Lighthiser v. Trump

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WWS System

Generation

Onshore/offshore wind

Solar photovoltaics

Storage

Hydropower reservoirs

Batteries

Equipment

Electric heat pumps

Electric induction cooktops

Grid

AC/HVAC/HVDC lines

Grid interconnection among WWS generators

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Exhibit 8 p.3

A Path to Sustainable Energy by 2030

Scientific American (2009)

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https //web.stanford.edu/group/efmh/jacobson/Articles/I/sad1109Jaco5p.indd.pdf
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Renewable Energy 184 (2022) 430–442

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Zero air pollution and zero carbon from all energy at low cost and without blackouts in variable weather throughout the U.S. with 100% wind-water-solar and storage

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ABSTRACT

This study analyzes 2050–2051 grid stability in the 50 U.S. states and District of Columbia after their all-sector (electricity, transportation, buildings, industry) energy is transitioned to 100% clean, renewable Wind-Water-Solar (WWS) electricity and heat plus storage and demand response (thus to zero air pollution and zero carbon). Grid stability is analyzed in five regions; six isolated states (Texas, California, Florida, New York, Alaska, Hawaii); Texas interconnected with the Midwest, and the contiguous U.S. No blackouts occur, including during summer in California or winter in Texas. No batteries with over 4-h storage are needed. Concatenating 4-h batteries provides long-duration storage. Whereas transitioning more than doubles electricity use, it reduces total end-use energy demand by ~57% versus business-as-usual (BAU), contributing to the 63 (43–79)% and 86 (77–90)% lower annual private and social (private + health + climate) energy costs, respectively, than BAU. Costs per unit energy in California, New York, and Texas are 11%, 21%, and 27% lower, respectively, and in Florida are 1.5% higher, when these states are interconnected regionally rather than islanded. Transitioning may create ~4.7 million more permanent jobs than lost and requires only ~0.29% and 0.55% of new U.S. land for footprint and spacing, respectively, less than the 1.3% occupied by the fossil industry today.

1. Introduction

The United States is currently undergoing a slow but consistent transition to clean, renewable energy. We define clean, renewable energy as energy that is both clean (emits zero health- and climate-affecting air pollutants when consumed) and renewable (has a source that continuously replenishes the energy). We call energy sources that meet these criteria Wind-Water-Solar (WWS) sources. WWS electricity-generating technologies include onshore and offshore wind turbines (Wind); tidal turbines, wave devices, geothermal electric power plants, and hydroelectric power plants (Water); and rooftop/utility solar photovoltaics (PV) and concentrated solar power (CSP) plants (Solar) (Table 1). WWS heat-generating technologies include solar thermal and geothermal heat plants. WWS electricity must be transported by alternating current (AC), high-voltage AC (HVAC), and high-voltage direct current (HVDC) transmission lines and AC distribution lines (Table 1). WWS energy must also be stored in either electricity, heat, cold, or hydrogen storage media (Table 1). Finally, a transition to WWS requires equipment for transportation, industry, and buildings that runs on electricity. Such equipment includes electric and hydrogen fuel cell vehicles, heat pumps, induction cooktops, arc furnaces, resistance furnaces, lawn mowers, leaf blowers, chainsaws, and more (Table 1).

For this study, we consider only WWS energy since we believe that WWS technologies result in greater simultaneous reductions in air pollution, climate damage, and energy insecurity than do non-WWS technologies. We do not include fossil energy, bioenergy, non-hydrogen synthetic fuels, blue hydrogen, carbon capture, direct air capture, or nuclear energy, since each may result in a greater risk of air pollution, climate damage, and/or energy insecurity. The only hydrogen considered is green hydrogen (from WWS electricity). If we can solve all three problems at reasonable cost with WWS alone, we will not need miracle or controversial technologies to help.

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0960-1481/

Zero Air Pollution and Zero Carbon from all Energy at Low Cost and Without Blackouts in Variable Weather Throughout the U.S. with 100% Wind-Water-Solar and Storage

Renewable Energy (2022)

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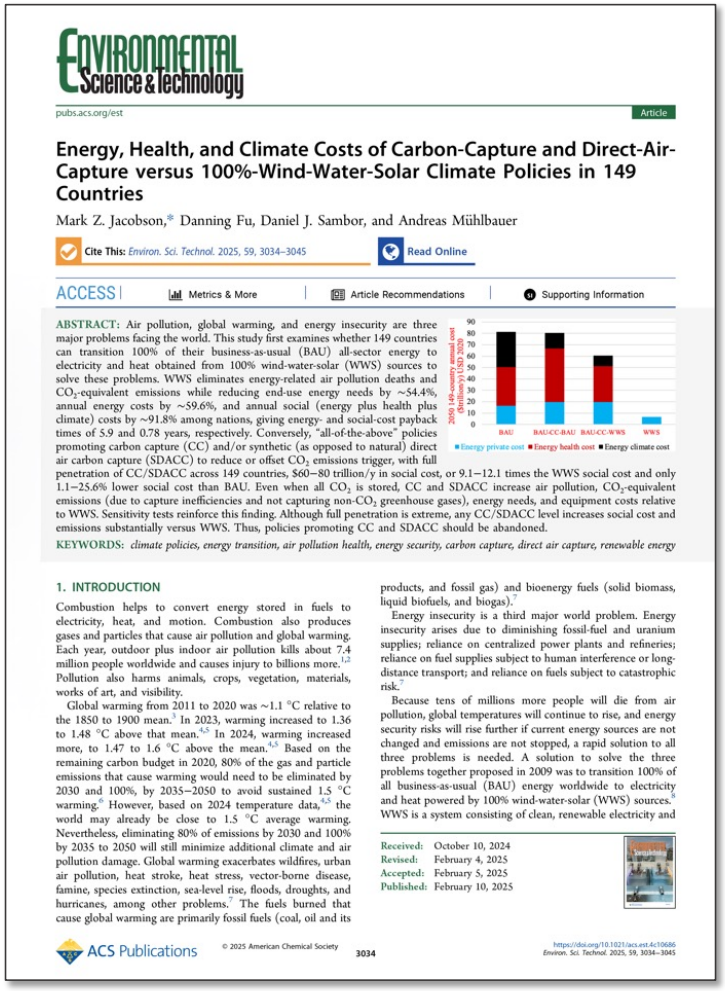
Exhibit 8 p.5



ENVIRONMENTAL Science & Technology

pubs.acs.org/est Article

Energy, Health, and Climate Costs of Carbon-Capture and Direct-Air-Capture versus 100%-Wind-Water-Solar Climate Policies in 149 Countries

Mark Z. Jacobson,* Danning Fu, Daniel J. Sambor, and Andreas Mühlbauer

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ABSTRACT: Air pollution, global warming, and energy insecurity are three major problems facing the world. This study first examines whether 149 countries can transition 100% of their business-as-usual (BAU) all-sector energy to electricity and heat obtained from 100% wind-water-solar (WWS) sources to solve these problems. WWS eliminates energy-related air pollution deaths and CO_2-equivalent emissions while reducing end-use energy needs by ∼54.4%, annual energy costs by ∼59.6%, and annual social (energy plus health plus climate) costs by ∼91.8% among nations, giving energy- and social-cost payback times of 5.9 and 0.78 years, respectively. Conversely, "all-of-the-above" policies promoting carbon capture (CC) and/or synthetic (as opposed to natural) direct air carbon capture (SDACC) to reduce or offset CO_2 emissions trigger, with full penetration of CC/SDACC across 149 countries, $60−80 trillion/y in social cost, or 9.1−12.1 times the WWS social cost and only 1.1−25.6% lower social cost than BAU. Even when all CO_2 is stored, CC and SDACC increase air pollution, CO_2-equivalent emissions (due to capture inefficiencies and not capturing non-CO_2 greenhouse gases), energy needs, and equipment costs relative to WWS. Sensitivity tests reinforce this finding. Although full penetration is extreme, any CC/SDACC level increases social cost and emissions substantially versus WWS. Thus, policies promoting CC and SDACC should be abandoned.

KEYWORDS: *climate policies, energy transition, air pollution health, energy security, carbon capture, direct air capture, renewable energy*

1. INTRODUCTION

Combustion helps to convert energy stored in fuels to electricity, heat, and motion. Combustion also produces gases and particles that cause air pollution and global warming. Each year, outdoor plus indoor air pollution kills about 7.4 million people worldwide and causes injury to billions more.[1,2] Pollution also harms animals, crops, vegetation, materials, works of art, and visibility.

