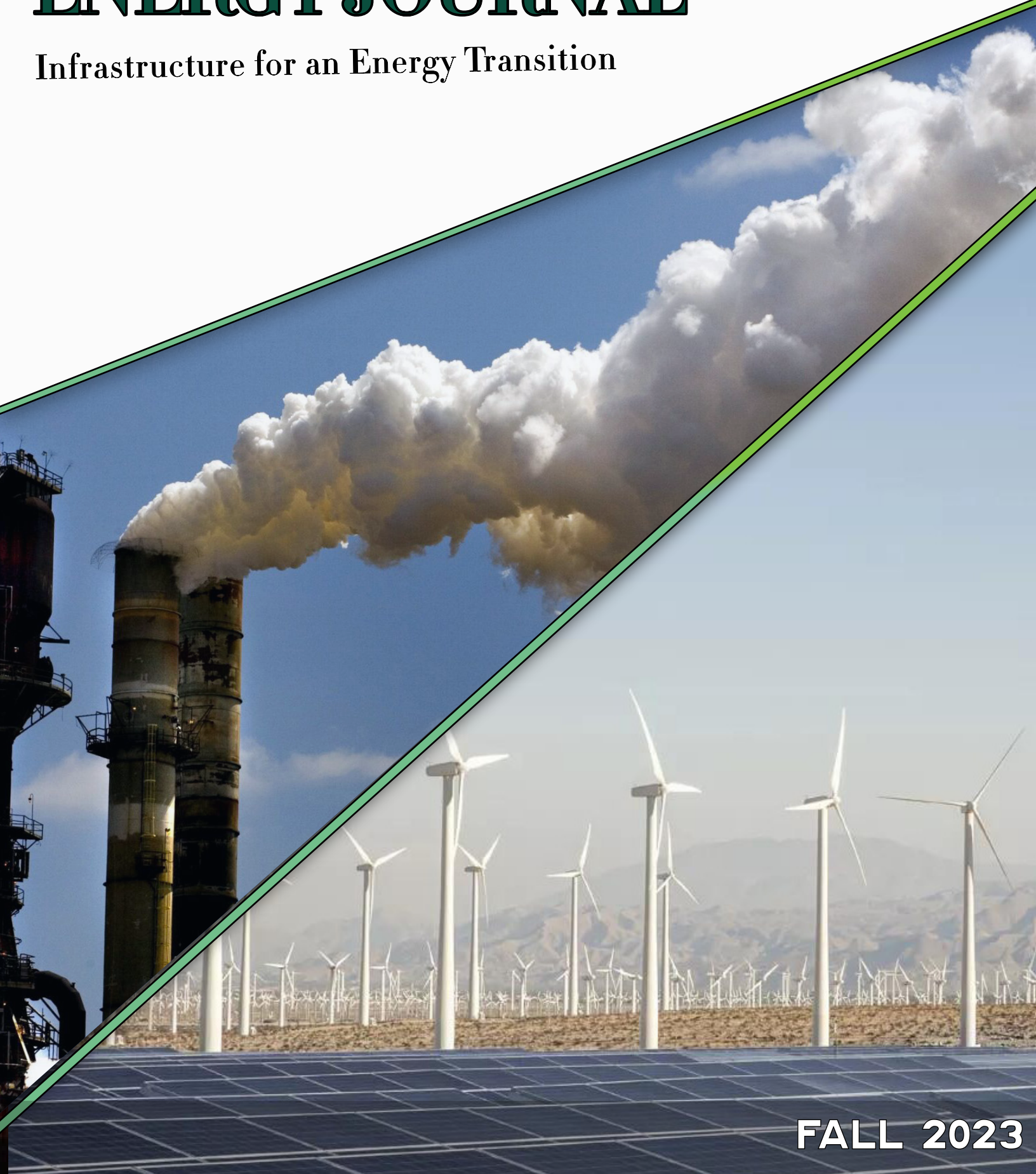


PRINCETON ENERGY JOURNAL



Infrastructure for an Energy Transition



FALL 2023

Acknowledgements

Thank you to the following supporters and sponsors of the Princeton Energy Association:



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Opening Statements

As the tenth President of Princeton University Energy Association (PUEA), I am proud to introduce the first edition of our undergraduate journal. The mission of the PUEA is to educate students of all backgrounds about the energy sector. This journal is the product of that vision, aimed at sharing knowledge about the energy transition from the perspective of students passionate about being part of it. Our student contributors spent time researching, writing, and editing articles while balancing a full class schedule out of a deep interest in energy and clean technology. I am truly proud of every member of our team. They are among the best and brightest students at Princeton University, and I'm truly grateful for having the opportunity to work with them. I hope you enjoy reading the inaugural edition of the Princeton Energy Journal. Please feel free to contact me at vkonuru@princeton.edu.

Sincerely,
Vinay Konuru '24
President
December 2023



It is my great joy to commend the students of the Princeton University Energy Association (PUEA) on their first edition of the Princeton Energy Journal. Participating in PUEA's energy conference and listening to senior thesis presentations of Sustainable Energy certificate earners belong to the most enriching highlights of my brief tenure as Interim Director of the Andlinger Center for Energy and the Environment. This dyad of talks and senior theses is now complemented by the collection of journal-length scientific papers. The breadth and depth of the papers presented in this first issue is indeed exceptional and wonderfully showcases the cutting-edge research carried out by the students in and around the PUEA and Princeton University more broadly. Congratulations to the authors and editors on their first edition of the Princeton Energy Journal. Your commitment to excellence gives hope to the world.

Claire F. Gmachl
*Eugene Higgins Professor
Electrical and Computer Engineering
Interim Director ACEE
Head of Whitman College
Princeton University*



As the director of the first PUEA Energy Journal, it is with great pleasure that I present our inaugural edition. It showcases the work of our dedicated members, all of whom were driven by passion and interest alone to embark on an exploration into the energy industry.

Thinking back on the journal, I recall a conversation I had with our president, Vinay, when first starting the project. We were trying to decide on a topic for the first edition. While we wanted it to have focus, we also discussed the need for flexibility. Essentially, we wanted member interests to guide the paper, not the other way around. By choosing a broad topic – “Infrastructure for an Energy Transition” – we strove to establish a common theme while allowing individual passions to drive writing. For this reason, articles in this journal cover an array of infrastructure-related topics, from legislation like the Inflation Reduction Act to battery technologies and the Chinese EV market. These were the genuine topics our members chose to pursue through writing. We hope you enjoy learning about our interests and experiences through this journal.

Thank you for your support and I hope you enjoy the read! For any questions, feedback, or inquiries, don't hesitate to reach me at camfarid@princeton.edu.

All the best,
Cameron Farid '26
Journal Director
December 2023



Professor Robert H. Socolow: Inaugural Message

Professor Socolow joined the Princeton faculty in 1971 with the mandate to invent and lead a multi-disciplinary technology-based energy center in the School of Engineering and Applied Science.

He has played a leading role in the Center for Energy and Environmental Studies, the High Meadows Environmental Institute, and the Andlinger Center for Energy and the Environment. He led the writing of five Andlinger Center “energy distillates” on low-carbon energy technologies (batteries, nuclear fission, nuclear fusion, solar, and wind). He is the co-winner of the 2023 John Scott Award, the oldest award for science in the United States.

In 1971 the Center for Environmental Studies was launched in the School of Engineering and Applied Science. (I was hired to invent its research, and I never looked back.) In 1974 the Center was renamed the Center for Energy and Environmental Studies. The novelty of “environment” was thrust upon academia as humans absorbed startling images of Earth taken from space, and the novelty of “energy” emerged as a second cross-cutting theme with the 1973 Arab Oil Embargo. It is almost exactly a half-century later, and – worth waiting for – Princeton undergraduates have launched their own energy journal. May it prosper and prove durable!

This inaugural issue contains 10 articles, each carefully referenced, on topics relevant to “the energy transition,” the next half-century or so (roughly the period the contributors’ careers), during which the world’s current commercial

energy system is expected to be swapped for one where fossil fuels, now dominant, become subordinate players. The ten articles are wide-ranging, and all, as intended, are accessible for the non-specialist. In their introductory welcoming statements, both Cameron Farid ’26 (head of the Princeton Energy Journal “team”) and Vinay Konuru ’24 (President of the parent Princeton University Energy Association) use the word “passion” to describe what has animated the journal – indeed, I would say, not only the individual articles, but the initiative as an entirety.

I hope that new journal will become a new Princeton institution. Student autonomy will be crucial to its success. So will be a demonstrated fierce independence on the part of its authors, complemented by broad article recruitment (beyond any “in-group”) and thoughtful peer review (not too strict, but nonetheless creating a way to say No). Down the road, perhaps some debates will be included, as well as some articles dedicated to climate science (what sorts of threats are we facing?) and to values (where do lifestyles and bucket lists fit in?). As for doing the “transition” well, that task requires not only the artful scaling up of alternatives but also the wholesome scaling down of the current system, a source of its own worthy topics.

