Use of biomass and hydrogen in thermal power plants towards EU carbon neutrality

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1. Energy transition on the right track?

Renewable energy has made a significant contribution to power generation over the past decade. Global investments in wind energy and PV in particular have led to a drastic reduction in the generation costs of renewable energy sources (RES). In many places already "grid parity" is reached, i.e. renewable electricity can be fed into grids in principle without subsidies. However, there are also setbacks.

1. Due to the rapid expansion of RES installations for several years a temporary surplus of generating capacity occurs, which has led to a decrease in whole sale electricity prices. In parallel taxes for support of RES expansion increase as part of electricity bill. After the shutdown of base load generation in the form of nuclear power plants (in Germany) and, gradual shut down of coal power plants, whole sale electricity prices are expected to rise again.
2. Other sectors such as industry, mobility, heating sector and agriculture have virtually made no progress in reducing emissions, due to the lack of incentives and alternatives.

Although it is expected that the European 2020 reduction target will be met, the policies and measures currently identified in the national projections are not sufficient to achieve the savings needed to meet the EU reduction target of at least 40% in 2030. Currently, greenhouse gas emissions reduction is projected to slow down after 2020, while achieving medium and long term targets requires a much faster reduction [1]. So it can no longer be expected to use fossil fuels by 2050 as we do today. This raises the big question, which technology options could be implemented in the energy sector, see figure 1. Since largely intermittent renewable energy sources (iRES) replace fossil fuels, gaps in the energy supply will come, which pumped hydro storage and batteries alone cannot fill.
Since previous policy initiatives especially outside the power sector did not manage to have a broad impact, the discussion about a general pricing of CO_2 emissions is at the forefront of political debate. It is undisputed that further regulation (either further support of low-emission technologies or CO_2 taxation) is needed.

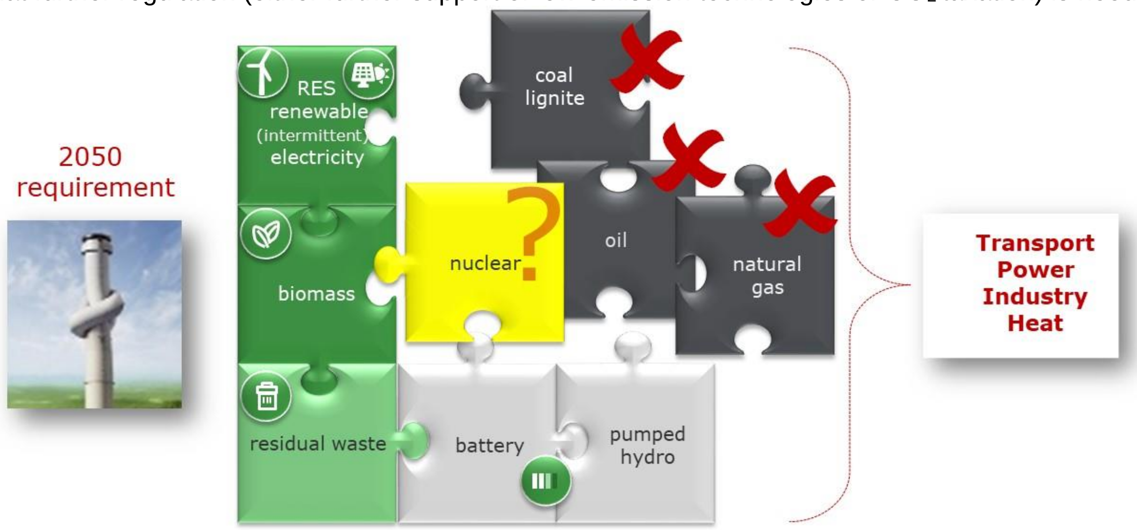


Figure 1: Looking ahead to the year 2050: Which energy supply options do we have?

2. The future role of biomass and hydrogen in power generation, mobility and industry

The use of biomass in the energy industry has been politically supported for two decades and promoted in various ways:

- Adding bioethanol and biodiesel to conventional fuels. Setting respective targets on GHG reduction and specific penalty schemes if the targets are not achieved. This was also supported on the European level by the Renewable Energy Directive
- Subsidizing biomass CHP plants and biogas plants
- Subsidizing biomass (pellet) heaters

While in Germany only small CHP plants are supported by the EEG (renewable energy law), in other EU states also large power plants (up to 660MWel) have been converted from coal to biomass. Further projects of this kind are expected, especially in the Netherlands and Scandinavia.
On the other hand, in the last decade - especially intense in the last two years - one energy carrier has set in motion the energy industry like no other: hydrogen. As only pure water is produced by burning it, hydrogen is considered the new energy carrier for power, heat, chemical and transport sector (in pure form) or as a raw material for conversion into secondary products. After decades of development towards production and use of clean hydrogen for various applications, it is assumed that the market is ready for take up now. This will be discussed in more detail below.

