Is it possible to achieve a reduction in greenhouse gas emissions with an increase in energy demand? Yes, if it is (an option) hydrogen from (Russian) natural gas produced by pyrolysis (no direct CO2 emissions) within EU "hydrogen valleys"

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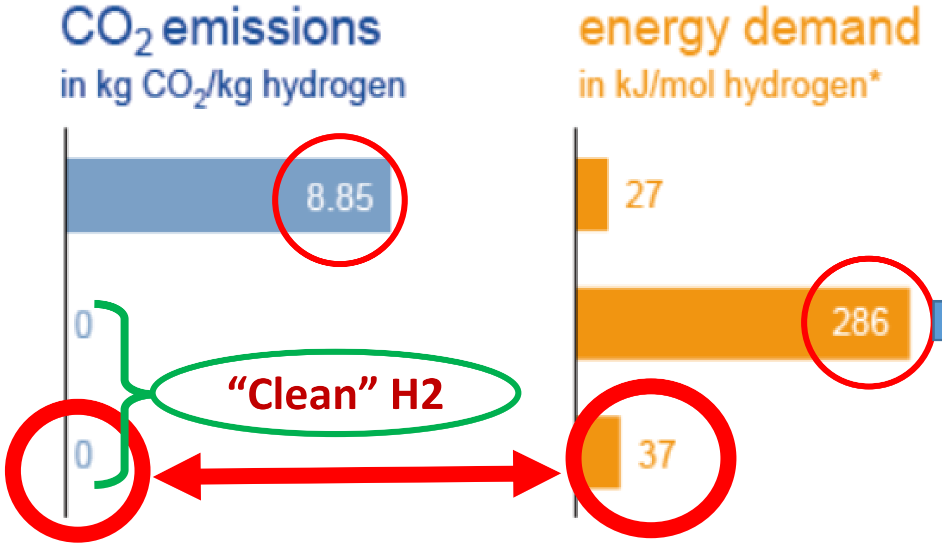
All other conditions being equal, methane pyrolysis (& similar technologies) have clear competitive advantages against two other key technologies in hydrogen production (MSR+CCS & electrolysis) under technologically neutral regulation

CC(U)S is needed!!! => additional imputed costs (CAPEX + OPEX) => add. 20/30+% (*) (CEC: twice as high (*)) => additional element of <u>cost</u> budget => <u>WORSENS financeability</u>

Vision to diminish high-cost energy density – to use excessive RES electricity at zero or negative prices => this leads to unstable (regularly interrupted by natural reasons) RES-based H2 production cycle => prolongation of pay-back periods (of debt-financed CAPEX) => <u>WORSENS financeability</u>

Steam reforming of natural gas	$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$
Water electrolysis	$2H_2O \rightarrow 2H_2 + O_2$
Methane pyrolysis	$CH_4 \rightarrow 2H_2 + C$



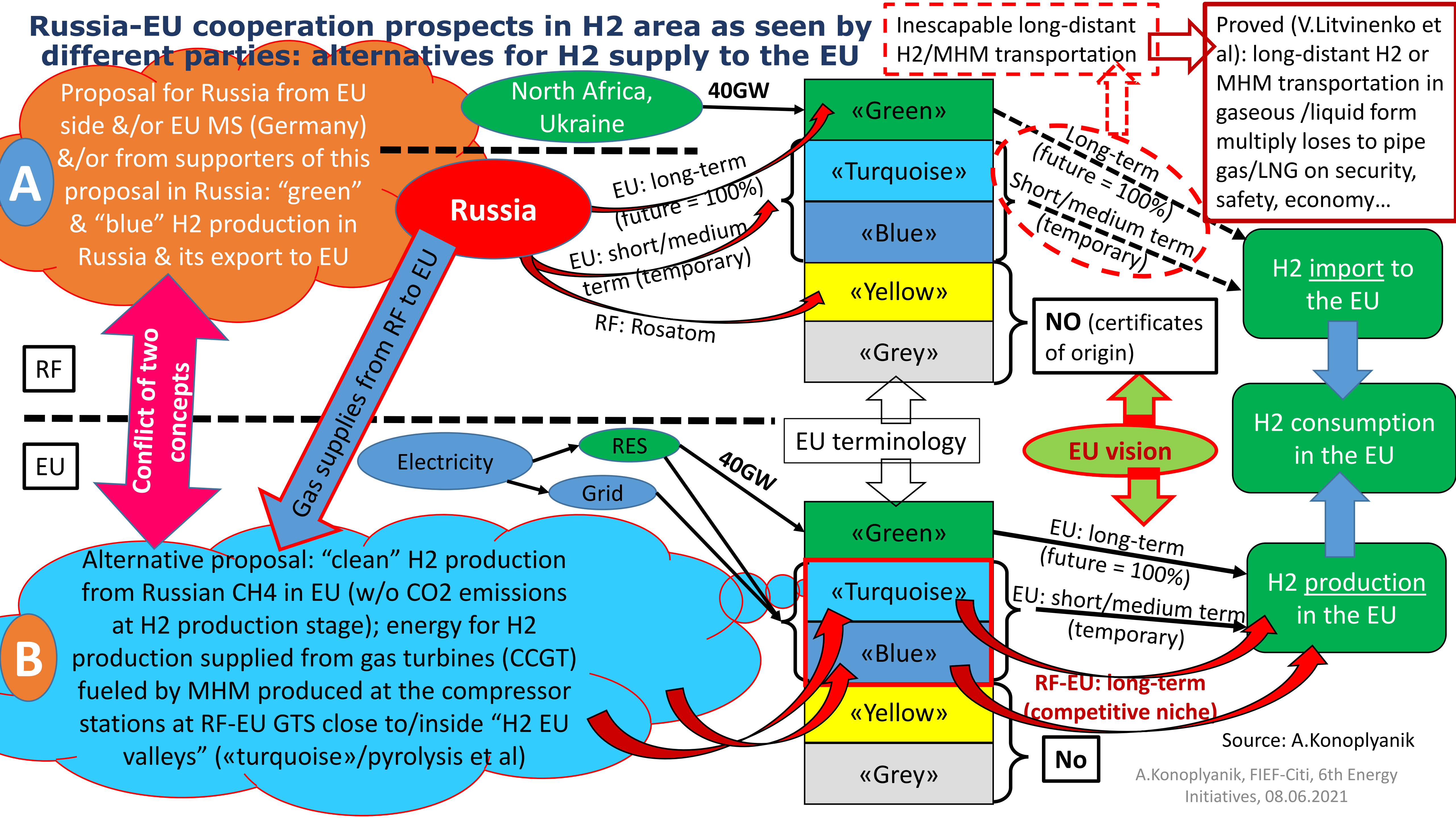
Source: A.Konoplyanik based on: Dr. Andreas Bode (Program leader Carbon Management R&D). New process for clean hydrogen. // BASF Research Press Conference on January 10, 2019 / (https://www.basf.com/global/en/media/events/2019/basf-research-press-conference.html)