Robert H Socolow

Professor emeritus,
Department of Mechanical
and Aerospace Engineering
January 8, 2024





Table of Contents

The U.S. Grid Needs an Overhaul - <i>Wilder Crosier '25</i>	5-7
A Critical Analysis of Nuclear Fission Rhetoric - <i>Alex Tseng '26</i>	8-10
Propane: An Underrated Fuel of the Future - <i>Cameron Farid '26</i>	11-13
The Inflation Reduction Act, Supply Chains, and the Changing Landscape of Energy in America - <i>Gabriella Myslo '26</i>	14-15
Alumnus Feature: Then and Now: Rural Energy Infrastructure is Vulnerable and Costly - <i>Angelo Campus '16</i>	16-18
The Future of Battery Technology - <i>Suhas Kanamarlapudi '24</i>	19-20
Refining Rare Earth Metals in the United States - <i>Stone Yang '24</i>	21
The Transition to Nuclear Propulsion in Naval Submarines - <i>Andrew Ryan '26</i>	22-23
China's EV Market: Growth, Challenges, and Concerns - <i>Siling Song '26</i>	24-25
The Double-Edged Sword of Direct Air Carbon Capture - <i>Vinay Konuru '24</i>	26-27

The U.S. Grid Needs an Overhaul

Author: Wilder Crosier

At 5:48 pm on September 6, 2022, 27 million cell phones on the West Coast buzzed with emergency alerts. The California ISO, the state’s non-profit electricity manager, urged residents to raise thermostats above 78 °F and unplug electronics until nighttime [1]. Amidst a massive heat wave, CAISO’s system set a record of over 52,000 megawatts of peak demand [2]. As the sun would soon set, the organization worried that a drop off in solar power supply will force outages for hundreds of thousands of residents. The community responded to the emergency message by reducing over 2,000 megawatts of demand, avoiding blackouts. This near outage in California may foreshadow future reliability problems across America. With the combination of increased demand due to electrification and variable supply from renewables, our antiquated electricity grid will not be able to handle our future power needs.

The U.S. electricity grid is the largest machine in the world. From the Great Plains to the Mid-Atlantic, thousands of power plants send electricity along 160,000 miles of crisscrossing high voltage power lines. These transmission lines reach substations where the voltage is stepped down and sent through smaller distribution cables to power everything from car factories and internet servers to MRI machines and the lights in your home [3].

Electricity is a desirable form of energy. It doesn’t need to be loaded on ships or stored in barrels. It can’t be burned improperly to produce toxic carbon monoxide. And it is more efficient when powering motors and lights. Because of electricity’s many

advantages, societies are becoming electrified. Fig.1 shows the steep increase in American electricity production in the second half of the 20th century. Notably, electricity supply has remained stagnant over the past 15 years, largely due to efficiency improvements of demand-side technologies [4]. However, this plateau is expected to change in the coming decades as sectors such as heating and transportation experience electrification. In the Net-Zero America Project, researchers at Princeton University projected that if the U.S. meets its goal of zero net carbon emissions by 2050, electricity demand will increase by two to four times [5].

Even a two-fold increase in electricity demand would lead to serious problems for the grid. Already, our power systems are starting to age and decay. In their last technology review in 2015, the Department of Energy found that over 70% of the grid’s transmission lines and power transformers are more than halfway through their 50-year lifetime. The report explains that “the age of these components degrades their ability to withstand physical stresses and can result in higher failure rates” [6]. Indeed, a study by Reuters found the past six years have seen twice as many power outages as the preceding six [7]. Without substantial investment, the expected increase in demand due to the electrification of various sectors of the economy will lead to grid failures and blackouts.

Author Spotlight



Wilder Crosier is a member of the class of 2025 studying physics. He is interested in applied math, modeling, and energy systems.

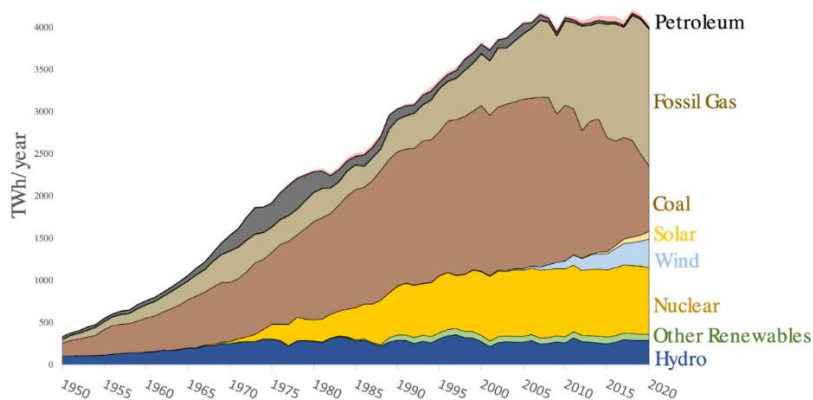


Figure 1: U.S. electricity production by source over time. In 2021, electricity production came from 38% gas, 22% coal, 19% nuclear, 9% wind, 6% hydro, 3% solar, and 3% other sources.

Source: [Kaj Tallungs](#) own work. Data source: [U.S. Energy Information Administration](#).

In addition to increased demand for electricity, the energy transition will include the widespread introduction of renewable sources. To eliminate emissions by 2050, the Net-Zero America Project found that solar capacity will need to increase by somewhere between 9 and 39 times and wind capacity by between 6 and 28 times their levels in 2020. While these estimates have a wide range, any scenario requires solar and wind projects to be added to the grid at “historically unprecedented rates” [5]. Without rebuilding and expanding the U.S. power grid, our energy transition goals will not become a reality.

The current U.S. grid cannot support such an increase in renewable energy projects for two main reasons: connection bottlenecks and supply variability. For decades, grid operators have reviewed proposals for new power plants on a “first-come, first served” basis. For each proposal, they conduct in-depth analysis to ensure the project will not disrupt the current grid. In the past, a limited number of proposals for large coal and gas plants were made each year, so this policy worked well. In recent years however, thousands of smaller renewable energy projects have created long interconnection queues for developers [8]. In 2020, 5,600 projects were waiting for permission to connect to the grid. By 2022, that number jumped to

over 10,000, with solar and battery projects accounting for 80% of the new proposals [9]. In July 2023, the Federal Energy Regulatory Commission announced new rules for transmission providers including a switch to a “first-ready, first served” policy for proposal review [10]. While the policy changes will help bottlenecks, the long wait times in queues are still leading to the eventual scrapping of four out of every five proposals.

In addition to connection challenges, the current grid cannot support the energy transition due to supply-side uncertainty introduced by renewables. The grid needs to provide a reliable voltage and frequency within a narrow range. Solar and wind power generation experiences both daily and seasonal variation, as well as uncertainty due to the weather. When their output falls, other sources ramp up to meet demand. This system works fine today because only 12% of electricity comes from wind and solar (Fig.1). As we reduce our reliance on fossil fuels, however, shutting down conventional power plants decreases this ramping capability and compromises the reliability of the grid [11]. In severe weather events, such as California’s heat wave last September, blackouts become more likely.

To stop strangling renewable energy projects and ensure a future of reliable, clean energy in America, we need to overhaul the electricity grid. There are



two key paths towards improving our grid: firstly, we need substantial investment in the grid's aging infrastructure, and secondly, we need a long-term transition of grid architecture from its current centralized structure to a more dynamic, distributed approach. To ensure we have the capacity to support future energy needs—and do so reliably—we need to spend money to update grid hardware such as cables and transformers. The most important infrastructure improvement will be expanding high-voltage transmission lines. Because wind and solar power are often generated in rural areas, we will need new lines to support its transport. Additionally, increasing these transmission lines allows for energy sharing across state lines, a necessary feature for a grid with large amounts of variable renewable energy.

Funds from the 2022 Inflation Reduction Act (IRA) have supported both the energy transition and grid infrastructure. Wind and solar projects have received tax credits, and \$3 billion has been allocated to build out transmission lines [12, 13]. However, some experts believe our investment in transmission lines must be closer to \$20 billion or \$30 billion per year [14]. Historically, rates of transmission line growth have been around 1% annually. Research out of Princeton University's Zero Lab found that if transmission expansion is kept at this rate, 80% of the potential emissions reductions from the IRA would be lost. To reap the full carbon reduction benefits of the IRA, the

researchers explain we need to expand transmission lines by 2.3% each year [15].

In addition to direct investment, we need a long-term shift in grid architecture to support 100% renewables. The grid was built to run on big, centralized power plants. Even today, 80% of electricity comes from large gas, coal, and nuclear plants. The shift to renewable sources will include many smaller-scale wind, solar, and battery projects. Additionally, many homes may have their own batteries, solar panels, and electric vehicles. As the way we produce and store electricity changes, the way we transport and deliver it should change as well. Much research and development has gone into creating these improved technologies under the name of smart grids. These modern smart grids will use digital technology to allow for two-way communication between customers and utility companies. With increased information and greater control capabilities, smart grids can reduce peak demand, restore power quickly following disturbances, and better integrate renewable technologies like wind farms and home batteries [16]. The shift away from conventional gas and coal power plants will create serious challenges if we do not invest substantially in grid improvements. With further research and the development of new grid architectures and technologies, we can create a system that efficiently delivers clean and reliable power.

