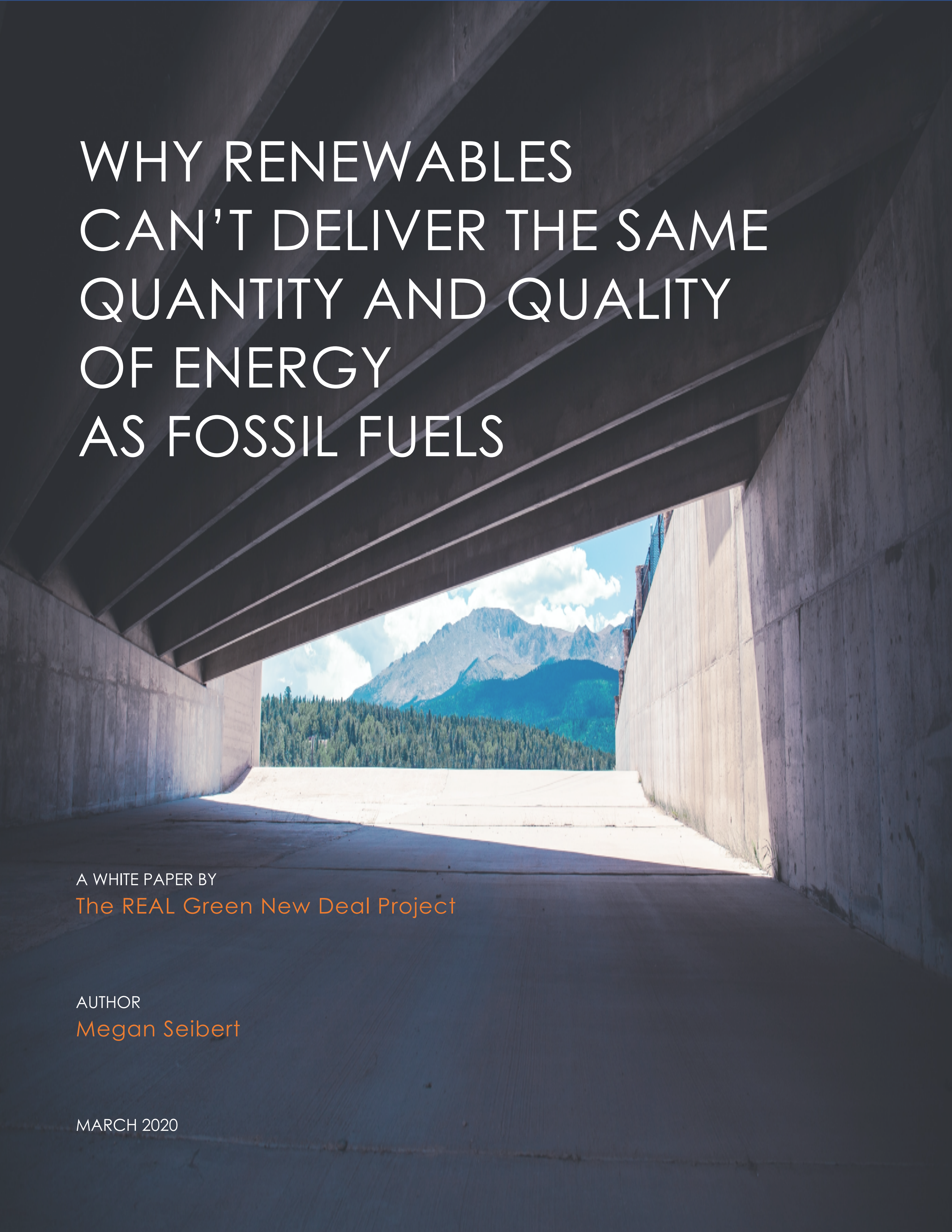

WHY RENEWABLES CAN'T DELIVER THE SAME QUANTITY AND QUALITY OF ENERGY AS FOSSIL FUELS

A WHITE PAPER BY

The REAL Green New Deal Project

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> *“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 characteristic educational approach of isolating variables in tunnel vision thinking, let us here seek common sense overview.”*
>
> – Howard T. Odum in Energy, Ecology, and Economics

The primary goal of The REAL Green New Deal Project (REALgnd Project) is to expand the scope of inquiry into renewable energy (RE) technologies from a holistic perspective. Here, 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). While we draw no definitive conclusions about tenability in this first look, what this examination does show is that RE cannot deliver the same quantity and quality of energy as fossil fuels. This alone shows 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 Project advocates for the abolition of fossil fuels – 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 and with minimal ecological degradation. Viability examines basic, practical issues for implementation.