2.1 Optimism towards the future

The reasons for the new mood of optimism in politics, industry and energy technology can be summarized in the following points, which have emerged over the past two years:

1. **No alternatives**. Looking at the need to apply low-carbon technologies in all sectors, other alternative solutions cannot be found. Although biomass and biomass based fuels are already used, the global trend of recent years has shown that we approach sustainability limits. Similarly, the electrification via heat pump systems (heating) or battery storage (mobility, short-term storage in the network) reaches technical and economic limits, when it comes to larger amounts of energy and longer storage durations. In this regard, hydrogen is considered to be the energy vector that enables the decarbonization of different areas through sector coupling.
2. **Ambition for complete solutions.** The increased use of hydrogen has the ambition to solve all problems at the same time: Seasonal Energy Storage (RES for use in winter), grid control, safe (industrial) energy supply and clean, restriction-free mobility can thus be guaranteed. In addition, hydrogen together with recycled CO_2 (carbon capture and utilization, CCU) or atmospheric nitrogen allows the production of methane, methanol or other carbon products or ammonia. These can be used as so-called e-fuels in the future to safely supply the chemical industry with raw materials and the transport sector with fuels [2 -4].
3. **Political departure.** European policy has recognized that other solutions than just more RES are needed. In various European legislations now also the support for hydrogen technologies and CCU is visible (Renewable Energy Directive [5], Clean Vehicles Directive [6]). Hydrogen is just one building block and in a rather technology-open formulation. There remains much room for different sources of hydrogen and for follow-on products and technology combinations including biomass gasification for hydrogen enriched syngas. Global political support for hydrogen has increased in recent years. Mission Innovation (MI) is a global initiative of 23 countries and the European Commission (on behalf of the European Union), which deals with the hydrogen economy. MI was announced at COP21 on November 30, 2015, when world leaders gathered in Paris to make ambitious efforts to tackle climate change [7]. In 2018, the world's first ministerial meeting on hydrogen took place in Japan with representatives from 21 countries. In summer 2019, world leaders met in Osaka, Japan, for the annual G20 summit and outlined the next steps towards the realization of a hydrogen economy and a hydrogen society [8].
4. **New business models.** Industry has concentrated a long time on the purely fossil business model. Ultimately, billions of euros were lost as stranded investments in the energy industry alone. Now most companies have realized that they have to change and are actively working on new medium and long-term business models, in which hydrogen plays a central role. In 2017, 39 of the world's leading energy companies and automakers founded the Hydrogen Council [8].
5. **Hydrogen gets colors.** "Green" hydrogen production is the use of renewable energy in water electrolysis or biomass gasification. While only "green" hydrogen has been discussed in recent years, there is still not enough RES electricity for significant production. So "blue" hydrogen is now also considered as a transitional technology. As "blue" hydrogen the hydrogen generated from fossil sources coupled with carbon capture and storage (CCS) is understood. Hydrogen (as today predominantly) is then produced from fossil sources such as natural gas via steam reforming (grey hydrogen). In contrast to the "grey", fossil hydrogen, the resulting CO_2 is captured and stored geologically. CCS is commercially available today, but is not yet used in Central Europe. In the North Sea area CCS projects are under development now.

Figure 2 shows in the summary the possible replacement of fossil fuels by green, blue hydrogen and CCU for the supply of all sectors with these new energy sources and for seasonal energy storage.

