It’s time to wake up

Assessment of the size and scope of non-fossil fuels systems to phase out oil gas & coal

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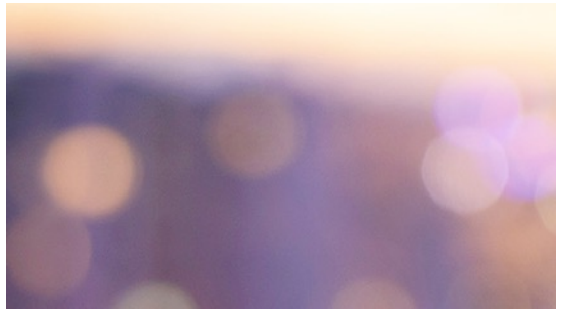
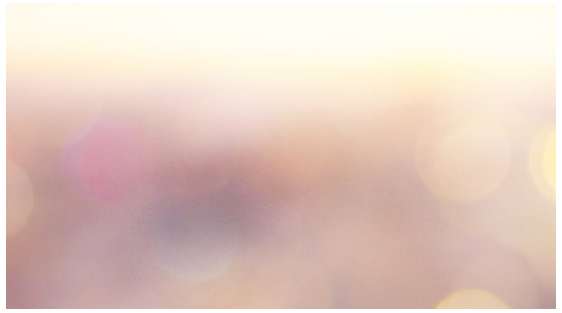


The good news



Scenarios for Finland

Summary

The research report made by Associate Research Professor Simon Michaux, Geological Survey of Finland:

1. The currently known global mineral reserves will not be sufficient to supply enough metals to manufacture the planned non-fossil fuel industrial systems.

The research report made by Associate Research Professor Simon Michaux, Geological Survey of Finland:

2. If we want to transition away from fossil fuels, mining of minerals and using recycled minerals and metals from industrial waste streams in new ways will have to increase greatly.

The research report made by Associate Research Professor Simon Michaux, Geological Survey of Finland:

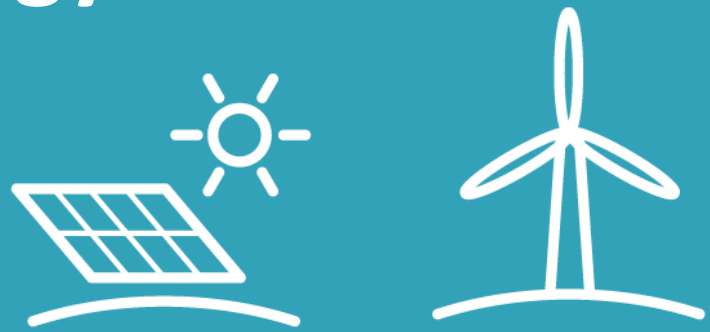
3. We need a new plan

with decisive actions to diversify sustainable material/metal/mineral sourcing, where manufacture could be done with parallel technology systems that require different material chemistries.

The research report made by Associate Research Professor Simon Michaux, Geological Survey of Finland:

Why?

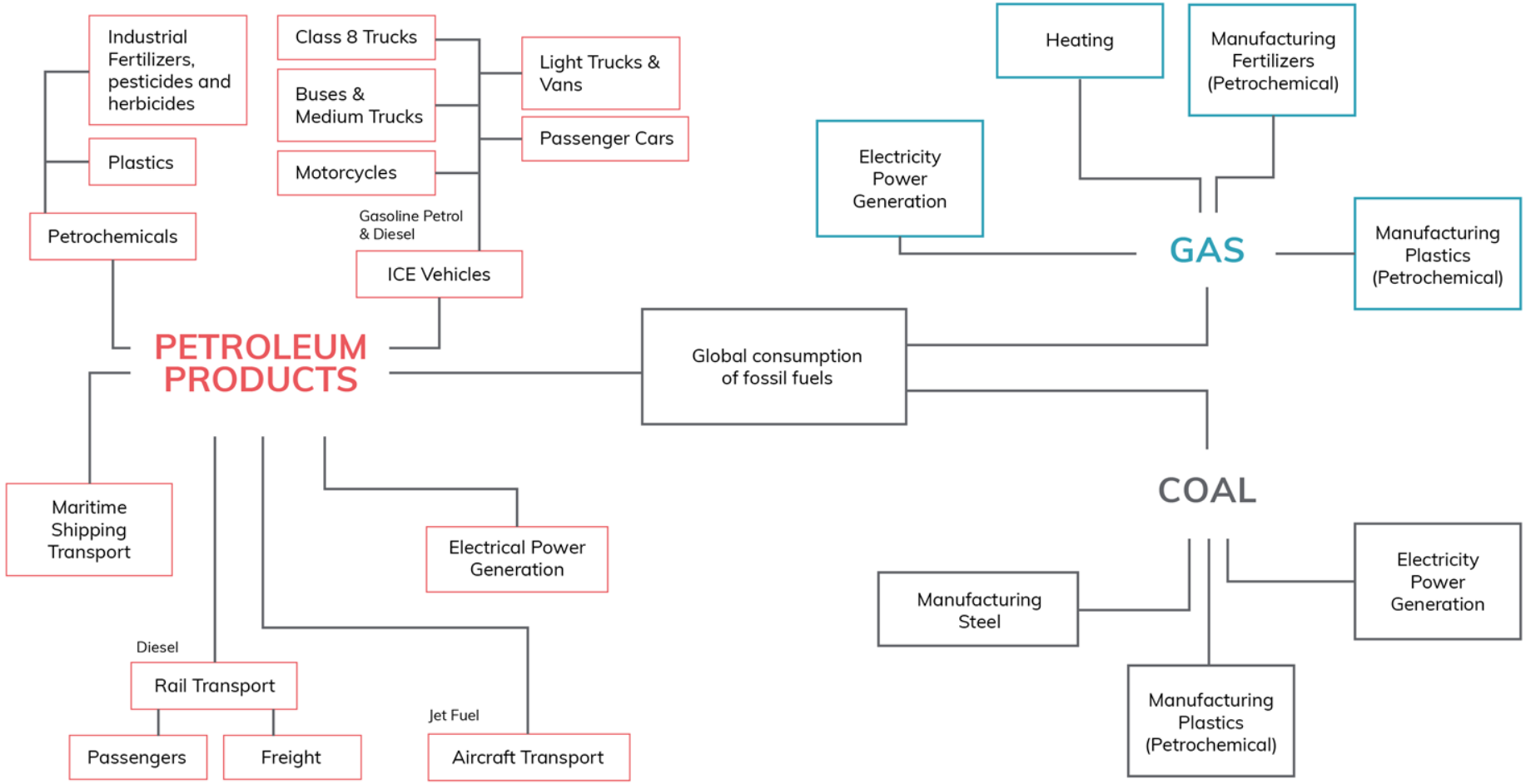
The renewable power sources require extensive mineral resources to manufacture the infrastructure for fossil-free energy.