A Critical Analysis of Nuclear Fission Rhetoric

Author: Alex Tseng

The continued use of fossil fuels in energy production is a major contributor to greenhouse gas (GHG) emissions and in turn climate change [1]. Given the environmental, economic, social, and ecological impacts of climate change, finding an emission-free form of reliable energy is key for sustainable development in the next century. Nuclear fission, which is a proven, emission-free source of baseload electricity, has the ability to fill this critical role [2,3]. While nuclear *fusion* remains decades away, other energy sources – including solar and wind – struggle from problems in intermittency, cost, grid infrastructure, and development [2]. Thus, increased use of nuclear fission energy is key to reducing global emissions and fighting climate change [2]. To quantitatively understand the scale of the nuclear energy industry and its impact on climate change: nuclear reactors have prevented 55 gigatons of CO₂ emissions in the last fifty years – that is nearly two years of all energy related emissions [4].

However, despite the need to increase nuclear energy production, the fission industry has started to die; about 25% of existing nuclear capacity is expected to shut down by 2025, with little new investment [4]. One is naturally led to wonder why this is: why the technology which may save us is slowly fading into the background. As many scholars have studied, a major reason for this death is public fear, skepticism, and dissent [5]. Additional critiques and questions about safety, sustainability, and economic viability have been raised and continue to challenge fission energy [6]. Historically, anti-nuclear campaigns have also gained large audiences, providing further hindrance to the development of fission [7–9].

In a larger project – out of the scope of this journal – we completed a rhetorical analysis of nuclear fission energy, examining the extent to which

Author Spotlight



Alex is an Electrical and Computer Engineering major with certificates in Creative Writing and Sustainable Energy. He is interested in sustainable energy production including solar, nuclear, and energy storage technology.

problems associated with fission are rhetorical. The project was organized in two parts: The first was an extensive literary analysis of historical and contemporary rhetorical frameworks and the current fundamental flaws of fission rhetoric. The second part explored possible solutions to resolving these flaws. Specifically, problems facing nuclear fission – such as nuclear waste, governmental oversight, economic viability, fuel, proliferation, safety, and negative impacts on indigenous communities – were interpreted as rhetorical as opposed to the common notion that they are solely technological. Such an examination provided praxis to an otherwise theoretical research project: connecting discursive solutions to material improvement of the fission industry.

Through the first stage of our research, we discovered two unique problems facing nuclear fission rhetoric. The first is a divide between anti-fission and pro-fission rhetoric in academic spaces. Despite a lack of exclusivity, these two camps have failed to recognize each other. This dichotomy has prevented a cooperative, and therefore productive, model of fission rhetoric. The second is a continuance of negative nuclear stigmas which come from a complex combination of anti-nuclear rhetorical packages developed throughout the late 20th century.

In the second stage, our research developed a contextualized understanding of how possible solutions in rhetoric could operate and resolve tensions in the material industry. Such examination also suggested the rhetorical nature of problems such as nuclear waste, government oversight, economic viability, limited fuel, proliferation, safety, and indigenous harm. Thus, this paper finds two key assertions: 1) Nuclear fission rhetoric is counterproductive and produces undue negative impacts on the industry and 2) resolution of the aforementioned rhetorical problems has the potential to greatly improve the productivity of the nuclear fission discursive space.

Using analyses of specific problems facing the nuclear industry, our research found possible solutions to resolving this rhetorical crisis. Key tenants of an improved fission rhetoric include:

Focus on Climate Change Mitigation: Fission is one of our most powerful tools against combating emissions [2] and should be portrayed as such. Given a history steeped in techno-utopian discourse, fission has only recently become seen as “green” in the public’s eye [10]. Thus, anti-fission sentiment has largely originated from environmental groups, whose emphasis on localized incidents of nuclear harm has begun to taint fission’s rhetorical connection to environmentalism. Instead, fission should be advertised first and foremost as a clean energy. By focusing on nuclear fission’s potential to achieve climate change mitigation, large divides in pro and anti-fission rhetoric can be deconstructed. Implications include: cooperation between environmental groups and the fission industry; improved investment in nuclear energy; funded research of fast reactors, efficient fuel systems, and long burning; popularization with the public and increased government support; and dissociation with negative environmental impacts.

Recognition of Risk: Trust, transparency, and communication are fundamental tenets of healthy technical-public relations [11] but have been absent in rhetorical frameworks [9]. Additionally, anti-fission rhetoric has historically been a result of, in

part, the lack of government and corporate transparency, which has fostered fear and apprehension of the unknown [9,12]. This lack of transparency paired with the Three Mile Island, Fukushima, and Chernobyl disasters have exacerbated poor public trust. Thus, the fission industry must stop trying to present itself as perfect but instead make a conscious effort to gain public trust by disclosing the dangers of nuclear fission. A possible position the industry could take is a stance of optimistic caution: continuing to inform the population of current safety measures while recognizing and acknowledging the risks. Two key impacts of this include: 1) keeping the government and industry alert and accountable. Such could prevent the complacency and incompetence that led to the disasters of TMI and Fukushima; 2) rebuilding trust in the community. This would entail improved cooperation, funding, government assistance, and acceptance in the event of a disaster. Additionally, trust and transparency will have major roles in fostering more productive and cooperative forms of HLW disposal – as well as public acceptance of the permanence of nuclear waste.

Dissociation with Cold War Rhetorical

Frameworks: This category encompasses many important factors such as: 1) Differentiating nuclear energy from nuclear weapons. Because the all-too-common equating of nuclear energy with nuclear weapons is a long-term misconception affecting public sentiment and attitude towards nuclear fission, the dissociation of nuclear energy from nuclear weapons will require an active and ongoing process. This is not only key to fission rhetoric, but also for the future of nuclear fusion, a promising new method of sourcing energy; 2) Creation and dissemination of pragmatic goals. Over-promising has plagued nuclear fission and must stop. Given its current economic strength compared to solar and wind, fission does not need to overestimate the economic returns it can offer. Reducing such expectations could play a large role in promoting generation three and four reactors, which resolve many of fissions previous problems, but at slightly higher price tags; 3) Dissociation with bureaucracy, capitalism, and discrimination. Historically, anti-

fission rhetoric has targeted the corporate reputation of nuclear fission [9]. Because reactors are so large, and have often been placed in marginalized communities [13], the fight against fission has become the fight against greed, capitalism, and destruction. In a world which prioritizes ecological and impact sensitivity, fission must dissociate from this historical portrayal.

These three points constitute the most important rhetorical changes that this critical analysis has identified. Although it is beyond the ability of this paper, or our more general research, to discuss every specific change and implication that could be implemented, it is left to the reader to take these key concepts and apply them to individual cases.

At the highest level, however, these rhetorical shifts provide the strong and necessary basis to break the dichotomy of pro and anti-fission rhetoric and destigmatize nuclear energy. Thus, this critical analysis concludes with these derived solutions to the broad flaws of fission rhetoric explained above.

At this moment, we stand at a critical junction in climate change and energy production. As we examine options to resolve this looming threat, nuclear energy remains a crucial factor. Thus, it is with great importance that we recognize, identify, and solve the complex array of issues which face nuclear fission rhetoric.

Propane: An Underrated Fuel of the Future

Author: Cameron Farid

While EVs bask in the spotlight of an energy transition, they cast a shadow on other fuels that can help offset conventional diesel and gasoline usage. Propane, a staple in many American households, is one of these underdog fuels. Propane, or liquified petroleum gas (LPG), is an energy-dense gas produced as a byproduct of natural gas processing and crude oil refining. It is typically stored as a liquid under pressure in tanks, powering appliances like grills, furnaces, and water boilers [1]. However, as will soon be revealed, its abilities extend far beyond smoking burgers on a Sunday afternoon. Affordable costs, abundant supply, and performance benefits suggest that propane, much like electrification, can help modernize America's transportation sector.

The transportation sector is undergoing a shift from conventional gasoline and diesel to alternative fuels, most notably electricity, but also fuels like CNG, biodiesel, and propane. Last summer, I had the pleasure of interning with the New Jersey Clean Cities Coalition, a nonprofit dedicated to promoting the use of alternative fuels in the state's transportation sector. My primary project was a fleet evaluation, where I analyzed the economic, energy security, and environmental impacts of alternative fuels on a gasoline and diesel work truck fleet. This involved research into fueling infrastructure, vehicle performance limitations, and costs and emissions modeling. Propane revealed itself to have attractive attributes that make it a compelling fuel for the future. In the following sections, I will evaluate the impacts of propane usage across several core competencies: financial viability (economics), environmental and energy security impacts, and performance viability. The first two sections concern the question: What benefits and drawbacks does propane use offer to individual fleets, the nation, and local/greater environmental health? The third section, on performance viability, concerns whether or not propane use is viable for a fleet, regardless of its potential benefits. After all, even if the numbers add up on paper, propane vehicles must be able to meet the sometimes intense demands of fleets, especially those performing emergency operations.

Economics of Propane Fleet Implementation:

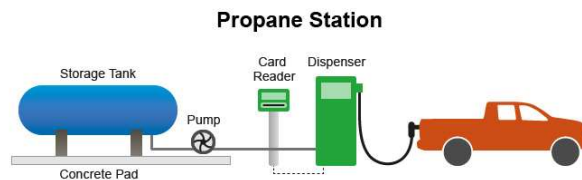
Propane often has a lower cost per gallon than gasoline at primary fueling stations (those dedicated to vehicle fueling). For instance, Alliance Autogas, a fleet conversion organization with a large propane fueling network, reported average propane prices for the week of September 1, 2023 between \$1.39 and \$1.71 per gallon, depending on the US region [2]. During the same week, gasoline prices in the United States averaged \$3.82 per gallon [3]. Thus, per-gallon costs can be more than halved by propane conversion. It should be noted that propane has roughly 27% less energy per gallon than gasoline [1]. However, the cost per gallon averaging less than half that of gasoline still makes it a more economical choice per unit of energy. Furthermore, propane is a higher octane fuel than gasoline, reducing maintenance needs and extending engine lifetime [1]. Taken together, reduced fuel and maintenance costs can often result in a net payback for fleets that implement propane vehicles.

