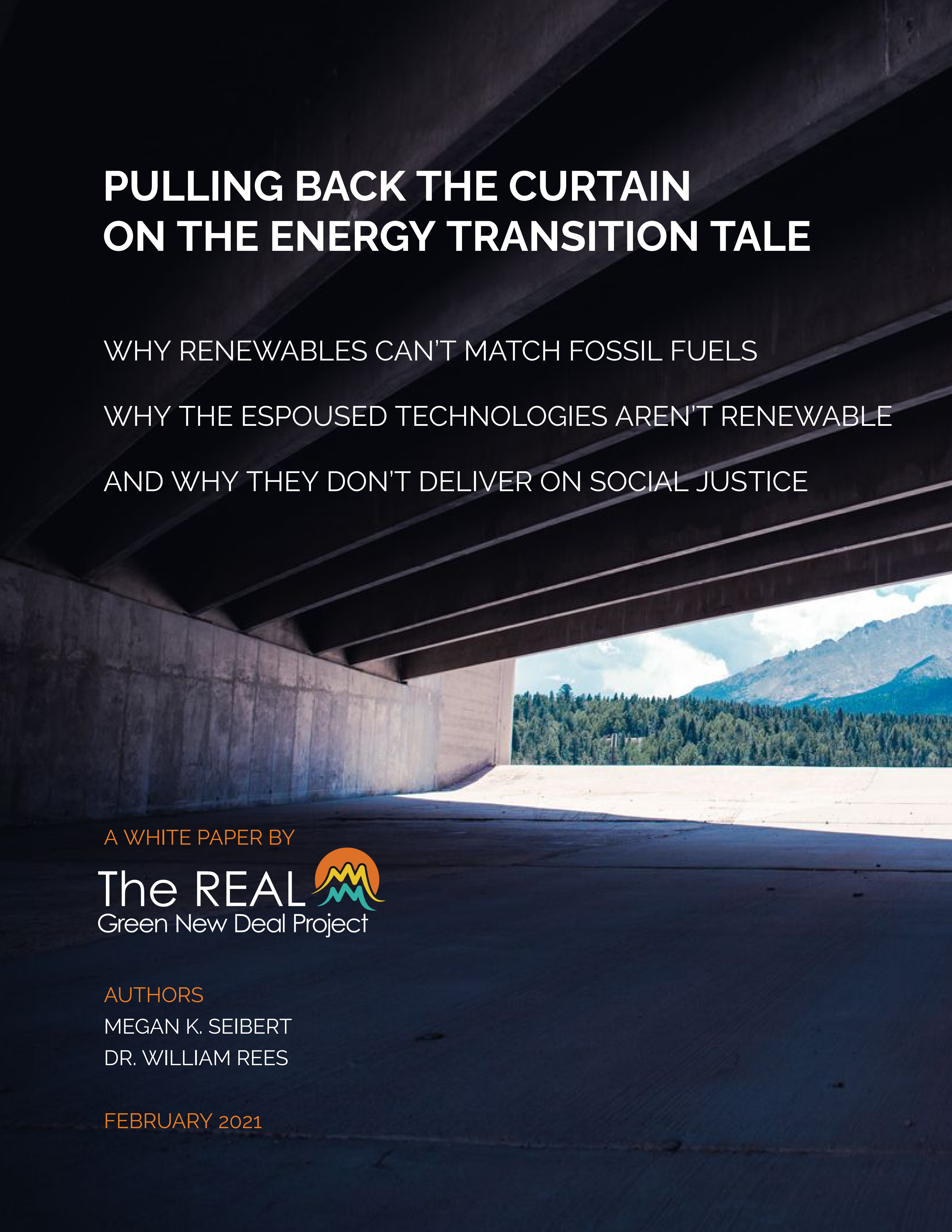

PULLING BACK THE CURTAIN ON THE ENERGY TRANSITION TALE

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

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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*
>
> ENERGY, ECOLOGY, AND ECONOMICS

The primary goal 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 heat (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. electrical energy generation in 2019 was (3):

62.6% fossil fuels
19.6% nuclear
7.1% wind
7.0% hydro
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 CO_2. 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).