Global challenge

Fossil fuels are to be phased out as they are widely recognized to be the origin of the industrial pollution that causes global warming. The largest driver of the warming is greenhouse gas emissions, of which more than 90% are carbon dioxide (CO2) and methane.

Burning fossil fuels for energy consumption is the main source of CO2 emissions



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There is a general plan to phase out fossil fuels

1.

Replacing all fossil fuel-based Internal Combustion Engine (ICE) vehicles with Electric Vehicle Technology (EVT)

- Lithium-ion batteries
- Hydrogen Fuel cells (H2-Cell)

2.

Phasing out coal and gas-fired electrical power generation

- Solar photovoltaic, wind turbine, hydroelectric, nuclear, geothermal or biowaste

The general plan to phase out fossil fuels means four major tasks

1.

Replacing current vehicles with electric and hydrogen vehicles

- Lithium-ion batteries
- Hydrogen Fuel cells (H2-Cell)

2.

Phasing out coal and gas fired electrical power generation

- Solar photovoltaic
- Wind turbine
- Hydroelectric
- Nuclear
- Geothermal or biowaste

3.

Heating buildings without the use of gas or coal

- Electrical heating systems
- Geothermal systems

4.

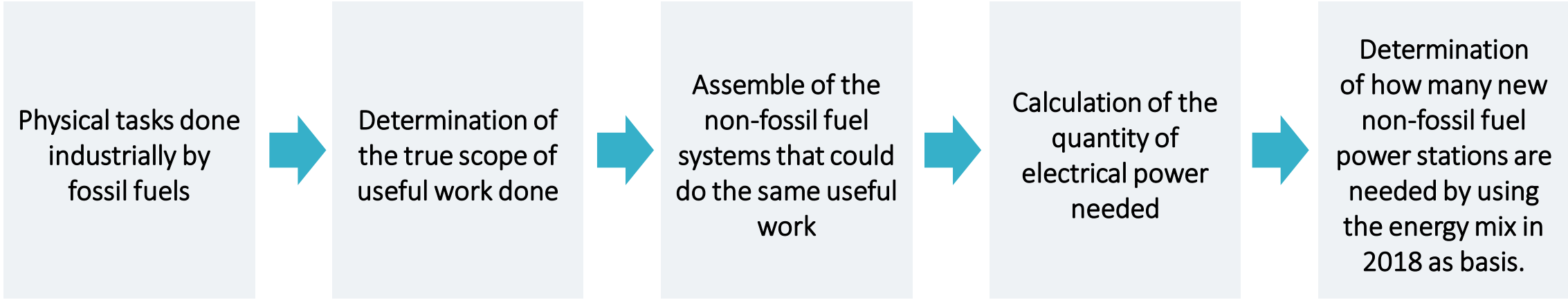
Creating a hydrogen economy

- Extra electricity to produce hydrogen with electrolysis

A wake-up call

Geological survey of Finland examined how many electric vehicles, H-cells, biofuels, solar panels, hydro, biomass to waste, wind turbines and extra nuclear power capacity would be needed to completely phase out fossil fuels from the existing energy system.

We developed a bottom-up calculation to determine what would be required to fully replace the existing fossil fuel supported global system



Previous studies have focused on estimated costs of production and CO2 footprint metrics, whereas the GTK report is based on the physical material requirements.

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 number and size of the required batteries/hydrogen cells/solar panels/wind turbines

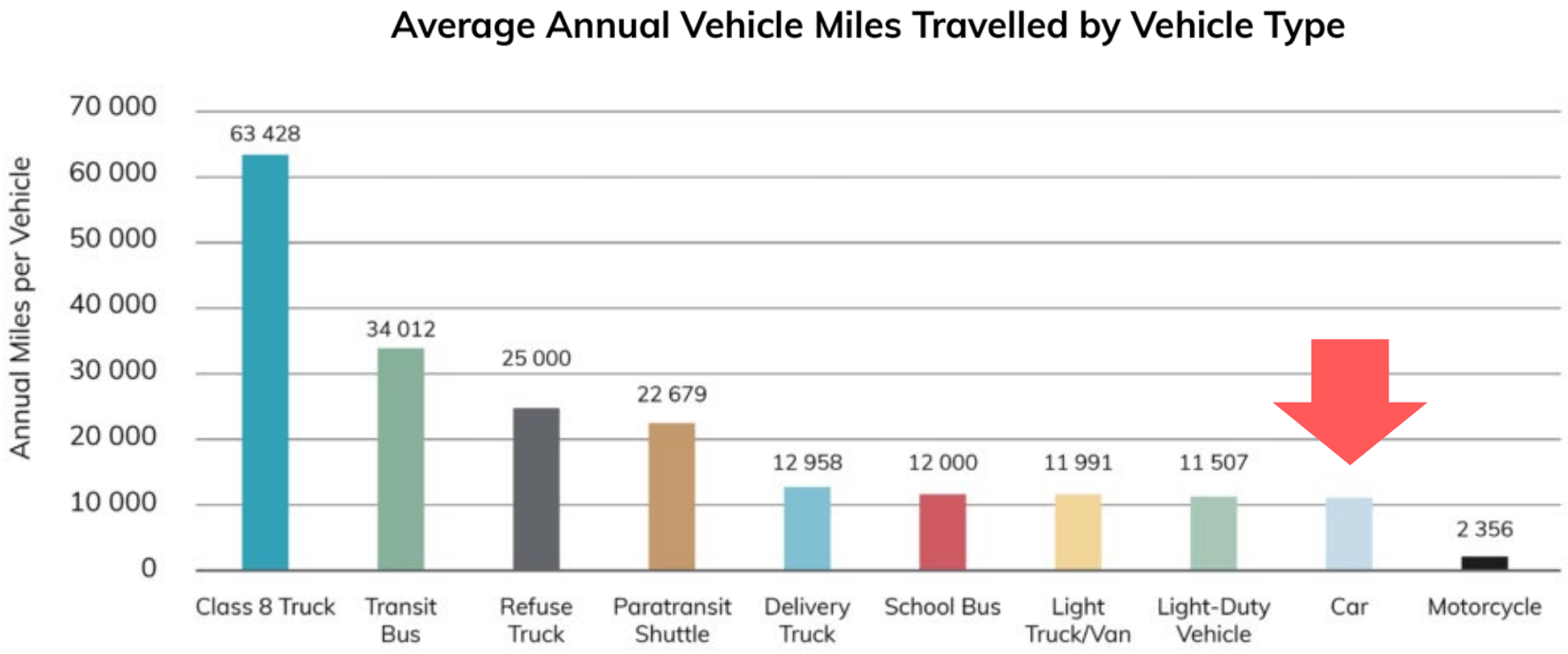
- In what proportional mix?
- In 2018, 84.5% of global primary energy consumption was fossil fuel based

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

During the research it was noted that previous studies had produced a lower estimate of the size of the required electrical power grid.

