Hydrogen technologies in 2021

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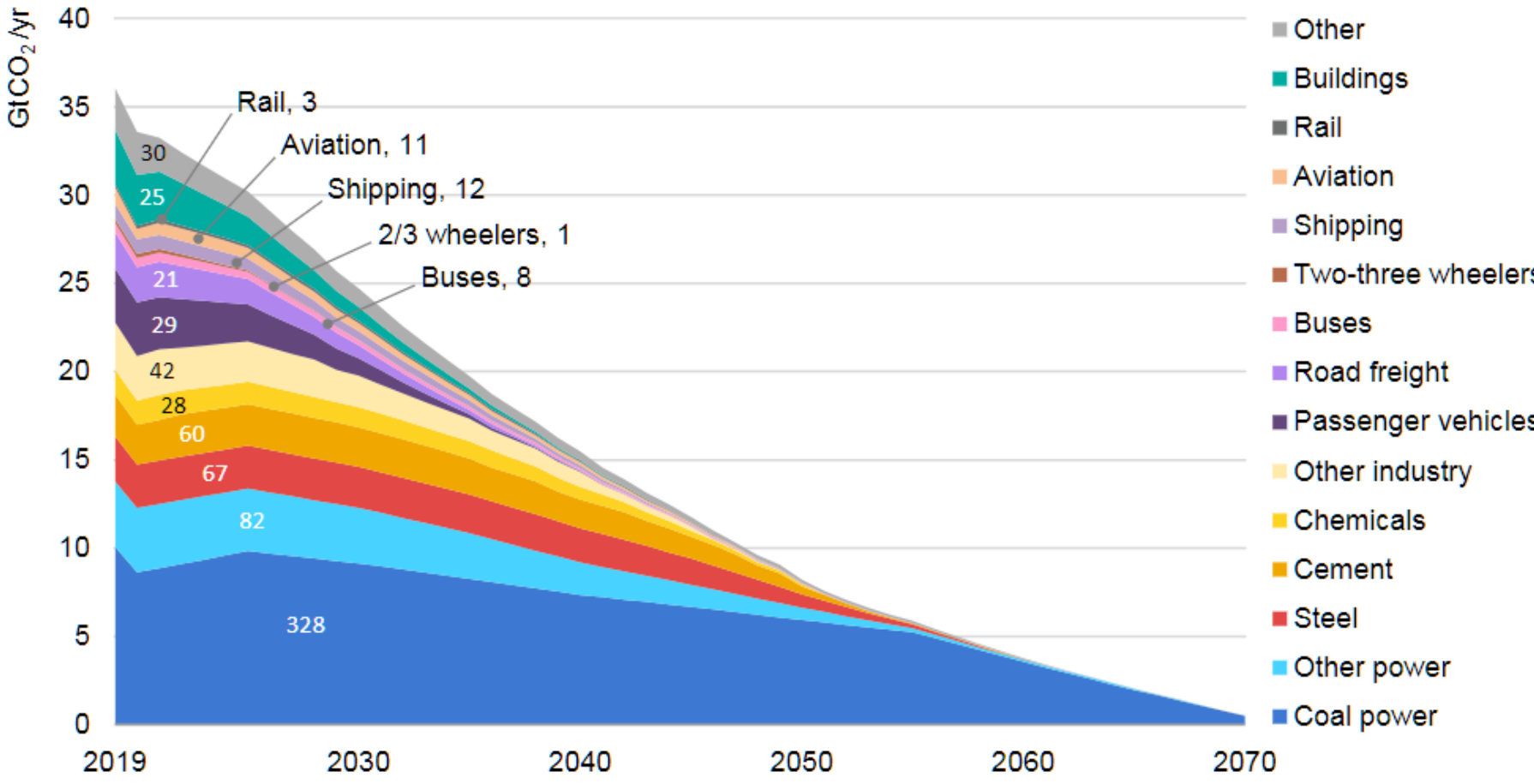
CO_2 Net Zero initiative (2050):
EU 1 Triljon €, USA 2 triljon USD;
China 1 triljon USD; Japan 22 triljon yeen, Korea 0. 3 triljon USD

¨New technological revolution up to 2070 is inevitable:
Reduction of the CO_2 equivalant generation in sectors:
Energy technology… 40%
Steel production… 80%;
Cement production… 65%;
Chemical industry… 95%.
Development of complete cycle economy, where CO_2, NOx ja VOC, NP and H_2O are reactants for chemical industry!!!! for synthesis of various chemicals.

Figure 1.11 Global CO_2 emissions from existing energy infrastructure by sub-sector, 2019-70

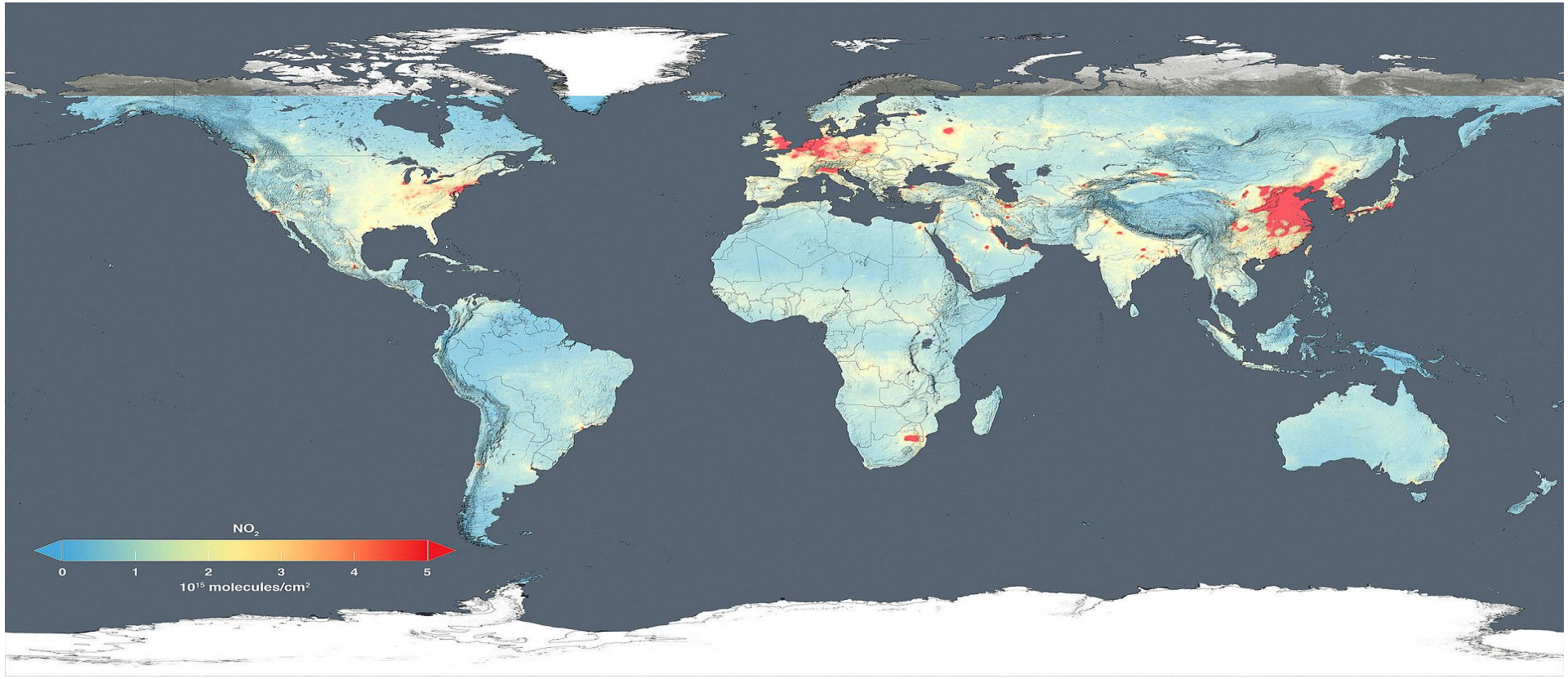


Notes: Includes assets under construction in 2019, the base year of this analysis. Numeric area labels on the graph denote cumulative emissions quantities by sub-sector in $GtCO_2$. Analysis includes industrial process emissions, and emissions are accounted for on a direct basis. Annual operating hours over the remaining lifetime are based on the level in 2019.

https://www.iea.org/reports/energy-technology-perspectives-2020?utm_campaign=IEA%20newsletters&utm_source=SendGrid&utm_medium=Email

There are 6-7 regions where air pollution with NOx and SOx is very heavy: China, South-Korea, Japan (Tokyo, Osaka) the Elsass-Lotring region (the Nederlands, Belgium, Luxemburg, and parts of Germany and France), Silesia, Berlin, Big-London, Lombardia region, USA east-coast, Chicago, Los Angeles, Mexico City, New Delhi, Calcutta, Cashemere, Moscow, Johhanesburg, Pretoria, etc.