Author Spotlight



Cam Farid is a sophomore mechanical engineering student at Princeton University. He is the director of the Energy Journal team of the Princeton University Energy Association and is fascinated by the intersection of technology, geopolitics, and the global energy system.

Infrastructure complexity and costs are also minimal with propane implementation. Traditionally, propane vehicle fueling stations simply consist of an above ground tank and dispensing equipment. Total infrastructure costs can be as low as \$65,000, and suppliers will often cover equipment costs in exchange for a fuel contract [1].



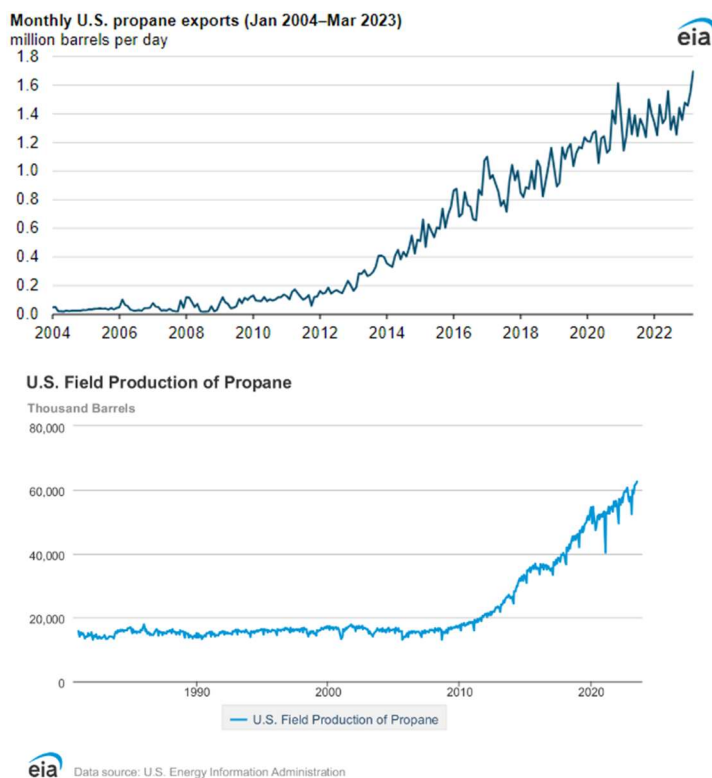
Propane Fueling Infrastructure Photo (Left) and Diagram (Right, AFDC)

Environmental and Energy Security Impact of Propane Fleet Implementation:

The emissions case for propane is favorable compared to its conventional counterparts. The Argonne National Lab GREET model estimates that conventional propane use reduces a vehicle’s lifetime greenhouse gas emissions by nearly 13% compared to a gasoline counterpart [1]. The use of renewable propane, sourced from feedstocks like fat, vegetable oil, and waste grease, can significantly increase this reduction. According to the AFDC, the carbon intensity of renewable propane can be four times less than conventional propane [1]. Thus, propane, especially when sourced renewably, can help fleets reduce their carbon footprint. Additionally, compared to diesel, propane use can cut nitrogen oxide emissions by roughly 95% in applications like school busing [4]. This is important considering the harmful effects of local air pollutants like nitrogen oxides, especially around vulnerable populations like children.

Since 2000, US propane production has more than tripled, with recent production near 2.6 million barrels per day (mbpd) [5]. Exports make up over half of this, at 1.5 mbpd, while imports are only 80,000 bpd, meaning that the fuel is largely sourced domestically [6]. It is thus an energy-secure fuel for use in the United States.

Furthermore, propane is sourced from crude oil refining and natural gas processing. When derived as a byproduct of natural gas production, according to the AFDC, it almost completely eliminates a fleet’s lifetime petroleum consumption [1]. While the US has recently become a net petroleum



*US Propane Exports (Top) and Production (Bottom)
Source: EIA*

exporter, foreign imports still average over 8 million barrels per day, near 40% of consumption [7]. Natural gas is domestically abundant, with imports less than 10% of domestic consumption and exports rapidly rising [8]. Thus, by relying on a fuel that is not solely oil-based, like gasoline or diesel,



fleets promote domestic energy security and reduce foreign oil reliance. Renewable propane, being sourced from domestic renewable feedstocks, has a similar energy security benefit.

Performance and Operational Viability of Propane Fleet Implementation:

Propane Autogas already has a solid market size, being the third most common transportation fuel, behind only gasoline and diesel. This is not surprising considering its performance characteristics. Propane vehicles can match or exceed the performance (power, acceleration) of conventional counterparts, even for heavy duty vehicles [1]. For example, propane-fueled school buses provide a range up to 400 miles. Compare this to electric bus options which can get 75-210 miles on a single charge [9]. Keep in mind that charging is a much more time consuming process than refueling with liquid propane. Additionally, the cost of a propane vehicle is roughly a third the price of an electric bus, allowing propane to replace conventional diesel fleets three times as fast as e-

buses [9]. Thus, even for heavy duty applications, propane is a functional choice for vehicle fleets. Furthermore, propane's higher octane rating and lower contamination characteristics can reduce engine wear and extend lifetime, making it an even more attractive option. New dedicated propane or bi-fuel (gasoline and propane) vehicles are widely available and can be purchased straight from manufacturers. Existing vehicles can be converted to run on propane as well [1].

Conclusion:

To conclude, the transition of the transportation sector requires all options on the table to be considered. Propane, with its domestic abundance, operational viability, affordability, and relatively simple fueling infrastructure, makes quite the case for economic, energy security, and environmental gains. Although electric vehicles dominate the passenger vehicle industry, and will likely continue to, propane is worth exploring for decarbonization efforts in other sectors of transportation- like heavy duty trucking operations.

The Inflation Reduction Act, Supply Chains, and the Changing Landscape of Energy in America

Author: Gabriella Myslo

In August 2022, the Inflation Reduction Act was signed into law [1], officially becoming the largest government investment towards addressing the climate crisis, and the “biggest victory for the environmental movement since the landmark Clean Air Act” under the Nixon administration [2]. The Inflation Reduction Act (IRA) is a ten-year plan involving the investment of over \$730 billion into healthcare, clean energy, and the federal deficit. While critics have expressed frustration over the discrepancy between the new policy’s name and the outcomes it is expected to achieve, the IRA will implement a climate strategy that promises tangible results by the next decade. In essence, the policy aims to: 1) decrease the price of prescription drugs by allowing the Department of Health and Human Services to negotiate prescription drug prices for the first time in history, 2) encourage corporations and households to invest in clean energy by providing grants and tax credits for purchases of electric vehicles and appliances powered by clean energy [3], and 3) increase the amount of taxes collected by the Internal Revenue Service from both households and corporations. The remainder of this massive budget will go towards paying off the deficit [4].

Although the IRA appears to incorporate both equity and sustainability into a vision of the future, the policy faced intense opposition in the House of Representatives, was barely passed by the Senate with a 51-50 vote [5], and remains shrouded in controversy. The tension surrounding the recently-passed Inflation Reduction Act gives rise to the questions: How have experts foreseen the potential consequences of incentivizing sustainability? What are the implications of a nationwide effort to transition to clean energy, both on the national and

international levels? The current and continued speculation regarding the ten-year plan raises concerns with respect to two types of infrastructure: America’s changing energy landscape and international supply chains.

When a policy as sweeping as the IRA is passed, it is wise to view the potential implications through both an optimistic and a cautious lens. A major concern IRA critics have brought to light deals with the long-term outcomes of the policy, placing the legislation in a global context. FOX news shifts its focus towards international trade, with particular interest in the IRA’s impact on China. In a critical article, Tucker Carlson of FOX news brings attention to the allotment of \$3 billion to the electrification of USPS vehicles, claiming “China is getting even richer from the electric mail truck batteries, which it makes” [6]. Evidently, a number of Americans are skeptical of the new law; some are prepared to question and refute those provisions of the IRA centered on the transformation of energy infrastructure for the transportation sector. Nonetheless, defenders of the IRA would point out Carlson’s failure to consider the legislation an investment in a sustainable future, arguing that the value of a clean environment was never factored into this analysis. In the midst of the partisan debate over whether the IRA’s climate approaches are progressive or plightful, effective or extreme, the issue remains as to what degree the legislation could impact trade relations with China by the early 2030s, and how the nation can responsibly address this concern.

Before assuming the same wariness expressed by FOX news over the IRA’s electrification initiative, it would be helpful to evaluate the matter through

Author Spotlight



Ella is a sophomore studying Electrical and Computer Engineering. She enjoys engaging in the integrated circuit fabrication process in the course Electronic and Photonic Devices and likes building miniature houses.

nonpartisan analyses. An article published by the Center for Strategic and International Studies (CSIS) informs an understanding of how China is involved in the electrification of America's transportation sector. Ilaria Mozzocco, Trustee Chair in Chinese Business and Economics, and other experts at the Center for Strategic and International Studies (CSIS), thoroughly identify the challenges faced by the U.S. in an effort to decrease emissions while maintaining competition with China. Data from the International Energy Agency illustrates a problem by revealing that "85 percent of solar cell manufacturing capacity is located in China, while only 0.6 percent is in North America", and "China produces three-quarters of all lithium-ion batteries and holds 70 percent of the production capacity for cathodes and 85 percent for anodes" [7]. Therefore, if the IRA will affect radical change to the energy infrastructure of the U.S., one can also expect it to define a growing U.S. dependence on China.

