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?"

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FOSSIL FUELS ARE BECOMING UNRELIABLE, SOON TO BE PHASED OUT WE NEED THE AFTER-OIL PLAN NOW

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

CO2 EMISSIONS & ASSOCIATED CLIMATE CHANGE

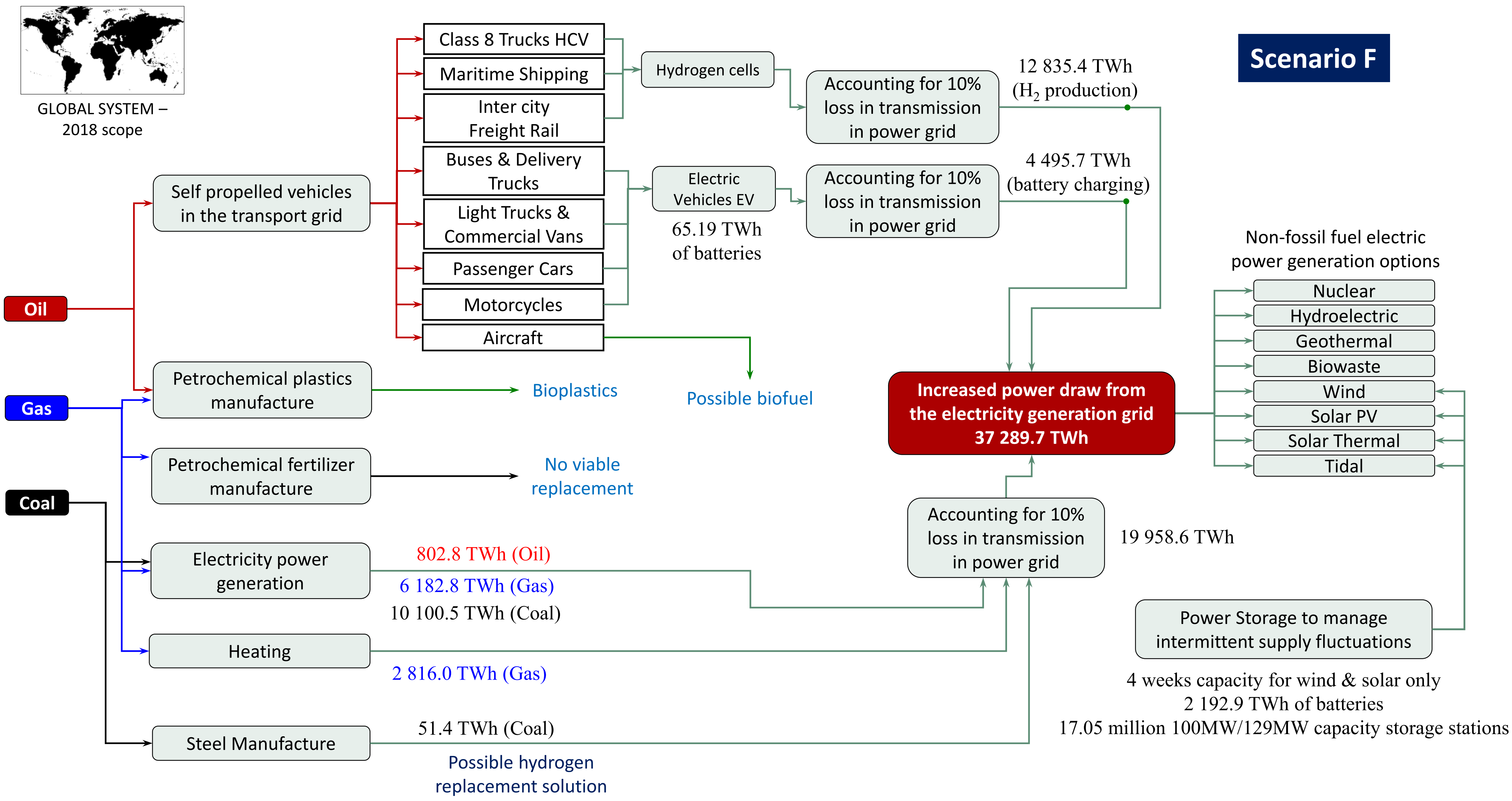
NOT BY

DWINDLING FINITE RESOURCES

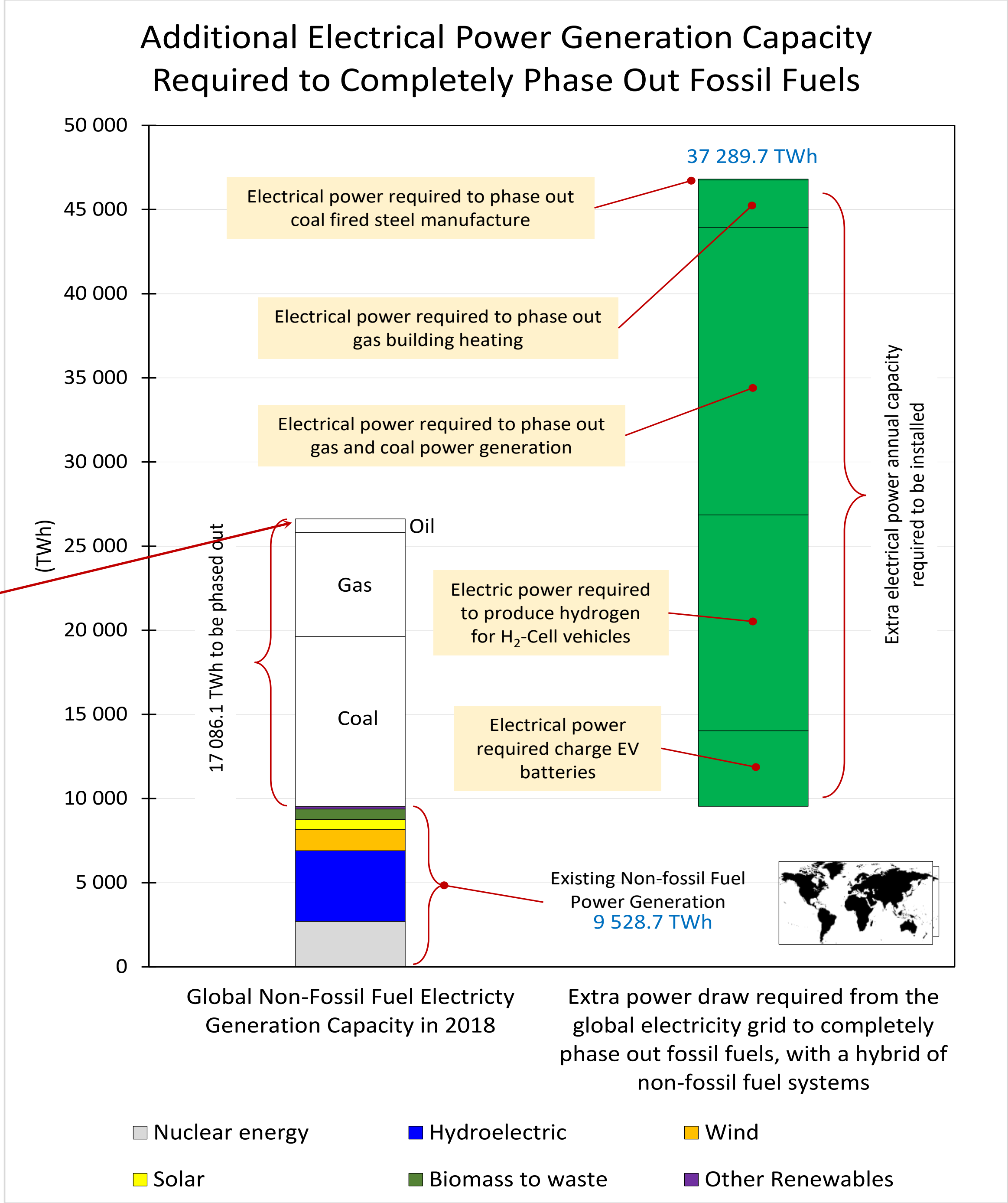
A NOVEL BOTTOM-UP APPROACH WAS USED TO ADDRESS THE UNDERLYING QUESTIONS

What is needed to fully replace the existing system and work back from there

WHAT ARE THE KEY FINDINGS


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

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)

CURRENT PLANS ARE NOT LARGE ENOUGH IN SCOPE, THE TASK BEFORE US IS MUCH LARGER THAN THE CURRENT PARADIGM ALLOWS FOR

THE CHALLENGE TO PHASE OUT FOSSIL FUELS IS LARGER THAN FIRST THOUGHT

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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