Within this context, the misnomer of “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. Determinations about what is sustainable are both objective and subjective (for example, metal supplies are a relatively objective criterion, whereas assessing the acceptability of environmental pollution and human health impacts are subjective). Assessments of viability are more straightforward.

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 which RE technologies are sustainable and viable in which contexts and how that can inform what the changes in our demand and behavior must be, keeping in mind that the two reduction levers to pull on are the number of people and the amount of energy we’re each consuming.

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.

ONLY 18% OF GLOBAL ENERGY CONSUMPTION IS IN THE FORM OF ELECTRICITY; THE OTHER 82% IS IN THE FORM OF LIQUID FUEL FOR TRANSPORTATION AND HEAT. IN THE U.S., ELECTRICITY ACCOUNTS FOR ABOUT 12% OF ENERGY CONSUMPTION.[1]

THERE ARE INSURMOUNTABLE OBSTACLES IN CONVERTING *EVEN JUST ELECTRICITY CONSUMPTION ALONE* TO RENEWABLES.

> *The green dream "only seem[s] clean if we first sharply narrow our focus (to one CO_2 output metric) and then proceed to disregard absolutely every other well-established and documented side effect, limitation, and long-term risk…"*
>
> – Ozzie Zehner in Green Illusions

For reference, the current breakdown of U.S. electrical energy generation is:[2]

- 64% fossil fuels
- 19% nuclear
- 7% hydro
- 7% wind
- 1.5% biomass
- 1.5% solar
- 0.5% geothermal

1. Estimated U.S. Energy Consumption in 2017 (Lawrence Livermore National Laboratory) https://upload.wikimedia.org/wikipedia/commons/f/fd/Energy_Flow_US_2017.png
2. What is U.S. Electricity Generation by Source? (USEIA) https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

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]

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

SOLAR

Manufacturing solar panels uses extremely toxic substances – not to mention lots of energy and water – and produces extremely toxic byproducts, including greenhouse gases that are thousands of times more potent than CO_2.[1,2]

- *Mono- and poly-crystalline solar panels*
  - At every step of the way, very high amounts of heat are needed. 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] – temperatures that can't be generated without fossil fuels.
  - Up to half of the silicon is lost in the wafer sawing process.
  - Toxic chemicals used:
    - Hydrochloric acid
    - Hydroflouric acid
    - Sodium hydroxide
    - Sulfuric acid
    - Nitric acid
    - Hydrogen fluoride
    - Phosphine and arsine gas
    - Phosphorus oxychloride and trichloride
    - Boron bromide and trichloride
    - Lead
  - Toxic byproducts:
    - Trichlorosilane gas
    - Silicon tetrachloride
    - Dangerous particulates from the wafer sawing
    - Greenhouse gases
      - Sulfur hexafluoride (SF_6) – 25,000 times more potent than CO_2
      - Nitrogen trifluoride (NF_3) – 17,000 times more potent than CO_2
      - Hexafluoroethane (C_2F_6) – 12,000 times more potent than CO_2
- *Amorphous (thin-film) solar panels*
  - While the toxic chemicals used to process silicon aren't used here, thin-film solar panels are made of cadmium, which is a carcinogen and genotoxin, meaning it can cause inheritable mutations.

The actual performance of installed solar panels is abysmal.[4]

- 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 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 – not just in terms of sheer materials, but toxic materials, as well. Even recycling requires lots of energy, water, and other inputs, and exposes workers to toxic materials that have to be disposed of in the environment in some way.

