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Challenges and Bottlenecks for the Green Transition

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It was possible that at some point in the near future, the European captains of industry would turn to the European geological surveys and ask:

WHY WAS THIS WORK DONE?

There was no credible feasibility plan for fundamental industrial reform that recognized the current physical industrial requirements to phase out fossil fuels **– anywhere in the world**

There was a clear lack of **hard numbers** in all publicly available strategic planning for the future

There was very little discussion about current industrial and economic **dependency on fossil fuels energy**

There was no discussion or visible situation awareness of the quantity or type of **minerals** to phase out fossil fuels

The whole commodity sector was **considered to be a market phenomenon**, not a series of finite non-renewable natural resources, that had engineering bottlenecks in extraction

Assumptions were being made regarding the mining, smelting & recycling industrial capabilities to **deliver the required volumes of metals,** that were not appropriate

“why did you not tell us of the mineral supply shortfall?”

GTK

ALTHOUGH IT IS WELL KNOWN THAT
OIL, GAS AND COAL RESERVES ARE FINITE

THE GLOBAL STRATEGIC DECISION ADOPTED BY MOST NATIONS

TO PHASE OUT FOSSIL FUELS SYSTEMS AND REPLACE THEM WITH RENEWABLE ENERGY GENERATION SYSTEMS

IS LARGELY DRIVEN BY

CO_2 EMISSIONS & ASSOCIATED CLIMATE CHANGE

NOT BY

DWINDLING FINITE RESOURCES

The Green Transition must and will happen, just not the way we think it will

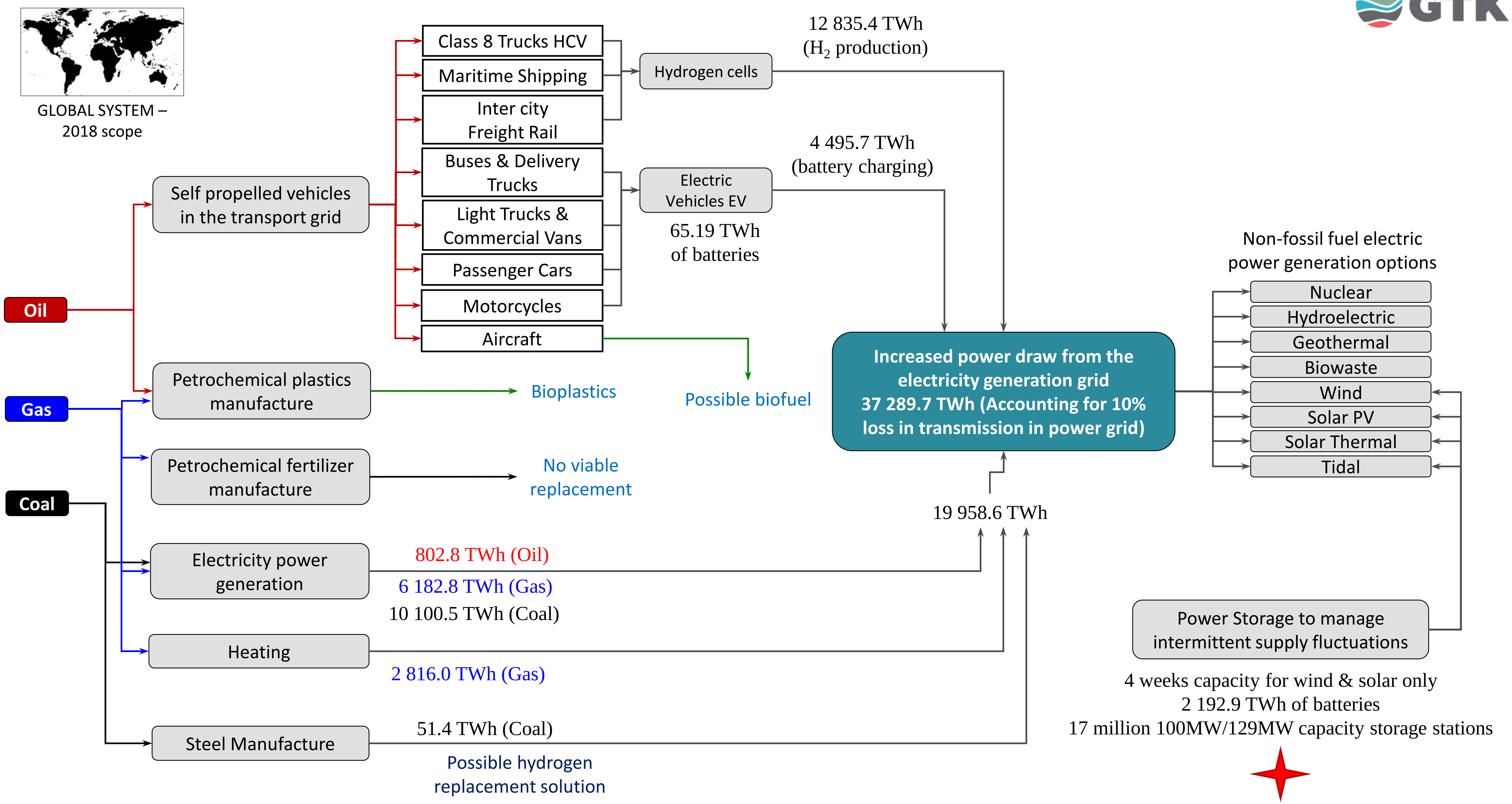
Baseline calculation

- The global fleet of vehicles is estimated to be 1.416 billion, which travelled an estimated 15.87 trillion km in the year 2018
  - *0.7% is EV in 2020*

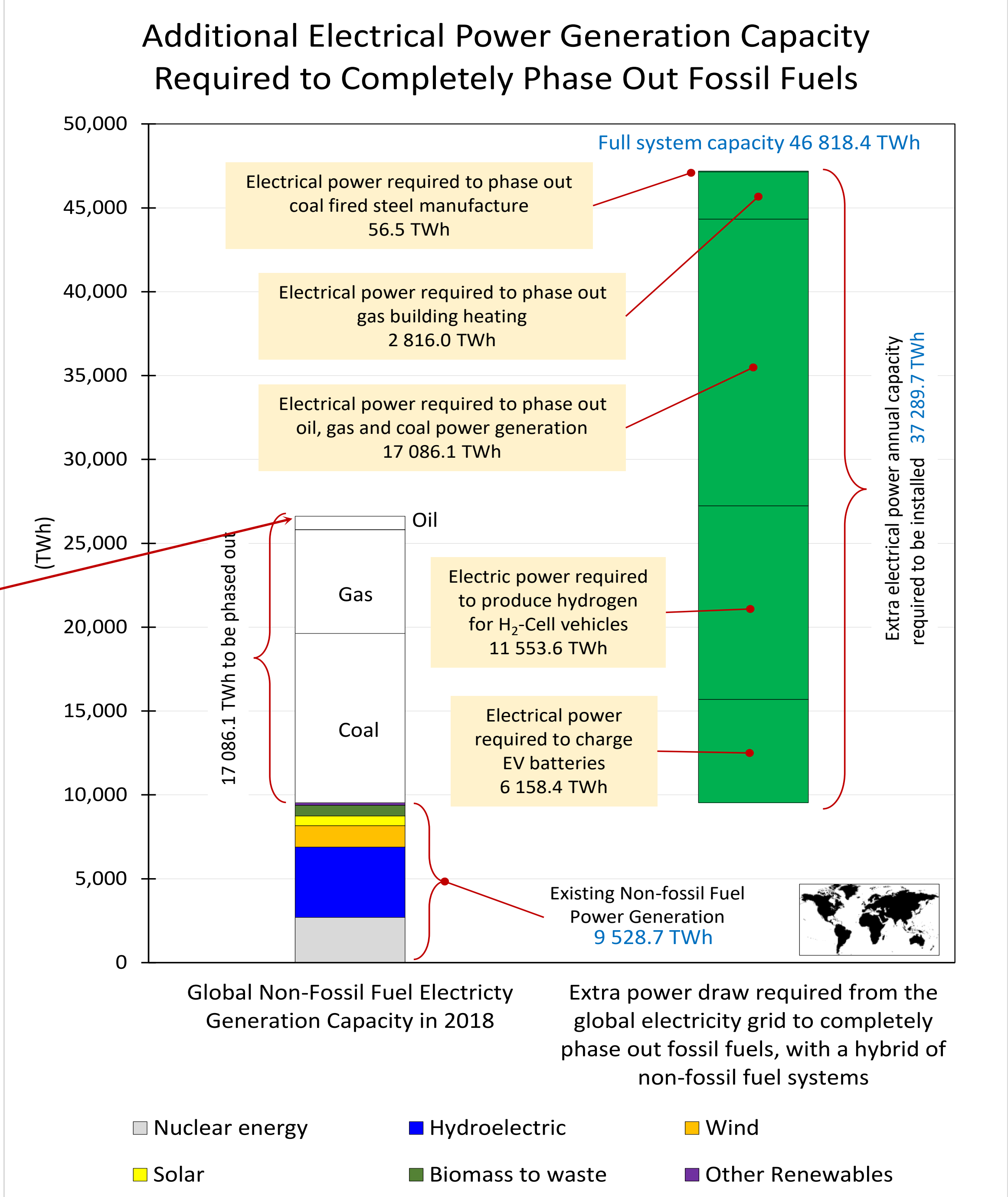
- For the same energy output:
  - *…an Electric Vehicle system requires **battery storage** mass **3.2 times** the fuel tank (@700bar) mass of a hydrogen H-Cell system*
  - *…meanwhile a hydrogen H-Cell system will require **2.5 times** more **electricity** compared to a Electric Vehicle system*

- All short-range transport could be done by Electric Vehicle systems
  - *All passenger cars, commercial vans, delivery trucks and buses (1.39 billion vehicles), would travel 14.25 trillion km in 365 days*
  - *This would require 65.19 TWh of batteries*

- All long-range distance transport could be powered with a hydrogen fuel cells
  - *All Class 8 HCV trucks, the rail transport network (including freight), and the maritime ship fleet*
  - *In total, 200.1 million tonnes of hydrogen would be needed annually*

