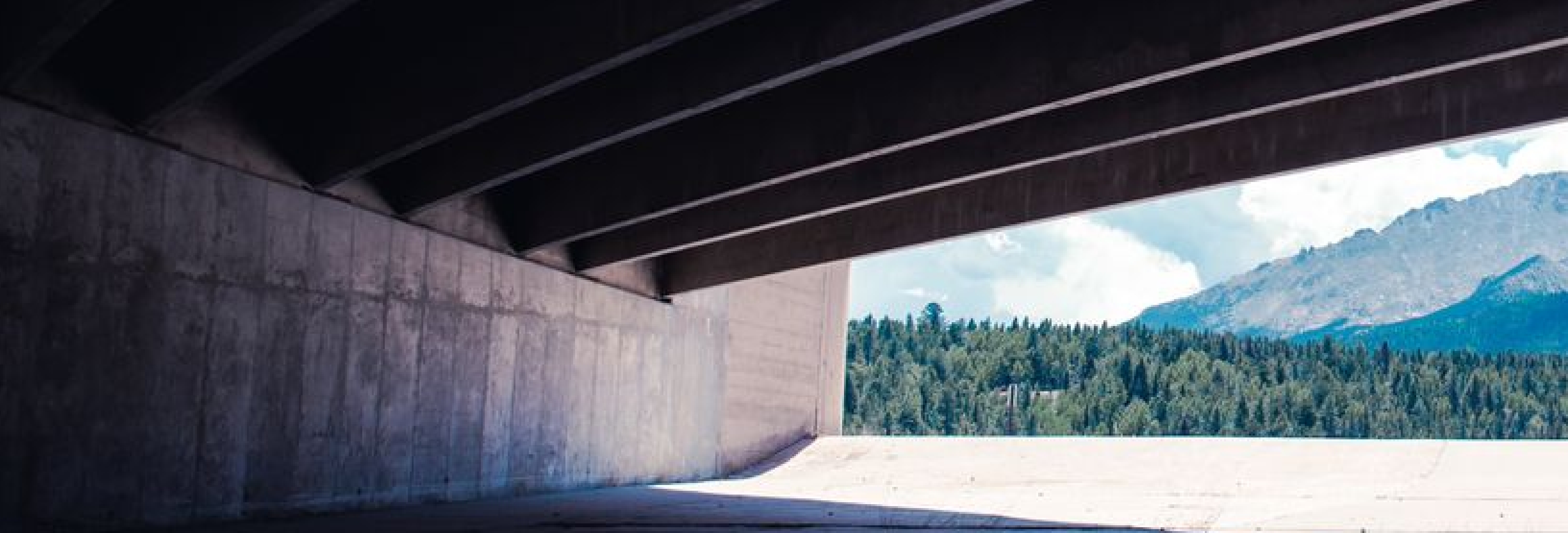
# PULLING BACK THE CURTAIN ON THE ENERGY TRANSITION TALE

## WHY RENEWABLES CAN'T MATCH FOSSIL FUELS

## WHY THE ESPOUSED TECHNOLOGIES AREN'T RENEWABLE

## AND WHY THEY DON'T DELIVER ON SOCIAL JUSTICE



A WHITE PAPER BY

The REAL Green New Deal Project

AUTHORS

MEGAN K. SEIBERT

WILLIAM E. REES

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# Executive Summary

> The world's leadership is mainly advised by specialists who study only a part of the system at a time. Instead of the confusion that comes from western civilization's...approach of isolating variables in tunnel vision thinking, let us here seek common sense overview.
>
> Howard T. Odum
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> ENERGY, ECOLOGY, AND ECONOMICS

Part of the mission of The REAL Green New Deal Project (REALgnd) is to expand the scope of inquiry into renewable energy (RE) technologies from a holistic perspective. We begin that inquiry with an initial examination of the widely overlooked limitations of the RE technologies commonly put forth as solutions (which do not constitute all possible RE options). This examination shows that RE cannot deliver the same quantity and quality of energy as fossil fuels, that the espoused technologies are not renewable, and that producing them—particularly mining their metals and discarding their waste—entails egregious social injustices and significant ecological degradation. From this, we conclude that the narrative of business-as-usual with a technological fix is not possible and that scale-back, transformation, and a re-assessment of RE options is needed.

It should be emphasized that comparisons to fossil fuels are not meant as an endorsement of their continued use—indeed, REALgnd advocates for their abolition—but rather as a baseline against which to assess whether RE technologies can match their output and versatility.

The challenge with assessing RE is to identify which technologies are both sustainable and viable. Sustainability means that it can persist in perpetuity within ecological limits with minimal negative environmental impacts. Viability examines basic, practical issues for production and implementation.

Within this context, the pat slogan "100% clean energy" must be dispelled. Every energy producing technology—no matter how rudimentary or advanced—uses inputs from the environment and produces some amount of pollution or ecological degradation over the course of its life. Trade-offs must be assessed. Just because sunlight and wind are renewable and clean doesn't mean that harnessing them to perform work is.

This paper shows that claims about transitioning our entire energy system at current levels of consumption and types of energy use (electricity versus liquid fuel) are impossible to deliver. While we inevitably face a future underpinned entirely by renewable energy, the question isn't how to meet current demand in its current form (we can't) but rather to determine: 1) which RE technologies are sustainable and viable, 2) the contexts in which they might be so, and 3) how we might most effectively and fairly reduce energy demand, recognizing that the key levers to pull on are population size and per capita consumption.

Here we take a first step at pulling back the curtain, shining a light on wild claims, and attempting to understand sustainability and viability with eyes wide open.

“ The green dream only seems clean if we first sharply narrow our focus (to one CO2 output metric) and then proceed to disregard absolutely every other well-established and documented side effect, limitation, and long-term risk. ”

*Ozzie Zehner*

GREEN ILLUSIONS

“ We must resist the temptation to only examine innovations at their point of deployment or use. We need to instead critically assess the entire lifecycle or ‘whole system,’ from the front end where metals and minerals are extracted to the back end where waste streams reside. ”

*Sovacool, Hook, Martiskainen, Brock, and Turnheim*

THE DECARBONIZATION DIVIDE

Only 19% of global energy consumption is in the form of electricity. The other 81% is in the form of liquid fuel for transportation and other uses (1). In the U.S., electricity accounts for about 17% of energy consumption (2).

**There are insurmountable obstacles to converting even just electricity consumption alone to renewables.**

The breakdown of U.S. electricity generation in 2020 was (3):

60.3% fossil fuels
19.7% nuclear
8.4% wind
7.3% hydro
2.3% solar
1.4% biomass
0.4% geothermal

1. Total Final Consumption (TFC) by Source, World 1990-2017 (IEA)
2. U.S. Energy Consumption by Source and Sector, 2019 (USEIA)
3. What is U.S. Electricity Generation by Source? (USEIA)

# BIG PICTURE SANITY CHECK

To provide global electricity consumption from solar panels, the solar cells would cost about $11 trillion. The mining, processing, and manufacturing facilities to build them would cost about $8 trillion. The batteries to store power for evening use would cost $4 trillion. Bringing the total to about $23 trillion. Plus about $125 billion per year for maintenance. Actual installed costs for a global solar program would cost roughly $252 trillion—about thirteen times the United States GDP. Mining, smelting, processing, shipping, and fabricating the panels and their associated hardware would yield about 27,000 megatons of CO2. And everyone would have to move to the desert, otherwise transmission losses would make the plan unworkable (1).

