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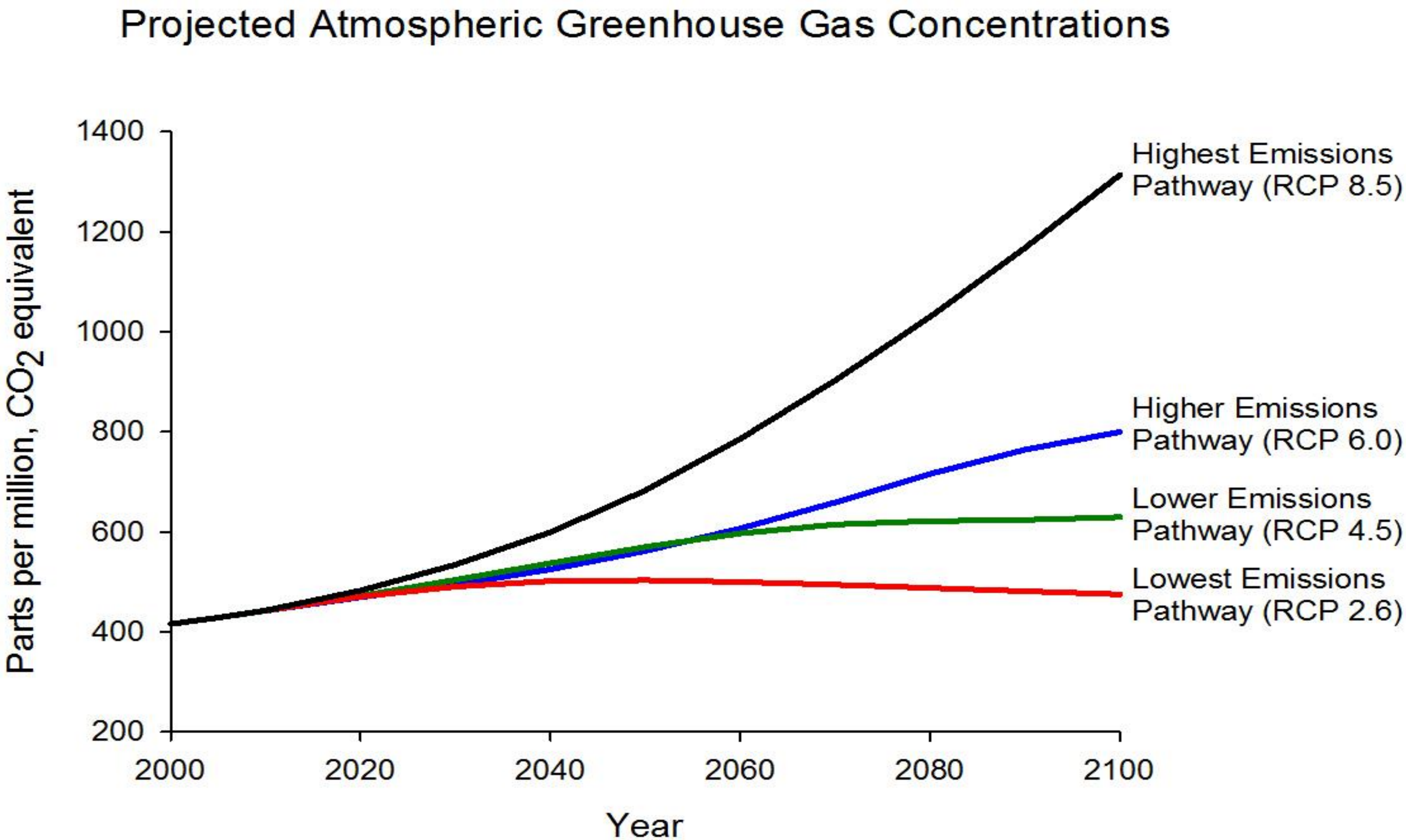

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New technologies for the Mid-century strategy