NOx is mainly produced by fuel combustion, transport (50%) and central/local heating systems (35%)!



https://et.wikipedia.org/wiki/Kasvuhoonegaasid#/media/File:15-233-Earth-GlobalAirQuality-2014NitrogenDioxideLevels-20151214.jpg

COVID-19 positive influence on air quality

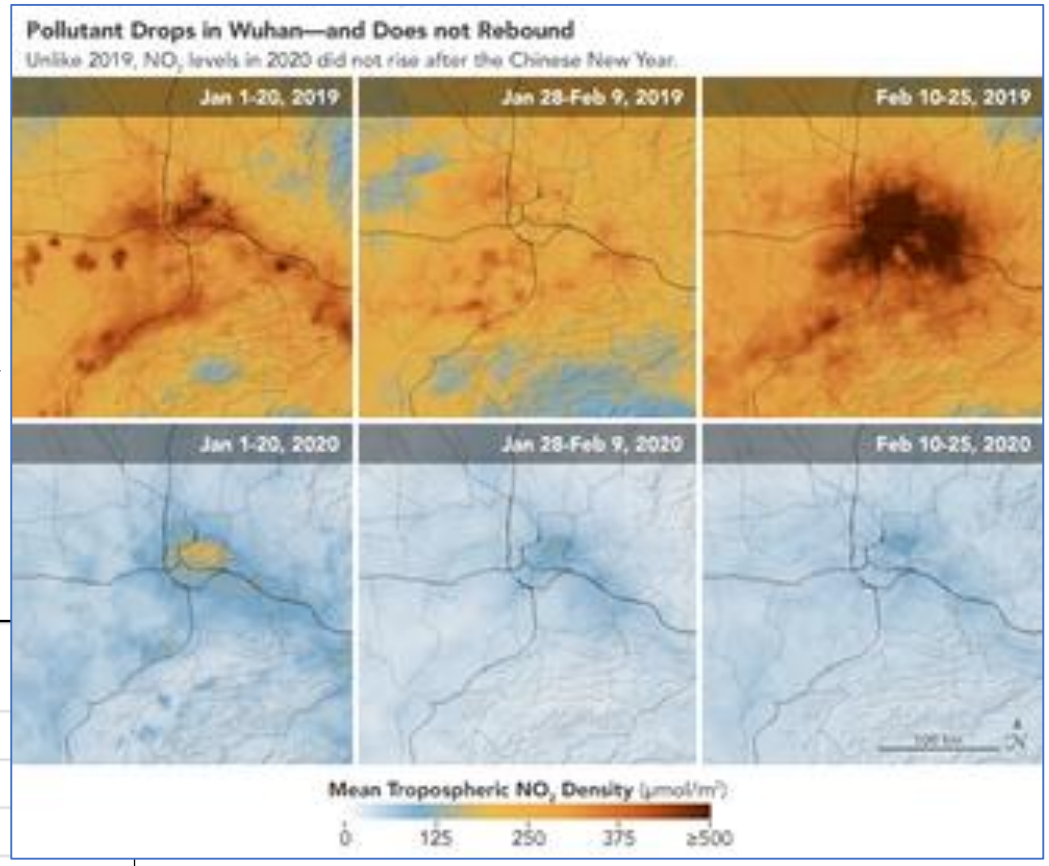
If there is no transport and burning of fossil fuels …no CO_2, CO, NOx, NP, VOC etc. contamination effect!

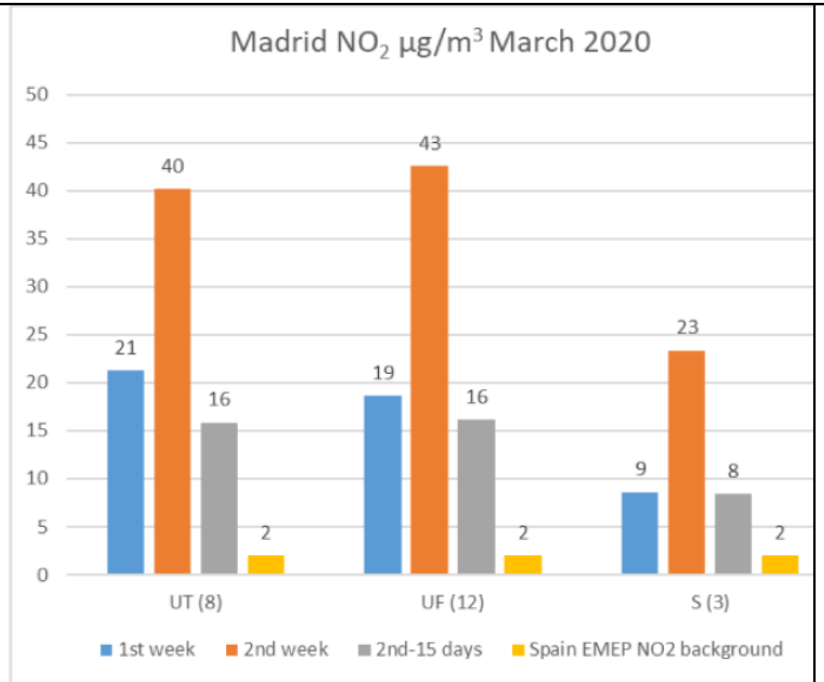
There is nothing to discuss… all is clearly visible!

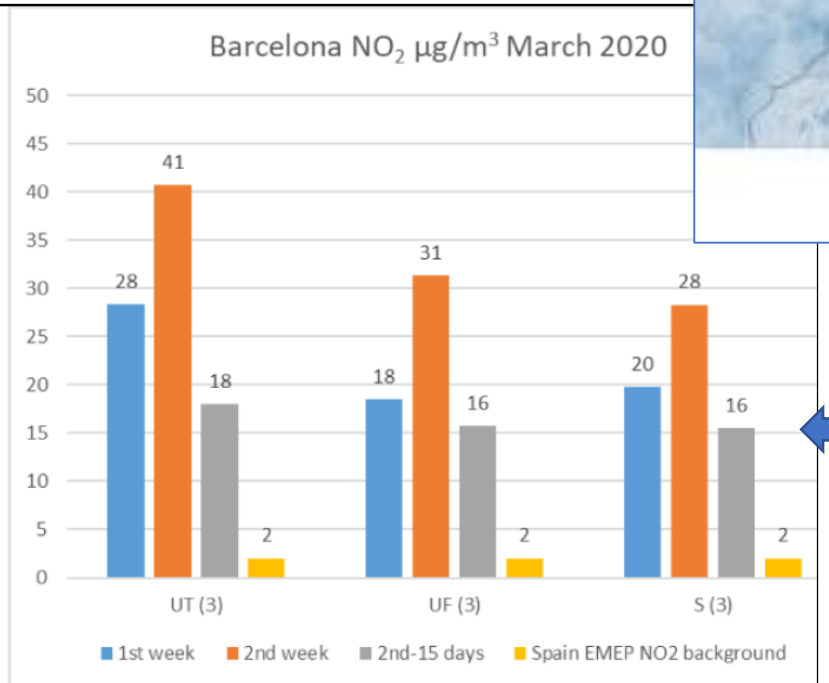
The old-facion energetics generates the contamination!

Images from the NASA Earth Observatory show a stark drop in pollution in Wuhan, when comparing NO_2 levels in early 2019 (topp) and early 2020 (bottom)

https://en.wikipedia.org/wiki/Impact_of_the_COVID-19_pandemic_on_the_environment#:~:text=The%20worldwide%20disruption%20caused%20by,large%20drop%20in%20air%20pollution.







J. M. Baldasano, Covid-19 lockdown effects on air quality by NO_2 in Barcelona and Madrid, *Science of the Total Environment* 741 (2020) 140353.