(1) No need in CC(U)S => CAPEX/OPES saving
(2) Marketing of carbon black = additional element of <u>revenue</u> budget => start of new investment cycle(s) based on carbon black
(3) In case of storage, carbon black does not provide same negative effects as CO2 => <u>IMPROVES financeability</u>

(*) René Schutte, N.V. Nederlandse Gasunie. Production of Hydrogen. // Masterclass in Hydrogen, Skolkovo – Energy Delta Institute, Moscow, May 23, 2019 (https://drive.google.com/open?id=1g_4TiiKAKGaJziXG8TWjTdpncfipj9x1)

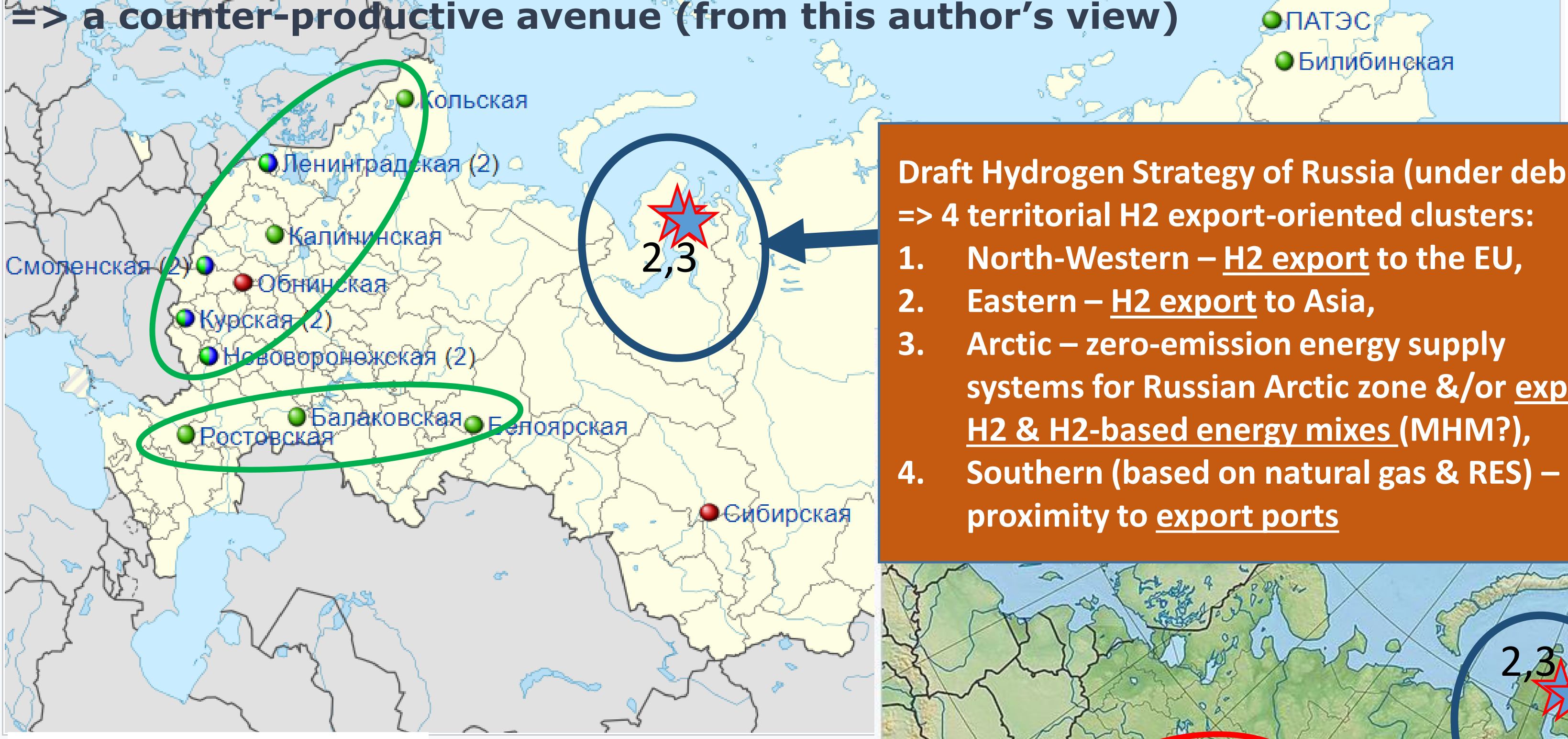
(**) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions. A hydrogen strategy for a climate-neutral Europe // EUROPEAN COMMISSION, Brussels, 8.7.2020, COM(2020) 301 final, p.4-5, footnote 26 (https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf)

Russia-EU cooperation prospects in H2 area as seen by different parties: alternatives for H2 supply to the EU



