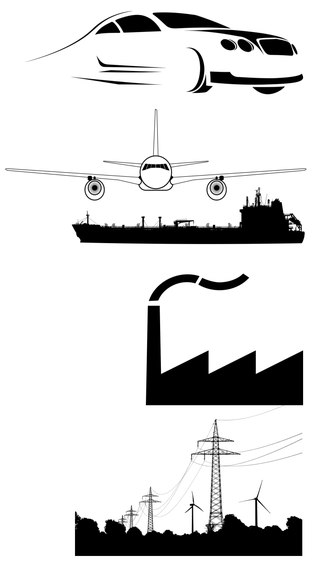
CHALMERS UNIVERSITY OF TECHNOLOGY

PROJECT #13
LIMITED RESOURCES FOR FUEL CELL EXPANSION

SCENARIO 2050



49

9

1

3

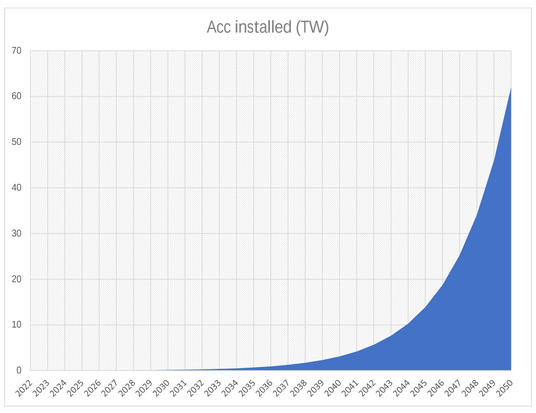
= 62 TW

Assumptions for scenario 2050:
400 million fuel cell road vehicles according to an ambitious vision by the Hydrogen Council (equals 25% of all road vehicles).[ref 1]

A modest use of fuel cells for aviation, shipping and rail is expected in the near future in the scenarios investigated (less than 1 TW). However, as science is emerging rapidly in this are it's reasonable to assume some technological breakthrough before 2050.

Large scale use of hydrogen in the industry is expected. However, most will probably be used for heating and chemical processes. Therefore, it's reasonable to assume a small share for fuel cells.

Fuel cells will be used to balance the electrical grid when the share of renewable sources have increased. Fuel cells is expected to provide 20-25% of the global production capacity in 2050.

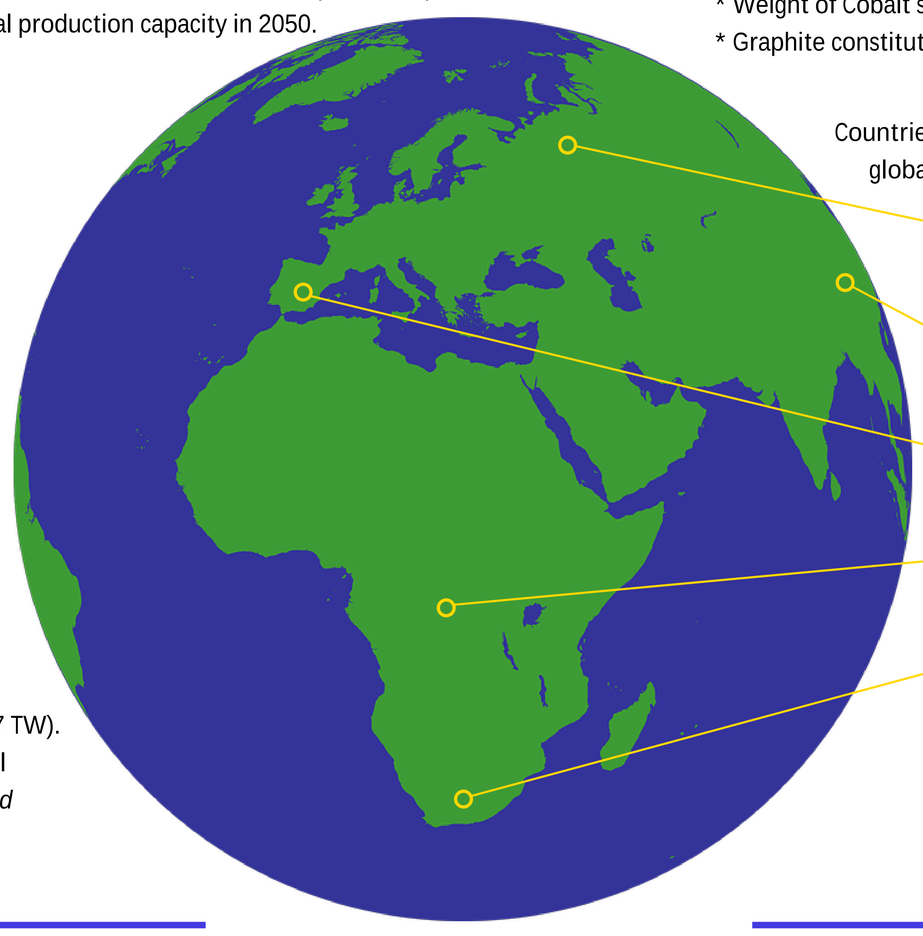


Assumption:
An exponential growth from low numbers in 2022 (0.0037 TW). 20 years lifetime on fuel cells. Since *total installed* fuel cell capacity in 2050 only diviates by 0.2 TW from *accumulated installed* fuel cells they are considered equal.