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.

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)

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).

Numerous RE heat sources for manufacturing are explored in reports (2)(3)(4)(5):

- Bioenergy
  - Biomass
    - Charcoal, achieved through pyrolysis at around 840˚F (450˚C)
    - Direct combustion of cord wood or waste products
  - Syngas
    - Generated through pyrolysis (570˚F to 1,100˚F / 300˚C to 590˚C) or gasification (1,470˚F to 1,830˚F / 800˚C to 1,000˚C) of biomass feedstock
  - Biogas
    - Generated through anaerobic digestion of agricultural waste, manure, municipal waste, plant material, sewage, green waste, or food waste
- Concentrated solar power (CSP)
- Hydrogen
- Geothermal
- Small modular reactors (SMR)
- Carbon capture and storage (CCS) and direct air capture (DAC)

Biogas, CSP, hydrogen, geothermal, SMR, and CCS can be ruled out of the highest temperature category for not generating positive net energy returns, for being impractical, too costly, too immature in the research and development stage, and/or too risky for ecological and human health.

BIOGAS

Better suited for small-scale buildings than manufacturing.

CONCENTRATED SOLAR POWER

Existing systems generate heat in the range of 300˚F to 570˚F (150˚C to 300˚C) (4), despite estimated upper limits ranging from 1,800˚F to 2,200˚F (1,000˚C to 1,200˚C) (2, p. 19-27), (4).

CSP plants typically cost in excess of $1 billion and require around 5 square miles of land (2, p. 19-29), (6, p. 106-107).

- The U.S. has only a handful of CSP plants totaling around 1,850 MW, all located in hot, arid climates (6, p. 106-107).

- CSP plants can store thermal energy in molten salt, however 1) almost all CSP plants have fossil backup to diminish thermal losses at night, prevent the molten salt from freezing, supplement low solar irradiance in the winter, and for fast starts in the morning, and 2) the molten salt stores less than one day's worth of electrical supply (2, p. 19-27), (6, p. 106-107).

HYDROGEN

It takes more energy to isolate the hydrogen than the hydrogen can later generate (2, p. 19), (3, p. 14), (6, p. 42-45), (7).

The only viable, large-scale feedstock for hydrogen is natural gas (3, p. 14), (6, p. 42-45), (7), and the gas reforming process requires temperatures ranging from 1,300˚F -1,830˚F (700˚C to 1,000˚C) (3, p. 14).

Gas reforming produces substantial GHG emissions (2, p.19-20).

Challenges (3, p. 16):

- Because hydrogen is a very small, corrosion-abetting molecule, leakage risks are substantial, especially in preexisting pipelines or devices. Special materials and gaskets are often required.

- Since hydrogen is colorless, odorless, and burns invisibly, special monitors and sensors are needed for hydrogen combustion units, as are special mitigation plans.

- At higher quantities, hydrogen can corrode conventional pipes and pose a leakage or safety concern.

GEOTHERMAL

Produces temperatures of around only 300˚F (150˚C) (4, p. 55, 59).

Can be located only in mountainous regions with active tectonic plate movement or near volcanic hot spots (4, p. 54).

Geothermal production wells are commonly up to two kilometers deep (4, p. 55), (5, p. 4-44). At present, these depths can be reached only with fossil fueled machinery and advanced technologies.

SMALL MODULAR REACTORS

For reasons identified in the "Nuclear" section below, SMRs are still in the R&D phase, still produce radioactive byproducts that must be disposed of, and pose the problem of transportability.

CARBON CAPTURE AND STORAGE (CCS) AND DIRECT AIR CAPTURE (DAC)

CCS presupposes the continued use of fossil fuels, which we do not consider as an option after the transformation period.

