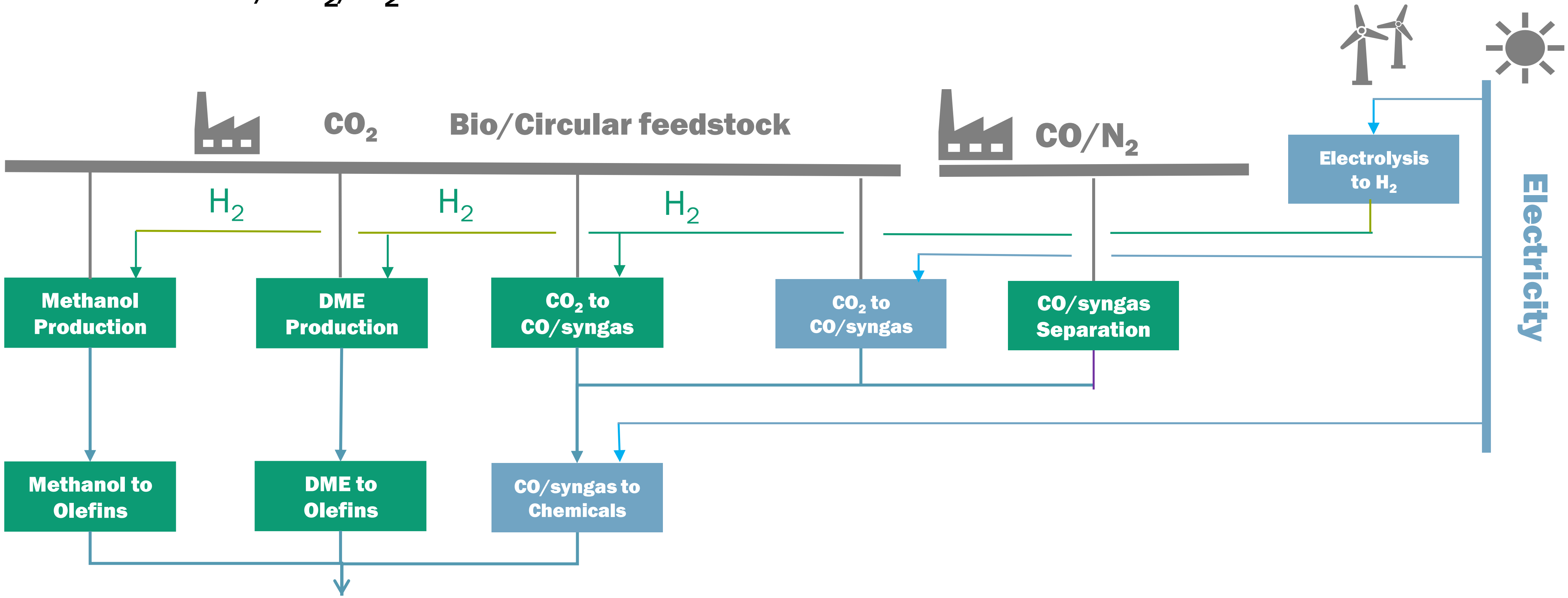
BIOMASS PYROLYSIS

FERMENTATION

SUSTAINABLE SUGAR AND WOODY BIOMASS CAN PROVIDE A CIRCULAR FEEDSTOCK FOR THE CHEMICAL INDUSTRY

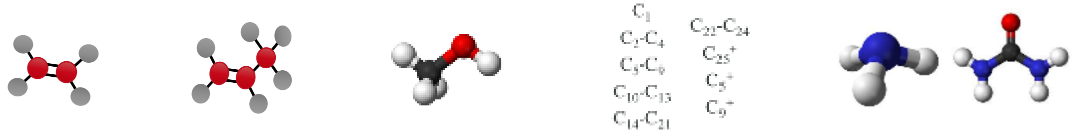
CIRCULAR FEEDSTOCKS

WASTE GASES $CO/CO_2/N_2$



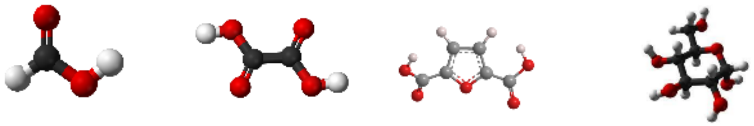
DROP-IN COMMODITIES

Ethylene · *Propylene* · *Methanol/DME* · *FT-Kerosine/-Diesel* · *Ammonia & Urea*