Transitioning the U.S. electrical supply alone away from fossil fuels by 2050 would require a grid construction rate 14 times that of the rate over the past half century (2, 6).

A June 2020 report from the Goldman School of Public Policy at U.C. Berkeley describes how the U.S. can virtually liberate its electricity sector from fossil fuels by 2035 (3). It says that "to achieve the 90% Clean case by 2035, 1,100 GW of new wind and solar generation must be built, averaging about 70 GW per year." What would this require?

- If we assume wind and solar split the burden evenly, that's 35 GW of new wind and 35 GW of new solar that needs to be built every year until 2035.
- Wind: the U.S. added 9.1 GW of wind capacity in 2019 (4). This is 26% of the 35 GW of annual additional capacity called for in the report. So, the U.S. would have to quadruple its last annual construction of wind turbines every year for the next 15 years.

- Solar: the U.S. added 13.3 GW of solar PV capacity in 2019 (5), which is 38% of the new annual capacity called for in the report. This means that the U.S. would have to roughly triple its last annual construction of solar PV every year for the next 15 years.

But remember –

- Wind turbines last as little as 15 years and solar panels have an average lifespan of around 25 years, so about when the build-out is complete, we would have to start all over—which we're already doing, since the first generation of wind turbines are now reaching the end of their operational lives.

- This only covers the conversion of U.S. electricity production, ignoring the other 83% of liquid fossil fuel use.

Despite shortcomings of their own, Clack *et al.* found that one of the most cited studies on 100% electrification in the U.S. is laden with untenable assumptions and modeling errors (6), and Heard *et al.* show that all energy transition studies ignore or fail to adequately account for transmission dynamics, including grid expansion, frequency control, and voltage management (7).


1. Green Illusions (Zehner), p. 9 (adjusted to reflect electricity consumption only)
2. The New Energy Economy: An Exercise in Magical Thinking (Mills), p. 6
3. The 2035 Report (University of California Berkeley)
4. 2019 Was the U.S. Wind Industry's Third Strongest Installation Year (Windpower)
5. The US Added 13.3 GW of Solar in 2019, Beating New Wind and Gas Capacity (PV Magazine)
6. Evaluation of a Proposal for Reliable Low-Cost Grid Power With 100% Wind, Water, and Solar (Clack et al.)
7. Burden of Proof: A Comprehensive Review of the Feasibility of 100% Renewable-Electricity Systems (Heard et al.)

# HEAT FOR MANUFACTURING

All manufacturing processes used today—which are responsible for making solar panels, high-tech wind turbines, and batteries, not to mention all other modern technologies—involve very high temperatures that are currently generated using fossil fuels. Despite the critical importance of heat in manufacturing, there is scant little information on how it can be generated with RE alone.

**30%** of industrial heating applications require temperatures below 212˚F (100˚C)

**27%** can be met with heat between 212˚ and 750˚F (100˚C and 400˚C)

**43%** require temperatures above 750˚F (400˚C) (1)

As pointed out in subsequent sections, solar panel manufacturing requires temperatures in the range of 2,700˚F to 3,600˚F (1,480˚C to 1,980˚C), and manufacturing the steel and cement that comprise high-tech wind turbines requires temperatures ranging from 1,800˚F to 3,100˚F (980˚C to 1,700˚C).

According to the U.S. EPA, most existing RE heating technologies can supply heat within the lowest indicated temperature range (1).

Natural gas, petroleum, electricity, and coal are the current sources of industrial energy, with natural gas and petroleum being predominant (2). Problems abound with all potential RE replacements for high-heat industrial manufacturing, which include bioenergy, hydrogen, geothermal, nuclear, concentrated solar power (CSP), solar PV, and wind.

## POSSIBLE REPLACEMENTS FOR NATURAL GAS

### Biomethane

Biomethane is a near-pure source of methane derived from one of two methods: the "upgrading" of biogas or gasified woody biomass. Biogas is a mixture of gases that results from the breakdown of agricultural, livestock, and household waste; sewage in wastewater treatment plants; and municipal waste. Gasification entails heating wood in a low oxygen environment to produce synthetic gas, or syngas. The upgrading process involves removing all gases in the biogas and syngas except for methane.

Biogas upgrading accounts for roughly 90% of all biomethane production, and all five commercially viable processes have disadvantages, if not outright roadblocks.

- The polyethylene glycol used in one type of physical scrubbing is a derivative of petroleum, and the other form of water-based physical scrubbing requires significant amounts of water and electricity (3-4).

- Chemical scrubbing involves toxic solvents that are costly and difficult to handle, and it has a high heat demand (3-5).

- Despite low energy and financial inputs (3), membrane separation involves fragile and short-lived membranes (lasting 5-10 years) (5) and produces relatively low methane purity (3).

- Pressure swing adsorption is a highly complex process (3),(5), and neither cryogenic separation nor biological methods are yet commercially viable (5-6).

- Not all upgrading technologies are energetically self-sufficient—many, if not most, rely on FF (4).

- Upgrading biogas produces $CO_2$ (4-5). Carbon capture and storage is one proposal for dealing with the resulting $CO_2$ but presents ecological problems and high costs (4).

- Gasification is not yet deployed at a large industrial scale (6).

There are addition problems with feedstock and co-location requirements.

- Current waste streams are insufficient to support the widespread use of biomethane in the transportation sector, let alone the industrial sector (7). It is estimated that the maximum practical contribution of biomethane via biogas and gasification is only around 11% of Europe's current total natural gas consumption (6).

- Harvesting woody biomass for gasification would have to be judiciously considered within the broader context of its sustainable management.

- Given the post-FF transportation limitations discussed later, biomethane production facilities would have to be co-located with feedstock sites, which would then have to be co-located with manufacturing sites.

Hydrogen

The single greatest problem with producing hydrogen is that, regardless of method, more energy is required to produce and compress the product than it can later generate (8-11).

The only viable, large-scale feedstock for hydrogen is natural gas, and the gas reforming process requires temperatures ranging from 1,300˚F to 1,830˚F (700˚C to 1,000˚C) (9-12). Gas reforming produces substantial greenhouse gas (GHG) emissions and presents numerous problems in the way of leakage, corrosion, and accidental combustion (8-9, 12).

## POSSIBLE REPLACEMENTS FOR PETROLEUM

Options include bioethanol (ethanol made from corn or other fermented plant matter) and biodiesel. As discussed later, the land requirements for feeding 8+/- billion people without FF inputs preclude the large-scale use of cropland and plant biomass for energy purposes, even if net energy were satisfactory.