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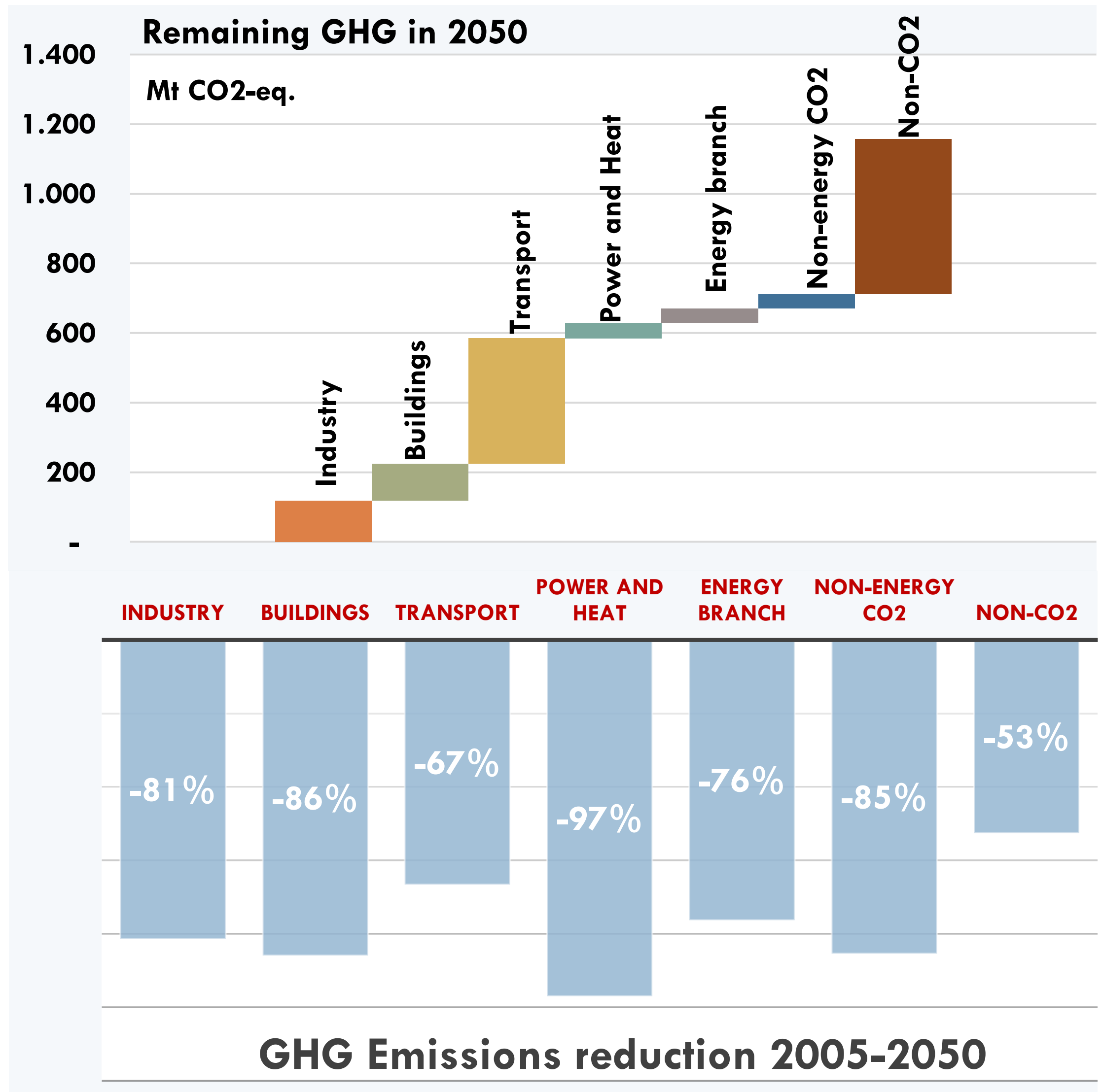
E3MLab, Athens November 2017

Remaining GHG in the basic EU decarbonisation scenario

- The challenge is to bring emissions down to zero or possibly below zero in the OECD
  - Is it possible?
  - In which way?
  - By when?
  - At which cost?
  - Based on which enablers?
- By 2050, the remaining GHG in the EU decarbonisation scenario are:
  - 58% due to energy
  - of which 31% in transport and 20% in stationary uses, energy supply accounting for only 9% of the total GHGs
  - 40% due to non-CO2 emissions
- From 2005 to 2050, the abatement effort is lower in transport and non-CO2, compared to the stationary uses, and higher in the power sector