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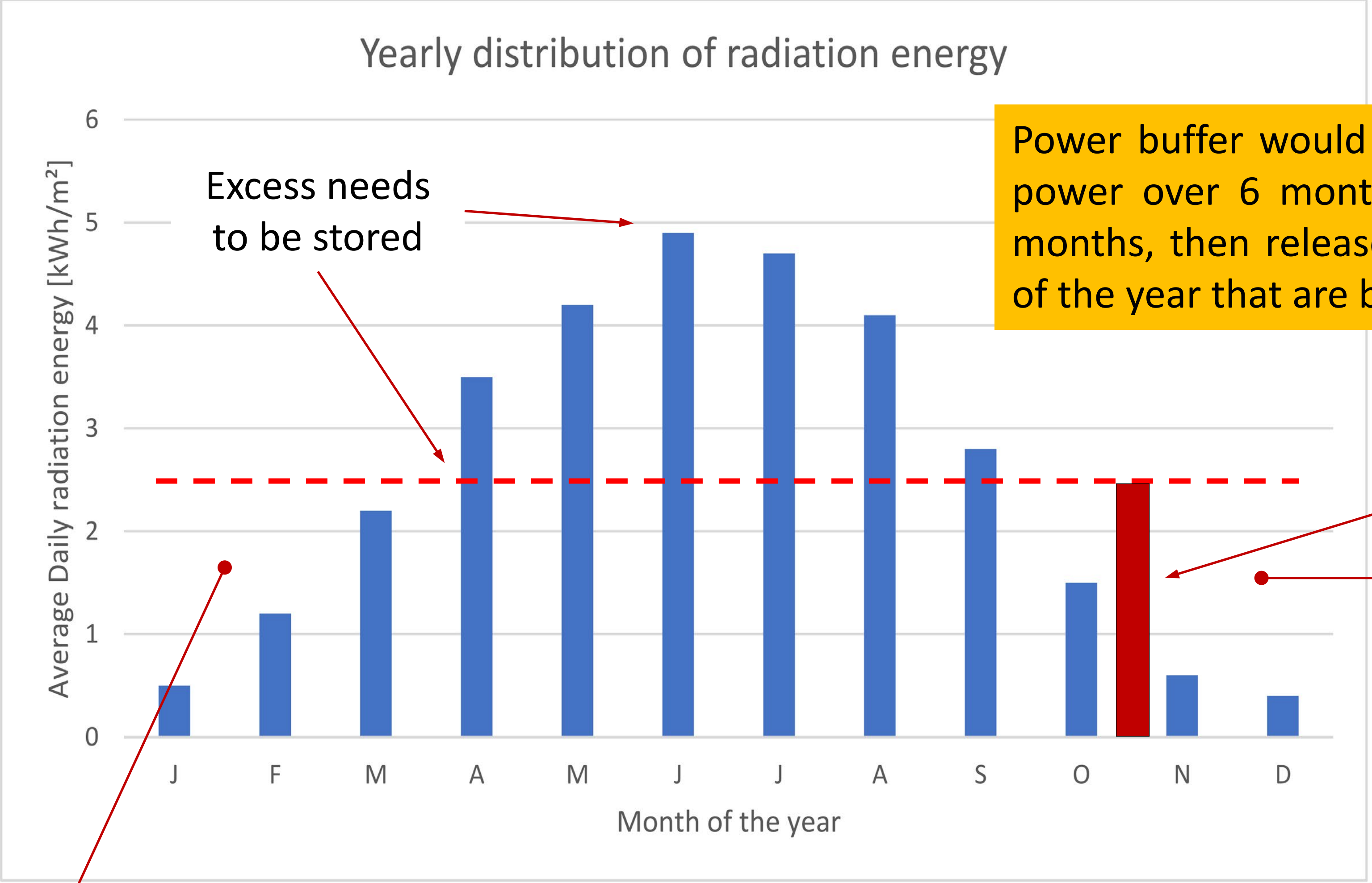
EXISTING RENEWABLE POWER SYSTEMS MAY NOT BE STRONG ENOUGH TO REPLACE FOSSIL FUEL SYSTEMS

EXISTING RENEWABLE POWER SYSTEMS LIKE WIND & SOLAR NEED MASSIVE POWER BUFFER SUPPORT – MORE THAN FIRST THOUGHT



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

This is what 4 weeks buffer for solar would look like

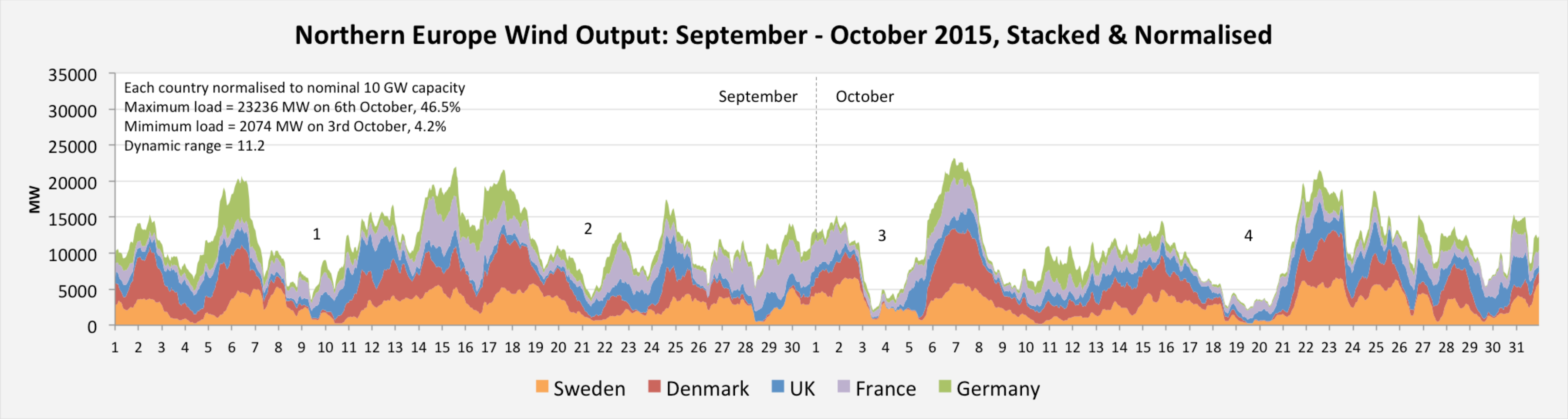
Distribution of the sun's radiation energy over the year in Germany (Wesselak & Voswinckel 2016)

Excess needs to be released

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
- 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*

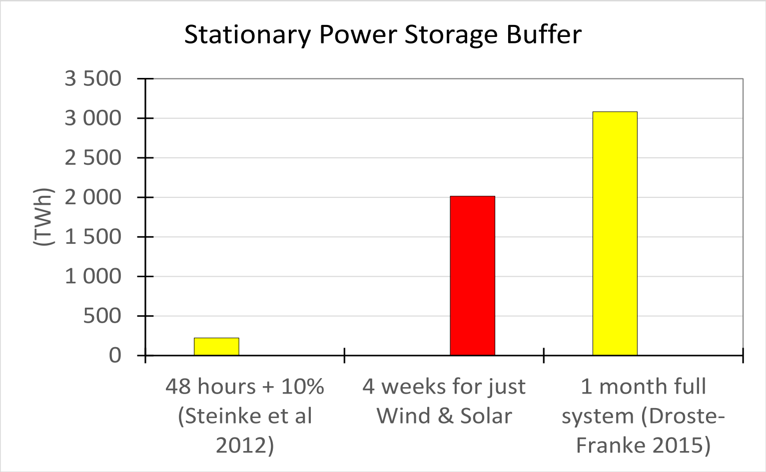
Highly variable of when power was produced



PROJECTED NEW ENERGY SPLIT FOR 2050

Developed from a combination of an IRENA 2022 projection and some of my own assumptions

Power Generation System	**Extra** required annual capacity to phase out fossil fuels (kWh)	Proposed Proportion of Energy Split on **new** annual capacity (%)	Estimated number of required **new** power plants of average size to phase out fossil fuels (number)
Nuclear	2.80E+12	7.50 %	218
Hydroelectric	4.98E+12	13.36 %	3 758
Wind Onshore (70% share)	1.00E+13	26.83 %	123 153
Wind Offshore (30% share)	4.29E+12	11.50 %	52 780
Solar PV (90% share)	1.29E+13	34.50 %	389 367
Solar Thermal (10% share)	1.43E+12	3.83 %	18 555
Geothermal	2.76E+11	0.74 %	457
Biowaste to energy	6.49E+11	1.73 %	18 762
Total (kWh)	3.73E+13		607 052
Total (TWh)	37 289.7		



- Global Wind & Solar capacity only (72.8%) = 26 220.7 TWh
- 28 days (4 weeks) Wind & Solar capacity only = **2 192.9 TWh**
- 48+10% hours Wind & Solar capacity only = **172.3 TWh**

This is the size of the needed power buffer

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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