MATERIALS

Material	Global extraction in tonnes (2020)	FCV demand per year from 2022	Demand per vehicle EV	Demand per vehicle FCV	Competing industries	Criticality
Platinum	200	280	-	10g	Autocatalysts (36%) Jewellery (26%) Industrial (24%)	High
Cobalt	115 000	280	15kg [ref 9]	10g	Li ion batteries (52%) Super alloys (17%) Chemicals (14%)	Low
Graphite	1 100 000	11 500	54kg [ref 8]	23kg	Refractories (29%) Foundries & crucibles (22%) Li ion batteries (19%)	Low

Assumption for materials:
* Reference fuel cell: Toyota Mirai - Weight 33kgs, 125kW [ref 7]
* 10g of Platinum used per vehicle
* Weight of Cobalt substituted is same as Platinum
* Graphite constitutes 70% weight of bipolar plates



Countries accounting for largest share of global supply of critical raw materials [ref 5]

Russia
Palladium 40%

China
Natural graphite 69%

Spain
Strontium 31%

DR Congo
Cobalt 59%

South Africa
Iridium 92%
Platinum 71%
Rhodium 80%
Ruthenium 93%

Recent events impacting supplies:

Russia is a large supplier of Platinum Group Metals. Right these very days new restrictions are set against Russia due to Ukraine issue.

Last two years the corona pandemic has had effects towards shipment, supply and businesses.

DISCUSSION

Aspects to consider regarding supply of raw materials

Political stability: Several countries are considered to be political unstable. This can lead to sudden interruptions in supply.

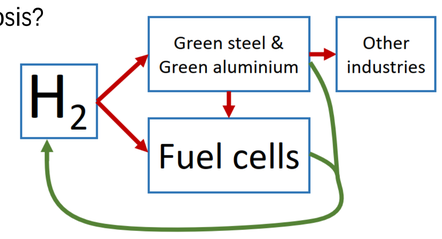
Working conditions: Fair-trade, poor working conditions (pay, working hours) and corruption.

Monopoly: If one (or very few) country has monopoly it can "set or change" the rules quickly; price, quantity, supply etc.

Recycling: Can we recycle materials for PEMFC and SOFC to improve sustainability and reduce dependency on virgin material.

Iridium for H2 production
Demand for Iridium will be much higher than the predicted supply from Eu Commissions for 2050. (2018 to 2050 -> from 5 to 24 tons) [ref 6]
Iridium required in process for H2 -> FC affected

H2 competition and/or symbiosis?
Competition: for H2 and green steel/aluminium
Symbiosis: creating demand/ infrastructure for H2



SOFC use in Unmanned Aerial Vehicles (UAV)
Investigation for use in crop management of large agriculture, visual inspection of water resources and in military. [ref 2]

Battery Electric Vehicles (BEV)
Majority of Graphite will be used in BEV
-> High demand (competition) of material for FC

Recycling
Improved sustainability & less dependency of critical raw materials -> Driven by legislations & demand; hazardous materials, economy and high demand impact. [ref 4]

See table to the right for recovery technologies for relevant fuel cell stack materials. [ref 3]

Table 2 – Recovery technologies for relevant FCH stack materials.

Material	Recovery technologies	
	Current[a]	Novel[b]
Ni; NiO	HTH; HMT	N/A
Ag	HMT	N/A
YSZ	HTH	N/A
Ir	HMT; PMT	TD
Ru	HMT; PMT	TD
Ionomer	N/A	AP; AD
PGM	HMT; PMT	SED; TD; AP
$LaMnO_3$; $LaCrO_3$	N/A	N/A

[a] HTH: hydrothermal treatment; HMT: hydrometallurgical treatment; PMT: pyro-hydrometallurgical treatment.
[b] TD: transient dissolution; AP: acid process; SED: selective electrochemical dissolution; AD: alcohol dissolution.

SUMMARY

* Assumed ambitious scenario (62 TW FC installed capacity in 2050) where the majority is for road vehicles.
* Focus on PEMFC and the demand for Graphite, Platinum and Cobalt.
* Cobalt and Graphite are not critical compared to today's extraction and demand for EV.
* Platinum could be critical if not replaced by other metal. However, same or less amount of Pt is used today for an diesel ICE car in the catalytic converter.
* Extraction of these materials concentrated to a few countries -> Large risks in global supply chains in case of unpredictable events.

22 Ti Titanium
Titanium
Application: For metallic bipolar plate and as anode composition of SOFC

38 Sr Strontium
Strontium
Application: In the composition of anode (together with Ti) in SOFC

27 Co Cobalt
Cobalt
Application: For metallic bipolar plate and as anode composition of SOFC

44 Ru Rutenium
45 Rh Rhodium
46 Pd Palladium
76 Os Osmium
77 Ir Iridium
78 Pt Platinum
Platinum-Group Metals (PGM)
Application: Catalyst in anode and cathode. Cobalt is an alternative metal.

6 C Carbon
Carbon / Graphite
Application: Used in bipolar plates/ end plates. Stainless steel / Titanium are alternative solutions

References:
[ref 1] The Hydrogen Council, Hydrogen scaling up (2017)
[ref 2] SAE 2021-04-06; "Investigation of a Piston Engine and Solid Oxide Fuel Cell Combined Hybrid Modular Powerplant for Unmanned Aerial Vehicles"
[ref 3] Loughborough University UK and Rolls-Royce Fuel Cell Systems Limited, An investigation into end-of-life management of solid oxide fuel cells (2007)
[ref 4] Valente et al, End of life of fuel cells and hydrogen products: From technologies to strategies (2019)
[ref 5] European Commission, Study on the EU's list of Critical Raw Materials – Final Report (2020)
[ref 6] TNO, Towards a green future part 1: how raw material scarcity can hinder our ambitions for green hydrogen and the energy (2021)
[ref 7] Toyota Mirai Specs & Options (2022)
[ref 8] Robert Pell, Battery Grade Graphite: It's Not All About Carbon (2020)
[ref 9] Pratima Desai, Victoria Waldersee and Heekyong Yang, Explainer: Costs of nickel and cobalt used in electric vehicles batteries (2022)

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