

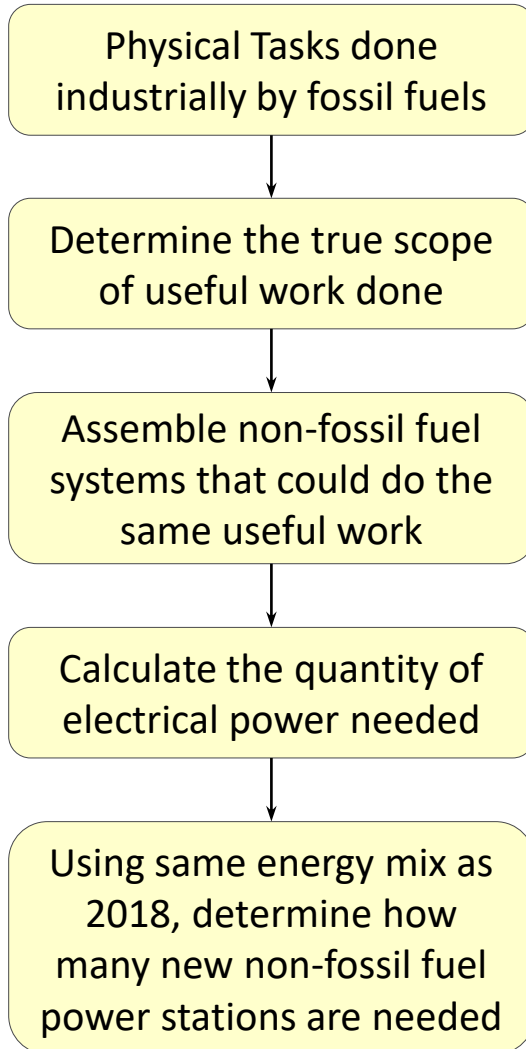
ASSESSMENT OF THE SIZE AND SCOPE OF NON-FOSSIL FUELS SYSTEMS TO PHASE OUT OIL GAS & COAL

Simon P. Michaux

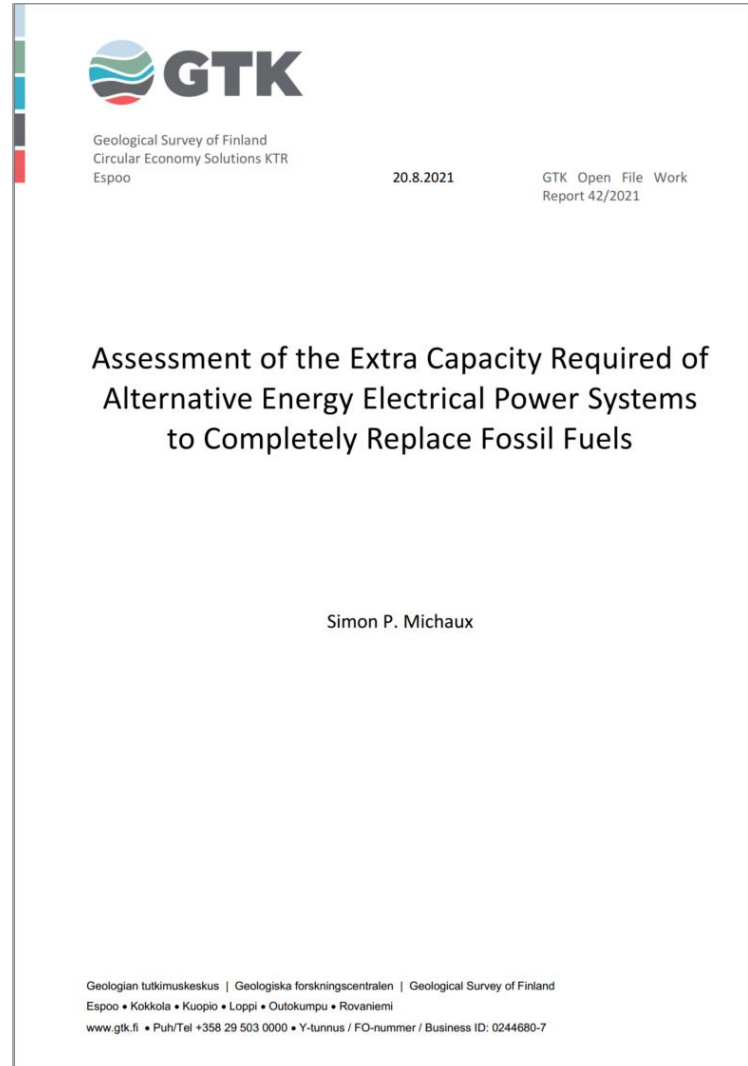
20/09/2021

Associate Professor Mineral Processing & Geometallurgy

SUMMARY



20.09.2021



Link to full report below

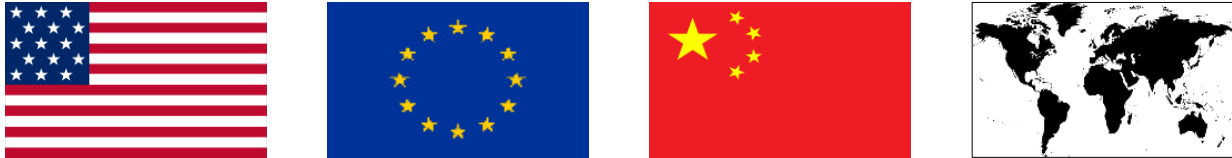
https://tupa.gtk.fi/raportti/arkisto/42_2021.pdf