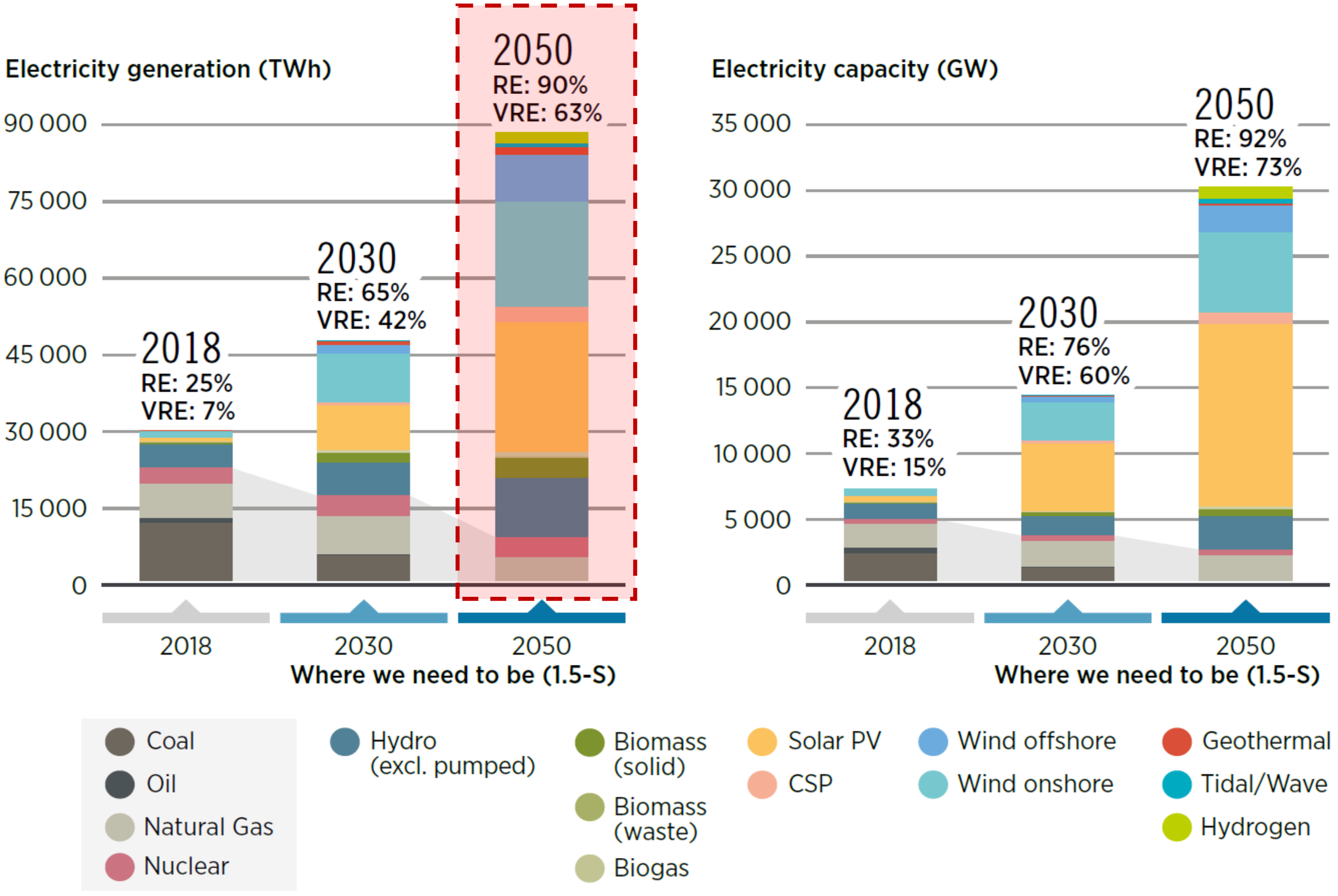

GLOBAL SYSTEM –
2018 scope
Class 8 Trucks HCV
Maritime Shipping
Inter city
Freight Rail
Buses & Delivery
Trucks
Light Trucks &
Commercial Vans
Passenger Cars
Motorcycles
Aircraft
Hydrogen cells
12 835.4 TWh
(H_2 production)
Electric
Vehicles EV
4 495.7 TWh
(battery charging)
65.19 TWh
of batteries
Self propelled vehicles
in the transport grid
Oil
Gas
Coal
Petrochemical plastics
manufacture
Bioplastics
Possible biofuel
Petrochemical fertilizer
manufacture
No viable
replacement
Increased power draw from the
electricity generation grid
37 289.7 TWh (Accounting for 10%
loss in transmission in power grid)
Non-fossil fuel electric
power generation options
Nuclear
Hydroelectric
Geothermal
Biowaste
Wind
Solar PV
Solar Thermal
Tidal
19 958.6 TWh
Electricity power
generation
802.8 TWh (Oil)
6 182.8 TWh (Gas)
10 100.5 TWh (Coal)
Heating
2 816.0 TWh (Gas)
Steel Manufacture
51.4 TWh (Coal)
Possible hydrogen
replacement solution
Power Storage to manage
intermittent supply fluctuations
4 weeks capacity for wind & solar only
2 192.9 TWh of batteries
17 million 100MW/129MW capacity storage stations

Total electrical power production in 2018 was
26 614 TWh



We wish to construct an electrical system much larger than the existing power grid, using energy that is more expensive and not as effective as what we have now

This does not include coal and gas used directly by industry to generate heat for manufacture (more than half of coal)



Note: 1.5-S = 1.5°C Scenario; CSP = concentrated solar power; GW = gigawatts; PV = photovoltaic; RE = renewable energy; TWh/yr = terawatt hours per year; VRE = variable renewable energy.

Figure 20. Global total power generation and the installed capacity of power generation sources in 1.5°C Scenario in 2018, 2030 and 2050 (Source: IRENA 2022, Figure 2.3, pg 61)

Energy split in this study

Power Generation System	Proposed Proportion of Energy Split on **new** annual capacity (%)
Nuclear	7,50 %
Hydroelectric	13,36 %
Wind Onshore (70% share)	26,83 %
Wind Offshore (30% share)	11,50 %
Solar PV (90% share)	34,50 %
Solar Thermal (10% share)	3,83 %
Geothermal	0,74 %
Biowaste to energy	1,73 %

IRENA (2022): World Energy Transitions Outlook 2022: 1.5°C Pathway, International Renewable Energy Agency, Abu Dhabi, ISBN: 978-92-9260-429-5, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Mar/IRENA_World_Energy_Transitions_Outlook_2022.pdf

Power delivered to global grid in 2018

Table 19. Maximum and minimum capacity of electrical power stations by source in 2018

Power Generation System Source	Maximum Installed Plant Capacity Found in Data for 2018 (Global Energy Observatory & Agora Energiewende and Sandbag 2019) (MW)	Power Produced by a **Single** Average Plant in 2018 (kWh)	Minimum Installed Plant Capacity Found in Data in 2018 (Global Energy Observatory) (MW)	Standard Deviation of Installed Plant Capacities for 2018 (Global Energy Observatory) (MW)
Coal	6 600 MW	7,028,812,030	0.9 MW	926.6
Gas	5 040 MW	2,223,247,834	1 MW	560.2
Nuclear	8 212 MW	12,803,184,576	20 MW	1339.4
Hydroelectric	22 500 MW	1,325,746,584	0.005 MW	703.5
Wind	610 MW	81,241,809		
Solar PV	850 MW	33,040,663		
Solar Thermal	392 MW	76,970,000	0.25 MW	73.78
Geothermal	1273 MW	603,226,027	0.05 MW	163
Biowaste to energy		34,581,818		
Fuel Oil Diesel	5 523 MW	850,797,343	0.7 MW	520.5

Global Energy Observatory (2018): Data obtained from http://GlobalEnergyObservatory.org/

Power delivered to global grid in 2018

Table 20. Availability and power produced by average sized stations by source in 2018

Power Generation System Source	Operating hours in practice of existing installed capacity in 2018 (Global Energy Observatory) (h)	Availablity across the year (%)	Average Installed Plant Capacity in 2018 (Global Energy Observatory) (MW)	Power Produced by a **Single** Average Plant in 2018 (kWh)	Power Produced by a **Single** Average Plant in 2018 (GWh)
Coal	8,161	93.2 %	861.3	7,028,812,030	7,028.8
Gas	5,120	58.5 %	434.2	2,223,247,834	2,223.2
Nuclear	6,256	71.4 %	2046.5	12,803,184,576	12,803.2
Hydroelectric	5,882	67.1 %	225.4	1,325,746,584	1,325.7
Wind	2,184	24.9 %	37.2	81,241,809	81.2
Solar PV	998	11.4 %	33.1	33,040,663	33.0
Solar Thermal	1,000	11.4 %	77.0	76,970,000	77.0
Geothermal	6,370	72.7 %	94.7	603,226,027	603.2
Biowaste to energy CHP	1,091	12.5 %	31.7	34,581,818	34.6
Fuel Oil Diesel	3,555	40.6 %	239.3	850,797,343	850.8

Global Energy Observatory (2018): Data obtained from http://GlobalEnergyObservatory.org/

Number of new power stations

Table 22. Energy split used and number of new power stations in this study

Power Generation System 	Proposed Energy Split non-fossil fuel electrical power systems (%)	Expanded extra required annual capacity to phase out fossil fuels (kWh)	Power Produced by a Single Average Plant in 2018 (kWh)	Estimated number of required additional new power plants of average size to phase out fossil fuels (number)
Nuclear	7.50%	2.80E+12	1.28E+10	218
Hydroelectric	13.36%	4.98E+12	1.33E+09	3,758
Wind	38.33%	1.43E+13	8.12E+07	175,933
Solar PV	34.50%	1.29E+13	3.30E+07	389,367
Solar Thermal	3.83%	1.43E+12	7.70E+07	18,555
Geothermal	0.74%	2.76E+11	6.03E+08	457
Biowaste to energy	1.74%	6.49E+11	3.46E+07	18,762
Total (kWh)	100.00%	3.73E+13		607,052
Total (TWh)		37,289.7		

GLOBAL SYSTEM III

Additional Annual Electrical Power Requires **37 289.7 TWh**

=

607 052 NEW Non-Fossil Fuel Power Stations

Power plant fleet in 2018 was **46 423** stations

HYDRO POWER 4 981.9 TWh 3 758 stations	**NUCLEAR POWER** 2 796.7 TWh 218 stations
WIND POWER 14 293.1 TWh 175 933 stations	**SOLAR POWER** 14 293.1 TWh 407 922 stations
OTHER RENEWABLES Geothermal & Tidal 275.9 TWh 457 stations	**BIOWASTE TO ENERGY** 648.8 TWh 18 762 stations

