MID-CENTURY STRATEGY FOR THE EU

Projections based on the PRIMES model

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The EU has already defined ambitious targets for 2020, 2030, 2050…

2020

20% reduction GHG emissions wrt 1990

20% of RES in energy consumption

20% reduction in primary energy consumption compared to a baseline projection;

and has implemented a comprehensive legislative package including mandatory obligations by Member-State for renewables, energy efficiency, ETS and non-ETS, as well as eco-design standards for appliances and CO2 standards for vehicles.

2030 (Clean Energy for all Europeans)

32% or RES in gross final energy consumption

32.5% reduction in primary energy consumption compared to a baseline projection

45-46% reduction in GHG emissions

The EU also started implementation of a Market Stability Reserve for the ETS which has already pushed carbon prices significantly upwards in 2018

2050 – Mid Century Strategy policy proposal by the EC, forthcoming end 2018

80-95% reduction in GHG emissions wrt 1990 in the EU as a whole; for the transport sector, at least, -60%.

The Target

In 2050, 1100 Mt GHG (-80% compared to 1990 levels) are consistent with a 2°C trajectory

By 2050, the remaining GHG (in a EUCO scenario) are 58% due to energy, of which:

- 31% in transport
- 20% in stationary use
- Power and heat and energy branch account for 9%

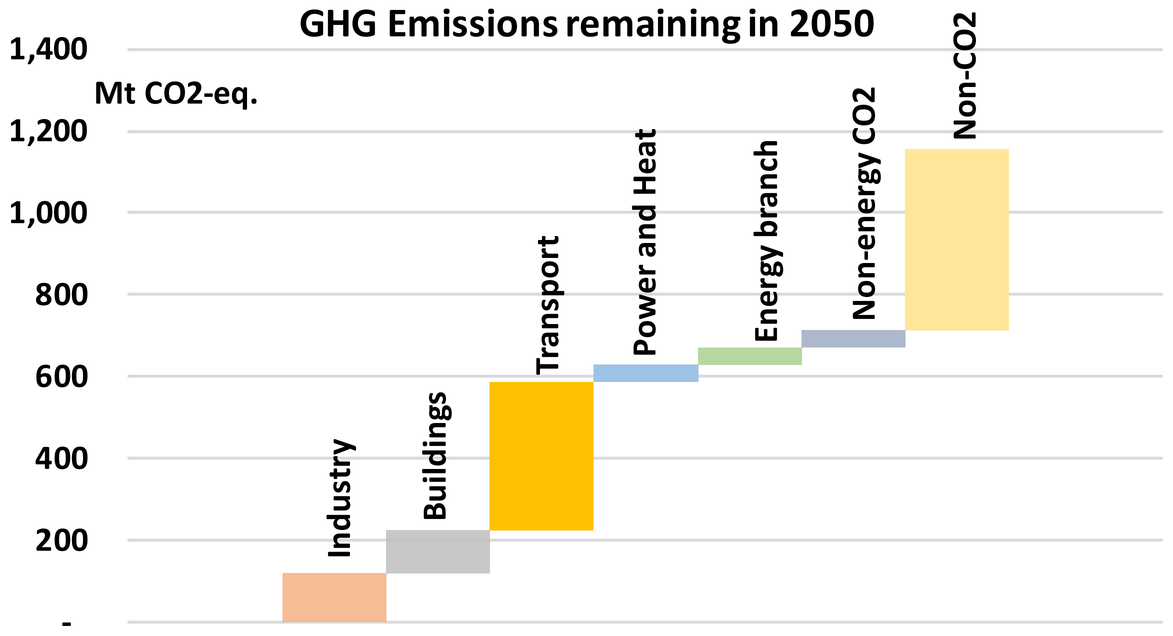
The challenge is to bring emissions close to zero