Link to 8 page summary

https://mcusercontent.com/72459de8ffe7657f347608c49/files/be87ecb0-46b0-9c31-886a-6202ba5a9b63/Assessment_to_phase_out_fossil_fuels_Summary.pdf

- Number of vehicles, by class
- Number and size of batteries
- An understanding of the EV to H₂-Cell split
- Estimates of EV & H₂-Cell rail transport
- Estimates of an EV & H₂-Cell maritime shipping fleet
- Estimates of phasing out of fossil fuel industrial applications
- Examination of the feasibility of expanding the nuclear NPP fleet
- Assessment of the feasibility of global scale biofuels
- Plastics & fertilizer industries

CALCULATION ARC

- What is the true scope of tasks to fully phase out fossil fuels, and the complete replacement with non-fossil fuel powered systems?
 - Existing ICE transport fleet size
 - *Cars & Trucks*
 - *Rail*
 - *Maritime shipping*
 - *Aviation*
- The image shows four icons in a row: the flag of the United States, the flag of the European Union, the flag of China, and a black silhouette of a world map.
- What is the number and size of required batteries/hydrogen cells/solar panels/wind turbines
 - *In what proportional mix?*
 - *In 2018, 84.5% of global primary energy consumption was fossil fuel based*
 - Required power grid expansion to charge the needed number of batteries, and make hydrogen
 - *Number of new power stations*
 - *Required power storage to manage intermittent supply*

Current plans are not large enough in scope, the task before us is much larger than the current paradigm allows for

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 (282.6 million tonnes of Li-Ion batteries)*
 - *An annual additional 6 158.4 TWh of electricity will be required from the global power grid to charge those 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*
 - *This would require, 11 553.6 TWh of additional electricity*

GLOBAL SYSTEM I



1.39 billion Electric Vehicles

695.2 million Passenger Cars	5.4 trillion km	1 545.9 TWh
29 million Buses & Delivery Trucks	803 billion km	1 597.5 TWh
601 million Vans, Light Trucks	7.9 trillion km	2 988.6 TWh
62 million Motorcycles	160 billion km	26.5 billion kWh

→ 6 158.4 TWh

Industry

Electrical Power Generation	17 086.1 TWh
Building Heating	2 816.0 TWh
Steel Manufacture	56.5 TWh

→ 19 958.6 TWh

GLOBAL SYSTEM II



Hydrogen Economy

H ₂ -Cell Vehicles	Hydrogen	Manufacture of H ₂
28.9 million Class 8 HCV Trucks Travelled 1.62 trillion km	129.9 million tonnes	7 503.7 TWh
Rail Transport 9 407 billion tkm freight 1 720 billion passenger-kilometers	18.5 million tonnes	1 066.5 TWh
Maritime Shipping cargo 72 146 billion tonne-km	51.7 million tonnes	2 983.4TWh