## POSSIBLE REPLACEMENTS FOR ELECTRICITY

Geothermal

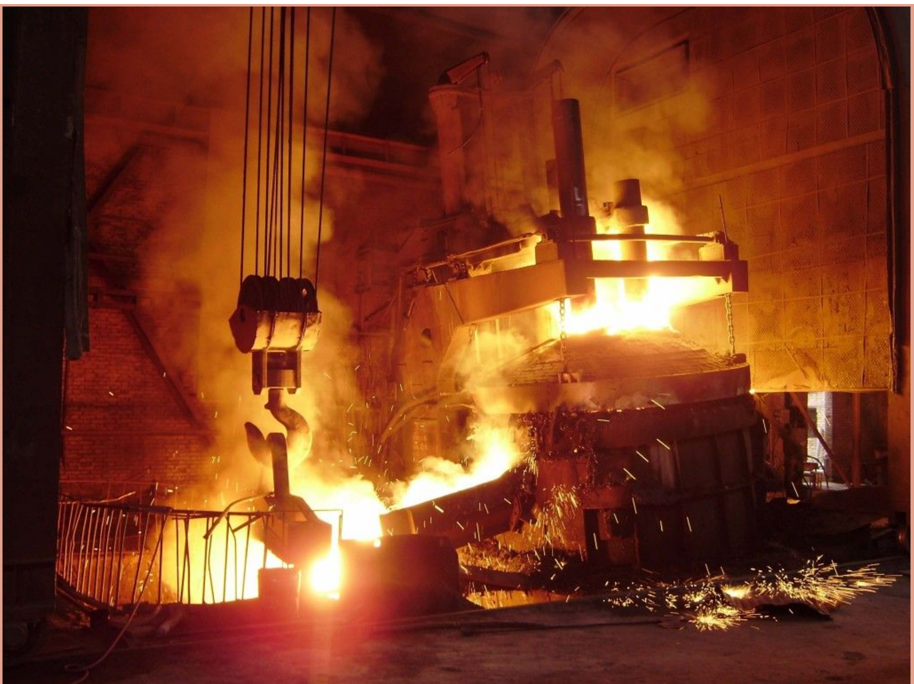
Geothermal systems produce temperatures of around only 300˚F (150˚C) and must be located in mountainous regions with active tectonic plate movement or near volcanic hot spots (13).

Production wells are commonly up to two kilometers deep (13-14)—depths that can be reached only with fossil-fueled machinery and advanced technologies.

Nuclear

As discussed later, nuclear has massive water and material requirements.

Facilities cannot be built and maintained without fossil-fueled machinery.



There is the still-unsolved problem of dangerous radioactive waste disposal.

Much-touted small modular reactors (SMRs) are still in the R&D phase, still produce radioactive byproducts that must be disposed of, and pose the problem of transportability.

Concentrated solar power (CSP)

Despite theoretical upper temperature limits ranging from 1,800˚F to 2,200˚F (1,000˚C to 1,200˚C), existing CSP systems generate heat in the range of only 300˚F to 570˚F (150˚C to 300˚C) (8, 13).

CSP plants typically cost in excess of $1 billion and require around five square miles of land (10).

Though they can store thermal energy in molten salt, the on-site salt stores less than one day's worth of electrical supply and almost all CSP plants have fossil backup to diminish thermal losses at night, prevent the molten salt from freezing, supplement low solar radiance in the winter, and for fast starts in the morning (8, 10).

Solar PV and wind turbines

The DC electricity generated by solar PV and wind can only be stored in batteries, which presents serious ecological and practical problems, as discussed later.

**POSSIBLE REPLACEMENTS FOR COAL**

The only potential replacement for coal is charcoal derived from wood. This poses two obvious problems.

- The remaining stock of woody biomass—vastly depleted during the Industrial Age—is nowhere close to supporting current manufacturing needs, particularly recognizing the need to set aside half of Earth's major eco-regions to ensure the functional integrity and health of the ecosphere (15).

- Even if a sustainable supply of an already-stretched renewable resource were not a concern, industrial furnaces/boilers and steel manufacturing equipment are specifically designed to function with thermal coal and coke (made from coking coal); switching to charcoal would require the redesign and reconstruction of entire systems.

Such roadblocks impede the electrification of *all* manufacturing processes that don't already use electricity. Even so, there has been little R&D on massive electrification options.

Since most existing fossil-powered equipment would require complex, large-scale system re-designs, 100% electrification of manufacturing would be extremely difficult, if not impossibly expensive (9).


1. Renewable Industrial Process Heat (EPA)
2. Use of Energy Explained (EIA)
3. Technologies for Biogas Upgrading to Biomethane: A Review (Adnan et al.)
4. Environmental Evaluation and Comparison of Selected Industrial Scale Biomethane Production Facilities across Europe (Lozanovski et al.)
5. Biogas Upgrading and Utilization: Current Status and Perspectives (Angelidaki et al.)
6. Biomethane: Production and Applications; Green Energy and Technology (Koonaphapdeelert et al.)
7. Economic Potential for Substitution of Fossil Fuels with Liquefied Biomethane in Swedish Iron and Steel Industry (Ahlström et al.)
8. Low-Carbon Heat Solutions for Heavy Industry- Sources, Options, and Costs Today (Columbia SIPA CGEP)
9. Industrial Heat Decarbonization Roadmap (ICEF) (sandalow)
10. When Trucks Stop Running (Friedemann)
11. Green Illusions, p. 106
12. Hydrogen Fever 2.0 (I) (Turiel)
13. Generation and Use of Thermal Energy in the U.S. Industrial Sector and Opportunities to Reduce its Carbon Emissions (JISEA)
14. Renewable Energy Options for Industrial Process Heat (ARENA)
15. Nature Needs Half

# SOLAR

Manufacturing solar panels uses toxic substances—not to mention lots of energy and water—and produces toxic byproducts (1-2).

## MONO- AND POLY-CRYSTALLINE SOLAR PANELS

High temperatures are needed at every step of the way. For example, temperatures of around 2,700° to 3,600°F (1,500° to 2,000°C) are needed to transform silicon dioxide into metallurgical grade silicon (3).

Up to half of the silicon is lost in the wafer sawing process.

For every 1 MW of solar produced (4):

- About 1.4 tonnes of toxic substances are used, including hydrochloric acid, sodium hydroxide, sulfuric acid, nitric acid, and hydrogen fluoride.
- About 2,868 tonnes of water are used.
- About 8.6 tonnes of emissions are released, 8.1 of which are the perfluorinated compounds sulfur hexafluoride ($SF_6$), nitrogen trifluoride ($NF_3$), and hexafluoroethane ($C_2F_6$), which are tens of thousands of times more potent than $CO_2$.

Other toxic byproducts, such as trichlorosilane gas, silicon tetrachloride, and dangerous particulates from the wafer sawing process, are produced.

## AMORPHOUS (THIN-FILM) SOLAR PANELS

While the toxic chemicals used to process silicon aren't used here, thin-film solar panels are made with cadmium, which is a carcinogen and genotoxin.

The actual performance of installed solar panels is abysmal (5).

Efficiency rates of solar panels are low (on average around 15%) and almost always less than what manufacturers advertise based on laboratory testing.

- Solar panels are highly sensitive and lose functionality in non-optimal conditions, e.g. when there's haze, if the panels aren't angled properly, or if any obstructions—bird droppings, snow, pollutions, etc.—block even small parts of the panel's surface, necessitating regular cleaning.