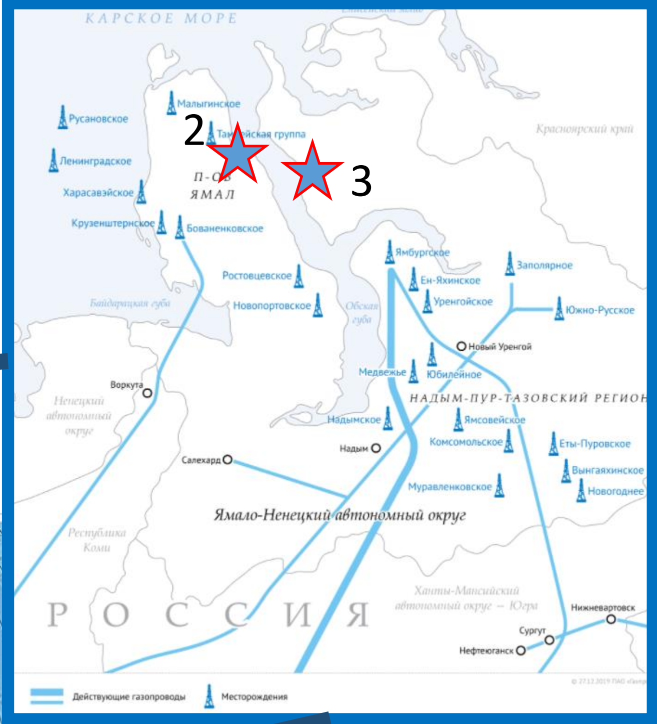
Source: A.Konoplyanik

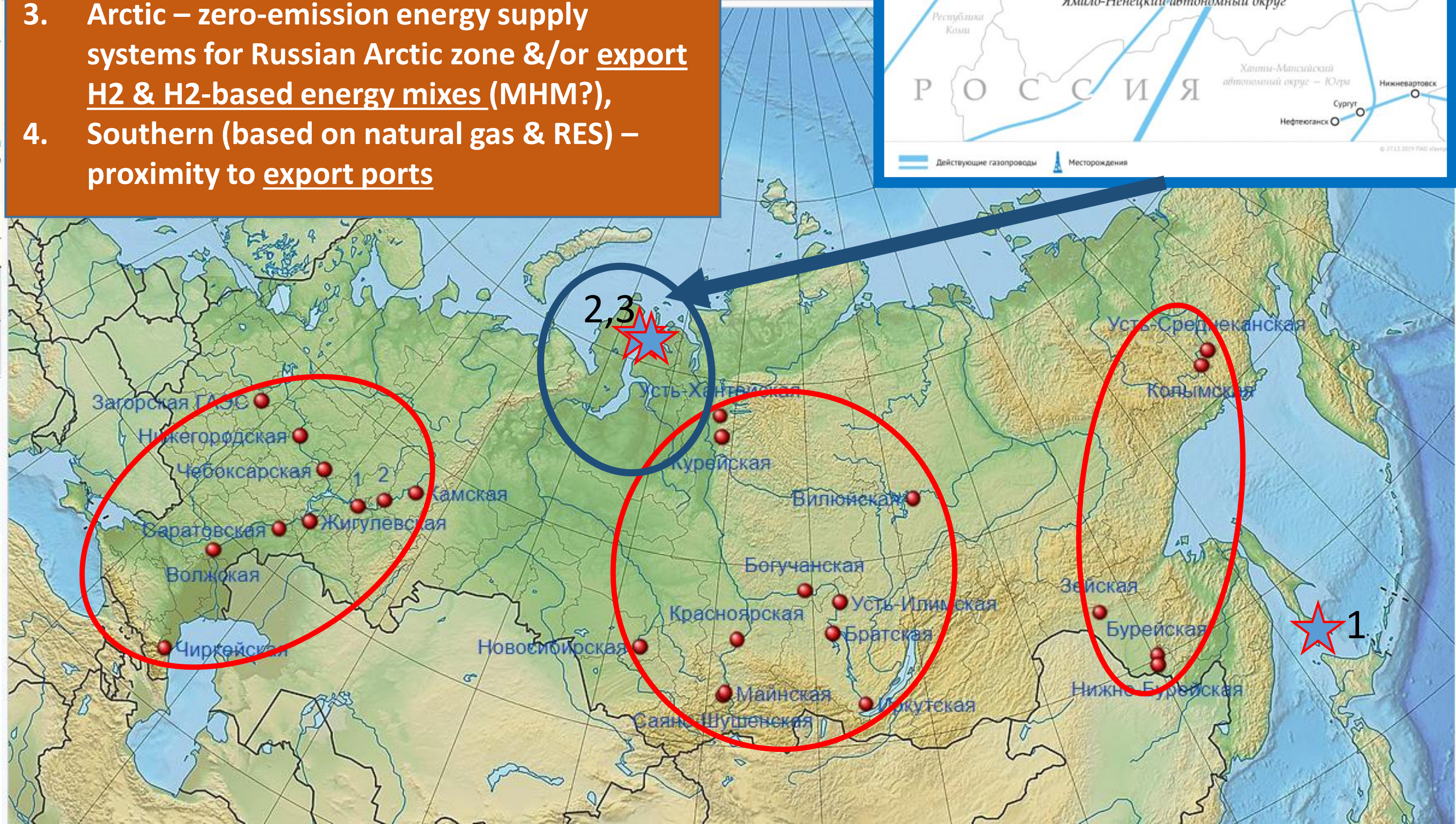
Geography of nuclear & hydro power stations and major area of gas production in Russia (Nadym-Pur-Taz & Yamal): proposed domestic production of H2 for export would be deep inside Russia & will require long-distant large-scale transportation of H2/MHM to the EU via existing RF-EU GTS, the latter to be deeply/costly modernized => a counter-productive avenue (from this author's view)



Draft Hydrogen Strategy of Russia (under debate) => 4 territorial H2 export-oriented clusters:

1. North-Western – H2 export to the EU,
2. Eastern – H2 export to Asia,
3. Arctic – zero-emission energy supply systems for Russian Arctic zone &/or export H2 & H2-based energy mixes (MHM?),
4. Southern (based on natural gas & RES) – proximity to export ports





Nuclear — Nadym-Pur-Taz & Yamal — Hydro

Large-scale LNG plants, acting: (1) Sakhalin-2; (2) Yamal LNG; (3) Arctic LNG

Sources of maps:
https://www.gazprom.ru/f/posts/15/770293/map-yamal-ru-2019-12-30.png;
https://ru.wikipedia.org/wiki/Атомная_энергетика_России;
https://ru.wikipedia.org/wiki/Список_гидроэлектростанций_России;

RF-EU gas decarbonisation to H_2 upstream? Some physical & chemical barriers to long-distant high-pressure transportation & storage of H_2 (acc. to Litvinenko et al, SPB Mining University) (*)

(1) Effectiveness of gas pipeline transportation is directly contingent upon quantities of the product, and thus on the density of gas. **As concentration of H_2 in MHM increases from 10 to 90 %, density of MHM decreases more than four times.**

(2) **Energy obtained from** one volume of **H_2 is 3.5 times less than the energy obtained from methane.**

(3) Increase in energy required to compress 1 kg of MHM to raise the pressure by 1 MPa with increasing proportion of H_2. While **H_2 content in MHM rises from zero to 100%, energy costs (work) are raised by around a factor of 8.5.**

(4) Increasing proportion of H_2 in MHM increases explosion risks of the MHM

(5) Export/storage of *liquid* H_2: **CH_4** liquefies at atmospheric pressure and temperature below - 161.5 °C, LNG volume is 600 times less than its gaseous form. **H_2** liquefies at atmospheric pressure and temperature below -252.87 °C, it reduces in volume by 848 times. **(ii)** The closer temperature of a substance to absolute zero, the more **quantum properties** (superfluidity, superconductivity, etc.) begin to appear. **(iii)** Under same conditions and tank capacity it is **possible to store or transport almost 5.9 times more LNG than liquid H_2.**