200.1 million tonnes



11 553.6 TWh

Biomass Economy

Biomass Sustainably Sourced from the Planetary Environment

Aviation	Biofuel ??? liters
Plastics Manufacture	Biomass Feedstock ??? tonnes

Sustainability audit

GLOBAL SYSTEM III



7

EV 6 158.4 TWh
Industry 19 958.6 TWh
H₂ 11 553.6 TWh

**Additional Annual
Electrical Power
Requires 37 670.6 TWh**

**=
221 594 NEW Non-Fossil Fuel
Power Stations**

Power plant fleet in 2018 was
46 423 stations

Hydro Power
16 576.9 TWh
12 504 stations

Nuclear Power
10 679.7 TWh
834 stations

Wind Power
5 154.4 TWh
63 445 stations

Solar Power
2 311.1 TWh
69 573 stations

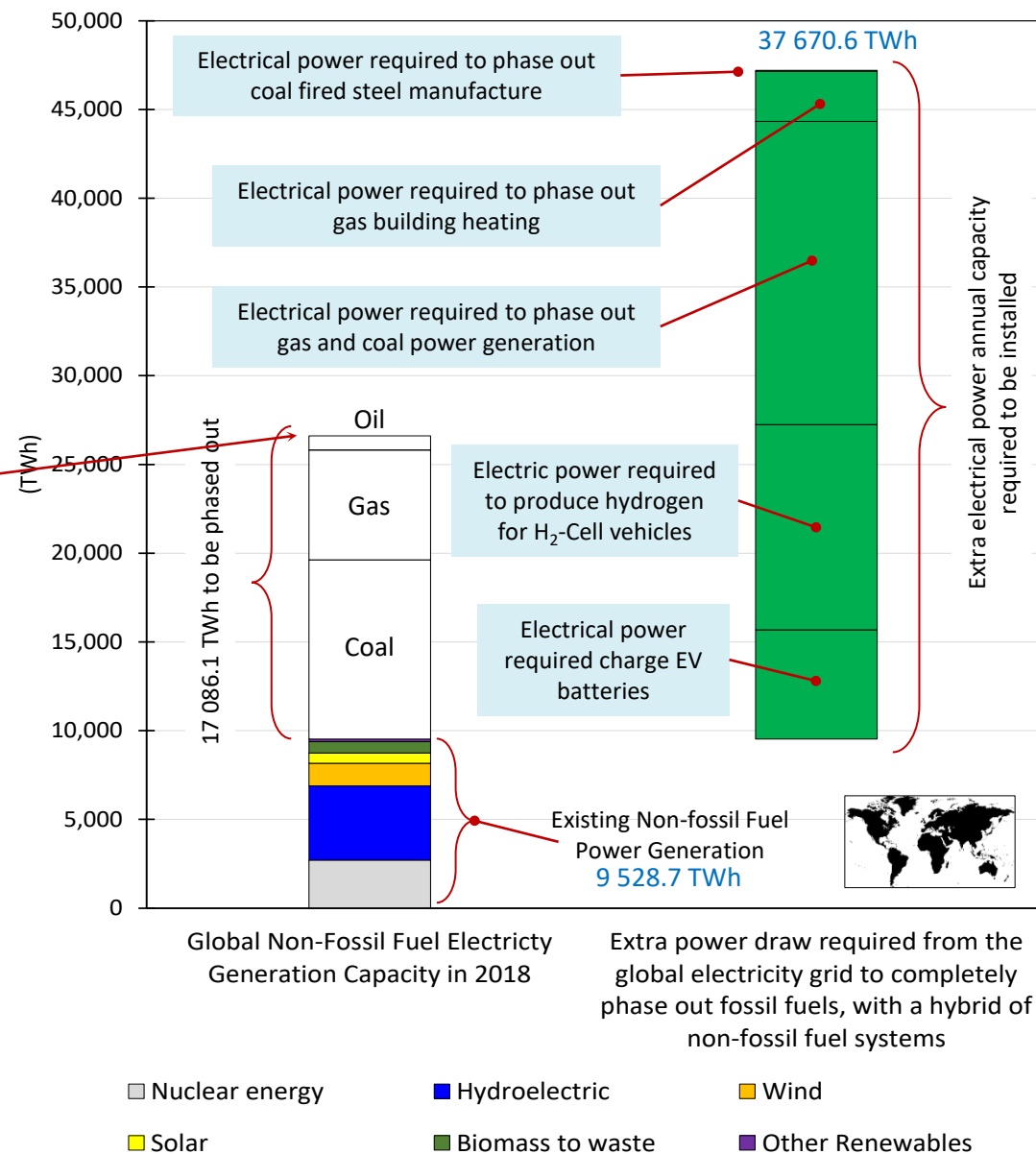
Other Renewables
Geothermal & Tidal
367.7 TWh
609 stations

