Circular Economy and Environmental Protection

Bilingual scientific journal / Kétnyelvű tudományos folyóirat

Körforgásos Gazdaság és Környezetvédelem

Official Journal of the
Environmental and Process Engineering Research
Group and Institute of Chemistry

Volume 4, Issue 3–4, 2020

EDITORIAL INFORMATION

Publisher:
Environmental and Process Engineering Research Group, and Institute of Chemistry – Mizsey, Peter

ISSN 2560-1024

Contact, manuscript submission: ceep@envproceng.eu

On the first page: 2021 Tesla Model Y (downloaded from https://www.caranddriver.com/tesla/model-y)

CONTENTS / TARTALOM

EDITORIAL PREFACE / SZERKESZTÖI ELŐSZÓ

Tisztelt / Kedves Olvasó,

Mostani kiadványunkban két témával foglalkozunk, az alternatív motorhajtóanyagokkal és a hidrogén gazdasággal. Mindkét téma a fenntartható fejlődés, a környezetvédelem és a körforgásos gazdaság céljait szolgálja. És mindkét téma a mai szakmai- és közbeszéd része, ezért a közlemények kitekintő része inkább pillanatfelvétel jellegű.

Az alternatív motorhajtóanyagokkal foglalkozó áttekintés röviden ismerteti az olajalapú hajtóanyagok kiváltását szolgáló megoldásokat, kitekint az ezekkel kapcsolatos egyes lokális és regionális tervekre (részlesebben foglalkozva az EU-s fejleményekkel. Rámutat a dekarbonizációs törekvésekre, amelyek megvalósítása egyes országok esetében célhatáridőhöz kötött. Ma a villamos energia meghajtású járművek térnyerésének lehetünk tanűi, és jelentős erőfeszítéseket érzékelhetünk a hidrogénes energiacellás megoldások elterjesztésre is.

Második, ismeretterjesztő közleményünk egy újabb kihívással, a hidrogén gazdaság megteremtésével foglalkozik. Az alapok áttekintése után egyes országok, régiók fejleményeibe és terveibe tekintünk be. A hidrogén gazdaság, a zöld hidrogén mozgalom zászlóvivője jelenleg Európa (nyugati fele)

Reméljük, hogy olvasóink érdekesnek találják mostani kiadványunkat és kedvet kapnak hozzá, hogy maguk is beküldjék saját munkájukat a szerkesztőségünkbe.

Kellemes és hasznos olvasást, sikerekben és örömökben gazdag boldog újévet, és jó egészséget kívánunk.

Budapest, 2020. december 29.

Racz, Laszlo (sr)

Alternative fuels for transport – An introduction

Racz, Laszlo (sr.)

liracz@gmail.com

Received: 1 December 2020 *Accepted: 5 December 2020*

ABSTRACT

Due to its dominant fossil fuel consumption, presently transport is responsible for one-quarter - one-third of the total greenhouse gas emissions worldwide. Alternative fuels aim to cut transport-related greenhouse gas emissions. The article reviews alternative fuels for the transports and provides an outlook to the changing targets.

Keywords: greenhouse gas emission, alternative fuel, fuel cell, electric vehicle

ALTERNATIVE FUELS FOR TRANSPORT

Introduction

According to a 2003 sophisticated EU definition, „Alternative fuels means fuels or power sources which serve, at least partly, as *a substitute for fossil oil sources* in the energy supply to transport *and* which have *a potential to contribute to its decarbonisation* and enhance the environmental performance of the transport sector" (European Union (2014B), and include natural gas (and biogas), LPG (liqued petroleum gases), biofuel, hydrogen and electricity (see Table 1).

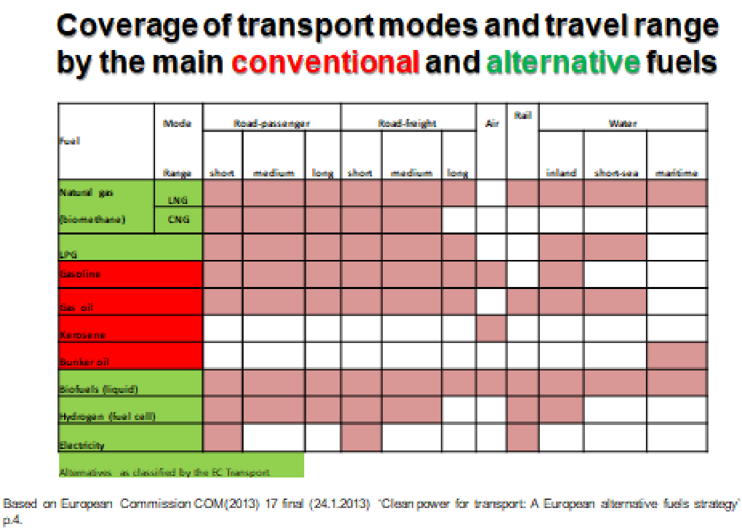

Table 1. Classification of transport fuels in the EU (European Union (2014))

Table 1 lists the crude oil based transport fuels (highlighted in red) and the alternative transport fuels (in green) as well as the main transport modes for each type of transport fuels (in claret). Since the publication of the related Communication (European Commission (2013)) newer transport modes emerged for some alternative fuels (see later). Newer hybrid vehicles with alternative transport mode capabilities appeared. Furthermore, starting from 2020, use of one one fossil fuel, bunker oil (containing up to 3.5% (w/w) sulphur) is limited, it could be burned only on ships equipped with exhaust gas cleaning systems (e.g. scrubbers) (according to the IMO regulation there is a 0.5% sulphur cap on marine fuels from 2020).

Carbon dioxide emissions factors of the fossil transport fuels are summarised in Table 2 (Greenhouse Gas Protocol (2014)). Table 2 proves that natural gas and LPG (liquified petroleum gases) have the lowest CO_2-emission factors and they are the 'cleanest' fossil fuels, thus they meet the abovementioned EU definition for renewable fuels. Lignite (at the bottom of the table) with the highest emission factor can be used in the railway transport.

Emission factors of different transport fuels

Fuels	kg CO2 / GJ	GJ / l	GJ / t
Natural gas	56.06 *(100)*	0.035 GJ/st.m3	0.035 GJ/st.m3
LPG	63.20 *(113)*	0.0249	45.9779
Aviation gasoline	69.11 *(123)*	0.0343	44.5900
Gasoline	69.25 *(124)*	0.0344	43.5674
Jet fuel	70.72 *(126)*	…	44.5900
Diesel fuel	74.01 *(132)*	0.0371	44.1667
Residual (bunker) oil (#6)	77.3 *(138)*	0.0405	40.7586
Lignite	101 *(179)*		

Relative emission factors (compared to natural gas)
GJ is based on lower heating values.
Source: viewed 10 Feb, 2014, www.ghgprotocol.org/files/ghgp/tools/co2-mobile.pdf;

Table 2. Emissions factors of different fossil transport fuels (Greenhouse Gas Protocol (2014))

Differing from the 'sophisticated' EU definition of alternative fuels, the Environmental Protection Agency (EPA) of the USA simply provides the list adding one condition:„Alternative fuels include gaseous fuels such as hydrogen, natural gas, and propane; alcohols such as ethanol, methanol, and butanol; vegetable and waste-derived oils; and electricity. These fuels may be used in a dedicated system that burns a single fuel, or in a mixed system with other fuels including traditional gasoline or diesel, such as in hybrid-electric or flexible fuel vehicles" (EPA (2017)). There is also the category of the 'emerging alternative fuels' that „may be newly available" in the USA and „may qualify for federal and state incentives and laws", like biobutanol, dimethyl ether, methanol, renewable hydrocarbon fuels (AFDC (2020)).

Among the transport modes, road transport is dominating historically in terms of energy consumption as Figure 1 shows. According to the Eurostat, "road transport represents 94% of the total energy consumed for internal transport within the

EU. In absolute terms, road transport and international aviation reported the largest increment in 2017 compared to 2016, while rail transport reported the lowest." Passenger cars and vans account for 73% of the total road emissions (Bioenergy Europe (2019); European Commission (2017)).

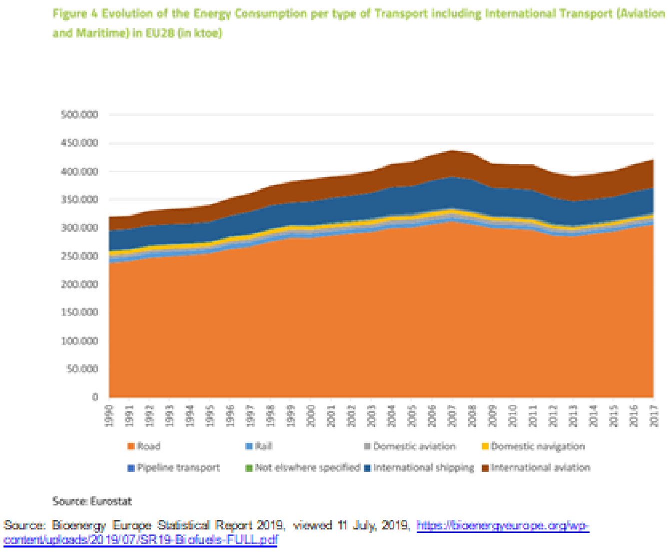

Figure 1. Historical energy consumption by transport modes in the EU (Bioenergy Europe (2019))

Importance of 'renewable energy sources'

According to the EU definition, alternative fuels "serve, at least partly, as a substitute for fossil oil sources." Fossil fuels can be substituted by or on the base of renewable energy sources.

In the EU, „'energy from renewable sources' or 'renewable energy' means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas". „Biomass means the biodegradable fraction of products, waste and residues from biological origin from agriculture, including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin" (European Union (2018)).

The International Energy Agency (IEA) defines renewable energy resources as those "derived from natural processes" and "replenished at a faster rate than they are consumed" (IEA 2002, OECD, IEA and Eurostat, 2005). The IEA definition of renewable energy includes the following sources: "electricity and heat derived from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources" (IEA 2002). These definitions vary in the type of sources included and in whether sustainability considerations are explicitly incorporated. These differences illustrate the fact that there is no common or global definition of renewable energy" (SEforAll (2013)); (IEA, 2002) ECD, EUROSTAT (2004)).

„Renewable electricity in transport increased 11% y-o-y in 2018 to reach just under 0.3 EJ. By the end of the forecast, consumption reaches 0.5 EJ with electromobility providing 10% of renewable energy in transport. This reflects 29% of electricity used for transport coming from renewable sources." China accounts for over 60% of renewable electricity used for transportation, shared roughly equally by road and rail. By 2024, road transport consumes more renewable electricity than rail in the United States, but still less than rail in Brazil, India, Japan and the European Union. Therefore, rail is anticipated to be responsible for just under two-thirds of transport sector renewable electricity demand globally in 2024, even though the global electric car fleet expands from 5 million in 2018 to around 40 million by the end of the forecast period" (IEA (2019)).

Renewable energy also could be directly used in transport. A new concept of *wind-powered sailing* freighter (i.e. propulsion by wind) was presented in September, 2020."The Oceanbird vessel is being developed by Wallenius Marine AB and a Swedish consortium including KTH Centre for Naval Architecture, maritime technology developer SSPA while the Swedish Transport Administration has agreed funding for the project through to 2022. The 200m long, 32,000t Oceanbird wind-powered car carrier (wPCC) can carry 7,000 vehicles, with retractable 80m high wings made of a blend of metal and composite which can be lowered in high winds. The vessel is designed for an average speed of 10knots under sail power alone and on favourable routes will reduce emissions by up to 90%. Estimated travel time across the Atlantic is 12 days, compared with about seven for fuel-powered car carriers. Shipping lines will be able to order a wPCC at the end of 2021 with the first operational vessel slated for 2024" (International Windship Association (2020)). „The future started a long time ago…To be able to get in and out of harbours – and as a safety measure – the vessel will also equipped with an auxiliary engine: Powered by clean energy, of course. The first vessel will be a cargo ship, but the concept can be applied to ships of all types, such as cruise ships" (Oceanbird (2020)).

The European Green Deal presented by von der Leyen, president of the European Commission in December 2019 in its chapter 'Sustainable mobility', seeks a 90% reduction in GHG emissions by 2050 through among others by

- The use of „different transport modes (more freight should be transported by rail or water and the Single European Sky should significantly (by 10%) reduce aviation emissions at zero cost to consumers and companies)
- Prices that reflect environmental impact (ending subsidies for fossil fuels, extending emissions trading (ET) to the maritime sector, effective road pricing in the EU and reducing free allowances to airlines under ET
- Boosting supply of sustainable alternative transport fuels: By 2025, about 1 million public recharging and refuelling stations will be needed for the 13 million zero-(ZEVs) and low-emission vehicles (LEVs) expected on European roads (2017: 140k

charging points and 975k ZEVs&LEVs), and
- Reducing pollution:
    - Stricter standards on car pollutions
    - Pollution reduction in EU ports
    - Air quality improvement near airports" (European Commission (2019)).

ZEVs do not produce tallpipe pollution, term LEV is used in general sence and could be differently specified.

TWO CONCERNS REGARDING THE 2014 EU ALTERNATIVE FUELS DEFINITION

Carbon dioxide emissions

A source of discussions, how to calculate CO_2 emissions caused by the use of any vehicle. According to the 2014 year EU definition, alternative fuels "have *a potential to contribute to ... decarbonisation* and enhance the environmental performance of the transport sector". Note that this definition limits the required decarbonisation and environmental performance enhancement *to the transport sector*. Therefore, for the analysis of production and use of alternative fuels life cycle analysis is unavoidable. Table 2 reflects a 'tank-to-wheel' (i.e. environmental impact assessment from the charging point to the discharge) approach, instead of the 'well-to-wheel' approach (or life cycle analysis – LCA, or 'environmental impact throughout the lifespan' assessment) approach, i.e. greenhouse gas emissions caused by the production, transport and storage of the fuels are omitted in the table. Total life cycle analysis should cover greenhouse gas emissions connected both to the vehicle production, use (i.e. tailgas emissions) and disposal, and the fuel production.

Geographycal specifics of (e.g. electric power) supply can not be omitted in the LCA, since this could lead to inaccurate results. Importance of local conditions are illustrated by the following examples.

„A new study by MIT and the Ford Motor Company finds that depending on the location, in some cases an equivalent or even bigger reduction in emissions could be achieved by switching to lightweight conventional (gas-powered) vehicles instead of EV – at least in the near term" (gas-powered means gasoline-driven, EV – electric vehicle). „The study looked at a variety of factors that can affect the relative performance of these vehicles, including the role of low temperatures in reducing battery performance, regional differences in average number of miles driven annually, and the different mix of generating sources in different parts of the U.S." (Chandler, D.L. (2019)).

"When CO_2 emissions linked to the production of batteries and the German energy mix - in which coal still plays an important role - are taken into consideration, *electric vehicles emit 11% to 28% more than their diesel counterparts*, according to the study, presented on 17 April, 2019 at the Ifo Institute in Munich." "It would have been preferable to opt for methane engines, "whose emissions are one-third less than those of diesel motors." (Brussels Times (2019)). According to another study published by ADAC (Allgemeiner Deutscher Automobil-Club) the lower life cycle CO2 emissions could be provided by natural gas (i.e. methane) driven cars (in Bayern) (ADAC (2019)).

Indirect land use change (ILUC)
Actually, introduction and / or increased use of the alternative fuels may cause detrimental effects on the other sectors.

ILUC „refers to land whose ultimate purpose is essentially changed from its previous use. An example would be a forest land that was cleared for the cultivation of biofuel crops" (e.g. under the impact of local or governmental incentives) and as a consequence the net the carbon-sequestration capacity of the products decreased (Farm Energy (2019)).

In this framework biofuel issue in the EU, their legislation metamorphosis from the early (2003) euphora to the disenchantment (2015&2018) could be also remembered. The 2003/30/EC EU directive on „the promotion of the use of biofuels or other renewable fules for transport" set up the objective of „20% substitution of conventional fuels by alternative fuels in the road transport sector by the year 2020".