Previous studies had examined only part of the requirements for a new global system



- Either the study was limited to one nation or only examined passenger cars, and did not include trucks, rail, or maritime shipping.
- The need for stationary power storage to act as a buffer for intermittent electricity supply did not seem to be considered in estimates for battery volumes.

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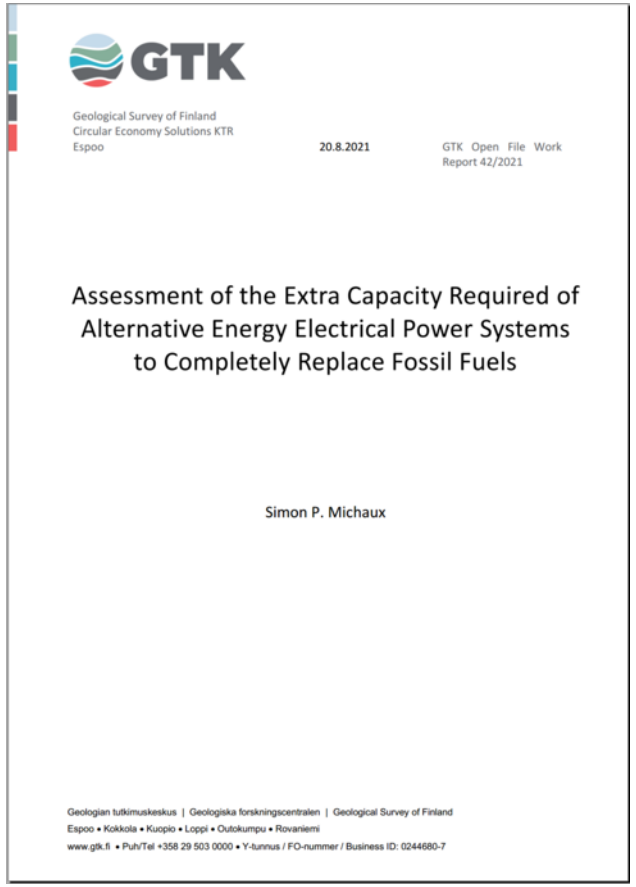
GTK research took a larger scope

- 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 power plant (NPP) fleet
- Assessment of the feasibility of global scale biofuels
- Plastics & fertilizer industries


GTK

Geological Survey of Finland
Circular Economy Solutions KTR
Espoo

20.8.2021

GTK Open File Work Report 42/2021

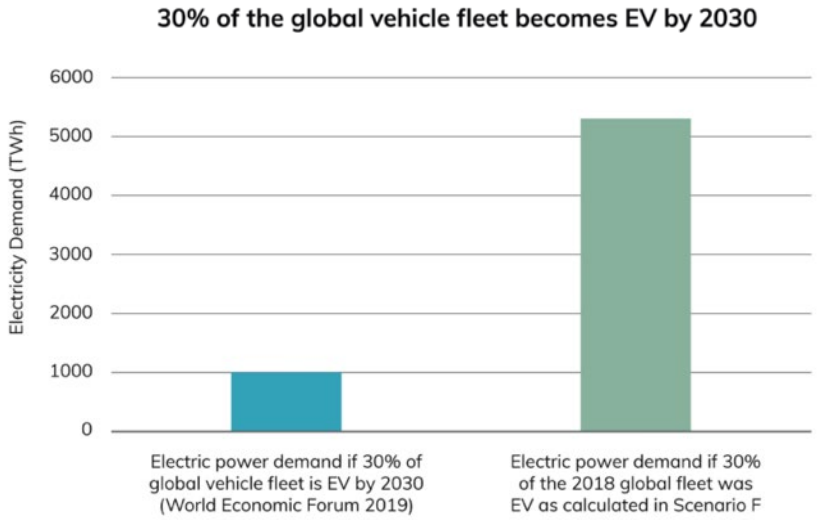
Assessment of the Extra Capacity Required of Alternative Energy Electrical Power Systems to Completely Replace Fossil Fuels

Simon P. Michaux

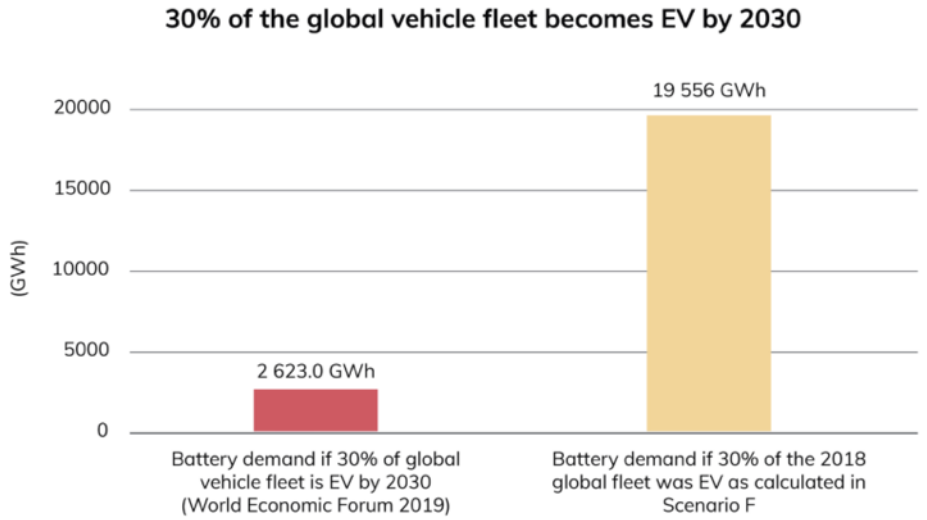
Geologian tutkimuskeskus | Geologiska forskningscentralen | Geological Survey of Finland
Espoo • Kokkola • Kuopio • Loppi • Outokumpu • Rovaniemi
www.gtk.fi • Puh/Tel +358 29 503 0000 • Y-tunnus / FO-nummer / Business ID: 0244680-7

Current thinking underestimates the scale

Current projections of the **required electric power** demand to charge EV batteries vs GTK scenario



Current projections of the **required battery to be manufactured** demand vs GTK scenario



The current policy targets hope to have 30% of the global energy and transport system to be renewable by 2030. Unfortunately, the report data indicates that we do not have time to deploy this strategy.