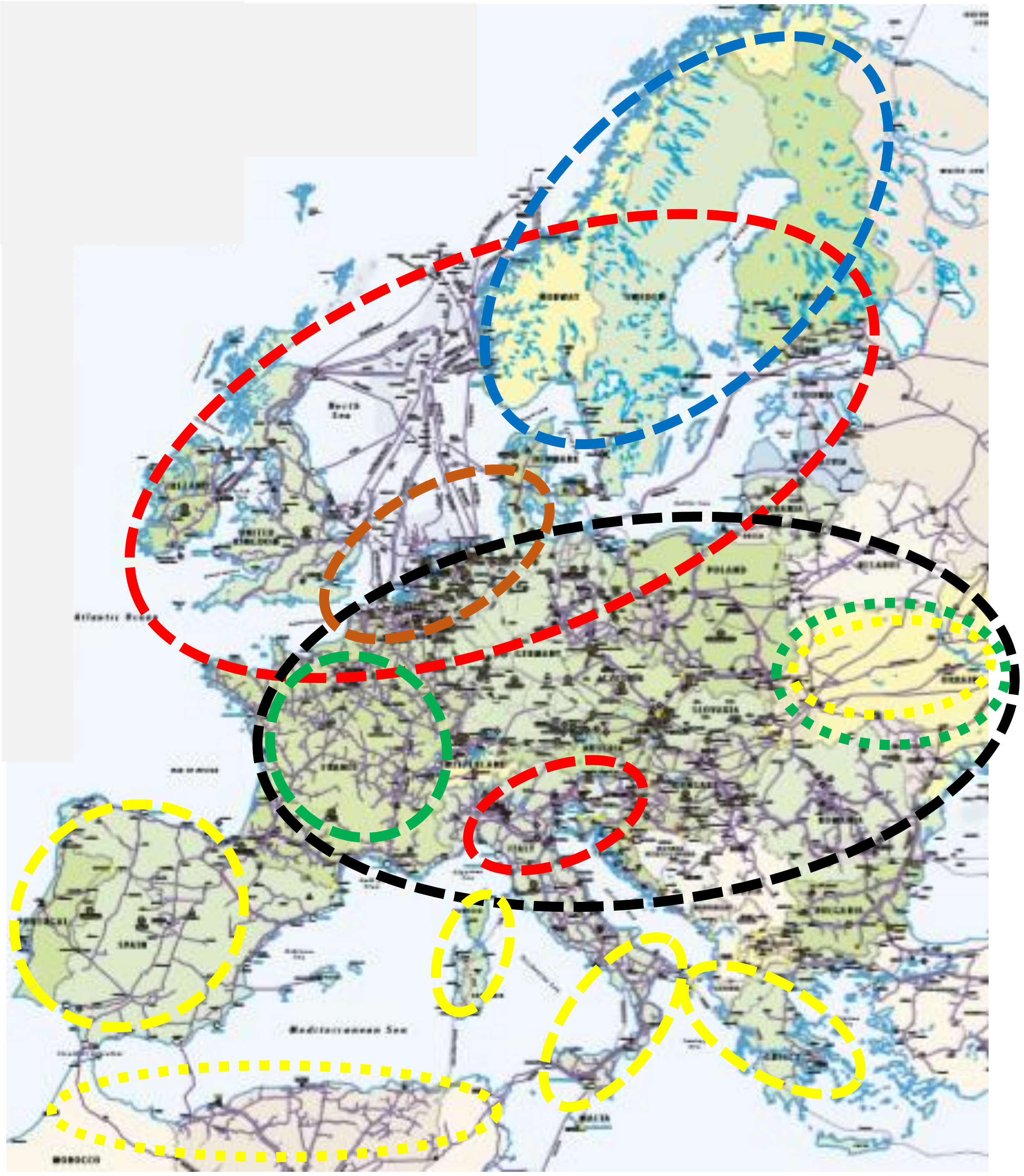
A.Konoplyanik, FIEF-Citi, 6th Energy Initiatives, 08.06.2021

(6) H_2 has extremely high penetrating ability, its molecules spread faster than molecules of all the other gases in the media of another substance and penetrate through almost any metal. **Pressurized H_2 is capable to escape even from airtight tanks during long-term storage.**

(7) Research into effect of H_2 on metals has been carried out for decades. Back in 1967 in USSR scientific discovery "Depreciative effect of hydrogen on metals“ was made (N 378), however, the reactivity of hydrogen is still not sufficiently studied, whereas its negative effects have already become a substantial technical issue (**stress corrosion**). Due to stress corrosion Gazprom replaced over 5,000 km of large-diameter pipelines.

*(*) Within **43** items of RF Gov't Action plan on H_2 Saint Petersburg Mining University is mentioned as co-participant in **42** items*

Source: *Litvinenko V.S., Tsvetkov P.S., Dvoynikov M.V., Buslaev G.V., Eichlseder W. Barriers to implementation of hydrogen initiatives in the context of global energy sustainable development. Journal of Mining Institute. 2020. Vol. 244, p. 428-438. DOI: 10.31897/PMI.2020.4.5*



Approximate potential areas of preferential use of key H2 production technologies in Europe under state regulation based on “technological neutrality” principles

P2G wind
P2G hydro
P2G solar
P2G nuclear

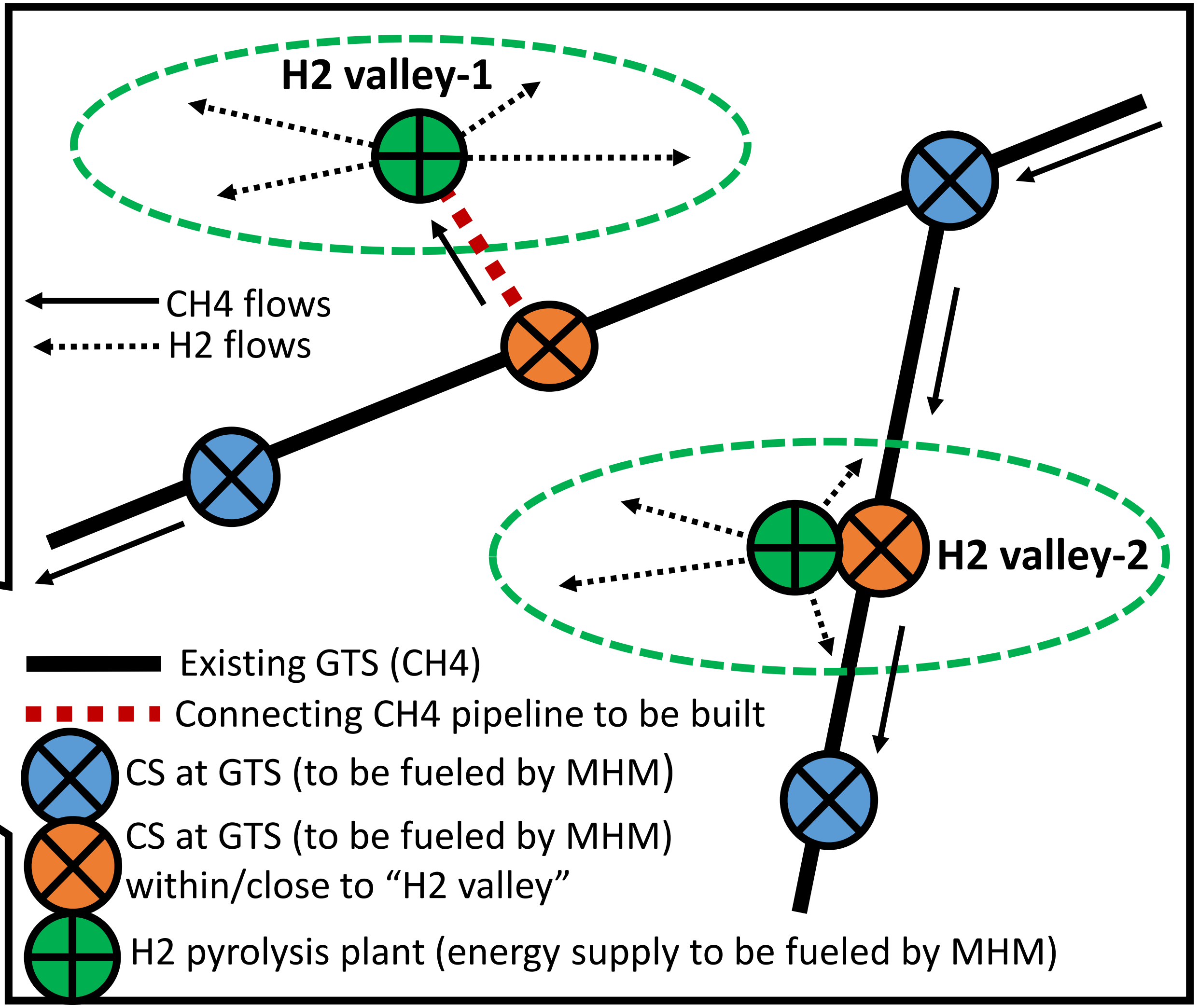
Electrolysis based on different primary electricity sources