Biowaste to Energy
2 580.8 TWh
74 628 stations

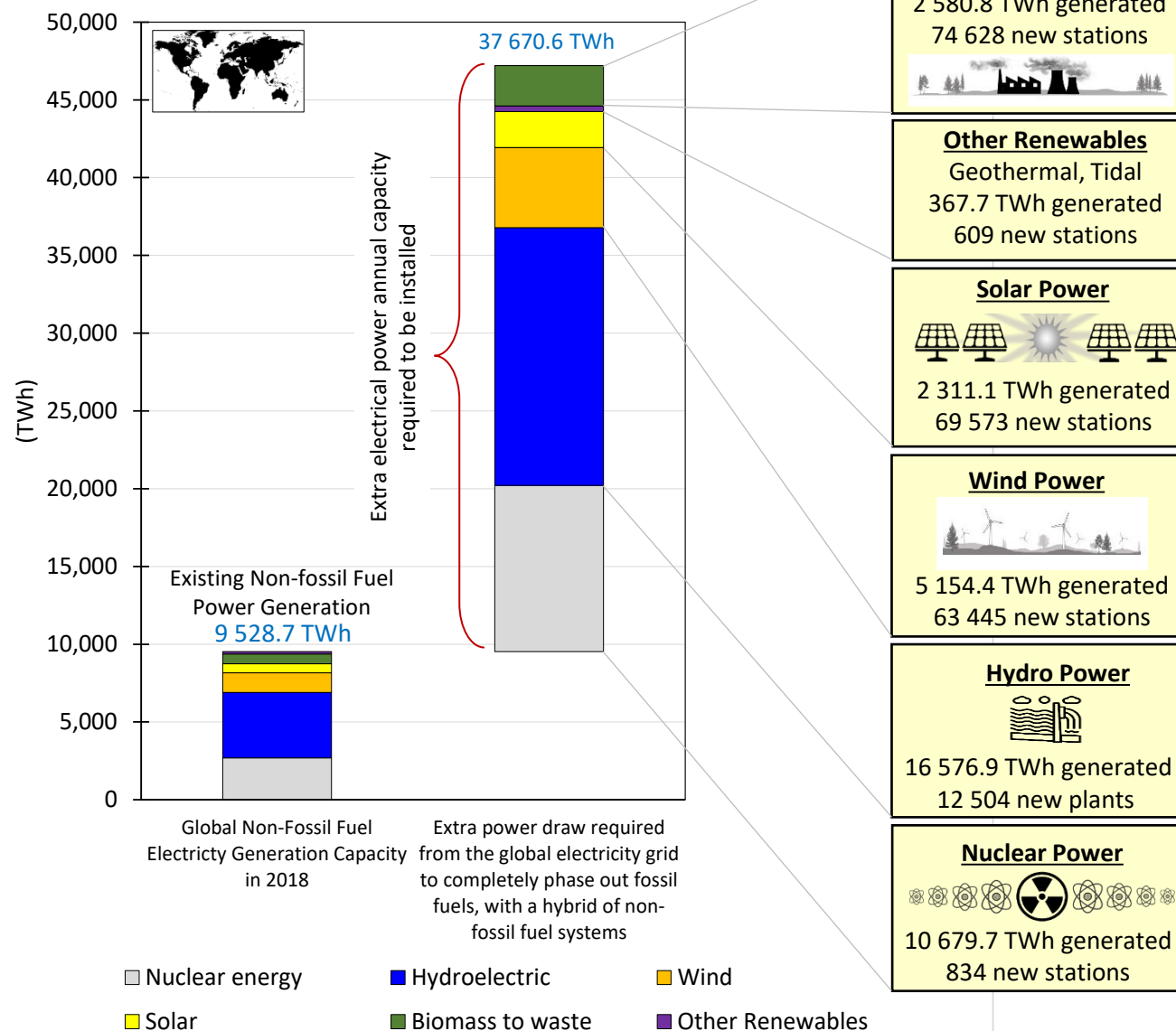
Power storage buffer 574.27 TWh

Total electrical power production in 2018 was 26 614 TWh

Additional Electrical Power Generation Capacity Required to Completely Phase Out Fossil