A Charcoal Sketch of the Energy System

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Smart Energy Academy 15-11-2021

The world is changing …

1990

5.3 Billion

1990

8 000 MTOE/year

1990

22,4 $btCO_2$/year

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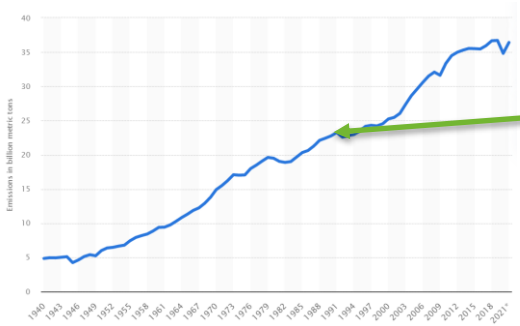
The world is changing …

1990	2050
5.3 Billion	9.7 Billion

1990	2050
8 000 MTOE/year	21 000 MTOE/year

1990	2050
22,4 $btCO_2$/year	0 $btCO_2$/year



CO_2

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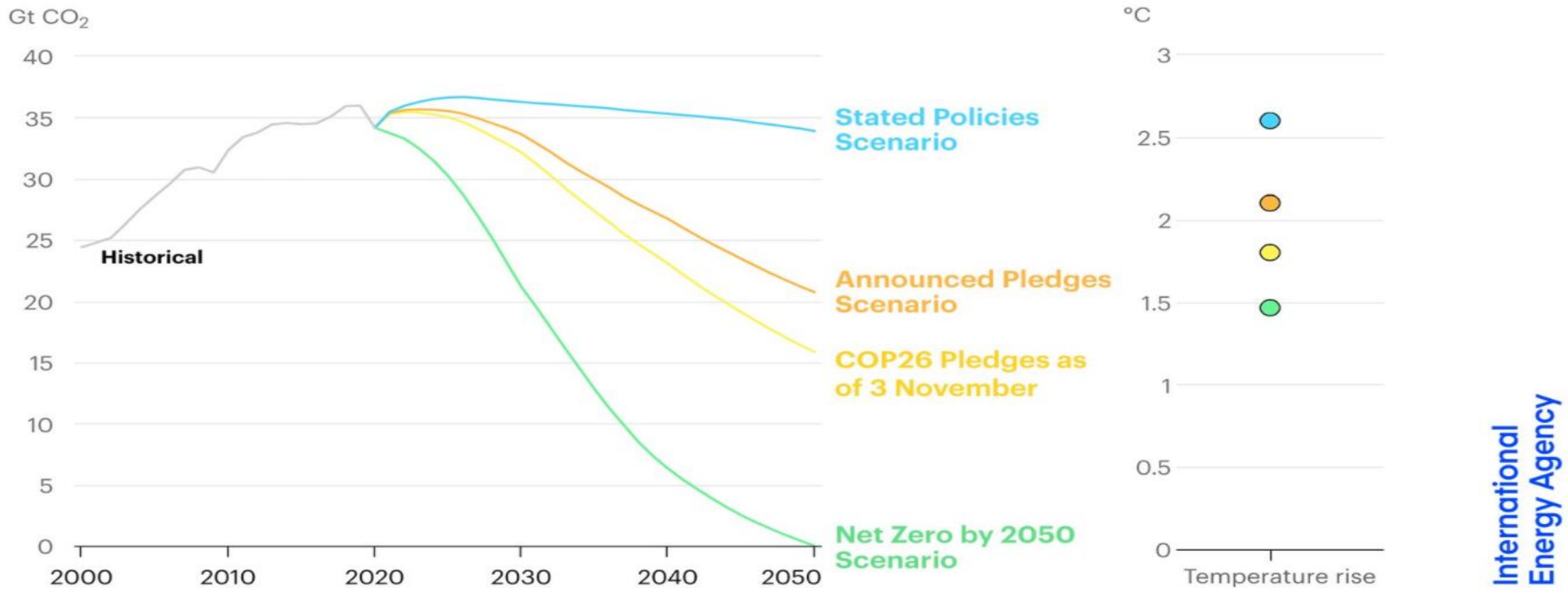
The climate is changing too.... what is needed for what goal?