- Solar panels become less efficient as they age, sometimes losing up to 50% of their efficiency.

Inverters (which transform the DC output of solar panels into the AC input required by appliances) need to be replaced every five to eight years in residential systems and cost roughly $8,000 a piece.

Solar panels have a life span of only 20 to 30 years, making for a massive waste management problem.

By the end of 2016, there were roughly 250,000 tonnes of solar panel e-waste globally (6), accounting for about 0.5% of the total 50 million tonnes of annual global e-waste.

By 2050, solar panels may account for 10% of all e-waste streams and their cumulative end-of-life waste may be greater than all e-waste in 2018 (7).

Recycling

- Requires lots of energy, water, and other inputs, while exposing workers to toxic materials that have to be disposed of in the environment in some way.

- There are only two types of commercially available solar PV recycling (9), and only a handful of recycling facilities exist around the world (8).

1. Green Illusions, p. 19
2. Solar Energy Isn't Always as Green as You Think (Mulvaney)
3. Refining Silicon (PV Education)
4. Environmental Life Cycle Inventory of Crystalline Silicon Photovoltaic Module Production (de Wild-Scholten)
5. Green Illusions, p. 21-24
6. An Overview of Solar Photovoltaic Panels' End-of-Life Material Recycling (Chowdhury et al.), p. 4
7. The Decarbonisation Divide: Contextualizing Landscapes of Low-Carbon Exploitation and Toxicity in Africa (Sovacool et al.), p. 3-4
8. Global Status of Recycling Waste Solar Panels: A Review (Xu et al.), p. 451

# BATTERIES AND OTHER STORAGE

There are four primary types of commercially proven, grid-scale energy storage:

- Pumped hydroelectric storage
- Compressed air energy storage
- Advanced battery energy storage
- Flywheel energy storage

Pumped hydroelectric storage is for hydroelectric dams only. Flywheel energy storage is used more for power management than long-term energy storage. Of the remaining two, compressed air storage is deployed at only two power plants in the world, with likely little expansion since it relies on large underground cavities with specific geological characteristics (1, 3). Only a few power plants in the U.S. have operational battery storage, accounting for around 800 MW of power capacity (1-2). Consider that the U.S. consumes around 4,000 terawatt-hours of electricity every year (or 450,000 MW) (4)—563 times the existing battery storage capacity.

The world's largest battery manufacturing facility—Tesla's $5 billion Gigafactory in Nevada—could store only three minutes' worth of annual U.S. electricity demand in its entire year of production. Fabricating a quantity of batteries that could store even two days' worth of U.S. electricity demand would require 1,000 years of Gigafactory production (5).

Storing just 24 hours' worth of U.S. electricity generation in the form of lithium batteries would cost $11.9 trillion, take up 345 square miles, and weigh 74 million tons (3).

A battery-centric future means mining gigatons of materials (not to mention the materials that go into building the solar panels and wind turbines themselves).

- One pound of battery requires 50-100 pounds of materials that need to be mined, transported, and processed (5).

- To fabricate the quantity of batteries necessary to store only 12 hours' worth of daily power consumption, 18 months' worth of global primary energy production would be needed just to mine and manufacture the batteries—and in the process, production limits would be reached for many minerals. Annual production would have to be doubled for lead, tripled for lithium, and increased by a factor of 10 or more for cobalt and vanadium (3).

Roughly speaking, it takes the energy equivalent of about 100 barrels of oil to fabricate a quantity of batteries that can store the energy equivalent of a single barrel of oil (5).

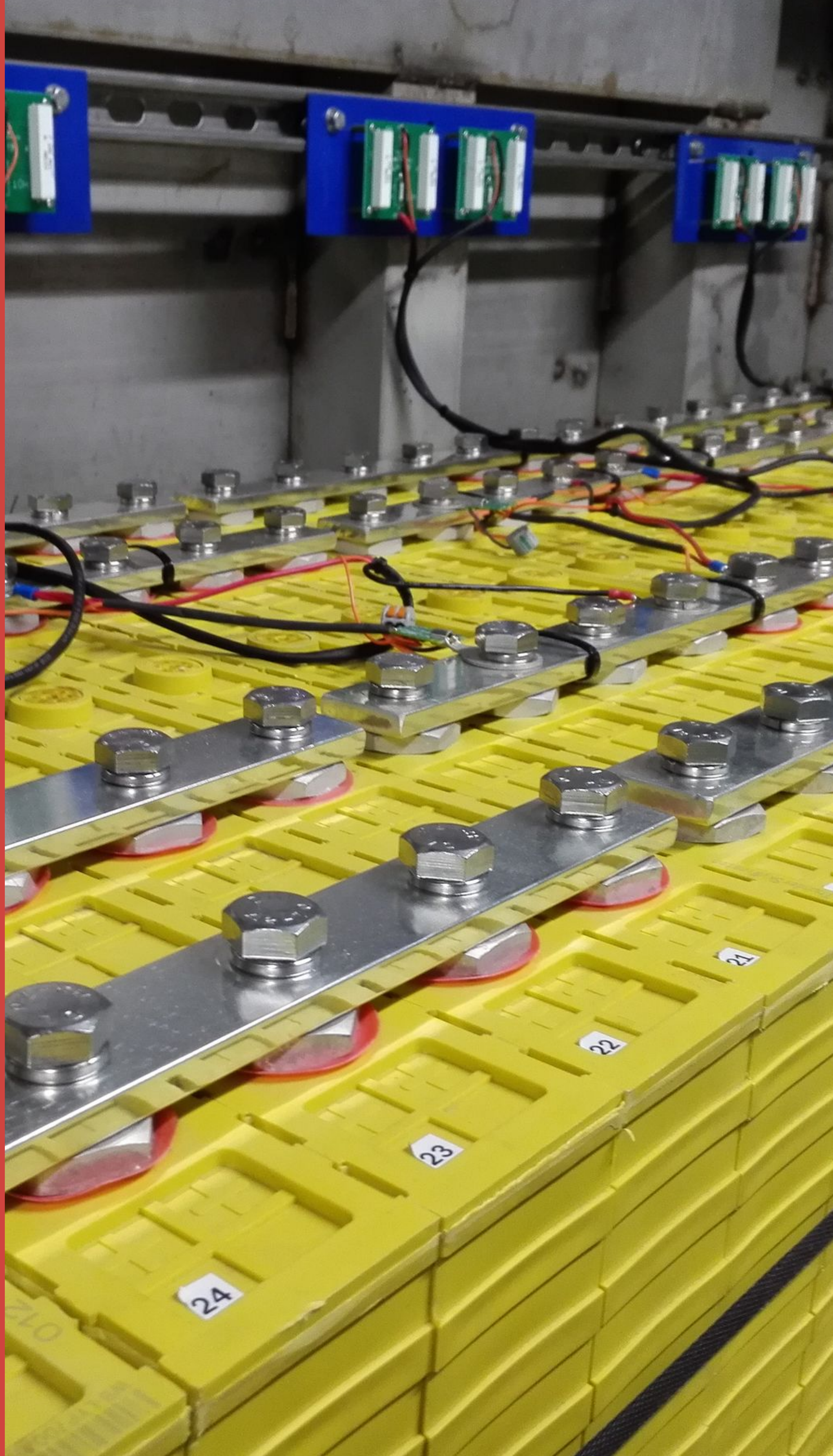
There are limits to how much energy a battery can store, and no matter the advances that are made in battery technology, that energy will always be a fraction of that in petroleum (6).