Power storage buffer

11 to 357 x amount of today

RIO pow... 41

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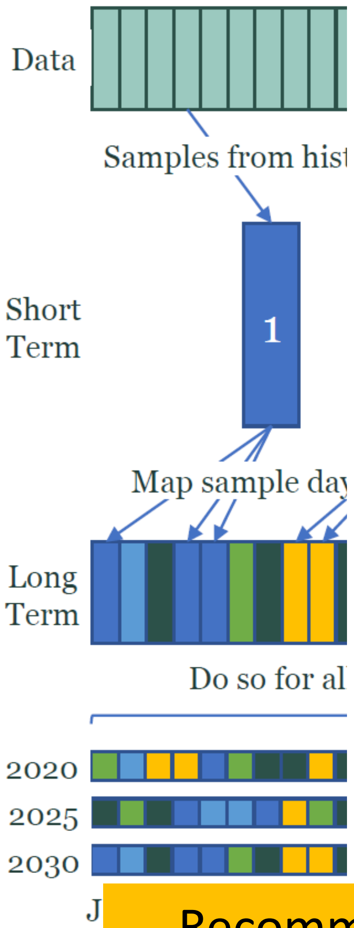
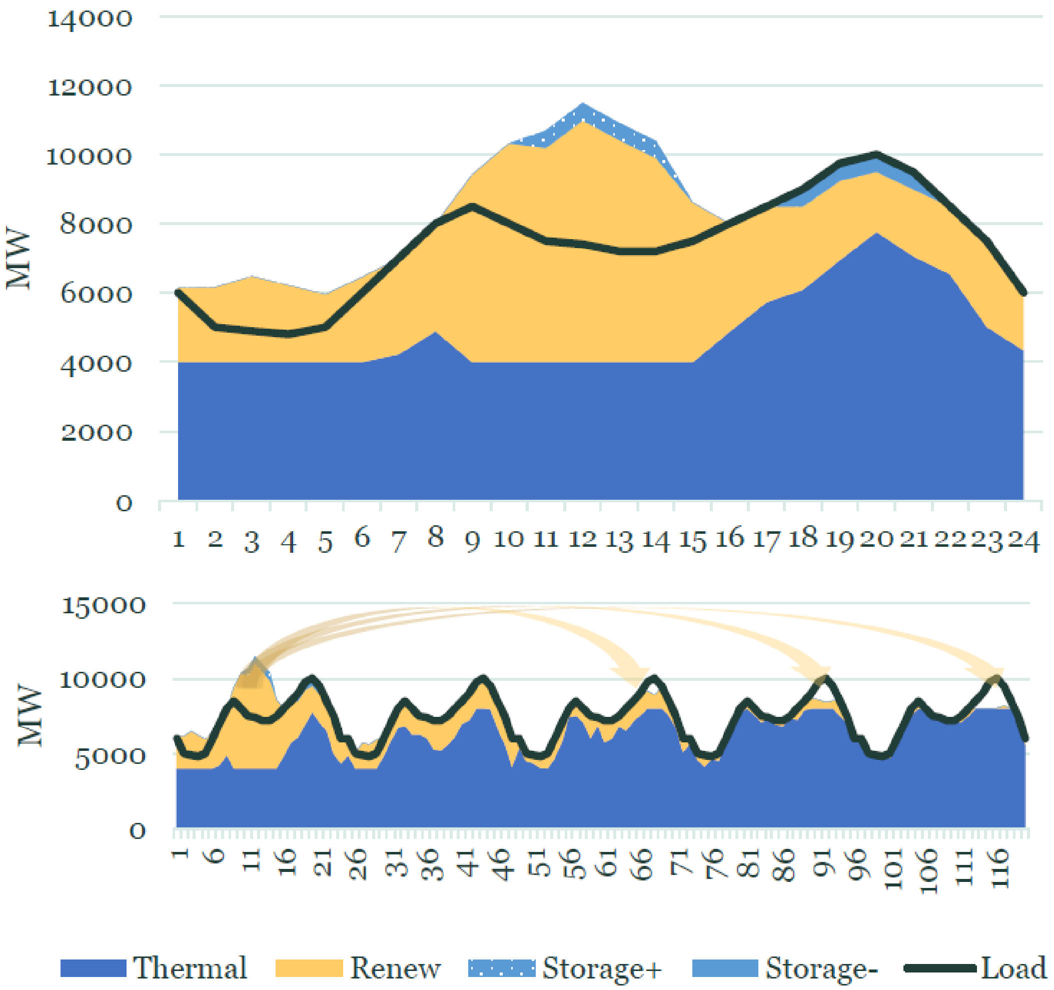
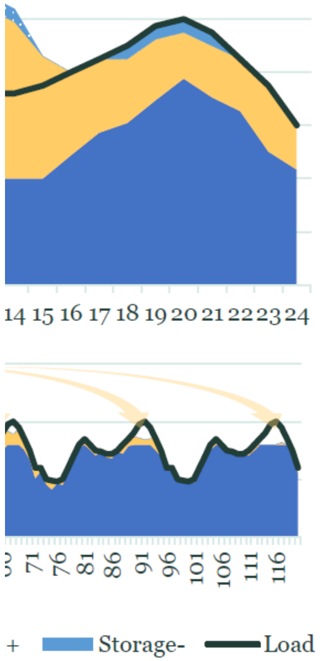
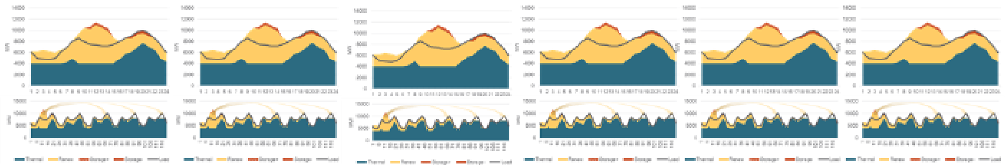


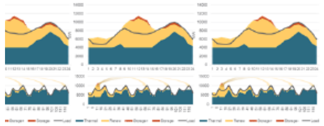
Detailed short term dispatch for every sample day. Dispatch decisions are the same across all days represented by the same sample day.

Time sequential long-term storage operations across sample day dispatches. Long-term dispatch decisions are different across days, based on long term needs.



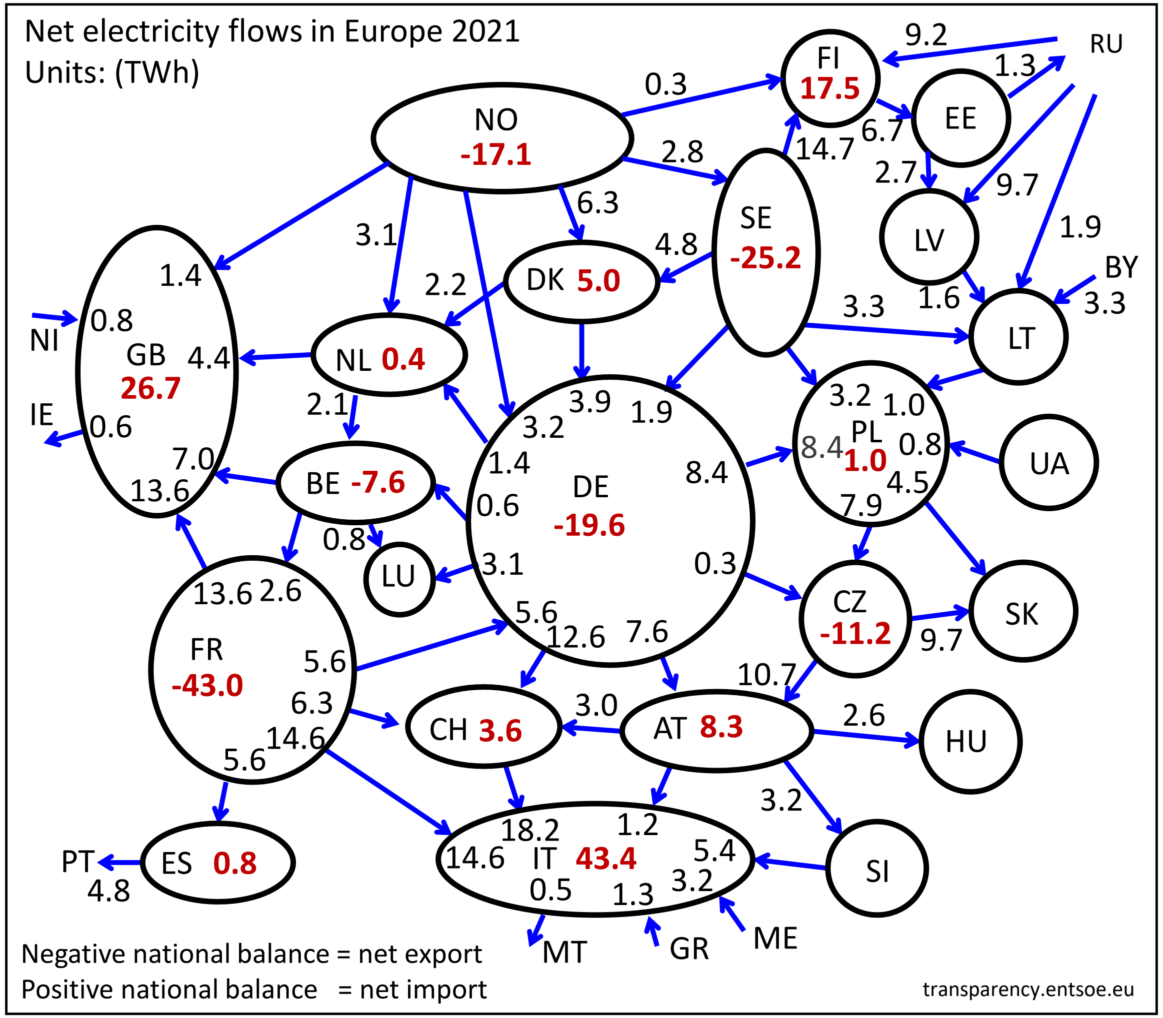






Recommend 5-7 hours power buffer storage

European net electricity exchanges in 2021



(Source: Entsoe)