Global warming from 2011 to 2020 was ∼1.1 °C relative to the 1850 to 1900 mean.[3] In 2023, warming increased to 1.36 to 1.48 °C above that mean.[4,5] In 2024, warming increased more, to 1.47 to 1.6 °C above the mean.[4,5] Based on the remaining carbon budget in 2020, 80% of the gas and particle emissions that cause warming would need to be eliminated by 2030 and 100%, by 2035−2050 to avoid sustained 1.5 °C warming.[6] However, based on 2024 temperature data,[4,5] the world may already be close to 1.5 °C average warming. Nevertheless, eliminating 80% of emissions by 2030 and 100% by 2035 to 2050 will still minimize additional climate and air pollution damage. Global warming exacerbates wildfires, urban air pollution, heat stroke, heat stress, vector-borne disease, famine, species extinction, sea-level rise, floods, droughts, and hurricanes, among other problems.[7] The fuels burned that cause global warming are primarily fossil fuels (coal, oil and its products, and fossil gas) and bioenergy fuels (solid biomass, liquid biofuels, and biogas).[7]

Energy insecurity is a third major world problem. Energy insecurity arises due to diminishing fossil-fuel and uranium supplies; reliance on centralized power plants and refineries; reliance on fuel supplies subject to human interference or long-distance transport; and reliance on fuels subject to catastrophic risk.[7]

Because tens of millions more people will die from air pollution, global temperatures will continue to rise, and energy security risks will rise further if current energy sources are not changed and emissions are not stopped, a rapid solution to all three problems is needed. A solution to solve the three problems together proposed in 2009 was to transition 100% of all business-as-usual (BAU) energy worldwide to electricity and heat powered by 100% wind-water-solar (WWS) sources.[8] WWS is a system consisting of clean, renewable electricity and

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Energy, Health, and Climate Costs of Carbon-Capture and Direct-Air-Capture versus 100%-Wind-Water-Solar Climate Policies in 149 Countries

Environmental Science & Technology (2025)

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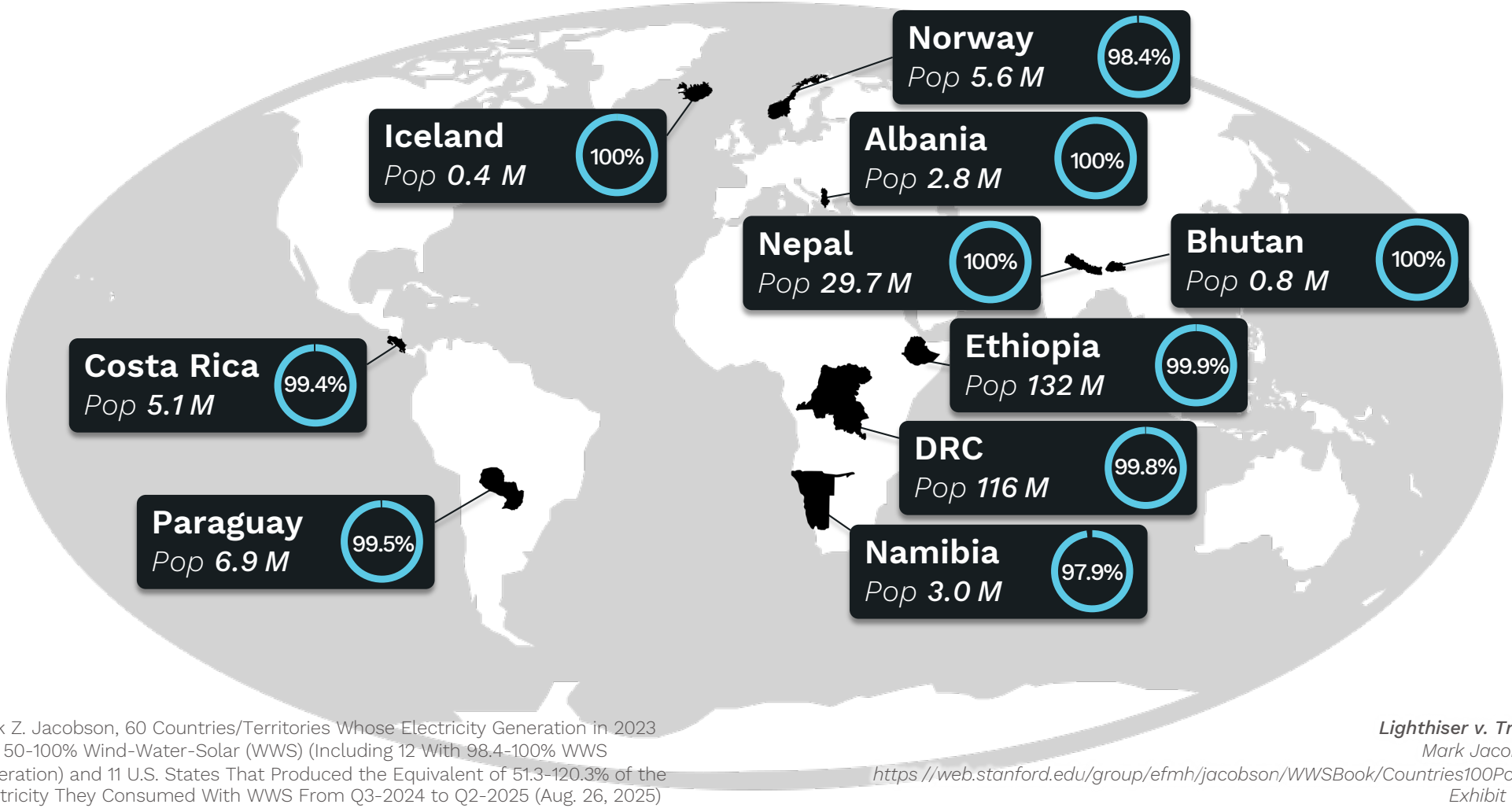
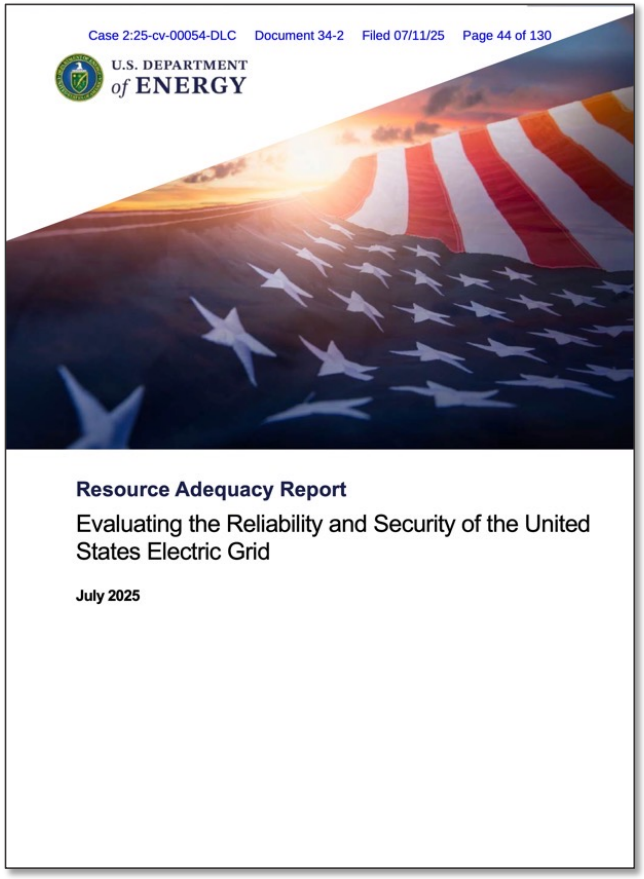
https //web.stanford.edu/group/efmh/jacobson/Articles/I/149Country/149-Countries.pdf
Exhibit 8 p.6

Countries Relying Over 97% on WWS, 2023



Mark Z. Jacobson, 60 Countries/Territories Whose Electricity Generation in 2023 was 50-100% Wind-Water-Solar (WWS) (Including 12 With 98.4-100% WWS Generation) and 11 U.S. States That Produced the Equivalent of 51.3-120.3% of the Electricity They Consumed With WWS From Q3-2024 to Q2-2025 (Aug. 26, 2025)

U.S. DOE Resource Adequacy Report, July 2025



Evaluating the Reliability and Security of the United States Electric Grid:

- Wrong that Renewables Cause Blackouts
- Flawed Methodology

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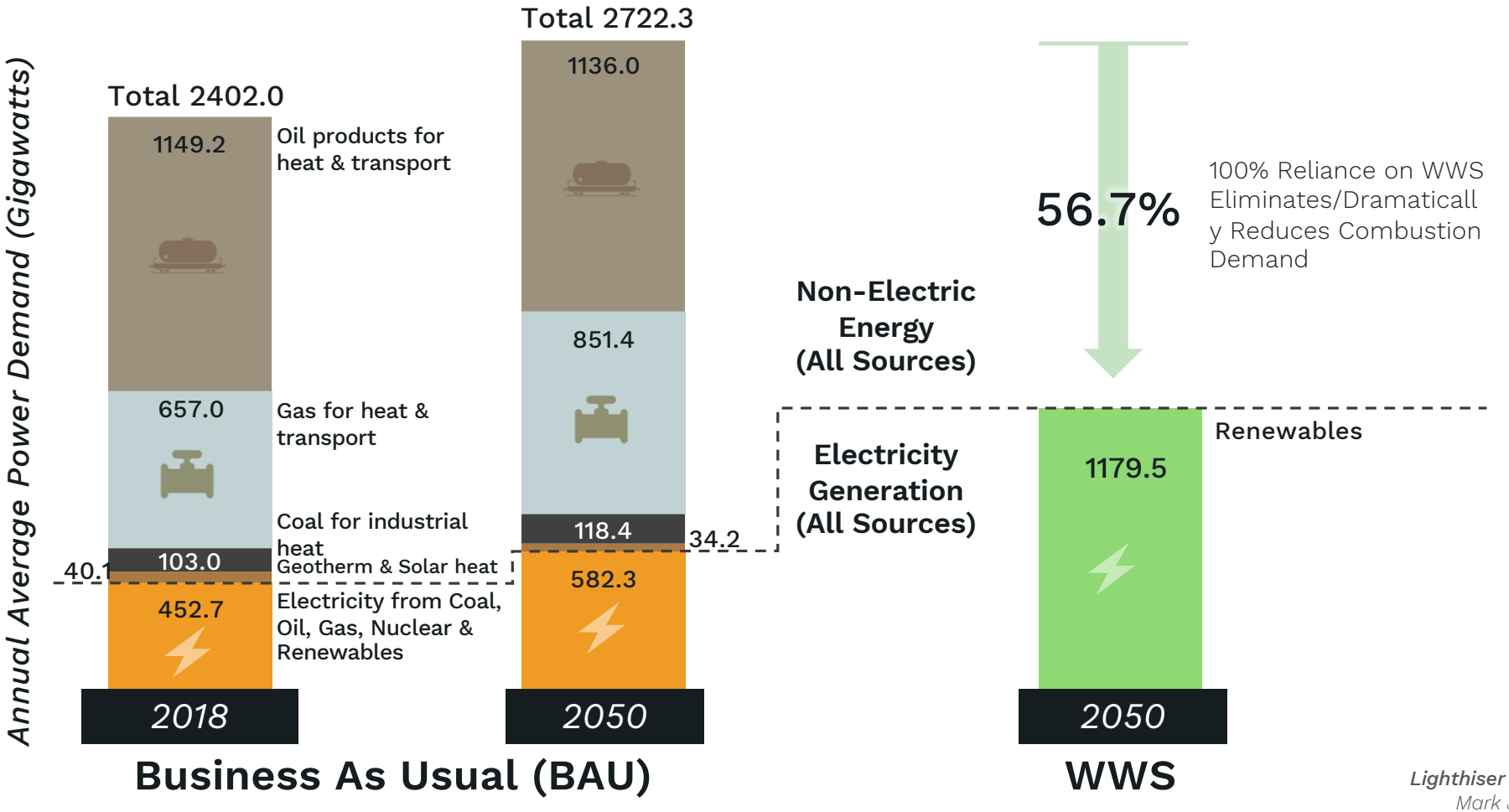
Doc. 1-2
Exhibit 8 p.8

Average U.S. Power Demand, 2018 and 2050



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https //web.stanford.edu/group/efmh/jacobson/Articles/I/21-USStates-PDFs/21-WWS-USATotal.pdf
Exhibit 8 p.9

Five Reasons 100% WWS Reduces Demand by 56.7%

1. Electric transportation is more efficient than internal-combustion-engine transportation. (22.5% Reduction)

2. Heat pumps for air and water heating & air conditioning are more efficient than combustion heaters. (10.3% Reduction)

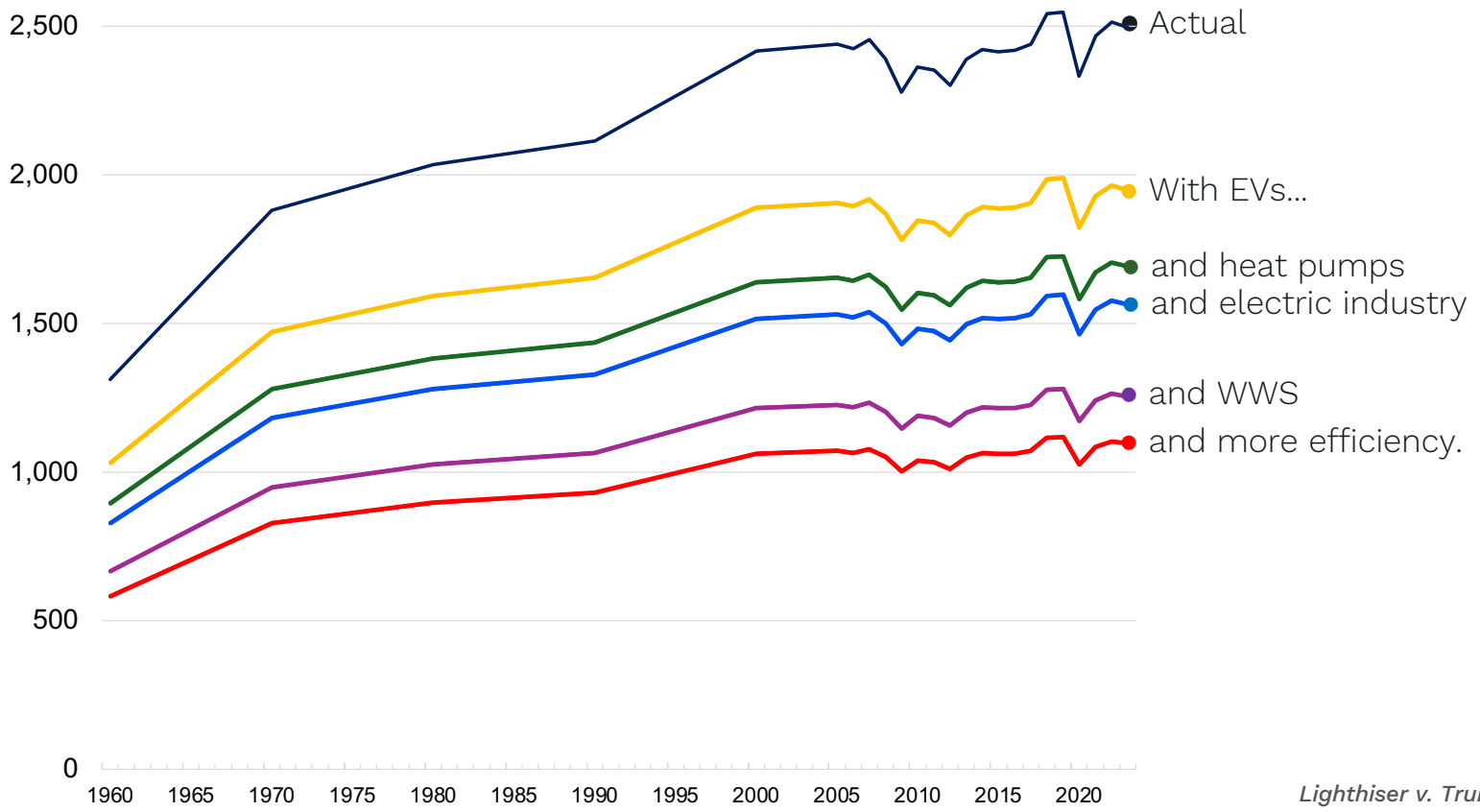
3. Electric heating is more efficient than combustion heating for industry. (5.1% Reduction)

4. WWS eliminates energy needed to mine, transport, and refine fossil fuels and uranium. (12.4% Reduction)

5. WWS increases end-use energy-efficiency improvements beyond those in a business-as-usual case. (6.3% Reduction)

U.S. Power Supply/Demand with Electrification

U.S. all-sector annual-average end-use power supply and demand (GW) from 1960 through 2023



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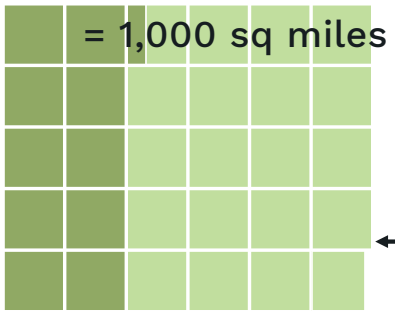
Source of base data Table CT3 https //www.eia.gov/state/seds/sep_use/notes/use_print.pdf
Source of reductions https //web.stanford.edu/group/efmh/jacobson/Articles/I/21-USStates-PDFs/21-USStatesPaper.pdf
Exhibit 8 p.11