Both pose energetic, ecological, resource, and financial problems (10).

- Over their life cycle, current technologies emit more CO2 than they capture.

- It would cost around $600 billion—for the technology alone—to sequester 1 Gt of carbon (11). For context, the world emitted 34 Gt CO2 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 CO2 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.

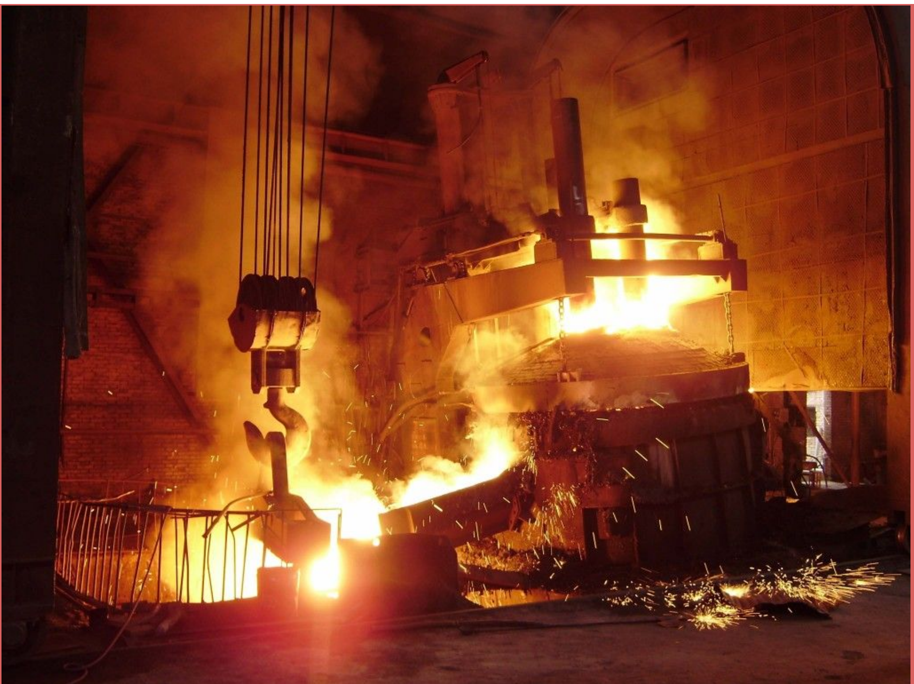
- Literature and public discussion largely ignores the ecological impacts of CCS and DAC, including CO_2 transportation and its injection and storage in the Earth as well as potential groundwater contamination, earthquakes, and fugitive emissions.

Biomass, syngas, and electrification are potential options for heat production, but they present questions, challenges, and limitations.

BIOMASS

Some sources say it generates heat in the lower to mid ranges only (1),(2). However, humans have smelted iron with biomass for thousands of years, which required temperatures in the range of 1,100˚F to 1,400˚F (590˚C to 760˚C) produced by wood charcoal (at the expense of large tracts of forest).

Capacities of bioenergy plants range from tens of kW to 240 MW in the case of the world's largest plant, a paper mill in Finland. Plants larger than 100 MW are generally only found when co-located with processing facilities, in which cases combined heat and power is common (5, p. 40).



Biomass can potentially substitute for coke and other heat in the BOF steel making process.

- Bio-coke may be able to replace coal-based coke, but further refinement is needed with respect to both performance and system modifications (3, p. 23-24). Basic oxygen furnace (BOF) steelmaking, which makes virgin steel (as opposed to electric arc furnaces (EAF), which use recycled steel), is a highly integrated process in which coke serves multiple functions, so it's not practical to replace any individual heating operation without a larger process redesign (3, p. 48).

- Charcoal may be used in the sintering process and blast furnace, but again, further refinement and wide-scale system modifications would be needed (3, p. 23-24).