MSR/ATR plus CC(U)S

Methane pyrolysis, plasma-chemical method et al w/o CO2 emissions *(to incorporate both Step 2 & Step 3 Cooperative measures from “Three Step Aksyutin’s Path”)*

Source: dashed lines - A.Konoplyanik, based on conversations with Ralf Dickel; dotted lines - Ukraine & North Africa are added based on “The 2x40GW Green Hydrogen Initiative Paper” (Hydrogen Europe study, incorporated in EU H2 Strategy) for illustration purposes with the observation of this author’s skepticism in regard to long-distance transportation of H2 produced in these geographical areas; source of map – ENTSOG

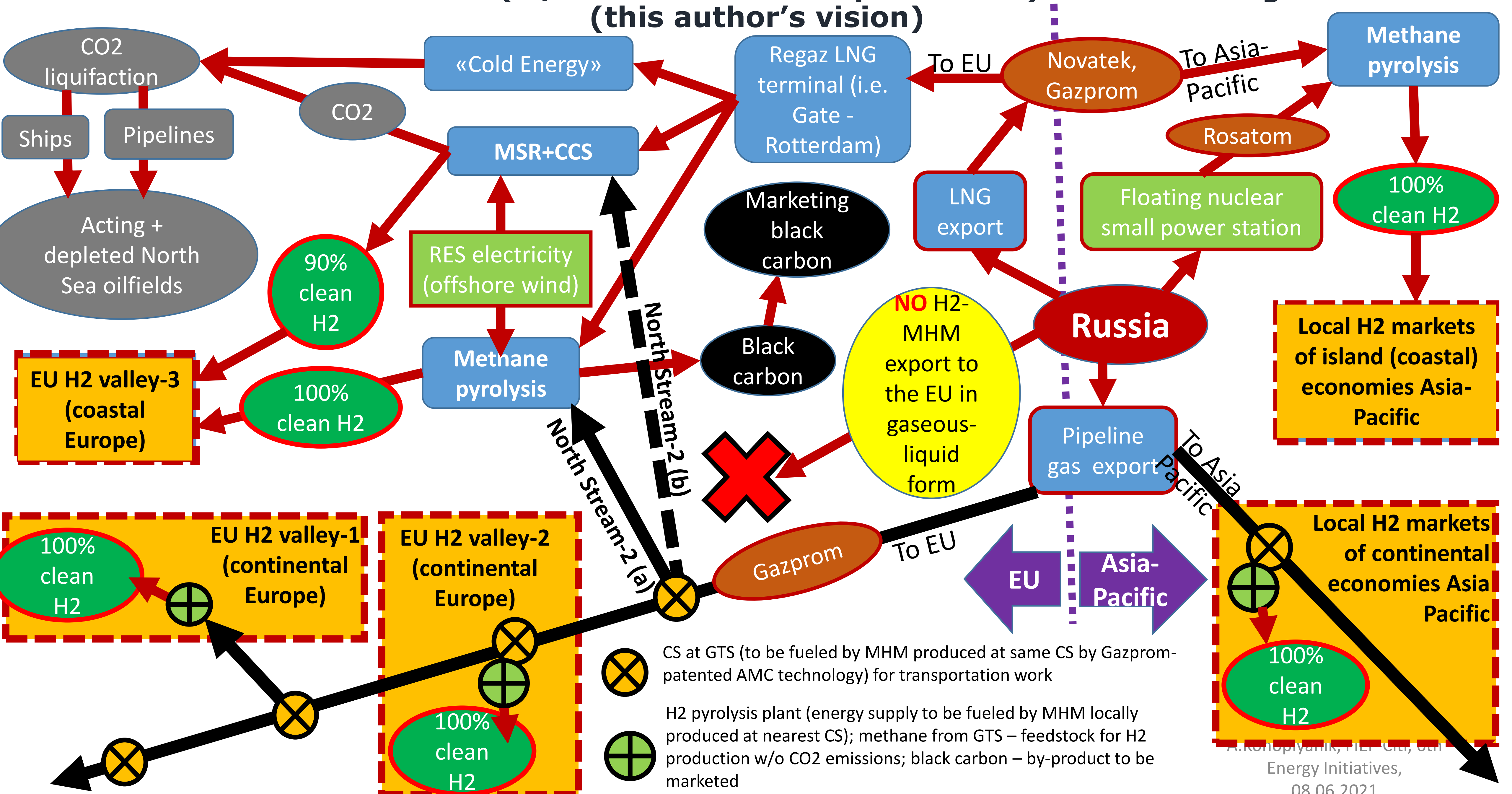
Complementarity of different H2 production technologies within the EU – and potential competitive niche for pyrolysis et al (this author's vision)