In 2008 Searchinger, T. et al. (Princeton University) concluded that the use of US croplands for biofuels (i.e. the 'indirect land use change' – ILUC) has increased the GHG emissions (Searchinger, T. et al. (2008)).

An EU Joint Research Centre study (2015) revealed that if the combined ILUC emissions of biodiesel and bioethanol were taken into account, conventional biofuels do not reduce but rather increase GHG emissions. This raises serious questions about the effectiveness of the EU's biofuel policy and the role of biofuels in reducing GHG emissions intensity (JRC (2015)). It can be added that an early article of our colleagues highlighting the life cycle GHG emissions problems of biofuels was refused by a prominent journal.

Conclusions have been drawn in the ILUC directive of 2015 and a 2018 agreement by the European Commission, the European Parliament and the Council (see details in subchapter 'Biofuels').

COST OF ALTERNATIVE FUELS

Introduction of most of the alternative fuels also needs investments in the vehicle technologies, and fuel infrastructure.

In 2017, the UK Transport and Energy said electric cars are the most efficient („Hydrogen may be quicker for refueling, but it reduces efficiency over a traditional EV and adds cost and unnecessary tech") (see Figure 2.) (Green Car Reports (2017)).

ALTERNATIVE FUELS PLANS

In this part the EU's 2011 year position, future targets of 2013 and of the consequitive years are highlighted with international outlook, by alternative fuel types.

Natural gas, biomethane, and LPG
Natural gas is a naturally occuring fossil, low carbon hydrocarbon mixture, containing typically 80-99 %(v/v) methane, with further possible constituents of ethane, propane, N_2, He_2, CO_2, H_2S, etc. Depending on the methane content - according to a widely-used categorisation - natural gas can be devided into L(ow calorific value) and H(igh calorific value) types, with methane contents of 80 - 87% and 87 - 99%, respectively. Natural gas from the producing wellhead goes to the processing plant, where it is purified from water vapour and non-hydrocarbons. Then the received dry gas can be odorised in order to easily detect the possible leaks on the systems. The odorised dry natural gas is to be transported into underground storage reservoirs or / and to gas distributors.

They can be used in the form of *compressed natural gas (CNG)* or *liquefied natural gas (LNG)* as transport fuel. CNG should be stored at high (200 bars) pressure at atmosheric temperature, while LNG should be stored at low cryogenic (-162 °C) temperature at atmospheric pressure. CNG is produced by series of compressors. Natural gas liquefaction (i.e. LNG) can be made by cascade refrigeration using various cooling media or by application of a turboexpander system (natural gas after liquefaction has about 600 times smaller volume than in the gaseous state at standard conditions, i.e.at temperature 15.6 °C and atmospheric pressure).

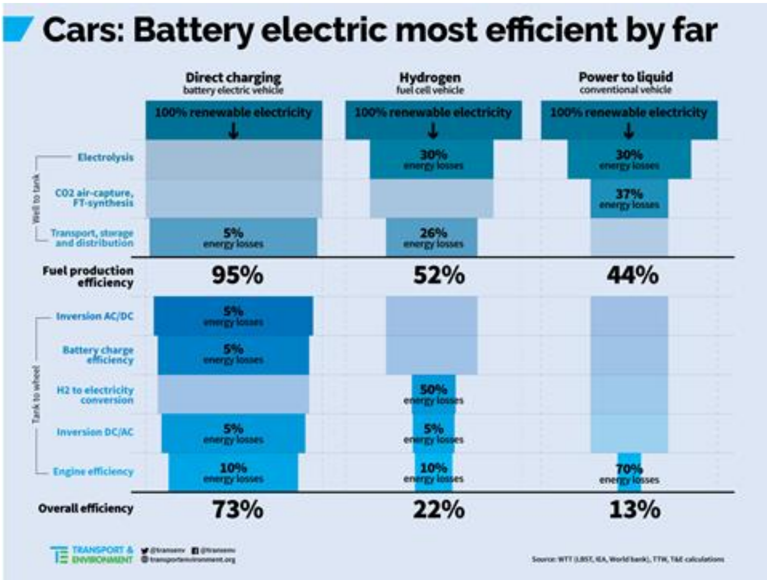

Fig. 2. Efficiency calculations of electric, fuel cell and convention vehicles (2017) (Green Car Reports (2017))

CNG and LNG are both used in road and water transports, while rail transport needs only LNG.

„Dedicated natural gas vehicles are designed to run on natural gas only, while *bi-fuel* vehicles can also run on gasoline or diesel. Bi-fuel vehicles allow users to take advantage of the wide-spread availability of gasoline or diesel but use a cleaner, more economical alternative when natural gas is available. Since natural gas is stored in high-pressure fuel tanks, bi-fuel vehicles require two separate fueling systems, which take up passenger/cargo space.

Natural gas vehicles are not available on a large scale in the U.S - only a few modelsare currently offered for sale. However, conventional gasoline and diesel vehicles can be retrofitted for CNG.” (EPA (2020)).

Biomethane is received from biogas by its purification. Biogas is produced from biomass by microbiological fermentation called anaerobic digestion and has a methane content of 40-80%. In the EU-28, in 2018 biogas provided only about 1% of the gross inland energy consumption, representing 11% of the total bioenergy and about 6% of the natural gas consumption. In Europe, in 2018, 72% of the more than 18 thousands biogas plants worked in the agricultural sector, thus contributing to the circular bioeconomy. The largest European biogas producers are Germany, Italy and the UK. In the EU-28, in 2018 transport consumed only 2% of the produced biogas (in the form of biomethane) (Bioenergy Europe (2020)). Biomethane has the characteristics of natural gas.

Liquified petroleum gas (LPG) can be received from natural gas and crude oil and its main constituents are propane and butane. LPG is used in internal combustion engines.

Beside the already mentioned relatively low CO_2 emissions (compared to the conventional fossil fuels), natural gas and LPG are available at better regional supply-demand balance, thus it could help the transition to the low carbon economy.

According to a February 2013 EU communication (European Commission (2013))

- LNG is to be used in the EU road-passenger, road-freight, rail, water (inland, short-sea, maritime) transport. In 2011, 83 ports, and 38 road filling stations were in operation. Port refuelling stations are to be installed in all the EU 139 maritime and inland ports by 2020 and resp. 2025 + fixed or mobile truck refuelling stations are to be installed every 400 km along the roads of the TECN – trans European core network
- CNG is to be used in road-passenger, road-freight (excl. long range) transport. In 2011 0.5% of the car fleet used it. Ten-fold increase is foreseen by 2020, EU-wide refuelling points should be established with common standards with max distances of 150 km by 2025
- LPG is used in road-passenger, road-freight, water (inland and short-sea) transport. In 2011 accounts for 3% of motor fuels, core infrastructure is already established; no new action is foreseen in the EU plans

In March 2014 the above listed fixed targets were substituted by ‘appropriate numbers’ by the Council and the Parliament. According to the new wording, national plans and targets should ensure that vehicles running on CNG can move freely in cities and urban areas by the end of 2020; that trucks and other vehicles using liquefied natural gas (LNG) and CNG can move freely along roads in the EU's TEN-T core network by the end of 2025; and that LNG-powered ships can move between TEN-T network maritime ports by the end of 2025 and between TEN-T network inland waterway ports by the end of 2030. These requirements are incorporated in the 2014/94/EU directive on the deployment of alternative fuels infrastructure (see Table 3). The plans should not add any extra costs to member states' budgets. However, they could include incentives and policy measures such as for example building permits, parking-lot permits and fuel-station concessions. These plans and common standards for refuelling installations should create stable conditions and investment security needed by the private sector to develop the infrastructure.

As an EU Transport and Energy official announced in October 2020, “cars that run on …fossil gas emit CO2 shouldn’t be allowed on the market after 2035” (EU T&E (2020)) The driving range of natural gas vehicles’ (NGVs) is generally less than that of comparable diesel or gasoline vehicles due to the lower energy density of natural gas. Extra storage tanks can increase range, but the additional weight may displace cargo capacity” (AFDC (2020)).

According to NGVA (the European Natural and bio Gas Vehicle Association), at the end of May, 2020 there are 3 840 CNG and 280 LNG filling stations in Europe (excl. the Ukraine and Russia), incl. 20 CNG and 1 LNG stations in Hungary. Italy, Germany and the Czech Republic have the largest CNG filling station networks in the region (1 373, 836 and resp. 210) (NGVA-EU (2020)).

According to the IEA, „electricity and liquid biofuels are the main vectors for decarbonising transport, but *biomethane* finds a niche in some countries and sectors." They are „currently displacing around 2 million barrels per day of oil demand. Natural gas is also playing a role in some sectors and countries; there are some 28 million natural gas-fuelled vehicles on the road today, representing around 1% of the global road fleet. This also opens up opportunities for biomethane." „The case for using compressed natural gas (CNG) or LNG for transport is strongest in transport segments where electrification is a more challenging prospect, such as long-haul road freight and shipping. Although the provision of gas fuelling infrastructure adds expense and complexity, there are possibilities to build infrastructure along established routes (for example those used by captive fleets such as municipal buses, refuse collection vehicles, or ferries and cruise ships) or along key transport corridors sustaining a significant portion of tonne- or passenger-kilometre activity."

„Around one-fifth of existing biomethane plants produce either CNG (bio-CNG) or more energy-dense liquefied gas (bio-LNG) for the transport sector, but their use in transport is currently very small. How far and fast this niche role expands depends to a large degree on policy design and the buildout of infrastructure.

The United States is the current leader in this area, due to incentives from the federal Renewable Fuel Standard and California's Low Carbon Fuel Standard. Several countries in Europe are also developing gas-based transport infrastructure; most of Sweden's biomethane production is used in vehicles, giving it the highest share of biomethane use in transport demand. Italy has a well-established natural gas vehicle fleet and an expanding fuelling network, and has recently introduced biomethane blending obligations. India also has ambitious plans to expand the use of biomethane in transport, targeting the buildout of 5 000 bio-CNG stations by 2025. Most of the small quantities of biomethane produced in China today are used in gas-fired vehicles – primarily buses and heavy-duty trucks.
The use of biomethane in transport reaches more than 25 Mtoe in STEPS" (Stated Policy Scenario) „by 2040, or around 30% of total biomethane consumption; a lack of policy commitments elsewhere limits overall growth. In the SDS" (Sustainable Development Scenario), „biomethane consumption in the transport sector is nearly twice as high, with India accounting for the largest share of vehicles running on biomethane by 2040." More precisely, according to the IEA forecast global biomethane demand of transport could reach 26.2 – 44.7 Mtoe by 2040 depending on the scenarios (and in 2025 it could account for 10.7 – 15.7 Mtoe) (IEA (2020A)). According to Shell, LNG bunker (i.e. marine fuel) demand – for the partial substitution of the restricted high sulphur content bunker oil from 2020 – could reach over 30 MTPA by 2040. Number of LNG-fuelled ships would double reaching 385 by 2027 (Shell (2020)),

Fuels	Coverage	Deadline
LNG	Maritime ports in TEN-T core network	End of 2025
	Inland ports in the TEN-T core network	End of 2030
	For HDVs min. along the existing TEN-T core network (every 400 km?)	End of 2025
CNG	In urban/suburban and other densely populated areas: appropriate number of refuelling points (every 150 km?)	End of 2020
	Along the existing TEN-T core network: appropriate number of refuelling points	End of 2025
Hydrogen	For road transport: appropriate number of refuelling points	End of 2025
Electricity	In urban/suburban and other densely populated areas: appropriate number of recharging points	End of 2020
	Additionally on the TEN-T core network	End of 2025

Table 3. Some requirements of EU directive 2014/94/EU on the deployment of alternative fuels infrastructure (TEN-T – Trans-European Network for Transport; HDVs – heavy duty vehicles; MSs – member states) (European Union (2014B))

Biofuels

The EU Renewable energy directive of 2009/28/EC defines biofuels as "liquid or gaseous fuel for transport produced from biomass". "Biomass means the biodegradable fraction of products, waste and residues from biological origin agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste". (Bioliquids means "liquid fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass". Biogas was briefly described in the previouos subchapter.)

According to the EU alternative fuels strategy issued in 2013 (European Commission (2013)) biofuels (liquids) are to be used in road-passenger, road-freight, air, rail, and water transport. [already nearly 6% of the fuel market; *their sustainability shall be ensured (10% of renewables is expected by 2020 according the renewable energy directive RED, 2009/28/EC).*

The EU ILUC directive of 2015 (EU) 2015/1513 (European Union (2015)) set up new targets as follows: 7 energy % cap on food crops biofuels in 2020 + indicative 0.5 e% by using feedstocks land fuels listed in Annex IX/A of the directive; feedstocks listed in Annex IX/A&B are double-counted towards the 2020 target; while ILUC effect is not counted, GHG savings must be must be for existing installations 35% until 31 December 2017 and 50% from 1 January 2018, and for new installations 60% from 5 October 2015. Annex IX/A&B specify 22 fuels and feedstocks.

According to a 2018 EU agreement by the EC, EP and the Council (EU T&E (2018)), from 2021 to the end of 2023 the EU member states shall ensure that 7-14% of their transport fuels come from renewable sources; but contribution of crop-based biofuels (having ILUC impact) shall not exceed 7% and could increase by 1% compared to the 2020 level. Contribution of high ’ILUC-risk’ corp-based biofuels (produced from food and feed crops) is capped at 2019 consumption level.

The revised EU renewable energy directive EU 2018/2001 (European Union (2018)) requests gradual phase out of crop-based biofuels from 7% planned in 2020 to 3.8% in 2030, effectively bringing the conventional biofuel use to pre-2008 levels. Member States may set a lower limit and may distinguish between different types of biofuels for instance by setting a lower limit for the contribution from food or feed crop based biofuels produced from oil crops, taking into account indirect land use change. Additionally, the share of low carbon and renewable fuels in transport should be increased totally up to 6.8% in 2030 through an EU blending mandate: in 2030

- biofuels produced from organic wastes and residues produced with mature technologies as included in Annex IX/B are capped in 1.7%
- advanced biofuels produced from feedstock included in Annex IX/A representing about 0.5% in 2021, should reach 3.6%, and
- renewable electricity, renewable fuels of non-organic origin and other eligible fuels should reach 1.5%
- aviation & maritime fuels are not in the blending obligation but can be used to comply with the obligation with a 1.2 multiplier (EU M&T (2017)).

As an officer of EU Transport and Energy indicated in October, 2020, „cars that run on biofuels… shouldn’t be allowed on the market after 2035” (EU T&E (2020)).

Biofuels are typically blended in conventional fuels (gasoline or gas oil) and sold at conventional refuelling stations.

„The overall production of biofuels in the EU has increased dramatically since the turn of the century, growing from 29.2 petajoules to 649.8 petajoules in 2019. In 2019, the production of biofuels in Europe was highest in Germany at 143.4 petajoules. This was almost 30 petajoules more than France, which produced the second highest volume that year. Germany has around 3.5 percent share of global biofuel production.” They are also used for energy generation and heating (Statista (2020B)). In 2018, as the EU energy statistics indicate, 2 365 ktoe biogasoline and 12 422 ktoe pure biodiesel were produced resulting in total 5.5% share in total liquid transport fuels (biogasoline – 3.8%, biodiesel – 6.5%) (EU Publication Office (2020)).

According to a recent IEA analysis and forecast from 2019 to 2024 (IEA (2019)) „Renewable energy met around 3.7% of transport fuel demand in 2018, with around 4 exajoules (EJ) of consumption. Biofuels provided 93% of all renewable energy, the remainder being renewable electricity. Biofuel output expands 24% (0.9 EJ) over the forecast period (2019-24), while renewable electricity in transport is anticipated to increase 70% (0.2 EJ) with greater use of electrified rail as well as electric vehicles, combined with higher shares of renewables in electricity generation. The biofuel share of renewable energy in transport in 2024 decreases slightly to 90%.”