CO_2 emissions in World Energy Outlook scenarios from 2000-2050 and the corresponding rise in global temperatures in 2100



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What does a global net-zero energy system look like?

- Views from industry, policymakers and researchers are slowly but surely converging – the contours of a sustainable energy system are emerging.
- We will look at four sectors:
  - Mobility
  - Industry
  - Buildings
  - Electric power sector

> 90% of domestic, energy-related CO_2 emissions in the EU in 2020*

- including their interactions and the specific roles of electricity and hydrogen
- Focus on Europe, main messages are valid for rest of the world

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*Source: EU Reference scenario 2020

Energy Sectors: what will happen, how will they interact?

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Mobility

Mobility

- Electrification of (almost) everything
- From vehicles with a battery to batteries that are also vehicles
- Molecules for long-distance flights and marine shipping, based on green H_2

Industry

Buildings

Electricity

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Mobility

>30% of energy-related emissions in 2020

- Transporting people: reduced growth of number of person-kilometres per year
  - Proper policies & spatial planning, *15 minute city*
  - Modal shift: Walking – Biking – Public Transport – Cars, high speed train – short-haul flights
  - Ridesharing, continued working-from-home, self-driving vehicles,…
- Transporting goods: growth of number of ton-kilometers per year
- Electrification is almost always the more efficient route … keeping growth in energy demand in check:
  - Commercial: cars, light-duty vehicles, buses
  - Developing: heavy-duty vehicles, inland ship transport, ferries, leisure
  - Early-stage: short-haul aviation
- **Electric vehicles have a large flexibility potential for power sector (smart charging, vehicle-to-home, vehicle-to-office, vehicle-to-grid)**
- Exceptions: long-haul aviation and long-distance shipping → synthetic fuels based on carbon-neutral hydrogen needed
  - This is already a lot of hydrogen: about 200 Mton in 2050, needing about half of the electricity produced today worldwide

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Electricity

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Buildings

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Industry

Buildings

- Deep renovation
- Electrification
- Local power production
- Energy storage, heat and electricity
- Energy Management

Electricity

Buildings and Districts

>13% of energy-related emissions in 2020

- Most technologies are available, but millions of decision makers and big investments needed.
  - Financial as well as policy innovations as important as technological innovations
- Necessary measures
  - Design and use low-embedded-energy materials for new-built houses and renovation projects
  - Deep renovation for all existing buildings (which will be about 80% of the building stock in 2050)
    - Insulation
    - Balanced ventilation with heat recovery
    - Low-temperature heat emission systems
  - Sustainable heating and cooling sources
    - Heat pumps
    - Heat networks, fed by residual heat from industry, heat pumps, geothermal sources; 5th generation heat and cooling networks
- Rooftop and facade-integrated PV in buildings; urban integration PV (infrastructure, parkings, etc..)
- Energy Storage in buildings & (heating) networks
  - Electricity and Heat
- **Digital Control to deliver flexibility to power sector**

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Industry

- Electrification of (almost) everything
- Flexibilization of processes
- Molecules based on green H_2 for
  - Steel and fertilizer production
  - Chemical industry
  - Chemical recycling of plastics

Buildings

- Deep renovation
- Electrification
- Local power production
- Energy storage, heat and elect
- Energy Management

Electricity

Industry

14% of energy-related emissions in 2020

- Electrification (make it flexible!)
  - Heat pumps (process heat up to 200 degrees)
  - Electric steam boilers (replacing natural gas boilers for steam production)
  - Electric furnaces (high-temperature process heat)
- Hydrogen
  - Reduction of iron ore in steel making
  - Methanol as basic building block for chemical industry
  - Ammonia as source for fertilizer production
  - Chemical recycling of plastics
  - (hydrogen need for oil-based refineries will disappear…)
- Disruptive innovations to avoid process emissions and/or CCS/U for residual (process) emissions (e.g., in cement sector)

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Electricity

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Electricity

- Doubling to tripling of demand
- Dominated by variable renewable energy sources; a few “stable CO_2-free plants”
- Flexibility crucial
- Low-cost H2-based plants for windless winter weeks