1. Green Illusions, p. 19
2. Solar Energy Isn't Always as Green as You Think (Mulvaney) https://spectrum.ieee.org/green-tech/solar/solar-energy-isnt-always-as-green-as-you-think
3. https://www.pveducation.org/pvcdrom/manufacturing-si-cells/refining-silicon
4. Green Illusions, p. 21-24

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 terrawatt-hours of electricity every year (or 450,000 MW).[4]

The world's biggest battery manufacturing facility – Tesla's $5 billion Gigafactory in Nevada – can only store three minutes' worth of annual U.S. electricity demand in its entire year of production. To fabricate 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 amount 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 orders of magnitude less than 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) weigh1.5 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 percent, the internal combustion engine outperforms the best battery in terms of energy-to-weight ratio. The capacity of a battery would need to increase 20-fold before it could compete head-to-head with fossil fuel.
- 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. 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
    - 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
    - Medium and heavy duty trucks[9]

Just as with solar panels, batteries have a life span of around 5 to 15 years, making for a massive waste management problem, including dealing with their toxic substances.

1. University of Michigan Center for Sustainable Systems, U.S. Grid Energy Storage Factsheet
http://css.umich.edu/factsheets/us-grid-energy-storage-factsheet

2. https://www.eia.gov/todayinenergy/detail.php?id=41813
3. When Trucks Stop Running (Friedemann), 105-109
4. https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html
5. The New Energy Economy, p. 12
6. When Trucks Stop Running, p. 60-62
7. https://batteryuniversity.com/learn/archive/batteries_against_fossil_fuel
8. Electric Container Ships Are Stuck on the Horizon (Smil) https://spectrum.ieee.org/transportation/marine/electric-container-ships-are-stuck-on-the-horizon
9. When Trucks Stop Running, p. 75-78

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).[1] The remaining 75% of wind turbines currently in operation use some form of conventional magnetic generator. Employment of PMSGs is expected to grow given their many advantages.[1]

- Steel production is dependent on coal. Steel is an alloy made of iron ore and metallurgical coal. The production of metallurgical coal requires temperatures of around 1,800°F (1,000°C) – temperatures that can't be generated without fossil fuels. 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]
- Fiberglass is a petroleum-based composite material that cannot be recycled. A 5 MW wind turbine contains more than 50 tons of unrecyclable plastic in the blades alone.[4]
- Mining and processing the rare earth metals that are now common in most wind turbines produces enormous amounts of toxic waste. Rare earths are bound up in ore deposits that contain thorium and uranium, both of which are radioactive.[5] Sulfuric acid is used to isolate the rare earths from the ore, exposing not only the radioactive residue but also producing hydrofluoric acid, sulfur dioxide, and acidic wastewater.[5,6] One ton of radioactive waste is produced for every ton of mined rare earths. In one year alone, rare earth processing for wind turbines produces just as much radioactive waste as the nuclear industry.[6]
- A tower is typically 80 feet tall and weighs 19,000 pounds. A nacelle typically weighs 22,000 pounds. And a blade typically weighs 2,5000 pounds. All require large trucks to be transported from manufacturing to installation sites and then large cranes to be erected once on-site. As previously discussed, neither can operate on battery power. As shown later, electrified freight is improbable, if not impossible.
- Massive concrete bases are needed to mount the tower to the ground. This requires large machinery to excavate the site. Cement, which is the primary ingredient in concrete, is produced in an industrial process in which kilns are heated to 2,700°F[7] (1,500°C)– again, temperatures which can't be reached without fossil fuels. 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.[8]

1. Substitution Strategies for Reducing the Use of Rare Earths in Wind Turbines (Pavel et al.) https://www.sciencedirect.com/science/article/pii/S0301420717300077

2. https://www.worldcoal.org/coal/uses-coal/how-steel-produced
3. https://www.worldsteel.org/publications/position-papers/steel-s-contribution-to-a-low-carbon-future.html
4. How to Make Wind Power Sustainable Again (de Decker) https://www.lowtechmagazine.com/2019/06/wooden-wind-turbines.html
5. Radioactive Waste Standoff Could Slash High Tech's Supply of Rare Earth Elements (Law) https://www.sciencemag.org/news/2019/04/radioactive-waste-standoff-could-slash-high-tech-s-supply-rare-earth-elements
6. Big Wind's Dirty Little Secret: Toxic Lakes and Radioactive Waste (Institute for Energy Research) https://www.instituteforenergyresearch.org/renewable/wind/big-winds-dirty-little-secret-rare-earth-minerals/
7. https://www.cement.org/cement-concrete-applications/how-cement-is-made
8. CO2 Emissions Profile of the U.S. Cement Industry (Hanle) https://www3.epa.gov/ttnchie1/conference/ei13/ghg/hanle.pdf