U.S. Land Area for Wind Water & Solar vs Oil & Gas



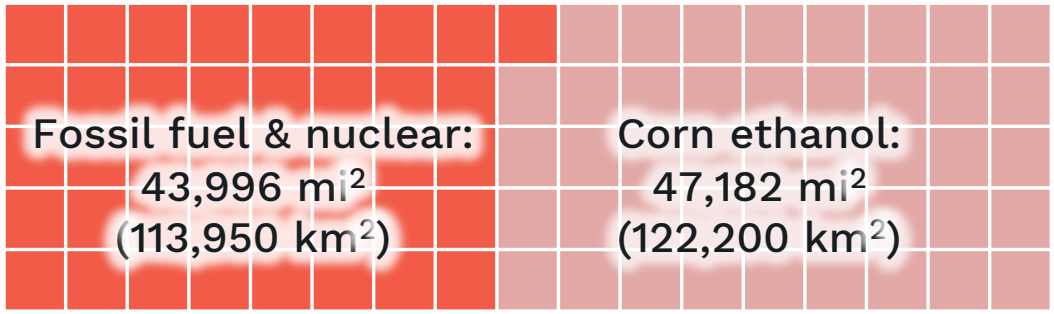
Total for WWS 2050:

29,891 mi² (77,418 km²)

0.85% of U.S. Land

← **Spacing Area: 19,558 mi² (50,655 km²)**
(Between wind turbines)

└ **New Footprint for Solar: 10,333 mi² (26,763 km²)** *(0.29% of U.S. Land)*



Fossil fuels & ethanol:

91,178 mi² (236,150 km²)

2.4% of U.S. Land

- *1.24% of U.S. Land for Ethanol*
- *1.16% of U.S. Land for Fossil Fuels*

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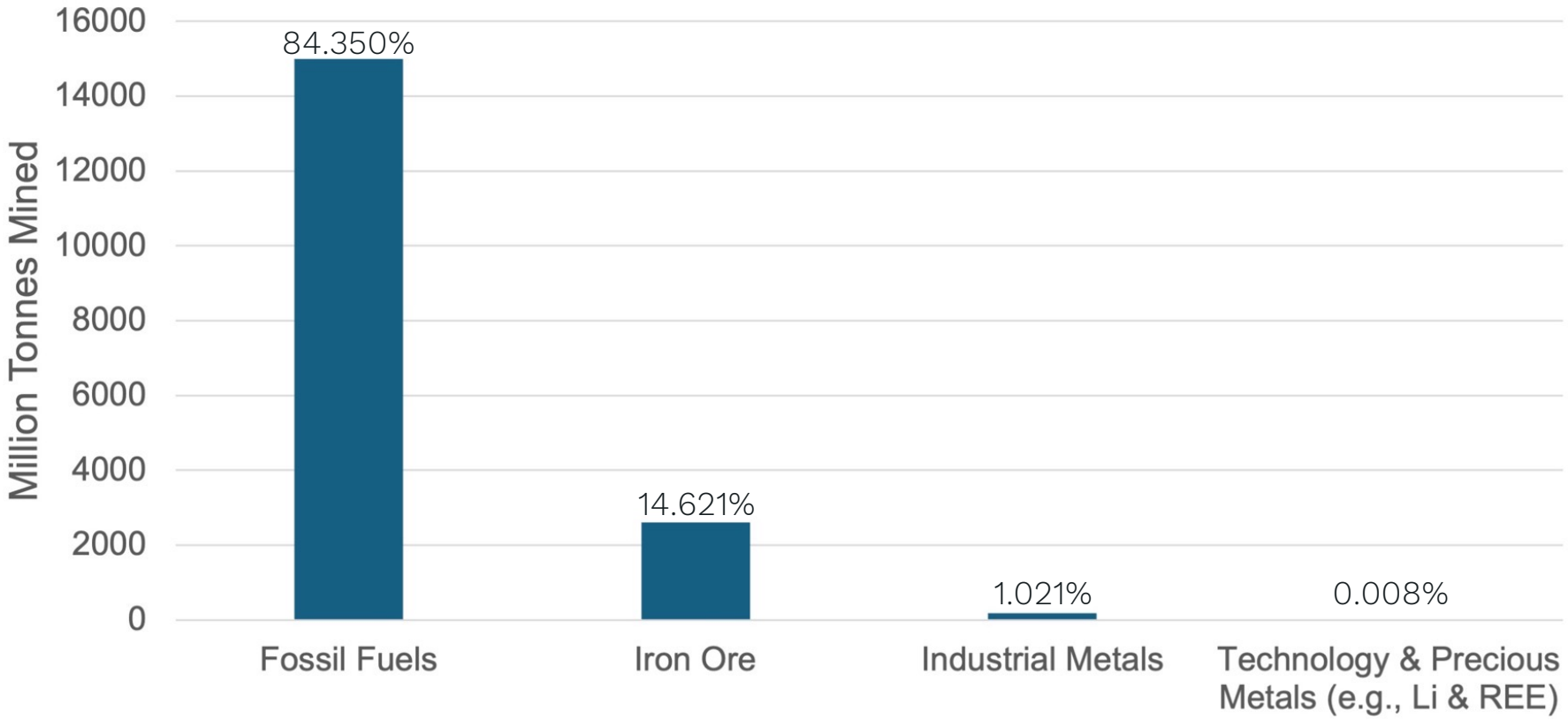
Source of data - https //web.stanford.edu/group/efmh/jacobson/Articles/I/21-USStates-PDFs/21-WWS-USATotal.pdf; https //web.stanford.edu/group/efmh/jacobson/Articles/I/LandFossil.pdf
Exhibit 8 p.12

Purposes of Mining for 2021-2023



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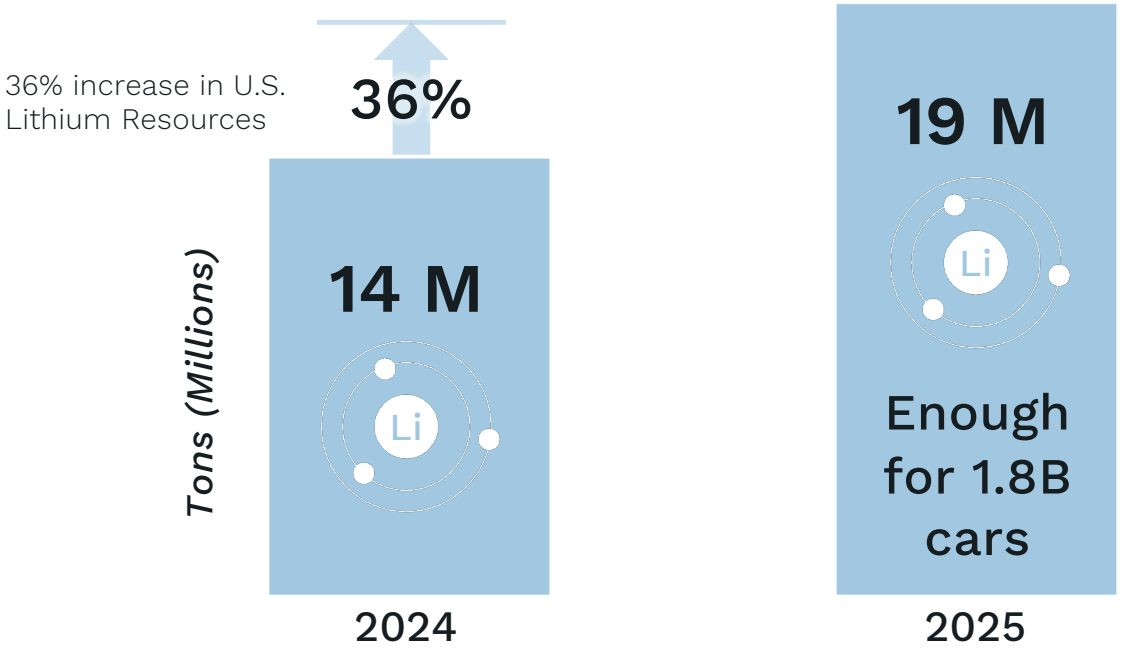
https //www.visualcapitalist.com/all-the-metals-we-mined-in-2021-visualized
Exhibit 8 p.13

USGS, *Lithium Resources*

Increase in U.S. Lithium Resources (2024-2025)



In 2025, the USGS estimated the U.S. had 19 million tons of lithium as known resource.

This was an increase of 36% from their 2024 estimate of 14 million tons.