NUMBER OF TECHNOLOGY UNITS

WIND TURBINES | SOLAR PANELS | POWER STORAGE BATTERIES

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

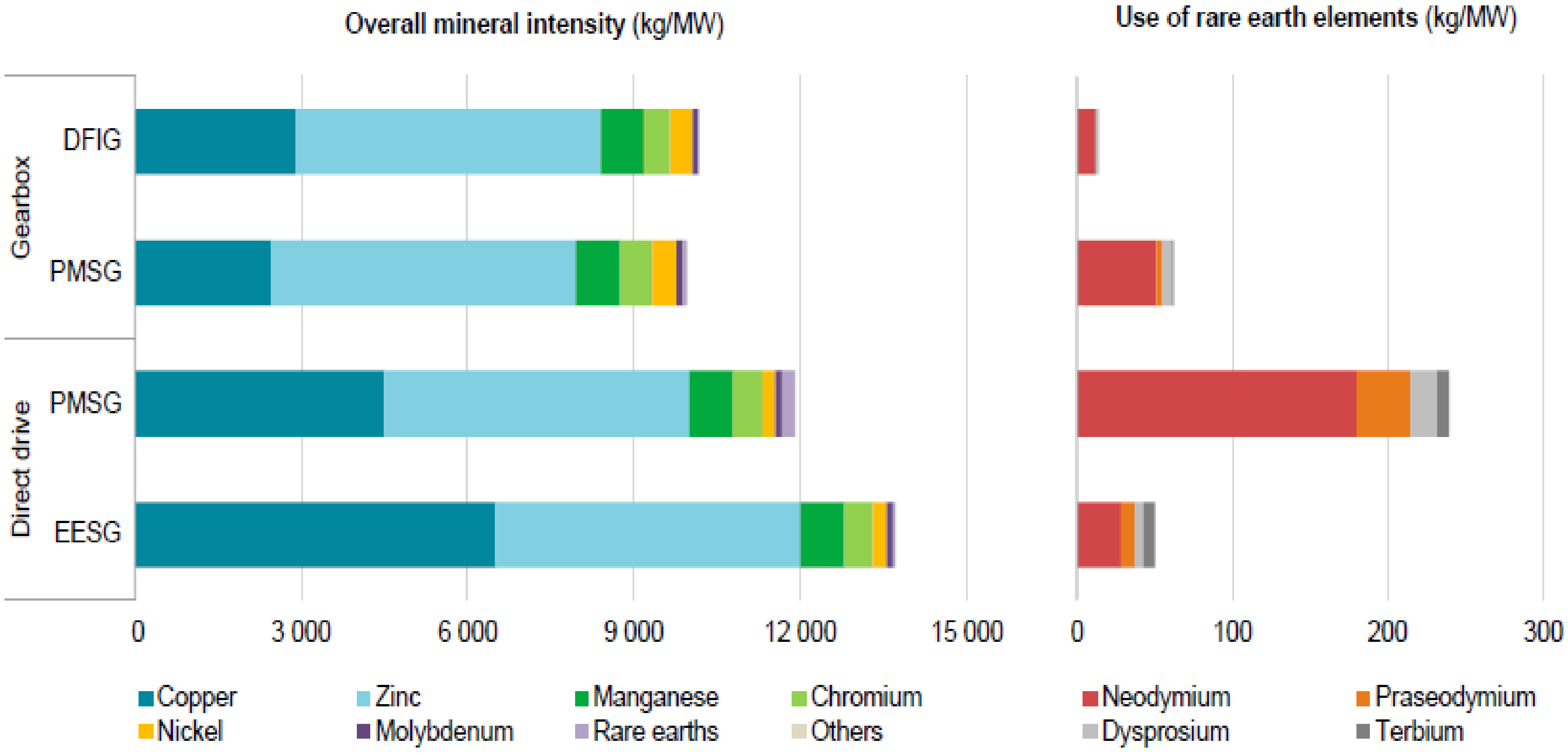
They harvest renewable energy like wind and sunshine. The units themselves are not renewable as they wear out (20 years). **They are replaceable.**

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.**

Minerals are the new oil



Metal content of different wind turbine units (Note: metal content intensity numbers are based on the onshore installation environment. More copper is needed in offshore applications due to much longer cabling requirements)

(Source: IEA) (Copyright IEA)

EVs use around six times more minerals than conventional vehicles

Typical use of minerals in an internal combustion engine vehicle and a battery electric vehicle

Notes: For this figure, the EV motor is a permanent-magnet synchronous motor (neodymium iron boron [NdFeB]); the battery is 75 kilowatt hours (kWh) with graphite anodes.

Sources: Argonne National Laboratory (2020b, 2020a); Ballinger et al. (2019); Fishman et al. (2018b); Nordelöf et al. (2019); Watari et al. (2019).

(Source: The Role of Critical Minerals in Clean Energy Transitions IEA)

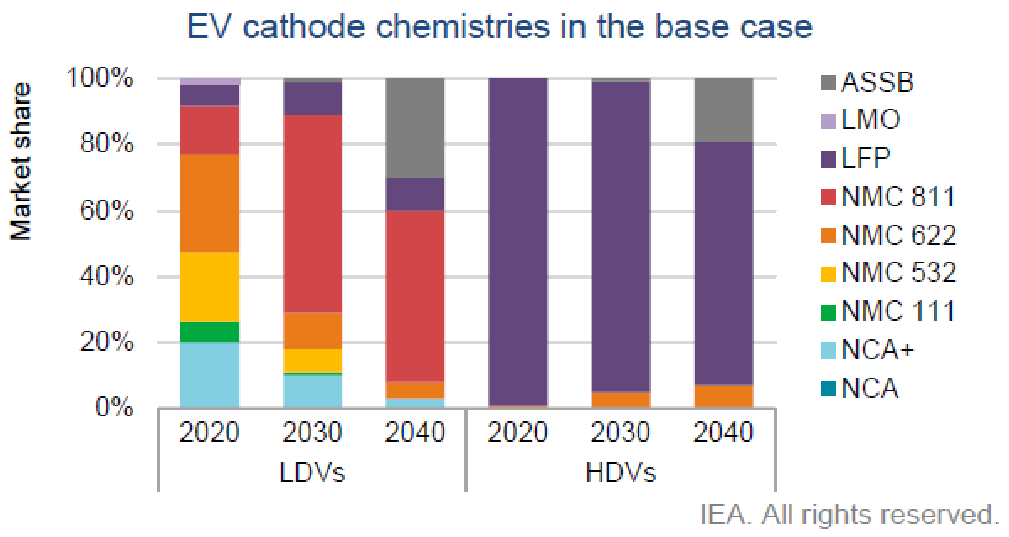
Table A17. Global market proportions of EV battery chemistries in 2040 (Source: IEA 2021)

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 %

Table A11. 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 (%)	Battery capacity in total power storage in 2040 (TWh)
Lithium Nickel Manganese Cobalt Oxides	NMC 532	100-135	3.3 %	66.3
	NMC 622	100-135	9.9 %	199.0
	NMC 811	100-135	9.9 %	199.0
Lithium Iron Phosphate	LFP	90-120	73.7 %	1 486.2
Vanadium Redox Battery	VRB	20 - 32	3.3 %	66.3
Total			100.0 %	2 017.0