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Electricity

31% of energy-related emissions in 2020

- *Demand* - Electricity consumption increases by factor 2+ due to electrification of land transport, heating/cooling and industrial processes
  - Hydrogen production by electrolysis might be added, but has to compete with hydrogen import
- *Generation* - Bulk production by (variable) renewables, mainly solar and wind, complemented with hydro and (remaining but declining) nuclear. Maybe in longer term new nuclear or geothermal plants
- *Flexibility* – short & long-term flexibility, activated demand side (residential, industrial,…) & dedicated resources (energy storage)
- *Resource adequacy* - back-up power plants to cover large seasonal differences in RES availability ("Dunkelflaute")
  - **Low-capital cost generators** needed (e.g. like current gas-fired power plants)
  - Hydrogen-derived fuels or complemented with CCS & negative emission technologies.
  - Amount of adequacy capacity needed, depends on rest of resource mix, level of interconnection, ….
  - Capacity remuneration (auction) as a market mechanism
- *Networks* – **strong transmission backbone (meshed HVDC wind energy islands at sea + at land)**, upgraded distribution networks & active network management; possibly nano-DC networks

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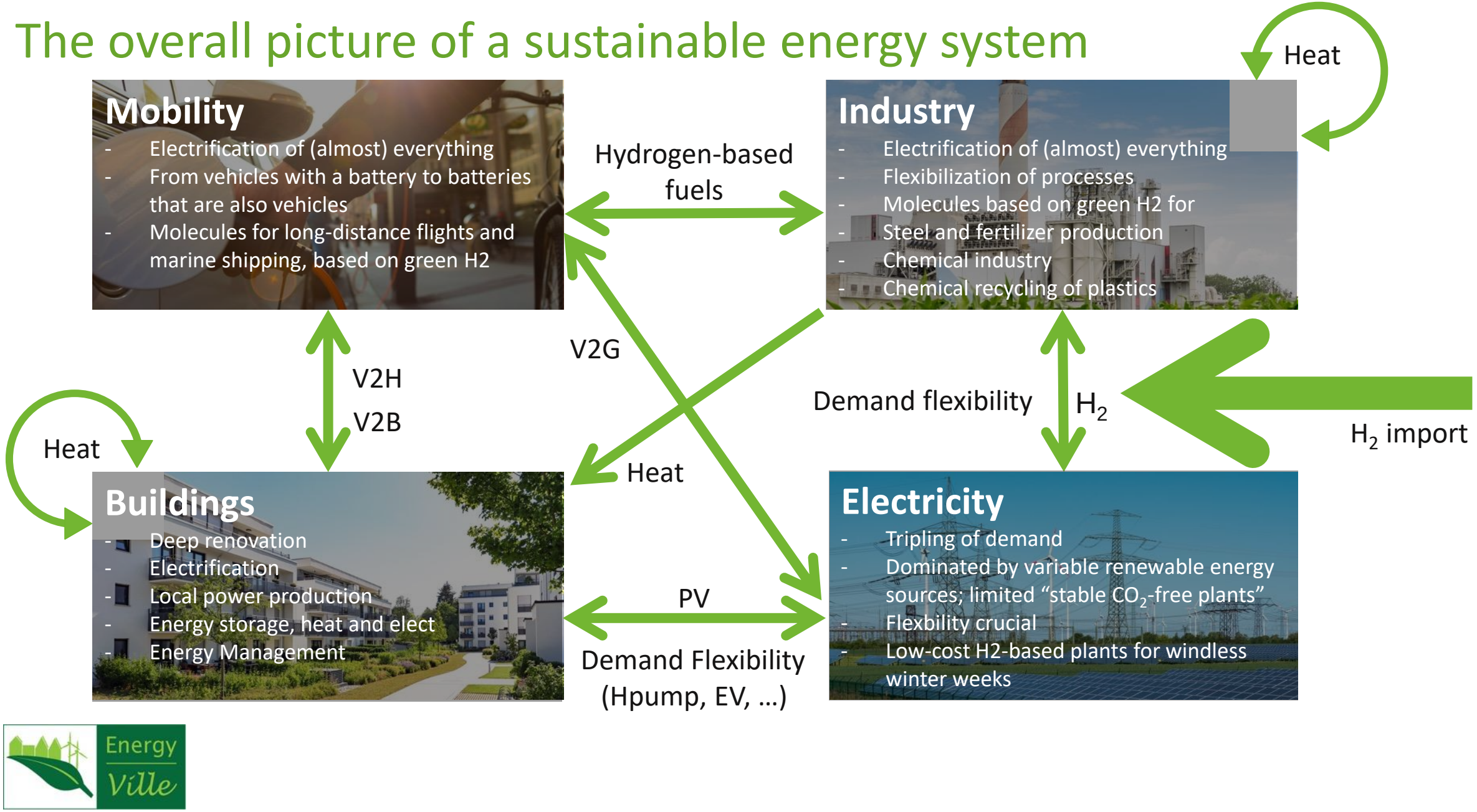
*Source: EU Reference scenario 2020