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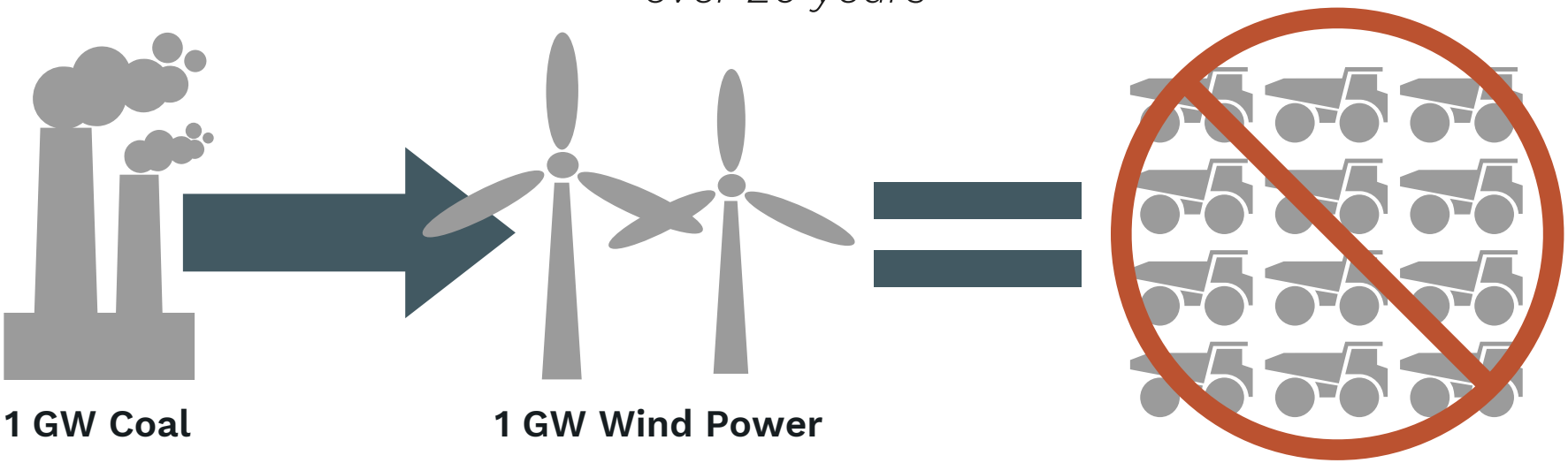
https //pubs.usgs.gov/periodicals/mcs2024/mcs2024-lithium.pdf; https //pubs.usgs.gov/periodicals/mcs2025/mcs2025-lithium.pdf
Exhibit 8 p.14

Coal Mining Replaced by Transitioning to WWS

Replacing 1 GW of Coal with 1 GW of Wind saves 25M tons of coal over 20 years



1 GW Coal

1 GW Wind Power

25 Million Tons of Coal
over 20 years

Jim Krane & Robert Idel, *More Transitions, Less* Risk: How *Renewable Energy Reduces Risks from Mining, Trade and Political Dependence*, 82 Energy Rsch. & Soc. Sci. 102311 (2021).

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https //www.sciencedirect.com/science/article/abs/pii/S2214629621004035
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Transition from Abandoned Wells to Wind

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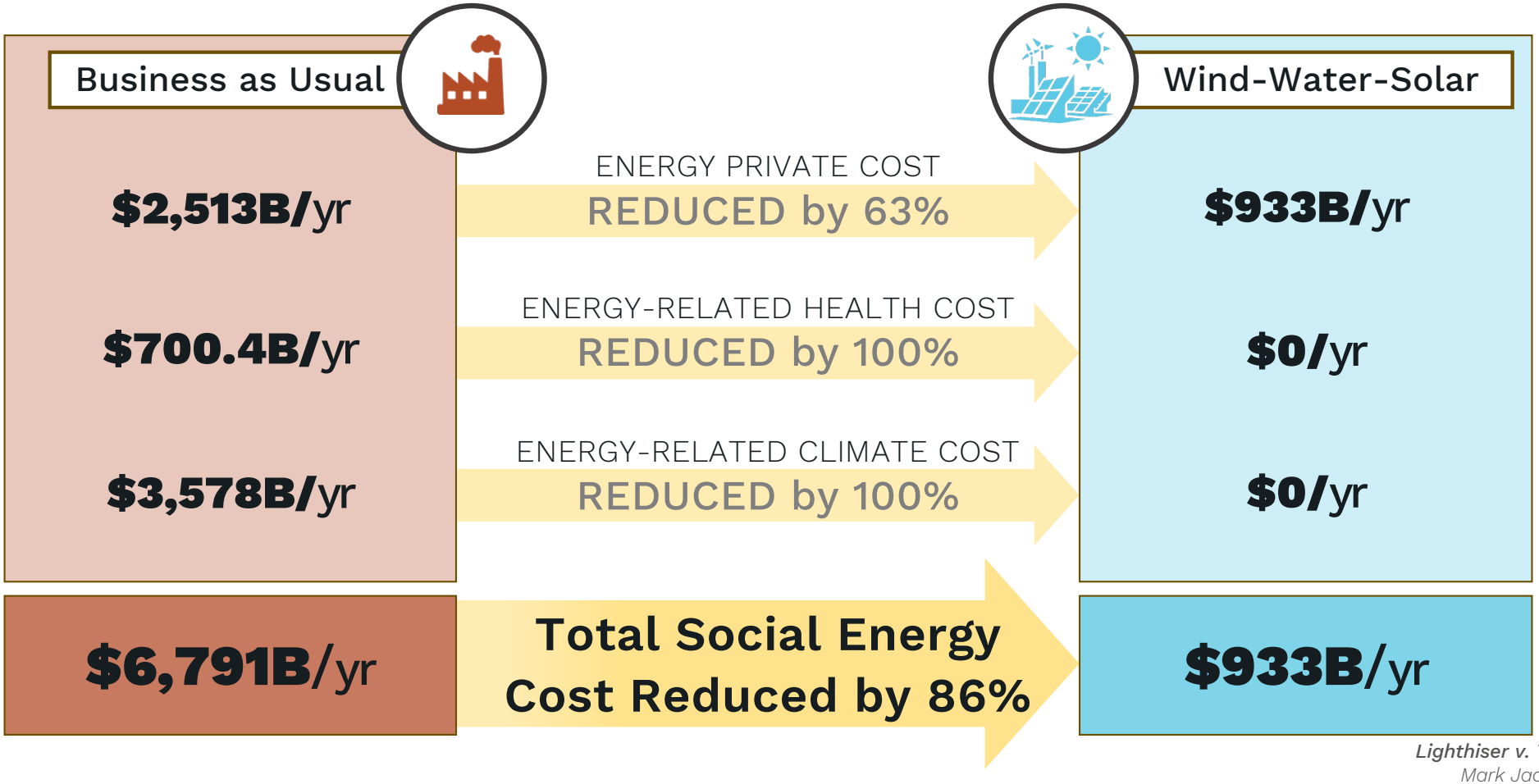
Image credit https //nationalaglawcenter.org/cleanup-of-abandoned-oilfield-locations-who-is-responsible/
Exhibit 8 p.16