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. 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, 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 1) it's other fission byproducts that are of the greatest concern for long-term safety, and 2) 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]

Nuclear power plants can't be built without large fossil-fueled cranes and lots of concrete, which, as discussed in the previous section, emits lots of CO_2 and requires high temperatures that only fossil fuels can generate.

Small modular reactors (SMRs) would offer the benefit of smaller size and transportability, and could hypothetically offer a solution to the problem of providing thermal heat for manufacturing, but SMRs are still in the R&D phase[4] 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.[5]

1. Carbon Civilization and the Energy Descent Future (Alexander and Floyd), p. 61-63
2. https://www.gen-4.org/gif/jcms/c_41890/faq-2
3. Burning Waste or Playing with Fire? Waste Management Considerations for Non-Traditional Reactors (Krall and Macfarlane) https://www-tandfonline-com.proxy.lib.pdx.edu/doi/full/10.1080/00963402.2018.1507791

4. Smaller, Safer, Cheaper: One Company Aims to Reinvent the Nuclear Reactor and Save a Warming Planet (Cho) https://www.sciencemag.org/news/2019/02/smaller-safer-cheaper-one-company-aims-reinvent-nuclear-reactor-and-save-warming-planet
5. Small Modular Reactors: A Challenge for Spent Fuel Management? (IAEA) https://www.iaea.org/newscenter/news/small-modular-reactors-a-challenge-for-spent-fuel-management

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 migration of fish and other aquatic species, and eliminate 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 to 1.43 from 1993 to 2011.[2]

Whether because of these reasons or because they no longer serve the purpose they did when they were originally built, some dams are strong candidates for removal.[3]

1. https://www.americanrivers.org/threats-solutions/energy-development/hydropower-climate-change/
2. Can Renewable Energy Power the Future? (Moriarty and Honnery), p. 5
3. https://www.americanrivers.org/threats-solutions/restoring-damaged-rivers/

METALS AND OTHER MATERIALS

As described above, building millions of wind turbines, millions or hundreds of millions of solar panels, enough batteries to store even small amounts of energy, and the facilities needed to manufacture them, would require an *enormous* amount of metals and other raw materials that are finite resources. Yet many of these finite resources have been significantly depleted throughout the modern Industrial Age.

Are there enough materials left to be harvested in such quantities? Can Mother Nature withstand the ecological devastation of that much more mining? Will there be enough energy to mine, process, and transport that much material if fossil fuels are removed from the equation?

Some of the information already presented suggests not.

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 (heavy fuel oil) and trucks that are powered by diesel.
- Manufacturing processes use tremendous amounts of very high heat that can only be generated reliably and at scale from petroleum and natural gas.
- The finished solar panels and wind turbines are transported from the manufacturing sites to their installation sites on trucks powered by diesel, and, in the case of industrial scale wind turbines, erected on-site with large petroleum-fueled machinery.

THERMAL HEAT FOR MANUFACTURING

Though just raised in the preceding section, this topic is important enough to warrant further attention. All manufacturing processes today – which are responsible for making solar panels, wind turbines, and batteries, not to mention all other modern technologies – require very high temperatures that are currently generated using fossil fuels. Despite the critical importance of thermal heat in manufacturing, there appears to be scant little information on how it can be generated with RE alone.

Roughly speaking, 30% of industrial heating applications require heat below 212°F, another 27% can be met with heat between 212° and 750°F, and the remaining 43% require heat above 750°F. According to the U.S. EPA, most existing renewable heating technologies can supply heat within the lowest indicated temperature range.[1] As discussed above, solar panels and wind turbine manufacturing requires temperatures in excess of 1,000°F.