Conversion of fuels emitting in 2050

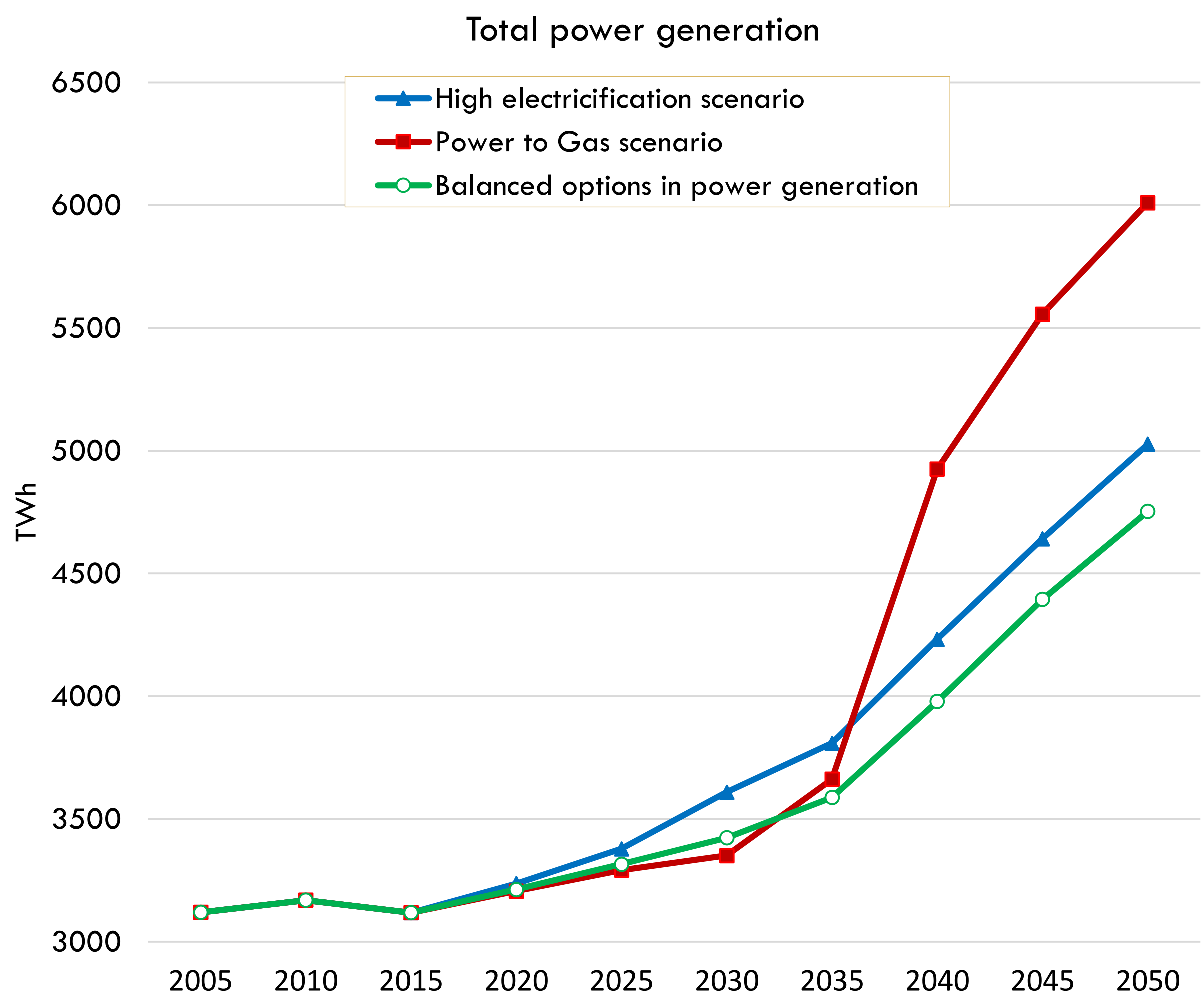
- The EU decarbonisation scenario by 2050, abates potential emissions at 83% of from coal, 43% from liquids and 64% from gas
- The emitting fuels remain mainly in transport (134 Mtoe liquids) and in stationary end-uses (71 Mtoe gas)
- Converting the remaining emitting fuels would require roughly between 30-110% increase of demand for electricity, depending on the technology

Mtoe	Total Solids	Solids in CCS	Total Liquids and transport biofuels	Of which transport biofuels	Total Gas	Of which Clean Gas	Natural Gas in CCS
Industry	1.3		3.2		75.9	37.7	
- rest with emissions	1.3		3.2		38.2		
Buildings	1.2		8.6		75.2	42.3	
- rest with emissions	1.2		8.6		32.9		
Transport	0.0		212.5	99.3	10.5	5.0	
- rest with emissions	0.0		113.2		5.5		
Power and Heat	12.8	12.7	0.3		64.4	13.8	49.0
- rest with emissions	0.1		0.3		1.6		
Energy Branch	0.1		8.8		7.3	1.3	
- rest with emissions	0.1		8.8		6.0		
Total energy system	15.4	12.7	233.3	99.3	233.2	100.0	49.0
- rest with emissions	2.7		134.0		84.2		
Electricity consumption to reach zero emissions (rough estimation)							
A. Substitution by electricity	2.4		53.6		38.3		
B. Clean fuels from electricity	3.8		268.1		120.3		
C. H2 from electricity	3.3		167.5		105.3		