All networks are balanced and buffered by other external networks

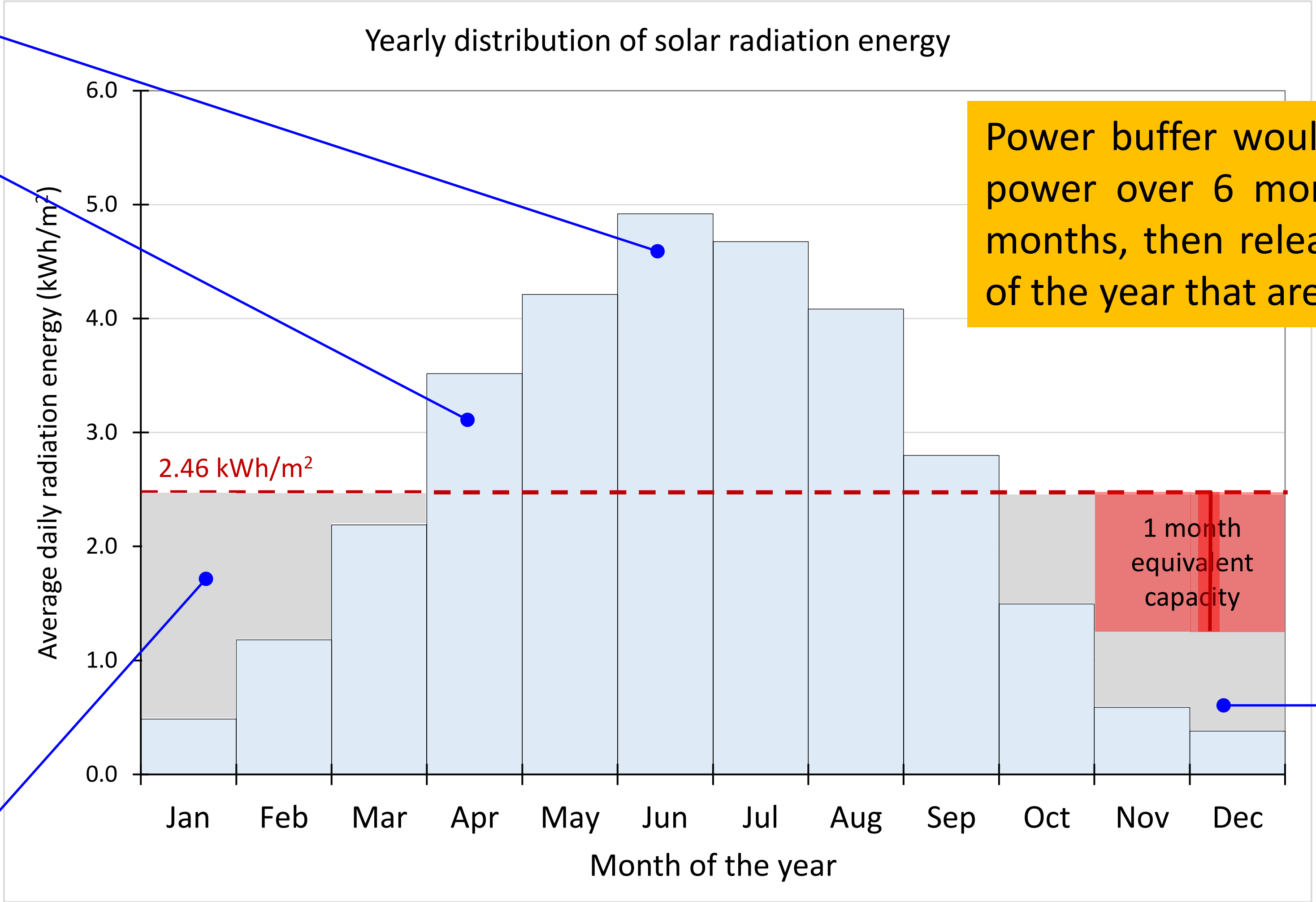
Almost always using fossil fuel sourced power generation (gas in particular)

Most existing renewable power grids are balance with fossil fuels systems

We have never had to run a large renewable network in a self sufficient manner

Distribution of the sun's radiation energy over the year in Germany (Wesselak & Voswinckel 2016)

Excess needs to be stored



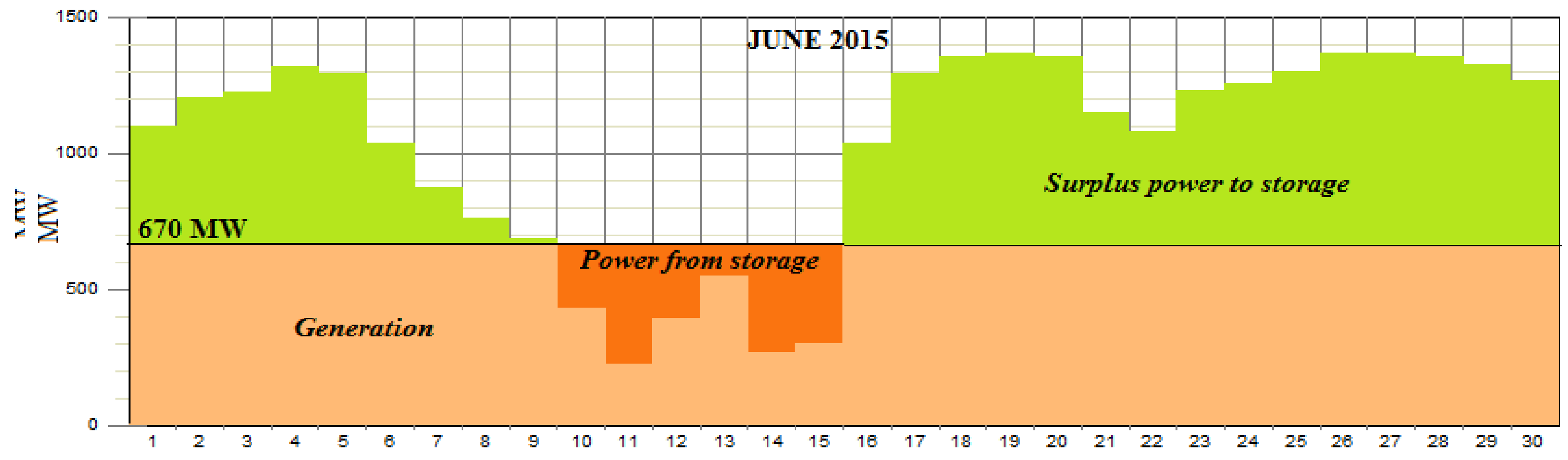
Power buffer would need to collect excess power over 6 months, store it for 6 to 7 months, then release it over the 6 months of the year that are below specification

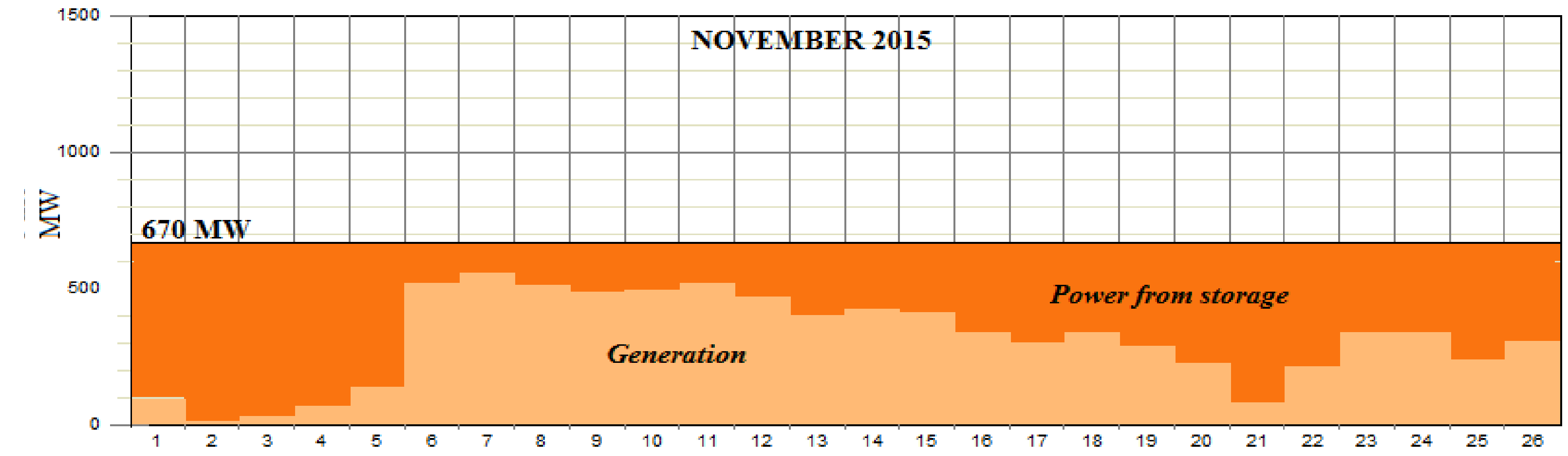
48 hours + 10% equivalent capacity

6 hours equivalent capacity

Excess needs to be released

Average daily CSP generation, June and November 2015





Spain

Power storage and release requirements that would have been needed to maintain a constant 670 MW of baseload generation during June and November (equivalent to 5.9 TWh per year)

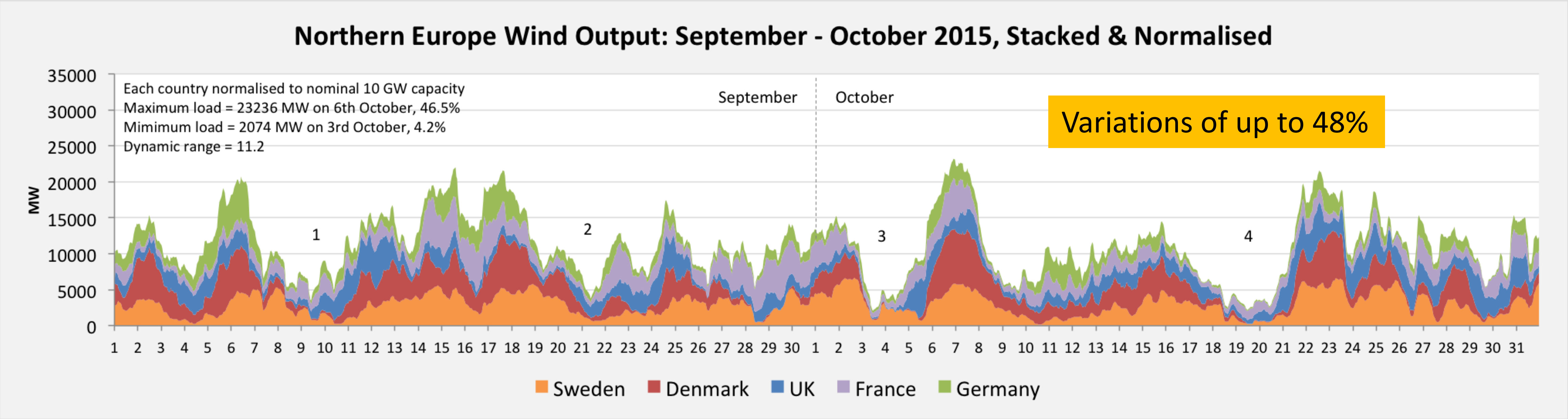
Approximately 260 GWh of storage would have been needed to cover the shortfalls in November alone. This is 16.2 days of buffer capacity, to be stored for approx. 4-6 months.