The overall picture of a sustainable energy system



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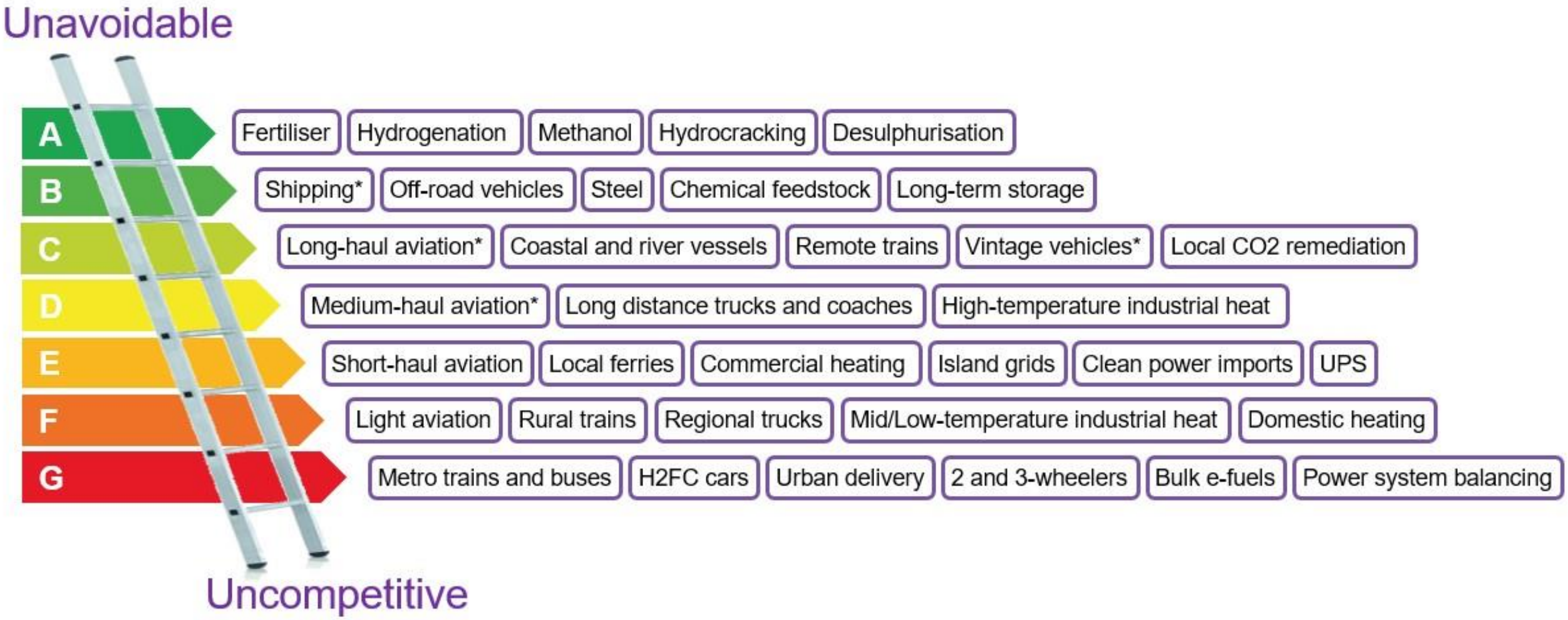
What about hydrogen?