WWS Reduces Annual U.S. Energy Costs Significantly



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https //web.stanford.edu/group/efmh/jacobson/Articles/I/21-USStates-PDFs/21-WWS-USATotal.pdf
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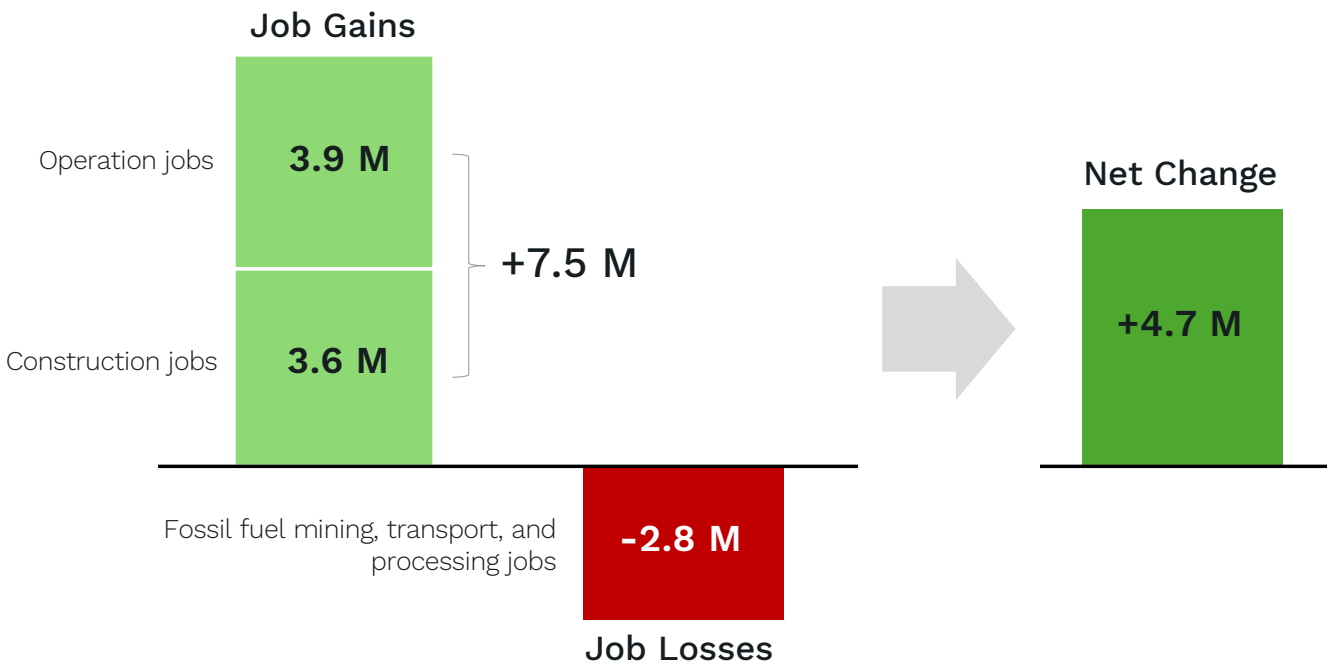
Net U.S. Job Gains Under 100% WWS by 2050



Mark Z. Jacobson et al., *Zero Air Pollution and Zero Carbon from All Energy at Low Cost and Without Blackouts in Variable Weather Throughout the U.S. with 100% Wind-Water-Solar and Storage*, 184 Renewable Energy 430 (2022).

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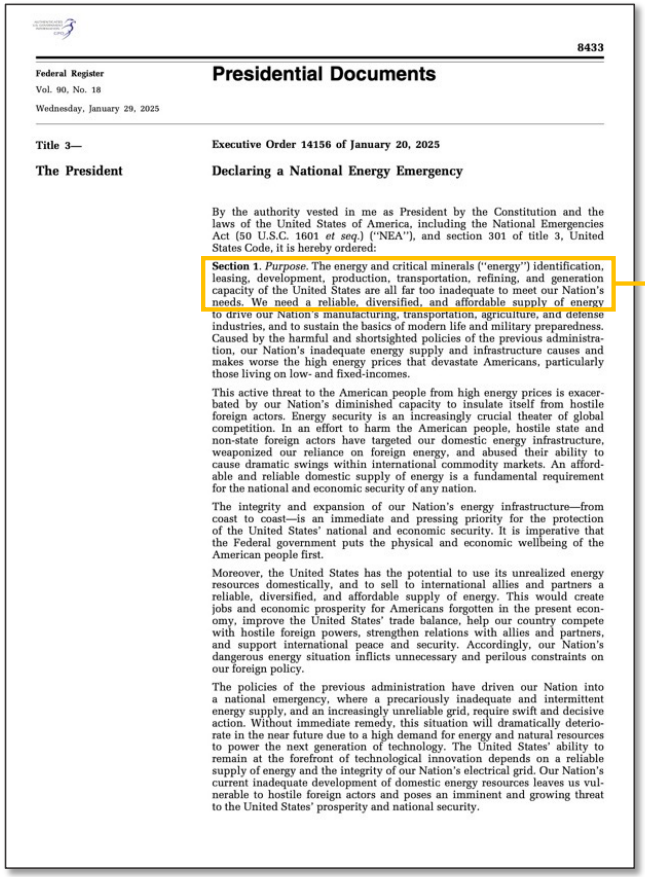
Exhibit 8 p.18

Executive Order 14156



8433

Federal Register
Vol. 90, No. 18
Wednesday, January 29, 2025

Presidential Documents

Title 3—
The President

Executive Order 14156 of January 20, 2025

Declaring a National Energy Emergency

By the authority vested in me as President by the Constitution and the laws of the United States of America, including the National Emergencies Act (50 U.S.C. 1601 *et seq.*) ("NEA"), and section 301 of title 3, United States Code, it is hereby ordered:

Section 1. *Purpose.* The energy and critical minerals ("energy") identification, leasing, development, production, transportation, refining, and generation capacity of the United States are all far too inadequate to meet our Nation's needs. We need a reliable, diversified, and affordable supply of energy to drive our Nation's manufacturing, transportation, agriculture, and defense industries, and to sustain the basics of modern life and military preparedness. Caused by the harmful and shortsighted policies of the previous administration, our Nation's inadequate energy supply and infrastructure causes and makes worse the high energy prices that devastate Americans, particularly those living on low- and fixed-incomes.

This active threat to the American people from high energy prices is exacerbated by our Nation's diminished capacity to insulate itself from hostile foreign actors. Energy security is an increasingly crucial theater of global competition. In an effort to harm the American people, hostile state and non-state foreign actors have targeted our domestic energy infrastructure, weaponized our reliance on foreign energy, and abused their ability to cause dramatic swings within international commodity markets. An affordable and reliable domestic supply of energy is a fundamental requirement for the national and economic security of any nation.

The integrity and expansion of our Nation's energy infrastructure—from coast to coast—is an immediate and pressing priority for the protection of the United States' national and economic security. It is imperative that the Federal government puts the physical and economic wellbeing of the American people first.

Moreover, the United States has the potential to use its unrealized energy resources domestically, and to sell to international allies and partners a reliable, diversified, and affordable supply of energy. This would create jobs and economic prosperity for Americans forgotten in the present economy, improve the United States' trade balance, help our country compete with hostile foreign powers, strengthen relations with allies and partners, and support international peace and security. Accordingly, our Nation's dangerous energy situation inflicts unnecessary and perilous constraints on our foreign policy.

The policies of the previous administration have driven our Nation into a national emergency, where a precariously inadequate and intermittent energy supply, and an increasingly unreliable grid, require swift and decisive action. Without immediate remedy, this situation will dramatically deteriorate in the near future due to a high demand for energy and natural resources to power the next generation of technology. The United States' ability to remain at the forefront of technological innovation depends on a reliable supply of energy and the integrity of our Nation's electrical grid. Our Nation's current inadequate development of domestic energy resources leaves us vulnerable to hostile foreign actors and poses an imminent and growing threat to the United States' prosperity and national security.

> The energy and critical minerals ("energy") identification, leasing, development, production, transportation, refining, and generation capacity of the United States are all far too inadequate to meet our Nation's needs.

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Doc. 1-2
Exhibit 8 p.19

Fossil Fuel Energy Insecurity

1. Fossil fuels are a limited and non-renewable resource.
2. Risk of severe power disruption due to the use of large, centralized plants rather than distributed energy (e.g., wind and solar).
3. Environmental and health degradation due to fossil fuel mining and waste.

Renewable Energy & Energy Security

Applications

JDMS

Journal of Defense Modeling and Simulation: Applications, Methodology, Technology
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journals.sagepub.com/home/dms
SAGE

Renewable energy and energy storage to offset diesel generators at expeditionary contingency bases

Scott M Katalenich and Mark Z Jacobson

Abstract

Expeditionary contingency bases (non-permanent, rapidly built, and often remote outposts) for military and non-military applications represent a unique opportunity for renewable energy. Conventional applications rely upon diesel generators to provide electricity. However, the potential exists for renewable energy, improved efficiency, and energy storage to largely offset the diesel consumed by generators. This paper introduces a new methodology for planners to incorporate meteorological data for any location worldwide into a planning tool in order to minimize air pollution and carbon emissions while simultaneously improving the energy security and energy resilience of contingency bases. Benefits of the model apply not just to the military, but also to any organization building an expeditionary base—whether for humanitarian assistance, disaster relief, scientific research, or remote community development. Modeling results demonstrate that contingency bases using energy efficient buildings with batteries, rooftop solar photovoltaics, and vertical axis wind turbines can decrease annual generator diesel consumption by upward of 75% in all major climate zones worldwide, while simultaneously reducing air pollution, carbon emissions, and the risk of combat casualties from resupply missions.