Mearns, E. (2015, Nov 17): A review of concentrated solar power (CSP) in Spain, Energy Matters blog, http://euanmearns.com/a-review-of-concentrated-solar-power-csp-in-spain/

Wind is highly variable

- Reliable capacity as a % of max capacity for wind 7-25% (UK Parliament 2014)
  - *Power production was so erratic it could not be predicted*
- Variations in power produced can last weeks and, in some cases, months

Highly variable of when power was produced



The full year of renewable generation capacity factors in the PJM RTO in the U.S.

the largest regional transmission organization, directly or indirectly affecting the electricity supply to nearly 100 million people

		PJM Monthly Wind and Solar Capacity Factors 2022/2023												
		January 1/31/22 thru 1/30/23	Feb-22	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22	Oct-22	Nov-22	Dec-22	Total
Solar 3,184 MW Capacity	MWh potential	2,837,616	2,563,008	2,837,616	2,746,080	2,837,616	2,746,080	2,837,616	2,837,616	2,746,080	2,837,616	2,746,080	2,837,616	**33,410,640**
	Actual MWh	336,822	432,939	586,966	718,934	745,154	865,656	771,788	765,286	677,478	524,646	420,135	311,577	**7,157,381**
	Capacity Factor	**11.9%**	**16.9%**	**20.7%**	**26.2%**	**26.3%**	**31.5%**	**27.2%**	**27.0%**	**24.7%**	**18.5%**	**15.3%**	**11.0%**	**21.4%**
Wind 9,991 MW Capacity	MWh potential	7,433,304	6,713,952	7,433,304	7,193,520	7,433,304	7,193,520	7,433,304	7,433,304	7,193,520	7,433,304	7,193,520	7,433,304	**87,521,160**
	Actual MWh	2,985,067	3,303,952	3,452,911	3,379,448	2,754,655	1,911,078	1,568,729	1,335,725	1,709,928	3,011,020	3,575,208	3,113,890	**32,101,611**
	Capacity Factor	**40.2%**	**49.2%**	**46.5%**	**47.0%**	**37.1%**	**26.6%**	**21.1%**	**18.0%**	**23.8%**	**40.5%**	**49.7%**	**41.9%**	**36.7%**
Blended Renewables Monthly and Annual Capacity Factors		**32.3%**	**40.3%**	**39.3%**	**41.2%**	**34.1%**	**27.9%**	**22.8%**	**20.5%**	**24.0%**	**34.4%**	**40.2%**	**33.4%**	**32.5%**

Not only are the capacity factors low, it turns out that both wind and solar capacity factors reach low points at precisely the seasonally worst possible times, wind at the peak of summer demand and solar at the peak of winter demand.

In practical terms, global power generation operating hours in 2018 (Global Energy Observatory)

- *Solar PV units produced 11.4% of the calendar year*
- *Wind units produced 24.9% of the calendar year*

Number of technology units

Renewable Technology Unit or Service	Number (number)	Estimated total battery capacity (TWh)	Estimated extra annual power output required (TWh)	Estimated extra total installed power generation capacity (MW)
Electric Vehicles				
Bus + Medium Delivery Truck	29 002 253	5.98		
Light Truck/Van + Light-Duty Vehicle	601 327 324	25.32		
Passenger Car	695 160 429	32.53		
Motorcycle	62 109 261	1.34		
Hydrogen Fuel Cells				
HCV Class 8 Truck	28 929 348		1 949.0	
Rail Freight Locomotive ♣	104 894		277.0	
Maritime Small Vessel (100 GT to 499 GT) ♣	53 854		7.75	
Maritime Medium Vessel (500 GT to 24 999 GT) ♣	44 696		131.73	
Maritime Large Vessel (25 000 GT to 59 999 GT) ♣	12 000		255.72	
Maritime Very Large Vessel (>60 000 GT) ♣	6 307		379.70	
Nuclear Power (Annual Production)			2 796.7	447 037
Hydroelectricity (Annual Production)			4 981.9	847 010
Geothermal Power (Annual Production)			275.9	43 320
Wind Turbines				
3MW Onshore wind turbines (70% share)	1 527 101		10 005.2	4 581 304
3MW Offshore wind turbines (30% share)	654 472		4 287.9	1 963 416
Solar Panels				
450 Watt commerical grade solar panels	28 640 112 291		12 864.9	12 888 051
Stationary power storage buffer				
28 days capacity for wind & solar PV only		2 192.92		
	Total	**2 258.1**		

♣ Numbers drawn from Michaux 2023, and Michaux 2021

- Electric Vehicles
- EV Batteries
- Hydrogen fuel cells
- Wind Turbines
- Solar Panels
- Power Storage Batteries

What battery chemistry?

Table 15. Global market proportions of power storage chemistries in 2040 (Source: drawn from IEA 2021, Diouf & Pode 2015)

Battery Chemistry	Acronym	Specific Energy Density (Wh/kg)	Projected Market Proportion for Power Storage in 2040 (%)
Lithium Nickel Manganese Cobalt Oxides	NMC 523	100-135	3,3 %
	NMC 622	100-135	9,9 %
	NMC 811	100-135	9,9 %
Lithium Iron Phosphate	LFP	90-120	73,7 %
Vanadium Redox Battery	VRB	20 - 32	3,3 %
Total			100,0 %

Table 25. Global market proportions of EV battery chemistries in 2040 (Source: IEA 2021)

Battery Chemistry	Acronym	Light Duty Vehicle (LDV) (%)	Heavy Duty Vehicle (HDV) (%)
Lithium Nickel Cobalt Aluminium Oxides	NCA+	3,5 %	
Nickel Manganese Cobalt	NMC 622	5,2 %	7,2 %
	NMC 811	52,2 %	
Lithium Iron Phosphate	LFP	10,1 %	73,9 %
All Solid State Batteries	ASSB	29,0 %	18,8 %
		100,0 %	100,0 %

IEA (2021): The role of critical minerals in clean energy transitions. Special Report of the World Energy Outlook (WEO) team of the IEA. IEA, Paris. 283 p. www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

Mining production & existing reserves are not enough to manufacture the first generation of renewable technology

Table 39. Total metal quantity required to manufacture one generation of technology units to phase out fossil fuels compared to 2019 global production

Metal	Element	Total metal required produce one generation of technology units to phase out fossil fuels (28 days buffer) (tonnes)	Total metal required produce one generation of technology units to phase out fossil fuels (48 hours + 10% buffer) (tonnes)	Global Metal Production 2019 (tonnes)	Years to produce metal at 2019 rates of production (assuming the 28 day buffer) (years)
Aluminium	Al	305 344 528	305 344 528	63 136 000	4.8
Copper	Cu	4 730 043 227	563 781 004	24 200 000	195.5
Zinc	Zn	36 945 387	36 945 387	13 524 000	2.7
Magnesium Metal	Mg	500 400	500 400	1 120 000	0.4
Manganese	Mn	235 494 311	31 793 521	20 591 000	11.4
Chromium	Cr	7 011 364	7 011 364	37 498 478	0.2
Nickel	Ni	970 817 173	149 281 798	2 350 142	413.1
Lithium	Li	976 274 657	95 404 313	95 170	10 258.2
Cobalt	Co	225 653 328	26 680 148	126 019	1 790.6
Graphite (natural flake)	C	9 280 273 442	872 181 376	1 156 300	6 778.8
Graphite (synthetic)	C			1 573 000 ♦	
Molybdenum	Mo	1 140 617	1 140 617	277094 ‡	4.0
Silicon (Metallurgical)	Si	51 345 993	51 345 993	8 410 000	6.1
Silver	Ag	150 790	150 790	26282 ‡	5.5
Platinum	Pt	2 682	2 682	190 ‡	14.1
Vanadium	V	704 448 633	55 349 535	96021 ‡	6 747.8
Zirconium	Zr	2 614 126	2 614 126	1 338 463 ‡	2.0
Germanium	Ge	4 163 162	4 163 162	143	29 113.0
Rare Earth Element	-				
Neodymium	Nd	983 617	983 617	23 900	41.2
Lanthanum	La	5 970 738	5 970 738	35 800	166.8
Praseodymium	Pr	238 605	238 605	7 500	31.8
Dysprosium	Dy	198 027	198 027	1 000	198.0
Terbium	Tb	17 370	17 370	280	62.0
Hafnium	Hf	224	224	66	3.4
Yttrium	Y	224	224	14 000	0.016

‡ Estimated from mining production. All other values are refining production values.

♦ Natural flake graphite and synthetic graphite was combined to estimate total production

Metal produced in 2019

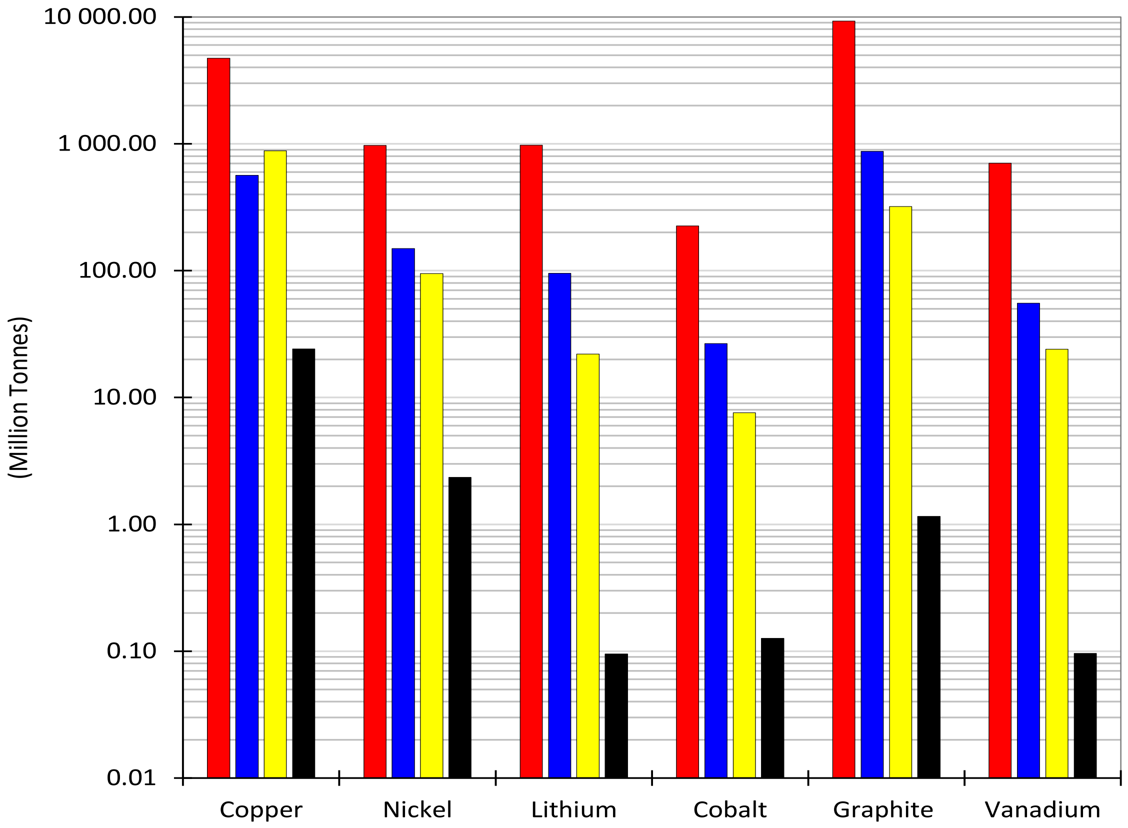
Metal in 2022 global reserves

Metal Source: USGS	Total metal required produce one generation of technology units to phase out fossil fuels (tonnes)	Reported Global Reserves 2022 (tonnes)	Global Reseves as a proportion of metals required to phase out fossil fuels (%)
Copper	4 730 043 227	880 000 000	18.60 %
Nickel	970 817 173	95 000 000	9.79 %
Lithium	976 274 657	22 000 000	2.25 %
Cobalt	225 653 328	7 600 000	3.37 %
Graphite (natural flake)	9 280 273 442	320 000 000	3.45 %
Vanadium	704 448 633	24 000 000	3.41 %

We can make batteries out of something else (Zinc, fluoride, sodium, etc.)