Battery chemistry is complex, and improvements in one criterion (energy density, power capability, durability, safety, cost) always come at a cost to another (6).

Batteries are heavy. The monitoring and cooling systems and the steel that is used to encase the flammable lithium (other types of batteries are also flammable) weigh 1.5 times as much as the battery itself (6).

No battery can match the performance of the internal combustion engine (7).

- While fossil fuel delivers an energy-to-weight ratio of 12,000Wh/kg, a manganese type lithium-ion battery offers 120Wh/kg, which is one hundred times less per weight. Even at a low efficiency of 25%, the internal combustion engine outperforms the best battery in terms of energy-to-weight ratio.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- The combustion engine delivers full power at freezing temperatures and continues to perform well with advancing age, a trait that is not achievable with the battery. Batteries may lose 40% of their range in cold weather, and a battery that is a few years old may deliver only half its rated capacity.

Not all vehicles and machinery that we use today can be powered by batteries.

What can (with the limitations discussed above, such as power delivery, charging speed, weight, range, sensitivities to temperature and outdoor exposure, and cost): small cranes (with low load capacities used in light duty manufacturing and construction), light and some heavy-duty construction equipment, and passenger cars.

What can't: large cranes (used to load and unload cargo, in large construction projects, in mining operations, and more), container and other large ships (8), airplanes, and medium and heavy duty trucks (9).

Batteries have a life span of around 5 to 15 years, creating an additional, significant waste management problem. They cannot be disposed of in landfills due to their toxicity, and they are one of the fastest growing contributors to e-waste streams (10).

Only 5% of all lithium batteries are recycled (10).


1. U.S. Grid Energy Storage Factsheet (University of Michigan Center for Sustainable Systems)
2. Most Utility-Scale Batteries in the U.S. are Made of Lithium-Ion (USEPA)
3. When Trucks Stop Running, 105-109
4. Electricity Domestic Consumption (Global Energy Statistical Yearbook 2020)
5. The New Energy Economy, p. 12
6. When Trucks Stop Running, p. 60-62
7. Batteries Against Fossil Fuel (Battery University)
8. Electric Container Ships Are Stuck on the Horizon (Smil)
9. When Trucks Stop Running, p. 75-78
10. The Decarbonisation Divide, p. 4

# WIND

The large metal wind turbines that have become ubiquitous today are composed primarily of steel towers, iron nacelles, and fiberglass blades. Roughly 25% of all large wind turbines use permanent magnet synchronous generators (PMSG) inside the nacelles—the latest generation technology that uses rare earth metals neodymium (Nd), praseodymium (Pr), dysprosium (Dy), and terbium (Tb). The remaining 75% of operating wind turbines use some form of conventional magnetic generator. Employment of PMSGs is expected to grow given their post-implementation advantages (1).

Steel production is dependent on coal. Steel is an alloy of iron and carbon, made from metallurgical, or coking, coal. The production of metallurgical coal requires temperatures around 1,800°F (1,000°C). Combining the two materials then requires blast furnaces that reach temperatures of 3,100°F (1,700°C) (2).

On average, 1.85 tons of $CO_2$ is emitted for every ton of steel produced (3-4).

Fiberglass is a petroleum-based composite material that cannot be recycled (5).

Mining and processing the rare earth metals now common in most wind turbines produces significant toxic waste. Many rare earths are bound up in ore deposits that contain thorium and uranium, both of which are radioactive (6). Sulfuric acid is used to isolate the rare earths from the ore, exposing the radioactive residue and producing hydrofluoric acid, sulfur dioxide, and acidic wastewater (6-7). One ton of radioactive waste is produced for every ton of mined rare earths. In one year alone, rare earth processing for wind turbines generates just as much radioactive waste as the nuclear industry (7).

For a typical 3 MW wind turbine (8-9):

- The tower is anywhere from 279 to 345 feet (80 to 105 meters) tall and weighs up to 628,000 pounds (285 tonnes)
- The rotor weighs about 90,000 pounds (41 tonnes)
- The nacelle weights around 154,000 pounds (70 tonnes)
- Each blade is about 155 ft (47 meters) long and weighs 27,000 pounds (12 tonnes)
- Totaling around 952,000 pounds, or 432 tonnes

All require large trucks to be transported from manufacturing to installation sites and then large cranes to be erected once on-site. As previously noted, neither can operate on battery power. As shown later, electrified freight is improbable, if not impossible.

Massive concrete bases—often requiring more than 1,000 tons of concrete and steel rebar and measuring 30 to 50 feet across and anywhere from 6 to 30 feet deep—are needed to mount the tower to the ground. Large machinery is required to excavate the site. Cement, which is the primary ingredient in concrete, is produced in industrial kilns heated to 2,700°F10 (1,500°C). The cement must then be transported to the installation site. At least one ton of CO2 is emitted for every ton of cement produced (11).

A 3.1 MW wind turbine creates anywhere from 772 to 1,807 tons of landfill waste, 40 to 85 tons of waste sent for incineration, and about 7.3 tons of e-waste (12). A 5 MW wind turbine contains more than 50 tons of unrecyclable plastic in the blades alone (5).

1. Substitution Strategies for Reducing the Use of Rare Earths in Wind Turbines (Pavel et al.), p. 349
2. Coal & Steel (World Coal Association)
3. Steel's Contribution to a Low Carbon Future (World Steel Association)
4. Industrial Heat Decarbonization Roadmap (ICEF 2019), p. 42
5. How to Make Wind Power Sustainable Again (de Decker)
6. Radioactive Waste Standoff Could Slash High Tech's Supply of Rare Earth Elements (Law)
7. Big Wind's Dirty Little Secret: Toxic Lakes and Radioactive Waste (Institute for Energy Research)
8. Vestas V90-3.0 (Wind Turbine Models)
9. Wind Turbine Blades: Big and Getting Bigger (Composites World)
10. How Cement is Made (PCA)
11. CO2 Emissions Profile of the U.S. Cement Industry (Hanle), p.9
12. The Decarbonisation Divide, p. 4

# HYDROPOWER

Large hydroelectric dams have enormous ecological impacts (1):

- They disrupt flows, degrade water quality, block the movement of a river's vital nutrients and sediment, destroy fish and wildlife habitat, impede the migration of fish and other aquatic species, and impede recreational opportunities.
- Reservoirs slow and broaden rivers, making them warmer.
- The environmental, economic, and societal footprint of a dam and reservoir may extend well beyond the immediate area, impacting drinking water, recreation, fisheries, wildlife, and wastewater disposal.

Many dams are not operating efficiently, are not up to environmental standards, are in need of significant repairs, or—shockingly—do not even have hydropower capacity (1). Empirical evidence has shown that hydroelectric dams produce less energy over time, with the global ratio of installed capacity to annual generation declining from 3.75 in 1993 to 1.43 in 2011 (2).

Whether for these reasons or because they no longer serve their intended purpose, some dams are strong candidates for removal (3).