„By 2024, the renewable energy share of transport demand increases only marginally to 4.6% (5.1 EJ). This increase is relatively small because transport fossil fuel demand also climbs 3% (3 EJ). In addition, most biofuel mandates require blending levels of only 10% or less, although policies in Brazil, Indonesia and Thailand are notable exceptions."

„Global biofuel production increased 10 billion litres (L) in 2018 to reach a record 154 billion L. Double the growth of 2017, this 7% year-on year (y-o-y) increase was the highest in five years. The United States and Brazil were the largest biofuel producers. Biofuel output is anticipated to increase 25% during 2019-24, to reach 190 billion L. The biofuel forecast is revised upwards from last year owing to better market prospects in Brazil, the United States and especially China. Asia accounts for half of growth, as the promise of using biofuels to diversify transport fuel supplies and boost demand for agricultural commodities has resulted in ambitious support policies. The United States and Brazil account for 40% of biofuel output growth over 2019-24, and still provide two-thirds of production by the end of the forecast." „Hydrotreated vegetable oil (HVO) production is set to more than double from around 5.5 billion L in 2018 to 13 billion L in 2024. EU and US policy-driven demand spurs investments of USD 5 billion in new projects. As a result, HVO accounts for one-fifth of forecast biofuel output growth, although still less than 10% of cumulative production in 2024."

Hydrogen

Today, hydrogen is the most often mentioned future transport fuel

Hydrogen, as the 'first element fuel' can be used in vehicles with internal combustion engines and fuel cells (FC) (FCs produce electricity which drives electromotor). Today, the largest consumers of hydrogen are crude oil refining and ammonia production (i.e. the chemical industry). Depending on its feedstock and production method, hydrogen could be classified as

- grey hydrogen produced from natural gas by steam reforming or from coal by gasification with intensive CO_2 emissions; currently, about 96% of hydrogen is produced from fossil fuels by these processes
- blue hydrogen is received from the previous feedstocks but the process also includes carbon capture and storage (CCS), i.e. the sequestration of the emitted CO_2, and
- green hydrogen is received from water by electrolysis using clean energy sources (solar or wind) with zero carbon emissions (WEC (2019)).

The EU requirements for hydrogen fuel, similarly to the biofuels, have changed over time The 2013 year European alternative fuels strategy (European Commission (2013)) lists plans for hydrogen use in fuel cells in the road-passenger, road-freight, rail, water (inland) transports. In 2013, in the EU around 120 hydrogen filling stations were in place. The EU Clean fuel strategy required to form a network with common standards for the EU states which had a hydrogen network (incl. Belgium, France, Germany, Italy, the Netherlands, Sweden, UK). The next year informal agreement of the EU Council and the Parliament fixed that „Member countries that *opt* to include hydrogen-refuelling stations in their national plans will have to ensure that enough of these stations are available to ensure smooth circulation by 2025" (see Table 3). "The plans should not add any extra costs to member states' budgets. However, they could include incentives and policy measures such as for example building permits, parking-lot permits and fuel-station concessions. These plans and common standards for refuelling installations should create stable conditions and investment security needed by the private sector to develop the infrastructure" (European Union (2014A)).

In July, 2020 the responsible EU Commission's vice-president, Mr. Timmermans, F. introduced the European 'Hydrogen strategy for a climate-neutral Europe' (European Commission (2020)). The priority for the EU is to develop renewable hydrogen, produced using mainly wind and solar energy. In the short and medium term, however, other forms of low-carbon hydrogen are needed. A roadmap to 2050:

> ‒"In the first phase, from 2020 up to 2024, the strategic objective is to install at least 6 GW of renewable hydrogen electrolysers in the EU and the production of up to 1 million tonnes of renewable hydrogen, to decarbonise existing hydrogen production… In addition, hydrogen refuelling stations will be needed for the uptake of hydrogen fuel-cell buses and at a later stage trucks. The European Clean Hydrogen Alliance will help build up a robust pipeline of investments
>
> ‒In a second phase, from 2025 to 2030, hydrogen needs to become an intrinsic part of an integrated energy system with a strategic objective to install at least 40 GW of renewable hydrogen electrolysers by 2030 and the production of up to 10 million tonnes of renewable hydrogen in the EU29. In this phase, … dedicated demand side policies will be needed for industrial demand to gradually include new applications, including … trucks, rail and some maritime transport applications, and other transport modes. …The back-bone of a pan-European grid will need to be planned and a network of hydrogen refuelling stations to be established.
>
> ‒In a third phase, from 2030 onwards and towards 2050, hydrogen and hydrogen-derived synthetic fuels, based on carbon neutral CO_2, could penetrate more largely across a wider range of sectors of the economy, from aviation and shipping to hard-to-decarbonise industrial and commercial buildings….

In transport, hydrogen is also a promising option where electrification is more difficult. In a first phase, early adoption of hydrogen can occur in captive uses, such as local city buses, commercial fleets (e.g. taxis) or specific parts of the rail network, where electrification is not feasible. Hydrogen refuelling stations can easily be supplied by regional or local electrolysers, but their deployment will need to build on clear analysis of fleet demand and different requirements for light- and heavy-duty vehicles. Hydrogen fuel cells should be further encouraged in heavy-duty road vehicles, alongside electrification, including coaches, special purpose vehicles, and long-haul road freight given their high CO_2 emissions. The 2025 and 2030 targets set out in the CO_2 Emission Standards Regulation are an important driver to create a lead market for hydrogen solutions, once fuel cell technology is sufficiently mature and cost-effective. Projects of the Horizon 2020 Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) are aiming to accelerate Europe's technological lead.

Hydrogen fuel-cell trains, could be developed to other viable train commercial routes that are difficult or not cost-effective to electrify: about 46 % of the mainline network is still being served by diesel technology today. Certain fuel-cell hydrogen train applications (e.g. Multiple Units) can already be cost competitive with diesel today. For inland waterways and short-sea shipping, hydrogen can become an alternative low emission fuel, especially since the Green Deal emphasises that CO_2 emission in the maritime sector must have a price. Scaling up fuel cell power from one to multiple megawatts and using renewable hydrogen for the production of synthetic fuels, methanol or ammonia - with higher energy density – are required for longer-distance and deep-sea shipping. Hydrogen can become in the longer-term an option to decarbonise the aviation and maritime sector, through the production of liquid synthetic kerosene or other synthetic fuels. These are "drop-in" fuels that can be used with existing aircraft technology, but implications in terms of energy efficiency have to be taken into account. In the longer-term, hydrogen-powered fuel cells, requiring adapted aircraft design, or hydrogen-based jet engines may also constitute an option for aviation.

To realise these ambitions will require a roadmap for the considerable long-term research and innovation efforts, including under Horizon Europe, the Fuel Cell and Hydrogen Joint Undertaking and possible initiatives as part of the Hydrogen Alliance. *The Commission will address the use of hydrogen in the transport sector in the upcoming Sustainable and Smart Mobility Strategy, announced in the European Green Deal and due to be presented before the end of 2020.* The key limiting factor for the use of hydrogen in industrial applications and transport is often the higher costs, including additional investments into hydrogen-based equipment, storage and bunkering facilities. Furthermore, the potential impact of supply chain risks and market uncertainty are amplified by the tight margins for final industrial products due to international competition" (European Commission (2020)).

Some hydrogen mobility initiatives in Europe and beyond

The Scandinavian Hydrogen Highway Partnership, SHHP (2006-) constitutes a transnational networking platform that catalyses and coordinates collaboration between five national networking bodies of Norway, Sweden, Iceland and Finland „The cooperation focus on maintaining a good dialogue with car, truck and bus manufacturers as well as politicians to ensure continued expansion of the Nordic hydrogen infrastructure (SHHP (2020)).

HyFive (Hydrogen for innovative vehicles, 2014) (BMW, Daimler, Honda, Hyundai, Toyota) agreed to deploy a total of 110/185 hydrogen fuel cell vehicles at several European locations (Bolzano, Copenhagen, Innsbruck, London, Munich, Stuttgart) and develop new clusters of hydrogen refuelling stations., Euro 39 million, Activity of HyFive is coordinated by the Greater London Authority. Boris Johnson, major of London that time, said that they want to „demonstrate that hydrogen is a viable option". (HyFive (2014)). Active network builders in Europe are Air Liquide, Daimler, Linde, OMV, Shell, and Total.

Hydrogen Mobility Europe (H2ME) project (September, 2016): „A large coalition of European partners has launched the Hydrogen Mobility Europe project (H2ME) in Sep 2016. H2ME is co-funded with €32 million from the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). The project will support the deployment of Fuel Cell Electric Vehicles (FCEVs) and Hydrogen Refuelling Stations (HRS) across Europe. H2ME is the largest European project of this nature and is based around an alliance of the four most ambitious hydrogen mobility initiatives in Europe: H2 MOBILITY Deutschland, Mobilité Hydrogène France, Scandinavian Hydrogen Highway Partnership and UK H2 Mobility. These initiatives originally brought together the key stakeholders in the hydrogen sector (vehicle manufacturers, hydrogen refuelling station providers and Government representatives), to study and develop strategies to make hydrogen-fuelled transport a reality in the respective regions", with fixed targets ("200 FCEVs, 125 fuel cell range-extended electric (FC RE-EVs) commercial vans and 29 new HRSs (hydrogen refuelling stations) in 10 countries (Austria, Belgium, Denmark, France, Germany, Iceland, Netherlands, Norway, Sweden and the UK) by 2019" (H2ME (2016)). („The three members of the FCH JU are the European Commission, fuel cell and hydrogen industries represented by Hydrogen Europe and the research community represented by the Research Grouping N.ERGHY.")

Hydrogen Council, January, 2017: 13 companies—most currently involved in fuel cells to some extent—announced the creation of the Hydrogen Council, with a mission to "position hydrogen among the key solutions" for carbon-free transportation and energy. Participants include: Air Liquide, Alstom, Anglo American, BMW Group, Daimler, ENGIE, Honda, Hyundai, Kawasaki, Royal Dutch Shell, The Linde Group, Total, and Toyota. Members pledged a combined $10.7 billion investment in vehicle and infrastructure development over the next five years (Edelstein, S. (2017)).

Hydrogen seems to be used in transport modes different from the originally targeted areas. Meanwhile, „Swiss firm ABB has signed a memorandum of understanding with Hydrogène de France (HDF) to develop a "megawatt-scale" power source for large vessels. The maritime system will be based on a stationary power plant developed by ABB and Ballard Power Systems, a manufacturer of the proton exchange membranes used in many fuel cells. HDF will handle manufacturing at a new facility in Bordeaux, France" (Edelstein, S. (2020)). In the air transport, „Airbus has revealed three concepts for the world's first zero-emission commercial aircraft which could enter into service by 2035. These concepts each represent a different approach to achieving zero-emission flight, exploring various technology pathways and aerodynamic configurations in order to support the Company's ambition of leading the way in the decarbonisation of the entire aviation industry. The three concepts – all codenamed "ZEROe" – for a first climate neutral zero-emission commercial aircraft include (all of these concepts rely on hydrogen as a *primary* power source)" (Airbus (2020)).

A 2020 IEA tracking report says that „the fuel cell electric vehicle (FCEV) market is beginning to flourish, catalysed by developments in Asia. The global FCEV stock nearly doubled to 25 210 units at the end of 2019, with 12 350 new vehicles sold – more than doubling the 5 800 purchased in 2018. At the end of 2019, 470 hydrogen refuelling stations were in operation worldwide, an increase of more than 20% from 2018…

Japan remains the leader with 113 hydrogen refilling stations, followed by Germany

(81) and the United States (64). The number of stations in operation expanded considerably in Korea (+20), Japan (+13) and Germany (+12) whereas the United States added only one HRS in 2019. Similar to FCEVs, the number of refuelling stations increased threefold in China in 2019 (from 20 to 61), giving China the fourth-largest number of stations, followed by Korea and France.

In non-road vehicles, new applications are gaining recognition. At the end of 2018, two fuel cell trains produced by Alstom became operational in Germany, and successful trials led to the announcement that another 14 will be put into service in 2021. The United Kingdom and the Netherlands have also shown interest in Alstom hydrogen trains, and a fuel cell tram began operating in Foshan (China) in 2019, with China exploring further possibilities for H_2-fuelled rail" (IEA (2020B)).

„In Europe, there were a total of 177 H2 filling stations at the end of 2019, 87 of which were in Germany. With 26 filling stations, France is in second place in Europe, and with 34 planned filling stations, dynamic expansion is expected to continue. The focus there, however, would be on refuelling buses and fleets of delivery vehicles and less on publicly accessible car filling stations as in the rest of Europe. A significant increase in refuelling facilities is also expected in the Netherlands, where 21 new filling stations are currently in concrete planning. Switzerland has 4 filling stations in operation and 6 more firmly planned… With regard to the worldwide distribution, according to the knowledge of Ludwig-Bölkow-Systemtechnik there were 152 hydrogen dispensing stations in Europe, 136 in Asia and 78 in North America by the end of 2018. Of these 369 filling stations, however, only 273 were public, the other locations were reserved for closed user groups. In 2018 48 hydrogen filling stations went into operation worldwide, 17 of them in Germany. The largest number of public H2 filling stations at that time was in Japan (96), followed by Germany (60) and the USA (42) (electrive-com (2020)).

As one another source indicates, in the middle of November, 2020 there are 117 hydrogen refuelling stations in Europe and erection of 47 other stations is in process. Most of them (88) are operating in Germany, where "The basic network for 700 bar refuelling will grow to 100 in the coming months". There are also 4 operational stations in Austria and 3 in progress phase in the Czech Republic (h2live (2020)).

For comparison, in 2005, the European Hydrogen and Fuel Cell Technology Platform estimated 500 000 FCEVs (incl. 1 000 buses), and 1 000+ hydrogen refilling stations in 2020 in the EU (FCH (2014)).

According to BloombergNEF estimates, at the beginning of 2020 there were worldwide only few fuel-cell vehicles: about 17 000 passenger cars, 4 250 buses and 1 000 commercial vehicles (Bloomberg (2020)).

„Commercialization of hydrogen vehicles has already started for passenger cars, where it is most suitable for larger segments. Three models of FCEVs (Honda Clarity, Hyundai ix35/Tucson Fuel Cell, and Toyota Mirai) are offered commercially in Japan, South Korea, the United States (specifically, California), and Germany, and ten additional models are slated for release by 2020. Ridesharing or taxi services, which require high uptime, could drive early adoption, and ambitious national targets—such as 1.8 million FCEVs on Chinese and Japanese roads by 2030—could create additional momentum. Hydrogen buses are starting to get traction due to concerns about local pollution, particularly in Europe, China, Japan, and South Korea. South Korea plans to convert 26,000 buses to hydrogen, and Shanghai alone plans to purchase and operate 3,000 fuel-cell buses by 2020. Vans and minibuses could also benefit from stringent regulations on delivery vehicles and other commercial fleets in cities. Trucks that carry heavy payloads over long distances are another priority segment. With long ranges and defined routes, they might require less infrastructure: some estimates suggest that 350 filling stations could cover the whole United States. Established manufacturers such as Toyota as well as new start-ups like Nikola Motors have started building heavy-duty and long-haul trucks to capture opportunities in the booming freight-transport industry. Fuel-cell trains could replace many diesel-powered locomotives on nonelectrified tracks. The first fuel-cell tramway is already operating in China, and the first “hydrail” train by Alstom will start taking passengers in Germany by the beginning of 2018. To reach the ambitious 2050 target outlined in the vision, important milestones need to be reached by 2030. The Hydrogen Council estimates that up to one in 12 cars sold in California, Germany, Japan, and South Korea could be powered by hydrogen if major efforts are made to roll out infrastructure and scale up production. Some 50,000 fuel-cell buses and 350,000 fuel-cell trucks could also be on the road globally, saving as much CO2 as some 3.5 million hydrogenpowered passenger cars…A group of regions—led by California, Germany, Japan, and South Korea—is driving developments, spending more than $850 million annually to advance hydrogen and fuel-cell technology… Other countries are following with vigor, including China, which is starting to scale up its own manufacturing capacity alongside its network of refueling stations. Globally, countries have already announced they will build some 2,800 hydrogen refueling stations by 2025. That’s a small number compared with the estimated 600,000 petrol filling stations worldwide, but it would be sufficient to cover the leading markets for hydrogen vehicles if realized (the German initiative H2Mobility estimates that nationwide coverage is reached with 400 stations)” (McKinsey (2017)).