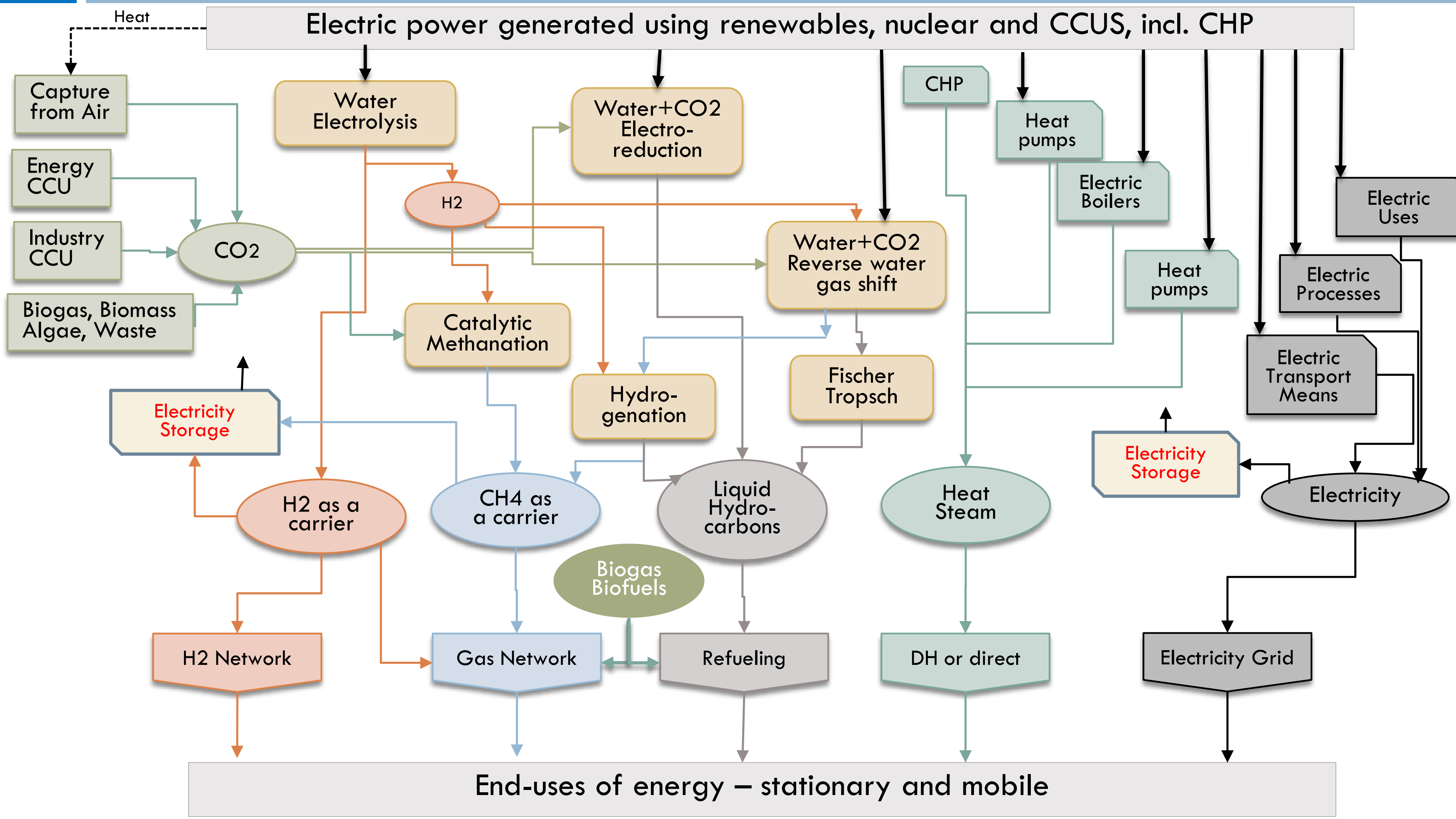
% increase of electricity demand compared to the basic EU decarbonisation scenario	
A. Substitution by electricity	26%
B. Clean fuels from electricity	110%
C. H2 from electricity	78%

Illustration using PRIMES model

- The graphic illustrates the impact of power-to-gas (red line) on demand for electricity, compared to intense electrification (blue line)
- In this older exercise
  - The old exercise assumed only 80% GHG emission reduction in 2050
  - The H2-economy option has not been included
  - The balanced power case has assumed significant contribution of nuclear and CCS