Keywords

Expeditionary/contingency base planning, renewable energy and storage, energy efficiency

1. Introduction

The US Department of Defense (DOD) is the single largest consumer of fuel worldwide.[1,2] In 2011 alone, the US military spent a reported $20 billion on air conditioning in Iraq and Afghanistan.[3] Much of this cost was merely for transporting energy:

> To power an air conditioner at a remote outpost in landlocked Afghanistan, a gallon of fuel has to be shipped into Karachi, Pakistan, then driven 800 miles over 18 days to Afghanistan on roads that are sometimes little more than "improved goat trails ... and you've got risks associated with moving the fuel almost every mile of the way."[3]

In fact, for every gallon of fuel used in Afghanistan, seven gallons were needed to transport it there.[4] Moreover, 18% of all US Army casualties in Iraq and Afghanistan were related to ground resupply operations, and between 2003 and 2007 alone, attacks on logistics convoys resulted in over 3000 wounded or killed in action.[5,6] In addition, the logistics required to assure energy security at military contingency bases (often called forward operating bases, or "FOBs") is no small measure. In the first months of 2008, over 241,000 troops and over 200,000 contractors were deployed to the US Central Command theater of operations, and, at various times, over 500 FOBs existed in Iraq and Afghanistan.[7–9] Approximately one-third of all wartime fuel is used by generators at FOBs, so there exists an opportunity to reduce the inefficiency of current energy consumption.[10] As one general implored: "unleash us from the tether of fuel."[11]

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Toward battery electric and hydrogen fuel cell military vehicles for land, air, and sea

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Battery electric
Hydrogen fuel cell
Clean renewable energy

ABSTRACT

A long-term solution to the climate and air pollution crises facing the world today includes electrification of almost all energy and obtaining that electricity from clean, renewable sources. Whereas electric alternatives exist for nearly all energy sectors, they do not exist for long-distance, heavy passenger aircraft, freight locomotives, or ships. Of particular note, solutions do not currently exist for military combat vehicles, such as armored tanks, oceangoing vessels, and rotary- and fixed-wing aircraft. Some have claimed such transport cannot be transitioned. This study evaluates whether such land, air, and sea vehicles can be replaced with battery electric and/or hydrogen fuel cell equivalents while maintaining vehicle range, mass, volume, and power- or thrust-to-weight ratio characteristics, more parameters than previously evaluated. Here we show that armored tanks, freight trains, boats, oceangoing vessels, helicopters, prop planes, and jumbo jets have potential to transition using identified technological advancements and solutions suggested achievable within literature. Furthermore, we provide an example of the impact to sustainability by showing that transitioning energy for United States Army vehicles could have the equivalent environmental improvement of taking nearly 700,000 passenger cars off the road today.

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1. Introduction

Military vehicles operating on land, in the air, and at sea represent some of the most challenging vehicle types to transition to run on clean, renewable energy. However, transitioning to zero emissions by using battery electric (BE) or hydrogen fuel cell (HFC) systems is critically important. Beyond supporting the similar transition of civilian vehicles, transitioning military vehicles could overcome the inefficiencies and risks of using fossil fuels (FF) in military operations. A U.S. Marine Corps study found that, for every gallon of fuel used in Afghanistan, seven gallons were needed to transport it there [1]. Attacks on resupply operations have resulted in thousands wounded or killed in action [2,3]. Since wind and/or solar power produced directly at contingency bases could recharge batteries or power electrolyzers to produce hydrogen, transitioning military vehicles to BE or HFC systems could potentially save lives. Furthermore, fully-electric military vehicles could significantly reduce greenhouse gas emissions. Still, no study to date has considered the feasibility of transitioning entire military fleets to either BE or HFC vehicles.

Some research suggests that transitioning heavy and/or long-distance vehicles is infeasible [4]. However, such assessments compare just the specific energy and energy density of onboard energy storage instead of considering the whole system. Other studies have enlarged the parameter space by comparing overall system efficiencies of FF burning, internal combustion engine (ICE) systems with BE systems or by benchmarking vehicles in terms of acceleration, gradeability, and speed characteristics [5,6]. This paper goes further and applies a design approach that optimizes efficiency of the whole vehicle system [7].

This study identifies and evaluates four major vehicle characteristics to assess the feasibility of transitioning: mass, volume, range, and either power-to-weight ratio (PWR) or thrust-to-weight ratio (TWR). Furthermore, the study investigates seven critical technologies: electric motor PWR, battery pack specific energy and energy density, hydrogen storage system specific energy and energy density, and HFC stack specific power and power density.

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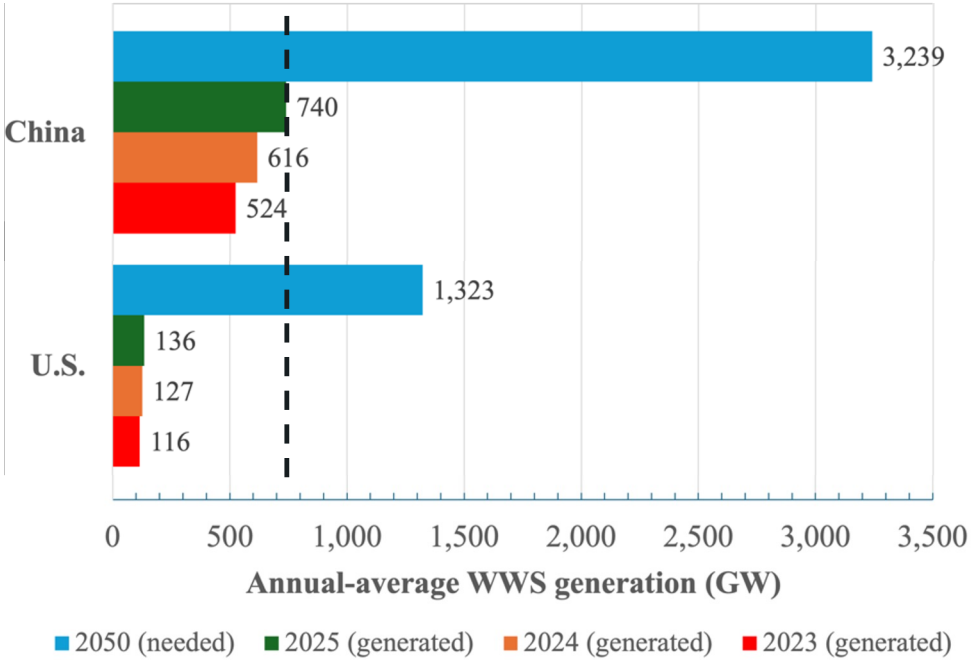
https //web.stanford.edu/group/efmh/jacobson/Articles/Others/21-REforFOBs.pdf;
https //web.stanford.edu/group/efmh/jacobson/Articles/Others/22-BEH2Vehicles.pdf
Exhibit 8 p.21

WWS Power Generation Needed to Meet 100% of All-Sector End-Use Demand in 2050 v. WWS Generation in 2023, 2024, 2025



If all energy sectors are electrified and electricity is provided with WWS ...

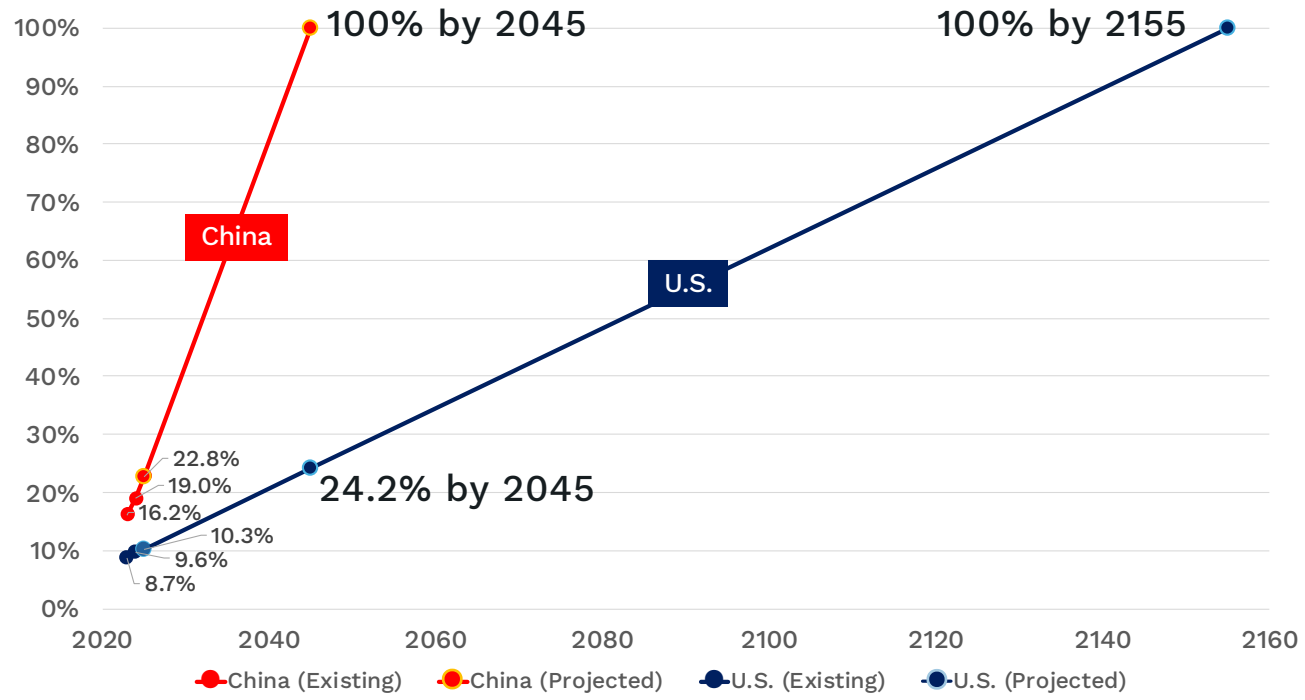
China trajectory for 100% WWS is by: 2045

U.S. trajectory for 100% WWS is by: 2155

The 2050 estimates are from Jacobson et al. (ES&T 59, 3034-3045, 2025), which start with 2022 IEA data. The 2023, 2024, and 2025 estimates are based on actual nameplate capacities and estimated capacity factors from Jacobson et al. (2025).