*Source: EU Hydrogen Strategy 2020

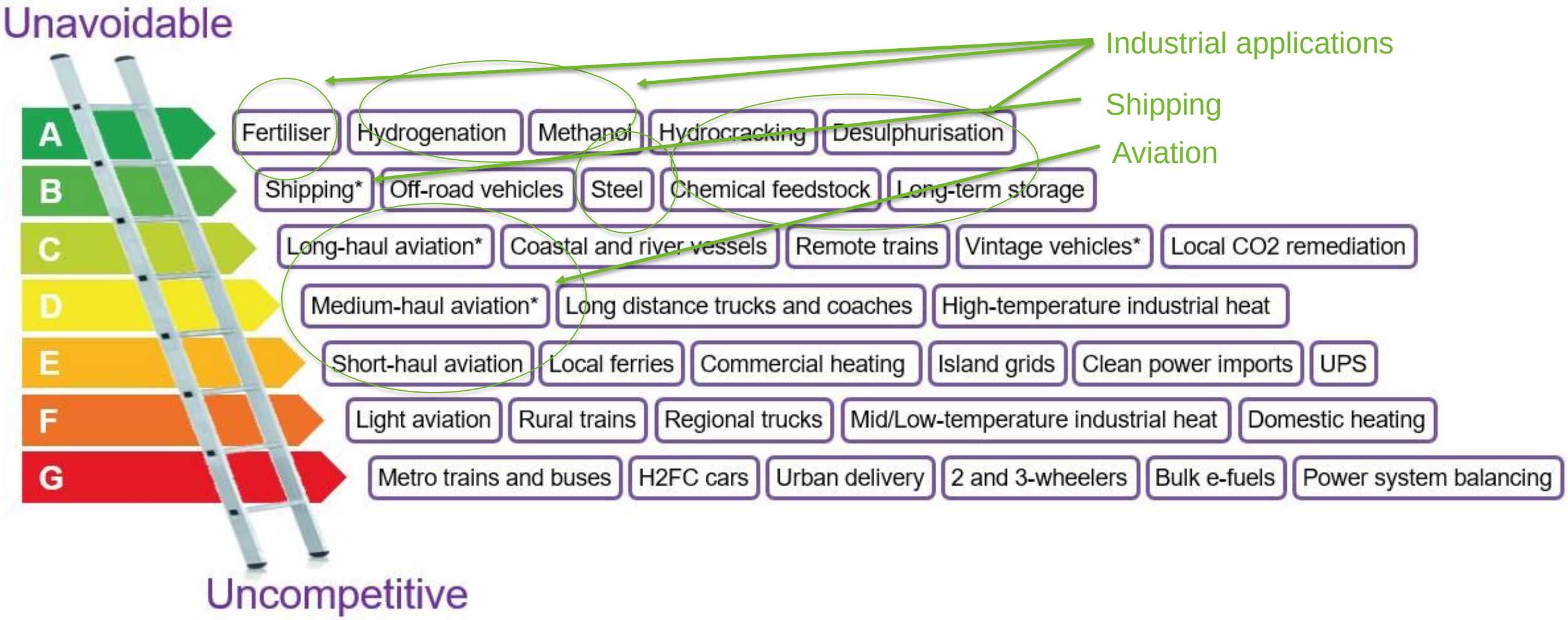
Hydrogen Ladder



** Via ammonia or e-fuel rather than H2 gas or liquid*

Source: Liebreich Associates (concept credit: Adrian Hiel/Energy Cities)