A growing dependence on China for EV batteries signifies a greater concern: China's unknown and problematic degree of control over the success of the IRA and the resulting uncertain trajectory of U.S. initiatives towards sustainability. IRA skepticism is thus founded on the potential consequences of a rapid switch to electric power. This cautious outlook regarding the IRA and its globalized context presents the nation with a challenge to avoid or resist dependence on China as a producer of EV materials while also sustaining progress towards phasing out fossil fuels and switching to clean energy. Considering the economic and political interplay, the question emerges as to what steps America's experts and leaders can take to ensure that the nation remains in control of its own journey towards a sustainable future.

One pathway the nation's leaders have begun to explore is the investment of federal dollars into the domestic EV battery manufacturing sector. To add a tone of optimism to the reasoning of Mozzocco and those at the CSIS, journalist Skip Descant focuses on governmental efforts to address the disparity between domestically-sourced and imported EV batteries in an article published in *Government Technology*. One such effort is the Battery Workforce Challenge, a three-year plan that will challenge students across the nation to "design, build, test, and integrate an advanced EV battery" [8]. What's more, the DOE will connect students with researchers from national laboratories such as Argonne National Laboratory to collaborate on developing solutions. Furthermore, the IRA was passed with the condition that in order to qualify for the \$7,500 EV tax credit, certain components of an EV's battery must not have been sourced from China [9]. This provision was included so as to prevent the ultimate profiting of China, and IRA optimists argue it will redirect EV battery manufacturing to the U.S. As the nation pursues sustainability, it also aims to revitalize domestic supply chains in the midst of the electrification initiative.

Because China produces such an overwhelming portion of supplies the electrification of mobile America demands, the IRA presents both an opportunity and challenge, offering benefits yet warranting reform. In its essence, the IRA acts as a door to a more sustainable future; the challenge, then, is ensuring that the U.S. holds the key. As stated by the U.S. Department of Energy's assistant secretary for sustainable transportation, Michael Berube, "We need the supply chain" (Descant). Analyzing both the risk of entanglement in a web of supply chains and the value of increasing domestic production of EVs and their parts will allow the nation's researchers and decision-makers to move forward.

Alumnus Feature: Then and Now: Rural Energy Infrastructure is Vulnerable and Costly

Author: Angelo Campus '16

In 1936, America took a groundbreaking stride with the Rural Electrification Act, an initiative set to drive electricity into the country's furthest corners. Power companies thought rural America too spacious and sparsely populated to provide the necessary returns on investment to invest in expanding the grid. Born out of necessity, this Act aimed to bridge the vast divide between urban and rural regions, providing energy to homes that had long stood in the dark. Rural electrification went from [33% in 1940 to 96% in 1956](#), electrifying the homes of 2.5M new customers. [1] However, this monumental task didn't come cheap. Stretching the tendrils of centralized energy sources into distant, often challenging terrains, was not only time-consuming but also expensive. At the time, it was granted an [initial budget of \\$50M for the first two years, then \\$40M a year for the following decade](#) [1]. Adjusted for inflation, the federal government ultimately provided approximately \$1B per year to rural service providers to expand their distribution territory.

Fast-forward over 80 years, and the infrastructure which was once hailed as transformative is now showing its age, withered by time and increasingly susceptible to natural disasters. With this deterioration comes a drop in reliability, adding another layer of complexity to the issue. As a testament to the escalating challenge, distribution spending has shot up by a staggering [64% since 2000](#), or approximately \$22 billion [2]. It's a striking parallel; just as the government subsidized the initial outlay in the 1930s, they find themselves once again dipping into the treasury to maintain, upgrade, and secure the aging web of distribution lines.

The urgency to address these challenges has never been more pronounced. Climate change accelerates

the ferocity and frequency of extreme weather events and natural disasters. As per the National Oceanic and Atmospheric Administration, there's been over a [fivefold uptick in billion-dollar disaster incidents since the 1980s](#) [3]. With an astounding [sixty percent](#) of U.S. distribution lines surpassing their 50-year life expectancy, according to Black and Veatch, the pillars of our grid reliability tremble under the strain [5]. Between 2011 and 2021, the average annual number of weather-related power outages increased by roughly [78% compared to 2000-2010](#) [5]. The Brattle Group's staggering projection, estimating that a colossal [\\$1.5 trillion to \\$2 trillion](#) will be necessary by 2030 just to maintain grid reliability, underscores the urgency [4]. Investing in rural grids has always been costly and without new technologies and/or more funding, grid reliability for rural customers will continue to suffer.

Wildfires

One of these disasters, wildfires, has most significantly impacted reliability and life in rural communities throughout the U.S. West as a result of aging and expensive distribution infrastructure. As depicted by a U.S. Forest Service study in 2019, the occurrence of fires and the average annual acres scorched have been on an [upward trajectory since the mid-20th century](#) [6]. Utility infrastructure is not just at the receiving end of these fires but can also be the spark that ignites them. Powerlines, in numerous instances, have been the catalysts for some of the nation's most devastating fires. From 1992 to 2020, a

Author Spotlight



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staggering [32,652 wildfires were attributed to powerline ignitions](#) [7]. California has borne the brunt with [six out of its 20](#) [8] most devastating fires since 2015 sparked by power lines.

Confronted with an aging infrastructure and the multi-dimensional challenge of disasters, utilities find themselves allocating billions toward distribution grid hardening to fix this 80-year-old problem. The solution of undergrounding, though seemingly effective, carries a hefty price tag, costing between [\\$2 to \\$5 million per mile](#) [9], or [five to ten times more](#) [10] than overhead distribution. California utilities reported around [75,000 total miles of powerlines in high-fire threat areas in 2021](#), which is equivalent to wrapping the earth three times over [8].

Undergrounding even a large portion of these lines is financially and geographically unfeasible.

As we evaluate this multi-faceted dilemma, it becomes evident that innovative solutions are not just desired but essential. The traditional approaches might no longer suffice, and the answer lies in pioneering models like Remote Grids.

Wildfires Spur Change

Since distribution lines, especially in rural and forested areas, have proven to be difficult to upgrade and harden against disaster threats, it is now easier for utilities to simply get rid of them instead. Remote Grids are distributed energy resources powered by local energy sources that are physically isolated from the central grid. Remote Grids operate on ‘island mode’ with solar power generation integrated with battery energy storage systems (BESS) and optional backup combustion generators, allowing the system to operate 24/7/365 through storms, cloudy days, and the darkest days of winter.

Most of the distribution lines that exist in high-fire threat districts (HFTD) traverse through mountainous terrain and dense forest, only to serve smaller rural communities and facilities. Instead of spending important years and millions of dollars upgrading miles of line, utilities have adopted standalone power systems in these areas erasing the need for distribution as a whole. Instead of bringing power from distant

locations, communities powered by Remote Grids exist close to the point of generation.

Remote grid systems driven by redundancy of multiple generation sources provide significant reliability increases compared to traditional methods. Furthermore, Remote Grids are more resilient than the grid. Since there are no distribution lines, inclement weather of all kinds -- including wildfires -- have no effect on providing power to nearby facilities.

Finally, Remote Grids are a useful tool in meeting carbon goals set by states, the US, and the world. Powered by renewable local energy sources such as solar and wind, at renewable fractions above 90%, Remote Grids have a much lower carbon intensity than the average grid, thus reducing the carbon footprint of the grid. Lastly, wildfires in 2020 alone made up [30% of California’s greenhouse gas emissions](#), so reducing wildfire risk with Remote Grids also reduces the often-overlooked emissions spewed by utility caused fires [11].



BoxPower’s SolarContainers powering a community in Buckland, Alaska

Tried and Tested: Now is the Time for Remote Grids

Driven by all these factors, California utilities are now rolling out programs to deploy hundreds of Remote Grids with 6 deployed and 80+ currently under development.

In 2020, Liberty Utilities identified a site within their service territory that was being fed by radial



powerlines in a high wildfire risk area. Instead of hardening and managing the line that served the Sagehen Creek Field Station, Liberty Utilities decided to build the United States' first Remote Grid in collaboration with BoxPower . Grid hardening costs for the Sagehen Creek Field Station were estimated at \$3M, while the 20-year cost of the microgrid (capital, operations, maintenance) for this project was less than \$1M. Then in 2021, PG&E decided to construct its first Remote Grid in the wake of the Briceburg Fire that destroyed the distribution lines serving the respective area. Kicking off PG&E's new Remote Grid Program, BoxPower was contracted to design, build, and operate a hybrid solar, battery, and generator standalone power system (SPS) to reduce replacement and maintenance costs compared to the traditional electrical distribution lines that once served this small, rural community in Northern California. Since June 2021, the Briceburg remote grid has experienced zero outages and has maintained a 99.99999 reliability percentage amidst historical heatwaves, winter storms, atmospheric river storms, and the 2022 Oak Fire and its associated PSPS events.