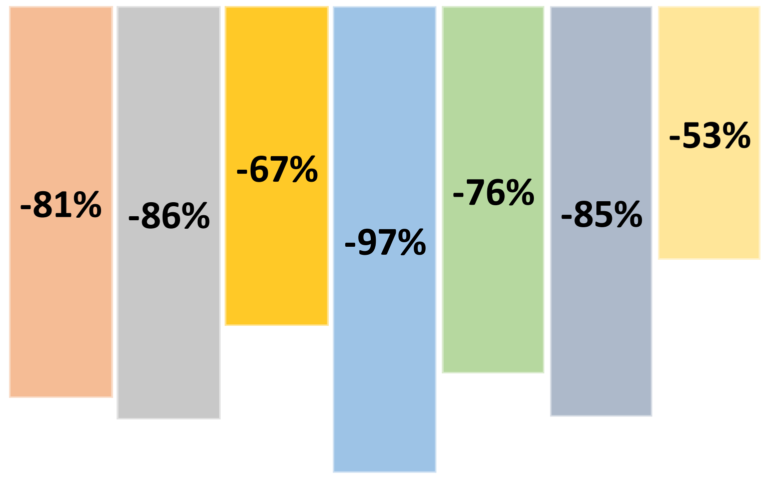
- ~80-85% in 2050 in a 2°C context
- ~92-94% in 2050 in a 1.5°C context

Is it possible?

How? When? At which cost?

Focus on transport: electrification? hydrogen? synthetic fuels?





GHG Emissions reduction 2005-2050

No regret actions

A. **Energy efficiency** effort in buildings, equipment and vehicles

B. **Electrify** transport and heating where cost-efficient, e.g.:
   1. Private transport in urban environments
   2. Heat pump in warmer climates

C. Enhanced renewable power generation
   1. Continue **investment in renewables**
   2. Reliable **integration of renewables** (grids, market integration, storage systems, demand response)

D. Incite final energy users to become pro-active and become clean self-producers (**prosumers**)

E. **Advanced (second-generation) biofuels** produced sustainably

F. Use **nuclear** and geological **storage of CO2** where acceptable

Possible disruptive changes

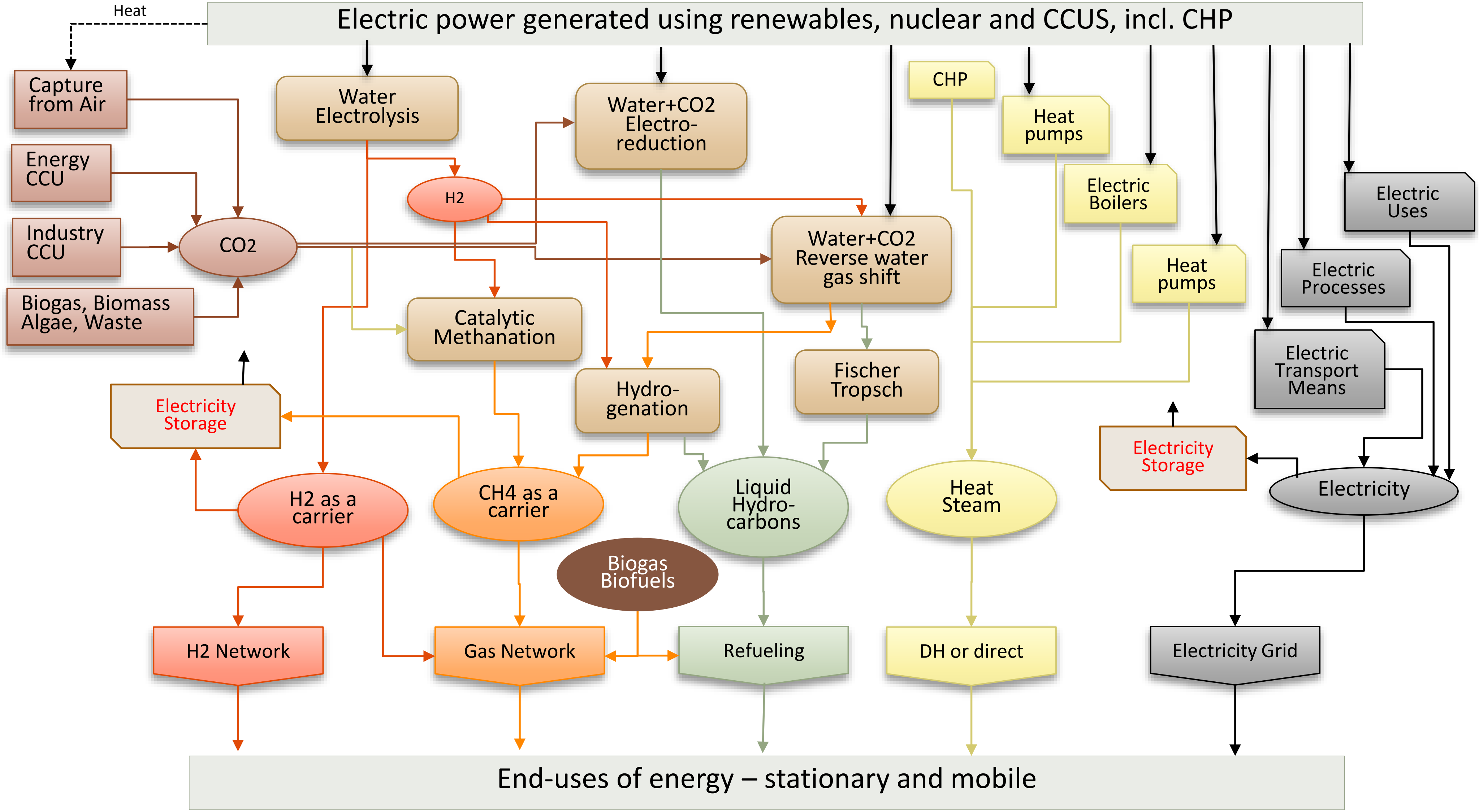
A. Reduce energy demand in all sectors **beyond conventional energy savings**, e.g. circular economy, sharing of vehicles, materials sequestering CO2