EXHIBIT 25: AIR POLLUTION IS A SEVERE CAUSE OF DEATHS AND ILLNESSES, WHICH HAS FORCED EU CITIES TO ACT

Impact on public health in the EU-28

Death because of air pollution[1]
467,000

Death because of road accidents
256,000

Life expectancy shortened by
7.4 months

Healthcare cost
EUR 4 bn

Death because of Alzheimer's
100,000

People falling sick with asthma, bronchitis, or strokes
6.5 m

Urban population citizens exposed to particulate matter above WHO guidelines in 2015
9 out of 10

Examples of action plans on city level

Low emission zones (LEZ), Berlin
Decrease of DPM emissions by 25% and NO_x by 14%

Green procurement, Copenhagen
Purchasing only electric or hydrogen cars

"Plan A" for 2018-20, Madrid
30 measures, incl. investment in public transport

Car-free day, Paris
Emissions cut by 40%

Free public transport, Bonn
Pilot project to test impact of free public transport

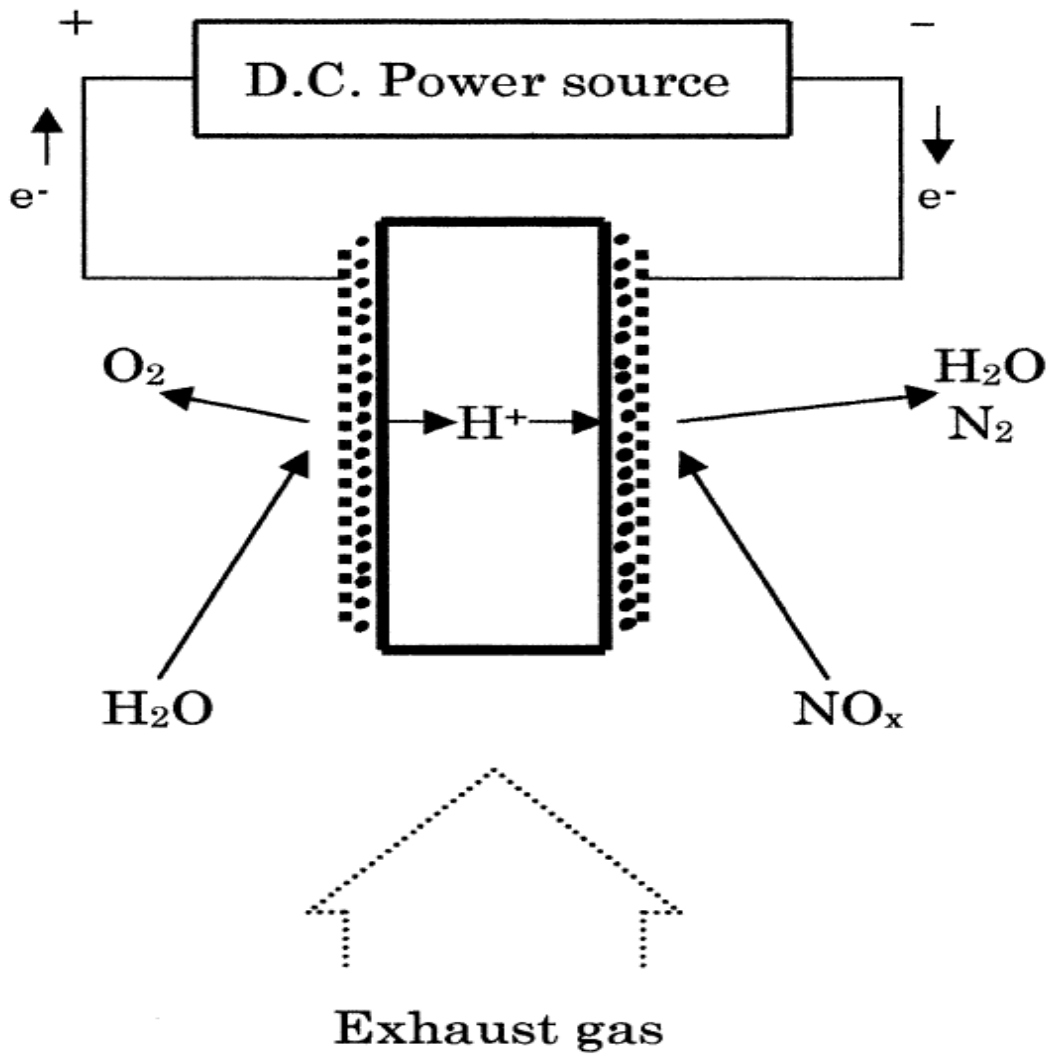
Lower urban speed limits, Stockholm
Roads are less hazardous and noise is reduced

1 Diseases accounted lung cancer, acute respiratory infections, cerebrovascular diseases, ischemic heart diseases, chronic obstructive pulmonary disease (WHO definition)

https://fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

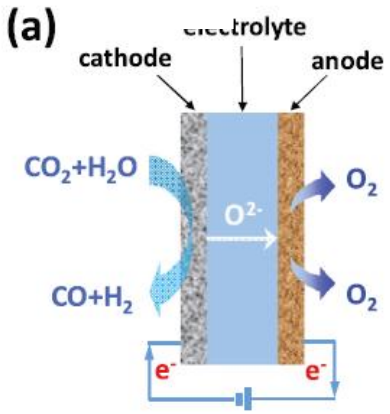
NO_x reduction by Complex Oxides - Proton Conducting Membrane Cells

New test projects (USA, Korea, Japan) for collection of NOx from MegaCity air (street air) and power station exhaust pipes



H. Iwahara et al., Solid State Ionics 168 (2004) 299.

CO_2 and H_2O co-elctrolysis – syngas production on application tootmine

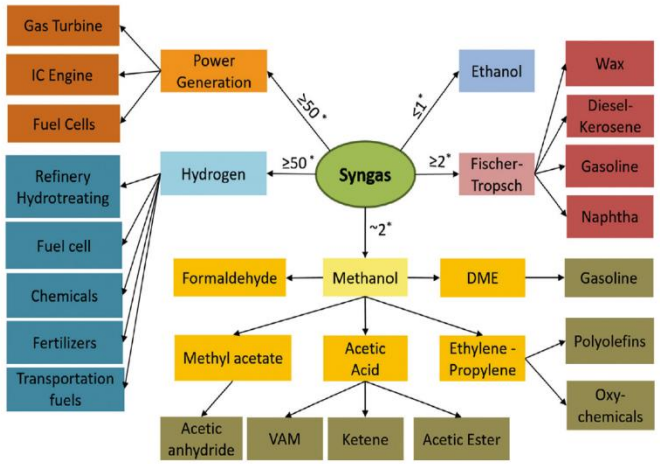


$$H_2O + 2e^- \rightarrow H_2 + O^{2-}$$

$$CO_2 + 2e^- \rightarrow CO + O^{2-}$$

RWGS

$$H_2 + CO_2 \leftrightarrow CO + H_2O$$



RTL 8+
Stabiility of electrodes is critical!
CO_2 chemical purity is very important!
99.99% is needed for sustaniable electrochemistry!

Syngas application possibilities (*H_2/CO ratio is decisive)

https://www.sunfire.de/en/company/news/detail/breakthrough-for-power-to-x-sunfire-puts-first-co-electrolysis-into-operation-and-starts-scaling