Now, utilities across the west are following suit and beginning to scale their respective Remote Grid plans to cost-effectively mitigate disaster and outage risk. BoxPower is currently working with four of California's investor-owned utilities, with over 30 design-build projects under contract. PG&E alone is planning to build 200+ Remote Grids in the next five years. And according to current economics, there are over 1000 viable sites in California alone. Utilities in the U.S. can look to the Australian model for inspiration, as Australian utilities were some of the first to implement stand-alone power systems as a cost saving and resilient solution. With a rural population over 3.5 million, Australian utilities have installed thousands collectively and identified over 20,000 Remote Grids sites so far. California is home to only 1.6 million of the 60 million living in rural parts of the US meaning there is significant opportunity to replicate this model across the US to provide more affordable, reliable, and clean energy.

With generational governmental support from the Inflation Reduction Act and the Infrastructure Investment and Jobs Act, it is time to reimagine what the grid can look like in rural areas. The reinstatement of the Investment Tax Credit (ITC), which once fueled the early growth of the solar sector, now encompasses a broader range, covering 30% to 60% of the construction costs for solar and storage projects, with 50% and 60% discounts reserved for low income and disadvantaged communities, many of which exist in rural areas. Moreover, the IRA has rolled out an array of federal grant and loan opportunities aimed at fortifying energy infrastructure. Initiatives like the Energy Improvements in Rural Areas (ERA), Empowering Rural Areas (New ERA), Grid Resilience and Innovation Partnership (GRIP), and the Grid Resilience Formula grant programs underscore the funding available to enhance the resilience and reliability of our energy grid. Each of these programs pave the way for utilities and rural electric cooperatives to collaborate, innovate, and develop solutions that address the pressing energy challenges of today.

In the same vein as the 1936 Rural Electrification Act, which recognized the critical importance of broadening access and optimizing infrastructure, we now stand at a pivotal juncture. Then, the emphasis was on expansion; now, the focus must pivot to cost, reliability, and sustainability. Remote Grids are no longer mere concepts, as they have been tried, tested, and proven. Remote Grids consistently demonstrate their capacity to more cost effectively serve rural customers, mitigate disaster risk, bolster resilience, and drive decarbonization. Just as the electrification of the rural landscape was a pressing need in the 1930s and '40s, the urgency to deploy Remote Grids in mass is palpable today. We must learn from our past and use the generational infrastructure bills to bring more reliable and affordable electricity to millions. The vast expanses once bridged by power lines now beckon a shift to more sustainable, decentralized, and resilient energy systems. The clock is ticking, and the time for mass deployment of Remote Grids is now.

The Future of Battery Technology

Author: Suhas Kanamarlapudi

The future of light duty transportation should be electric. It has been shown that over their lifetime, electric vehicles (EV) emit less Carbon Dioxide than their internal combustion engine (ICE) counterparts, even including the emissions from production [1]. As such, it is imperative that we migrate the world's light-duty fleet to electric propulsion in order to mitigate the climate crisis.

However, as compared to ICE vehicles, EVs work completely differently, and as such, are complex in different ways. Whereas the “key” complex components of an ICE vehicle are the engine and transmission, for EVs there is only one complex component: the battery. In a nutshell, an EV works by pulling electricity generated from chemical potential in their batteries and shoveling it into motors that propel the car [2]. They are surprisingly similar to a child's RC car. Due to the battery being the only complex component in the vehicle, the properties and characteristics of the battery determine several key aspects of the vehicle. Namely, driving range, refueling (recharging) time, safety profile, and cost. Therefore, if EVs are to be the zero emission transportation of the future, it is in our best interest to make the batteries that power them as great as possible.

To begin, let us enumerate and understand the current battery technologies that power the EVs of today. Every mass market EV uses Lithium-ion batteries. These batteries work (this is a simplification) by storing electrons in an anode (a negative side) when charged, and letting them go to the cathode (the positive side) by moving ions through an electrolyte (a solution between the anode and cathode) [3]. While every EV uses lithium-ion batteries, the specific materials that compose the batteries are different among types.

Beginning with the cathode, there are generally two types of cathodes used in Li-Ion: Nickel-based cathodes, and Iron-based cathodes. Nickel-based cathodes are good for energy density, that is the

amount of energy that can be stored per unit of mass or volume, which is important for driving range. Some examples of cathodes include

Panasonic/Tesla's Nickel-Cobalt-Aluminum, LG Chem/General Motors' Nickel-Manganese-Cobalt-Aluminum, or the industry wide Nickel-Manganese-Cobalt. Iron-based cathodes are lower in energy density, but are generally cheaper and safer [4]. The main Iron-based cathode used is Lithium Iron Phosphate. They are currently used mainly in China, although in the US they are found in the Tesla Model 3 RWD.

In terms of anodes, the industry largely uses Graphite, although some cutting edge tech has been mixing Silicon into the anode, yielding increases in energy density. We will examine this technology more later on.

The problem is that these battery technologies have various flaws. Let's begin with safety. The electrolyte in batteries is highly flammable, and since a battery pack is composed of many cells, a single spark can ignite a cell and create a chain reaction that is very difficult to put out. This is a higher risk for Nickel-based cathodes, as Nickel is very reactive with the electrolyte. As such, other materials, such as Cobalt, are needed to stabilize the cathode [5]. That brings us to the next issue with batteries: cost, both financial and ethical. Cobalt is expensive, as is Nickel, but also fuels human rights abuses. Most Cobalt comes from Democratic

Author Spotlight



Suhas is a senior at Princeton University studying Computer Science. He is fascinated by everything low-carbon transportation and battery related. He successfully convinced his parents to buy a Plug-In-Hybrid and is currently in the process of acquiring his very own EV.

Republic of the Congo, where child labor is often used in artisanal mining to get Cobalt. Additionally, the Lithium that acts as ions in the battery needs to be mined, and doing so is often environmentally damaging, trading climate friendliness for environmental preservation [6].

Batteries are also limited in the amount of energy they can store as well as the rate of energy they can accept while charging. Current EV ranges are much better than years prior and are sufficient for many consumers, but they still lag behind the ranges of ICE competitors. For example, a Tesla Model 3 Long Range gets an EPA estimated range of 333 miles (although the real world range is often less) whereas a similarly priced Mercedes Benz C-Class gets 470 miles of range (both ranges are from fueleconomy.gov). Furthermore, the C-Class's range can be refilled quickly at any gas station whereas the Tesla must wait 20 minutes or so to recharge enough to get to the next DC fast charging station (EV's gas station equivalent). Additionally, EV Batteries can degrade faster when consistently fast charged. While these metrics and statements are not enough to summarily judge EVs as better or worse than ICE vehicles, it does state that there is a lot of room for improvement with regards to battery technology.

So if it is prudent to improve battery technology, what are the new developments that we can expect? Beginning with the less novel developments, we are seeing new enhancements in battery packaging and efficiency. The introduction of structural packs, which are battery packs that are part of the load bearing structure of the vehicle. Certain versions of the Tesla Model Y use structural packs. Integrating the battery pack in this manner helps reduce weight and cost. We are also seeing improvements in efficiency, both in terms of battery manufacturing and EV drivetrains. Tesla's 4680 cell, for example,

uses a tab-less design, in which the "tabs" that need to be soldered on to normal batteries are eliminated, making production easier and simpler [7]. In a similar vein, small incremental improvements in the energy efficiency of EV drivetrains helps EVs get more range out of batteries by using less energy. There are also chemical changes that can be made to the battery. As alluded to above, adding Silicon to a battery's anode vastly improves energy density. This is because each atom of Silicon can hold more Lithium ions than that of Graphite [8]. Tesla adds small amounts of Silicon to certain batteries, and Ampirus Technologies' full Silicon anode shows that there are significant energy density gains to be made should the anode be all silicon [9]. The current challenge to overcome is the volume expansion that Silicon undergoes when holding lithium ions, so it remains to be seen if full silicon anodes will become viable.

While these improvements are good (some EVs already have them), it is the more novel technologies that are the most exciting and will hopefully yield significant improvements to batteries. These technologies include Lithium Metal batteries, Cobalt-free batteries, Solid-State Batteries, and Sodium Ion Batteries. Solid-State batteries are particularly interesting, as they do not have the liquid electrolyte that make lithium ion batteries flammable. Additionally, Solid-State battery development companies like QuantumScape and SolidPower have advertised significant energy density improvements and quicker fast-charging abilities [10,11]. Many of these technologies are years away, and it is important to note that for batteries to make their way into EVs, there is a lot of testing, validation, and factory ramp up that needs to occur. However, if these technologies come to fruition, we will hopefully see the cheaper, longer range, faster charging EVs of the future.

Refining Rare Earth Metals in the United States

Author: Stone Yang

As the demand for renewable sources of energy rises due to increasing concerns about the environment, the United States contends with an inability to supply crucial components to manufacturing and maintaining renewable sources of energy: rare earth metals. Rare earth metals—a set of 17 elements [1]—have a variety of renewable applications such as constructing magnets contained within wind turbines [2]. Currently, the United States accounts for about 16 percent of the world’s rare earth metals extraction, with more extraction operations nearing upstart. The United States is not necessarily lacking on the ability to mine the rare earth metals out the ground [3]. The primary issue of concern is that the United States has essentially zero rare earth metal refining capacity to turn the raw rare earth metals into usable material.