Japan was the first country to adopt a "Basic Hydrogen Strategy" and plans to become a “hydrogen society” (2017). Japan is the host country of the next (2021) Olympics. “The nationwide hydrogen market is expected to grow 56-fold to JPY 408.5 billion (approx. CHF 3,7 billion) by 2030, providing exciting business opportunities…. Increasing demand for hydrogen will have a particular impact on the market for hydrogen filling stations. This market is expected to grow 6.5 times to JPY 37.2 billion (approx. CHF 328 million) by 2030. The number of fueling stations will approximately rise from 111 at present to 581 by 2025, and then to 1.321 throughout Japan by 2030. Toyota, Honda, Nissan, Tokyo Gas and Iwatani Corp. together with 6 other companies, including Japanese infrastructure developers and investment companies, founded the joint venture “Japan H2 Mobility (JHyM)” in 2017 to accelerate the deployment of hydrogen filling stations throughout Japan with the help of government subsidies. In cooperation with the Japanese government, JHyM plans to build a total of 80 new hydrogen filling stations by early 2022. The joint venture now has more than 20 participating companies” (SGE (2020)).

In the **USA**, „USA Senate bill (July 2019), ’America's Transportation Infrastructure Act of 2019’ plans to spend $287 billion on transportation projects (hydrogen, natural gas, ethanol, or even biodiesel stations or other infrastructure) over the next five years, and up to $1 billion of that could go toward projects favoring clean transportation. Most of that money seems more likely to be spent on public electric-car charging stations” (Evarts, E.C. (2019)).

USA House bill (June, 2020), ’INVEST in America Act (Investing in a New Vision for the Environment and Surface Transportation) would allocate $494 billion over five years. The House bill would step Senate bill up to $350 million annually for fiscal years 2022 through 2025—including grants toward electric vehicle charging and hydrogen fueling infrastructure, with funding focused on Alternative Fuel Corridors and “projects that demonstrate the most effective emissions reductions” (Halvorson, B. (2020A)).

In November, 2020 Department of Energy (DoE) of the USA released its ’Hydrogen Program Plan’ to outline high-level focus areas in research, development and demonstration activities on hydrogen technologies. The Plan updates and expands upon previous versions on the topic since 2004. Among the present DOE (Department of Energy) key targets are caps on hydrogen production, delivery, storage, as well as fuel cell system costs (DOE (2020)).

President elect Biden, J. „is proposing to make US electricity production carbon-free by 2035 and to have the country achieve net zero emissions by the middle of the century” (BBC (2020B)).

In April, 2020 in the USA 270 million gasoline&diesel-powered, over 1 million EV and 8 525 FCV cars and 42 FCV buses were reported. The leading FCV states were California and Hawai with 41 and 1 refuelling stations, respectively. The goal is 250 station in California by 2025 and 1 000 is envisioned by 2030. Liquid hydrogen could be better (liquid stations could serve 167−267 cars, gas H stations only 50−67) (Vaughn, M. (2020)).

„In a 15-year plan for new-energy vehicles released on Nov. 2, 2020, **China**’s State Council said the country will focus on building the fuel-cell supply chain and developing hydrogen-powered trucks and buses. President Xi Jinping in September set a 2030 deadline for China to begin reducing carbon emissions… China is targeting to have 1 million fuel-cell vehicles in operation by 2030, according to an energy savings vehicle development plan drafted by authorities, despite only 2,700 such cars selling in the country last year.

As the supply of hydrogen generated by solar and wind power grows, the economics may improve. One utility is spending more than $3 billion on a wind and solar farm in Inner Mongolia that would produce as much as 500,000 tons of hydrogen a year, with operations expected to begin in 2021.

State-owned oil refiner Sinopec said Oct. 29 it’s investing in hydrogen production, transportation and fuel cells and is building hydrogen vehicle refueling stations.

The new infrastructure will likely support hydrogen-powered trucks and buses, with lithium-ion batteries” (i.e. electric vehicles) „remaining dominant for cars. Hydrogen makes sense for commercial vehicles since a fuel-cell automobile can go for longer on a single tank of hydrogen versus a battery-powered one on a single charge of electricity… China would become the No. 1 market within three year (Bloomberg (2020)).

In **Hungary**, the first hydrogen refilling stations would be implemented after 2020. According to the estimations, published recently in the ‘Brochure of FCH Hungary’, “the hydrogen refuelling station network will by 2030 encompass between 80-160 stations for 45 000-90 000 fuel cell vehicles on the road" „With the NECP's" (NECP - National Energy and Climate Plan) „additional measures, Hungary could cover about 1% of its transport needs with hydrogen by 2030, and around 5% in 2040 (for a total of around 30% of renewable energy for transport" (FCH (2020)).

Let us recall **some concerns**. Nobel lauretate professor Olah, G., alumnus and former head of Department of BME and his colleagues argued that hydrogen is not a natural energy source on earth as it is incompatible with the high oxygen content of our atmosphere. Although it creats water when burning, its generation is a highly energy-consuming process. Additionaly, the hydrogen economy must solve not only technical but also social, economical and political problems (Olah, G.A., Goeppert, A. & Surya Prakash, G.K. (2005)). „…hydrogen fuel cells will never live up to their promise" – said Voelcker, J. first editor of Green Car Report (Voelcker, J. (2020)). And a more harsh statement from Musk, E., CEO of the electric vehicle manufacturer Tesla, the world's most valuable automaker (as of 1 July 2020): „Exactly, fuel cell = fool cell" (Musk, E. (2020)).

Advantages of hydrogen fuel are its clean (emission-free) burning. abundant resources in the form of water, relatively high range of FCVs, fast refuelling comparable with fossil liquid fuels and silent operation of the engine. Disadvantages of hydrogen fuel are its lower efficiency (due to high energy losses), high flammability and explosiveness, the present poor infrastructure of refilling stations, and relatively high costs related to purchase and maintaining (Kane, M. (2020)).

Electricity

Tipically, electric energy is stored in a battery pack and powers an electric motor to turn the wheels. Today, the most frequently used batteries ar lithium-ion batteries (Li is the lightest metal and the least dense solid element). Electric vehicles (EVs) could be classified as

- hybrid (HEV), comprised from an internal combustion engine (ICE) and an electric motor; its battery is charged by the ICE and through regenerative braking
- plug-in hybrid (PHEV), it is a HEV whose battery could be also recharged from an external power source of electric energy, and
- battery electric vehicle (BEV), using exclusively energy stored in the rechargeable battery pack (i.e. no ICE).

Renewable energy is preferred when generating electricity. Some may remember Swiss pilots' around-the-world *solar flight*. Their plane, Solar Panel 2 was "powered by 17,000 solar panels set on its wings (which are wider than a Boeing 747's) and fuselage. A 633kg bank of lithium batteries, around a quarter of the entire weight"… stored „the energy to run the motors overnight" (Guardian (2015)). The successful journey of pilots Bertrand Piccard and Andre Borschberg from Abu Dhabi to Abu Dhabi „took a very long time—505 days to fly 26,000 miles (42,000 km) at an average speed of about 45 mph (70 kph)" (Atlantic (2006)). On Philippine waters *wave energy is used in shipping*. „The hybrid trimaran has this machinery – a wave energy converter – in the form of hydraulic pumps integrated into its outriggers. As the pumps move through the waves, they harvest the momentum of these waves, converting their kinetic energy into electrical energy, which will then be fed into a generator that will supply electricity to the ship. The electricity then provides propulsion via a motor" (BBC (2020A)).

The 2013 Europe alternative fuels strategy required more electic vehicles in short-range road (passenger and freight) and rail transport and (fixed) significant increase of recharging points using a common standard plug by 2020 (European Commission (2013)).

The 2014 EU Council and Parliament informal agreement substituted fixed targets by 'appropriate numbers', stating that "National plans and targets should ensure that electric cars can move freely in cities and urban areas by the end of 2020…The plans should not add any extra costs to member states' budgets. However, they could include incentives and policy measures such as for example building permits, parking-lot permits and fuel-station concessions. These plans and common standards … for recharging installations should create stable conditions and investment security needed by the private sector to develop the infrastructure" (European Union (2014A)).

The 2014 EU directive on the deployment of alternative fuels infrastructure requires member states' actions „in order to ensure that electric vehicles can circulate at least in rban/suburban agglomerations and other densely populated areas, and, where appropriate, within networks determined by the Member States. The number of such recharging points shall be established taking into consideration, inter alia, the number of electric vehicles estimated to be registered by the end of 2020, as indicated in their national policy frameworks, as well as best practices and recommendations issued by the Commission. Particular needs related to the installation of recharging points accessible to the public at public transport stations shall be taken into account, where appropriate." Furthermore, it should be also ensured, „that an additional number of recharging points accessible to the public are put in place in each Member State by 31 December 2025, at least on the TEN-T Core Network, in urban/suburban agglomerations and other densely populated areas" (see Table 3) (European Union (2014B)).

Today, electric vehicles are also to be used in shipping operations and aviation.

Now, electric vehicles are much more popular as measured by their number and recharging network extension, than the hydrogen-driven fuel cell vehicles. Demand is often influenced by specific incentives e.g. subsidies, toll exemptions and parking fees.

A critical point in the evaluation of electric vehicles is the battery price. „The cost of batteries for electric vehicles is falling markedly. Industry reports show that sales-weighted battery pack prices in 2019 were an average of USD 156 per kilowatt-hour, down from more than USD 1 100/kWh in 2010. The average battery pack size across electric light-duty vehicles sold (including battery electric vehicles and plug-in hybrid electric vehicles) continues an upwards trend; it is now 44 kWh, up from 37 kWh in 2018, and battery electric cars in most countries are in the 50-70 kWh range. This increase is driven by two trends: battery electric vehicle models with longer ranges are becoming available and are increasingly in demand, and the share of battery electric vehicles relative to plug-in hybrid electric vehicles is rising" (IEA (2020C)). One another issue is the future supply of the catode elements (lithium, cobalt, nickel) for the lithium-ion batteries.

According to the recent (June 2020) IEA 'Global EV outlook 2020', „Sales of electric cars (BEV and PHEV) topped 2.1 million globally in 2019, surpassing 2018 – already a record year – to boost the stock to 7.2 million electric cars. 47% of which were in The People's Republic of China ("China"). Nine countries had more than

100 000 electric cars on the road. At least 20 countries reached market shares above 1%. … Electric cars, which accounted for 2.6% of global car sales and about 1% of global car stock in 2019, registered a 40% year-on-year increase….With 90% of global electric car sales concentrated in China, Europe and the United States… In 2019, there were about 7.3 million chargers worldwide, of which about 6.5 million were private, light-duty vehicle slow chargers in homes, multi-dwelling buildings and workplaces". There were 598 000 publicly accessible slow chargers (52% of them in China), and 264 000 publicly accessible fast charger (82% in China). In Europe, most of the publicly accessible chargers were operating in Netherlands, France, UK, Germany and Norway. Furthermore, „about half a million electric buses are in circulation, most of which are in China." „Global sales of electric trucks hit a record in 2019 with over 6 000 units, while the number of models continue to expand... Electrification of shipping operations at ports is increasingly common and is gradually being mandated by legislation in Europe, China, and, in the United States, California. In aviation, electric taxiing (i.e. the electrification of ground operations in aircraft) offers immediate potential for pollutant and CO2 emissions reductions and operational cost savings for airlines" (IEA (2020C)).

In Hungary, in 2019 above 7 000 vehicles with electric drive were sold, reaching 6% market share in total sales and raising their stock near to 17 000 (incl. above 7 000 EVs). Hungary's declared objective is to turn the country into a leader within Central Europe in the field of e-mobility. According to the Jedlik Anyos Plan and Cluster what is to facilitate this process, in the case of a realistic spread by the end of 2020 the total electric vehicle stock should reach 21 000, in 2025 – over 81 000 and in 2030 – over near 182 000. Actually, in the first ten months of 2020 over 8 600 HEVs and PHEVs, and 2 200 EVs were sold in Hungary, representing 11% of the new car total sales. In this period of the year more electric driven vehicle was sold in Hungary than diesel fuel driven ones (Portfolio (2020); Infostart (2020)).

In 2019, more than 170 000 charging stations were in service in Europe (Statista (2020C)). „Even though Europe has seen a stark increase in the available infrastructure for charging PEVs…, the number of PEVs per charging station has increased from two in 2010 to 9 in 2020" (Statista (2020D)). There were 747 PEV chargers in Hungary as of 2020, among them 592 normal charge (not exceeding 22 kW) (Statista (2020E)).

„Between 2019 and 2026, the size of the global electric vehicle market is expected to increase almost five-fold to reach an estimated global market size of 567 million U.S: dollars in 2026. This translattes to a noteable compaund annual grotwth rate (CAGR) of around 15.6% between 2019 and 2026" (Statista (2020A)).

IEA foresees that the global electric vehicle stock would account for about 138 million (about 55% of them are BEVs), reaching a 7% market share in 2030 on the basis of the stated policies of the related countries. Their „ Sustainable Development Scenario, which is fully compatible with the climate goals of the Paris Agreement… incorporates the targets of the EV30@30 Campaign to collectively reach a 30% market share for electric vehicles in all modes except two-wheelers by 2030" (this would mean about 240 million EVs) (IEA (2020C)). According to a recent IEA analysis and forecast from 2019 to 2024 (IEA (2019)) „… renewable electricity in transport is anticipated to increase 70% (0.2 EJ) with greater use of electrified rail as well as electric vehicles, combined with higher shares of renewables in electricity generation" (Halvorson, B. (2020B)).

According to a EU Transport and Energy (T&E) officer's recent (October, 2020) announcement, under the impact of the EU fleet-wide CO_2-emissions target (g CO_2 per km), in the EU following the 2019 EU passenger EV market share of about 3%, in 2020 „standards are driving electric cars towards 10% of sales and 15% in 2021…„electric car sales are booming". The officer urged the introduction of more ambitious CO_2 emissions targets for 2025 and 2030. „T&E said the EU needed to set 2035, as the latest, as the end date for sales of combustion engines – including current PHEV technology" (EU T&E (2020)).

Let us mention one new intitative. In November, 2020, 28 businesses (led by Tesla) „which empoly hundreds of thousands of workers across all 50 USA states launched the Zero Emission Transportation Association (ZETA) advocating for national policies that will enable 100% electric vehicle sales throuhout the light-, medium-, and heavy-duty sectors by 2030....ZETA is calling for five key policy pillars that can, in aggregate, put America on the pathway to full EV adoption by 2030…:

- Outcome-driven consumer EV incentives…
- Emissions / performance standards enabling full electrification by 2030…
- Infrastructure investments…
- Domestic manufacturing…
- Federal leadership and cooperation with sub-national entities" (Zeta (2020)).

Advantages of the elecricity driven vehicle are: „battery technology is nearly ready", „infrastructure is simpler and cheaper", „battery trucks ar easier to design" (Beedham, M. (2020)), furthermore, they maybe zero-emission, low noise (may be controversial, e.g. Nissan Leaf incorporates vehicle sound for pedestrian) and easier driving (instant torque, strong and smooth acceleration). Concerns, connected to the EVs include range anxity, durability of batteries, recharging time, total cost of ownership.

CONCLUSIONS

Alternative transport fuels can contribute to the carbon-free economy. The presently known alternative fuel types are under assessment. In the EU some of them, first of all the carbon based alternative fuels (natural gas, biogas, LPG, biofuel) would be withdrawn by 2035. Presently it seems that the future belongs to the green hydrogen-driven fuel cell and the green electricity driven electric vehicles. Economic viability of these alternative fuels and their vehicles will be decisive.