B. Changes in the way users **use energy**, e.g. extreme electrification in industry and transport, direct use of distributed hydrogen

C. Changes in the **production and nature of energy commodities**, e.g.:
   i. e.g. mix hydrogen and biogas in gas distribution
   ii. replace fossil gas by renewable gas
   iii. fossil liquids by synthetic fuels (electro-fuels from hydrogen and captured or biogenic CO_2)

D. Use and storage of **CO_2**
   i. establish circuits of CO2 capturing
   ii. use and sequestering in storage areas, materials and/or fuels, e.g. CO2 captured in industrial processes used in ammonia or petrochemicals, replacing reforming of fossil fuels, biomass CCS and CO2 capture from the air

Alternative pathways, indicated by different colors (i.e. H2, e-gas, e-liquids, electrification)



Scenarios meant to deliver near zero CO_2 emissions in 2050 and >80% Renewables

Maximum Electricity

Pros

- High efficiency in end-use
- Convenience-cleanness
- Can be self-produced
- Reliability

Cons

- Not fully applicable in all end-uses
- Almost impossible to have full electric transport
- Lack of competition among energy carriers in retail
- Electricity storage other than chemical are only short term

Clean e-gas and e-liquids

Pros

- Use of existing infrastructure
- Convenience in end-use
- No disruption in transport
- Chemical storage of electricity
- Competition among carriers

Cons

- CO_2 capture from air expensive
- E-fuel technologies expensive
- High end-use price unless very significant learning
- Too high increase of total power generation challenging the potential of resources

Hydrogen as a carrier

Pros

- Can cover all end-uses
- No range issues in transport
- Chemical storage of electricity
- Competition among carriers
- Less expensive than e-fuels
- Less electricity intensive
- Can coexist in gas infrastructure

Cons

- New infrastructure
- Hydrogen storage has difficulties
- Not fully convenient in some energy uses
- Depends on learning success of fuel cells

Max Efficiency & Circular Economy

Pros

- Environment-friendly
- Reduces costs for consumers
- Reduces investment in the supply side
- Low resources in the supply side

Cons

- Depends on investment by individuals
- Depends on disruptive changes in industry
- Uncertain regarding the circular potential
- The reduction of demand discourage investment in supply and slows down technology progress