Currently, China dominates all aspects of rare earth metals. The country accounts for 63 percent of the world’s rare earth mining, 85 percent of rare earth processing, and 92 percent of rare earth magnet production [4]. Whereas the United States has insignificant rare earth metals refining capacities, requiring it to export the metals mined domestically to be refined, much of which goes to China [5]. This places the United States in a precarious position that may not be of concern when relations are normalized between the United States and China. However, recent increases in geopolitical tensions between the two nations highlight the leverage China has over the United States in regard to rare earth metals. In order for the United States to truly secure its energy future, the nation has realized that it must secure its access to refined rare earth metals.

There are two main approaches to securing American access to refined rare earth metals. The first is increasing domestic refining capacity. There are already efforts underway to increase this domestic refining capacity. MP Materials, the owners of the Mountain Pass Mine which is the only operating rare earth metal mine in the U.S., is currently developing separation and purification processing plants in Texas [4]. Another approach to securing American access to refined rare earth metals is “friendshoring”, which is when the United States shifts sourcing of refined rare earth metals to friendly nations. An example of “friendshoring” can be seen in the Department of Defense awarding a \$120 million contract to Australia-based Lynas Rare Earths to process heavy rare earth metals [6].

Although current domestic rare earth refining capacities are near non-existent, the United States has recognized the need to develop domestic and friendly refining capacity. As efforts such as developing American refining capacity as well as “friendshoring” are continued, America’s renewable energy future becomes more secure.

Author Spotlight



Stone is a senior studying Economics. From a small town in Oklahoma, he is interested in the intersection of finance and the energy, chemicals, metals and mining, and infrastructure industries. Upon graduation, he will be working in investment banking covering related companies.

The Transition to Nuclear Propulsion in Naval Submarines

Author: Andrew Ryan

In World War II, U.S. submarines destroyed 1,314 enemy warships in the Pacific and 5.3 million tons of shipping, representing 55% of all Axis power warships lost [1]. As a military technology, submarines' ability to sink ships from an undisclosed position revolutionized how wars could be fought. Thus, in the time period that followed World War II, the U.S. sought to improve their submarine technology. This improvement was spearheaded by Admiral Rickover, who became the father of the Nuclear Navy.

One of the main issues with the submarines during World War II was their diesel power supply. Diesel engines require air to function, as air drives the motion of the cylinders when initially pumped in and supplies oxygen for the combustion reaction when compressed diesel is pumped into the engine. This critically forces diesel submarines to remain near the surface of the ocean to snorkel or intake air via long tubing. When submarines snorkel, they become much easier for an enemy to spot as they generate a noticeable wake and the snorkel itself is visible above the water. To remedy this issue, diesel submarines were equipped with a large number of lead-acid batteries [2]. The diesel engines would be used to charge these batteries while snorkeling, then when the submarine was ready to dive, it would switch to electric power, relying on a smaller electric engine for propulsion. While this partially solved the problem diesel engines created, U.S. diesel submarines still could only remain underwater for 48 hours [3]. Moreover, the reliance on a small electric engine for propulsion when underwater meant these submarines operated at relatively low speeds, approximately 2 knots per hour [3]. Additionally, diesel engines had to refuel often, requiring diesel tanks to be refilled around every 90 days.

Rickover noticed that many of these issues could be solved by converting the submarine force to nuclear propulsion. The nuclear reactor that the Navy

decided to implant in the *USS Nautilus* in 1955 proved itself capable of completing a fully submerged transit under the North Pole as a part of "Operation Sunshine," which demonstrated the nuclear submarines' superiority in undersea operations endurance [4].

Although nuclear propulsion resolves many of the issues of diesel propulsion, there were still many unique engineering hurdles to overcome in designing a safe nuclear reactor that could be operated on a submarine. The primary design philosophy behind the submarine reactors was safety and reliability [5]. Submarines can suffer from collisions and turbulence and thus require a sturdy reactor. Submarines are also very limited in space. From these concerns, a pressurized water reactor (PWR) was chosen to insert into submarine design. A PWR can be made smaller and more resilient than other reactor designs due to its dual systems: the primary system and secondary system. The primary system circulates water which is pressurized to prevent boiling in a fully-welded, closed loop that flows through the reactor vessel, piping, pumps and steam generators. This water is heated by the reactor, serving a dual function of both capturing heat and moderating the nuclear chain reaction by slowing down the fast neutrons emitted by fission to a velocity at which they can cause another fission reaction. This moderation of neutrons by the water coolant acts as both a convenient step in producing a fission chain reaction and as an automatic safety

Author Spotlight



Andrew is incredibly interested in nuclear power, both fission and fusion. A chemical engineering major and member of Navy ROTC, he hopes for a career with the nuclear navy. He also enjoys grappling and Brazilian Jiu Jitsu.

feature [6]. The moderating of neutrons will occur more when the water is denser or at a lower temperature as opposed to when the water is at a higher temperature, as there are more gaps between the water molecules and thus less chance of a neutron colliding with them. Thus, if the reactor heats to an unwanted extent and the fission reaction becomes uncontrollable, the water coolant will expand, reducing the amount of fission available neutrons, slowing the reaction [6]. The secondary system allows water to flow into the steam generators where heat from the primary system is transferred across a watertight boundary to the water in the secondary system. The water in the secondary system boils, creating steam that drives both the main propulsion turbines that turn the propellers and the turbine generators that supply the submarine with electricity. The watertight boundary between the two systems allows each system to be a fully closed loop, which can be welded to resist external damage [5]. Moreover, the separation ensures that radiation from the primary system does not contaminate the water in the secondary system, making the design safer for its operators and smaller to implement with less radiation shielding and water treatment. Thus, a PWR reactor serves as an incredibly safe and sturdy method of nuclear propulsion.

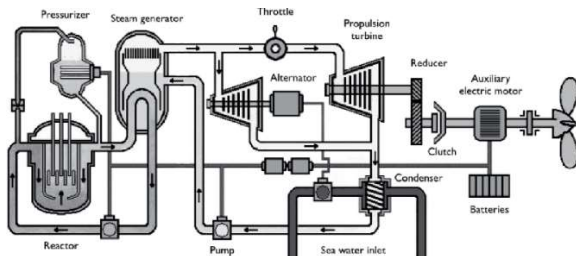


Diagram of PWR Reactor (Source: Philippe 2014)

As with any power generation and propulsion implementation, the submarine comes with a few unique challenges and constraints. As the submarine is not a stationary platform, the control rods must be

secured with springs. While landlocked nuclear reactors may rely on gravity to shut down the reactor in the event of power loss, submarines bank at angles that could significantly impact the control rods and cause them to shift within the reactor. Thus, springs are used to both secure the rods into position and provide a failsafe in the event the submarine loses power [7].

Another challenge the submarine reactor faces is access to freshwater. The water within the reactor should be as pure as possible due to the high pressures within the primary and secondary loop. High pressures drive dissolved particles out of the coolant solution, which can deposit in locations of thermodynamic significance, damaging the reactor. This issue is handled in two ways [8]. First, the water provided to the reactor is purified from seawater using extremely powerful pumps to pressurize and desalinate the water and second, the water regularly passes through a demineralizer that removes contaminants. As an innovative secondary use, seawater also acts as the condenser coolant. As the submarine is constantly moving, the seawater flowing around the submarine flows into the condenser to remove heat from steam immediately after it moves through the propulsion turbine [5]. The temperature and pressure difference created allows for efficient energy extraction via the turbine.

While the civilian sector has difficulty implementing nuclear power due to cost and public perception, the US Navy has demonstrated the success of nuclear power in the military through Admiral Rickover's safe and effective transition to nuclear propulsion. Despite the unique engineering challenges relating to nuclear fission, it has many beneficial properties such as fuel density, waste generation, and oxygen availability that could signal nuclear fission's ability to tackle large issues in other public environments.

China's EV Market: Growth, Challenges, and Concerns

Author: Siling Song

In September 2020, at the UN General Assembly, China committed to reach peak carbon emissions before 2030 and accomplish carbon neutrality before 2060 [1]. This commitment to energy transition and decarbonization, if continuously adhered to, would be one of the most vital pivots in combating global climate change, as China has been topping the world's largest emitters of greenhouse gasses with 10,668 million metric tons emitted in 2020 alone. Talk is cheap, and the Chinese economy seems determined to take it the hard way: targeting and seizing the most lucrative opportunity

in decarbonization — the Electric Vehicles (EV) Market.

Author Spotlight



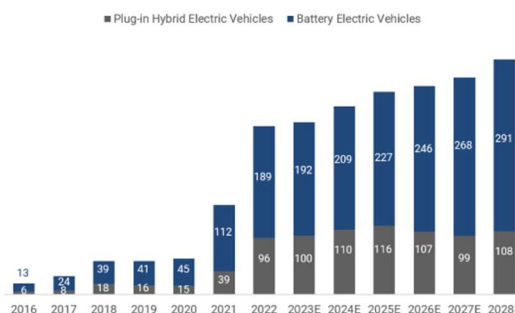
Siling is a sophomore economics student on PUEA's research team. Fascinated by the way technology and energy shapes a market's growth trajectory, she finds it fulfilling to explore the world of commerce in the energy industry.