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Time to discuss

Our research points out that the real challenge is how to produce enough of these substitute non-fossil systems to perform the same tasks as before, on a global scale.

The key challenges in the current plan

Unrealistic schedule

The current plan

- Not large enough in scope
- Missing vital elements
- Does not consider how the different non-fossil fuel transport systems might interrelate.

Smaller capacity

The planned future non-fossil fuel energy system may well be smaller in capacity than the current fossil fuel supported energy system, due to practical constraints.

Lack of minerals

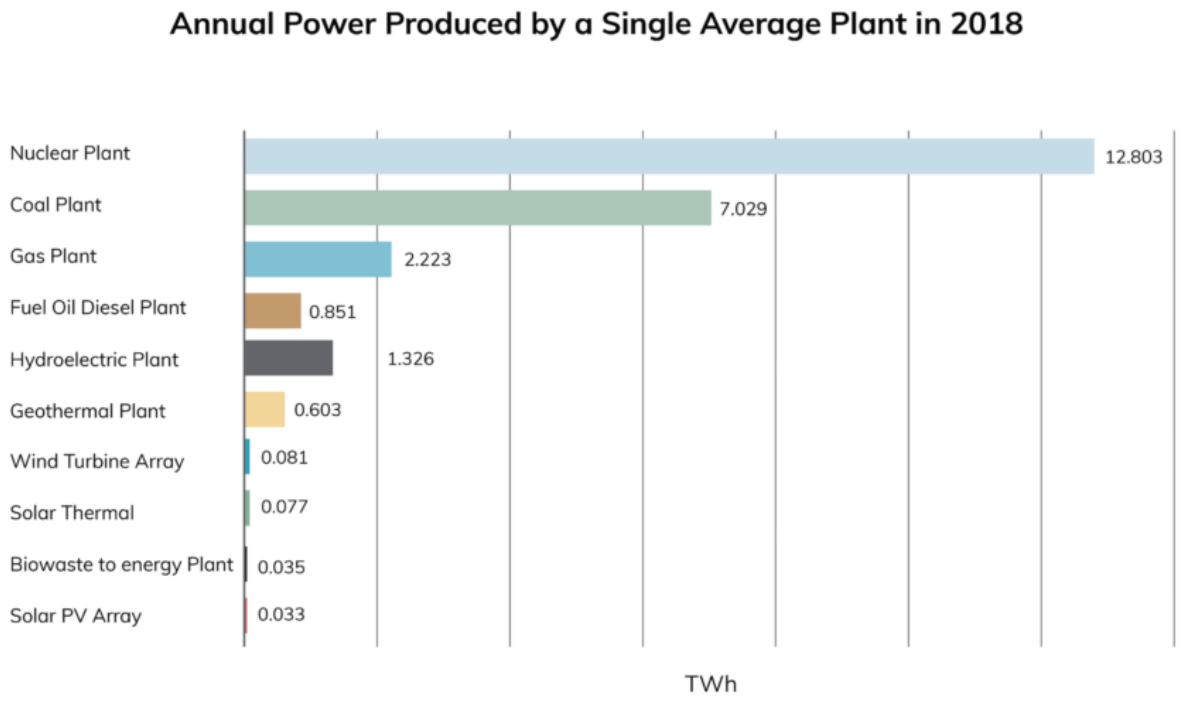
There is not enough lithium, cobalt or nickel in our currently reported global mineral reserves to produce just one generation of batteries, to phase out and replace the current existing ICE transport fleet and fossil fuel power generation systems.

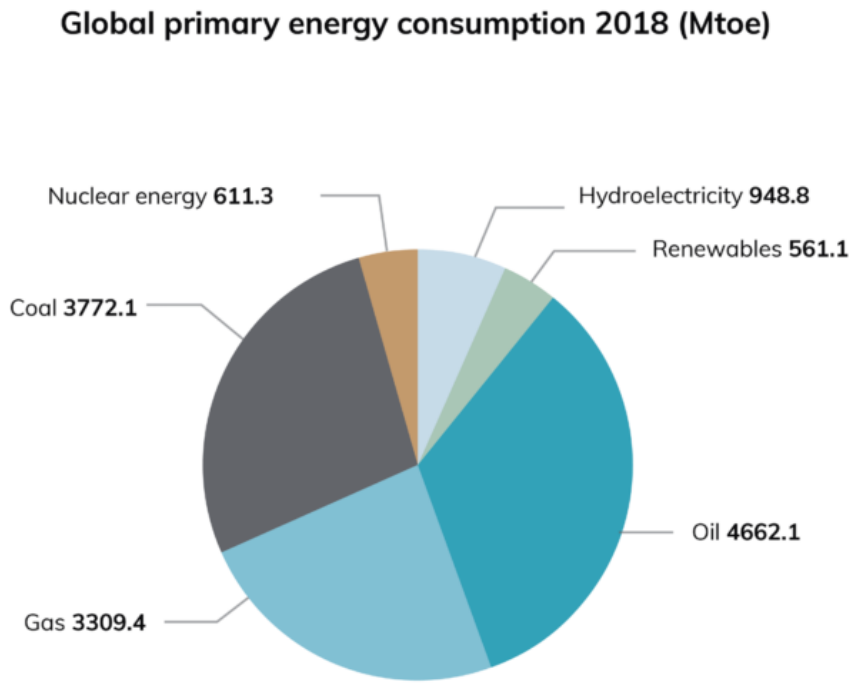
Non-scalability

Biofuel and Biomass are needed but they cannot be scaled-up.

The nuclear power plant (NPP) fleet cannot be expanded fast enough to be the primary energy source for the global industrial ecosystem


Smaller capacity: The renewable energy power stations are not as productive as fossil fuel power stations





To phase out fossil fuels requires a reliable energy source (an ERoEI ratio of 50:1 or even higher) that is available to most of the human population.