Hydrogen uses

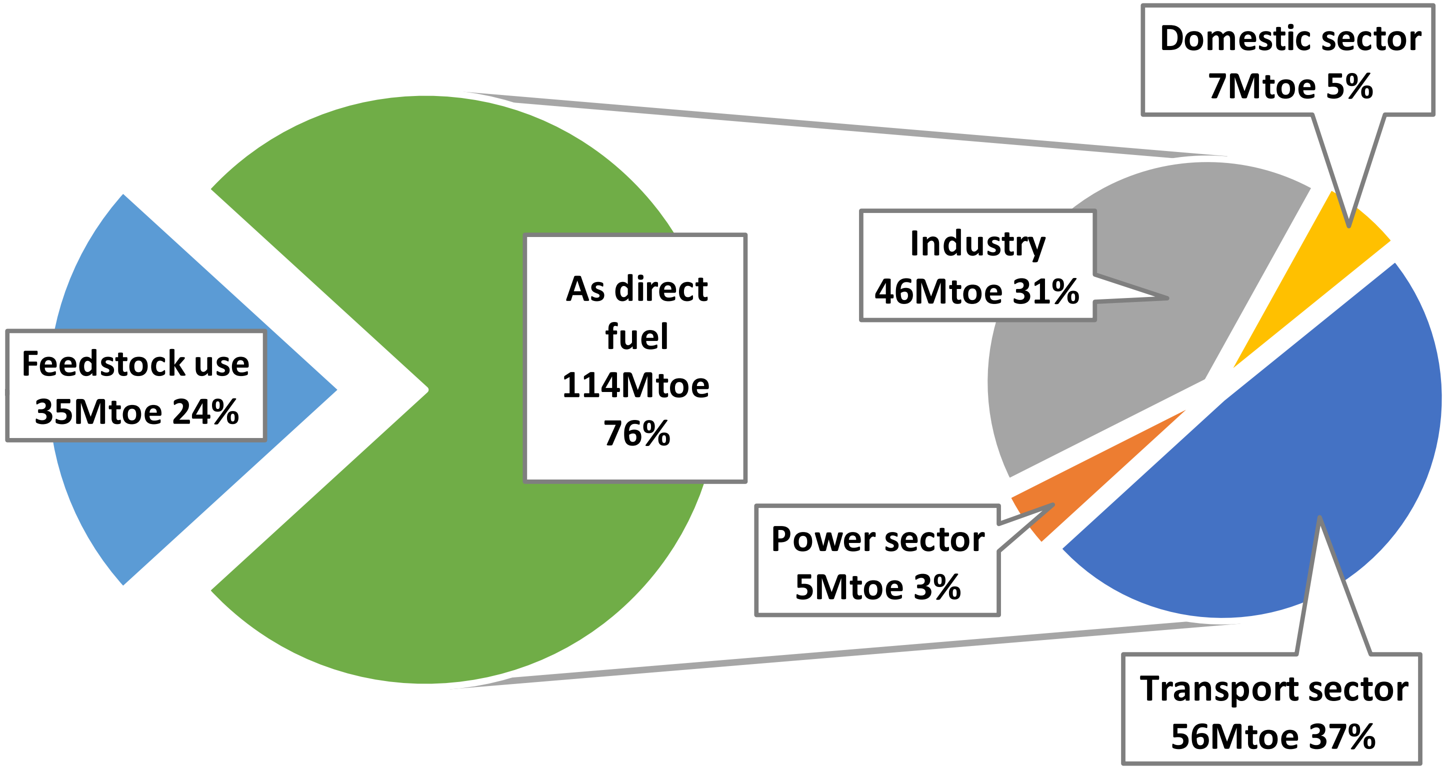
1. Mix up to 15% in gas distribution
2. Use fuel cells using H2 in vehicles that cannot run in batteries, such as trucks, buses, taxis, duty vehicles. Combine with large-scale H2 refueling stations, which may include electrolysis and H2 storage.
3. Use H2 directly in high temperature furnaces in industry combined with local electrolysis and storage
4. Produce clean methane in methanation plants using CO2 captured from air, integrated in power utility facilities well interconnected. H2 produced in these locations also serve electricity storage.