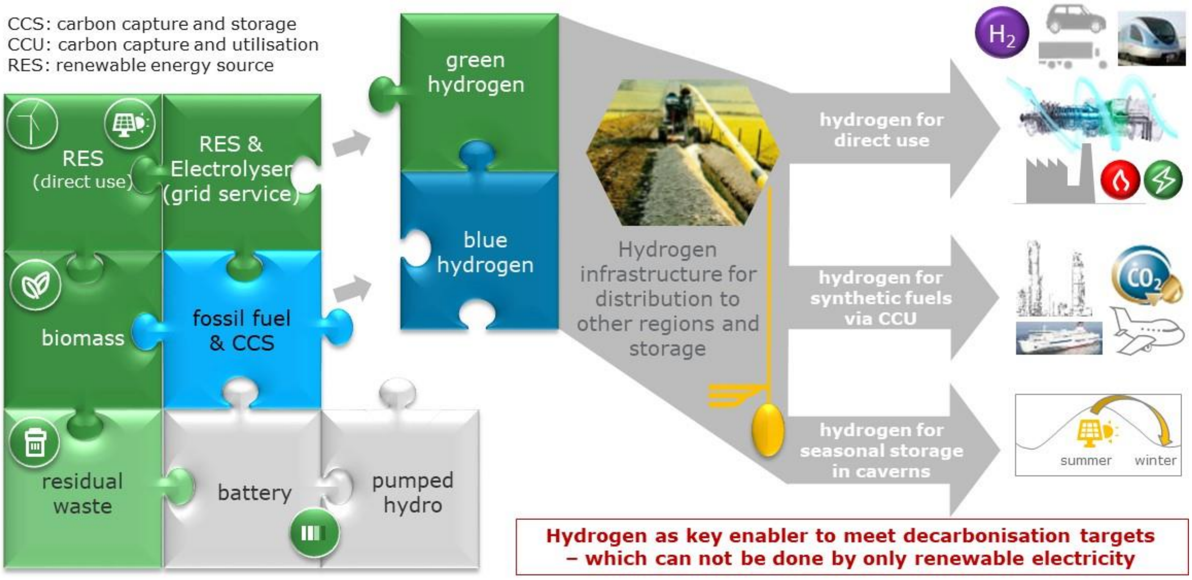


Figure 2: Hydrogen and CCU as new energy vectors

2.2 Business models for Hydrogen

The fundamental obstacle to the widespread use of hydrogen is the lack of infrastructure paired with the lack of (large) consumers. This is a classic "chicken and egg" problem, which may be dissolved by major initiatives in energy and transport sectors.

Mobility. Driven by the issue of emissions and political pressure and financially supported by governments, a network of hydrogen refilling stations (HRS) is under construction. Since the mobility sector and local transport companies have no other alternatives in the medium term [6], there is a move towards hydrogen drives on busses (as an alternative to the purely electric drive) and trucks. Hydrogen busses based on fuel cells (FC) today are up to four times as expensive as ordinary busses. Battery-electric busses still cost twice the price of a normal bus. Therefore, the development of hydrogen combustion engines is also ongoing as a cheaper solution. The EU is supporting the procurement of 142 H_2 busses in 2017/18 [10]. In addition, for larger fleets (Public transport and point - to -point connections of logistics centers) a few large HRS are sufficient and infrastructure costs are limited. The IEA estimates that 8,000 hydrogen fuel cell electric vehicles (PHEV) drive on the roads of the world (including United States: 4500, Japan: 2400) [11]. In Germany, H2 Mobility GmbH has the target to operate in 2019 100 HRS (700 bar) in seven German metropolitan areas (Hamburg, Berlin, Rhein-Ruhr, Frankfurt, Nuremberg, Munich and Stuttgart), as well as along the connecting roads and motorways [12]. The infrastructure can be more easily set up in the Ruhr region when the existing hydrogen pipeline [13] will be integrated into the infrastructure.

Industrial consumers. The first large-scale electrolysers in refineries or the steel industry are already being planned or under construction in several EU countries. Hydrogen that is already required today is now generated electrically rather than from fossil sources [14, 15]. Similarly, electrolysers can be used in the chemical industry.

Power plants. Particularly in the energy sector, the use of "green" hydrogen is still difficult because the costs are currently too high. Nevertheless, there are first pilot projects with hydrogen engines (electricity / CHP) which are under construction or in operation in Germany - always in connection with demonstrators for electrolysis for HRS and / or network services [10]. MITSUBISHI POWER is preparing the large-scale conversion of an 440 MWel power plant unit of the Magnum plant (Vattenfall power plant in Eemshaven, Netherlands, 3x440MWel) in 2024 [16]. In the future, the plant will be supplied with blue hydrogen, with Equinor and partners jointly preparing the storage of CO_2 in the North Sea [17].

Infrastructure projects and combined business models.