REFERENCES

Airbus (2020): Airbus reveals new zero-emission concept aircraft, viewed 30 November 2020, https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html.

ADAC (2019): Elektroautos brauchen die Energiewende: Die Klimabilanz, viewed 26 Aug., 2019, https://www.adac.de/verkehr/tanken-kraftstoff-antrieb/alternative-antriebe/co2-treibhausgasbilanz-studie/.

AFDC (2020): Emerging alternative fuels, viewed 29 November, 2020, https://afdc.energy.gov/fuels/emerging.html.

Atlantic (2016): Flying Around the World in a Solar Powered Plane, viewed 30

November 2020, https://www.theatlantic.com/photo/2016/07/flying-around-the-world-in-a-solar-powered-plane/493085/#:~:text=The%20journey%20took%20a%20very,the%20power%20of%20the%20Sun.

BBC (2020A): The revolutionary boat powered by the ocean, viewed 30 November 2020, https://www.bbc.com/future/article/20200718-the-revolutionary-electric-boat-powered-by-the-ocean).

BBC (2020B): Joe Biden: How the president-elect plans to tackle climate change, viewed 30 November 2020, https://www.bbc.com/news/science-environment-54858638.

Beedham, M. (2020): 3 reasons why batteries will power our future trucks, not hydrogen fuel cells, *SHFT*, viewed 30 November 2020, https://thenextweb.com/shift/2020/11/26/3-reasons-why-batteries-will-power-our-future-trucks-not-hydrogen-fuel-cells/.

Bioenergy Europe (2019): Statistical Report 2019, viewed 11 July, 2019, https://bioenergyeurope.org/wp-content/uploads/2019/07/SR19-Biofuels-FULL.pdf.

Bioenergy Europe (2020): Biogas. Statistical Report 2020, viewed 29 November, https://bioenergyeurope.org/article.html/250.

Bloomberg (2020): China Defies Elon Musk's Warnings and Pushes Ahead With Hydrogen, viewed 30 November 2020, https://finance.yahoo.com/news/china-defies-elon-musk-warnings-210000644.html.

Brussels Times (2019): Electric vehicles emit more CO2 than diesel ones, german study says, viewed 29 November 2020,,http://brusselstimes.com/business/technology/15050/electric-vehicles-emit-more-co2-than-diesel-ones,-german-study-shows.

Chandler, D.L. (2019): What's the best way to cut vehicle greenhouse-gas emissions? PhysOrg, viewed 27 Aug., 2019, https://phys.org/news/2019-08-vehicle-greenhouse-gas-emissions.html.

DOE (2020): Hydrogen program plan, viewed 30 November 2020, https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf).

Edelstein, S. (2017): Carmakers, fuel and oil companies form Hydrogen Council to promote fuel cells, *Green Car Reports,* January 31, viewed 30 November 2020, https://www.greencarreports.com/news/1108621_carmakers-fuel-and-oil-companies-form-hydrogen-council-to-promote-fuel-cells.

Edelstein, S. (2020): Megawatt-scale fuel cell agreement could bring large hydrogen-powered ships, *Green Car Reports,* April 10, viewed 30 November, https://www.greencarreports.com/news/1127769_megawatt-scale-fuel-cell-agreement-could-bring-large-hydrogen-powered-ships.

electrive-com (2020): 83 hydrogen gas station went online in 2019, viewed 30 November 2020, https://www.electrive.com/2020/02/19/83-fuel-cell-gas-stations-went-online-in-2019/.

EPA (2017): Renewable fuel standard program. Alternative fuels, viewed 29 November, 2020, https://www.epa.gov/renewable-fuel-standard-program/alternative-fuels#:~:text=Alternative%20Fuels,%2Dderived%20oils%3B%20and%20electricity.

EPA (2020): Natural gas, viewed 29 november 2020, https://www.fueleconomy.gov/feg/bifueltech.shtml).

European Commission (2013): Communication – Clean power for transport: A European alternative fuels strategy, viewed 29 November, 2020, https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2013:0017:FIN:EN:PDF.

European Commission (2017): Impact assessment, viewed 29 November, 2020, https://eur-lex.europa.eu/legal-content/ET/TXT/?uri=CELEX:52017SC0650.

European Commission (2019): Sustainable mobility, viewed 29 November, 2020, https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6726.

European Commission (2020): Communication – A hydrogen strategy for a climate-neutral Europe, viewed 30 November 2020, https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf.

European Union (2014A): EU Council and Parliament informal agreement on clean power for transport, viewed 20 March, 2014, http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-%2f%2fEP%2f%2fTEXT%2bIMPRESS%2b20140317IPR39144%2b0%2bDOC%2bXML%2bV0%2f%2fEN&language=EN.

European Union (2014B): Directive on the employment of alternative fuels infrastructure, viewed 29 November, 2020, https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32014L0094&rid=5#d1e743-1-1.

European Union (2015): Directive … on the promotions of the use of energy from renewable sources, viewed 29 November 2020, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L1513&from=ro.

European Union (2018): Directive on the promotion of the energy from renewable sources (recast), viewed 29 November, 2020, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN).

EU M&T (2017): EU biofuels policy, viewed 29 november 2020, https://www.icao.int/Meetings/altfuels17/Documents/5%20-%20PVis_03Feb.pdf).

EU Publication Office (2020): EU energy in figures. Statistical pocketbook 2020. viewed 29 November 2020, https://op.europa.eu/en/publication-detail/-/publication/87b16988-f740-11ea-991b-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search.

EU T&E (2018): EU ends target for food-based biofuels…, viewed 29 Nevember 2020, https://www.transportenvironment.org/press/eu-ends-target-food-based-biofuels-and-phases-out-palm-oil-cars-only-2030.

EU T&E (2020): Electric cars will treble market share this year as most carmakers on track to meet EU emissions target – analísis, viewed 29 November 2020, https://www.transportenvironment.org/press/electric-cars-will-treble-market-share-year-most-carmakers-track-meet-eu-emissions-targets.

Evarts, E.C. (2019): Senate bill includes up to USD 1 B for clean car infrastructure, *Green Car Reports,* viewed 30 November 2020, https://www.greencarreports.com/news/1124310_senate-bill-includes-up-to-1b-for-clean-car-infrastructure.

Farm Energy (2019), What is direct land use, or direct land use change?, viewed 29 November, 2020, https://farm-energy.extension.org/what-is-direct-land-use-or-direct-land-use-change/.

FCH (2014): FCV technologies in Europe, viewed 13 April 2017, http://www.fch-ju.eu/sites/default/files/111026%20FCH%20technologies%20in%20Europe%20%20Financial%20and%20technology%20outlook%202014%20-%202020_0.pdf.

FCH (2020): Opportunities for hydrogen energy technologies… – Hungary, viewed 30 November 2020, . https://www.fch.europa.eu/sites/default/files/file_attach/Brochure%20FCH%20Hungary%20%28ID%209473092%29.pdf.

Green Car Reports (2017): viewed 11 Oct, 2017, https://www.greencarreports.com/news/1113175_electric-cars-win-on-energy-efficiency-vs-hydrogen-gasoline-diesel-analysis.

Greenhouse Gas Protocol (2014): CO_2 emissions, viewed 10 Feb, 2014, www.ghgprotocol.org/files/ghgp/tools/co2-mobile.pdf.

Guardian (2015): Swiss pilots attempt first around-the-world solar flight, viewed 30 November, 2020, https://www.theguardian.com/environment/2015/mar/08/swiss-pilots-attempt-worlds-first-around-world-solar-flight.

Halvorson, B. (2020A): EV charging, carbon reduction included in USD 500 B transportation infrastructure bill, *Green Car Reports,* viewed 30 November 2020, https://www.greencarreports.com/news/1128396_ev-charging-carbon-reduction-included-in-500b-transportation-infrastructure-bill.

Halvorson, B. (2020B): Why a Biden presidency will accelerate change to electric cars: 10 talking points, *Green Car Reports*, viewed 30 November 2020, https://www.greencarreports.com/news/1130224_why-biden-presidency-electric-cars-auto-industry-10-talking-points.

HyFive (2014): viewed 13 April, 2017, http://www.hyfive.eu/latest-news/gallery-post-tpye/.

h2live (2020): Filling up with H2, viewed 30 November, 2020, https://h2.live/en.

H2ME (2016): viewed 17 April, 2016, http://www.itm-power.com/news-item/hydrogen-mobility-europe-launched-with-e32m-funding.

IEA (2002): Renewable Energy…into the mainstream, viewed 29, November 2020, https://library.um.edu.mo/ebooks/b1362376x.pdf.

IEA (2019): Renewables 2019, viewed 29 November, 2020, https://www.iea.org/reports/renewables-2019/transport.

IEA (2020A): Outlook for biogas and biomethane: Prospects for organic growth, viewed 29 November 2020, https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/the-outlook-for-biogas-and-biomethane-to-2040).

IEA (2020B): Hydrogen – Tracking report, viewed 30 November 2020, https://www.iea.org/reports/hydrogen.

IEA (2020C): Global EV outlook, viewed 30 november 2020, https://www.iea.org/reports/global-ev-outlook-2020.

IEA, OECD, EUROSTAT (2004): Energy Statistics Manual, viewed 29 November, 2020, https://ec.europa.eu/eurostat/ramon/statmanuals/files/Energy_statistics_manual_2004_EN.pdf.

Infostart (2020): (in Hungarian) viewed 30 November 2020, https://infostart.hu/belfold/2020/11/17/leeloztek-az-elektromos-autok-a-dizeleket.

International Windship Association (2020): Wallenius Marine AB, viewed 29 November, 2020, http://wind-ship.org/wallenius-marine-ab-iwsa-member/

JRC (2015): Estimates of indirect land use change from biofuels based on historical data, viewed 29 November, 2020, https://publications.jrc.ec.europa.eu/repository/bitstream/JRC91339/eur26819_online.pdf.

Kane, M. (2020): Battery Electric Vs Hydrogen Fuel Cell: Efficiency Comparison, *InsideEVs*, viewed 30 November 2020, https://insideevs.com/news/406676/battery-electric-hydrogen-fuel-cell-efficiency-comparison/.

McKinsey (2017), Hydrogen: The next wave for electric vehicles?, viewed 30 November 2020, https://www.mckinsey.com/~/media/McKinsey/Industries/Automotive%20and%20Assembly/Our%20Insights/Hydrogen%20The%20next%20wave%20for%20electric%20vehicles/Hydrogen-the-next-wave-for-electric-vehicles-final.pdf?shouldIndex=false).

Musk, E. (2020): (on Twitter) viewed 30 November 2020, https://twitter.com/elonmusk/status/1270991790401699841?lang=en.

NGVA-EU (2020): Statitions map, viewed 29 November, 2020, (https://www.ngva.eu/stations-map/)

Oceanbird (2020): The future started a long time ago, viewed 29 November 2020, https://www.oceanbirdwallenius.com/the-vessel/.

Olah, G.A., Goeppert, A. & Surya Prakash G.K. (2005): Beyond oil and gas: The methanol economy, John Wiley and Sons.

Portfolio (2020): (in Hungarian) viewed 30 November 2020, https://www.portfolio.hu/gazdasag/20200519/breking-holnap-bejelenti-a-kormany-az-olcso-elektromos-autok-nagyobb-tamogatasat-432654.

Searchinger, T. et al. (2008): Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change, *Science*, vol. 319, issue 5867, pp. 1238-1240.

SEforAll (2013): Ch. 4. Renewable energy, viewed 29 November, 2020, https://www.seforall.org/sites/default/files/l/2013/09/9-gtf_ch4.pdf.

SGE (2020): Japan, the new hydrogen nation, viewed 30 November 2020, https://www.s-ge.com/en/article/global-opportunities/20201-c5-japan-hydrogen-market.

Shell (2020), LNG outlook 2020, viewed 29 November 2020, https://www.shell.com/promos/overview-shell-lng-2020/_jcr_content.stream/1584588383363/7dbc91b9f9734be8019c850f005542e00cf8ae1e/shell-lng-outlook-2020-march.pdf.

SHHP (2020): The Scandinavian Hydrogen Highway Partnership, viewed 30 November 2020, http://www.nordichydrogenpartnership.com/shhp/about-shhp./

Statista (2020A): Size of the global market for electric vehicles in 2019 and 2026, viewed 30 November 2020, https://www.statista.com/statistics/271537/worldwide-revenue-from-electric-vehicles-since-2010/.

Statista (2020B): Biofuels production in selected European countries 2019, viewed 29 November 2020, https://www.statista.com/statistics/332510/biofuels-production-in-selected-countries-in-europe/#:~:text=The%20overall%20production%20of%20biofuels,to%20649.8%20petajoules%20in%202019.&text=Biofuels%20are%20fuels%20derived%20from,an%20alternative%20to%20fossil%20fuels.&text=The%20main%20biofuels%20are%20bioethanol%20and%20biodiesel.

Statista (2020C): Number of public electric vehicle charging stations in Europe from 2010 to 2019, viewed 30 November 2020, https://www.statista.com/statistics/955443/number-of-electric-vehicle-charging-stations-in-europe/.

Statista (2020E): Number of electric vehicle charging stations in Hungary from 2013 to 2020, by type, viewed 30 November 2020, https://www.statista.com/statistics/933078/number-of-electric-vehicle-charging-stations-in-hungary/.

Vaughn, M. (2020): 10 Things You Didn’t Know about Hydrogen Fuel Cell Vehicles in America, *Autoweek*, viewed 30 November 2020, https://www.autoweek.com/news/technology/g32203425/10-things-about-hydrogen-fuel-cell-vehicles-in-america/.

Voelcker, J. (2020): Why we still can’t deliver on the promise of hydrogen cars, *Drive,* viewed 30 November 2020, https://www.thedrive.com/tech/33408/why-we-still-cant-deliver-on-the-promise-of-hydrogen-cars.

WEC (2019): New hydrogen economy – hope or hype, viewed 30 November, 2020, https://www.worldenergy.org/assets/downloads/WEInsights-Brief-New-Hydrogen-economy-Hype-or-Hope-ExecSum.pdf

Zeta (2020): Clean Transportation Leaders Launch Zero Emission Transportation Association, viewed 30 November 2020, https://www.zeta2030.org/news/clean-transportation-leaders-launch-zero-emission-transportation-association/.

On the treshold of a new world – The hydrogen economy

INTRODUCTION

A recent IEA report (‚The future of hydrogen', June, 2019, https://www.iea.org/publications/reports/thefutureofhydrogen/): says „Hydrogen has never enjoyed so much international and cross-sectoral interest…"

According to a Japan evaluation, „In a future clean energy system, hydrogen and electricity could be complementary energy carriers, since electricity can be readily transformed into hydrogen and back again. Hydrogen could therefore help solve problems of intermittent renewable electricity generation by providing a means of storing energy over time and transporting it over long distances. However, formidable technical problems around production, distribution and storage need to be overcome (June, 2019, http://the-japan-news.com/news/article/0005838818).

In August 2020, the UK-based research and consulting firm Wood Mackenzie declared „the 2020s the decade of hydrogen" (https://oilprice.com/Energy/Energy-General/Australia-Pivots-To-Hydrogen-In-Carbon-Neutral-Push.html).

A September, 2020 study of WeltEnergieRat-De and Ludwig Bölkov Systemtechnik reported that „major economies around the globe are currently assessing their position and are discussing, preparing, and agreeing on dedicated hydrogen strategies… In a high-level review of countries representing over 90% of global GDP we found that 20 countries representing 44% of global GDP already have passed a national hydrogen strategy or are on the verge of doing so. Additionally, another 31 countries (another 44% of global GDP) are supporting national projects and discussing policy action. Main drivers are GHG emission reduction goals, the integration of renewables, as well as the opportunity for economic growth" (https://www.weltenergierat.de/wp-content/uploads/2020/09/WEC_H2_Strategies_finalreport_200922.pdf).