- Brazil has the highest utilization of biomass in its steelmaking industry (upwards of around 34%) (3, p. 23-24) due its vast forest resources (often harvested illegally), whereas only low substitution rates have been achieved elsewhere.

A new method called HIsarna (developed by Tata Steel in Europe) could potentially replace the conventional BOF (3, p. 47), (8).

- Instead of pre-processing iron ore and metallurgical coal into sinter (lumps of iron ore), pellets (small balls of iron ore), and coke, the HIsarna process would make this phase obsolete, instead converting powdered raw materials directly into liquid iron.

- However, this process requires temperatures of 2,190˚F (1,200˚C) and is still in the R&D phase with only a small-scale pilot project.

Cement (3, p. 36-39)

- Bioenergy can substitute for only a fraction of the heat in cement making due to its low heating value. While it's not suitable for providing the high temperatures required in the kiln, it can be used in the calciner for lower temperature heat.

- Burning alternative fuels in the calciner requires the use of multichannel burners and careful monitoring of impurity levels, which is done today at facilities that burn alternative fuels.

- A higher degree of biomass substitution could be achieved by gasification, but this is in the research stage only.

SYNGAS (9)

While gasification and pyrolysis are generally considered mature technologies, few facilities dedicated to producing biomethane exist.

While there are many technologies available, no one design has emerged as significantly cheaper, more efficient, or better than any other.

As discussed above, systems integration remains a challenge.

How can the temperatures in excess of 1,470˚F (800˚C) required for gasification be reached without fossil fuels?

Gasification and pyrolysis facilities can cost in the range of hundreds of millions of dollars.

ELECTRIFICATION (3, p. 64)

There has been little R&D on massive electrification options.

Most existing equipment is fossil fuel-powered and difficult, if not impossible, to electrify.

No RE technology or system is viable if it cannot generate sufficient energy both to produce itself (literally from the ground up) *and* supply sufficient surplus to provide for society's end-use consumption.

1. Renewable Industrial Process Heat (EPA)
2. Low-Carbon Heat Solutions for Heavy Industry- Sources, Options, and Costs Today (Columbia SIPA CGEP)
3. Industrial Heat Decarbonization Roadmap (ICEF)
4. Generation and Use of Thermal Energy in the U.S. Industrial Sector and Opportunities to Reduce its Carbon Emissions (JISEA)
5. Renewable Energy Options for Industrial Process Heat (ARENA)
6. When Trucks Stop Running (Friedemann)
7. Green Illusions, p. 106
8. Hisarna: Game Changer In The Steel Industry (Tata Steel)
9. Conversion and Processing of Biogas and Syngas (PG&E)
10. Assessing Carbon Capture: Public Policy, Science, and Societal Need (Sekera & Lichtenberger)
11. Cost Plunges for Capturing Carbon Dioxide from the Air (Service)

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.

- 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 CO_2 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).