Basic Changes

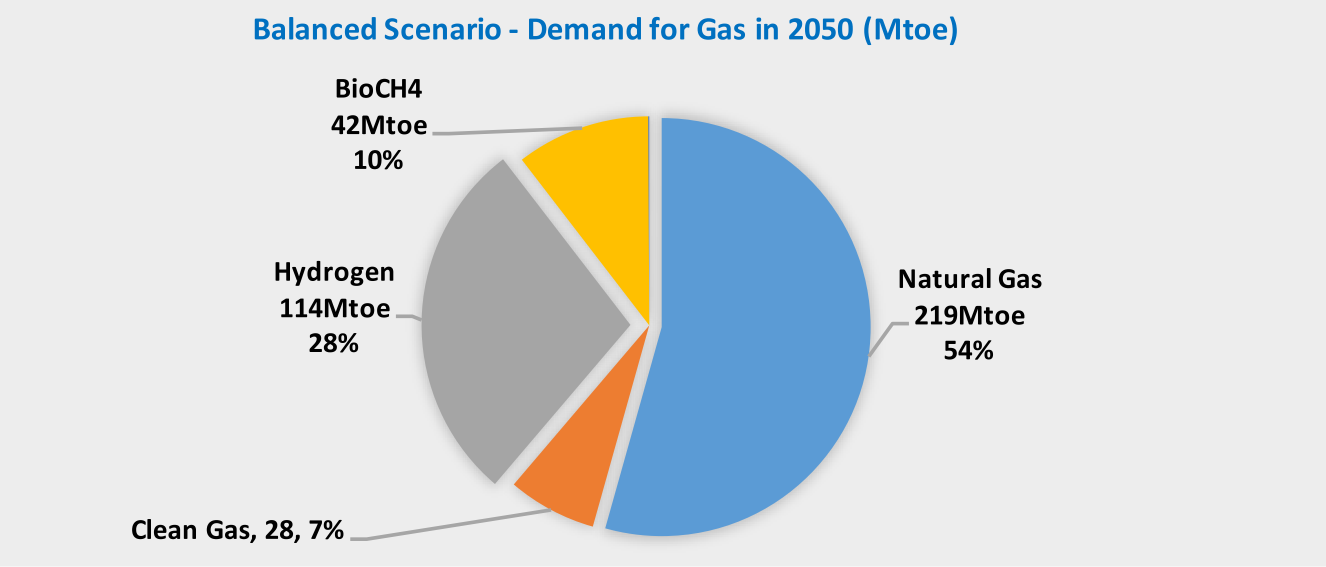
1. Full decarbonisation of the power generation using maximum contribution by RES, dispersed and centralized, complemented by nuclear and CCS where possible. Direct storage and chemical storage, as well as interconnections, succeed to balance the RES.
2. Maximum possible potential of energy efficiency in buildings and industry
3. Electrify car mobility and heating in a large segment of the markets
4. Advanced sustainable biomass feedstock to produce fungible jet fuels and ship fuel, as well as bio-methane mixed in the gas grid

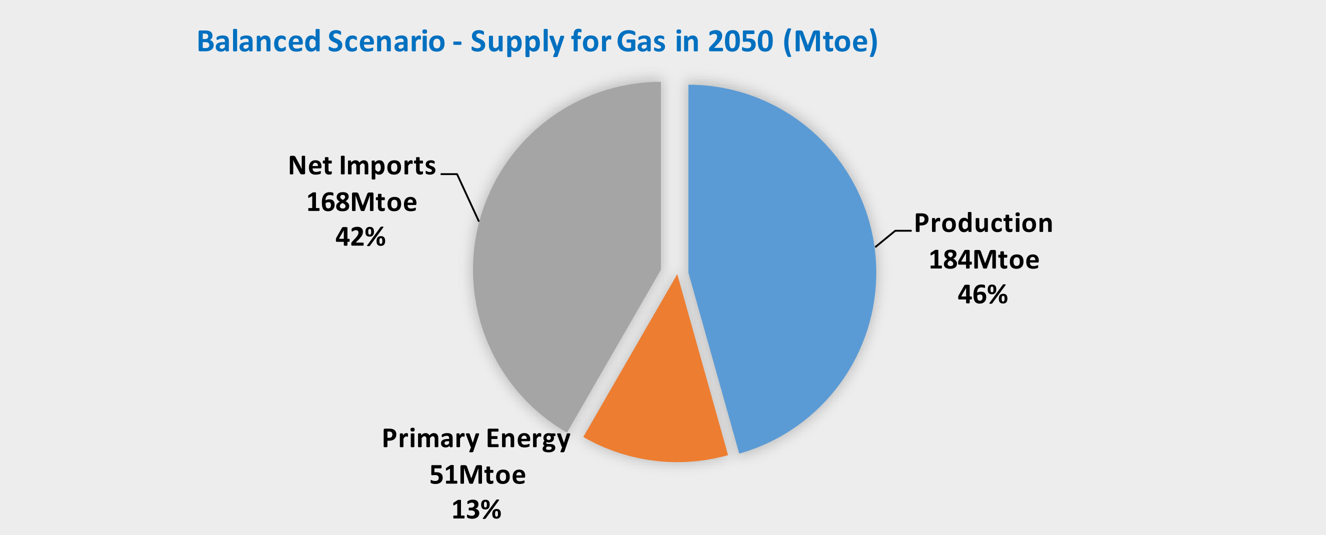
A. Used directly in final consumption (3/4 of total)
   - 15% mixed in gas distribution
   - Directly in high temperature furnaces in industry
   - In transport via fuel cells
B. Used directly in power generation to perform electricity storage (chemical storage)
C. As a feedstock (1/4 of total) to produce clean methane (CH4), which is mixed in gas distribution and is used in the power sector for electricity storage