2nd generation of work done

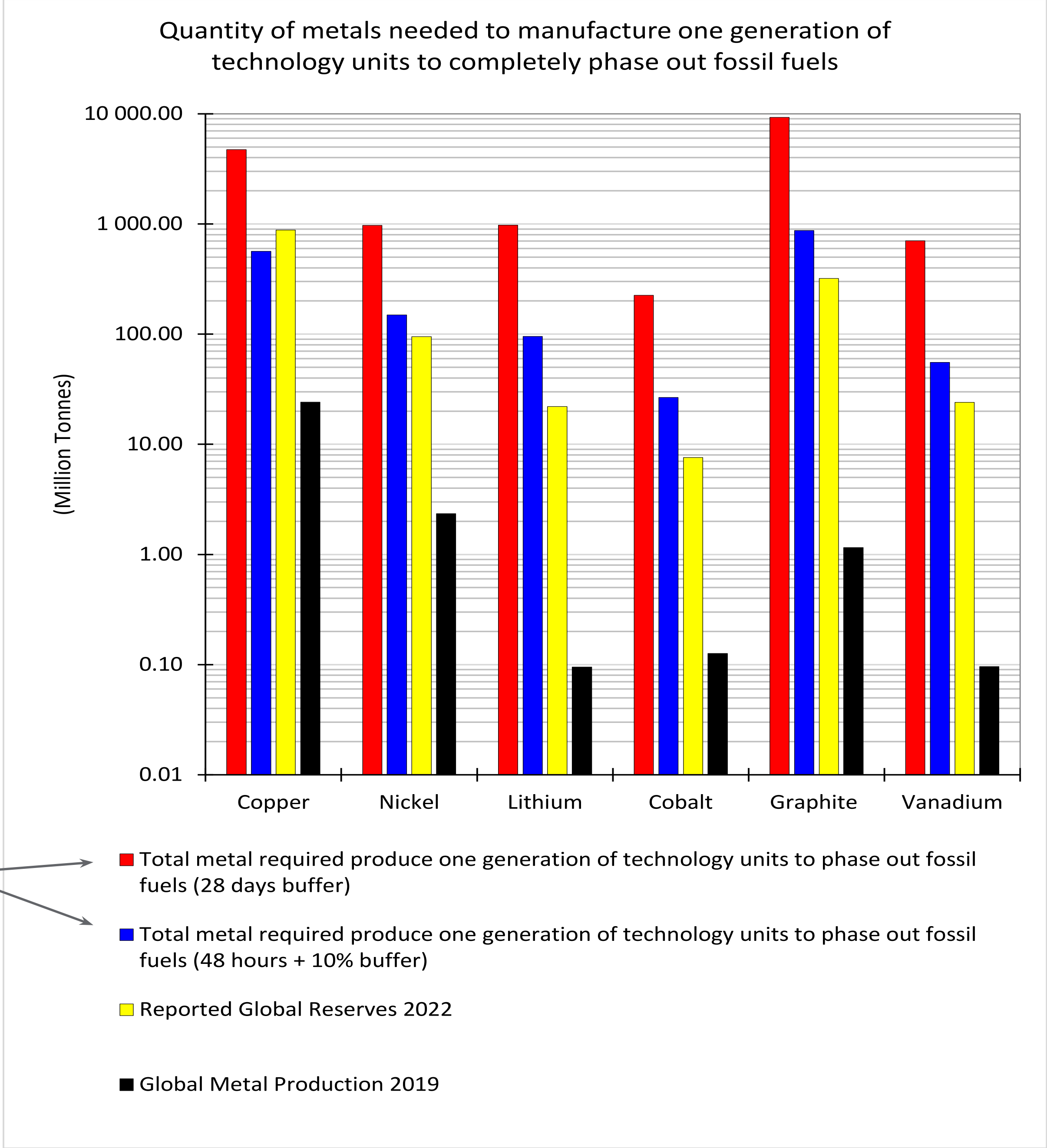


Notes: LDVs = light-duty vehicles (passenger cars and vans, light commercial vehicles, and 2- and 3-wheelers); HDVs = heavy-duty vehicles (trucks and buses).

(Source: The Role of Critical Minerals in Clean Energy Transitions IEA)

Table A28. Metal required for stationary power storage batteries to phase out fossil fuels

Battery Chemistry	NMC 532 (tonne)	NMC 622 (tonne)	NMC 811 (tonne)	LFP (tonne)	VRB (tonne)	Total (tonnes)
Copper (Cu)	70 636 359	208 323 452	208 166 274	3 671 625 026		4 158 751 111
Lithium (Li)	27 167 830	75 351 036	72 616 142	704 147 265		879 282 274
Manganese (Mn)	52 977 269	101 945 519	48 410 761			203 333 550
Cobalt (Co)	39 393 354	110 810 347	48 410 761			198 614 462
Vanadium (V)					647 928 875	647 928 875
Nickel (Ni)	95 087 406	327 998 627	396 968 244			820 054 277
Graphite (C)	169 798 939	540 754 493	590 611 290	7 091 768 885		8 392 933 607



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

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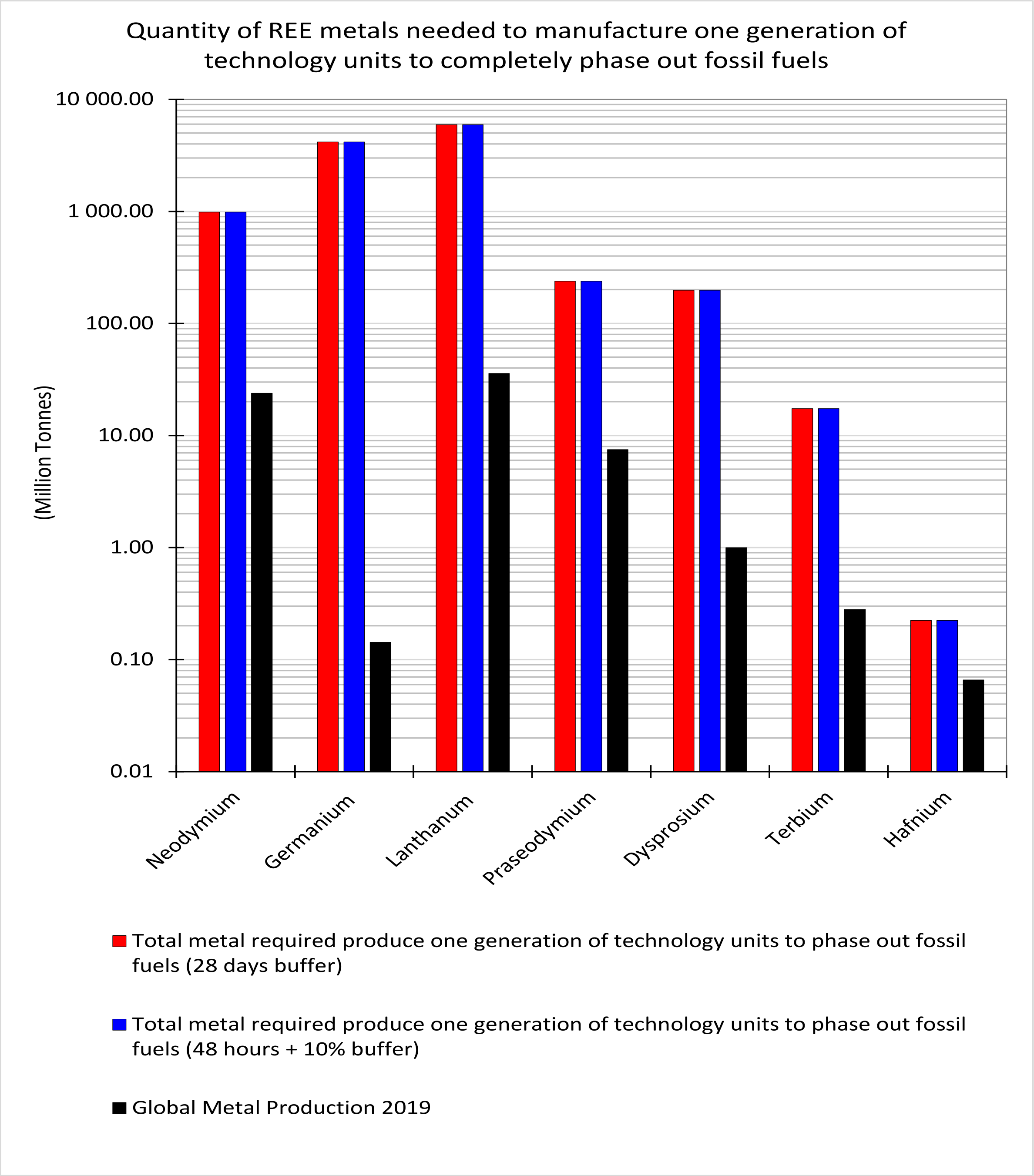
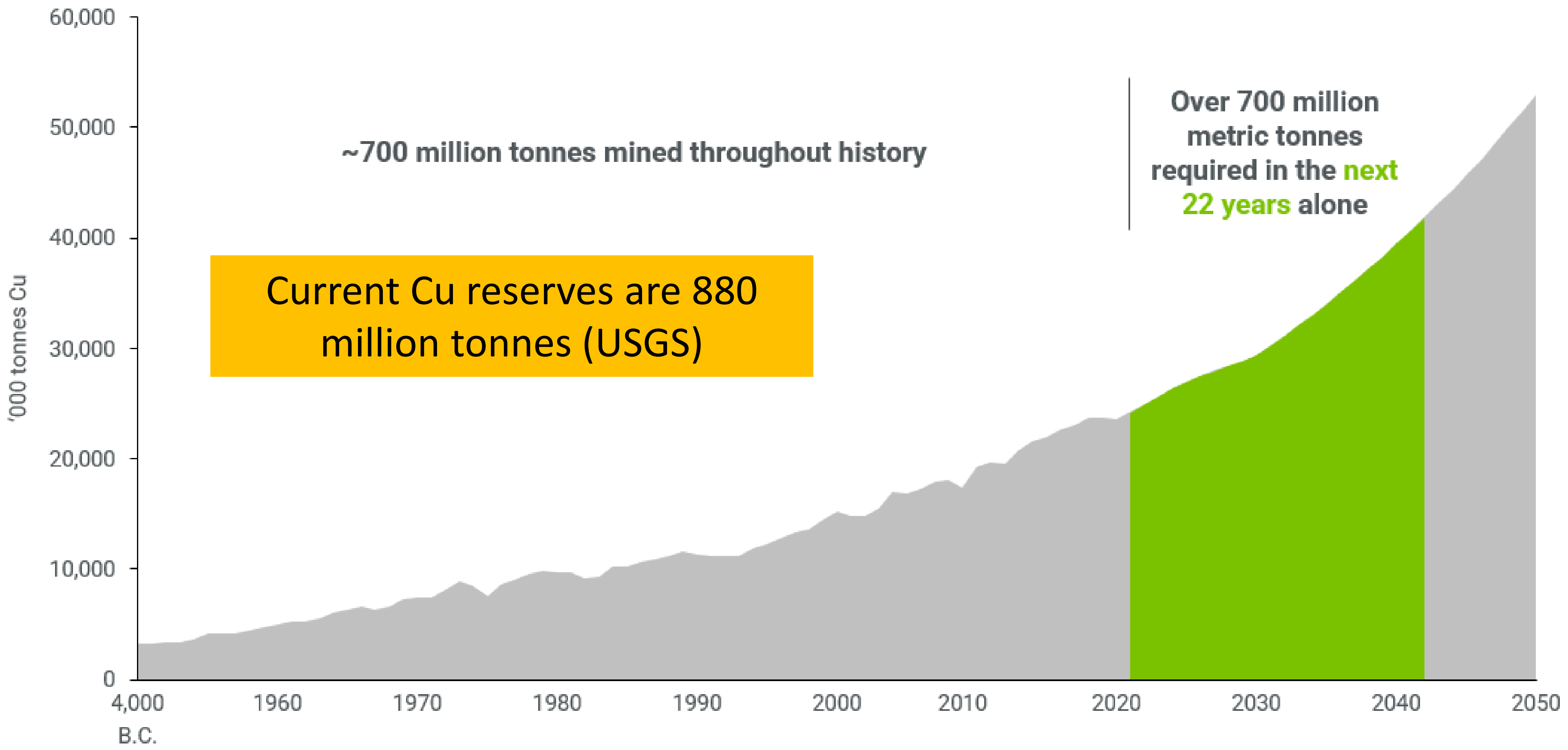