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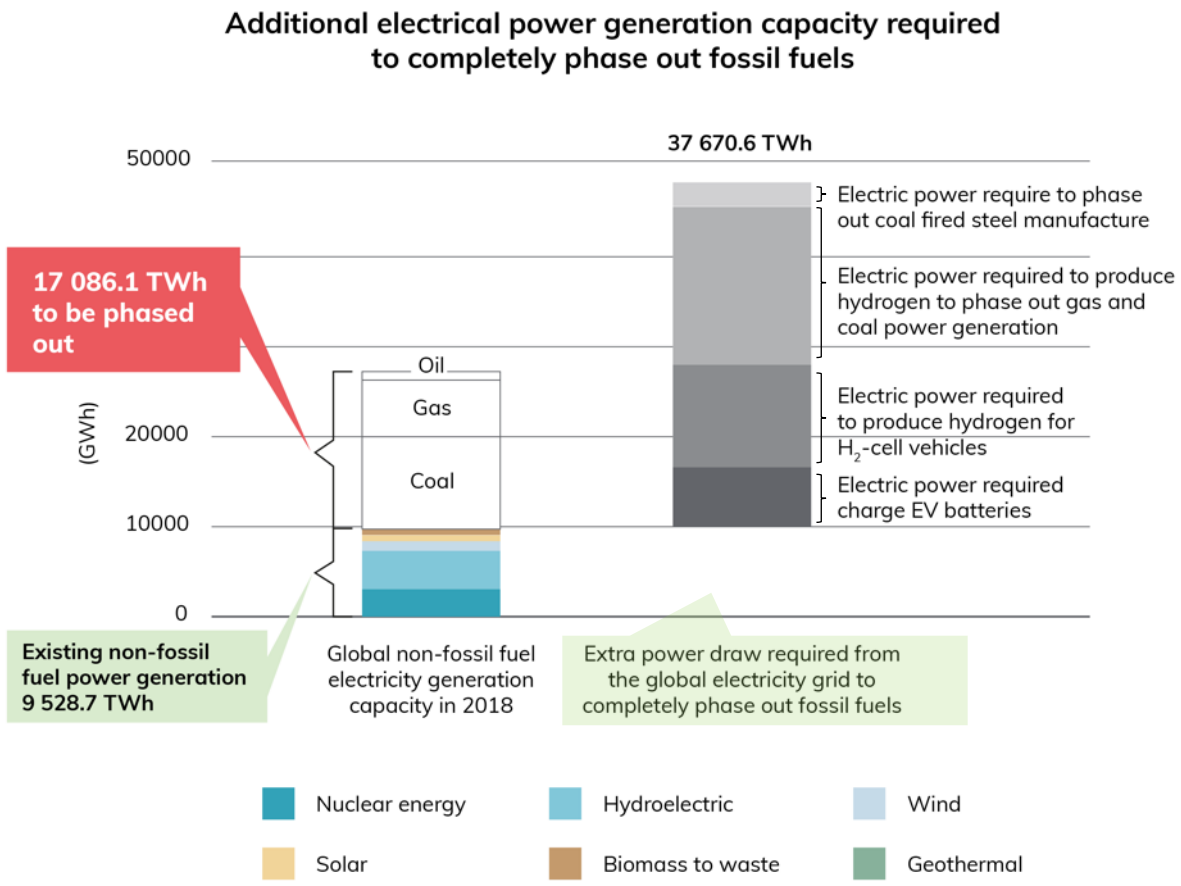
As most of the planned non-fossil substitute technologies are less efficient, we need more capacity

- Total electrical power production in 2018 was 26 614 TWh
- Additional electrical power generation would need 221 594 NEW non-Fossil Fuel Power Stations
- To put this in context, the total power plant fleet in 2018 was only 46 423 stations (all types including fossil fuel plants)



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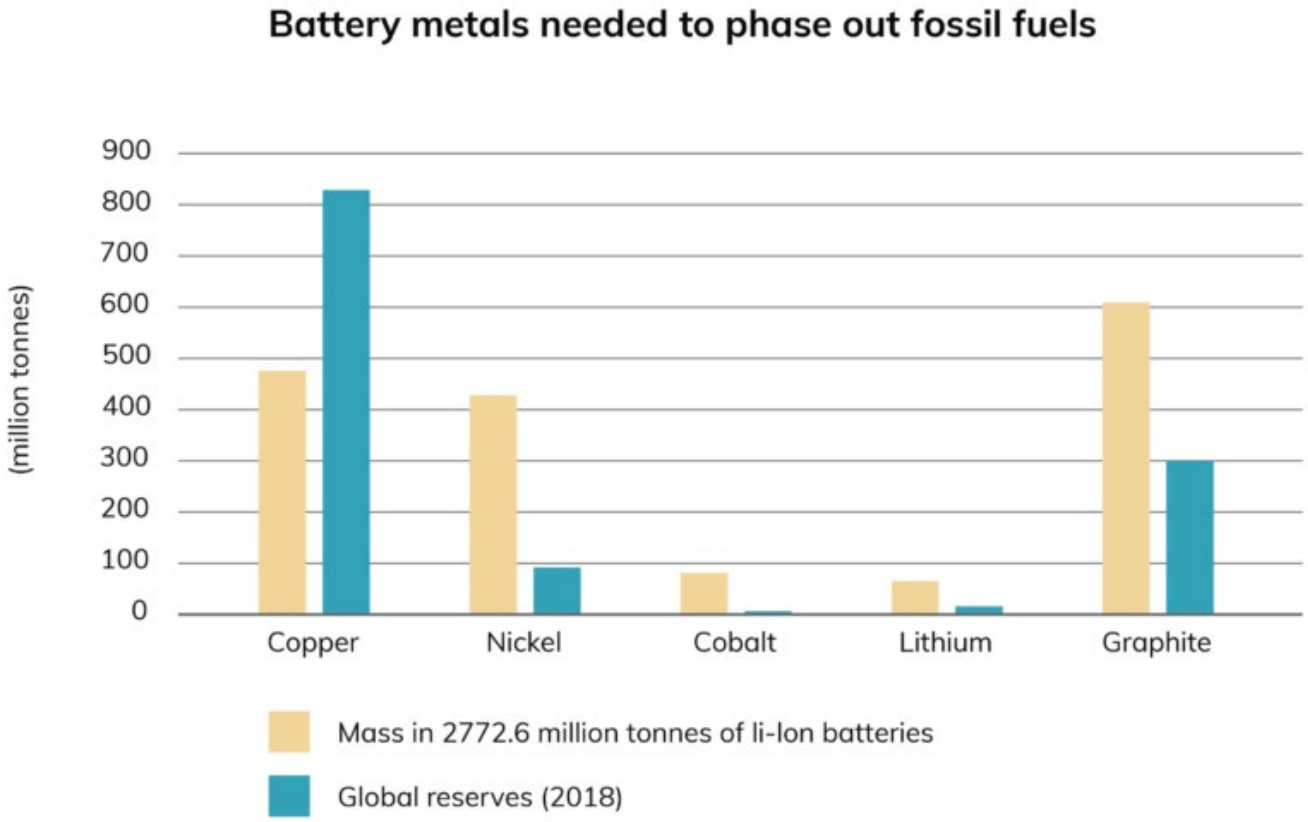
Lack of minerals: The currently reported global mineral reserves are not enough for all EV's and stationary power storage

- The current paradigm is to focus exclusively on lithium- ion battery chemistry, to the exclusion of all other possible chemical systems that could be resourced with different minerals.
- In 2019, only 0.51% of the global fleet was currently electric, which means that 99.49% of the global fleet is yet to be replaced.