THE BASICS

Depending on its feedstock and production method, hydrogen could be classified as

- grey hydrogen produced from natural gas by steam reforming or from coal by gasification with intensive CO_2 emissions; currently, about 96% of hydrogen is produced from fossil fuels by these processes
- blue hydrogen is received from the previous feedstocks but the process also includes carbon capture and storage (CCS), i.e. the sequestration of the emitted CO_2, and
- green hydrogen is received from water by electrolysis using clean energy sources (solar, wind, tide, hydropower) with zero carbon emissions (https://www.worldenergy.org/assets/downloads/WEInsights-Brief-New-Hydrogen-economy-Hype-or-Hope-ExecSum.pdf; http://www.bbc.com/future/story/20190516-the-islands-turning-the-tide-electric).

Hydrogen is odorless and tasteless gas, and highly combustible. It is abundant and burns with oxigen creating only water vapour. Its heat value (120-142 MJ/kg) is 3–4 times higher than of natural gas, gasoline and diesel fuel. Generally, 'green' hydrogen can be produced from water by electrolysis using renewable energy sources (solar, wind). Presently, „making hydrogen using electrolysis is thermodynamic lunacy… Put in 30kjoules and get 10kjoules back?" (Smith, W., https://community.oilprice.com/topic/21517-is-it-time-to-talk-about-hydrogen/). The imagined new future hydrogen economy needs heavy research and development, and investments.

There are problems, connected to the production, physical storage and transport of hydrogen.

Production

Actual „demand for pure hydrogen is around 70 Mt per year, mostly for oil refining and chemical" production" (the latter mainly covers ammonia and methanol) and steel manufacturing (https://www.iea.org/reports/hydrogen). (New sectors, like transport, domestic heating and power generation increase the demand.) Hydrogen can be manufactured by conventional technologies, water electrolysis and waste gasification (in laboratory scale), and newer technologies as a result os the continuous research and development.

Presently, it is *produced* dominantly from hydrocarbons (or coal) by *conventional technologies*: by steam methane reforming (SMR), partial oxidation of liquid hydrocarbons (POx), and autothermal reforming of hydrocarbons, all accompanied with high energy consumption and CO_2-emissions. In case of steam biomethane reforming biohydrogen is received (biomethane is recovered from biogas). „Coupling conventional technologies with CCUS (carbon capture and utilization or storage) is still the main route for low-carbon hydrogen production and will likely remain so in the short to medium term because production costs are lower than for other low-carbon technologies such as electrolysis. Interest in projects that combine conventional technologies with CCUS is growing. Six projects, with a total annual production of 350 000 tonnes of low-carbon hydrogen, were in operation at the end of 2019, and more than 20 new projects have been announced for commissioning in the 2020s, mostly in countries surrounding the North Sea" (https://www.iea.org/reports/hydrogen).

Further production method is the presently relatively costly *water electrolysis* (*Olah*, G.A., Goeppert, A. & Surya Prakash G.K. (2005): Beyond oil and gas: The methanol economy, John Wiley and Sons.). Some national and regional strategies prefer renewable electricity based water electrolysis and target significant individual capacity increases and cost reductions. A recent IHS Market study foresees 2030 when hydrogen price from the high capacity renewable electricity based electrolysis would be in the range (of about 1.8–3.1 Euro/L) of the hydrogen price received through steam methane reforming and subsequent carbon capture and storage (see Figure 1). Let us recall, that the energy in 1 kilogram of hydrogen gas is about the same as the energy in 1 gallon (2.8 kilograms, about 3.7 litres) of gasoline (https://afdc.energy.gov/fuels/hydrogen_basics.html#:~:text=The%20energy%20in%202.2%20pounds,driving%20range%20of%20conventional%20vehicles).

Others also forecast significant hydrogen price drops. „Cost to produce the fuel" (i.e. hydrogen) „is seen falling up to 80% by 2030."..However, „without political support, a hydrogen economy wouldn't likely develop, leading to a slight rise in electrolyzers in

2050"(https://www.bloomberg.com/news/articles/2019-08-21/cost-of-hydrogen-from-renewables-to-plummet-next-decade-bnef). „Green hydrogen costs will fall by up to 64% by 2040, according to new research from Wood Mackenzie (https://www.woodmac.com/press-releases/green-hydrogen-costs-to-fall-by-up-to-64-by-2040/).

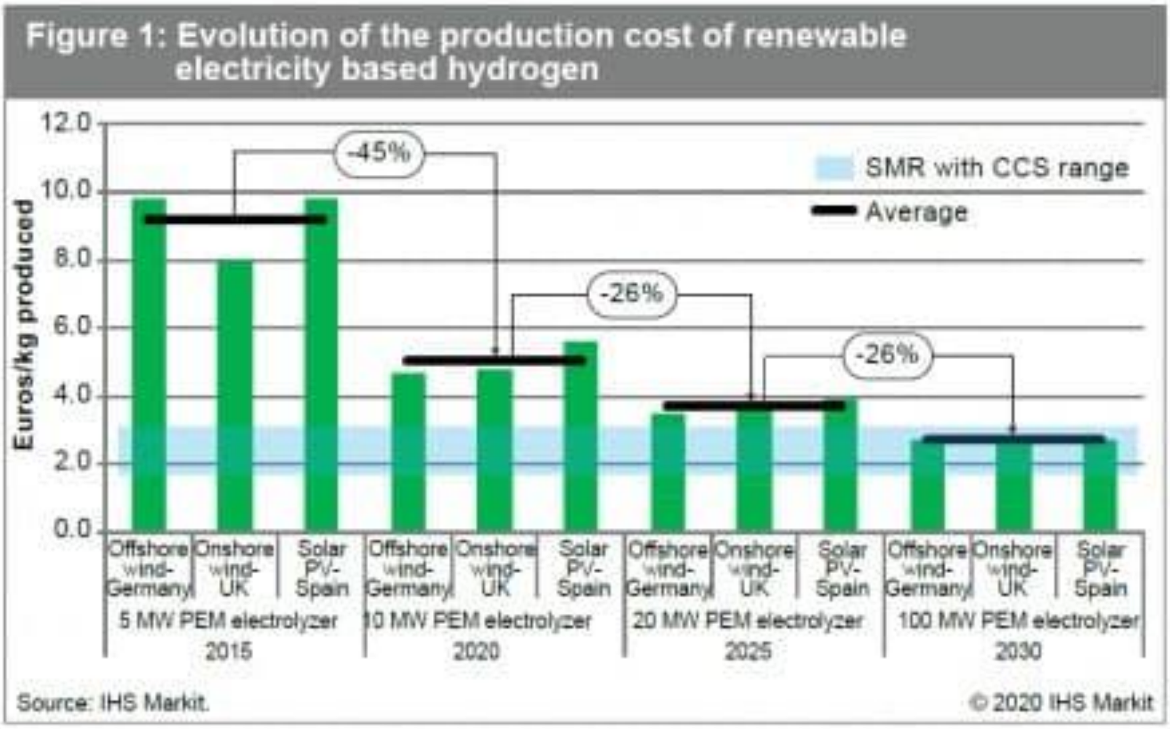

Fig. 1. Forecasted cost reduction (and capacity increase) of renewable electricity based hydrogen production compared to the cost of hydrogen produced through steam methane reforming plus CO_2 capture and storage (CCS). (PEM - polimer electrolyte membrane) (https://oilprice.com/Alternative-Energy/Fuel-Cells/Hydrogen-Fuel-Economy-Is-Finally-Going-Mainstream.html)

„In recent years, the number of projects and installed electrolyser capacity have expanded considerably, from less than 1 MW in 2010 to more than 25 MW in 2019. Furthermore, project size has increased significantly: most projects in the early 2010s were below 0.5 MW, while the largest in 2017–19 were 6 MW and others fell into the 1 MW to 5 MW range. In March 2020, a 10 MW project started operation in Japan, and a 20-MW project in Canada is under construction. Plus, there have been several announcements for developments in the order of hundreds of MWs that should begin operating in the early 2020s …As alkaline electrolysers are the most mature electrolysis technology, they dominate the market, especially for large-scale projects (both already operational and announced). However, many new projects are now opting for polymer electrolyte membrane (PEM) designs. PEM electrolysers are at an earlier stage of development than alkaline electrolysers, but they can operate more flexibly and are therefore more compatible with variable renewable electricity generation. Projects involving high-efficiency solid oxide electrolyser cells (SOECs) are also beginning to be announced, nearly all of them in Europe to produce synthetic hydrocarbons. However, electrolyser users remain divided over whether the operational benefits of PEMs (flexibility) and SOECs (efficiency) are worth the additional costs compared with alkaline electrolysers" (https://www.iea.org/reports/hydrogen).

From hydrogen produced using renewable electricity and carbon dioxide recovered from industrial exhaust gases or from the air, electrofuels (also called E-fuels, synthetic fuels, power-to-liquid - PtL) can be received (Concawe Review, vol. 28, no. 1, pp. 4, 5.).

SGH2's patented new *waste gasification* (waste-to-fuel – WtF) process, 'Solena Plasma Enhanced Gasification' (SPEG) accoordingly processes any kind of waste. „The unique gasification process uses a plasma-enhanced thermal catalytic connversion process optimized with oxigen-enriched gas. In the gasification island's catalyst-bed chamber, plasma torches generate such high temperatures (3 500–4 000°C), that the waste feedstock disintegrates into its molecular compaunds, wihout combustion ash or toxic fly ash. As the gases exit the catalyst-bed chamber, the molecules bound into a very high quality hydrogen-rich biosyngas free of tar, soot and heavy metalls. The syngas then goes through a Pressure Swing Absorber system resulting in hydrogen at 99.9999% purity…The end result is high purity hydrogen and a small amount of biogenic carbon dioxide, which is not additive to greenhouse gas emissions….SGH2 is in negotiations to launch similar projects in France, Saudi Arabia, Ukraine, Greece, Japan, South Korea, Poland, Turkey, Russia, China, Brazil, Malaysia and Australia" According to the company, hydrogen can be produced at a cost of USD 2/kg which is comparable with the cost of hydrogen received by SMR (https://www.sgh2energy.com/technology). Due to the long and unsuccessful attempt to commercialise plasma technology, SGH2's announcement should be handled with due care and reservations (see comments to https://www.greencarcongress.com/2020/05/20200521-sgh2.html).

Let us also recall a newer recommendation for hydrogen manufacturing called '*Hygenic earth energy*' *(HEE)* process: „injecting oxygen into" abandoned „oil fields raises the temperature and liberates H_2, which can the be separated from other gases via specialist filters" (membranes). They anticipate to „be able to use the existing infrastructure and distribution chains to produce H_2 for between 10 and 50" australian "cents per kilo". "Standard reservoir recovery rates are less than 40%, so HEE can work everywhere." Hydrogen content of crude oil is 10–14%. In this case scaling up of membrane separation would represent a great challenge (https://phys.org/news/2019-08-scientists-hydrogen-gas-oil-bitumen.html; http://proton.energy/hygenic-earth-energy/).

Storage

For *storage* (and long range transport) of high volumes its volumetric energy density should be increased. Principally it can be stored in comprised or liquid forms and in chemical substances. Compression of hydrogen up to 35–70 MPa consumes 10–15% of hydrogen energy content. Compressed hydrogen is used for pipeline transport and storage in vehicle tanks. Temperature of liquid hydrogen at atmospheric pressure (with density of about 71 kg/m^3) is about –253°C, which can be reached through three-stage cooling (using ammonia, nitrogen and helium as cooling agents), consuming 30–40% of hydrogen energy content. „During liquefaction, the energy density increases by almost 3 orders of magnitude.” Chemical substances for storage of hydrogen are of two types:

- Substances that can absorb hydrogen (e.g. by chemical bonding) and release it again by supplying high temperature thermal energy). These are metal hybrides (TiFe, $ZrMn_2$, $LaNi_5$) bonding 1–3 m/m% hydrogen, or MgH_2 – bonding about 7%, and liquid organic chemicals, like dibenzyltoluene, methylcyclohexane
- Other chemicals, e.g. ammonia, methanol and other more complex hydrocarbons. „Generally more complex hydrocarbons have a higher volumetric energy density, but will also require more effort for extracting the hydrogen” (*Olah*, G.A., Goeppert, A. & Surya Prakash G.K. (2005): Beyond oil and gas: The methanol economy, John Wiley and Sons.; https://www.weltenergierat.de/wp-content/uploads/2020/09/WEC_H2_Strategies_finalreport_200922.pdf). In case of ammonia, it can be transported using the existing infrastructure and hydrogen can be recovered at the point of use by membrane technology. For example, CSIRO’s „membranes are a thin layer of metal which allows hydrogen to pass, while blocking all other gases. By coupling membranes with a suitable catalyst for ammonia decomposition” they “can efficiently extract pure hydrogen from ammonia. (https://www.csiro.au/en/Research/EF/Areas/Renewable-and-low-emission-tech/Hydrogen/Hydrogen-membrane#:~:text=Decomposed%20ammonia%20passes%20through%20CSIRO's,a%20hydrogen%20carrier%20are%20low).

It must never be forgotten that hydrogen forms explosive mixture with oxigen in the air, therefore, no hydrogen gas leaks are allowed. Recent explosions, connected to the extended use of hydrogen recall the danger (e.g. https://www.greencarreports.com/news/1123449_hydrogen-supply-pinch-affects-san-francisco-fuel-cell-drivers; https://electrek.co/2019/06/11/hydrogen-station-explodes-toyota-halts-sales-fuel-cell-cars/).

Transport

Pressurised (20 MPa) hydrogen can be *transported* on roads in tankers (distribution trailers). A tanker with self weight of 40 tonnes is capable to deliver 400 kg hydrogen (i.e. 1% of its net weight). In 2019 France demonstrated technical feasibility of „blending hydrogen up to 20% on a volumetric basis into the” *distribution „gas grid*” what „requires minimal or potentially no modifications to grid infrastructure or to domestic end-user appliances.” „Injecting hydrogen into the *gas transmission grid* is more challenging due to material incompatibilities at high pressures and a lower hydrogen concentration tolerance in the blending that industrial users can accept. However, …a project developed by Snam in Italy has already demonstrated the feasibility of blending hydrogen up to 10%. Several projects around the world are already injecting hydrogen into gas grids… A growing number of countries is interested in gas grid hydrogen-blending because the increasing use of variable renewable electric generation leads to periods of surplus and curtailment” (*Olah*, G.A., Goeppert, A. & Surya Prakash G.K. (2005): Beyond oil and gas: The methanol economy, John Wiley and Sons.; https://www.iea.org/publications/reports/thefutureofhydrogen/). In case of pipeline transport of clean hydrogen, special steel or plastic pipelines are needed (since hydrogen may cause rigidity and corrosion of steel pipelines).

„Kawasaki Heavy Industries in Japan has launched the world's first-ever liquefied hydrogen carrier ship… This vessel was developed to provide a means of transporting liquefied hydrogen at 1/800 of its original gas-state volume, cooled to –253°C, safely and in large quantities over long distances by sea. Kawasaki plans to install a 1 250 m^3 vacuum-insulated, double-shell-structure liquefied hydrogen storage tank, currently being manufactured at Harima Works, on the ship and complete the vessel's construction by late 2020" (https://jalopnik.com/kawasaki-launches-the-worlds-first-liquefied-hydrogen-c-1840366632).