1. Hydropower and Climate Change (American Rivers)
2. Can Renewable Energy Power the Future? (Moriarty and Honnery), p. 5
3. Restoring Damaged Rivers (American Rivers)

# NUCLEAR

Many existing reactors are nearing the end of their lives and will soon face decommissioning (1).

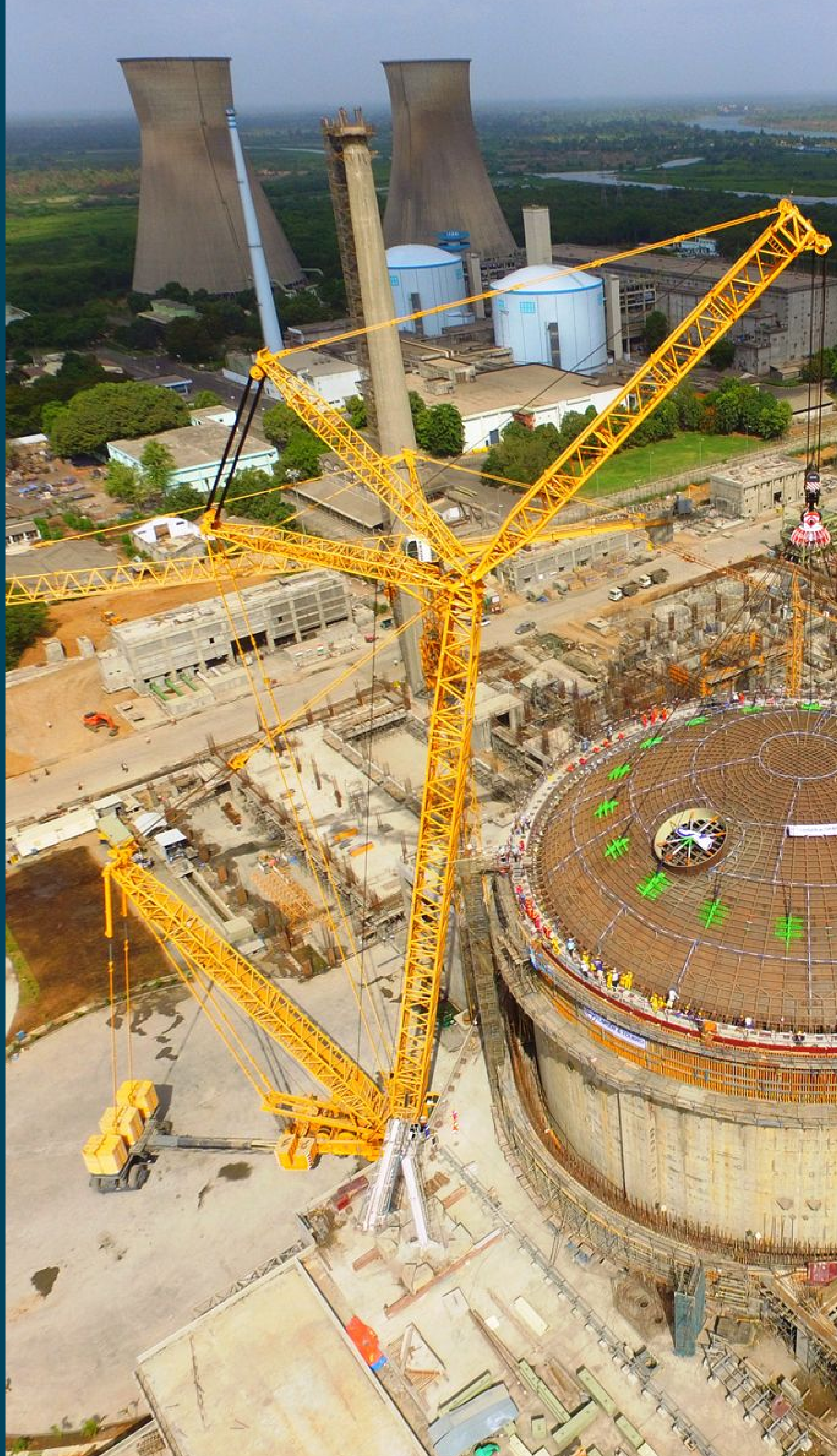
To meet global electricity demand, we would need to build anywhere from 14,500 to 26,000 nuclear power plants (depending on what demand quantities we use). The world currently has 449. Energy return on energy invested (EROI) and critical materials for facility construction and operation aside, the enormous financial costs, regulatory time frames, social opposition, and waste disposal hurdles make this daunting option a near—if not outright—impossibility (1).

Only two prototype Generation IV "intrinsically safe" reactors have been built (one in China and one in Russia), with significant R&D remaining and commercialization forecasted to be two to three decades out (2). Even though Generation IV reactors burn fuel more efficiently and can even burn some nuclear waste, claims about their greatly reduced radioactive waste have been criticized as misleading, pointing to the narrow focus on reduced actinides as irrelevant since:

- It's other fission byproducts that are of the greatest concern for long-term safety, and
- The fuel retreatment process to reduce actinide quantities relies on exceptional technological requirements and itself generates waste that must be disposed of in repositories (3).

The holy grail of fusion is plagued by immense problems (4).

To replicate fusion here on Earth, we would need a temperature of at least 100 million degrees Celsius—about six times hotter than the sun.



The heavier neutron-rich isotopes of hydrogen, deuterium and tritium, that we are using for fusion experiments on Earth are 24 orders of magnitude more reactive than the ordinary hydrogen burned by the sun. This means that human-made fusion has to work with a billion times lower particle density and a trillion times poorer energy confinement than the sun.

In Earth-bound fusion, energetic neutron streams comprise 80% of the fusion energy output of deuterium-tritium reactions—the only potentially feasible reaction type, as opposed to deuterium-deuterium. These neutron streams lead to four problems with nuclear energy:

- Radiation damage to structures
- Radioactive waste
- The need for biological shielding
- The potential for the production of weapons-grade plutonium 239

In addition, fusion reactors would share some of the other serious problems that plague fission reactors:

- Daunting water demands for cooling. A fusion reactor would have the lowest water efficiency of any type of thermal power plant, whether fossil or nuclear. With drought conditions intensifying around the world, many countries would not be able to physically sustain large fusion reactors.

- The use of a fuel (tritium) that is not found in nature. Due to technical difficulties in recovering tritium from the reaction process, fusion reactors would be dependent upon fission reactors, which produce tritium.

- Unavoidable on-site power drains that drastically reduce the electric power available for sale. Below a certain size (about 1,000 MWe), parasitic power drain makes it uneconomic to run a fusion power plant.

- The release of radioactive tritium into the environment. Tritium exchanges with hydrogen to produce tritiated water, which is biologically hazardous.

- High operating costs.

Small modular reactors (SMRs) would offer the benefit of smaller size and transportability, and could hypothetically offer a solution to the problem of providing heat for manufacturing. But SMRs are still in the R&D phase (5) and pose two main problems:

- Just as with large wind turbines, SMRs need to be transported long distances, which isn't possible without large fossil-fueled trucks and cranes.

- SMRs still produce the same radioactive waste products that large reactors do (6).