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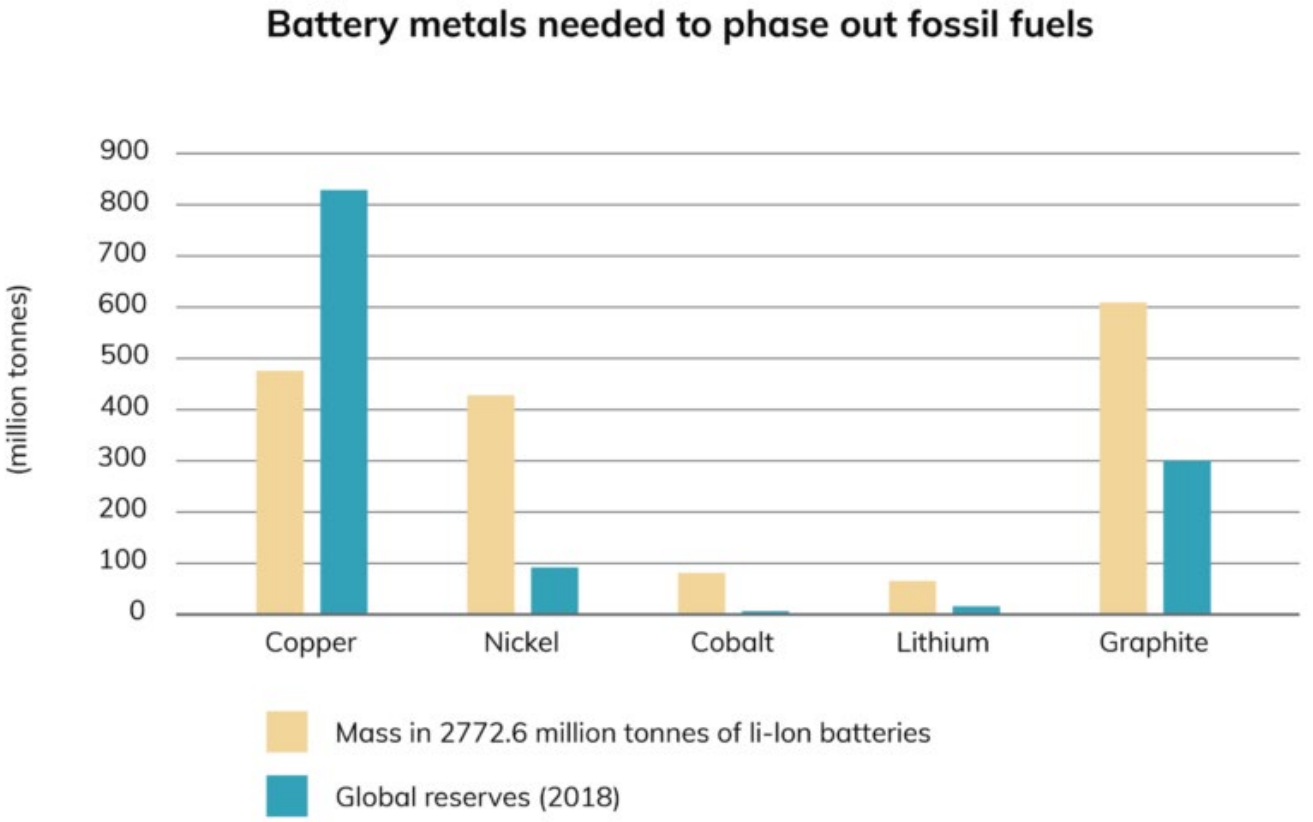
Unrealistic schedule: It takes about 20 years to develop a discovered deposit into a mine

- Currently for every 1000 deposits discovered, only 1-2 become mines
- For every 10 mines,
  2-3 lose money and shut down
- Ore grades are decreasing
- Energy consumption in mining is increasing per unit of metal
- Potable water consumption in mining is increasing per unit of metal