SOME PLANS

„The political momentum for hydrogen use continued to gather strength in 2019. This is fundamental for the advancement of hydrogen technologies and markets, since climate change ambitions remain the main impetus for widespread low-carbon hydrogen use. An increasing number of countries announced hydrogen strategies and roadmaps in 2019, in many cases establishing targets for the deployment of hydrogen technologies:

- In May 2019, a new *Hydrogen Initiative* was launched at the 10th Clean Energy Ministerial (CEM10) held in Vancouver (Canada) to spotlight the role hydrogen and fuel cell technologies can play in the global clean energy transition. This initiative, co-led by Canada, Japan, the Netherlands, the United States and the European Commission, aims to boost international collaboration on policies, programmes and projects to accelerate the commercial deployment of hydrogen and fuel cell technologies across all sectors of the economy. The IEA was selected to co-ordinate this initiative.
- In September, 35 countries and international institutions attending the *2nd Hydrogen Energy Ministerial Meeting* agreed to the Global Action Agenda as a principle to guide expanded RD&D on hydrogen. The document included a target to reach 10 million hydrogen vehicles and 10 000 HRSs in ten years to encourage the use of hydrogen and fuel cells in mobility.
- In June, hydrogen was the focal point of the *G20 discussions in Osaka (Japan)*, where G20 leaders acknowledged the opportunities offered by further development of innovative, clean and efficient hydrogen technologies.
- Japan, the European Commission and the United States signed a *partnership* for future co-operation on hydrogen and fuel cell technologies.
- The European Fuel Cells and Hydrogen Joint Undertaking launched *the Hydrogen Roadmap for Europe* highlighting all the opportunities hydrogen provides to decarbonise the gas grid and the transport and industry sectors, and its systematic role in the transition to a sustainable energy system. In turn, the certification scheme developed under the *CertifHy* project issued the first

Guarantees of Origin for projects producing low-carbon hydrogen.

- *Korea* announced its *Hydrogen Economy Roadmap* in January 2019, targeting FCEV passenger car production capacity of 6.2 million and the deployment of 40 000 FC buses, 30 000 FC trucks and 1 200 HRSs by 2040.
- In March 2019, *Japan updated the Strategic Road Map for Hydrogen and Fuel Cells* (initially published in 2017), confirming previous targets for mobility, the hydrogen supply chain and the domestic sector.
- The *Netherlands* published a Climate Agreement containing a package of measures having broad societal support, including *targets for hydrogen production* (500 MW of installed electrolysis capacity by 2025 and 3 GW to 4 GW by 2030) and mobility (15 000 FCEVs, 3 000 FC heavy-duty trucks and 50 HRSs by 2025, and 300 000 FCEVs by 2030).
- Australia's government published *Australia's National Hydrogen Strategy* defining 57 actions in areas such as regulation, infrastructure, mobility and R&D with the aim of positioning Australia as a world leader in hydrogen production and exports.
- In October, Natural Resources Canada published *2019 Hydrogen Pathways - Enabling a Clean Growth Future for Canadians* defining ten high-level actions to make hydrogen and fuel cell technologies part of the clean growth solutions that provide environmental and economic benefits to Canadians.
- Several *regional governments* such as the Occitanie region (France), the South Australian Government and a number of German Landers have also unveiled hydrogen plans" (https://www.iea.org/reports/hydrogen).

A recent German „analysis clearly shows that we should expect a dynamically growing market for hydrogen. Scaling upper hydrogen demand expected for 2050 in national strategies to global level indicates a potential of up to 9000 TWh or around 270 million tons of hydrogen per annum, this is an amount as large as the annual primary energy currently provided globally by renewables… Target sectors of national strategies notably include transport and industry, the latter particularly in countries with a strong industrial sector and a high priority on greenhouse gas reduction…. Green hydrogen is central to all strategies…. The expected development of the green hydrogen market can be differentiated in three phases. In the current decade, market activation will help to transform current demonstration into an early market (phase 1), which is expected to subsequently experience sustainable growth (phase 2), eventually leading to a large and well-established market by 2050 (phase 3)…. Large industrial partnerships will be formed for production and export/import…. Refineries and chemical industry to become the first important large-scale hydrogen markets in the mid-term…. Road transport (vehicles and trucks) and fuel cell market currently stronger in Asia than in Europe…. Green synthetic liquid e-fuels (PtL) can grow into an interesting opportunity with large potential quantities particularly in the aviation and/or maritime sector…. A green hydrogen certification needs to be put in place" (https://www.weltenergierat.de/wp-content/uploads/2020/09/WEC_H2_Strategies_finalreport_200922.pdf).

„BloombergNEF estimates that to generate enough green hydrogen to meet a quarter of the world's energy needs would take more electricity than the world generates now from all sources and an investment of $11 trillion in production and storage. That's why the focus for now is on the 15 percent of the economy with energy needs not easily supplied by wind and solar power, such as heavy manufacturing, long-distance trucking, and fuel for cargo ships and aircraft" (https://e360.yale.edu/features/green-hydrogen-could-it-be-key-to-a-carbon-free-economy).

In the **USA**, cheap natural gas is available, and „green hydrogen costs about three times as much as natural gas." Earlier 2020, „the U.S. Department of Energy announced a $100 million investment to help develop large, affordable electrolyzers and to create new fuel cell technologies for long-haul trucks". „California is racing to become a world-leading hydrogen market. California's interest in hydrogen is driven partly by aggressive decarbonization targets, including phasing out all diesel or natural-gas-powered buses by 2040, and partly by the presence of some of the industry's most high-profile technology developers." „The Los Angeles Department of Water and Power, for example, is helping fund the construction of the green hydrogen-fueled power plant in Utah. It's scheduled to go online in 2025". Energy company SGH2 is bringing the world's biggest green hydrogen production facility to Lancaster, California. The plant will feature SGH2's technology, which will gasify 42,000 tons of recycled waste annually to produce 3 800 tonnes of green hydrogen" (daily up to 11 tons) – „nearly three times more than any other green hydrogen facility, built or under construction, anywhere in the world... The City of Lancaster will supply guaranteed feedstock of recyclables, and will save between $50 to $75 per ton in landfilling and landfill space costs…SGH2 anticipates breaking ground in Q1 2021, start-up and commissioning in Q4 2022, and full operations in Q1 2023" (https://www.greentechmedia.com/articles/read/10-countries-moving-towards-a-green-hydrogen-economy; https://e360.yale.edu/features/green-hydrogen-could-it-be-key-to-a-carbon-free-economy; https://www.greencarcongress.com/2020/05/20200521-sgh2.html). Under the Biden administration, and after rejoining the Paris Agreement by the USA, other states can follow California's push to hydrogen, similary to the California's initiative to electrify trucks and buses (https://www.theverge.com/2020/7/14/21324552/electric-trucks-buses-clean-air-zero-emissions-states#:~:text=The%20states%20that%20signed%20the,Island%2C%20Vermont%2C%20and%20Washington).

In 2017, **"Japan** was the first country to adopt a "Basic Hydrogen Strategy" and plans to become a "hydrogen society". The nationwide hydrogen market is expected to grow 56-fold to JPY 408.5 billion (approx. CHF 3,7 billion) by 2030, providing exciting business opportunities. …This strategy primarily aims to achieve cost parity with competing fuels such as gasoline in the transportation sector or liquefied natural gas (LNG) in power generation and covers the entire supply chain from production to downstream market applications. To this end, the government in 2014 began investing in R&D and providing, including support for low-cost, zero-emission hydrogen production, an expansion of the hydrogen infrastructure for import and transport abroad within Japan, and an increase of hydrogen use in various areas such as mobility, cogeneration of power and heat, as well as power generation. However, even in Japan the hydrogen market is not yet economically viable. At present, almost all hydrogen and fuel cell technologies are highly dependent on public funding. The retail price for hydrogen is currently around 100 yen per cubic metre (yen/Nm3). The goal is to reduce it to 30 yen/Nm3 by 2030 and to 20 yen/Nm3 in the long term. Increasing demand for hydrogen will have a particular impact on the market for hydrogen filling stations. This market is expected to grow 6.5 times to JPY 37.2 billion (approx. CHF 328 million) by 2030. The number of fueling stations will approximately rise from 111 at present to 581 by 2025, and then to 1.321 throughout Japan by 2030. Toyota, Honda, Nissan, Tokyo Gas and Iwatani Corp. together with 6 other companies, including Japanese infrastructure developers and investment companies, founded the joint venture "Japan H2 Mobility (JHyM)" in 2017 to accelerate the deployment of hydrogen filling stations throughout Japan with the help of government subsidies. In cooperation with the Japanese government, JHyM plans to build a total of 80 new hydrogen filling stations by early 2022. The joint venture now has more than 20 participating companies" (https://www.s-ge.com/en/article/global-opportunities/20201-c5-japan-hydrogen-market). „The Fukushima Hydrogen Energy Research Field (FH2R), a green hydrogen facility that can generate as much as 1,200 … Nm^3 of hydrogen per hour, opened in Japan in March", 2020 (https://e360.yale.edu/features/green-hydrogen-could-it-be-key-to-a-carbon-free-economy). „The facility makes hydrogen by decomposing water, using electricity generated from its solar power plant. It contains a total of 20 megawatt capacity of solar panels in an area of 180 000 sq. kilometers in Fukushima Prefecture." "Hydrogen made at the plant in Namie will be carried by tanker trucks to consumption areas such as Tokyo." „During the Games, hydrogen will also be used as electric power generation at lodging and rest areas in the Olympic Villages" (https://asia.nikkei.com/Business/Energy/Fukushima-powers-up-one-of-world-s-biggest-hydrogen-plants).

Based on its excellent wind and solar potential and water resources „**Australia** … is looking to step up its participation" in green hydrogen production …."as a way of replacing fossil fuel exports with an alternative created with the country's plentiful renewable energy resources." Likely destinations for Australian green hydrogen include Japan and South Korea.
In summer of 2019, "Canberra announced that it had awarded "major project status" to the Asian Renewable Energy Hub (AREH)", near Pilbara. "That would use 1,600 large wind turbines and 30 square miles of solar panels to run a 23-gigawatt electrolysis factory." "The move will accelerate the development of 15,000MW wind and solar power for the production of hydrogen and ammonia for export to the Asia-Pacific region with plans to scale that up to 26,000MW, making it the largest of its kind in the world…AREH could generate up to 100 terawatt-hours a year, or nearly 40% of Australia generated 265 terawatt-hours" in 2018… In the first phase hydrogen is to be blended with natural gas in a 1:4 ratio what "could save up to ~6 million tonnes of CO_2 emissions every year…Australia plans to complete this phase of its green hydrogen strategy in just two years. AREH's second phase will involve compressing and supercooling hydrogen" for export… This phase could kick off in about four years and take another three years to fully ramp up production. The third phase of the project actually is the most exciting: Using green hydrogen to manufacture green steel for export…A big chunk of Australia's hydrogen exports will head to Japan… The Hydrogen Energy Supply Chain (a joint Australian-Japonese

project) will attempt to establish a durable supply of liquid hydrogen from Australia, to be used as fuel in Japan. However, this hydrogen will be green type because it will be extracted from lignite, aka brown coal" (https://www.greentechmedia.com/articles/read/10-countries-moving-towards-a-green-hydrogen-economy; Kimani, A., https://oilprice.com/Alternative-Energy/Fuel-Cells/Australia-Could-Lead-The-11-Trillion-Hydrogen-Boom.html).

.

In October, 2019 a Siemens-backed „massive new renewable hydrogen production facility has been unveiled for Western Australia, with plans for up to 5,000MW of combined solar and wind projects to supply the production of low-cost hydrogen at the Murchison House Station near Kalbarri", also in Western Australia (W.A.). „The two projects could position W.A. has a leading producer in a burgeoning global market for renewable fuels, led by investments by Japan and South Korea in new hydrogen fuel technologies, providing Australia with an opportunity to tap into abundant resources of wind and solar energy to establish a new export economy…The strategic co-location of variable renewable sources like wind and solar farms, can minimise the amount of infrastructure investment necessary to support the production of electricity, particularly if the different energy resources are available at different times." (https://reneweconomy.com.au/massive-5000mw-solar-and-wind-projects-set-to-fuel-was-hydrogen-expansion-91993/).

A further plan is „The Star of the South wind farm, which is being pursued by the Danish fund management company Copenhagen Infrastructure Partners would be the first offshore wind farm in the southern hemisphere, ... off the Gippsland coast in the south of Victoria".It „has a planned capacity of up to 2,200MW and would be expected to produce roughly the same amount of energy each year as the now de-commissioned Hazelwood brown-coal power station (https://reneweconomy.com.au/australias-first-offshore-wind-project-moves-forward-with-labour-market-study-33139/).

The **Middle East**, with the world's cheapest wind and solar power, would be a major player in green hydrogen. „Air Products & Chemicals, the U.S. industrial gas giant, announced plans" in July, 2020, "to build a green hydrogen plant in *Saudi Arabia* powered by 4 gigawatts of wind and solar power…The $5 billion plant will be jointly owned by Air Products, Saudi Arabia's ACWA Power and Neom, a new mega-city planned near Saudi Arabia's borders with Egypt and Jordan. The completed facility will produce 650 tons of green hydrogen daily, enough to run around 20,000 hydrogen-fueled buses, Air Products said. The fuel will be shipped as ammonia to end markets globally then converted back to hydrogen. Ammonia production is expected to start in 2025"(https://www.greentechmedia.com/articles/read/us-firm-unveils-worlds-largest-green-hydrogen-project).

„*Morocco* has forged close ties with Germany, signing a memorandum of understanding in July", 2020 „to develop its PtX industry and build Africa's first industrial green hydrogen plant… By 2030, the country aims to derive 52pc of its electricity from renewable sources, which equates to c.11GW… Morocco's potential capacity is 20,000GW for photovoltaic and 6,500MW for wind, according to Iresen, the country's solar and new energy research institute… Iresen says locally made green hydrogen could be used in the short term as an industrial feedstock and for export—as liquid fuels, hydrogen and ammonia. In the medium term, it can power trucks and public transport as well as stabilise the electricity grid. Long term, the hydrogen may provide industrial heating and power passenger vehicles, aeroplanes and trains, Iresen claims… Morocco has launched a tender to build a pilot green ammonia plant, which will test twoelectrolyser techniques to compare the impact of electricity generation intermittence. Fraunhofer estimates it will produce around 4t of ammonia daily. Construction will take around 15 months and should start in 2021, says Ikken. Morocco also plans to build a 100MW green hydrogen plant. This should be operational in 2024 or 2025, predicts Ikken, noting Germany is participating in the pilot. Eventually, one-third of Morocco's green hydrogen could be consumed domestically, with two-thirds exported, he predicts. Europe could import hydrogen manufactured in North Africa through the existing gas pipeline network, according to the Dii Desert Energy report. Ikken, who co-wrote the report, believes Morocco could export hydrogen via gas pipelines in the long term, but initially it makes more sense to convert hydrogen into ammonia or methanol for export via ship (https://www.petroleum-economist.com/articles/low-carbon-energy/energy-transition/2020/morocco-aims-for-global-green-hydrogen-role).

„Looking increasingly isolated from trading partners in Europe yet blessed with one of the world's top offshore wind markets, the **U.K.** is looking to renewable hydrogen as a way to reduce gas imports and help decarbonize the heating sector at the same time." In September, 2020 „the U.K. government unveiled a £12 billion ($15 billion) plan to use 4 gigawatts of offshore wind for renewable hydrogen production in the early 2030s. Meanwhile, U.K. hydrogen interests have been attracting international attention, with the chemicals giant Linde this month paying £38 million ($46 million) for a 20 percent stake in listed technology developer ITM Power" (https://www.greentechmedia.com/articles/read/10-countries-moving-towards-a-green-hydrogen-economy).
In November, 2020, „the U.K. Prime Minister Boris Johnson has unveiled a 10-point plan to set the country on its way toward its 2050 net-zero goal; an accelerated EV rollout and a new hydrogen target are the standout pledges." While short on detail, the plan includes between £4 billion ($5.3 billion) and £12 billion ($15.9 billion) of new public funding to help decarbonize the nation...A new 5-gigawatt "low-carbon" hydrogen target for 2030 has been revealed, along with an ambition to heat an entire town with hydrogen by the end of the decade. Two carbon capture and storage (CCS) clusters will be supported with an additional £200 million of support by the middle of this decade with another two following by 2030. A pledge of £800 million is already in place" (https://www.greentechmedia.com/articles/read/uk-unveils-ten-point-plan-to-be-net-zero-by-2050?utm_medium=email&utm_source=Daily&utm_campaign=GTMDaily).