Nuclear power plants can't be built without large fossil-fueled cranes and enormous amounts of concrete, which, as pointed out earlier, emit significant $CO_2$ and require high temperatures that cannot currently be generated without fossil fuels.


1. Carbon Civilization and the Energy Descent Future (Alexander and Floyd), p. 61-63
2. When Will Gen IV Reactors Be Built? (GenIV International Forum)
3. Burning Waste or Playing with Fire? Waste Management Considerations for Non-Traditional Reactors (Krall and Macfarlane), p. 330-331
4. Fusion Reactors: Not What They're Cracked Up to Be (Jassby)
5. Smaller, Safer, Cheaper: One Company Aims to Reinvent the Nuclear Reactor and Save a Warming Planet (Cho)
6. Small Modular Reactors: A Challenge for Spent Fuel Management? (IAEA)

# CARBON CAPTURE & STORAGE AND DIRECT AIR CAPTURE

Carbon capture and storage (CCS) presupposes the continued use of fossil fuels, which we do not consider as an option after the transformation period.

Both CCS and direct air capture (DAC), which removes $CO_2$ directly from the air through technological as opposed to natural processes, pose energetic, ecological, resource, and financial problems (1).

Over their life cycle, current technologies emit more $CO_2$ than they capture.

It would cost around $600 billion—for the technology alone—to sequester 1 Gt of carbon (2). For context, the world emitted 34 Gt $CO_2$ in 2020.

The amount of carbon currently captured is minuscule compared to what is needed. The largest DAC facility in the world captures only 4,000 t $CO_2$ per year, which is only 0.000004 Gt.

Vast quantities of natural resources and land would be needed to scale up such operations.

"Renewable"-powered DAC would use all wind and solar energy generated in the U.S. in 2018—and this would capture only one-tenth of a Gt of $CO_2$.

Literature and public discussion largely ignores the ecological impacts of CCS and DAC, including $CO_2$ transportation and its injection and storage in the Earth as well as potential groundwater contamination, earthquakes, and fugitive emissions.

1. Assessing Carbon Capture: Public Policy, Science, and Societal Need (Sekera & Lichtenberger)
2. Cost Plunges for Capturing Carbon Dioxide from the Air (Service)

# METAL EXTRACTION AND ITS SOCIAL INJUSTICES

A shift to the RE technologies covered here would simply increase society's dependence on non-renewable resources—not just FF but also more metals and minerals, adding massive exploitation of the geosphere to the existing over-exploitation of the atmosphere (1).

The demand for minerals is expected to rise substantially through 2050.

- Increases of up to 500% from 2018 production levels are projected, particularly for those used in energy storage (e.g., lithium, graphite, and cobalt) (2).

- The IEA estimates that reaching "net zero" globally by 2050 would require six times the amount of mineral resources used today (3). This would entail a quantity of metal production—requiring considerable FF combustion—over the next 15 years roughly equal to that from the start of humanity until 2013 (1).

- The production and consumption of industrial minerals increased 144% between 2000 and 2018. Precious metal consumption is up by 40% and base metal consumption by 96% (4).

However, both the rate of mineral discovery and the grade of processed ores are well into decline.

- "Global reserves are not large enough to supply enough metals to build the renewable non-fossil fuels industrial system or satisfy long term demand in the current system" (4).

- Without extraordinary advances in mining and refining technology, the 10% of world energy consumption currently used for mineral extraction and processing would rise as poorer and more remote deposits are tapped (1).

Social injustices abound in the production of so-called RE technologies, confounding the need for social justice in the energy transition.

While so-called RE technologies may deliver cleaner point-of-use conditions in the Global North, substantial ecological costs and social damage have been displaced to the Global South (5) (though such harms are increasingly spilling over into North America and Europe (6)).

Much of the mining and refining of the material building blocks of so-called renewables takes place in developing countries and contributes to environmental destruction, air pollution, water contamination, and risk of cancer and birth defects (5).

Low-paid labor is often the norm, as is gender inequality and the subjugation and exploitation of ethnic minorities and refugees (5).

Mining often relies on the exploitation of children, some of whom are exposed to risks of death and injury, are worked to death in e-waste scrapyards, or drown in waterlogged pits (5).

Land grabs and other forms of conflict and violence are routinely linked to climate change mitigation efforts around the world (6).

Deep-sea and volcanic mining are not yet viable, nor are they "green" alternatives to conventional mining (7-10).

They are still in the exploratory phase and would thus take too long to produce results.

The multi-kilometer deep wells and operations require advanced technology that cannot function, let alone be constructed, without FF.

Like all other advanced techno-industrial activities, both processes would involve significant ecological degradation/destruction.

1. Metals for a Low-Carbon Society (Vidal et al.), p. 895
2. Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition (World Bank), p. 73
3. The Role of Critical Minerals in Clean Energy Transitions (IEA)
4. The Mining of Minerals and the Limits to Growth (Michaux)
5. The Decarbonisation Divide
6. Who are the Victims of Low Carbon Transitions? (Sovacool)
7. History's Largest Mining Operation is About to Begin (The Atlantic)
8. How Green Mining Could Pave the Way to Net Zero and a Sustainable Future
9. Impacts of Deep Sea Mining (Deep Sea Conservation Coalition)
10. Protect the Oceans in Deep Water: The Emerging Threat of Deep Sea Mining (Greenpeace)

# FOSSIL FUEL SUBSIDY

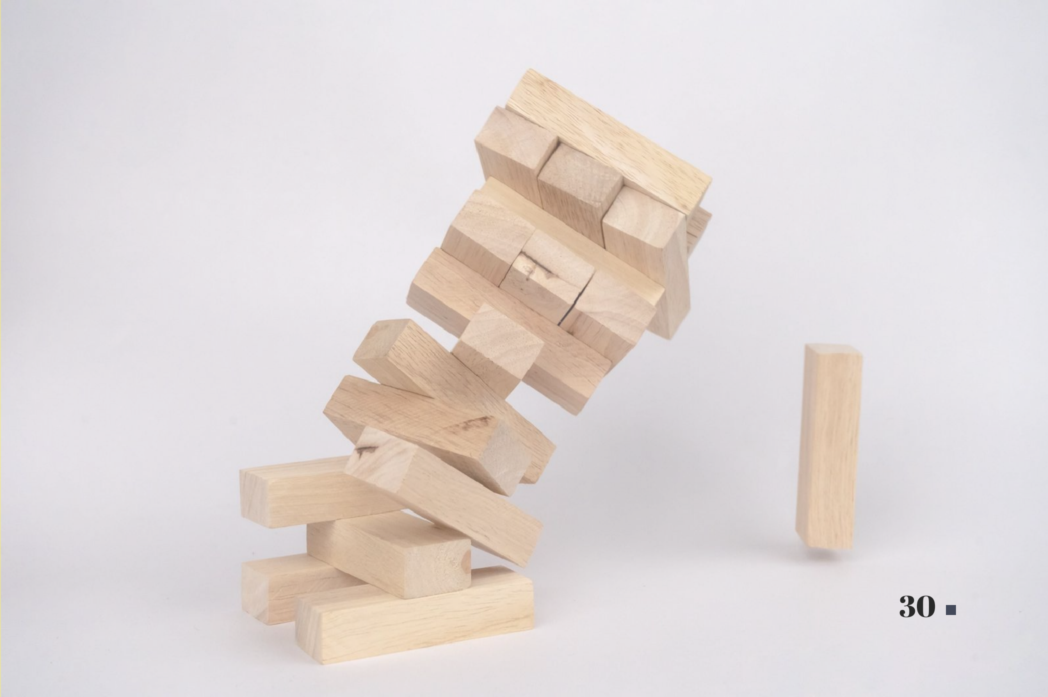
Every so-called RE technology today depends on fossil fuels for its entire life cycle. Take, for example, the lifespan of a solar panel or wind turbine.