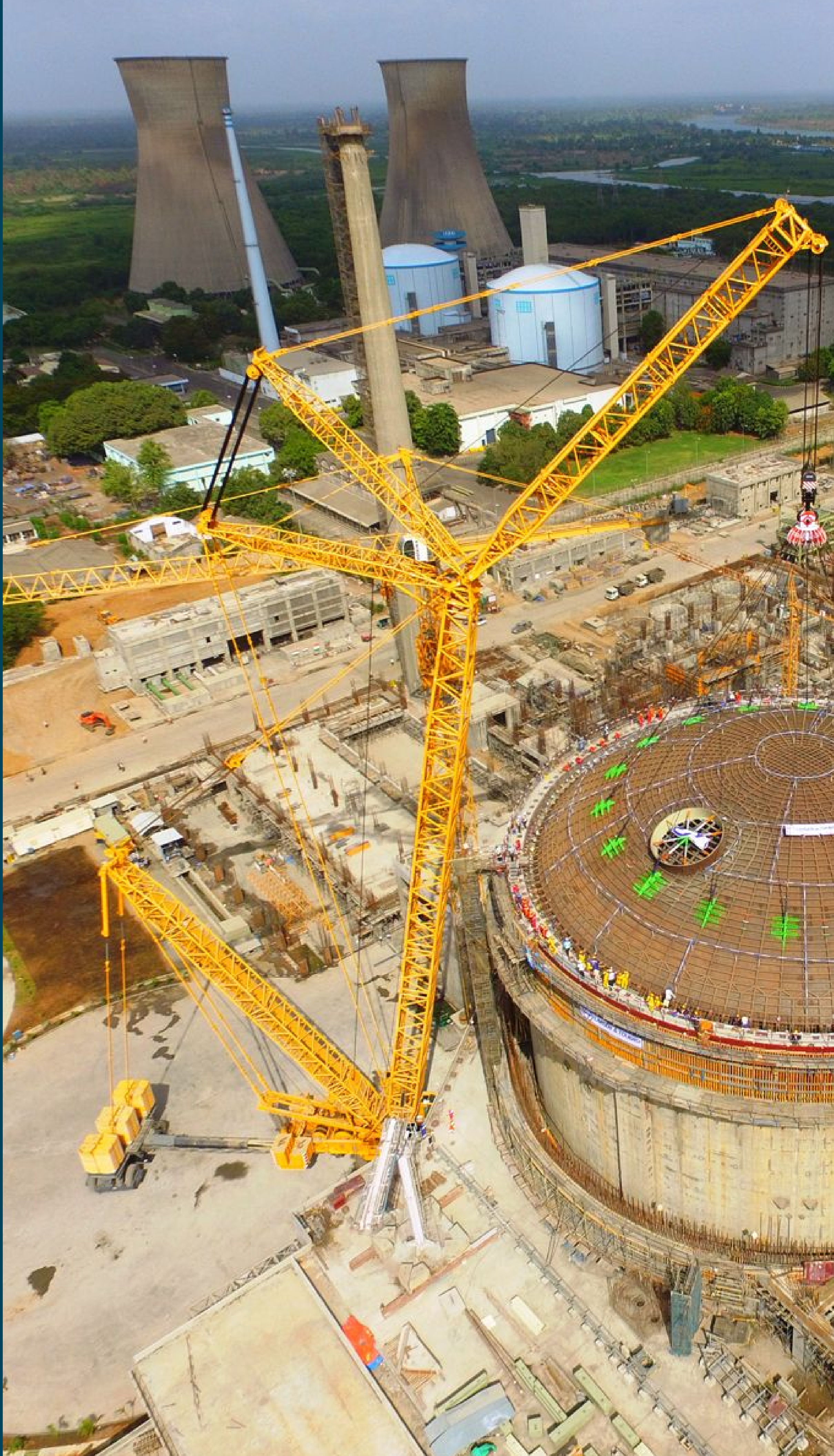
To meet global electricity demand, we would need to build anywhere from 14,500 to 26,000 nuclear power plants (depending on what demand quantities we use). The world currently has 449. Energy return on energy invested (EROI) and critical materials for facility construction and operation aside, the enormous 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)

METAL EXTRACTION AND ITS SOCIAL INJUSTICES

A shift to the RE technologies covered here will replace one non-renewable resource (fossil fuels) with another (metals and minerals) (1).

The demand for minerals to build them is expected to rise substantially through 2050, increasing up to nearly 500% from 2018 production levels for certain minerals, especially those used in energy storage technologies, such as lithium, graphite, and cobalt (2).

The demand for base metals is currently increasing by 5% annually. If this trend continues, the quantity of metal production for the next 15 years will need to match that from the start of humanity to 2013 (1).

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

Solar and wind facilities require up to 15 times more concrete, 90 times more aluminum, and 50 times more iron, copper, and glass than equivalent generating facilities using fossil fuels or nuclear energy (1).