Quantity of REE metals needed to manufacture one generation of technology units to completely phase out fossil fuels
10 000.00
1 000.00
100.00
10.00
1.00
0.10
0.01
(Million Tonnes)
Neodymium
Germanium
Lanthanum
Praseodymium
Dysprosium
Terbium
Hafnium
Total metal required produce one generation of technology 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)
Global Metal Production 2019

ECONOMIC GROWTH AND RESOURCE SUPPLY



Current Cu reserves are 880 million tonnes (USGS)

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

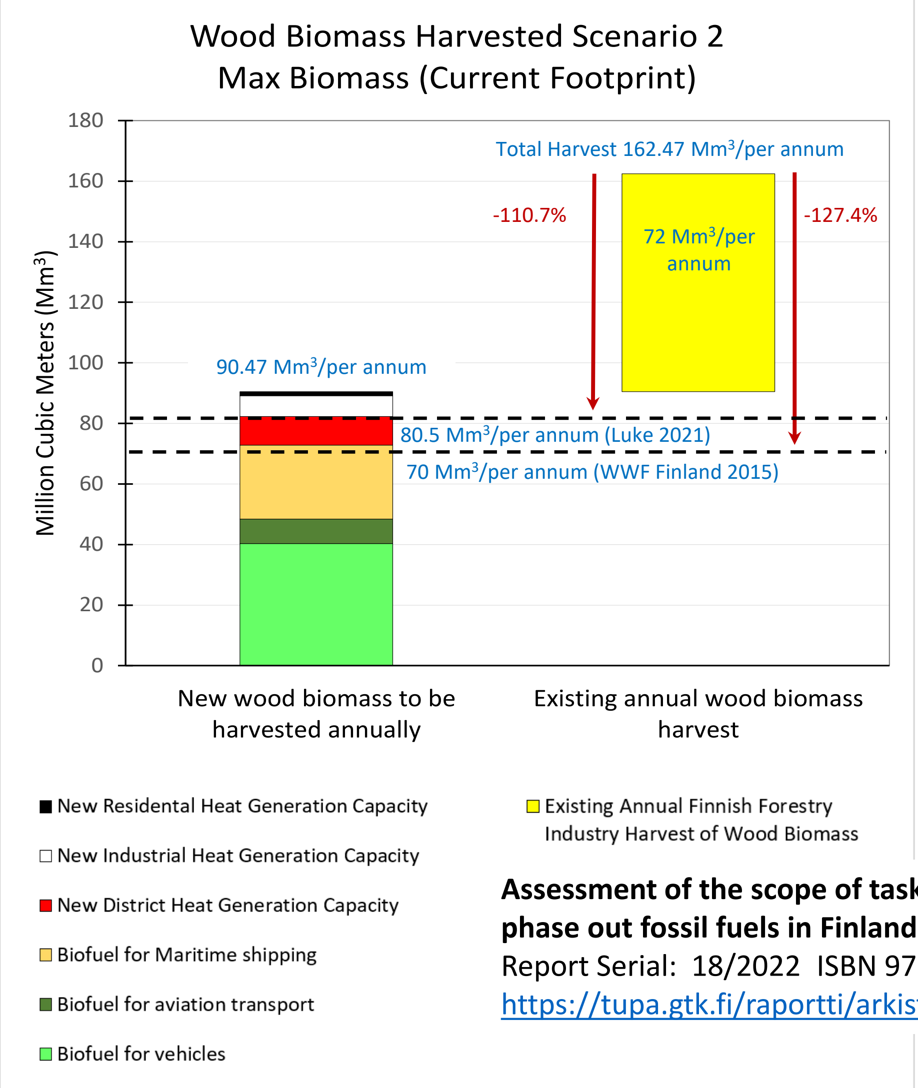
We want 4.36 billion tonnes of Cu, just to manufacture one generation of renewable technology (6.2 x historical Cu mining)

MINING PRODUCTION & EXISTING RESERVES ARE NOT ENOUGH TO MANUFACTURE THE FIRST GENERATION OF RENEWABLE TECHNOLOGY

BIOMASS IS A SECTOR THAT COULD MAKE A DIFFERENCE

- Food
- Bio waste to energy CHP
- Biofuels
- Bioplastics
- Organic derived fertilizers
- Building materials/ manufacture technology
  - *Bamboo*
  - *Hemp*

A brutally frank discussion around what is considered sustainable vs. what is absolutely needed is required in context of what is annually extracted from the Finnish biosphere



Assessment of the scope of tasks to completely phase out fossil fuels in Finland

Report Serial: 18/2022 ISBN 978-952-217-416-1
https://tupa.gtk.fi/raportti/arkisto/18_2022.pdf

BIOFUELS CAN'T REPLACE GASOLINE & DIESEL - 1

Table 22.2. Estimated arable land required to grow corn and soy to produce enough biofuels to substitute 2018 annual petroleum product consumption

Fossil Fuel	Fuel consumed in 2018 (Liters)	Bioethanol to be produced (Liters)	Biodiesel to be produced (Liters)	Arable land needed to produce the same quantity of biofuel: Corn (km^2)	Arable land needed to produce the same quantity of biofuel: Soybeans (km^2)
Petrol	1.48E+12	1.48E+12		3,424,277.7	
Diesel	1.66E+12		1.66E+12		31,129,195.9
Marine fuel	2.63E+11		2.63E+11		4,929,981.7
Jet fuel	3.59E+11	3.59E+11		831,465.8	
Total	3.76E+12 (liters)	1.84E+12 (liters)	1.92E+12 (liters)	4.26 (million km^2)	36.06 (million km^2)