Balanced scenario in 2050



- Natural gas (fossil) covers only 54% of a total of 404Mtoe consumption of gaseous fuels in 2050
- Natural gas is roughly the only remaining fossil in the system, being used in the power balancing and mostly in CCGT-CCS plants
- Methanation and bio-energy plants produce 184Mtoe (45% of total gaseous)
- Tremendous independence from natural gas imports by 2050



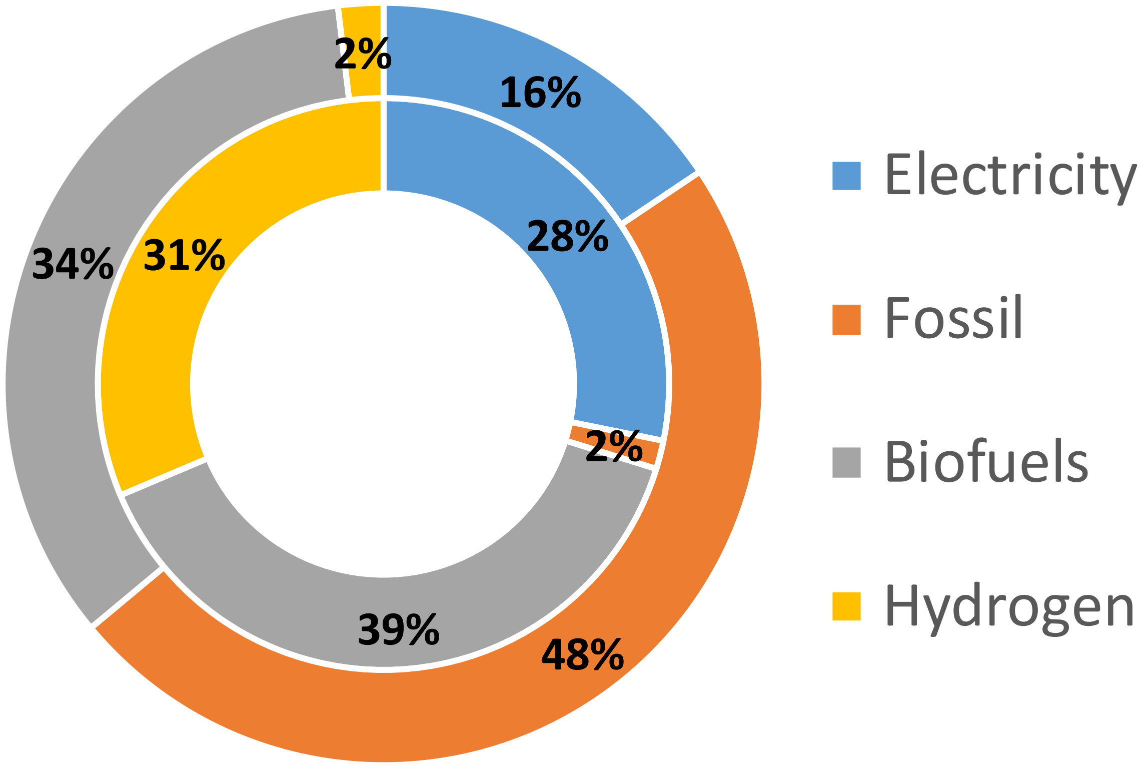


Fuel mix in transport in 2050

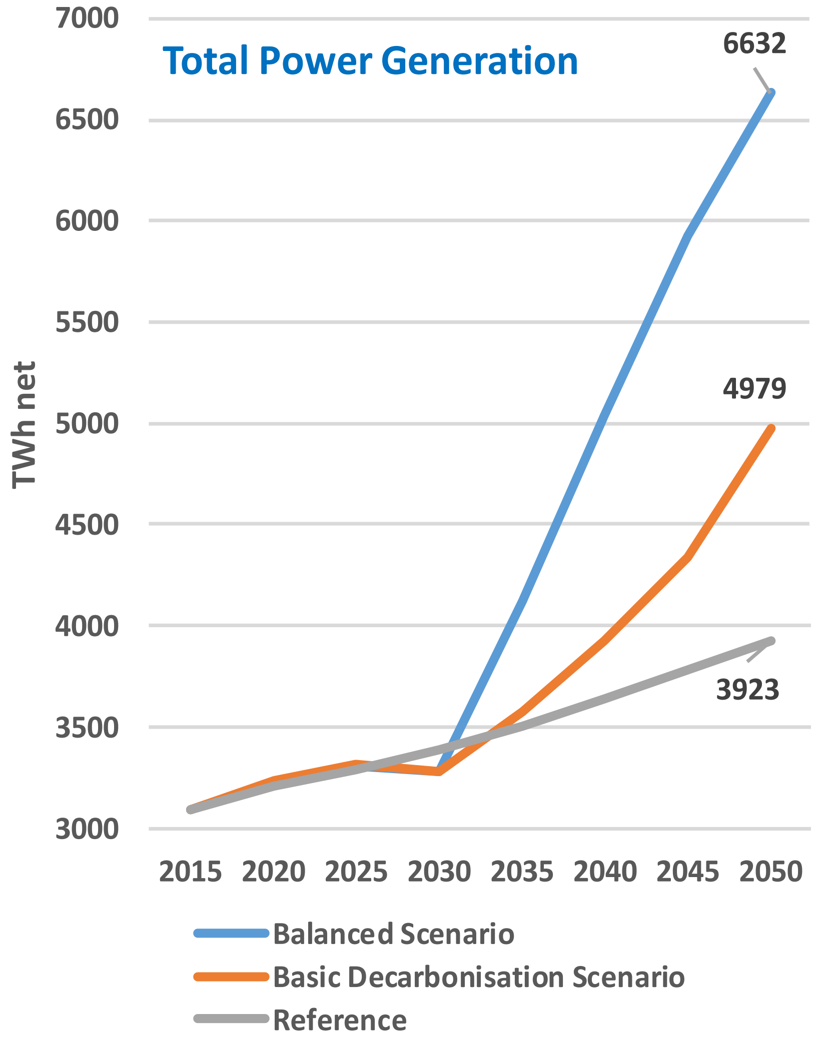
In the balanced scenario:

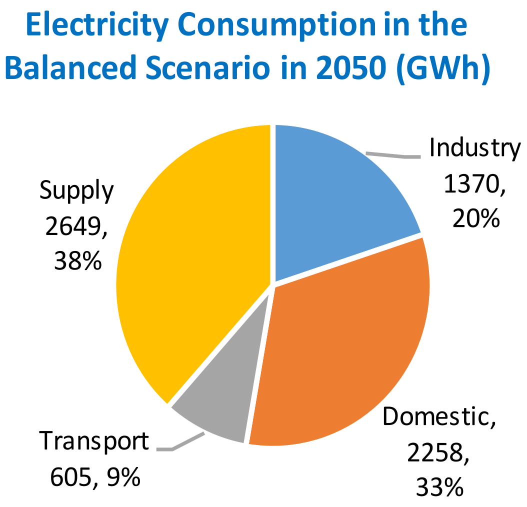
- Almost no fossil fuels
- Complementary market segments for battery and fuel-cell vehicles
  - Battery-charged cars in cities and short-medium distance trips
  - Fuel cells heavy duty vehicles and cars with high mileage
- Lower total amounts of biofuels than in the basic decarbonisation scenario
  - The fuel cells move biofuels from trucks to aircrafts and ships
- Optimistic learning assumptions, both for batteries and fuel cells, allow for full substitution of fossil fuels in the car market at lower total cost, compared to the basic decarbonisation scenario