- For every 1000 deposits discovered, 1 or 2 become mines
- Time taken to develop a discovered deposit to a mine 20 years
- For every 10 producing mines, 2 or 3 will lose money and shut down

Quantity of metals needed to manufacture one generation of technology units to completely phase out fossil fuels

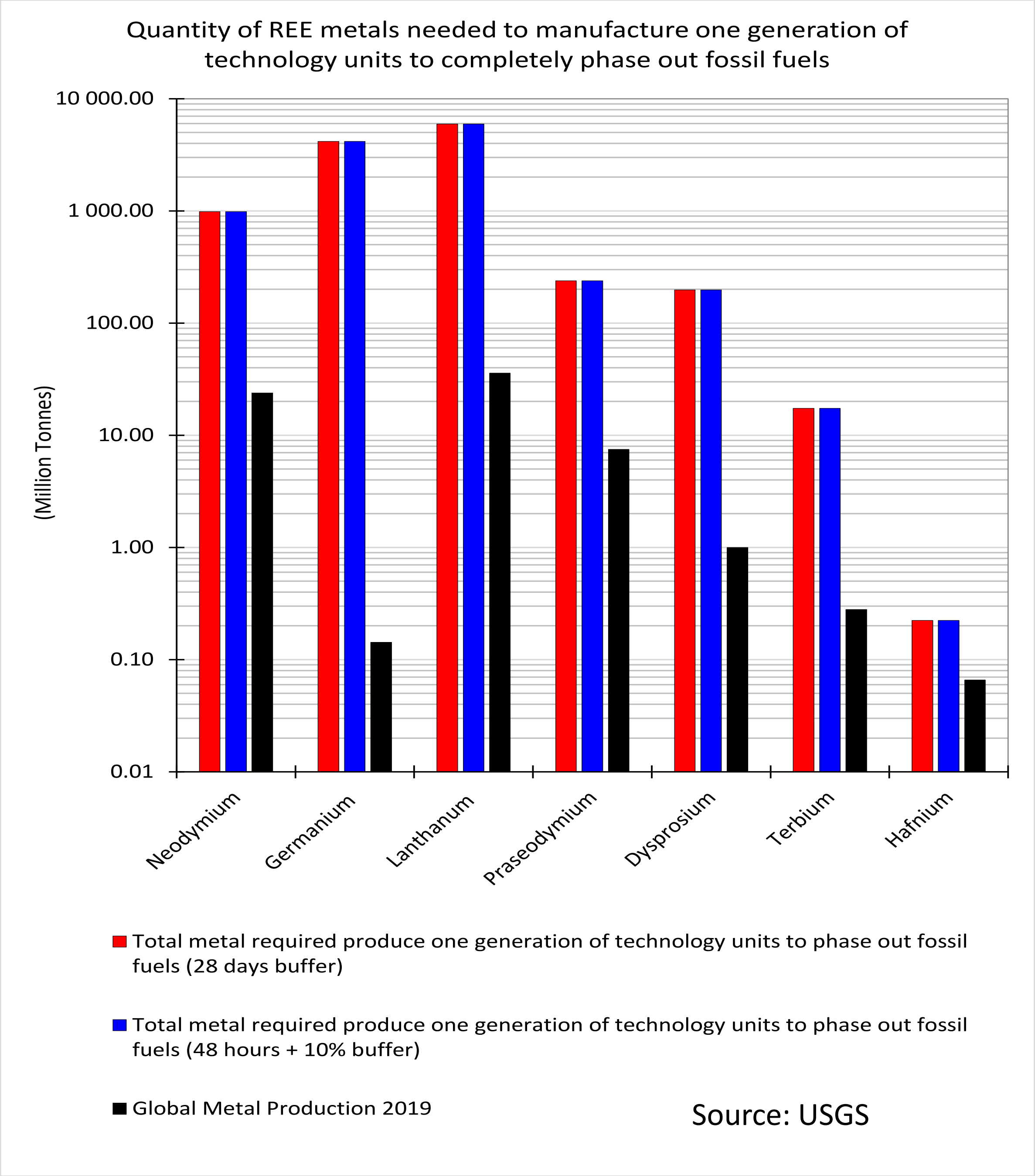


- Total metal required produce one generation of technology units to phase out fossil fuels (28 days buffer)
- Total metal required produce one generation of technology units to phase out fossil fuels (48 hours + 10% buffer)
- Reported Global Reserves 2022
- Global Metal Production 2019

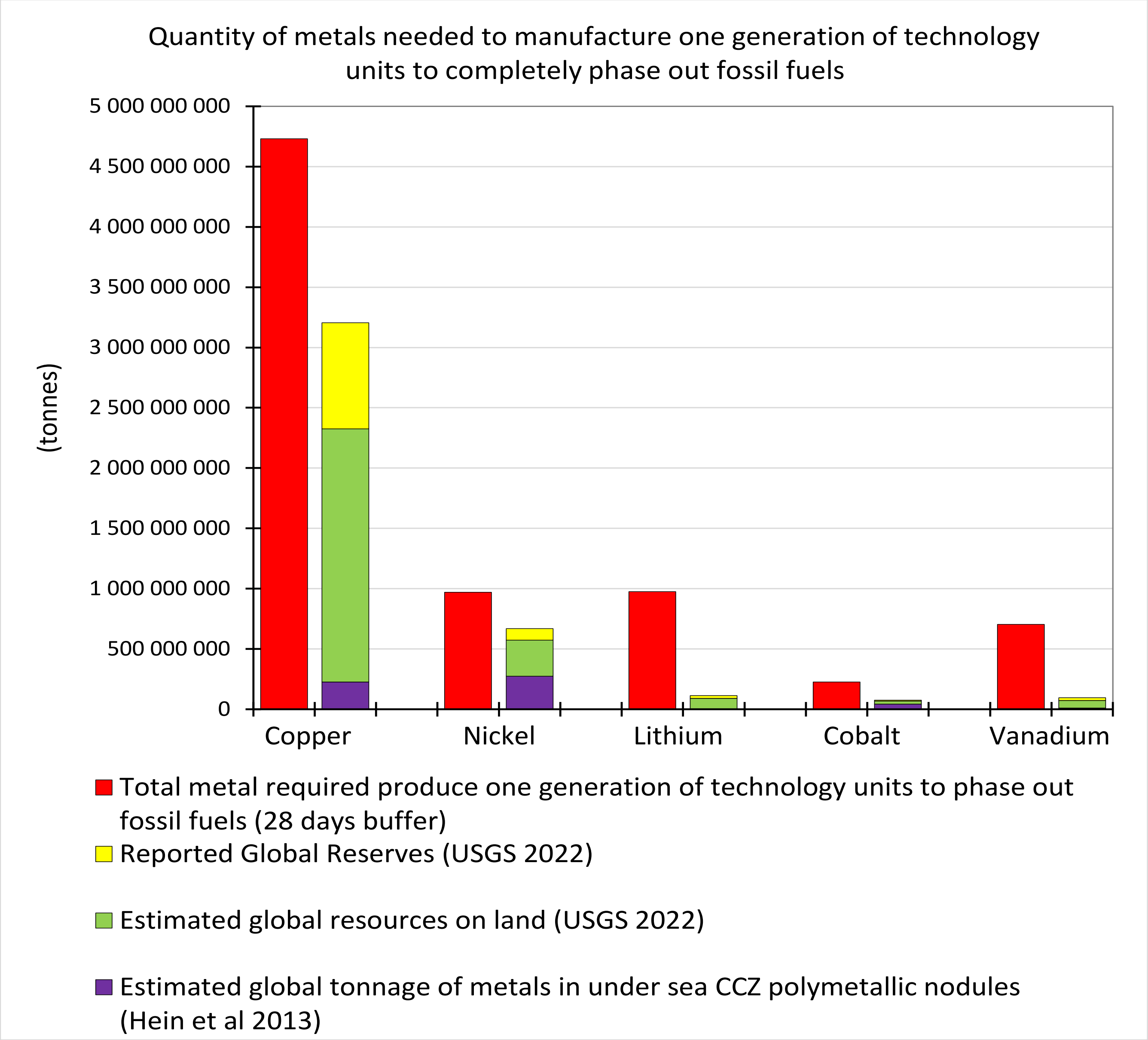
Source: USGS

Remember,
this is for just the first generation of units.