For facility construction alone, a solar plant requires 170,000 tons of metals and materials. A wind plant requires 410,000 tons and a nuclear plant requires 217,000 tons (3).

Many assume that transitioning to these sorts of RE technologies represents a more just way of producing energy. However, injustices abound in existing mining, processing, and refining processes, many of which take place in developing countries using low-paid workers, including child labor (4).

The transition to these technologies is paradoxically contributing to environmental destruction, air pollution, water contamination, and risk of cancer and birth defects. It can deepen existing gender inequalities. It is worsening the subjugation and exploitation of ethnic minorities and refugees. And it relies on the exploitation of children, some of whom are exposed to extreme risks of death and injury while mining, are worked to death in e-waste scrapyards, or drown in waterlogged pits (4).

While these technologies may contribute to cleaner end-point conditions in the Global North, much of the environmental and social harm is simply made invisible and displaced to the Global South (4).

Can Mother Nature withstand the ecological devastation of this much more mining?

Will there be enough energy to mine, process, and transport that much material without fossil fuels?

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 Decarbonisation Divide, p. 4
4. The Decarbonisation Divide, p. 8

FOSSIL FUEL SUBSIDY

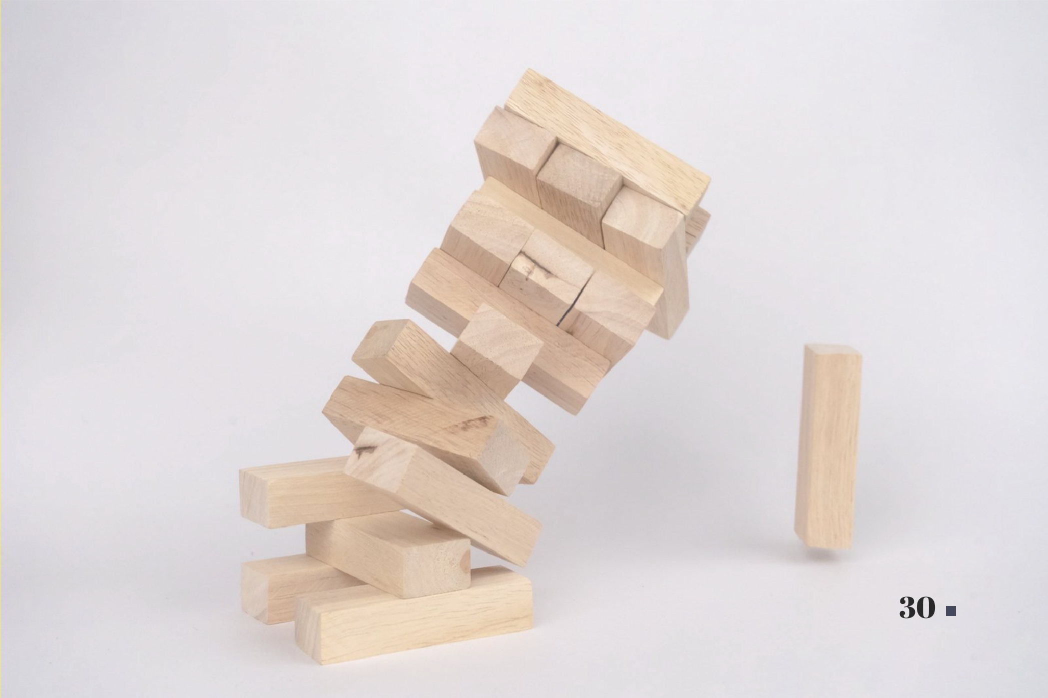
Every single solar panel and wind turbine today depends on fossil fuels for its entire life cycle.

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

These metals and raw materials are 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'd 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 to electricity and 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 isn't a solution for the reasons identified earlier in the "Heat for Manufacturing" section.

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 can't 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)