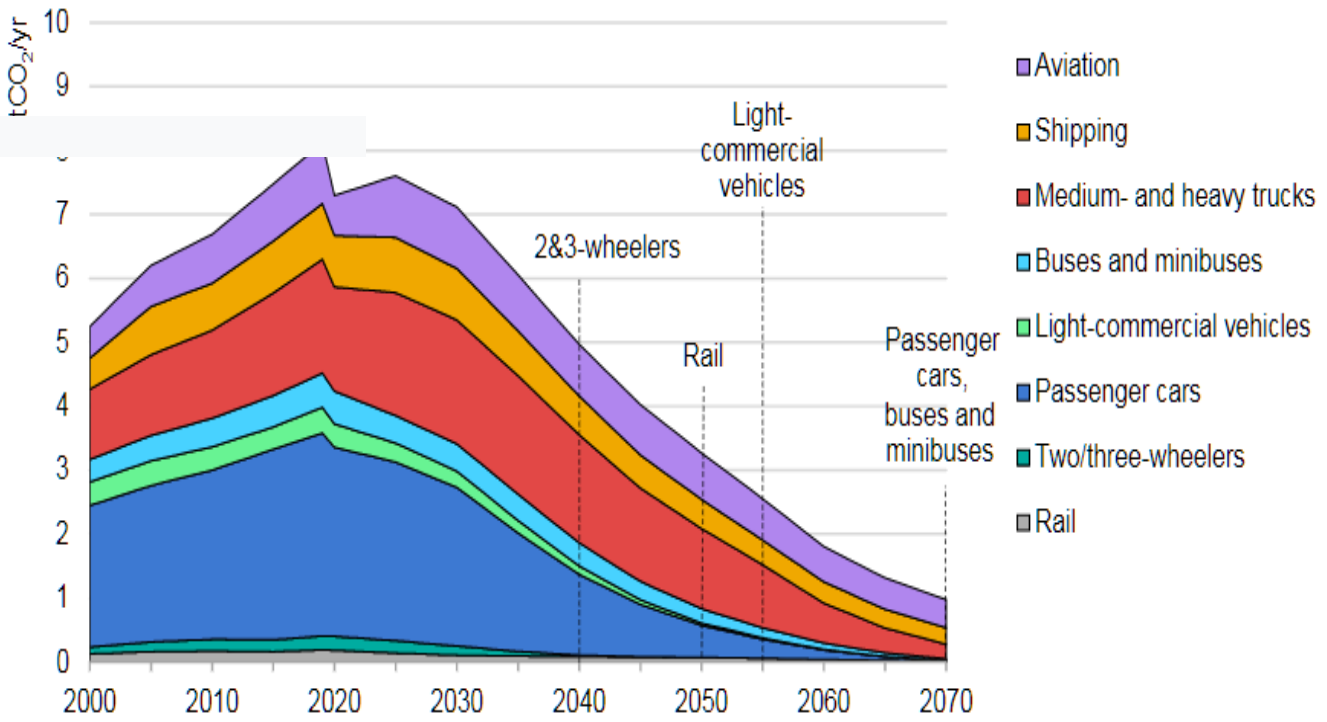
Fuel cells and Hydrogen observatory data (sept,2021) Progress in 2020.
FC installations in World: 1.3GW; 148,6 MW in EU.
HRS 570 ; in EU 162, Japan 133
FCEV 27 000, EU 2774 only, South Korea 10 000,
Stationary FC 57 800 (mainly US) and Korea

Forecast for 2070 (World):

- 17 000 H_2 refuelling stations (HRS);
- 650-750 miljon FC-vehicles
- 800-950 million BEVs
- 17 million fast sharging stations for BEVs

FC and BEV will be used in paralleel for very long time/ period;
BEV: mainly small cars and smaller vans;
FC: mainly trucks, busses, trains, metro, ships, airplanes, forcklifts, etc.

Figure 3.16 Global CO_2 emissions in transport by mode in the Sustainable Development Scenario, 2000-70



Notes: Dotted lines indicate the year in which various transport modes have largely stopped consuming fossil fuels and hence no longer contribute to direct emissions of CO_2 from fossil fuel combustion. Residual emissions in transport are compensated by negative emissions technologies, such as BECCS and DAC, in the power and other energy transformation sectors.

Most modes of transport are decarbonised by 2070 in the Sustainable Development Scenario, but trucking, shipping and aviation continue to produce some emissions due to practical difficulties with their decarbonisation.

https://www.iea.org/reports/energy-technology-perspectives-2020?utm_campaign=IEA%20newsletters&utm_source=SendGrid&utm_medium=Email

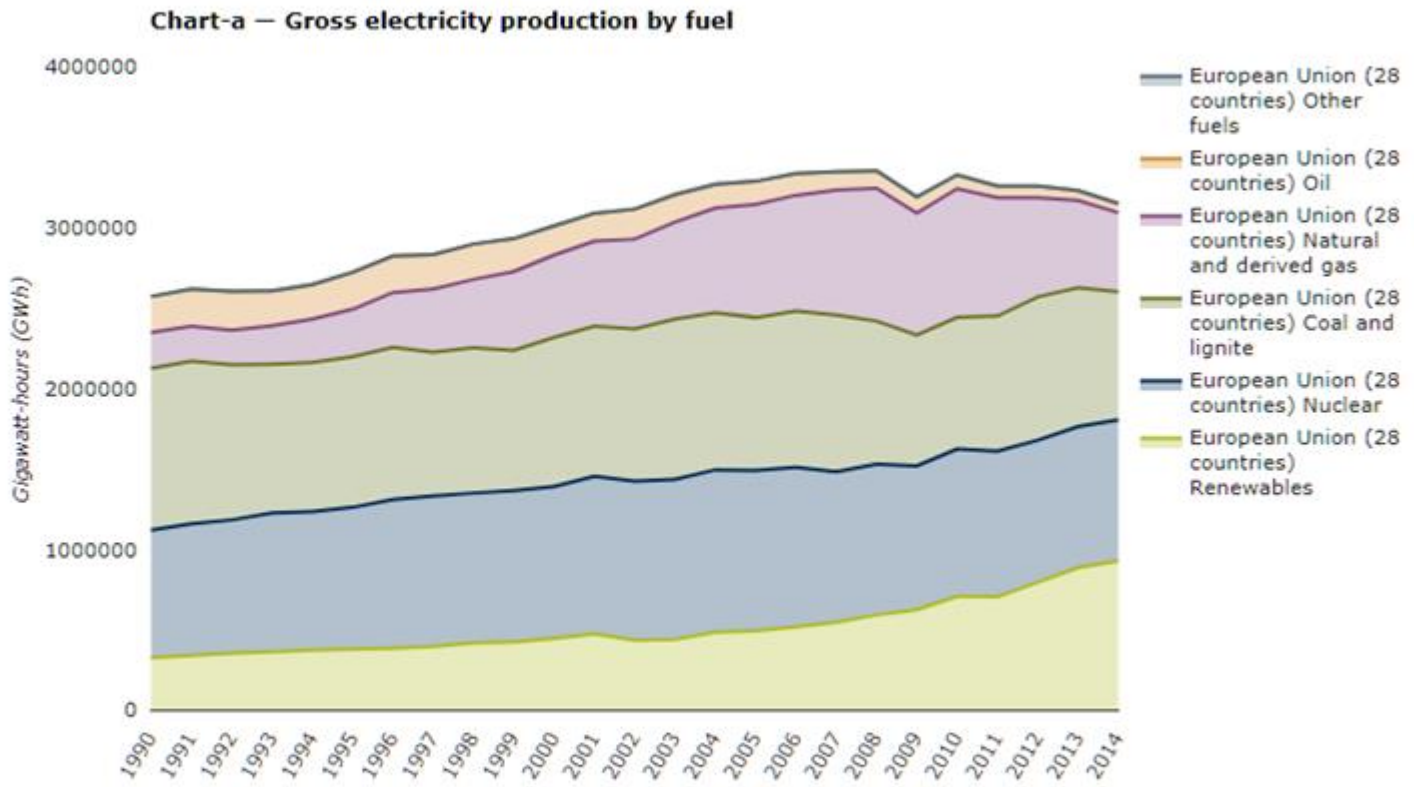
Electricity generation by fuel, Net Zero by 2050, USA - 2035!
Main energy carrier is green electricity, 50-55 %, H_2 14-20%

CO_2 Net Zero:

- IT 2040;
- automotive 2040-2050;
- energy sector 2050.
- Globally 350 big projects
- 500 billion USD total (up to
- 2030), huge number of various medium and small projects
- H2 price in USD kg:
  - Austraalia 1.5-2.0;
  - China 1.5-2.0
  - USA 2.0-2.5:
  - Korea 3.5-3.9;
- FC vehicles:
  - Hyundai NEXO, 16 000cars;
  - 100kW;6.6kg-666km;
  - 46 trucks, 100-350 kW; 32 kg-400km (350 kW);
  - 115 busses, 180-300 kW,
  - 34 kg -> 474 km.