Fuels Scenario F- Hybrid Solution (GLOBAL)



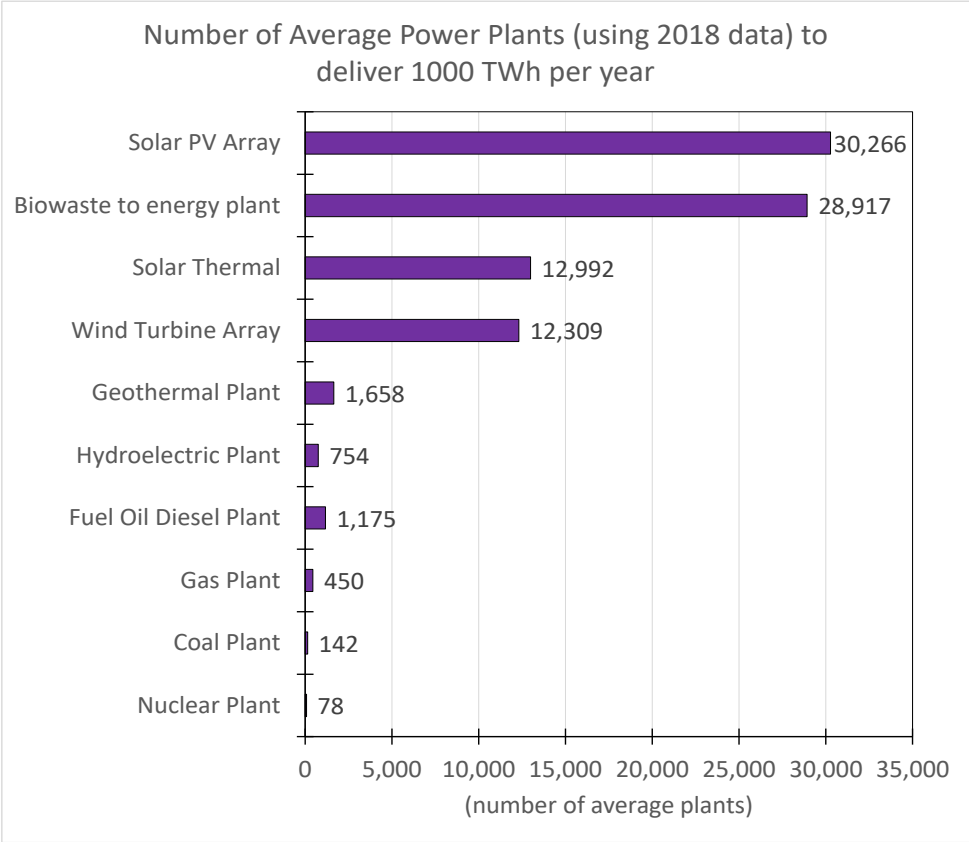
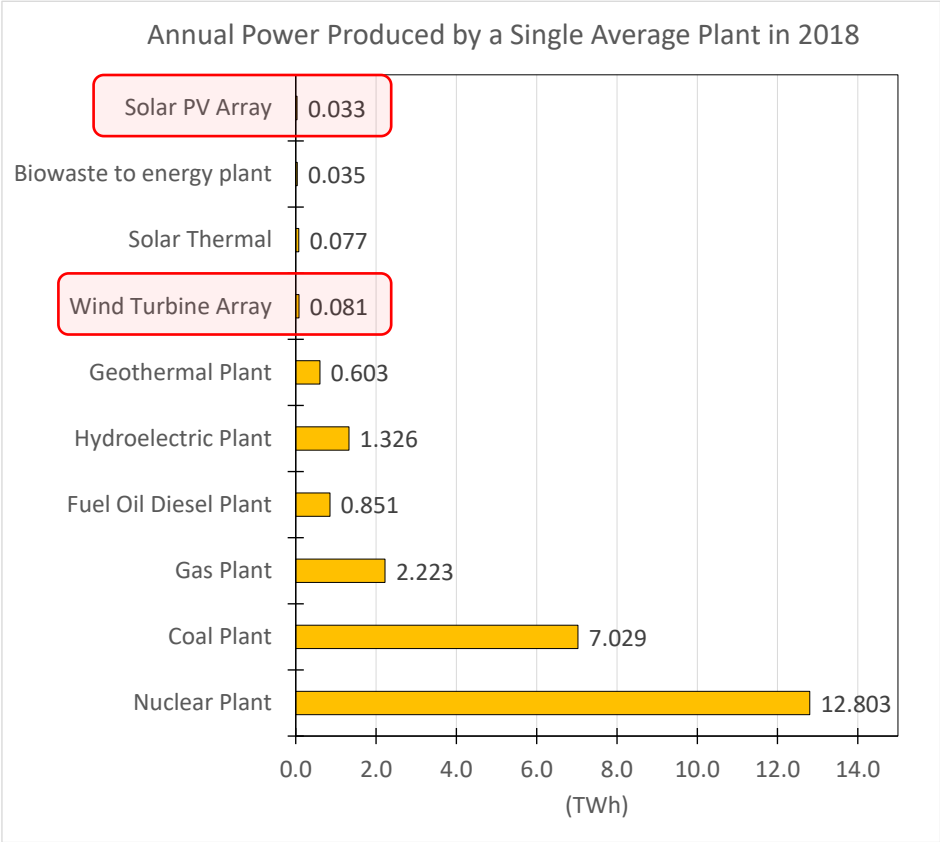
Additional Electrical Power Generation Capacity Required to Completely Phase Out Fossil Fuels Scenario F- Hybrid Solution (GLOBAL)