China is Projected to Reach 100% WWS 110 Years Before the U.S.

Percent of energy needs met by WWS



The 2050 estimates are from Jacobson et al. (ES&T 59, 3034-3045, 2025), which start with 2022 IEA data. The 2023, 2024, and 2025 estimates are based on actual nameplate capacities and estimated capacity factors from Jacobson et al. (2025).

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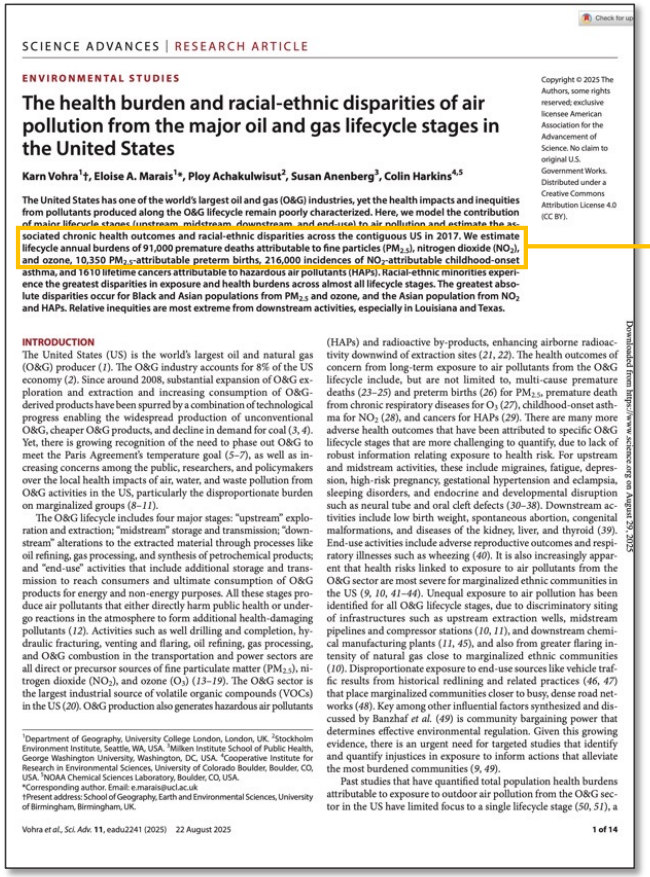
Exhibit 8 p.23

U.S. Premature Deaths from Fossil Fuel Pollution



SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL STUDIES

The health burden and racial-ethnic disparities of air pollution from the major oil and gas lifecycle stages in the United States

Karn Vohra[1]†, Eloise A. Marais[1]*, Ploy Achakulwisut[2], Susan Anenberg[3], Colin Harkins[4,5]

The United States has one of the world's largest oil and gas (O&G) industries, yet the health impacts and inequities from pollutants produced along the O&G lifecycle remain poorly characterized. Here, we model the contribution of major lifecycle stages (upstream, midstream, downstream, and end-use) to air pollution and estimate the associated chronic health outcomes and racial-ethnic disparities across the contiguous US in 2017. We estimate lifecycle annual burdens of 91,000 premature deaths attributable to fine particles ($PM_{2.5}$), nitrogen dioxide (NO_2), and ozone, 10,350 $PM_{2.5}$-attributable preterm births, 216,000 incidences of NO_2-attributable childhood-onset asthma, and 1610 lifetime cancers attributable to hazardous air pollutants (HAPs). Racial-ethnic minorities experience the greatest disparities in exposure and health burdens across almost all lifecycle stages. The greatest absolute disparities occur for Black and Asian populations from $PM_{2.5}$ and ozone, and the Asian population from NO_2 and HAPs. Relative inequities are most extreme from downstream activities, especially in Louisiana and Texas.

INTRODUCTION

The United States (US) is the world's largest oil and natural gas (O&G) producer (*1*). The O&G industry accounts for 8% of the US economy (*2*). Since around 2008, substantial expansion of O&G exploration and extraction and increasing consumption of O&G-derived products have been spurred by a combination of technological progress enabling the widespread production of unconventional O&G, cheaper O&G products, and decline in demand for coal (*3*, *4*). Yet, there is growing recognition of the need to phase out O&G to meet the Paris Agreement's temperature goal (*5*–*7*), as well as increasing concerns among the public, researchers, and policymakers over the local health impacts of air, water, and waste pollution from O&G activities in the US, particularly the disproportionate burden on marginalized groups (*8*–*11*).

The O&G lifecycle includes four major stages: "upstream" exploration and extraction; "midstream" storage and transmission; "downstream" alterations to the extracted material through processes like oil refining, gas processing, and synthesis of petrochemical products; and "end-use" activities that include additional storage and transmission to reach consumers and ultimate consumption of O&G products for energy and non-energy purposes. All these stages produce air pollutants that either directly harm public health or undergo reactions in the atmosphere to form additional health-damaging pollutants (*12*). Activities such as well drilling and completion, hydraulic fracturing, venting and flaring, oil refining, gas processing, and O&G combustion in the transportation and power sectors are all direct or precursor sources of fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3) (*13*–*19*). The O&G sector is the largest industrial source of volatile organic compounds (VOCs) in the US (*20*). O&G production also generates hazardous air pollutants (HAPs) and radioactive by-products, enhancing airborne radioactivity downwind of extraction sites (*21*, *22*). The health outcomes of concern from long-term exposure to air pollutants from the O&G lifecycle include, but are not limited to, multi-cause premature deaths (*23*–*25*) and preterm births (*26*) for $PM_{2.5}$, premature death from chronic respiratory diseases for O_3 (*27*), childhood-onset asthma for NO_2 (*28*), and cancers for HAPs (*29*). There are many more adverse health outcomes that have been attributed to specific O&G lifecycle stages that are more challenging to quantify, due to lack of robust information relating exposure to health risk. For upstream and midstream activities, these include migraines, fatigue, depression, high-risk pregnancy, gestational hypertension and eclampsia, sleeping disorders, and endocrine and developmental disruption such as neural tube and oral cleft defects (*30*–*38*). Downstream activities include low birth weight, spontaneous abortion, congenital malformations, and diseases of the kidney, liver, and thyroid (*39*). End-use activities include adverse reproductive outcomes and respiratory illnesses such as wheezing (*40*). It is also increasingly apparent that health risks linked to exposure to air pollutants from the O&G sector are most severe for marginalized ethnic communities in the US (*9*, *10*, *41*–*44*). Unequal exposure to air pollution has been identified for all O&G lifecycle stages, due to discriminatory siting of infrastructures such as upstream extraction wells, midstream pipelines and compressor stations (*10*, *11*), and downstream chemical manufacturing plants (*11*, *45*), and also from greater flaring intensity of natural gas close to marginalized ethnic communities (*10*). Disproportionate exposure to end-use sources like vehicle traffic results from historical redlining and related practices (*46*, *47*) that place marginalized communities closer to busy, dense road networks (*48*). Key among other influential factors synthesized and discussed by Banzhaf *et al.* (*49*) is community bargaining power that determines effective environmental regulation. Given this growing evidence, there is an urgent need for targeted studies that identify and quantify injustices in exposure to inform actions that alleviate the most burdened communities (*9*, *49*).

Past studies that have quantified total population health burdens attributable to exposure to outdoor air pollution from the O&G sector in the US have limited focus to a single lifecycle stage (*50*, *51*), a

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We estimate [oil & gas] lifecycle annual burdens of 91,000 premature deaths attributable to fine particles ($PM_{2.5}$), nitrogen dioxide (NO_2), and ozone

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Exhibit 8 p.24