At the end of November, 2020, „the UK and Scottish authorities announced they would fund the world's first trial of a 100 percent green hydrogen generation, storage, and distribution network to heat 300 homes in Scotland as part of the UK and Scottish ambitions to achieve net-zero emissions within three decades. The UK's energy regulator Ofgem it was awarding US$24 million (18 million British pounds) to the H100 Fife project in Fife, Scotland, which will see 300 homes heated with and cooking with green hydrogen made from electrolysis from offshore wind power. The project also receives a further investment of US$9.2 million (6.9 million pounds) from the Scottish Government" (https://oilprice.com/Alternative-Energy/Renewable-Energy/Commercial-Green-Hydrogen-Just-Got-A-Step-Closer.html).

In July, 2020 the **EU** presented a 'hydrogen stategy for a climate-neutral Europe', and a roadmap to 2050. „The priority for the EU is to develop renewable hydrogen, produced using mainly wind and solar energy. In short and medium term, however, other forms of low-carbon hydrogen are needed.

In the first phase, from 2020 to 2024, the strategic objective is to install at least 6 GW of renewable hydrogen electrolysers int he EU and the production of up to 1 million tonnes of renewable hydrogen, to decarbonise existing hydrogen production, e.g. in the chemical sector and facilitating take up of hydrogen consumption in new end-use applications such as other industrial processes and possibly in heavy-duty transport. In this phase, manufacturing of electrolysers, including large ones (up to 100 MW), needs to be scaled up. These electrolysers could be installed next to existing demand centres in larger refineries, steel plants, and chemical complexes.

In the second phase, from 2025 to 2030, hydrogen needs to become an intrinsic part of an integrated energy system with a strategic objective to install at least 40 GW of renewable hydrogen electrolysers by 2030 and the production of up to 10 million tonnes of renewable hydrogen in the EU.

In the third phase, from 2030 onwards and towards 2050, renewable hydrogen technologies should reach maturity and be deployed at large scale to reach all hard-to-decarbonise sectors where other alternatives might not be feasible or have higher costs.
From now to 2030, investments in electrolysers could range between €24 and €42 billion. In addition, over the same period, €220–340 billion would be required to scale up and directly connect 80–120 GW of solar and wind energy production capacity to the electrolysers to provide the necessary electricity. Investments in retrofitting half of the existing plants with carbon capture and storage are estimated at around €11 billion. In addition, investments of €65 billion will be needed for hydrogen transport, distribution and storage, and hydrogen refuelling stations. From now to 2050, investments in production capacities would amount to €180–470 billion in the EU.

Finally, adapting end-use sectors to hydrogen consumption and hydrogen-based fuels will also require significant investments. For instance, it takes some €160–200 million to convert a typical EU steel installation coming to end-of-life to hydrogen. In the road transport sector, rolling out an additional 400 small-scale hydrogen refuelling stations (compared to 100 today) could require investments of €850–1000 million.

To support these investments and the emergence of a whole hydrogen eco-system, the Commission kick-starts today (8 July, 2020) the European Clean Hydrogen Alliance – announced in the Commission's New Industrial Strategy. The key deliverable of the Alliance will be to identify and build up a clear pipeline of viable investment projects". (https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf).

…in July, 2020 a group of eleven European gas infrastructure companies from nine EU member states presented a plan to create a dedicated hydrogen pipeline network of almost 23,000 km by 2040, to be used in parallel to the natural gas grid (the present pipeline length is around 1,600 km).

„The “European hydrogen backbone” was presented in a vision paper developed by transmission system operators Enagás, Energinet, Fluxys Belgium, Gasunie, GRTgaz, NET4GAS, OGE, ONTRAS, Snam, Swedegas (Nordion Energi), Teréga, and consultancy company Guidehouse.

The proposed network will run through Germany, France, Italy, Spain, the Netherlands, Belgium, Czech Republic, Denmark, Sweden and Switzerland.

The “backbone” will connect future hydrogen supply and demand centres across Europe, such as industrial clusters, carbon capture and storage locations and large scale renewable electricity production sites, including off-shore wind farms in the North Sea and solar power plants in the South of Europe.

Constructing a hydrogen infrastructure will make it easier to scale up both the production and use of hydrogen, the gas operators say.

“This paper concludes that the cost of such a European Hydrogen Backbone can be very modest compared to the foreseen size of the hydrogen markets. That is why we now propose to launch it as a ‘first mover’, facilitating developments on the supply and demand side,” the group adds.

Once volumes and distances of hydrogen transport increase, pipelines will be an efficient and cost-effective option, the operators explain.

The amount of electricity required for transporting hydrogen over a distance of 1,000 km is comparable to around 2% of the energy content of the transported hydrogen – although that electricity will not necessarily be produced from hydrogen, the report says.

According to a “preliminary estimation” cited in the report, the proposed network should be able to transport more than the expected 1,130 TWh of annual hydrogen demand in Europe by 2040 and cost between €27 and €64 billion.

“These costs are relatively limited in the overall context of the European energy transition and substantially lower than earlier rough estimations,” the report states.

The “modest” price tag of the project is partly due to the assumption that 75% of the network will consist of retrofitted natural gas pipelines – which are gradually expected to become redundant as volumes of natural gas decrease in the future”….

According to the eleven operators, the proposed network will gradually develop over fifteen years, starting from the mid-2020s:

- By 2030, an “initial” pipeline network of 6,800 km will connect local clusters of hydrogen production and use – so-called “hydrogen valleys”.
- By 2035, a stretched network will start connecting consumers in the centre of the continent to regions with “abundant green hydrogen resource potential” – such as Danish offshore wind farms or solar and wind farms in the south of France.
- By 2040, a true pan-European network of just over 22,900 km is foreseen, which will be running across ten European countries and allow connections with global import routes.

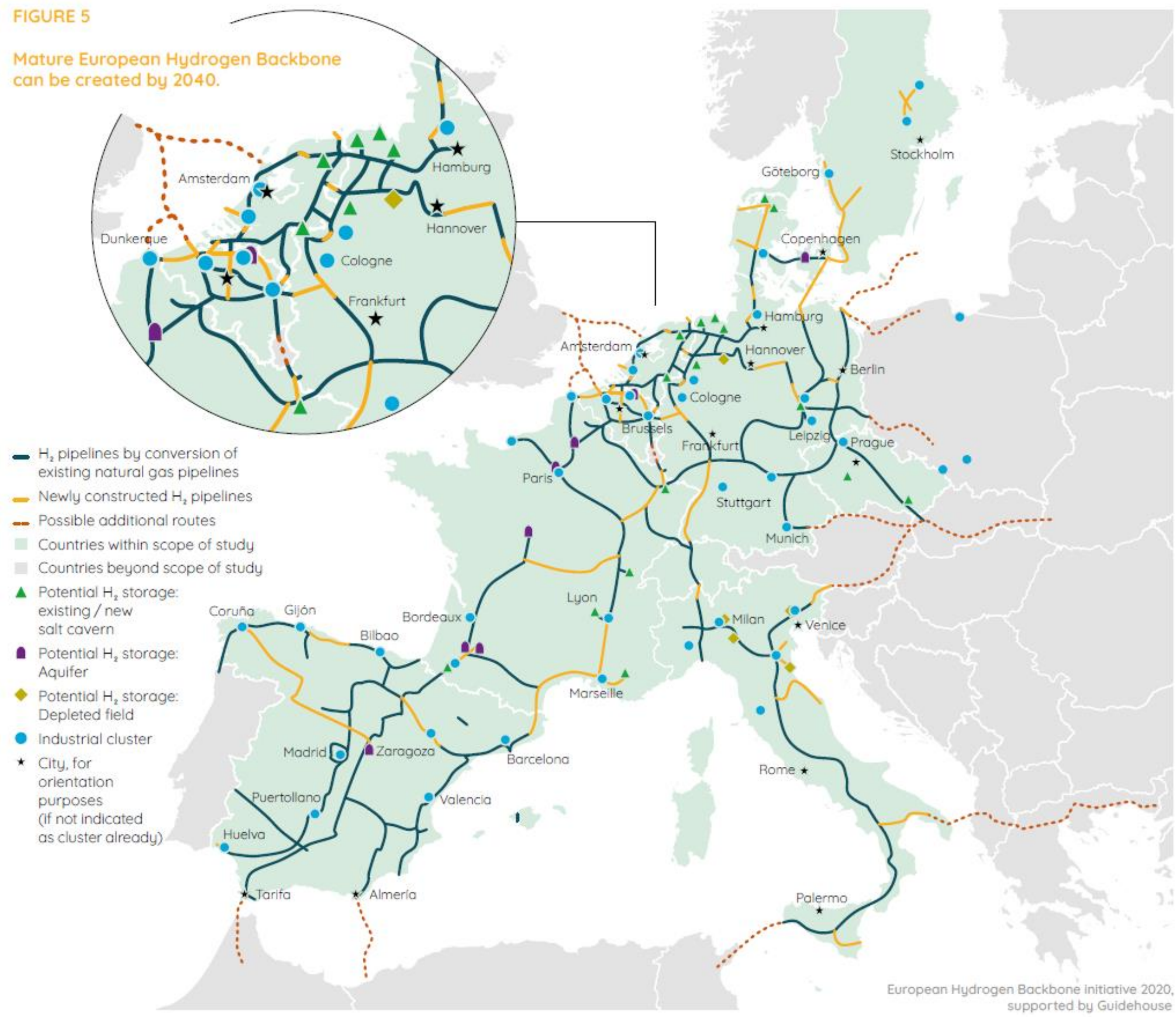

Fig. 2. The planned European hydrogen backborn network in 2040

All in all, around 60% of the total investment costs will be related to pipeline works, with compression equipment accounting for the remaining 40%.

Transporting a kg of hydrogen is estimated to cost between €0.09–0.17 per 1,000 km, depending mainly on what the compressor costs will turn out to be.

“These values show that pipeline transmission costs only represent a small portion of total hydrogen costs when considering the full value chain from production through to end consumption,” the paper concludes.

“Even assuming future production costs of 1–2 €/kg for green and blue hydrogen, transport through the hydrogen backbone will add less than 10% on top of production costs for 1,000 km transported.” (https://www.euractiv.com/section/energy/news/gas-grid-operators-unveil-plan-for-european-hydrogen-infrastructure-backbone/)

Germany aims to become world’s hydrogen hotspot. „The German authorities are investing tremendous energy in a H_2 strategy. Recently, German pipeline operators unveiled plans for the world’s largest hydrogen network (H2 Startnetz). Until 2030 appriximately 1,100 km…of former natural gas pipelines will be converted to make it suitable for hydrogen. Also, 100 km of new pipelines will be laid which in total will cost €660 million. The network will link 31 hydrogen production projects with consumers in Germany's most populous states of North Rhine Westphalia and Lower Saxony.

Germany's aspirations extend beyond the energy transition and climate change as policy makers realize that hydrogen could be the technology of the future and therefore, an important export product. The ambition to extend the network could be raised even further in the next couple of years if costs to produce, transport, and store hydrogen decrease further than expected.

Germany's Economics Minister Peter Altmeier in 2019 announced Berlin's ambition to become a global leader in hydrogen related technologies. Europe's largest economy is exceptionally well suited to reach its goal because it already produces 20 percent of the world's electrolysers. Berlin's long-term objectives promise significant economic benefits for its industry which is already regarded as one of the best in the world.

On top of that, Berlin has raised its already ambitious goals when it comes to substituting fossil fuels. The mandatory share of renewable fuels in transportation by 2030, including hydrogen, is increased to 20 percent instead of 14 percent. Also, by the year 2030 three to five gigawatts of electrolysers will be built to convert green electricity into H_2 (https://oilprice.com/Alternative-Energy/Renewable-Energy/Germany-Aims-To-Become-Worlds-Hydrogen-Hotspot.html).

Germany's cabinet … committed to invest €9B (about $10.2B) in hydrogen technology in a bid to decarbonize the economy and cut CO_2 emissions. The government has proposed to build an electrolysis capacity of 5,000MW by 2030 and another 5,000MW by 2040 over the following decade to produce fuel hydrogen (https://www.ogv.energy/news-item/australia-could-lead-the-11-trillion-hydrogen-boom).

The **Netherlands** are also planning for an H_2-based economy. The successful and rapid construction of large offshore windfarms is creating uncertainty concerning profitability as 70 percent of Dutch power production will be renewable by 2030. Increasing capacity will decrease financial efficiency as the market is flooded with cheap energy on windy days. Hydrogen is regarded as an important tool to improve profitability and prevent negative prices through peak shaving.

The Dutch government and Germany's most populous state, North Rhine Westphalia, intend to cooperate when it comes to system integration and hydrogen production. The Ministry of Economic Affairs of the Netherlands, North Rhine Westphalia and the Germany federal government are conducting a joint study into the feasibility of transnational green hydrogen. The study includes the production of H_2 from offshore windfarms in the Dutch North Sea which will be transported to major German industrial clusters through existing pipelines" (https://oilprice.com/Alternative-999999Energy/Renewable-Energy/Germany-Aims-To-Become-Worlds-Hydrogen-Hotspot.html).

According to the estimations published recently in the 'Broshure of FCH Hungary', in **Hungary** in 2030 the hydrogen refuelling station network will … encompass between 80–160 stations for 45 000–90 000 fuel cell vehicles on the road. In addition, the analysis estimates substitution of up to 1% of the conventional steel production by renewable hydrogen-based steelmaking. Further use of renewable hydrogen is foreseen in ammonia production (up to 5%). Finally, the introduction of 1 470–6 420 stationary fuel cells for combined power and heat production is estimated." In 2030, hydrogen would account for 0.5–1.4% of total energy demand, or 1.7–4.9% of final gas demand of Hungary. „Hungary has fixed a specific target regarding the use of renewable energy sources in the cooling and heating sector by 2030: 51 ktoe hydrogen originating from renewable energy" (solar photovoltaic and wind) (https://www.fch.europa.eu/sites/default/files/file_attach/Brochure%20FCH%20Hungary%20%28ID%209473092%29.pdf).

CONCLUSIONS

Introduction to the imagined hydrogen economy represents a great challenge for the humanity. Mass-scale production of green hydrogen would need huge amount of additional green electricity manufacturing capacities. Beyond the seemingly preferred water electrolysis other, cheaper production technologies, solutions should be elaborated and commercialised. Green hydrogen manufacturing cost should be significantly cut. Green hydrogen infrastructure, incl. storage and transport facilities should be established. Potential consumers should be perceived, the new hydrogen economy should be not only 'sexy', but also economically viable. Entire green hydrogen supply chains should be set up.

The geographically well-positioned (renewable resource rich) countries could benefit from a hydrogen economy. Some countries are in position to change their hydrocarbon export to (green) hydrogen export and other renewable resource rich states may be newcomers in the energy market.

At the end of 2020 the EU carries the flag of the hydrogen economy, announcing an impressive plan to significantly extend the green hydrogen production, transport and use until 2050. Most propably, Germany is the world leader of this initiative. Although a great part of the proposed (envisioned) for 2040 European hydrogen backbone pipeline network is based on the conversion of the existing natural gas pipelines, the Central-Eastern European countries (with the exception of the Czech Republic) are 'beyond the scope of the study'.

There is an ongoing transition of supermajors from Big Oil to Big Energy, especially in Europe. The majors sell off oil assets or doubling down oil and gas investments. Instead, they invest in renewables in Europe (like BP, Shell and others), or small nuclear power plants or carbon capture in America (like Chevron, ExxonMobil).

„Ben Gallagher, an energy analyst at Wood McKenzie who studies green hydrogen, said the fuel is so new that its future remains unclear. "No one has any true idea what is going on here," he said. "It's speculation at this point. Right now it's difficult to view this as the new oil. However, it could make up an important part of the overall fuel mix" (https://www.bbc.com/future/article/20201112-the-green-hydrogen-revolution-in-renewable-energy).

Racz, Laszlo (sr)