- Throughout the Dutch region, there are plans to create a transition to minimized CO_2 emissions through a combination of "blue" hydrogen and, in future, "green" hydrogen. Here in some clusters

(Rotterdam, Eemshaven), which already have a high hydrogen consumption, implementation of CCS can quickly start. New natural gas reforming and hundreds of MWs electrolysis are considered to be installed during the next years. These clusters are to be connected by hydrogen pipelines. This infrastructure and additional cavern storage means that the entire manufacturing and logistics costs can be kept low - provided that the economic and political conditions are adjusted in parallel and that, as planned, investments are also made in bulk consumers. Industry, gas suppliers, pipeline operators and power plant operators work closely together here [18].

- **Regionally**, large-scale electrolysers are planned in Europe (currently, especially in the north of the Netherlands and in northern Germany) as support systems for the electric grid [18, 19]. They will absorb excess electricity and thus reduce the costs of grid expansion. This means that electricity and gas network operators (for feed in) as well as possibly gas producers (hydrogen and oxygen) or gas consumers are natural partners in such projects, in order to realize maximum added value or minimal costs. Examples of such projects have been submitted in Germany as part of a call for tenders by the BMWi ("Reallabore") and individual projects include large-scale electrolysis up to 100 Megawatts.
- Today there is not sufficient hydrogen consumption / RES availability **locally** everywhere. Therefore, combined HRS, electrolytic hydrogen production and compressed gas storage with optional reconversion in the range of 10 to 20MWel is technically feasible as an extension of today's large battery storage projects. When installed near other industries, such installations can sell grid services (positive & negative control power) but also hydrogen, oxygen and waste heat from the electrolysis. This is especially true for (brown field, power plant integrated) electrolysis that produces hydrogen for fuel cell vehicles. The very high market price of this hydrogen allows economic operation plus additional incentives from support schemes for the HRS network and mobility.
- **At the global level**, various consortia are studying the production of ammonia at locations around the world where low cost RES production can be implemented. This ammonia can be delivered in liquefied form to consumers. Already today, ammonia is the largest commodity of the chemical sector, traded internationally. Ammonia could take the place of LNG in the energy sector, since the technology is comparable. Later use would then be possible by direct use in FC or after splitting into nitrogen and hydrogen. For example, "green" ammonia from hydropower in Norway or solar energy in Australia could be transported to Japan as an energy source. After switching off most nuclear power plants, Japan is already one of the largest LNG importers. Therefore, it is not surprising that it is precisely Japan, which is investigating and promoting the introduction of a hydrogen economy with the help of ammonia imports [20]. Investments in such infrastructure are also attractive for large utilities, which developed gas fields, mine projects and value chains for wood pellets in the past.
- In locations with a **surplus** of green, low - cost electricity (e.g. Scandinavia), plans are developed (also with participation of MITSUBISHI POWER) for the construction of large power-to-fuel CCU projects, producing methanol or synthetic fuels. Only in such places, "green" production facilities are able today to operate economically in base load.

Absolute statements about the profitability of applications are still difficult. However, one can say that a reconversion of H_2 in electricity is difficult due to lack of high peak prices in the electricity market. Green synthetic fuels (and also use of H_2 in refineries) have (like bioethanol and biodiesel) a market price of 100 to 130 € / MWh(th) and H_2 at HRS is sold at 8-10 €/kg, that is more than 200 € / MWh(th). The evaluation of grid services is to be examined on a case-by-case basis and regionally.

3 Technical challenges for fuel switches

3.1 Steam power plants and gas turbines

Hydrogen is used successfully in various fields of power engineering since decades (in principle for over hundred years) firstly, as compound of coke oven gas in city gas networks and today in particular as boiler fuel in steam power plants and gas turbine plants. The industry has experience with to use more than 60 vol.-% H_2 in normal power plants and gas turbine combustors and almost 100% in special applications. In addition to the steel industry, these include refineries and the chlor-alkali industry, which today often uses and burns by-product hydrogen. There is a need for development in a few areas:

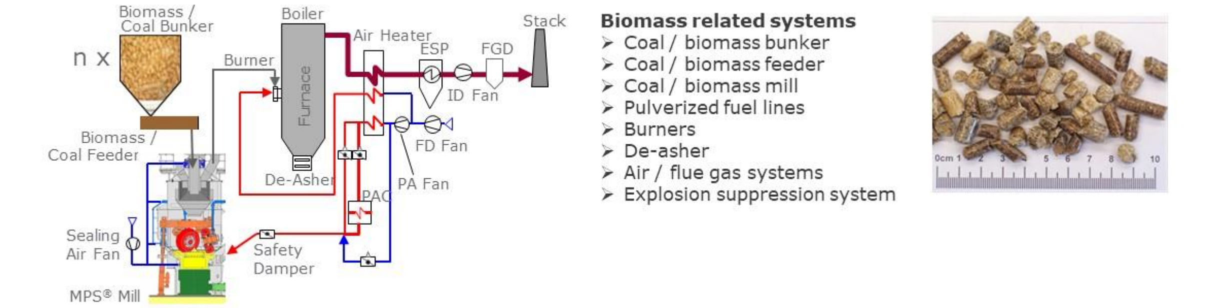
- Due to the high temperature and flame speed, existing burner system must be further developed to ensure save operation (avoidance of high temperatures and back-ignition) and the lowest emissions. If necessary, flue gas cleaning systems must be added during conversion projects.
- Safety systems, material selection and seals must be adapted to changing conditions.