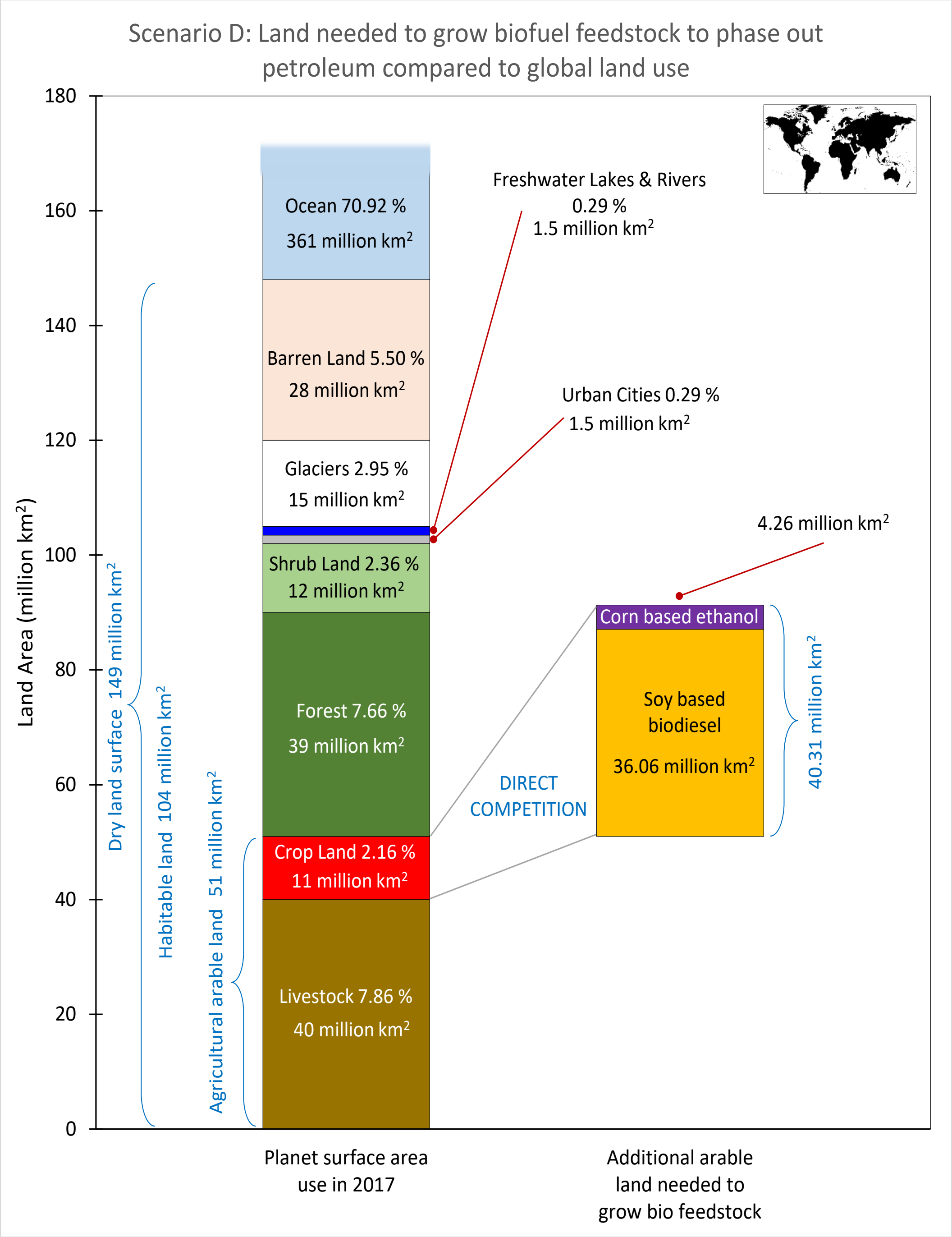


Figure 22.4. Comparison of additional requried arable crop land to grow enough biofuels to substitute global 2018 annual demand of petroleum products (Image: Simon Michaux) (World Map Image by Clker-Free-Vector-Images from Pixabay)
(Planet surface area source: United Nations 2019)

BIOFUELS CAN'T REPLACE GASOLINE & DIESEL - 1

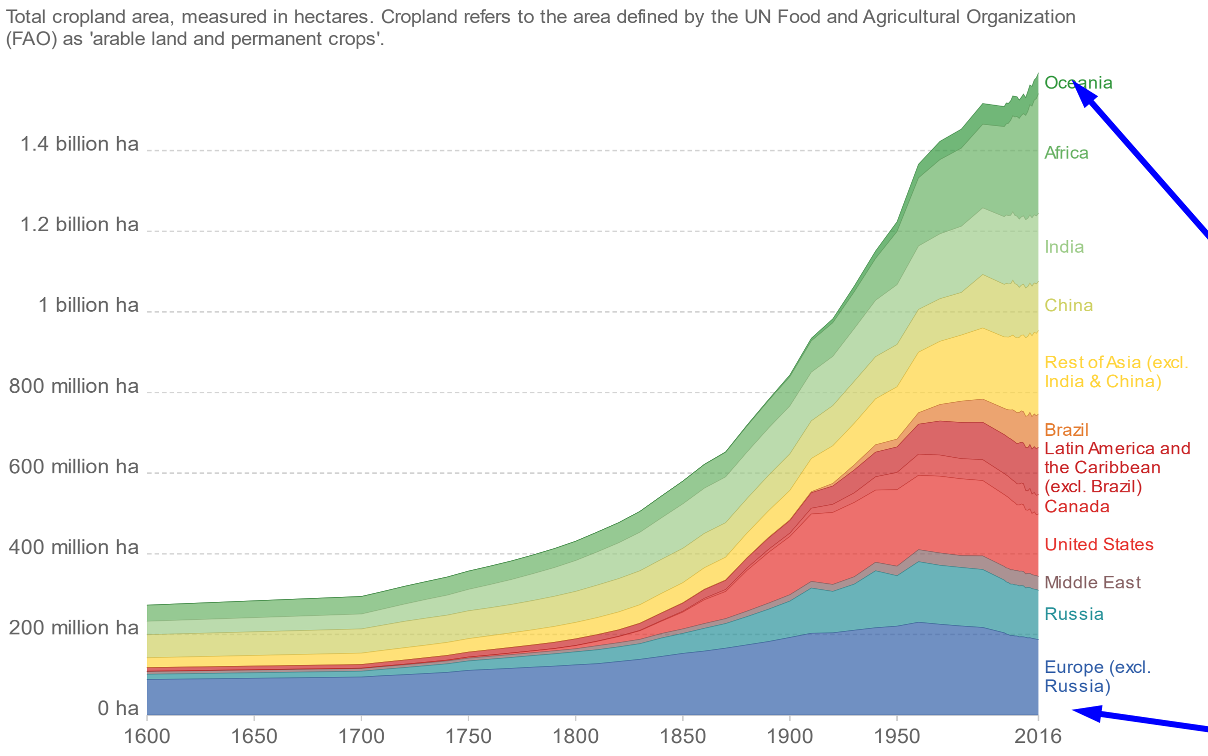
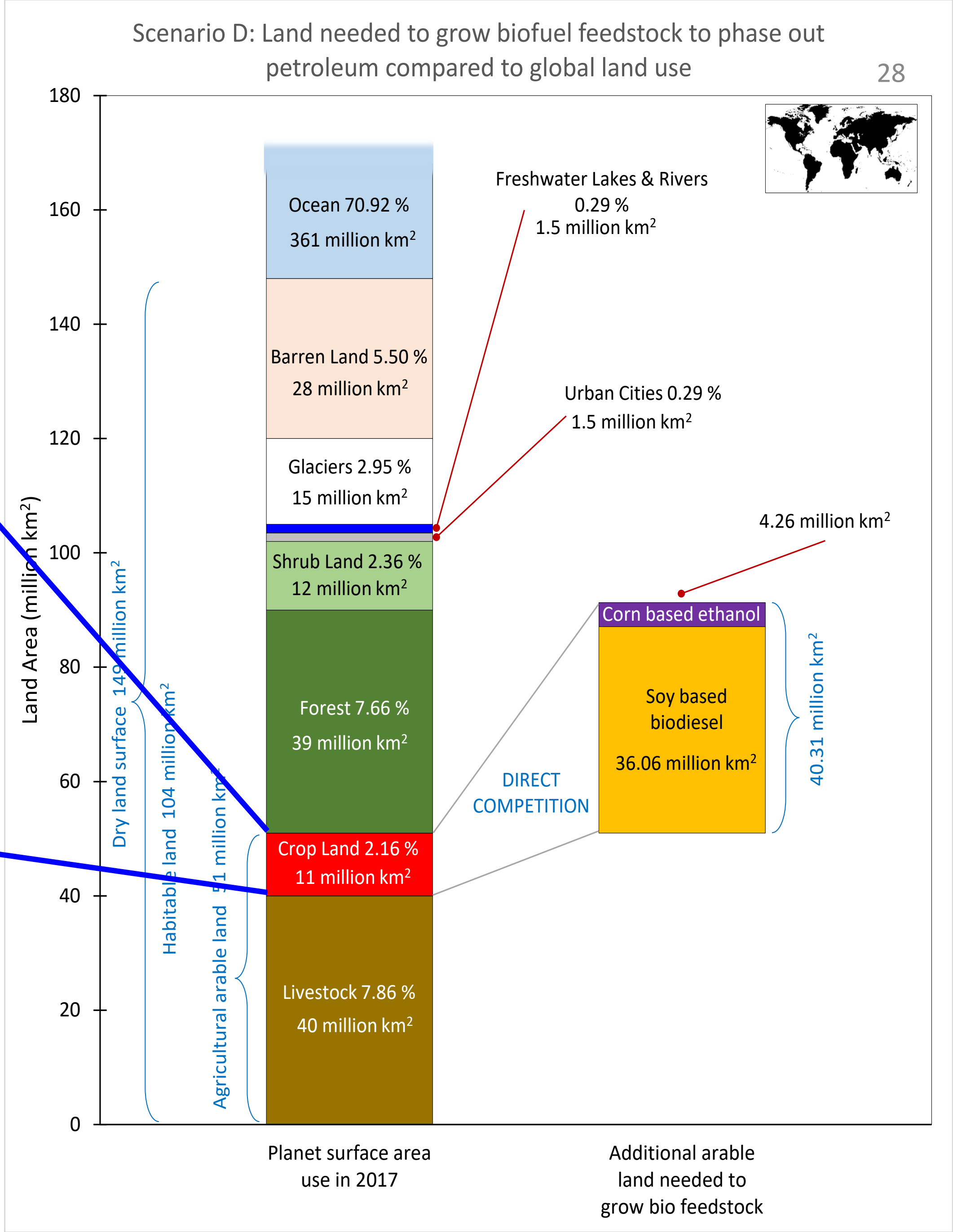