Potential sources of non-fossil thermal heat may include:

- Electric arc furnaces (currently used to recycle steel)[2]
    - Primary drawbacks are quality of heat, ability to transfer heat across the reactor, and ability to perform under specific requirements for all applications
- Woody biomass[1,2]
    - Appears to generate heat in the lower to mid ranges only
- Resistive heating[2]
    - Appears to be in the research phase only, with temperatures reaching 3,300°F (1,800°C)
- Concentrated solar power (CSP)
    - Appears to have a maximum temperature limit of 2,200°F (1,200°C)[2]
    - CSP plants typically cost in excess of $1 billion and require around 5 square miles of land[2,3]
    - The U.S. only has a handful of CSP plants totaling around 1850 MW, all located in hot, arid climates[3]

- 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[2,3]

The obvious question is whether RE alone can produce enough energy not only for end-use consumption but also for its own production in the first place.

1. https://www.epa.gov/rhc/renewable-industrial-process-heat
2. Low Carbon Heat Solutions for Heavy Industry (Friedmann et al.), p. 19-27 https://energypolicy.columbia.edu/research/report/low-carbon-heat-solutions-heavy-industry-sources-options-and-costs-today
3. When Trucks Stop Running, p. 106-107

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. Moore's Law 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. (Interestingly, even Moore's Law as applied to information technology is now coming to an end).[1,2]

Combustion engines are subject to the Carnot Efficiency Limit, solar cells are subject to the Shokley-Queisser Limit, and wind turbines are subject to the Betz Limit.[1]

- Solar – Shokley-Quisser 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.
- Wind – Betz Limit: the amount of kinetic energy a blade can capture from the air is limited to about 60%. Turbines today exceed 45%.

Which brings us to the concept of energy vs. exergy. Starry-eyed optimists who point out that the amount of solar radiation that reaches the Earth's surface far exceeds global energy consumption are missing this basic point. Said solar radiation is energy, whereas harnessing energy to perform work is exergy. It takes energy – and lots of other inputs – to "make" exergy, and, as demonstrated above, our exergy-generating technologies are subject to limits imposed by the laws of physics and thermodynamics.

1. The New Energy Economy, p. 14-16
2. The Chips are Down for Moore's Law (Waldrop) https://www.nature.com/news/the-chips-are-down-for-moore-s-law-1.19338

IT IS NEARLY IMPOSSIBLE TO SEE HOW LIQUID FUELS – WHICH ACCOUNT FOR THE REMAINING 82% 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 we begin taking immediate action to reduce the global population, in a best-case scenario, we'll still be left feeding roughly 8 billion people until the end of the century, and still many, many billions for decades thereafter. This means that virtually every inch of arable land must be dedicated to growing food, leaving biofuels (i.e. ethanol and biodiesel) as likely niche products that will only be produced in very small amounts. Even assuming massive reforestation and afforestation with a dedicated siphoning for energy consumption, woody biomass will contribute to electricity and heat generation, not liquid fuel production.

Algae isn't a solution.[1]

- Many Life Cycle Analyses show that more energy is consumed to fabricate the algae than it usefully generates.
- There are still tremendous technical difficulties that need to be overcome despite 60 years of research.
- Algae uses as much nitrogen as large-scale commercial agriculture. To supply just 5% of U.S. transportation fuel, algae would require 44–107% of total nitrogen fertilizer use and 20–51% of total phosphorus use.
- Protozoans that invade a pond can eat them all 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 the amount of water needed to grow algae for biofuels could "approach the same order of magnitude as large-scale agriculture" and that "systems for large-scale production of biofuels from algae must be developed on scales that are orders of magnitude larger than all current worldwide algal culturing facilities combined."

Hydrogen isn't a solution, since:[1,2]

- It takes more energy to isolate the hydrogen than the hydrogen can later generate
- The only viable, large-scale feedstock for hydrogen today is natural gas

1. When Trucks Stop Running, p. 42-45
2. Green Illusions, p. 106

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 with RE technologies listed here alone demanding so many of our remaining metal supplies.
- Where the plastic to build the cars will come from in a post-fossil fuel world.
- How the high temperatures required 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, then it 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. http://energyskeptic.com/2016/why-is-passenger-rail-so-damned-inefficient/
4. http://energyskeptic.com/2019/challenges-facing-californias-high-speed-rail-house-hearing-2014/