Fig. 2: Gross electricity production by fuel

Chart-a Chart-b Table

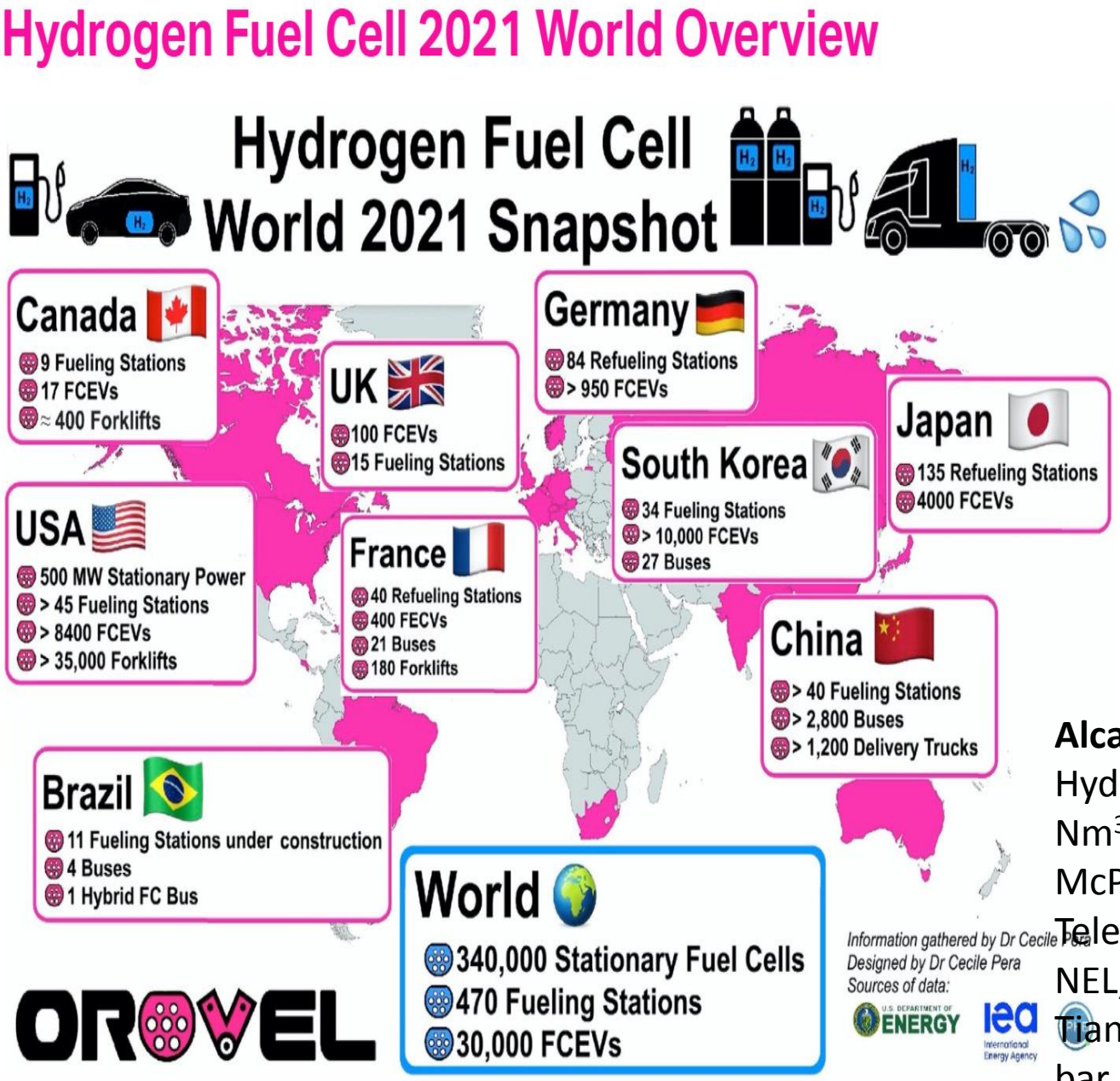


Note: Data shown are for gross electricity production and include electricity production from both public plants and auto-producers. Renewables include electricity produced from hydro (excluding pumping), biomass, municipal waste, geothermal, wind and solar photovoltaics. The share of renewables presented in the chart is for production and hence it differs from the share of renewables in consumption (renewable energy consumption targets are set in the Renewable Energy Directive 2001/77/EC). 'Other fuels' includes electricity produced from power plants not accounted for elsewhere, such as those fuelled by certain types of industrial wastes. It also includes the electricity generated as a result of pumping in hydro-power stations.

https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment

Leading Fuel Cells producers:
(Journal,Electronic,2020,9060912)
Hyundai Fuel Cell,
Doosan Fyel cell,
Horizon Fuel Cell,
Ballard Fuel Cell,
Nuvera Fuel Cell,
Air liquid Fuel Cell
Hydrogenics Fuel Cell,
Intelligent Energy Fuel cell

PEM Electrolyser producers:
NEL (10-30 bar; 413 Nm^3h^{-1}),
Proton OnSite (13.8 bar, 6 Nm^3h^{-1})
H-Tec Systems,
Avreva H2gen (35 bar, 200 Nm^3h^{-1})
Hydrogenics (7.9 bar, 2 Nm^3h^{-1})
ITM Power,(15 bar, 35 Nm^3h^{-1})
Siemens, (35 bar, 225 Nm^3h^{-1})
Linde



Top electrolysis H_2 produsers:
NEL (Norwegian)
Ecolectro Inc, 2015,
Boston Metal, 2012,
ITM Power, 2001,
DTU,
Paragon Space Development Corp.,
Commissariat a`l Energie Atomique,
Planetary Hydrogen,
Sunfire,
Iberlyzer, etc.

Alcaline electrolysers:
Hydrogenics, 25 bar,60 Nm^3h^{-1},
McPhy, 30 bar, 800 Nm^3h^{-1},
Teledyne En. Sys,10 bar,
NEL, 200 bar, 3880 Nm^3h^{-1},
Tianjin Mainland Hyd.Eq., 5 bar, 1000 Nm^3h^{-1}

https://www.orovel.net/insights/hydrogen-fuel-cell-world-number-fcev-2021

Production of FC in World in 2019 (Shell`s data and prognosis data)

- PEMFC 934.2 MW; (Pt and Nafion are limiting row materials) Ballard is incresing Nafion production 6-7times (2024-2025).
- PAFC 106.7 MW;
- SOFC 78.1 MW;
- MCFC 10.2 MW;
- DMFC 0.4 MW. Direct ammonia and methanol FC are under intensive research stage.
- Biggest producer Hyndai NEXO produced 680MW PEMFC systems, but installations in Europe only 41 MW; USA+ Canada = 384 MW, in Asia 256 MW
- Next biggest producer is Ballard FC Systems (180 MW);
- Toyota FC (Aisin Seiki group) (110MW)

- By 2050 113 miljon PEMFC vehicles, used 68 million tons less fosil fuels and avoided 200 million tons CO_2 production
- In 2050 250 miljon tons hydrogen for feeding of FC systems will be used and 80% less fosil fuels will be used in comparision with 2018.
- 12500 TWh green electricity will be used for hydrogen generation, i.e. 2.5 times less than nuclear and all sustainable electricity generation in 2018 .
- It is inevitable to complete 10-15 % energy storage complexes (1 250 - 1 875 TWh) for pulsating PV and wind electricity stabilisation.
- Electrolysers market capacity: 213.1 million USD (2018); 426.3 million USD (2028), 1.1 billion in 2040.
- In 2018 60% alkaline EL, market value 124.3 million USD; PEMEL 95 million USD, SOEL only 4 million USD.
- In 2040 50-55% PEMEL and 25-30 % SOEL.
- For rapid reduction of CO_2 concentration in atmosphere 2000 CCS /CCU complexes is urgently needed to take under explotation (2040) , but 18 (2019) have been constructed and are producing financial losses.
- Usually they are not working regulary, only as democentres.
- During next 10 years the grid-based electricity storage must be reduced 90% (in comp. 2019) (USA Deparment of Energy)

Ballard Power Systems increases Nafion membrani production 6 times!