Figure 22.5. Cropland use over the long term 1600 to 2016 (Source: Hannah Ritchie and Max Roser (2013) - "Land Use". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/land-use' [Online Resource])



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(Planet surface area source: United Nations 2019)

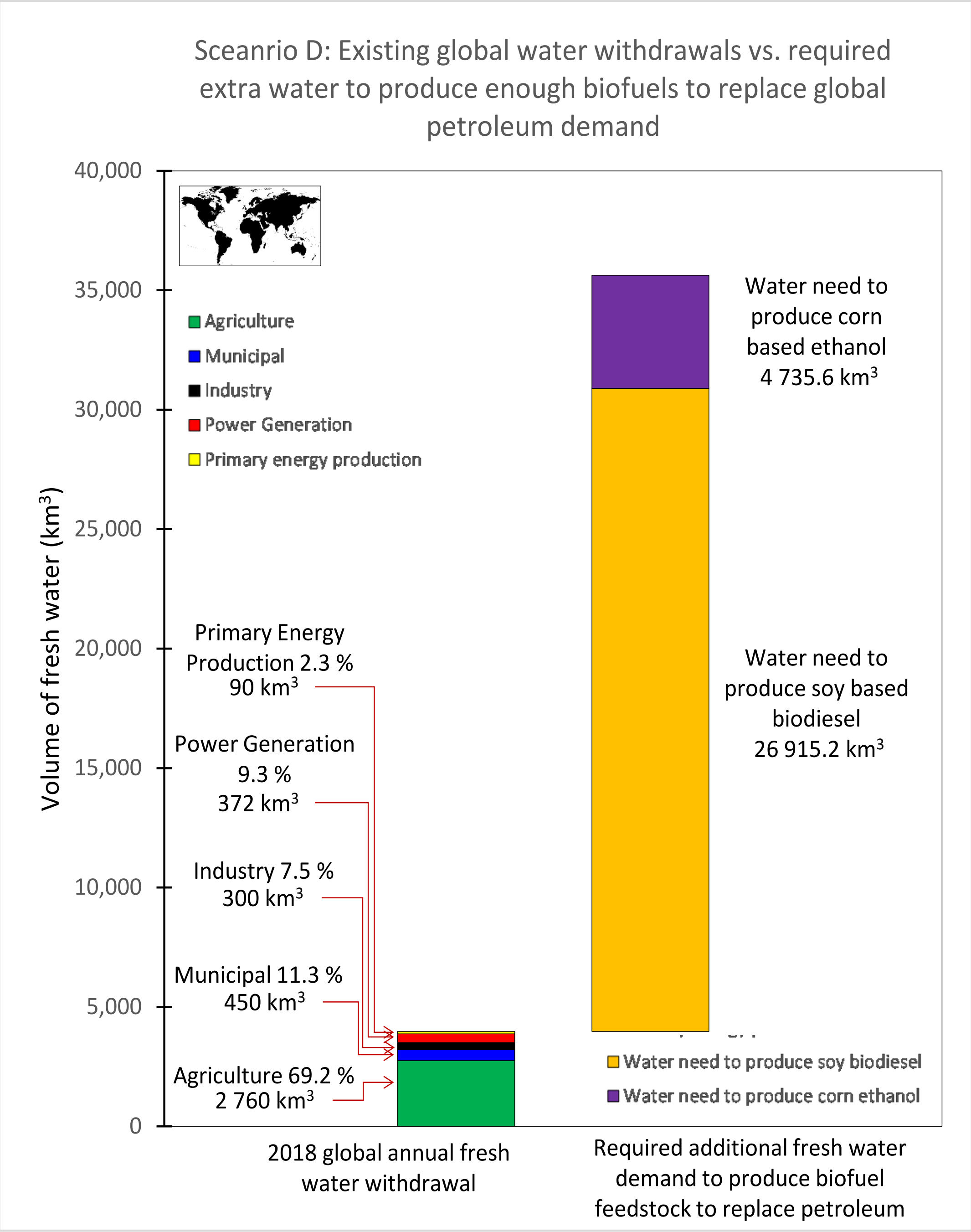
BIOFUELS CAN'T REPLACE GASOLINE & DIESEL - 2

Table 22.4. Estimated water consumption footprint for 1 years production of corn and soy feedstock to produce biofuel to substitute petroleum products (based on 2018 consumption)

	Volume of fresh water (liters)	Volume of fresh water need to produce biomass (liters)	Volume of fresh water need to produce biomass (m^3)	Volume of fresh water need to produce biomass (km^3)
Soy biodiesel liters to be produced annually	1.92E+12	2.69E+16	2.69E+13	26,915.2
Water needed per liter of fuel	1.40E+04			
Corn ethanol liters to be produced annually	1.84E+12	4.74E+15	4.74E+12	4,735.6
Water needed per liter of fuel	2.58E+03			

Total annual volume of fresh water required to produce corn and soy biomass: 31 650.8 km^3

Figure 22.6. Existing global freshwater withdrawal for the global human society (LHS), compared to estimated annual freshwater required to produce enough biofuels using corn and soy biomass feedstock to substitute for annual petroleum product demand (based on 2018 consumption rates). (Source data: UNESCO 2019 and WWAP 2019, and OECD Data Statistics Database) (World Map Image by Clker-Free-Vector-Images from Pixabay)