The manufacturers of power plants have extensive know-how also from past fuel switches / power plant conversions and developments [16] and can thus offer all necessary technologies for furnaces and gas turbines promptly. The commercialization has already started in principle.
The development demand for gas turbines is confined to burner technology, since the high excess air of gas turbines already makes it possible to control the combustion temperature well today. The Magnum plant is the first major combined cycle power plant (CCGT) in Europe to be retrofitted. The plant was originally designed to use gasification gas and has enough space also to retrofit a denitrification catalyst.
For steam boilers high excess air should be avoided to minimize NOx and waste heat losses. The increased adiabatic flame temperature of hydrogen combustion and the reduced exhaust gas mass flow are challenges to be considered for a retrofit evaluation. Furthermore the convective heating transfer is expected to decrease. To overcome this issue, the simplest measure is exhaust gas recirculation, which reduces both flame and furnace exit temperature and allows sufficient heat and mass flow for the convective pass in the retrofit case, cf. Table 1. In the combustion of the H_2/N_2 - mixture from the ammonia splitting no recirculation of flue gas would be needed, since the ballast of nitrogen leads to sufficient flame cooling and mass flow increase. Unlike the use of hydrogen from ammonia for mobility no separation of H_2 and N_2 must be carried out in the power plant area after the splitting.

Table 1: flue gas (FG) composition for different fuels it in steam generators. For all calculations, an excess air of 1.1 and a temperature of the combustion air of 350°C are assumed. Mass flows, volume flows and amounts of heat (Q) are normalized with the value of the design of a hard coal boiler and shown as percentages. RC=recirculation.

flue gas	hard coal	wood pellets	natural gas	H_2 without FG RC	H_2 with 7% FG RC	H_2/N_2 from NH_3
	Vol%	Vol%	Vol%	Vol%	Vol%	Vol%
H_2O	8.3%	13.9%	17.8%	32.4%	32.6%	29.3%
CO_2	15.6%	15.9%	8.7%	0.0%	0.0%	0.0%
O_2	1.8%	1.7%	1.7%	1.6%	1.5%	1.4%
N_2	73.3%	67.8%	70.9%	65.2%	65.1%	68.6%
SO_2	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
HCl	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
HF	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ar	0.9%	0.8%	0.8%	0.8%	0.8%	0.7%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
FG [kg/s]	100%	102.6%	99.7%	79.1%	86.3%	88.5%
FG [m²/h @ 1300°C]	100%	104.6%	107.3%	94.9%	103.7%	104.9%
FG Q (1300-120°C) [MW]	100%	106.0%	105.4%	91.9%	100.4%	100.9%
T_{ad} [° C]	2189	2066	2089	2304	2149	2122

For biomass conversions, such a recirculation is normally not needed as numbers in the table show and experience has been collected by MITSUBISHI POWER over more than 15 years, cf. Figure 3. For conversion to natural gas firing a flue gas recirculation may be used to limit NOx emissions.



Retrofit experience for existing plants since 2002 (Netherlands, UK, Denmark, Canada)

2002:	P.S. Amer 9 in Geertruidenberg, Netherlands, 1 Mill converted (more followed)
2014:	P.S. Studstrupvaerket (SSV), Denmark, 930 MWth, 100% conversion (fuel switch coal-biomass-coal possible during operation)
2014:	P.S. Avedøreværket (AVV1), Denmark, 611 MWth, 100% conversion, burner replacement, mill refurbishment
2015:	P.S. Atikokan in Ontario, Canada, one burner level, one mil refurbished (more followed)
2010-2014:	P.S. Drax Unit 1-3, United Kingdom, 3x660MWel 100% conversion (biomass burners)

Figure 3: Retrofit experience and components to be modified / added during retrofits of coal fired power plants for wood pellet firing

3.2 Fuel cells

In decentralized applications, hydrogen can be used as clean fuel for fuel cell (FC) based power (and heat) production. Following several demonstrators of 250kWel SOFC (solid oxide fuel cell) units, MITSUBISHI POWER has now commissioned the first prototype of a 1 MWel SOFC. The main advantages of SOFC - technology are high electrical efficiency (~ 55%), the low emissions and noise level, fuel flexibility (from natural gas through biogas to hydrogen and ammonia) via the integrated gas reforming step. It is to be expected that with increasing demand the manufacturing capacity for FC will increase and costs will fall. This means that in the MW scale FC can also become an alternative to reciprocal engine CHP [21].