Before the world caught sight of what was happening, China rose to become a global leader in EV sales and production on an exponential growth trajectory [2]. Supported by generous subsidies

and incentive policies from the government, new energy vehicle sales grew from 1.3 million in 2021 to 6.8 million in 2022, a staggering six fold growth in the number of EVs sold annually. In comparison, the number of EVs sold in the US in 2022 was roughly 13.5% of that in China [3]. Revenue of China's EV industry rose by 68% and hit a remarkable 285 billion dollars by the end of 2022, which captures 59% of EVs sold globally [4]. Now, almost one in every four vehicles sold in China is

electric [5]. The trend to switch to EVs is unprecedented in China's automotive industry, underlying a huge potential to fully electrify passenger transportation by 2035 [6]. According to estimates from the Belfer Center, widespread EVs adoption can cut China's GHG emissions by 6% in 2030 despite anticipated higher emissions in the manufacturing phase of EV production [7]. The potential in emission reduction would be even higher with improved life-cycle efficiency of batteries and ameliorated production methods in EV manufacturing, that are all quickly accelerated by China's EV boom.

2016-2028E Revenue of China's EV by category (in billion USD)



daxue consulting
Leading in Shanghai Hong Kong

Graph Source: Statista, designed by daxue consulting, 2016-2028E Revenue of China's EV by Category

Not only is the EV product market booming, complementary infrastructure and upstream supply chains are quickly adapting to keep up with the EV explosion in China. At the end of 2022, China's charging infrastructure reached 5.21 million units, an almost 100% increase from 2021 [8]. The latest data revealed that China is now home to 65% of public EV charging stations [9], supplementing highway service areas and traditional gas stations. Convenience of recharging is among the utmost concerns of consumers when it comes to purchase of EVs. With increasingly established infrastructure for EV usage, it's likely that more consumers will be lured against traditional automobiles and instead look for cleaner alternatives, even as the government starts to phase out fully-armed consumer-side incentives on EV purchasing. With respect to the supply chain, China holds a

prominent position in the upstream industry of EV manufacturing, namely lithium and cobalt processing, a market share of 60 to 70 percent [10].

These magnificent transformations are fueled by unwavering fiscal support from the government, which on a global scale, stays highly disputed. For China, the long targeted EV industry could be said as one of the most successful cases of industrial policy in its recent economic history, which is also criticized internationally as creating unfair advantages for Chinese EV producers by lowering prices of EVs sold abroad. We are observing an intensifying political tendency in the United States and most recently in Europe to reduce reliance on the Chinese economy for energy production out of geopolitical interests and considerations for national security [11,12]. However, it should be noted that if such competition goes beyond possible industrial subsidies and extends to trade policy, we need to rationally weigh the potential impact of high tariffs

or quotas on the development of the EV industry in the US. In the short run, these trade retaliations could push up prices of Chinese-made EVs and benefit US domestic producers. Nonetheless, in the long run, these barriers deter introduction of cheaper and more efficient imports as forces of market competition, reducing choice sets of consumers while dragging the transition to decarbonization that is critically needed in the US.

Concerns remain as China's entire economy witnessed a slower than expected growth rate in 2023 dragged by weak consumer demand and cautious spending. At the same time, the momentum in the EV industry seems to have slightly stagnated with the entire economy [13]. Yet, hope remains as the rest of the world starts to catch up on what China has initiated. The race in the EV industry, if properly directed, has huge potential to help us accelerate into a fast-track transition to a decarbonized world.

The Double-Edged Sword of Direct Air Carbon Capture

Author: Vinay Konuru



[1] Climeworks Orca direct-air carbon capture plant

Direct air carbon capture, often denoted as DAC, has been one of the most active topics in decarbonization discussions this year. Governments and companies across the world are actively encouraging development in the sector through incentives and contracts. Earlier this month, the US opened its first commercial DAC facility from Heirloom Carbon Technologies [2]. And this past summer, Occidental Petroleum and Blackrock purchased the largest DAC facility in history with a capture capacity of 0.5 million tons of CO₂ per year for \$1.1 billion [3,4], expected to begin operations by late 2024. But why has this technology gotten so much attention recently? And what role could it play in the energy transition?

What is DAC?

Direct air carbon capture is the process of removing carbon dioxide directly out of ambient air. It is currently one of the few “negative emissions technologies” commercially supported. Many policy makers and innovators believe it could be the most viable means of achieving deep decarbonization across the energy sector. DAC technology is nascent and expensive: the leading DAC facilities remove CO₂ at about \$600/ton – six times higher

than market price for carbon credit at under \$100/ton[5]. Lowering the cost of CO₂ removal will require innovation and large-scale deployment within the coming decade for DAC to play a meaningful role in achieving 2050 decarbonization goals. Government incentives in the Inflation Reduction Act and climate funds such as the Frontier Fund and the XPrize have bolstered innovation in the sector. Yet, progress is slow and costly, with many claiming that DAC will never be able to achieve market competitive prices. So why are investors taking on a high-risk to build this technology? And where is demand for this technology coming from? The answer lies in the goal of “deep-decarbonization.”

Author Spotlight



Vinay Konuru, President of PUEA, is a senior in the electrical and computer engineering department interested in accelerating the energy transition through technology innovation and business.

What is deep decarbonization?

Many sources of emissions such as those from aviation, steel, cement, and agriculture are referred to as “hard-to-abate” because they cannot be decarbonized by using renewable electricity or existing clean fuels. These industries rely on high-temperatures, energy-dense fuels, or finely tuned chemical cycles. Together, these hard-to-abate sectors make up nearly a third of global annual emissions[6]. Deep decarbonization refers to the process of reducing emissions across these hard-to-abate industries, and achieving this will be one of the largest hurdles to reaching net zero emissions targets.

Policymakers and businesses are searching for ways to achieve progress on this front. Many see DAC as a means of achieving system-wide deep-decarbonization at the lowest cost through carbon

offsets. DAC presents a viable opportunity for many hard-to-abate sectors to achieve emissions reductions without needing to make major changes to their existing facilities or processes. This has been the rallying point for major investments over the past year, but it has also led to heated discussions about whether this technology may cause more harm than good.

The Double-Edge of DAC

Advocates for direct air carbon capture argue that the technology can be used to offset the emissions from hard-to-abate sectors that can't use standard carbon capture processes like airlines and agriculture. Pressure on these sectors to curb their emissions has grown in recent years, leading them to look for solutions. For example, legislation from the EU called CORSIA has mandated decarbonization requirements across the aviation sector beginning in 2027 [7]. With sustainable aviation fuels still in development, airlines are looking towards DAC as their lowest-cost solution to meeting these decarbonization standards.

But direct-air carbon capture is a fundamentally energy-intensive process and is an unfavorable long-term solution when alternatives are available. DAC offers an important pathway for such hard-to-abate sectors to offset their emissions as they continue developing lower cost, permanent solutions.

We've also already begun to see how DAC could be used to slow decarbonization. Occidental Petroleum has publicly stated that they plan to use their recently purchased direct-air carbon capture plant to sell "net-zero" petroleum products. Such products could motivate sectors currently dependent on petroleum products like trucking and manufacturing to delay adopting alternative, cleaner processes. For example, purchasing net-zero petroleum may reduce investment into hydrogen fueling infrastructure, which could be used to decarbonize the trucking sector rather than simply offsetting emissions. Although this may lower the cost of decarbonization in the short term, it could slow

investment and progress towards long-term, permanent decarbonization. For instance, as Daniel Kullenward, a senior fellow at the Kleinman Center for Energy Policy put it, "When you have an oil company whose leadership is vocal about DAC providing a social license to continue oil production 80 years in the future, it's directly at odds with a strategy that gets us to climate stabilization." [8]

Nevertheless, direct air carbon capture has an important role to play in the decarbonization of our energy systems. And given the high cost of capital to innovate in this sector, the initiative of Occidental Petroleum is still critical and should not be understated. With continued investment, DAC could soon be the lowest-cost solution to achieving deep-decarbonization by 2050 in many sectors. Thus, we need to be more proactive in collaboration between research, industry, and policymaking to develop dynamic carbon accounting policies and market incentives to both encourage development and prevent abuse of this technology. I'm truly hopeful for the future that DAC can offer.

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Princeton University Energy Association Gallery 2023



New member dinner Spring '23



PUEA Weekly Professor Dinners featuring Professor Kelsey Hatzell



5th Annual PUEA Conference Organizing Team



PUEA Conference Keynote Address

UNCOMMON GROUND

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Princeton University Energy Association's sixth annual student-run energy conference brings together industry professionals, researchers, academics, investors, analysts, students, and other community members that are spirited about the energy industry and new technologies.

Our conference will feature panels on a variety of topics including Energy Diversity and Intermittency, the Role of Oil and Gas, and a Just Transition. To learn more about and stay updated on our schedule, speakers, and networking opportunities, check out our website

CONFERENCE INFORMATION



SATURDAY
3 FEB, 2024



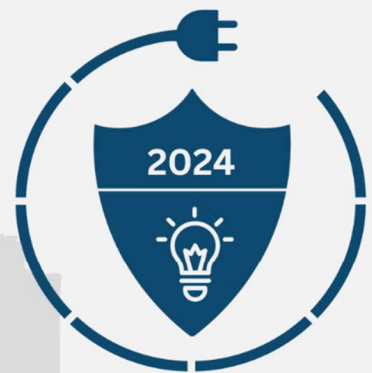
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