221 594 NEW Non-Fossil
Fuel Power Stations

To put this in context, the total
power plant fleet in 2018
(all types including fossil fuel
plants) was only 46 423 stations

TO DELIVER 1000 TWH OF POWER TO THE GRID OVER 1 YEAR...



(Source Data: Global Energy Observatory, Agora Energiewende and Sandbag 2019)

Renewables have a much lower ERoEI ratio than fossil fuels and may not be strong enough to power the next industrial era

MINERALS NEEDED VS. RESERVES

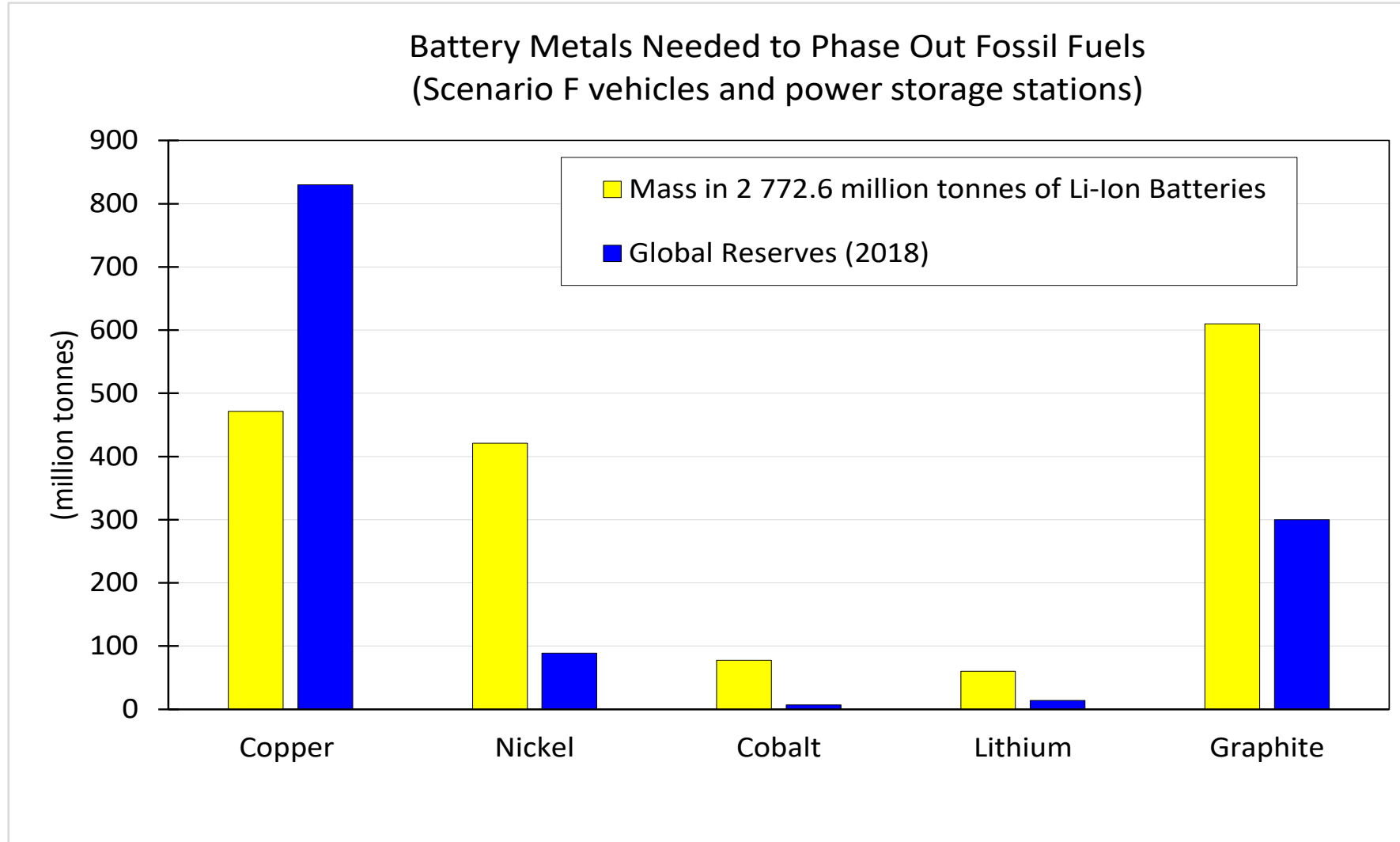
11

Metal	2018 Global Annual Production (tonnes)	Mass in 2 772.6 million tonnes of Li-Ion Batteries (million tonnes)	Years of Production at 2018 Capacity Required to Phase Out Fossil Fuels (years of production)
Copper	21,000,000	471.3	22.4
Aluminium Metal from smelter production	60,000,000	235.7	3.9
Nickel	2,300,000	421.2	183.1
Cobalt	140,000	77.4	552.5
Lithium	85,000	60.2	707.8
Graphite	930,000	610.0	655.9

(Source: USGS Mineral Statistics)