3.3 Reciprocal engine power stations

Due to the change of fuel from coal to natural gas and changed requirements for cogeneration plants, gas engines have experienced a booming market in recent years. Virtually no upper power limit for such plants exists today after the commercialization of the latest generation of engines in the 10MWel class. The largest so far implemented system is the Küstenkraftwerk Kiel with 20 units of 9.5 MW. Such plants designed for highest efficiency and natural gas plants will certainly be difficult to be converted to hydrogen. On the other side of the power spectrum hydrogen engines of 200kWel class for trucks are under development and successfully tested. The company Keyou is developing conversion concepts for engine manufacturers who want to offer a true alternative to fuel cell applications for trucks and busses. Initial test results of such engines show very high efficiencies of over 40% [22]. By avoiding costly batteries and electric components, such vehicles can become a real option in the near future. The engine technology can then also become the basis for decentralized CHP based on hydrogen – competing with FC technology.

3.4 Ammonia and synthetic fuels as energy sources in power and heat generation

The combustion of ammonia produces large amounts of NOx (depending on the combustion conditions). This can be avoided when ammonia before combustion is catalytically split into nitrogen and hydrogen (in an endothermic reaction). Together with the necessary investment in infrastructure, imported ammonia is therefore a likely option for large centralized consumers, who have a port connection and can also integrate large-scale plants for splitting the ammonia. The necessary heat for splitting can be most easily produced in a heat integration with a power plant and a normal combustion requires (unlike the use in fuel cell vehicles) no absolute purification of the fuel. Nitrogen as ballast in the combustion gas rather simplifies the control of combustion temperatures and gas mass flows as shown above. The necessary technology for ammonia separation is known and can be commercialized in larger scale for this new application. Thus, the ammonia is an alternative for large power plants and fertilizer industries, but probably not for small applications or e-mobility. Likewise, synthetic CCU fuels such as methane and methanol could be used without significantly changing the existing infrastructure for heat and power applications.

4. Market trends today: Fuel switch to biomass and natural gas

The energy transition of all European countries is currently developing rapidly but not in a completely uniform way. On the one side the need of CO_2 reduction according to the objectives of the Paris Agreement is common within all countries. Most EU countries have recognized the need to abandon coal combustion and set national roadmaps for the coal phase-out. However, the handling of alternative technologies such as nuclear energy and biomass is different, as well as the speed of increase of RES capacity.

Biomass: Increased biomass use has begun over 20 years ago in particular in the northern EU countries via retrofit of coal plants to biomass and new build units. MITSUBISHI POWER alone has so far built or retrofitted globally (with a focus in Europe) about 3GWel power plant capacity for the use of wood pellets [16]. Assuming the roll out of new technologies for the use of waste biomass via hydrothermal treatment or gasification a high potential of further biomass resources could be utilized.

Natural gas: Centralized biomass use on a scale of several million tonnes per year is, however, not transferable to countries with a large industrial sector such as Germany. Here natural gas is needed as a bridge solution during energy transition. The retrofit of existing power plants as well as development of new build projects is ongoing. All natural gas technologies are represented here.

- New builds of smaller combined heat and power units and retrofits of coal boilers with simultaneous installation of topping cycle gas turbines for municipal heat supply
- Reciprocal gas engine power plants in small and medium-sized cities
- Steam generators for primarily heat-dependent industry
- Highly efficient gas-fired combined cycle power plants in the electricity market in competition with subsidized reserve power plants (open cycle gas turbines)

It is also likely that old coal-fired power stations with or without fuel switching to natural gas will continue to be connected to the grid, in order to be available as reserve for the winter months and in the event of power shortages.

In Eastern Europe, the transition from coal to gas is being prepared by building up of new gas pipelines. The necessary structural change from coal mining and coal based power generation to other industries has begun there much later than in the rest of Europe.