Sep 28, 2020

Ballard Expanding MEA Production Capacity 6x to Meet Expected Growth in Fuel Cell Electric Vehicle Demand

VANCOUVER, CANADA – Ballard Power Systems (NASDAQ: BLDP; TSX: BLDP) today announced the company is expanding manufacturing capacity for production of its proprietary membrane electrode assemblies, or MEAs – a critical component of every fuel cell – 6x by early 2021 at its headquarter facility in Vancouver. The upgraded capacity for production of 6 million MEAs annually, equivalent to approximately 1.66 Gigawatts of product, will make Ballard's Vancouver facility the largest fuel cell MEA production operation globally for commercial vehicles. Details of the expansion plan will be reviewed at Ballard's virtual *"Investor and Analyst Day 2020"* event being held on September 29th, with further event details available **here**.

https://www.ballard.com/about-ballard/newsroom/news-releases/2020/09/28/ballard-expanding-mea-production-capacity-6x-to-meet-expected-growth-in-fuel-cell-electric-vehicle-demand

Let's make some fuel cells - PEM and hydrogen tech overview - 8k, T. Romann, https://www.youtube.com/watch?v=yrAAVOgBmcE

The American Jobs Plan The White House 10/8, 2021, 7.35 PM (president J. Bidens plans)

- 621 billion in transportation infrastructure and resilence
- 80 billion to address Amtrak`s repair backlog: modernize the high traffick Northest Corridor
- 174 billion investments to win the EV market to spur the domectic supply chain from maining to final products (PV panels ,inverters, CSP systems).
- Complete a national network of 500 000 EV chargers by 2030 (in 2021 more than 200 000 quick EV chargers)
- Replace 500 000 diesel transit vehicles and electrify at least 20 000 yellow school busses -> first step toward 100% clean hydrogen busses! (2040-2045).
- 25 billion for airports modernisation, (H_2 power based solutions)
- 17 billion for modernisation of inland waterways, coastal ports and Hydrogen ferries (helthy ports programm),
- 20 billion for a new neighborhoods programm to connect new and historical infrastructures
- 25 billion for dedicated fund to support ambitious projects that have tangible benbefits to the regional or national economy but are too large or too complex for exsisting programs,

Advance U.S. learership in critical technologies and upgarde Americaś research infrastructure: total 180 billion USD for NSF
(Biden-Harris initiative to Congress; October 8,2021)

- 50 billion for NSF (National Science Fondation) to create technology directorate: advanced energy technologies and computing, communication technologies and semiconductors and electricity conducting materials industry,
- 40 billion for research infrastructure;
- 30 billion for science laboratories in rual areas,
- 35 billion for the areas connected with climate crisis and technological solutions,
- 15 billion for climate neutral demo complexes,

- 300 billion for strengthening the manufacturing supply chain for critical goods (REEs, Pt-metals, graphite, semiconductors)
- 50 billion for semiconducters research and development of prototypes,
- 52 billion for development of different domestic REEs based high-tech devices,
- 100 billion on workforce development in critical areas

IEA Global Hydrogen Review 2021 (IEA report + DOE prognoses)

- In 2020, 90 Mt hydrogen produced from fossil sources generating 900Mt CO2.
- Only 16 projects with CCS/SCCU are active and only 0.7 Mt of hydrogen is produced with avoiding 7Mt CO2 formation.
- 300 MW electrolysers are needed to produce 8 Mt clean hydrogen by 2030.
- 350 active projects (40% electrolysers are running in EU) are under exploitation with capacity of 54 GW (2020), 40 new projects have been accepted with 35 GW capacity.
- 8 Mt of green hydrogen should be produced in 2030 and 80 Mt in 2050.
- Huge investments (1600 billion USD in low-carbon hydrogen supply through to 2030) are inevitable to invest to realize the EU clean hydrogen production plans!!!!!
- Only 37 billion USD (state investments) +300 billion USD (private sector) have been announced up to 2030.
- Noticeable increase in the number of FC vehicles from 7000 (2017) to 43 000 by mid 2021 should be stressed (mainly passenger small cars (80-85%)). 15-20% are trucks, buses, experimental trains (40-50) (Alstom, Stadler, General Electric), etc.
- The cost of FC for cars has fallen 70% since 2008.
- Clean hydrogen price (2.8 to 6 USD, 2021, depending on green electricity price) will become competitive with „blue“ hydrogen very soon: 1.5 to 3.7 USD (including CCU/CCS expenses, depending on the natural gas prises, and CCS/CCU additional taxes/storage cost, thus, depending on the region /state/area where natural gas is produced and CCS/CCU is applied).
- Based on IEA`s Net Zero Emission by 2050 Scenario, one kg hydrogen cost should be lower than 1.3 USD.
- In longer term, 1kg of hydrogen can be cheaper than 1 USD for cars (99.99%).
- Very slow acceleration has been taken place in EU, thus, not quick enough to reach Net Zero CO_2 transport by 2050.

Europe speeds up… slowly

The USA has the most installed stationary fuel cell power in the world, primarily industrial- scale 100 kW+ units supplied by one of three US-based businesses: Bloom Energy of California and Delaware; Doosan Fuel Cells America and Fuel Cell Energy, both located in Connecticut.

Deployment of stationary fuel cell systems in Europe remains slower than in Korea, Japan or the USA. Although support overall is strong, support of large-scale rollout is not yet there. So financial incentives for deployment of domestic fuel cell CHP systems tends to be for thousands not ten-thousands of units, and little exists to promote larger scale commercial and industrial systems

E4tech, The fuel cell Industry review 2019:
https://fuelcellindustryreview.com
/FCIRarchive.php

The EU Hydrogen Strategy describes a roadmap with three phases

1st phase (2020-2024): activation.

- 6 GW electrolysers, 1 Mt of green hydrogen
- Scaling up of manufacturing of electrolysers
- Setting up the regulatory and enabling framework for a hydrogen market
- Planning of transmission and carbon capture infrastructure

2nd phase (2025-2030): upscaling.

- Install at least 40GW electrolysers, 10 Mton green hydrogen
- Increasing cost-competitiveness of renewable hydrogen,
- Hydrogen for steel making industry, trucks, rail, maritime transport, electricity based hydrogen offering flexible services to the power system
- Development of Hydrogen Vallyes, 16 vallies,
- Development of EU-wide logistical and transport infrastructures

3rd phase (2031-2050): (market uptake).

- Low carbon technologies reaching maturity, able to be deployed at large scale to reach to all sectors hard to decarbonise
- Significant research and innovation efforts should be conducted