They will wear out in **10 to 25 years**, after which they will need to be replaced



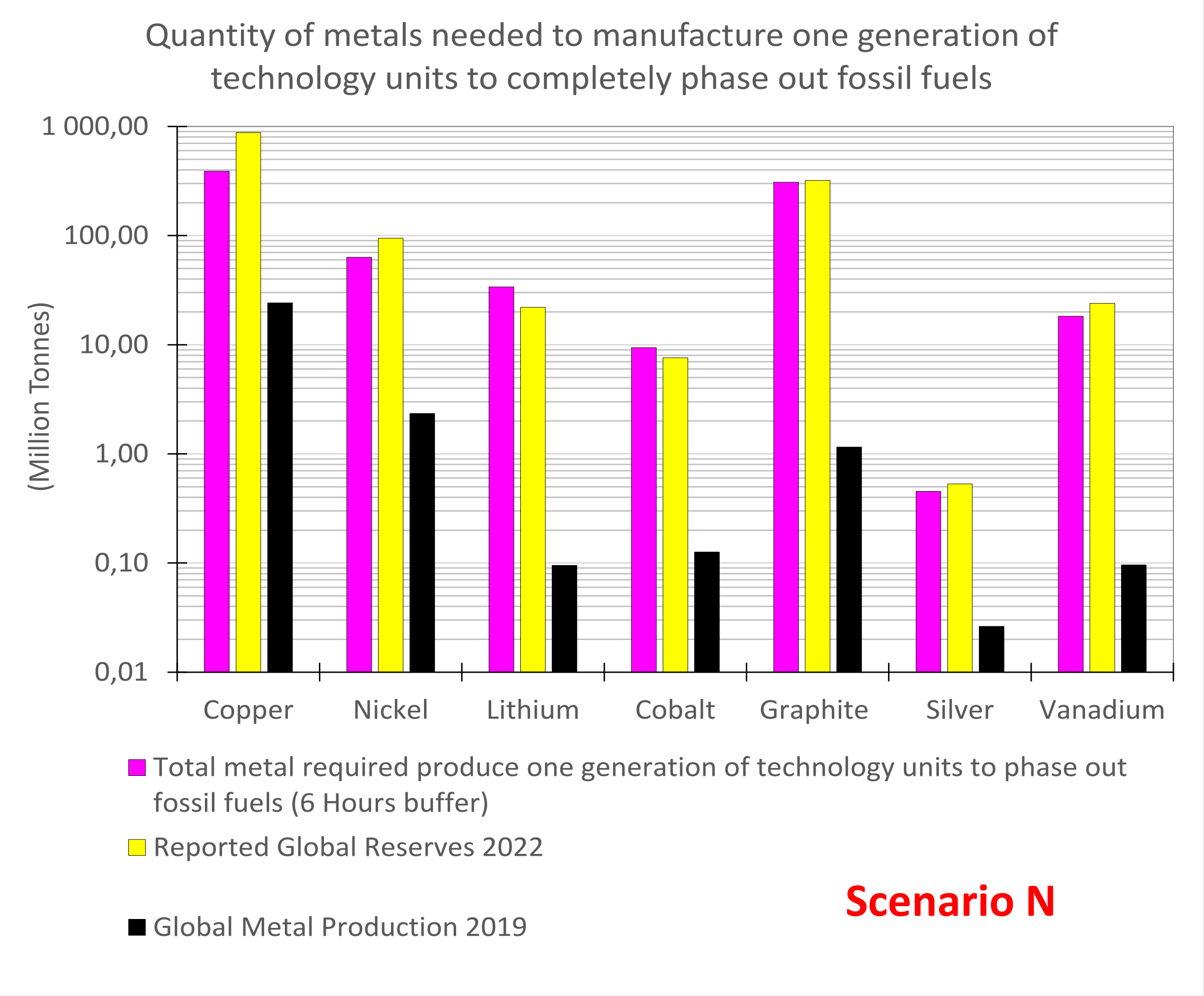
No data on reserves or resources



That part of a Mineral resource, which has been fully evaluated and is deemed commercially viable to work , is called a Mineral reserve. Usually associated with a pre-feasibility study

A mineral resource is a concentration of natural solid inorganic or fossilized organic material, including metals, coal and minerals in sufficient quantity and quality to exceed background minerology and might have reasonable prospects for economic extraction.

The 6 hour buffer – Scenario N



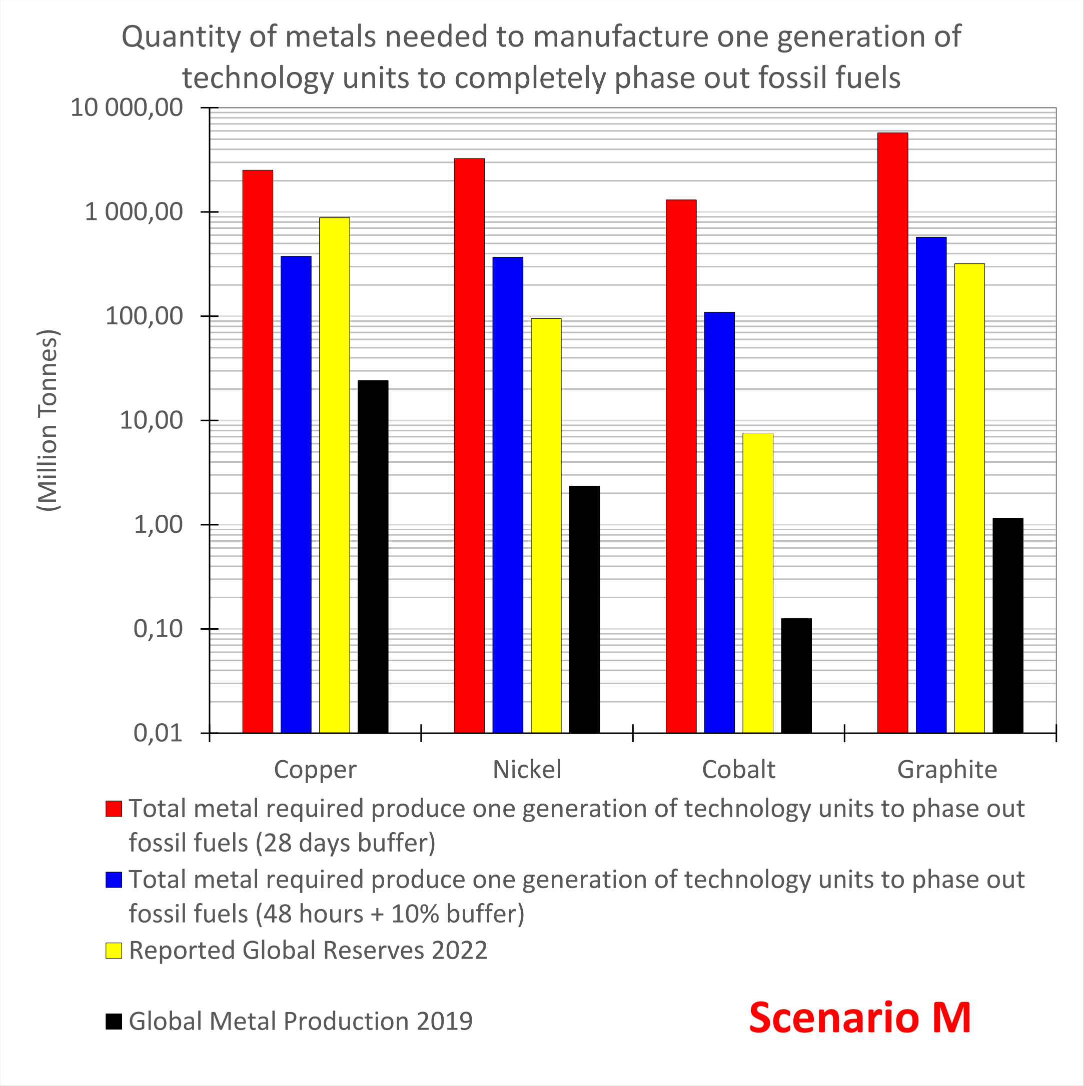
- The passenger car fleet is cut back to 10% (automated AI shared fleet)
- The commercial van fleet is cut by 30% (so now 70% of the commercial van fleet are doing what the whole fleet does now)
- The distance travelled in a calendar year is the same (so now 1/10th of the cars are running flat out doing the same tasks for existing passenger car fleet)
- Heavy trucks, buses, rail and maritime shipping are unchanged
- The power storage buffer is cut back to 6 hours
- There is a 3X build out of wind and solar installed capacity
- Power needs outside the transport fleet are the same

The 6 hour buffer – Scenario N

Metal	Element	Total metal required produce one generation of technology units to phase out fossil fuels (**6 Hours** buffer) (tonnes)	Global Metal Production 2019 (tonnes)	Number of years of production at 2019 rate (number)
Copper	Cu	389 139 158	24 200 000	16,1
Nickel	Ni	63 396 449	2 350 142	27,0
Lithium	Li	33 898 570	95 170	356,2
Cobalt	Co	9 404 502	126 019	74,6
Graphite	C	308 674 200	1 156 300	266,9
Silicon (Metallurgical)	Si	154 037 980	8 410 000	18,3
Silver	Ag	452 371	26 282	17,2
Vanadium	V	18 240 680	96 021	190,0
Neodymium	Nd	1 730 781	23 900	72,4
Germanium	Ge	4 163 162	143	29 113,0
Lanthanum	La	5 970 738	35 800	166,8
Praseodymium	Pr	321 087	7 500	42,8
Dysprosium	Dy	199 353	1 000	199,4
Terbium	Tb	52 110	280	186,1
Hafnium	Hf	224	66	3,4
Yttrium	Y	224	14 000	0,0

Scenario N

All batteries are made without lithium – Scenario M



- All batteries are made without lithium. This is using a variant of the NMC 532 Battery chemistry

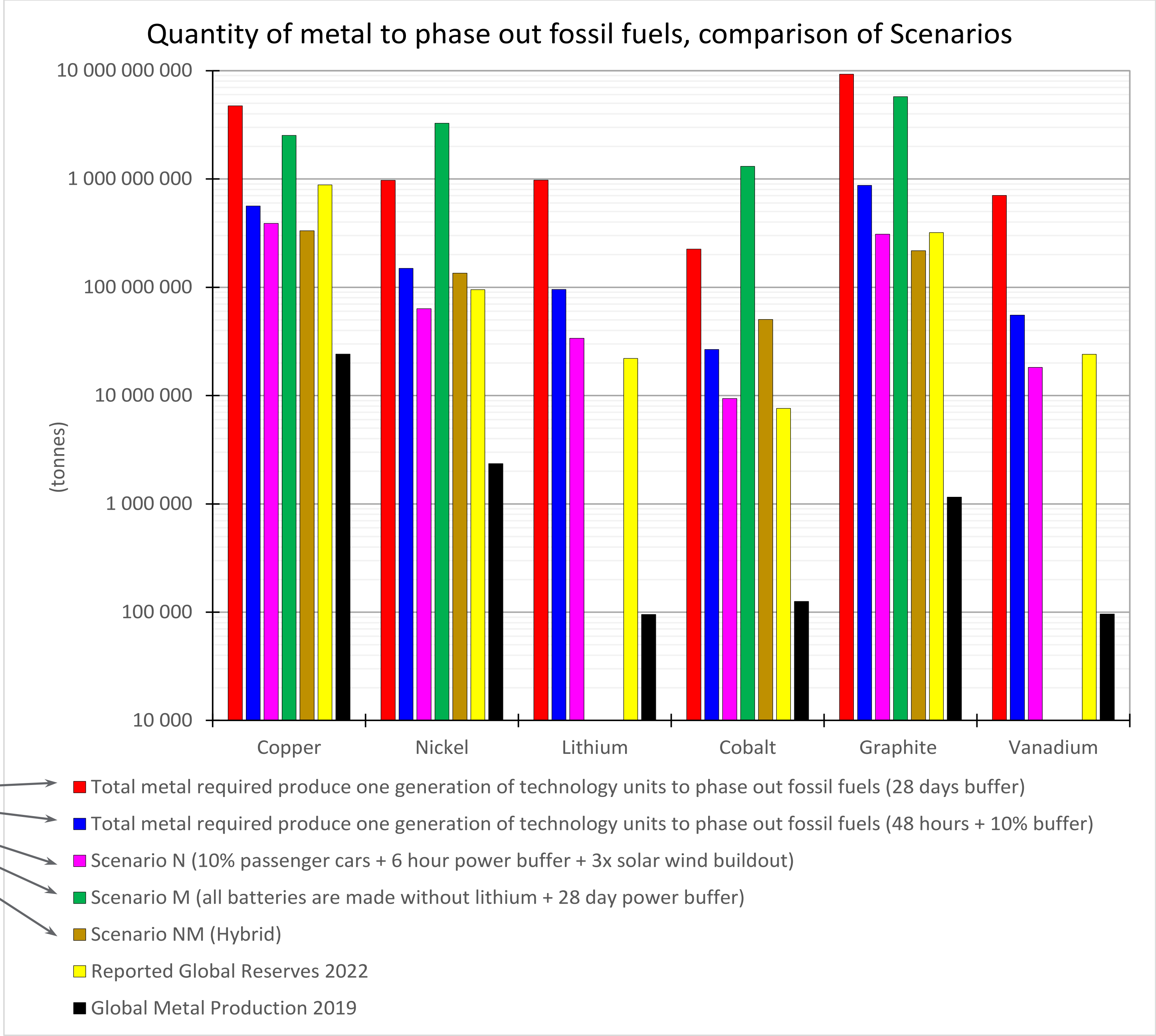
- Based on Elon Musks Master Plan 3 2023 Investor Day (https://www.youtube.com/watch?v=Hl1zEzVUV7w)