Fuel flexibility, load flexibility and energy storage: Especially systems for electricity and heat supply are becoming more complex. In order to operate independently in the electricity and heating market, new district heating power plants are almost exclusively equipped with **hot water heat storage.** Thus heat storage in GWh scale is technically feasible just like at the power plant Avedoere in Denmark or in the Küstenkraftwerk Kiel. **Topping cycle gas turbines** attached to steam power plants (Avedoere II) or the possibility to **operate the heat recovery steam generator of CCGTs in air mode** (without GT) allow to respond quickly to positive or negative load demand. Fuel flexibility can also be implemented as in the power plant Avedoere, which can be fired with mixtures of coal, biomass and natural gas over a wide range in the boiler, allowing maximum fuel flexibility and security of supply.

For **mixed firing of biomass and hydrogen** in the future first preliminary studies have been done. Here, too, the integration of topping (hydrogen) gas turbines in existing steam cycles is being investigated.

In Germany, the Netherlands and the United Kingdom, the first investigations are also being carried out on demonstration plants that will integrate electrolysers, hydrogen storage and HRS plus small gas turbines for peak power supply (**integrated storage plus external hydrogen commercialization**). By combining various technologies (cf. Figure 4) and end-products, economic operation should already be possible in the coming years.

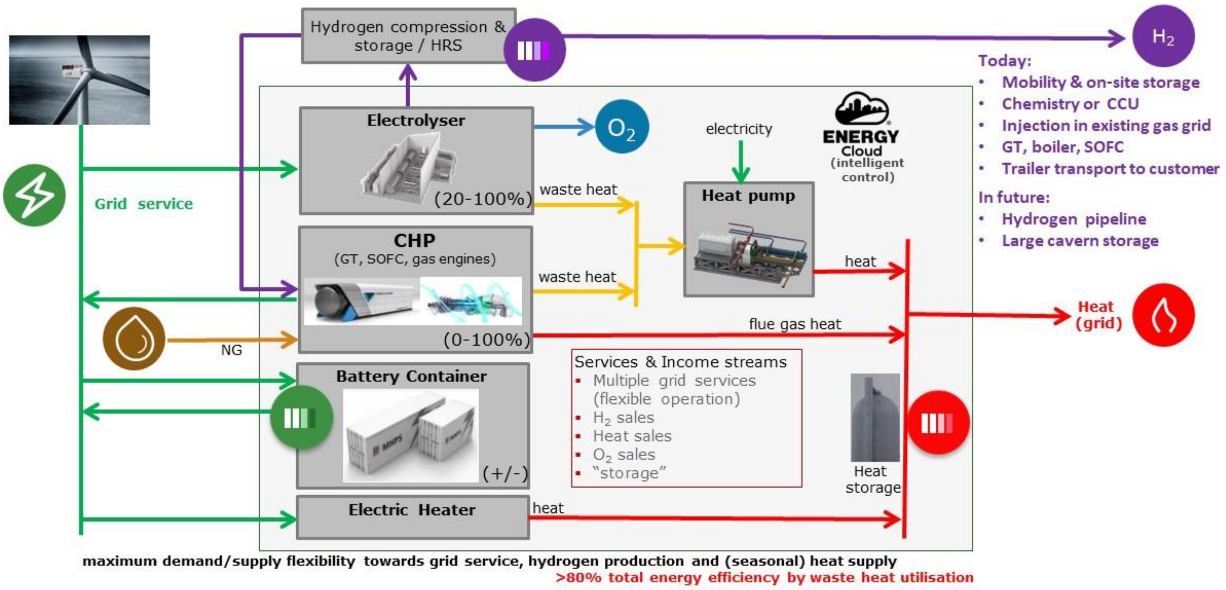


Figure 4: Technology blocks under consideration for power generation flexibility and sector integration, energy storage

Moreover, CHP plants used for district heat production have already partially integrated **electrical steam/hot water generators**. Initial planning is also under way for **large heat pumps**, which can completely take over the supply in summer operation using environmental heat (rivers) or wastewater heat. In addition, **compressed air energy storage combined with hydrogen** is under consideration in some locations.

"Hydrogen Readiness" of new equipment is now on the agenda for new investments like CCGTs, as gas grid operators are going to plan injection of "green" hydrogen into their pipelines in near future.