BIOFUELS CAN'T REPLACE GASOLINE & DIESEL - 2

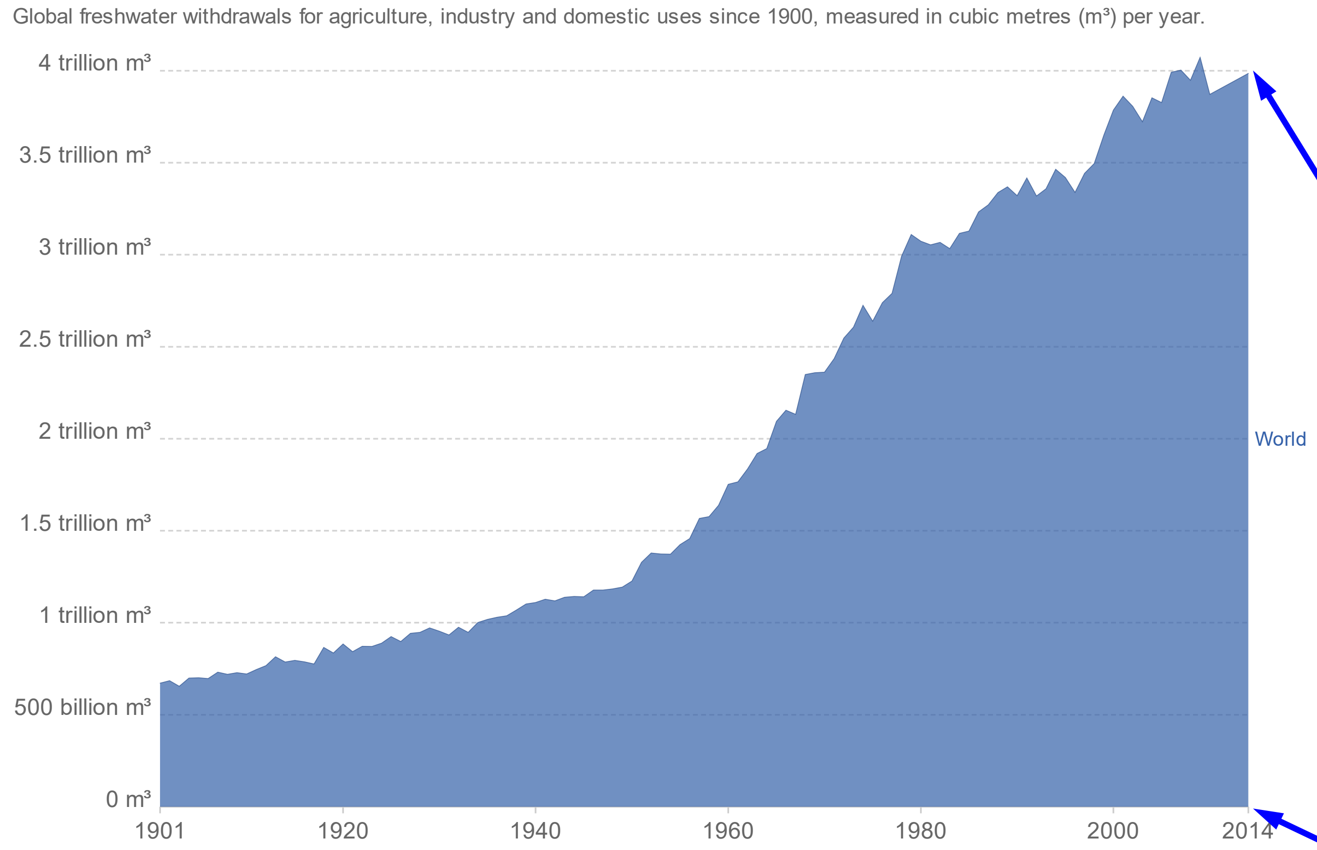
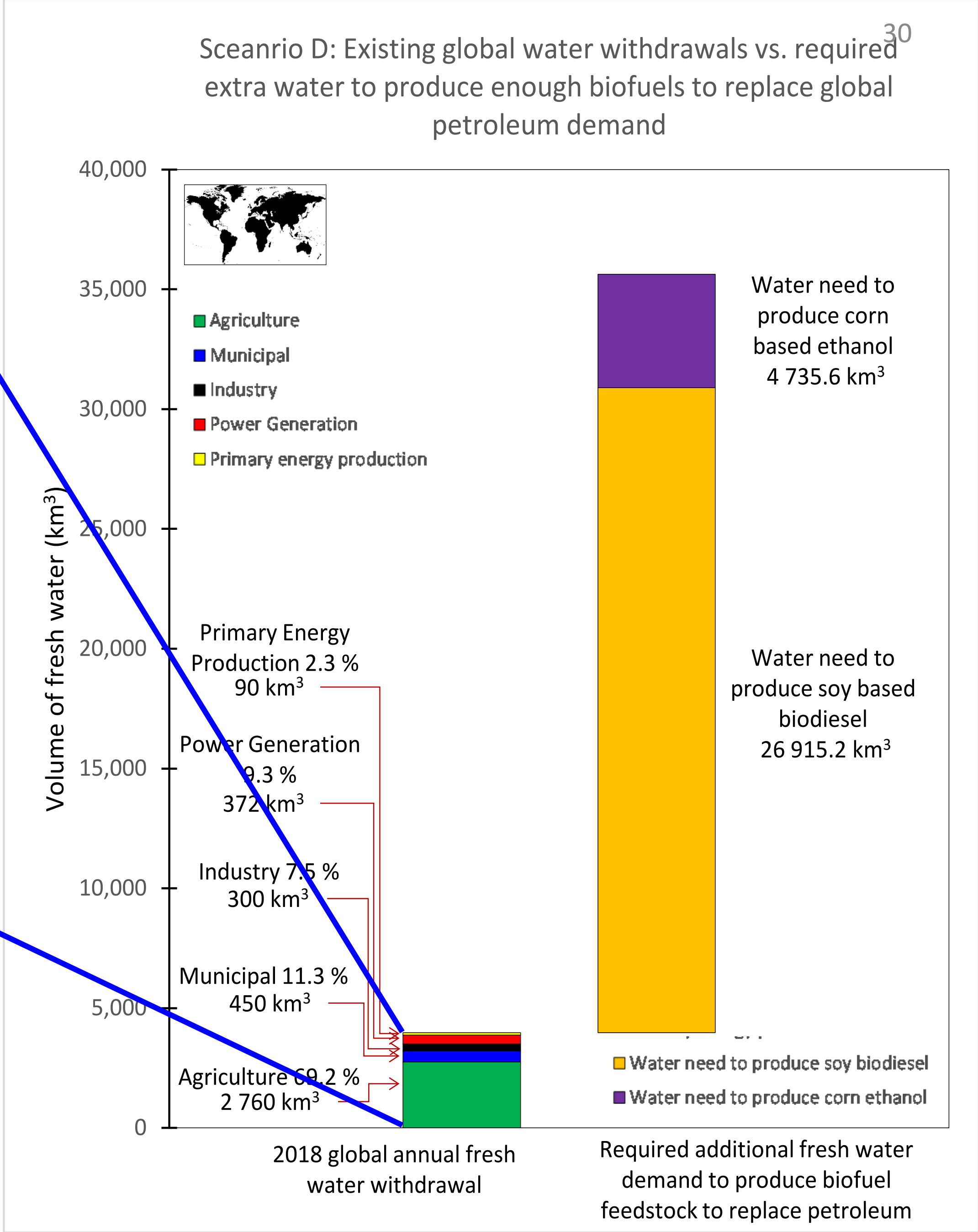


Figure 22.7. Global freshwater use between 1900 and 2014
(Source: Hannah Ritchie and Max Roser (2017) - "Water Use and Stress". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/water-use-stress' [Online Resource])



WHAT DO THESE FINDINGS MEAN

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

THE WHOLE SYSTEM IS ABOUT TO EVOLVE, WE IN RESPONSE NEED A BETTER PLAN

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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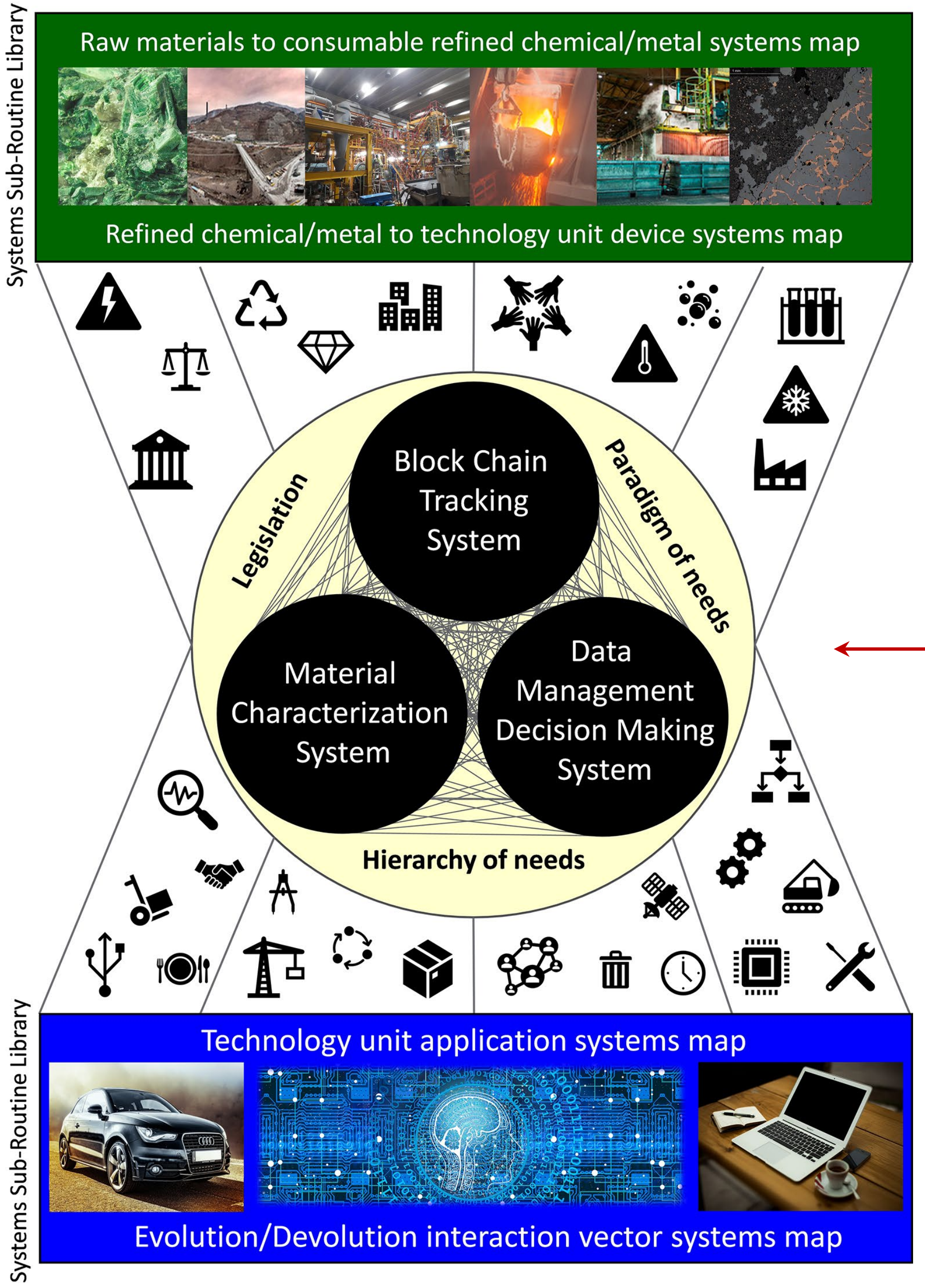

How do we source raw materials?

How do transform raw materials into technology products?

Decision making system

How do we use technology products?

How do we manage old technology dropping out and new technology starts up?

Kiitos & Thank you

November 18, 2022