A process flow diagram



Three stylized scenarios

- Start from the EU decarbonisation scenario
- Use the new PRIMES model version extended up to 2070
- All three stylized scenarios aim at eliminating all energy related emissions in the period 2050-2060 (to specify) and verify sustainability of zero emissions until 2070
- All three stylized scenarios include policies, trends and technologies in addition to those deployed in the EU decarbonisation scenario (renewables, energy efficiency, e-mobility, advanced biofuels)
- Assume technology success and adequate policy enablers, differently per scenario

A. Enhanced electrification
   - Maximum possible electrification of transport means and heat processes in stationary energy uses
   - Apply power-to-H2 and power-to-gas at a relatively limited extent mainly for storage purposes
   - Maximum possible use of biofuels and biogas

B. Clean synthetic fuels
   - Expand electrification and biofuels/biogas more than in the EU basic decarbonisation scenario but where reasonably possible
   - Complex Power-to-X (X: H2, gas, liquids, heat) factories develop to supply clean synthetic methane and hydrocarbons through the existing distribution infrastructure and provide storage to the power system

C. Hydrogen economy
   - Power-to-H2 produces a carrier addressing the entire system, both mobile and stationary uses
   - New H2 infrastructure, and maturity of H2 using technologies
   - Electrification and biofuels/biogas are develop somehow less than in the EU basic decarbonisation scenario

- Variants
  1. Negative emissions using Biomass-CCSU
  2. Enhanced actions at an early stage (i.e. 2030)

Common features of the stylized scenarios

In relation to the EU basic decarbonisation scenario

- Maintain highest priority of energy efficiency and RES
- Push electrification as much as possible in mobility and heating, with proven technologies
- Develop advanced biofuels as much as possible
- Maintain the nuclear option but also the constraints per country
- Re-consider CCS in the long term but with limitations per country
- Enhance the grids and the internal markets

Regarding the power sector

- Co-existence of two trends in the power system:
  - Dispersed generation, smart systems, small-scale batteries, prosumers
  - Highly concentrated carbon-free generation, long-distance and meshed HV network
  - Common management of the system and markets in the long term
- No dependency to imported fuels - autarky

Pros and Cons by stylized scenario

Main Uncertainties

Enhanced electrification

- Electric aircrafts, ships and long distance trucks
- Electrification of all industrial processes
- Electrification of all residential energy uses

Clean synthetic fuels

- CO2 capture from Air
- Too high increase in demand for electricity
- Costs

Hydrogen economy

- Distribution and transport network specifically for H2
- Cost of fuel cells
- H2 storage

Negative emissions – Biomass CCS

- Transport uses drive high market values of biomass resources
- Most probably the feedstock will be imported
- Biomass CCS is technologically not fully mature
- Use of CC has limited industrial potential compared to the amounts captured

Main advantages

Enhanced electrification

- High efficiency of electricity in end-uses
- Feasible from the power system perspective
- Power-to-H2 used mainly for storage purposes, where proven efficient

Clean synthetic fuels

- Continued use of existing distribution infrastructure for gas and liquid fuels
- Continued use of convenient energy applications, equipment and processes
- No major disturbance of transport system

Hydrogen economy

- H2 is an energy carrier valid for the entire system
- No excessive increase in power generation
- Can accommodate H2 to fuel processing if technology reached maturity in the future

Pros and Cons of Energy Carriers

Maximum Electricity

- Pros
  - High efficiency in end-use
  - Convenience-cleanness
  - Can be self-produced
  - Reliability
- Cons
  - Not fully applicable in all end-uses
  - Lack of competition among energy carriers in retail
  - System balancing and grid services become a mostly powerful energy monopoly
  - Electricity storage other than chemical are only short term

Clean gas and fuels

- Pros
  - Use of existing infrastructure
  - Convenience-cleanness
  - No loss of utility or productivity in end-use
  - Can fully cover transport adequately
  - Chemical storage of electricity
  - Competition among carriers and synergies
- Cons
  - CO_2 capture from air is expensive and not mature
  - Methanation not mature
  - Expensive end-use price unless very significant learning
  - Too excessive increase of total power generation challenging the potential of resources

Hydrogen as a carrier

- Pros
  - Can cover end-uses both stationary and mobile
  - No range limitations in transport, can accommodate al specificities of the various transport means
  - Chemical storage of electricity
  - Competition among carriers
  - Less expensive than clean methane or clean liquids
  - Less electricity production requirements than clean gas and clean liquids
  - Can coexist in gas infrastructure with natural gas in the transition phase
- Cons
  - New infrastructure
  - Hydrogen storage has difficulties
  - Not fully convenient in some energy uses
  - Depends on learning success of fuel cells