5 Summary

The energy transition is ongoing with different speed in EU countries. In Northern, Central and Western Europe, the timetables for the coal phase-out are set between 2025 and 2038 and even natural gas appears only as a transitional fuel. The pioneers for strict carbon reduction via hydrogen are the North Sea countries like Great Britain, the Netherlands and Norway, where a (substantial) switch to CO_2-free energy system is expected by 2030 with blue hydrogen, wind energy for green hydrogen as well as with more biomass combustion in existing coal-fired power plants. It is also undisputed here that the vast majority of existing and new thermal power plants are still necessary in future, in order to ensure a secure power supply.

As now the industrial sector and the transport sector are included in the considerations, there is a convergent picture: On the basis of hydrogen, it is not necessary to create a completely new, but only a modified infrastructure. The cost burden is carried by all sectors, which also have the benefits of low carbon energy. This minimizes the overall economic impact and a more or less smooth transition is possible through the connection of hydrogen clusters and decentralized applications. The available RES capacity as well as the acceptance and diffusion of hydrogen technologies are a limiting factor in the speed of transition. Here, the expansion of the coastal hydrogen infrastructure in the Netherlands and Germany, which today already includes hydrogen pipelines, plays an important role. Here it will also be possible to commercialize blue hydrogen early with CCS starting via CO2 collected and transported with barges as intended by Equinor. Although the spread of infrastructure to areas further away from the coast will be somehow slower, nationwide or across the EU coverage will take about one to two decades, partly because additional RES installation will cost a lot of time and money. Nevertheless, compared to the introduction of electricity and natural gas networks, this would be a very high speed.

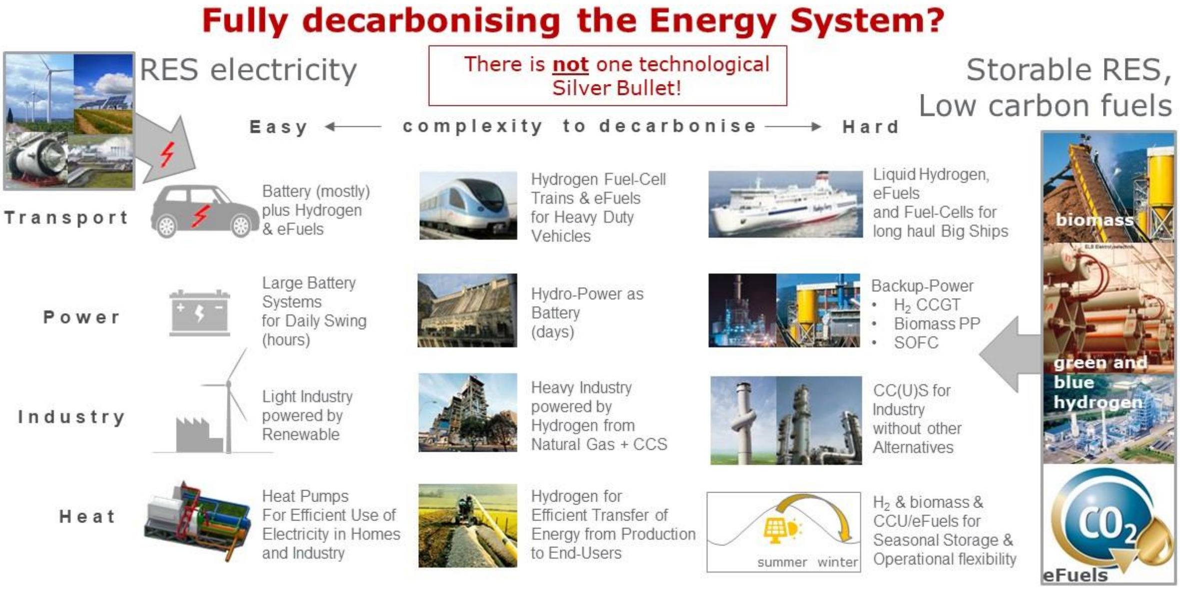


Figure 5: Low-carbon energy technologies enabling the phase out of fossil fuels

At the same time, further low-carbon technologies will be needed to meet the emission reduction targets in all sectors, cf. Figure 5. However, the achievement of decarbonization targets will also depend on the willingness of policy makers and the public to bear the necessary costs and also to accept building new energy infrastructure (hydrogen pipelines and reserve power plants). At least in the initial phase, significantly higher costs for new infrastructure and increasing RES shares in the energy mix are to be expected. Therefore, the realization of the presented, future energy world can only succeed, if CO_2 emissions in all sectors receive a higher price in the near future, if demonstration plants are promoted, and at the same time a technology-based consensus is found between politics, population and economy about the right pathway and the speed of implementation.

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