The metals and other raw materials are mined and processed using petroleum-fueled large machinery.

These metals and raw materials are then transported around the world on cargo ships that burn bunker fuel and on trucks that are powered by diesel and travel on roads constructed using fossil fuels.

Manufacturing processes use tremendous amounts of very high heat that can only be generated reliably and at scale from coal, oil, and natural gas.

The finished solar panels and wind turbines are transported from manufacturing to installation sites on trucks powered by diesel, and, in the case of industrial scale wind turbines, erected on-site with large petroleum-fueled machinery.



# PERFORMANCE GAINS AND ENERGY VS. EXERGY

Over the past 60 years, Moore's Law—which has governed the information technology revolution—has been responsible for the billion-fold exponential increase in the efficiency of how microchips use energy to store and process information. It states that the number of transistors on a microprocessor chip will double every two years or so. But Moore's Law—which is sometimes used to assure us of the coming exponential increases in renewable energy output—governs information processing systems, not the physics of energy systems. (Even information technology gains are slowing) (1-2).

Combustion engines are subject to the Carnot Efficiency Limit, solar cells are subject to the Shockley-Queisser Limit, and wind turbines are subject to the Betz Limit (1).

- Solar — Shockley-Queisser Limit: a maximum of about 33% of incoming photons can be converted into electrons. State-of-the-art commercial PVs achieve just over 26% conversion efficiency — close to their theoretical efficiency limit.

- Wind — Betz Limit: the amount of kinetic energy a blade can capture from the air is limited to about 60%. Turbines today exceed 45%, making additional gains difficult to achieve.

Starry-eyed optimists who point out that the amount of solar radiation that reaches the Earth's surface far exceeds global energy consumption confuse energy with exergy. Solar radiation is energy, whereas exergy is the fraction of that energy actually harnessable to perform work. As shown above, our exergy-generating technologies are subject to limits imposed by the laws of physics.

1. The New Energy Economy, p. 14-16
2. The Chips are Down for Moore's Law (Waldrop)

**It is nearly impossible to see how liquid fuels —which account for the remaining 81% of global energy consumption—can be produced in any more than small quantities for niche applications.**

“We are headed toward a day not too far away when the system as we know it will break down. We will not have enough transportation fuel to sustain our way of life. Denial is not a strategy.”

*Alice Friedemann*

WHEN TRUCKS STOP RUNNING

# LIQUID FUELS

Fossil fueled agricultural inputs are the only reason we're able to feed 8 billion people.

The synthetic pesticides, herbicides, and fungicides, not to mention the petroleum-fueled heavy machinery, responsible for what is known as The Green Revolution, have allowed for much higher than normal agricultural outputs per unit of land area than under normal conditions (at a massive ecological cost). Remove fossil fuels from the agricultural system and we're left with significantly reduced output.

Even if a global one-child policy were enacted soon, we would still have 8 billion to 3.5 billion mouths to feed between now and the end of the century. Failure to enact fertility reduction policies would spell an even more dire scenario. This means that virtually every inch of arable land must be dedicated to growing food, leaving ethanol and biodiesel as likely niche products only.

Even assuming massive reforestation and afforestation with a dedicated siphoning for energy consumption, woody biomass will contribute primarily to heat generation —likely not liquid fuel production given its energetic requirements.

Algae isn't a solution (1).

More energy is consumed to fabricate the algae than it usefully generates.

Tremendous technical difficulties still need to be overcome despite 60 years of research.

Protozoans that invade a pond can eat all the algae within 12–18 hours.

The National Research Council concluded that scaling up algal biofuel production to replace even 5% of U.S. transportation fuel would place unsustainable demands on energy, water, and nutrients.

The U.S. Department of Energy found that "systems for large-scale production of biofuels from algae must be developed on scales that are orders of magnitude larger than all current world-wide algal culturing facilities combined."

Hydrogen is not a solution for the reasons identified earlier related to manufacturing.

1. When Trucks Stop Running, p. 42-45

# ELECTRIFICATION OF TRANSPORTATION

Battery-powered cars have limitations, as discussed above, not to mention they raise many of the same questions regarding the resource, manufacturing, and end-use dilemmas of:

- Where the steel, aluminum, and other metals to build the cars will come from in a resource constrained world.
- Where the plastic to build the cars will come from in a post-fossil fuel world.
- How the high temperatures for manufacturing can be achieved without fossil fuels.
- How the roads—made of a certain type of petroleum-based product and laid with heavy machinery—to drive the cars on will be maintained and built.

Large trucks cannot run on batteries.

Electrifying the freight system seems improbable (1).

The current U.S. fleet of 25,000 locomotives would use as much electricity as 55 million electric cars, and it's not clear where that electricity would come from.

Electrifying major routes (say 160,000 of the 200,000 miles of tracks) would require the equivalent power of 240 power plants, keeping in mind that railway load is one of the most difficult for an electric utility to cope with.

It would require a national grid—which we don't even have today—or at least a much-expanded grid (2).

Electric passenger rail is equally as improbable.

Just as with freight, it would require an expanded grid.

It's inefficient due to the constant stopping and accelerating (3).

It's incredibly costly. California's attempt to build high-speed rail connecting the length of the state was originally estimated to cost $33 billion. It then increased to $55 billion, and, by 2019, the estimate had ballooned to $79 billion, with annual operation and maintenance costs pegged at $228 million (4).

1. When Trucks Stop Running, p. 67-69
2. When Trucks Stop Running, p. 85
3. Why is Passenger Rail so Damned Inefficient? (Energy Skeptic)
4. Will California's High Speed Rail Go Off the Tracks? (Energy Skeptic)

# Conclusion

> “We cannot solve our problems with the same thinking we used when we created them.”
>
> Albert Einstein

We have exposed fatal weaknesses in the technologies widely advanced as solutions to the climate crisis. The notion of clean energy is an illusion that ignores innumerable biophysical realities and costs that cannot be afforded by any reasonable measure. So-called RE technologies are neither renewable nor possible to construct and implement in the absence of FF. They are not carbon neutral and will simply increase human dependence on non-renewable resources and cause unacceptable social and environmental harm.

Clearly, business-as-usual by alternative means is not a solution. To avert even greater catastrophic impacts of climate change than we already face, we need to situate climate disruption within its broader context of *human ecological dysfunction*. We need to understand the paradigmatic source of this underlying cancer and formulate entirely new narratives and pathways for a genuine renewable energy and sustainability transition.

The REAL
Green New Deal Project