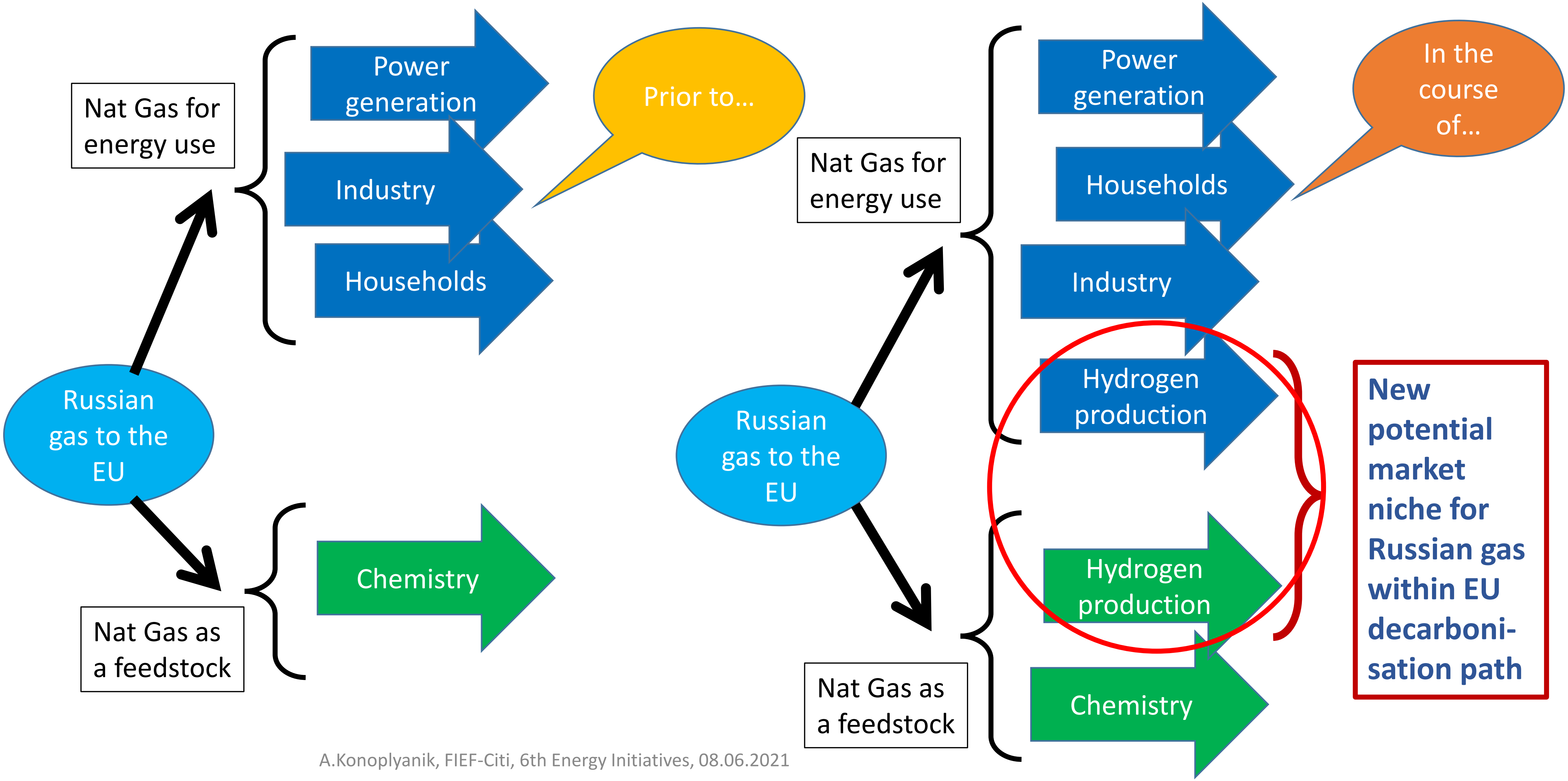
Clean H_2 production (w/o CO_2 emissions) from natural gas downstream EU based on existing Russia-EU GTS & MHM (as energy source) produced at CS on-site

- Clean H_2 production close to EU demand centers (H_2 valleys) located close to existing compressor stations (CS) at cross-border RF-EU GTS. To use gas from the grid:
- As **energy source** for:
  - (1) transportations work:
    - to produce MHM on-site at CS on transportation routes of Russian gas to the EU;
    - to use this MHM at these CS as a fuel gas instead of methane for further gas transportation.
    - Such substitution of CH_4 by MHM as fuel gas at CS diminishes CO_2 emissions by 30% (acc.to Gazprom);
  - (2) clean H_2 production:
    - at the H_2 production plants which are to be built close to these CS in “H_2 valleys”;
    - scale of production adequate to H_2 demand of particular “H_2 valley”;
    - energy supply of CCGT of adequate capacity - acc.to above-mentioned scheme in (1).
    - Though substitution of CH_4 by MHM as fuel gas is not for transportation work, but for energy supply (electricity &/or heat) to H_2 production plant;
- As a **feedstock** for:
  - (3) clean H_2 production:
    - new plants for clean H_2 production from CH_4 (pyrolysis et al);
    - plants to be located close to CS and aimed to cover H_2 demand of local “H_2 valley” (this will exclude demand for long-distance transportation of H_2 or MHM).

Alternative concept for export-oriented segment of Russian hydrogen energy economy – based on clean H2 (w/o CO2 emission in production) from natural gas (this author's vision)



Competitive niches for Russian gas at the EU gas market prior to (existing) and in the course of (possible incremental) EU decarbonisation path



Reserve slides:

- Wrong perceptions as if renewable H2 is the only clean H2 and, moreover, that it is clean at all…
- questionable perceptions for H2 cost curves…

What is clean energy? Depends on how you calculate/consider it…

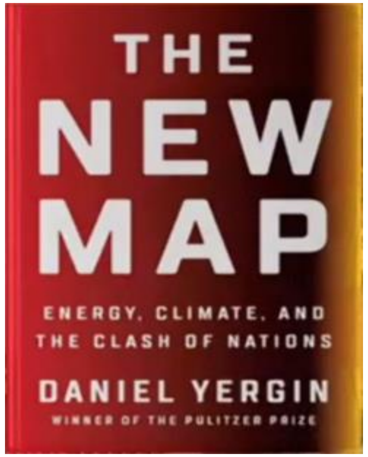
<u>A hydrogen strategy for a climate-neutral Europe</u> <u>(Brussels, 8.7.2020 COM(2020) 301 final):</u>

‘**Renewable hydrogen**’ is hydrogen produced through the electrolysis of water (in an electrolyser, powered by electricity), and with the electricity stemming from renewable sources. The **full life-cycle greenhouse gas emissions of the production of renewable hydrogen are close to zero.**

‘Clean hydrogen’ refers to renewable hydrogen.

<u>Siemens/Gascade/Nowega</u> <u>(Hydrogen infrastructure – the pillar of energy transition…, 2020):</u>

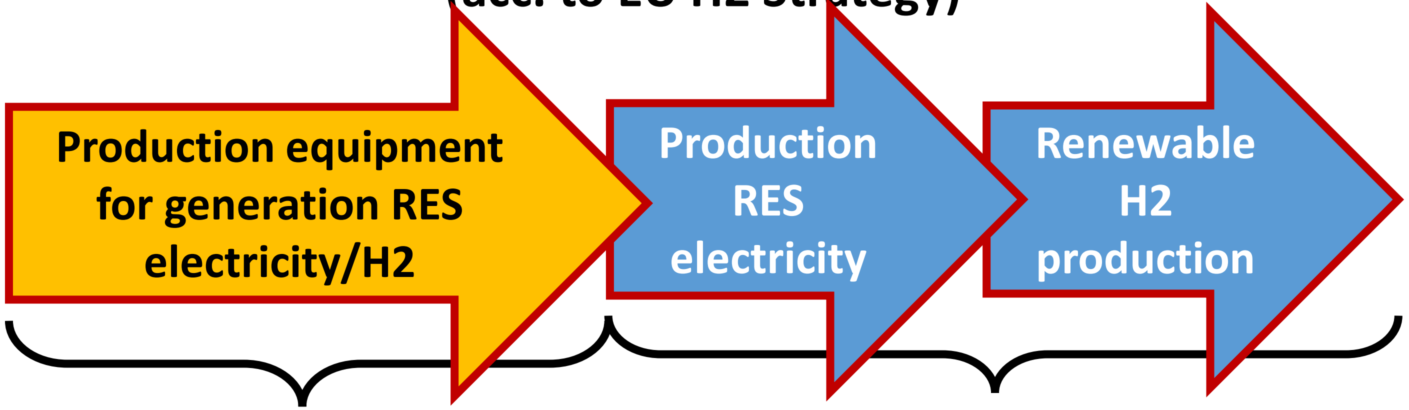
“If the electricity required for electrolysis comes exclusively from renewable, CO2-free sources, the **entire production process is completely CO2-free**.”