New initiatives from EC, docoment: (COM (2021)558; July 14, 2021

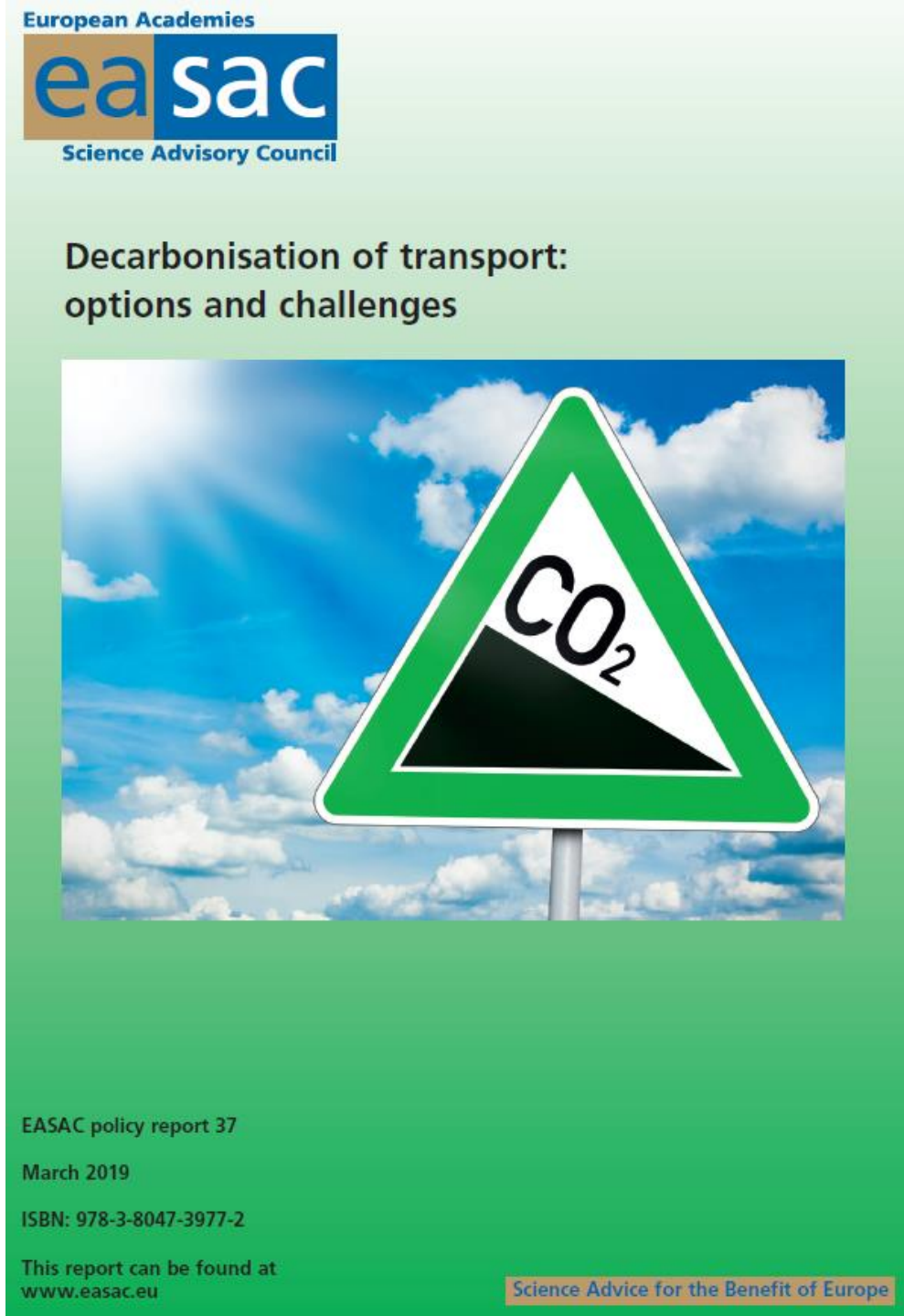
- New projects: increse energy efficiency first - higher enengy efficiency in electricity and gas applications
- Increase energy application efficiency and therefore decrese energy utilisation (final application) from 32.5% (old directive) to 36% (new directive) and decrease primary energy consumption 39% (2030)
- New reference year for calculations is 2020!!!!! Thus, increse efficiency from 2020 level and decrease the primary energy application 9% (in comparison with 2020). This is coherent directive!
- Every year energy saving obligation for January 1 /(2024) to December 31, 2030 is 0.8% (old) to 1.5% new obligation! Thus 2 times increase. New regulations for EU ETS!
- For public sector new energy efficiency OBLIGATION: 1.7% DECREASE PER YEAR
- Renovation of public sector buildings 3% in a year (according to Near-Zero buildings regulations)
- Intensive application of smart technologies - IT controlled energy management of buildings. (Limiting borders - 10 TJ/y (2.77 GWh/y) and complex systems managers (100TJ/y (27.7 GWh/y)).
- New Energy application regulations for data centres, heat energy and cooling energy producers

Fit for 55 package

- Hydrogen as an energy carrier role from 2% (2020) to 12-14 % by 2050 should be achived,
- Electrolysers capacity up to 37-65 GW by 2035 and 650 GW by 2050, i.e., 9% of total energy (green hydrogen energy) should be established
- EU electricity 65% free of CO_2 by 2030 and 80-85 % by 2050 should be achieved
- In USA, 100 % CO_2 free electricity by 2035 is a target! (DOE report, sept.2021)
- The revised Renewable Energy Directive: 150 km distance between HRS at TEN-T corridors and 25-50 km even in urban nodes by 2030. 5 € / kg H_2 at the pump for transportation and 2 -3 Euro for industry. These are the competitive prices compared with traditional fossil *fuels* (diesel), without health protection compensation corrections (penalties for fossil fuels).
- CO_2 standards for cars and vans, the Fuel EU Maritime proposal (including ammonia and methanol applications????)
- Corrections into the EU ETS Document.
- New policy proposals are expected by the end of 2021 (so-called The Hydrogen and Gas Markets Decarbonisation Package).

- In EU, no fossil fuels using new cars production after 2035-2040.
- All fossil fuels based cars exploitation should be finished after 2050: no natural gas , gasoline and diesel fuels in EU market after 2050!
- 25% CO_2 production, 50% NOx , VOC and NP generation can be avoided **if this initiative will be realised**.
- Very important is taking into account the **health protecting aspects**!

https://easac.eu/fileadmin/PDF_s/reports_statements/Decarbonisation_of_Tansport/EASAC_Decarbonisation_of_Transport_FINAL_March_2019.pdf



CO_2 total cycles (well to wheels) for FC car 3 times less than for a diesel and 3.5 times less than a petrol car!

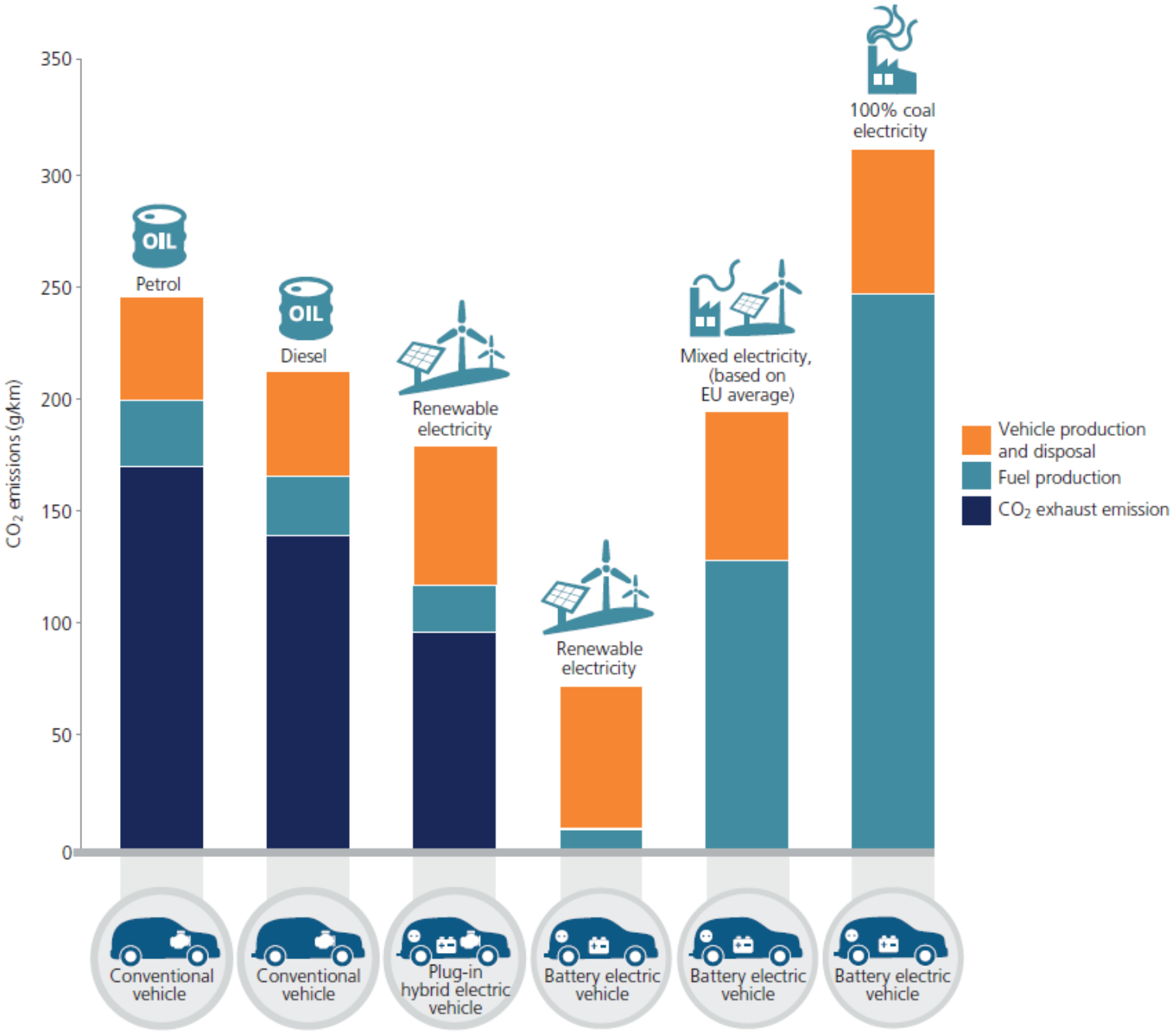
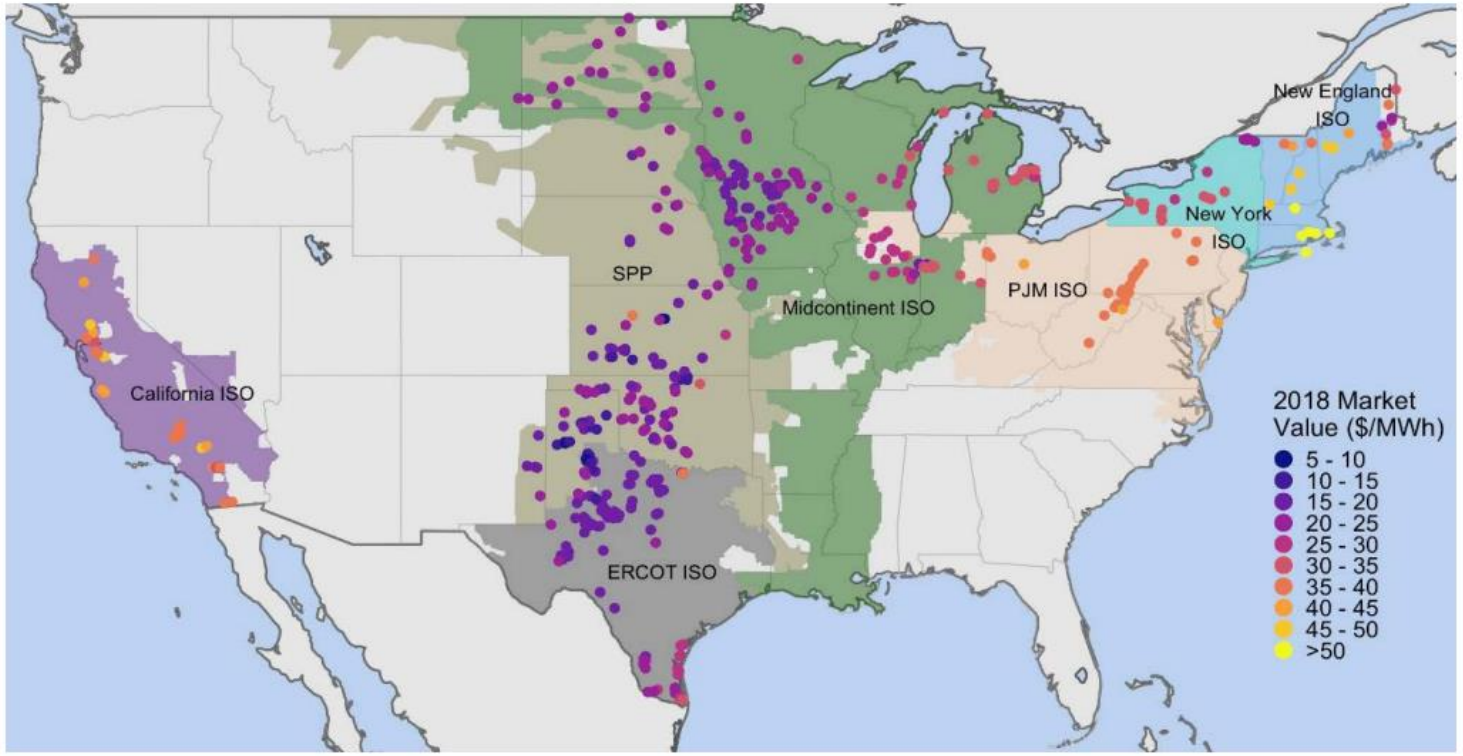