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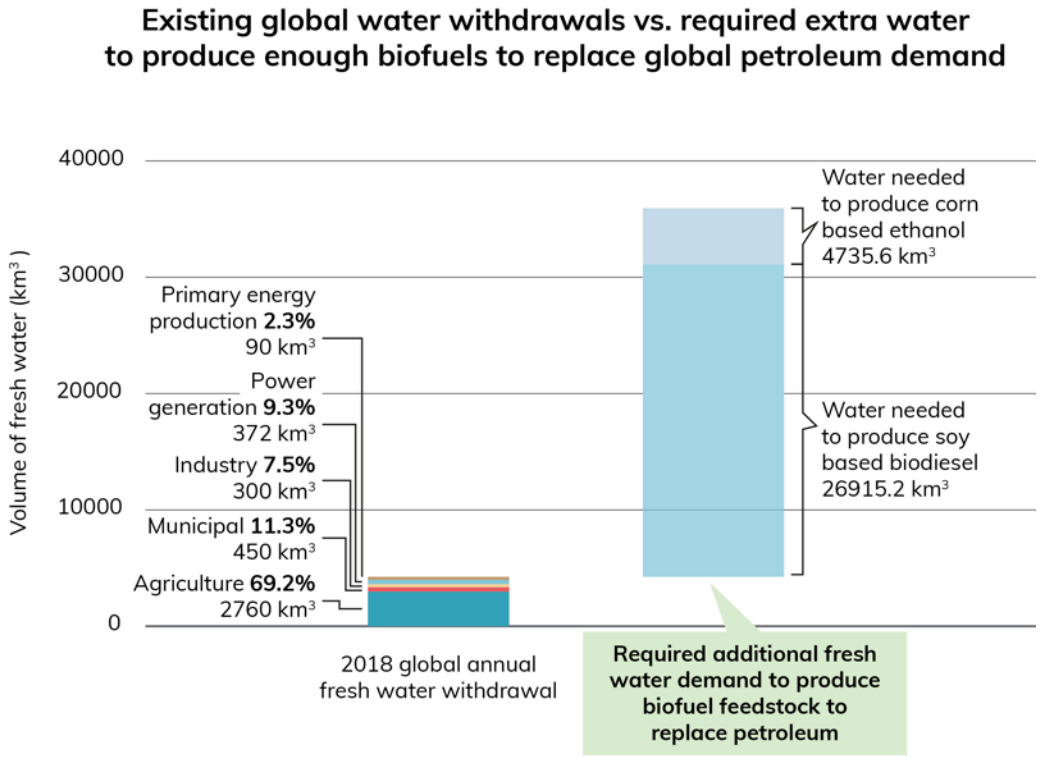
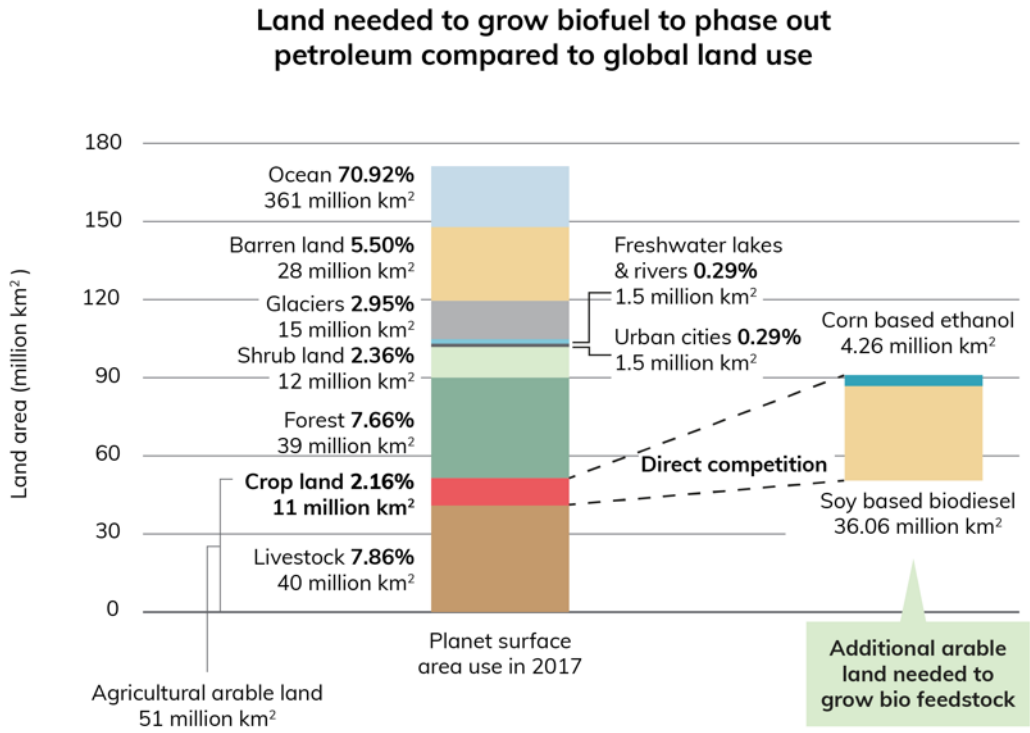
Non-scalability: Biofuel and Biomass are needed but cannot be scaled-up





The footprint of the proposed biofuel production to substitute petroleum product consumption far exceeds the planetary environmental capability.

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There is no scale solution that can replace gas in the industrial fertilizer manufacturing

Could food production be reorganized to be supplied from several small-scale organic farming operations?

Is it time to restructure society and the industrial ecosystem to consume less?

The good news

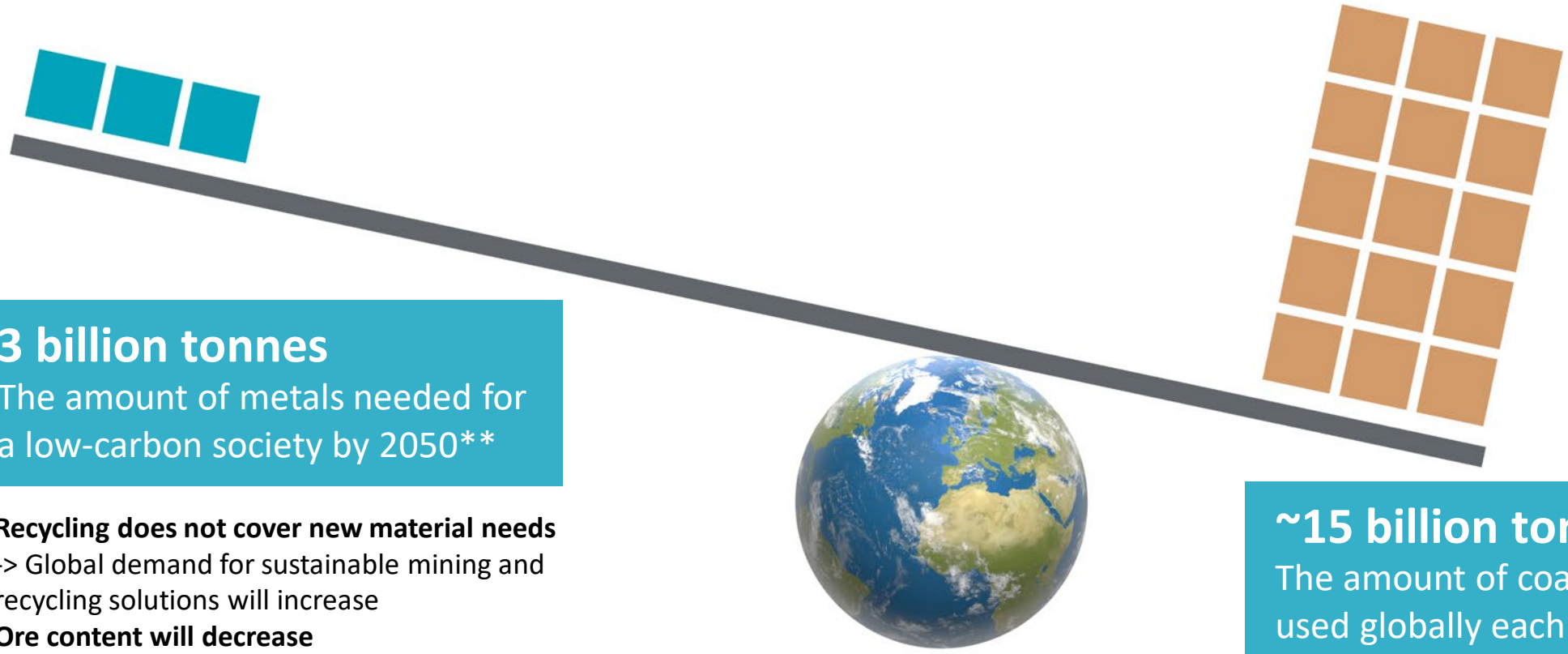
Regardless of the challenges, non-fossil fuel system substitution for the current ICE technology is technologically viable.