Hydrogen Ladder



** Via ammonia or e-fuel rather than H2 gas or liquid*

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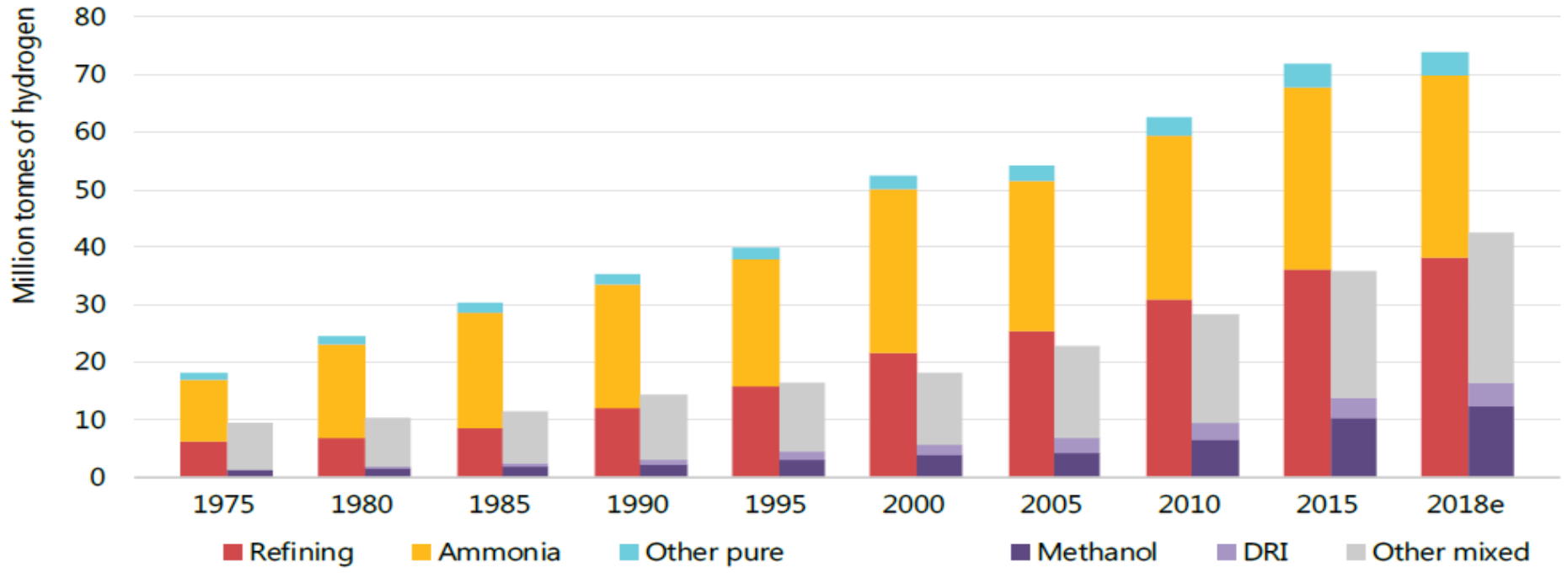
Global demand for all hydrogen (source IEA 2019) (industrial)

Figure 1. Global annual demand for hydrogen since 1975



Notes: DRI = direct reduced iron steel production. Refining, ammonia and "other pure" represent demand for specific applications that require hydrogen with only small levels of additives or contaminants tolerated. Methanol, DRI and "other mixed" represent demand for applications that use hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock.

Around 70 MtH_2/yr is used today in pure form, mostly for oil refining and ammonia manufacture for fertilisers; a further 45 MtH_2 is used in industry without prior separation from other gases.

Estimated global hydrogen need in 2050

Only unavoidable applications: together 350 - 400 Mton

- Industrial applications
  - Currently 125 Mton; trend is about 1.5 to 2 Mton per year in addition (where refineries are replaced by steel and recycling of plastics -> estimate 2050 = **175 Mton hydrogen**
- Shipping
  - According to DNV-GL 11 EJ or 270 Mtoe in 2050
  - Suppose replaced by ammonia: about 530 Mton ammonia
  - 17,6% of ammonia (3xHx1 / (1xNx14 + 3xHx1)) is hydrogen -> **95 Mton hydrogen**
- Aviation
  - According to IATA 700 billion liter kerosine => 560 Mton kerosin
  - 15,3% of kerosine (26xHx1 / (12xCx12 + 26xHx1)) is hydrogen => **90 Mton hydrogen**

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How much green electricity is needed to produce this?

- Minimally needed….: **350-400 Mton in 2050**
  - **20.000 – 25.000 TWh green electricity is needed** (dependent on losses along the value chain) (50-60 kWh/kg H2)
- **Current global power production ≈ 27.000 TWh (2019)**
- There are many hydrogen scenarios up till 2050. They go up to **800 Mton** green hydrogen (Bloomberg New Energy Finance Green Scenario), **which would need 40.000 – 50.000 TWh**
- Main conclusion: avoid hydrogen where and if possible. We will need already massive amounts for the hard-to-abate sectors.

Thank you for your attention!

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