<u>Daniel Yergin,</u>
Pulitzer Prize winner for “The Prize” book at presentation of his new book “The New Map”:
“**<u>NEW SUPPLY CHAINS FOR NET-ZERO CARBON REQUIRES CARBON!!! …</u>**
They require diesel to operate shuttle in mining…”

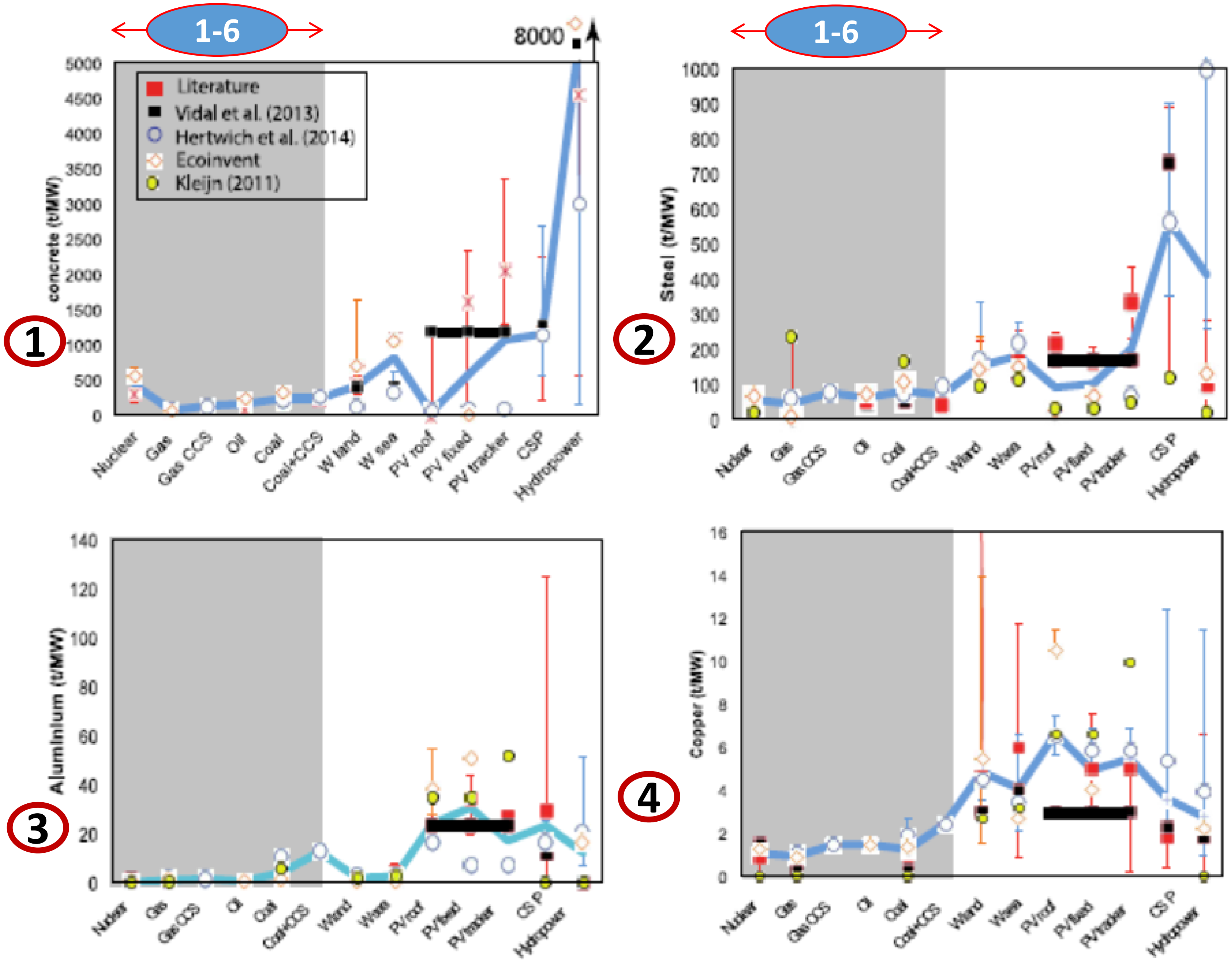
Source: A conversation with Pulitzer Prize winner and energy expert Daniel Yergin, Atlantic Council, 25.09.2020 (<u>https://www.youtube.com/watch?v=hWMOU8IjRhI</u>)

Carbon track of renewable H2 through the full life-cycle (acc. to EU H2 Strategy)



CO2 emissions: **NOT equal to Zero**
EU H2 Strategy: **not included**
Geographical location: **beyond EU**

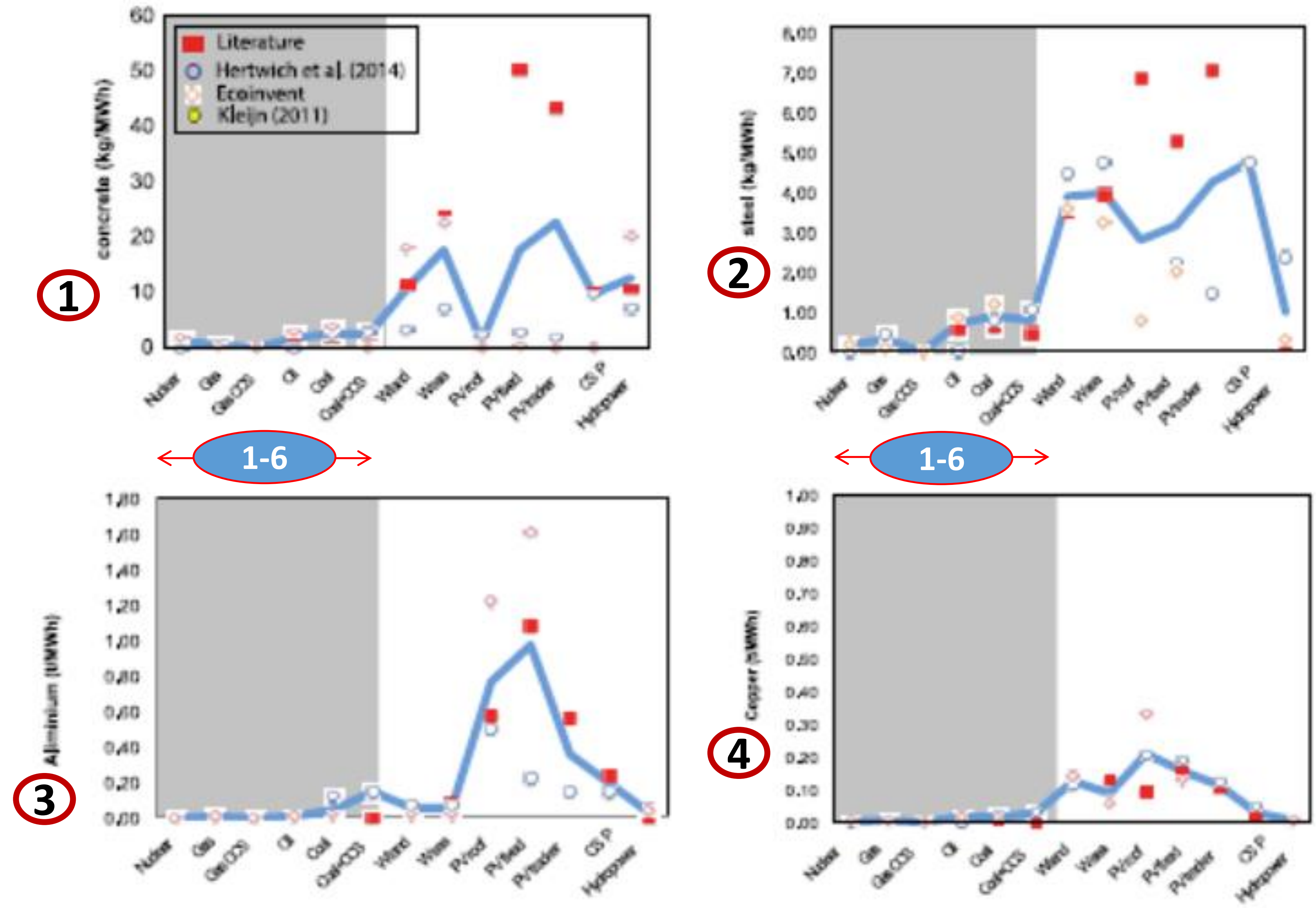
CO2 emissions: equal to Zero
EU H2 Strategy: included
Geographical location: within EU