The ultimate challenge is to produce enough of the substitute non-fossil systems to perform the same tasks as before, on a global scale.

- There is enormous potential in the **secondary materials** like furnace ash, smelter slag and the industrial process dust.
- A fleet of **hydrogen fuel cell powered transport** network could be useful in parallel to the electric vehicle fleet.
- **Biofuels** may be the most sensible way to keep aviation going.
- **Biomass** can be used to produce bioplastics, replacing a proportion of the existing plastics industry.
- In the manufacturing industry, remaining hydrocarbon energy could be used to secure the time to develop the new industrial ecosystem.
- **Nuclear power** can be expanded moderately from the current capacity to support some industrial operations and heating buildings.

Summary and conclusions

Metals boost the low-carbon society



3 billion tonnes

The amount of metals needed for a low-carbon society by 2050**

- **Recycling does not cover new material needs**
  -> Global demand for sustainable mining and recycling solutions will increase
- **Ore content will decrease**
  -> enrichment processes are key in the development of material, chemical, water and energy efficiency and mimimizing environmental damage

GTK Mintec

~15 billion tonnes

The amount of coal, oil and gas* used globally each year

- Phasing out fossil fuels will open up many new material needs
- The impacts of emissions are global, the impacts of metal mining are local

* Gas turned into tonnes of oil equivalent (TOE) in the calculation

**The Beyond 2 Degrees Scenario (B2DS): Aims to limit with a 50% chance global temperature rise to 1.75°C. above pre-industrial levels. (Hund, K., La Porta, D., Fabregas, T.P., Laing, T. & Drexhage, J. 2020.)

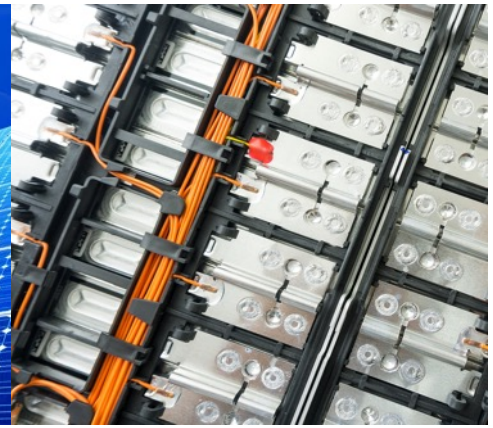
Conclusions: To phase out fossil fuels

37 670.6 TWh
additional non-fossil fuel electrical power annual capacity

The same non-fossil fuel energy mix of 2018 translates into 221 594 new power plants

46 423
Power plant fleet in 2018 including all types

221 594
New power plants needed



4 weeks
buffer of power

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.

573.4 TWh
storage buffer capacity for the global electrical power system

5.7 million
100 MW stations

2.78 billion tonnes
the total mass of lithium-ion batteries required to phase out fossil fuels

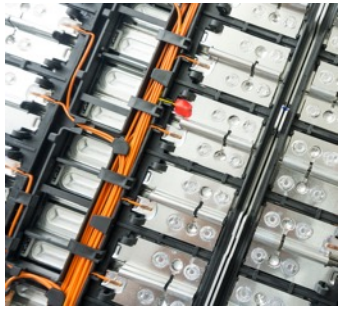
Conclusions: To phase out fossil fuels

Current thinking has seriously underestimated the scale of the task ahead

Biofuels cannot be scaled up to replace petroleum.

Nuclear is vital to keep industry going but can't be scaled up to be the only energy source

Biofuels may be the only way to power aviation and plastics.



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

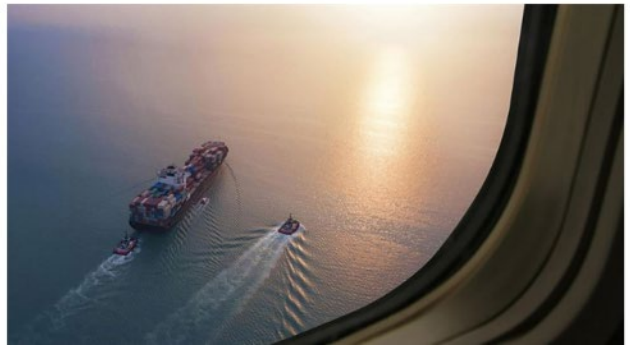
Metals of all kinds are about to become much more valuable -> Evolution of the industrial ecosystem and its market is likely. There is a coming Renaissance for the exploration for and mining of minerals

There is hope as well as good going in many industries

17 May 2022

Neste introduces co-processed marine fuel in partnership with Nordic Marine Oil – a new solution for the maritime sector enabling up to 80% GHG emission reduction

Published in Releases and news under Renewable solutions, Marine
Neste Marine, Neste Marine 01 Co-processed



The world's first fossil-free steel ready for delivery

AUGUST 18, 2021 15:00 CEST 6 MIN READ

SSAB has now produced the world's first fossil-free steel and delivered it to a customer. The trial delivery is an important step on the way to a completely fossil-free value chain for iron- and steelmaking and a milestone in the HYBRIT partnership between SSAB, LKAB and Vattenfall.

01 APR GTK IS INVESTING SIGNIFICANTLY TO RENEW THE GTK MINTEC PILOT PLANT

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The Geological Survey of Finland (GTK) is investing significantly to renew the GTK Mintec pilot plant located in the Outokumpu town, North Karelia. The GTK Mintec pilot plant is one of the most comprehensively equipped mineral processing pilot plants in the world. To strengthen the position as a world leader in mineral processing research, some of the most significant investments are listed below.

Metal-free batteries could make the industry more ethical and sustainable

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

Vuorimiehentie 2
02151 Espoo, Finland

simon.michaux@gtk.fi
+358 50 348 6443
gtk.fi/en/time-to-wake-up


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