- So, the metals needed for all batteries will be based on NMC532, except lithium. In a tip of the hat to Musk and his team, it is assumed that the mass of the battery is smaller, thus the mass shortfall of removing lithium is not projected onto the remaining metals. This is to reflect an advance in materials engineering, with a lighter battery mass per kWh.

All batteries are made without lithium – Scenario M

Metal	Element	Total metal required produce one generation of technology units to phase out fossil fuels (28 days buffer) (tonnes)	Total metal required produce one generation of technology units to phase out fossil fuels (48 hours + 10% buffer) (tonnes)	Global Metal Production 2019 (tonnes)	Number of years of production at 2019 rate (number)
Copper	Cu	2 527 472 059	376 248 435	24 200 000	104
Nickel	Ni	3 264 498 462	368 620 506	2 350 142	1 389
Lithium	Li	0	0	95 170	
Cobalt	Co	1 309 586 408	109 865 541	126 019	10 392
Graphite	C	5 746 153 216	574 942 582	1 156 300	4 969
Neodymium	Nd	983 617	983 617	23 900	41
Germanium	Ge	4 163 162	4 163 162	143	29 113
Lanthanum	La	5 970 738	5 970 738	35 800	167
Praseodymium	Pr	238 605	238 605	7 500	32
Dysprosium	Dy	198 027	198 027	1 000	198
Terbium	Tb	17 370	17 370	280	62
Hafnium	Hf	224	224	66	3
Yttrium	Y	224	224	14 000	0

Scenario M



Remember,
this is for just the first generation of units.

They will wear out in **10 to 25 years**, after which they will need to be replaced

Number of technology units

WIND TURBINES | SOLAR PANELS | POWER STORAGE BATTERIES

All of these tech units are to replace a fossil fuel technology system

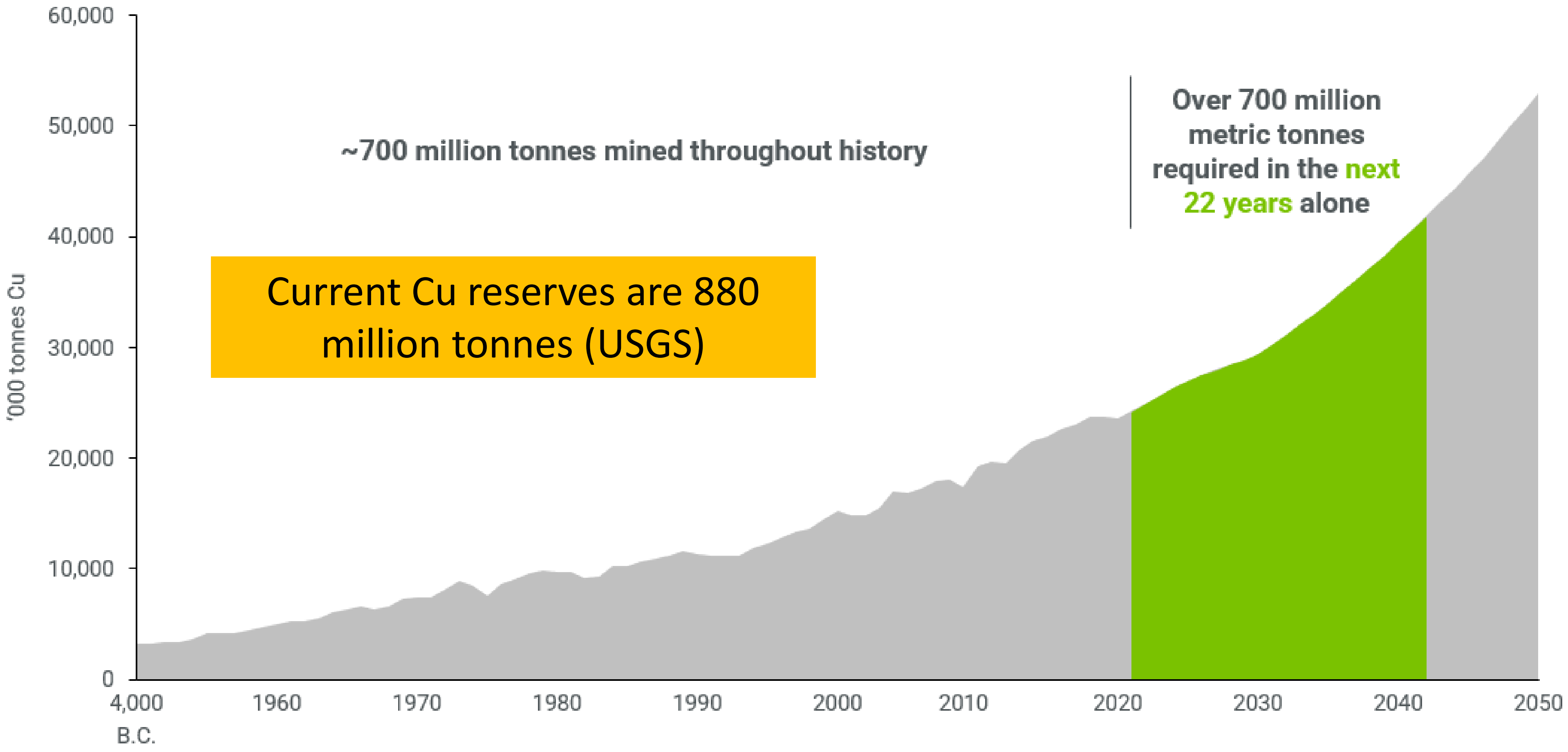
They harvest renewable energy like wind and sunshine. The units themselves are not renewable as they wear out (20 years). **They are replaceable.**

Each one is **manufactured from metals.**

As this system has yet to be constructed, it **cannot be recycled.**

The first generation at least will be sourced from the **mining of minerals.**

Economic growth and resource supply



Current Cu reserves are 880 million tonnes (USGS)

Source: U.S. Geological Survey, BMO Capital Markets

We want 4.73 billion tonnes of Cu, just to manufacture one generation of renewable technology (6.75 x historical Cu mining)

DISCUSSION

WHAT DOES IT MEAN?

The current plans for 'after oil' are **simply not good enough** on multiple levels

- Complexity of supply chain needed
- Energy requirements of manufacture
- Logistical capability of existing fossil fuels

Current thinking has **seriously underestimated** the scale of the task ahead

Battery chemistries other than lithium-ion should/will be developed, each with **different mineral resources required**

The EROEI ratio for renewable energy systems is much lower than fossil fuel energy systems. Renewable energy technology **may not be strong enough to replace** fossil fuels

Hopes for future technology breakthroughs to 'somehow' deliver more commodity resources do not seem to consider the nature of **what mineral resources that are left**

The current ecosystem has no concept of its **dependency on minerals** and does not consider long term concepts like continuous growth in production against finite resources

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IN CONCLUSION

THIS REPORT SUGGESTS

Replacing the existing fossil fuel powered system (oil, gas, and coal), using renewable technologies, such as solar panels or wind turbines, **will not be possible for the entire global human population.**

There is simply just **not enough time, nor resources** to do this by the current target set by the world's most influential nations.

What may be required, therefore, is **a significant reduction of societal demand** for all resources, of all kinds.

This implies a very different social contract and **a radically different system of governance** to what is in place today.

Inevitably, this leads to the conclusion that the existing renewable energy sectors and the EV technology systems are **merely steppingstones to something else**, rather than the final solution.

It is recommended that some thought be given to this and **what that something else might be.**

Ecological reality and biophysical limitations will reassert itself

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The whole system is about to evolve, we in response need a better plan

So far there has been too much talky talky and not enough wickedy whack!!!!

NEXT STEPS

TASKS TO BE DONE

Conduct a Maslow hierarchy of needs analysis loop in context of industrial activity and capacity

- What is truly needed for society to function – work back from there
- What is truly needed for industry to function – work back from there

Reorganize industrial value chain around a low energy future and very short supply chains that are inconsistent in performance

Re-tool the existing power grid into a network of microgrids, that can transfer power between them and can still function if part of the grid is temporarily shut down. Each grid supports a vital industrial or social activity

Develop engineering technology that can cope with variable power supply, and power spikes

Power buffer to intermittency would no longer be needed

Plan for a re-prioritization of industrial capacity. For example pyrolysis of plastics and rubber to produce fuel oil may become more important

Plan for a systemic merging of energy and raw material feedstock supply with all industrial action – they are no longer just a costs of doing business, but are now rate determining steps

Plan for a economy where some industrial capability **can periodically shutdown and start-up without damage**. Also a possible period of dormancy over part of winter.

Develop an engineering decision making system that can defined whether an industrial outcome is logistically sensible or economically viable to a new set of constraints (e.g. using exergy)

Develop the capability to quickly find substitutions for material products, or industrial outcomes as their supply becomes non-linear, unreliable or unavailable.

Evaluate what is really needed, then plan to do it in a regional scope

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Kiitos & Thank you

RAILFORUM

KOUVOLA | FINLAND

Vihreän siirtymän vuosikymmen