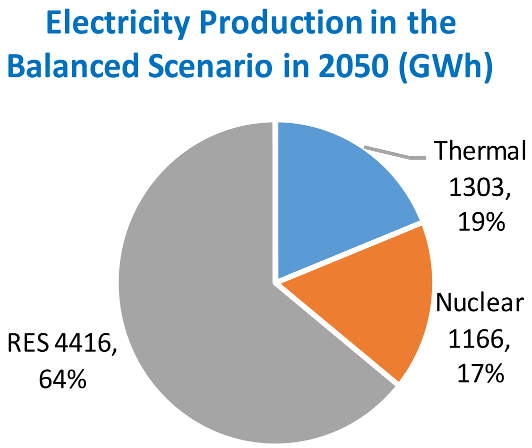
outer cycle: basic decarbonisation scenario
inner cycle: balanced scenario



- Hydrogen and clean gas from electricity requires a large scale and a non-interrupted supply of electricity to become cost-efficient
- RES from different origins, with complementary production profiles and nuclear are an optimum input portfolio
- Large scale interconnections, full completion of the internal market and optimum location of large-scale power-to-X factories
- The power sector thus combines dispersed generation (prosumers) and a centralized generation segment over a mesh grid







Issues for discussion – Strategic aspects

1. Central role of electricity including electrification in heating and road transport, but difficulty to electrify further as the required technologies are uncertain (e.g. high temperature heat pumps, electric long-haul trucks, aircrafts, ships, etc.)?
2. Significant increase in power generation (mainly from RES) is necessary to replace fossil fuels by GHG-free fuels, as they are electricity-intensive. However, using hydrogen in final demand implies a relatively smaller increase in power generation than for the e-fuels
3. No-regret option to enhance energy efficiency (renovation of buildings, advanced appliances, heat recovery in industry, highly efficient transport) but uncertainty surrounds further advancements, such as the circular economy, zero-energy buildings everywhere, new chemical materials and transport system restructuring
4. Self-production using RES by consumers, demand response and intelligent systems are no-regret developments.
5. However, in addition, hydrogen and e-fuels can become affordable only if they reach large economies of scale. Their role is also crucial as chemical storage techniques, with versatility that is essential to complement batteries, hydro-pumping and others.

Issues for discussion – Technology aspects

- Competition between e-gas and e-liquids:
  - E-gas can emerge as an robust solution for long-haul road freight
  - The scaling of certain technologies (small scale liquefaction and regasification) is key for the competiveness of e-gas
  - E-liquids technologies have a high potential for highly valued chemicals and as fuels have the advantage of maintaining the status-quo in the structure of transports
- Hydrogen as an energy carrier
  - Practicality of widespread use of hydrogen use is promising but questionable because of
    - Public concern about safety in residential areas
    - Distribution requires an update of the whole distribution network – inconvenient
    - Replacement of equipment at he end-user level
- How should the clean fuels be produced?
  - Green vs blue hydrogen:
    - Electrolysis: Proven but expensive but with high potential of economies of scale, costs highly depending on electricity prices
    - Steam natural gas reforming & CCS: Geological storage of CO2 questionable (possible in the North Sea region but refused in the continent), still relying on imported natural gas, low overall efficiency
  - Origin of carbon for the production of e-gas and e-liquids
    - Direct capture form air: Proven but expensive, requires large learning by doing and lower dependence on land
    - Biogenic origin: possible and affordable but it make sense economically only when CO2 captured from biomass burning plants
    - Carbon capture from coal or industrial process plants and re-use for e-fuels: Not carbon neutral, can be seen as a transitional solution, however sequestered in materials (plastics) is carbon neutral.