NEW (BIOBASED) ALTERNATIVES

Formic Acid · *Oxalic Acid* · *FDCA* · *Other sugar derivatives*

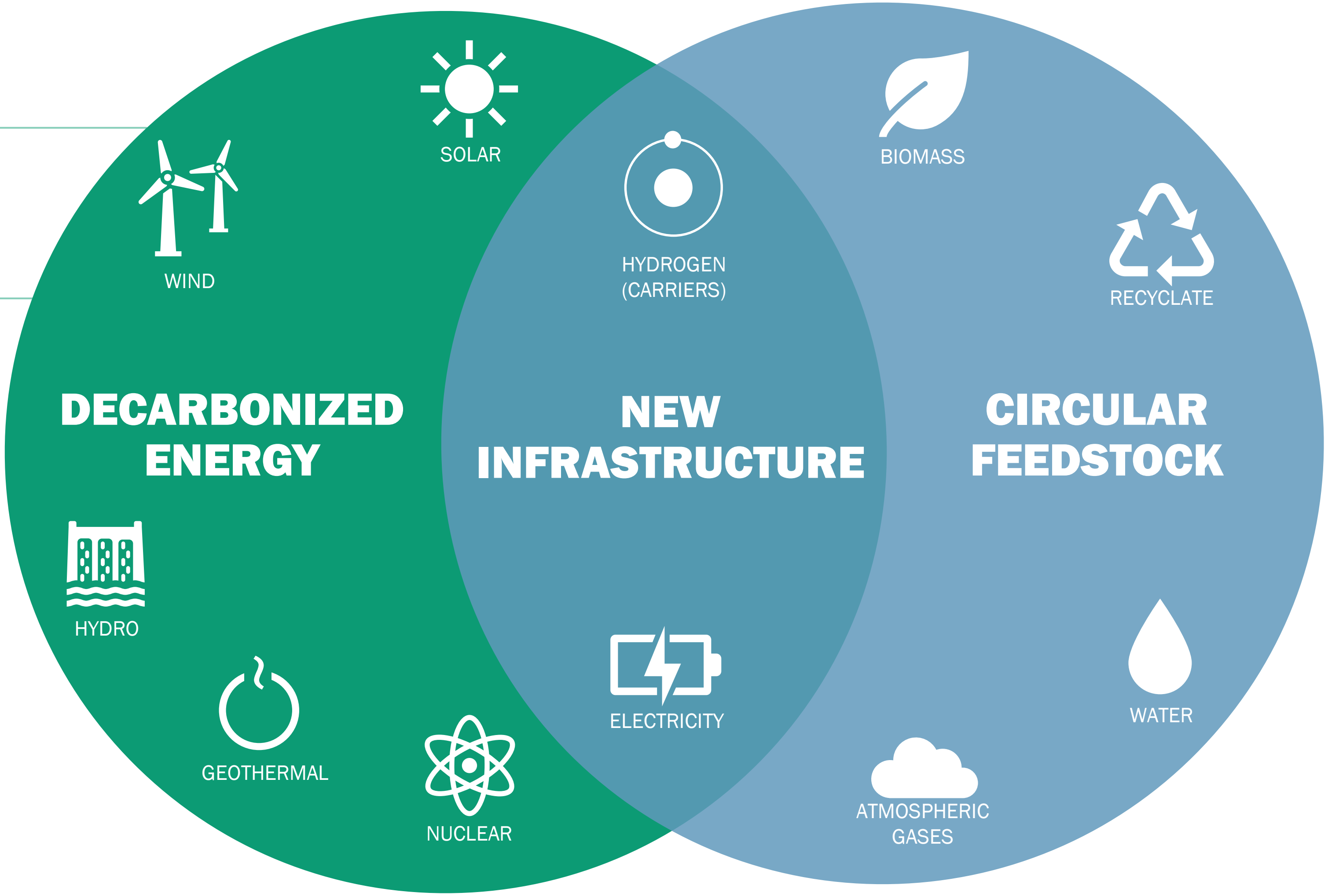


INDUSTRIAL TRANSFORMATION

A 2050 VISION FOR EUROPEAN PROCESS INDUSTRIES

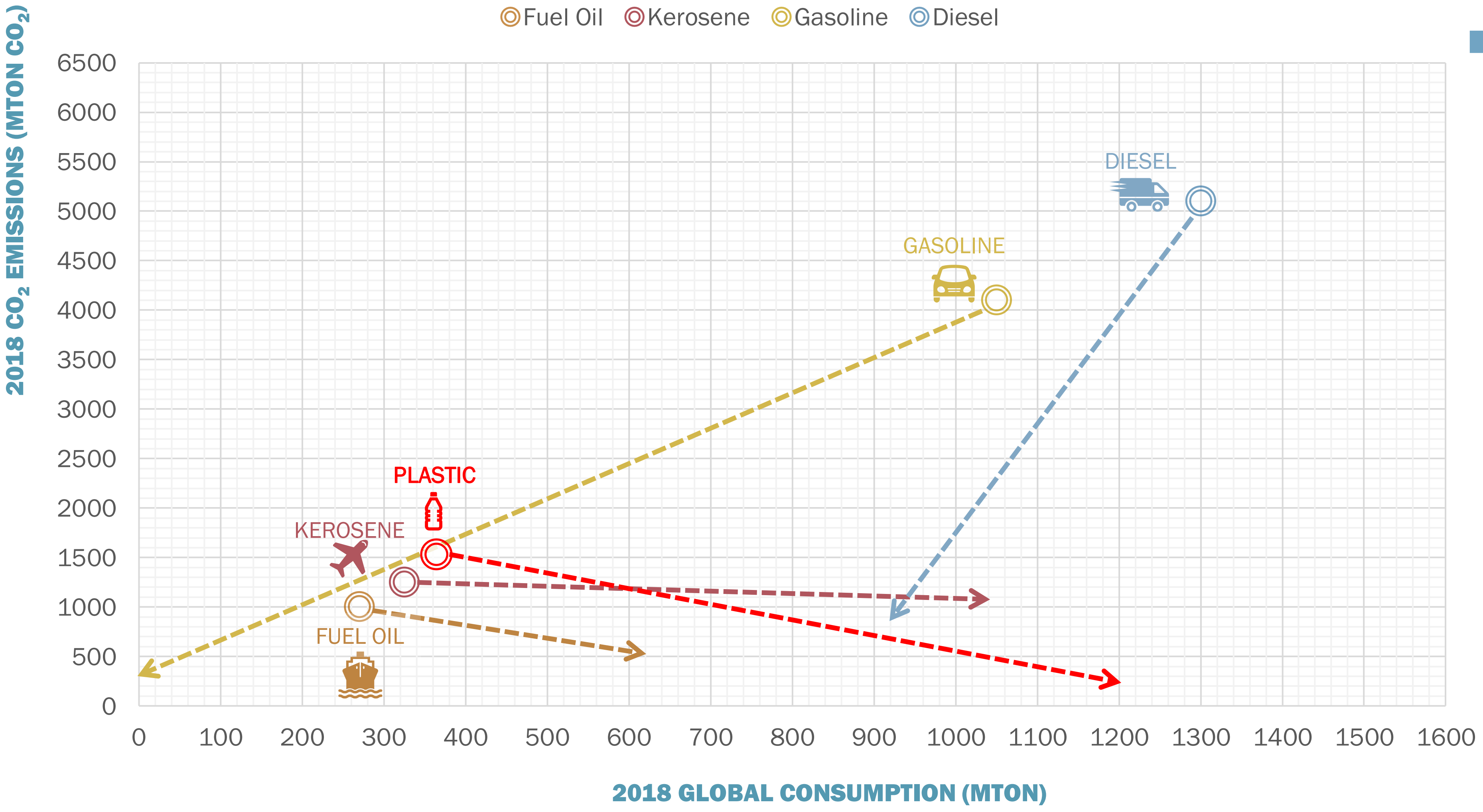
KEY TAKE AWAYS

INDUSTRIAL TRANSFORMATION



WHAT WILL NEED TO HAPPEN GOING TO NET ZERO BY 2050?

GLOBAL GHG EMISSIONS OF TRANSPORTATION AND PLASTICS 2018 TO 2050



Refineries will shift their output from **80/20** in 2018 to **20/80** by 2050 (Fuels/Feedstocks ratio)

CARS: 2018→2050
100% electric

AVIATION: 2018→2050
25% bio-fuel, 75% e-fuel

TRUCKS: 2018→2050
70% electric, 20% bio-fuel, 10% e-fuel

PLASTICS: 2018→2050
Recycling (63%) + CCU (26%) + bio-feedstock (11%)

SHIPPING: 2018→2050
50% bio-fuel + 50% e-fuel

KEY TAKE-AWAYS

INDUSTRIAL TRANSFORMATION AND CONSEQUENCES FOR STORAGE AND TRANSPORT IN THE EU

A The Transformation of the EU Process Industry to Net Zero will be driven by the EU Green Deal.

B Related risks and opportunities for the Piping Industry:

1. **Decarbonized Energy**: Electrification is a highly efficient decarbonization pathway
   - Substantial oil and gas volumes will be replaced by direct electrification and electricity storage
   - Seasonal electricity storage is still a big challenge, a.o. expected to be covered by hydrogen (carriers)
2. **New infrastructure** : Bridging the energy- and feedstock transition
   - Huge expansion of power grids and batteries
   - Transport and storage infrastructure for hydrogen, methanol, ammonia and carbon dioxide (CCUS)
3. **Feedstock transition**: Required to go circular and reduce scope 3 emissions
   - Fossil feedstocks will be phased out and replaced by circular feedstocks such as plastic waste, biomass, carbon dioxide and metals required for massive electrification

C Industrial piping and storage infrastructure will have to be gradually adjusted from oil and gas to hydrogen, carbon dioxide, ammonia and methanol


Q&A


THANK YOU FOR
YOUR TIME
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