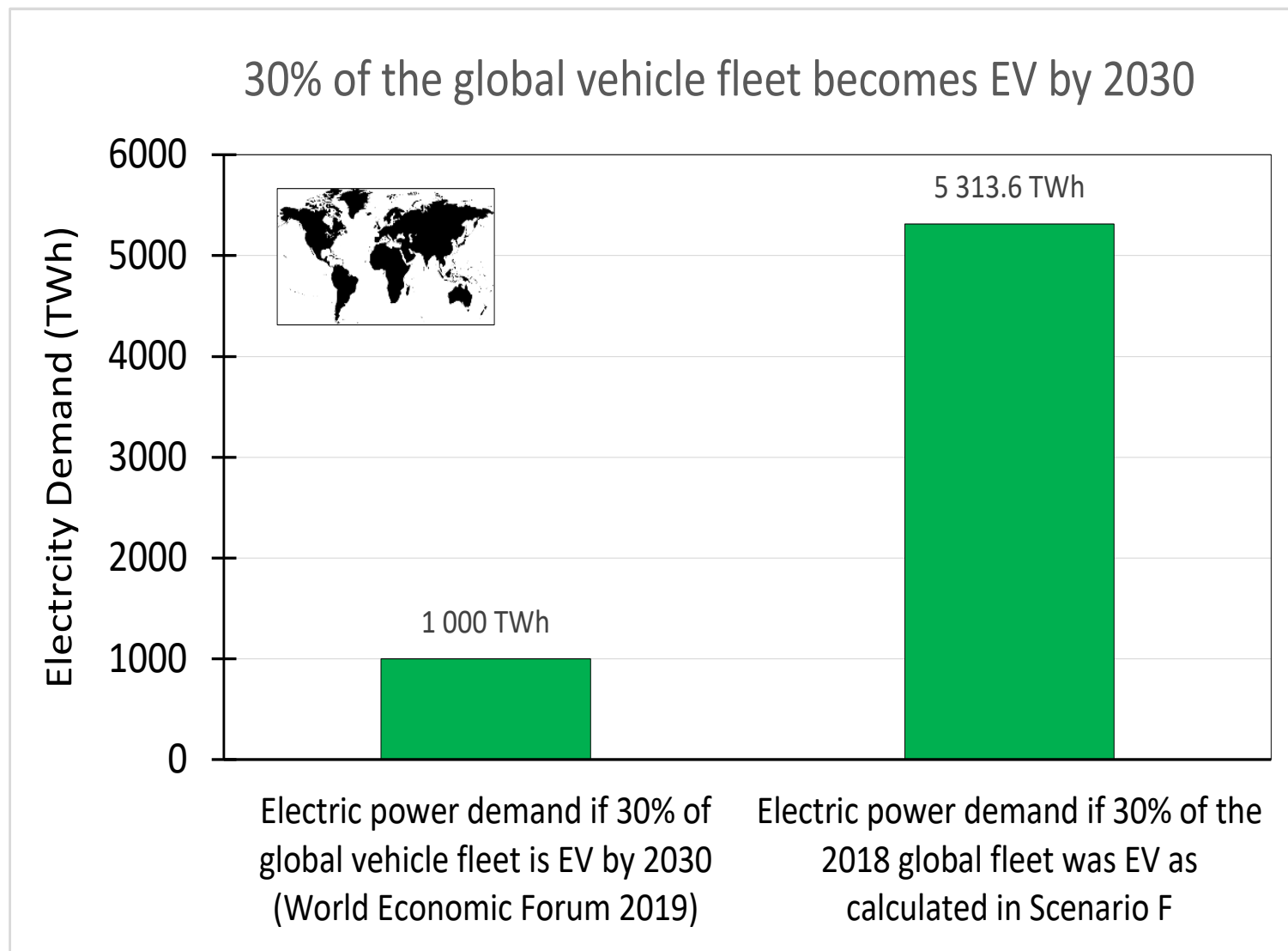
MINERALS NEEDED VS. RESERVES

12



Currently for every 1000 deposits discovered, only 1-2 become mines

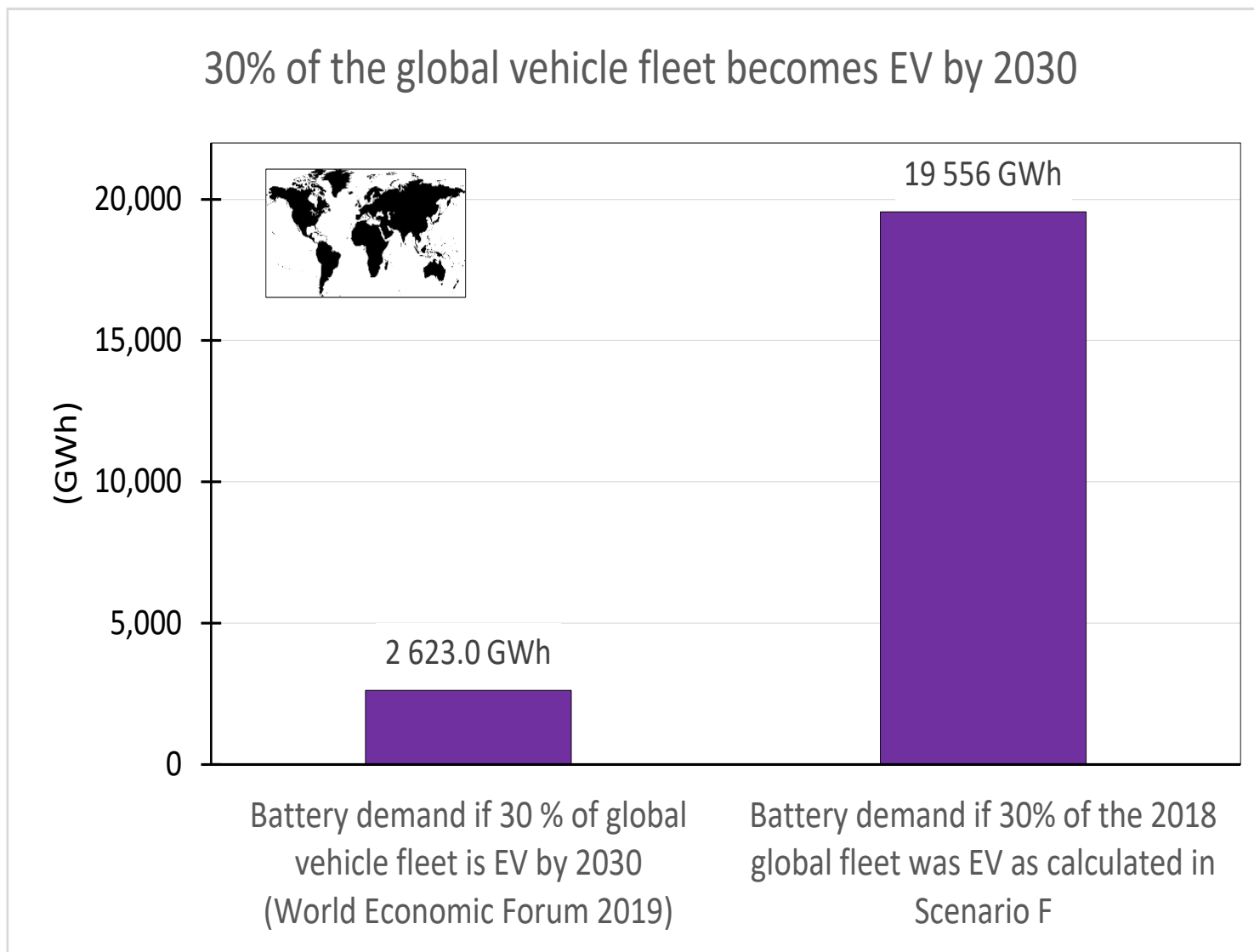
CURRENT THINKING UNDERESTIMATES THE SCALES



Comparison:
current
projections of
required
electric power
demand to
charge EV
batteries vs.
outcomes of
Scenario F

(World Map Image by
Cler-Free-Vector-Images
from Pixabay)