Quantities (t/MW) of four structural materials used to manufacture different power generation infrastructure (material intensity) :
1 – concrete,
2 – steel,
3 – aluminium,
4 – copper
(fossil fuel power generation technologies are in the gray shaded area;
colour version of the figure at: www.iste.co.uk/vidal/energy/zip)

Source: Olivier Vidal. Mineral Resources and Energy. Future Stakes in Energy Transition. // ISTE Press Ltd - Elsevier Ltd, UK-US, 2018, 156 pp. (Figure 5.2./p. 72)

From left to right: (1) Nuclear, (2) Gas, (3) Gas+CCS, (4) Oil, (5) Coal, (6) Coal+CCS, (7) Wind land, (8) Wind sea, (9) PV roof, (10) PV fixed, (11) PV tracker, (12) CSP, (13) Hydropower



Mass of material in kg required to produce 1 MWh electricity:
1 – concrete,
2 – steel,
3 – aluminium,
4 – copper
(calculated with the material intensities shown in Figure 5.2 and Table 5.1; the gray shaded area indicates fossil fuel-based electricity production; colour version of the picture at: www.iste.co.uk/vidal/energy.zip)

Source: Olivier Vidal. Mineral Resources and Energy. Future Stakes in Energy Transition. // ISTE Press Ltd - Elsevier Ltd, UK-US, 2018, 156 pp. (Figure 5.3./p. 74)

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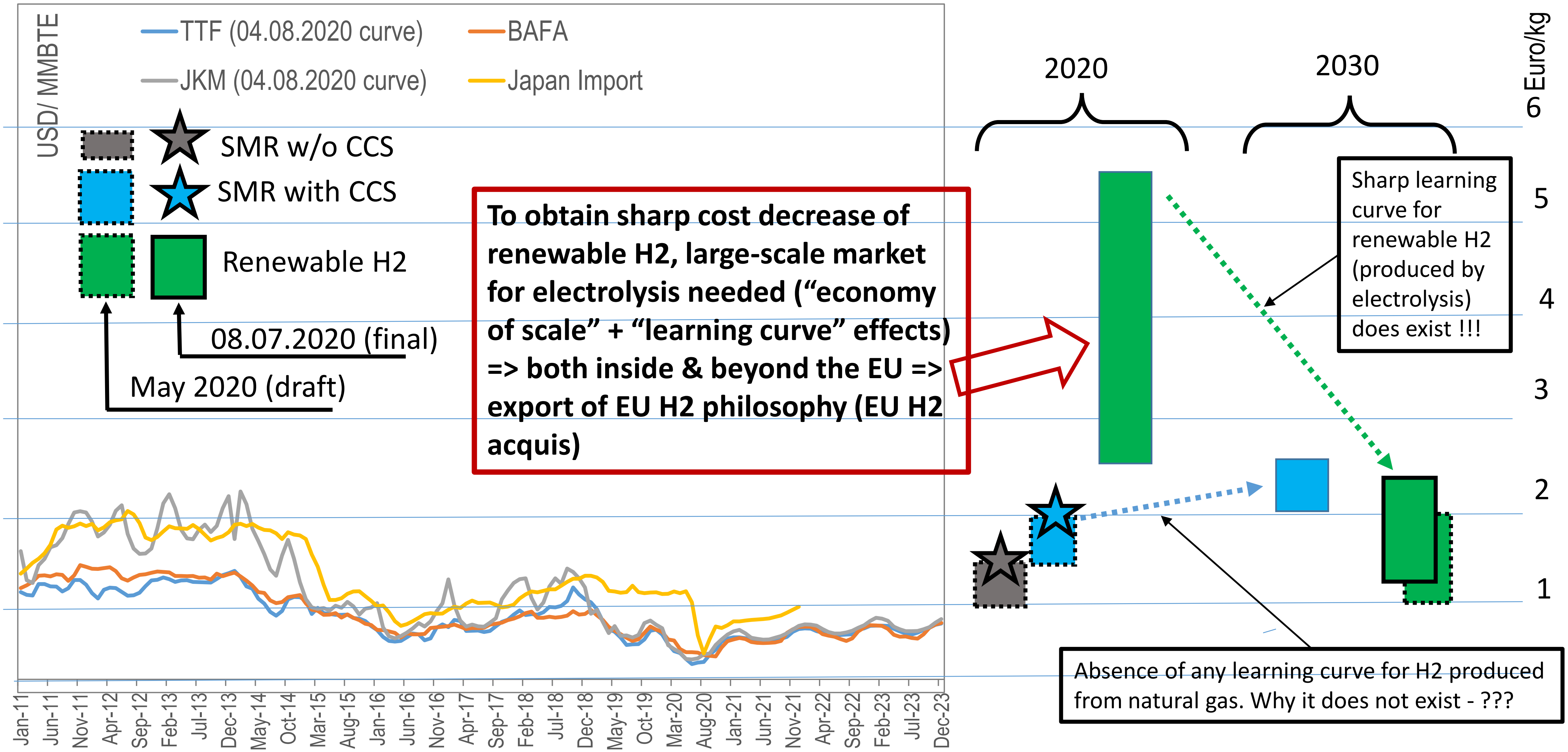
European Commission's estimated costs of H2 production by the key technologies (as presented in the EU Hydrogen Strategy as of 08.08.2020) – and natural gas prices



Source: natural gas prices – Gazprom export; H2 costs – European Commission (EU Hydrogen strategy: dotted lines – draft version, May 2020; solid - final document, 08.07.2020)

Thank you for your attention!

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