Figure 3.4 The range of life cycle CO_2 emissions for different vehicle and fuel types. Values are estimated for an average mid-class vehicle, based on 220,000 km. (Reproduced courtesy of the European Environment Agency (EEA 2016a).)

https://easac.eu/fileadmin/PDFs/reports_statements/Decarbonisation_of_Tansport/EASAC_Decarbonisation_of_Transport_FINAL_March_2019.pdf

The Wholesale Market Value of Wind Energy in 2018 Varied by Region: Lowest in ERCOT, Highest in ISO-NE



- Market value estimates in 2018 at project level span a wide range, from a low of $7/MWh to a high of $72/MWh, with a median value of $22/MWh

U.S. DEPARTMENT OF ENERGY | OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY

2020- 5.6 USD/MWh; in some areas even 3.5 S/MWh! Without subsidies : 0.175 USD 1 kg H2. (2021 two quaters). Median 19.8 USD /MWh (2020). (0.95 USD 1kg H2)

In Australia PV electricity produced H2 = 1.5 Aust. dollars (1.1 USD 1kg H2)
Liquidified H2 transport (Hydrogen shuttles to Japan, Singapore, Korea, etc.,

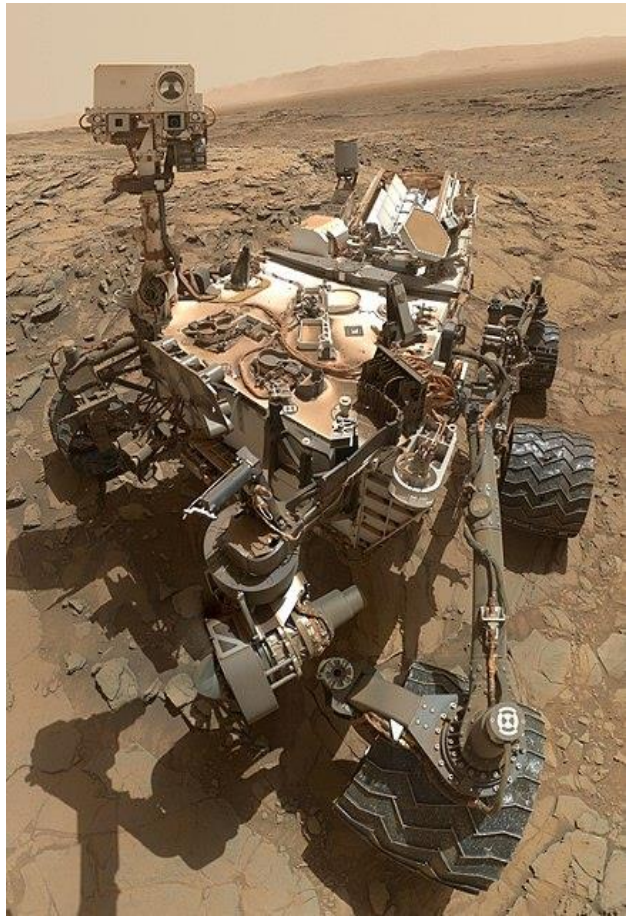
1kg H_2 = 0.35 $ (1kg H2 50 kWh electricity) passage -130-200 km
1kg H_2 = 3.685 dm^3 diesel (diesel price should be 0.1 $) – passage pnly 45-50 km

https://www.energy.gov/sites/prod/files/2019/08/f65/2018%20Wind%20Technologies%20Market%20Report%20Summary.pdf

10-20 % of energy storage capacity is inevitable for stabilisation of wind and solar energy based electricity nets

TARTU ÜLIKOOL

- 10-30% storage of total power of wind and solar farms is a normal amount.
- Very short-term storage method: in supercapacitors
- Moderate: in batteries (Li-ion, Na-ion, Pb/PbO_2, redox flow batteries, etc.)
- Long scale and seasonal: hydrogen electrolyses, compessed air, pumped hydro, etc.
- E-fuel technologies
- Bay-back time is even shorter than in wind-farms without storage (USA DOE calculations).



https://www.nytimes.com/2019/08/20/business/walmart-tesla-lawsuit-fires.html
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Distribution of fuel cells

US Department of Energy hydrogen and fuel cell technologies perspectives

Eric L. Miller, Simon T. Thompson, Katie Randolph, Zeric Hulvey, Neha Rustagi, and Sunita Satyapal

"The fuel cell market, for example, has seen consistent growth in the last few years, with nearly 70,000 fuel cell systems and 800 MW in fuel cell power shipped worldwide in 2018, and with approximately USD $2.3 billion in fuel cell revenue.[2]"

"Globally, there are more than 300,000 stationary fuel cells in operation, 14,000 hydrogen-powered fuel cell cars on the road, and approximately 300 hydrogen refueling stations. In the United States, we currently have more than 500 MW of stationary fuel cells, more than 7800 fuel cell cars, and more than 28,000 hydrogen fuel cell forklifts operating at major companies.[3]"

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