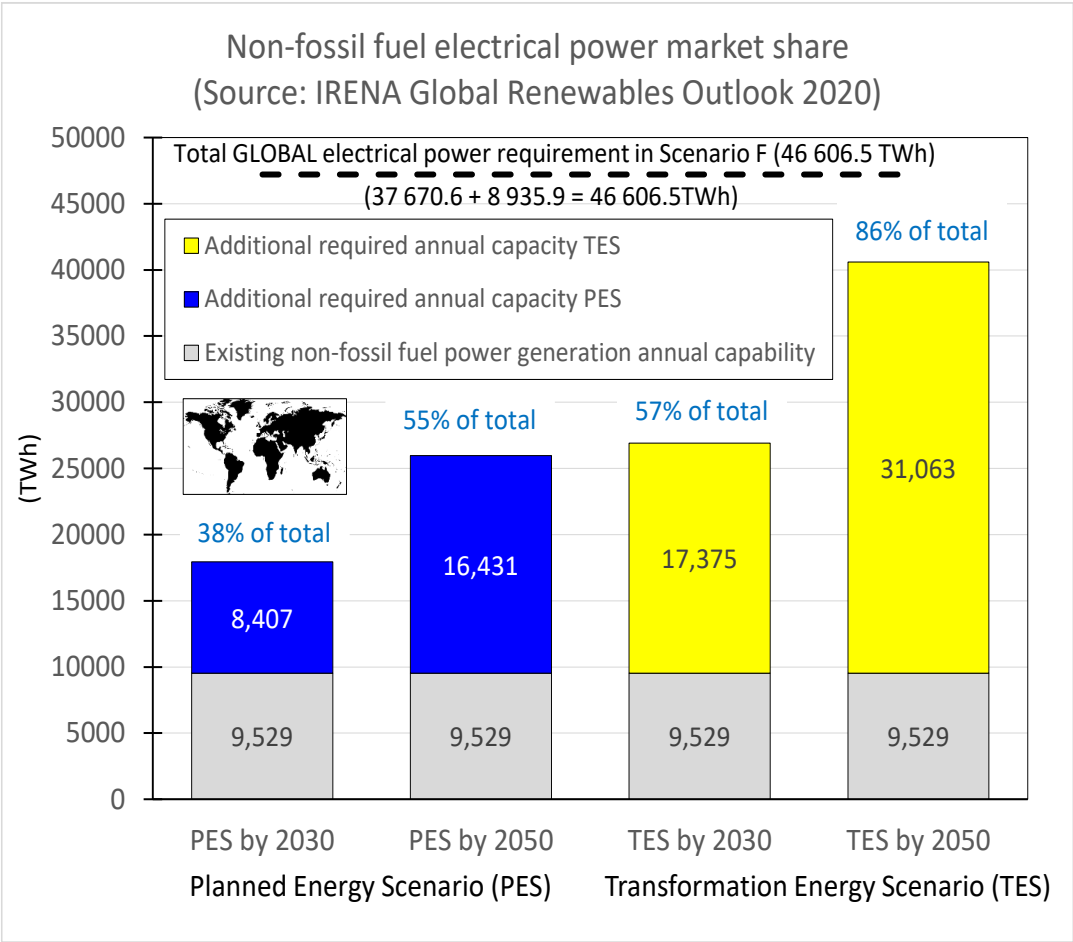
CURRENT THINKING UNDERESTIMATES THE SCALES



Comparison of
current
projections of
required battery
to be
manufactured
demand vs.
outcomes of
Scenario F

(World Map Image by Clker-
Free-Vector-Images from
Pixabay)

ESTIMATED ADDITIONAL ANNUAL GLOBAL NON-FOSSIL FUEL ELECTRICAL POWER CAPABILITY REQUIRED TO MEET PES AND TES SUSTAINABILITY TARGETS (SOURCE: IRENA GLOBAL RENEWABLES OUTLOOK 2020)



Non-fossil fuel generation System	Global PES non-fossil fuel power generation by 2030 (number of new plants)	Global PES non-fossil fuel power generation by 2050 (number of new plants)	Global TES non-fossil fuel power generation by 2030 (number of new plants)	Global TES non-fossil fuel power generation by 2050 (number of new plants)
Nuclear	338	489	507	764
Hydroelectric	5,063	7,328	7,595	11,459
Wind	25,691	37,184	38,536	58,142
Solar PV	28,057	40,609	42,086	63,498
Solar Thermal	114	166	172	259
Geothermal	247	357	370	559
Biowaste to energy	2,777	4,020	4,166	6,286
	8 754.5 TWh	16 683.1 TWh	17 614.7 TWh	31 122.9 TWh
	38% of global electrical power generation	55% of global electrical power generation	57% of global electrical power generation	86% of global electrical power generation

- The Planned Energy Scenario (PES).** This is the primary reference case for the IRENA study, providing a prediction outcome based on current energy plans and other planned targets and policies (as of 2019).
- The Transforming Energy Scenario (TES).** An energy transformation pathway based largely on renewable energy sources and steadily improved energy efficiency.

CONCLUSIONS

- Additional non-fossil fuel electrical power annual capacity is 37 670.6 TWh
- The same non-fossil fuel energy mix of 2018 translates into 221 594 new power plants
 - *To put this in context, the total power plant fleet in 2018 (all types including fossil fuel plants) was only 46 423 stations*
- Electrical power generated from solar and wind sources are highly intermittent, both across 24-hour cycle and in seasonal context.
 - *A power storage buffer is required if these power generation systems are to be used on a large scale.*
- A conservative estimate is a 4-week power capacity buffer for solar and wind
 - *From Scenario F, the power storage buffer capacity for the global electrical power system would be 573.4 TWh*
 - *The number of 100 MW stations would be 5.7 million, and the mass of lithium ion batteries would be 2.5 billion tonnes*
- The total mass of lithium ion batteries required to phase out fossil fuels is 2.78 billion tonnes

CONCLUSIONS

- 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
- There is a projected mineral shortage to supply raw materials for battery manufacture
 - *2018 production rates are not even close to being appropriate*
 - *Current mineral reserves are also not large enough to deliver the needed volumes*
- **Metals of all kinds are about to become much more valuable**
 - *Evolution of the industrial ecosystem and its market is likely*
- **There is a coming Renaissance for the exploration for and mining of minerals**



GTK

**KIITOS
&
THANK YOU**



Simon P. Michaux

Associate Professor Geometallurgy

Unit Minerals Processing and Materials Research - Circular Economy Solutions

Ore Characterization, Process Engineering & Mineral Intelligence

Geological Survey of Finland/Geologian tutkimuskeskus

PO Box 96, (Vuorimiehentie 2)

F1-02151 Espoo, FINLAND

simon.michaux@gtk.fi

Mobile: +358 (0)50 348 6443