Linear Generator – A Solution to Energy Issues

Yu-Che, Chou

Taipei Municipal Chien Kuo High School, No.56, Nanhai Rd., Zhongzheng Dist., Taipei City, 100052, Taiwan(R.O.C.); andrewchou0125@gmail.com

ABSTRACT: The world faces climate change and fossil fuel depletion, so people should take steps toward clean energy. However, the disadvantages of renewable energy are that they may depend on weather and be intermittent. Linear generators overcome these obstacles while remaining clean and efficient, making them a solution to the issues mentioned. This paper aims to compare current electricity generators with linear generators, a novel technology, to see how they compare with the available data and to popularize linear generators to the public. When running zero-carbon fuels such as green hydrogen or ammonia, linear generators have an efficiency second to hydrogen fuel cells, producing zero-carbon and near-zero nitrogen oxide emissions via a flameless reaction. This makes linear generators clean, safe, and efficient. However, given how new the technology is, the linear generators' costs remain unknown. Nonetheless, the merits of linear generators make it an emerging technology worth tracking now.

KEYWORDS: Energy: Physical; Sustainable Design; Fuel Comparison; Emerging Technology; Linear Generator.

Introduction

The world faces extreme environmental issues such as climate change and energy depletion. These issues can be solved by progressively replacing fossil fuels with clean or renewable energy like hydrogen, solar, wind, waves, etc. However, some of these types of energy are either unstable or not efficient enough for people to rely on them fully. Solutions include improving the generators used and the power grid to make renewable energy a reliable source of electricity. The first solution seems more practical, so this research focuses on what generators to use for solving the problems mentioned. After reading and analyzing documents, linear generators appear to be a potential candidate for complementing renewable energy. They can power up quickly whenever renewable energy sources are down, making them more reliable.

Linear generators resolve the problems mentioned above. They are stable and efficient, run on clean energy, produce zero carbon emissions when running zero-carbon fuels, are stackable, and do not depend on weather.[1] However, few people realize the existence of the linear generator and even fewer know its merits. This paper aims to compare mainstream electricity generators with linear generators to see how they compare with available data. This comparison would permit an analysis of whether linear generators could contribute an important new generation solution to the energy crisis and climate change and inform people of the linear generator's potential.

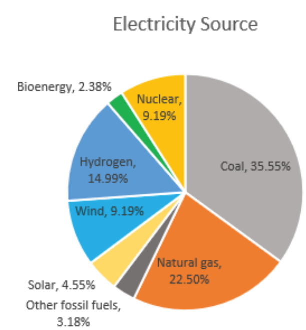

Figure 1: Electricity source (Ember, 2023).[2]

Figure 1 is a graph of fuel sources used to generate electricity. In 2022, 61.23% of global electricity was generated by fossil fuels: 35.55% from coal, 22.50% from natural gas, and 3.18% from other fossil fuels. 29.59% of global electricity came from renewable energy: 4.55% from solar, 9.19% from wind, 14.99% from hydrogen, 2.38% from bioenergy, and 9.19% from nuclear.[2] Most electricity comes from fossil fuels like coal, natural gas, gasoline, etc. This shows that the world is far from a decarbonized world and there is a need to shift electricity sources from fossil fuels to renewable energy.

Fossil fuels used in the present:

The principle of fossil fuel generators is that fuels like coal, natural gas, diesel, gasoline, and propane are burned to create steam or other kinetic energy. After combustion, they spin a shaft connected to the turbine and generator. The generator will then start producing electricity through magnetic induction.[3-5]

Fossil fuels have the advantages of being easy to store and transport and being more stable. However, they have disadvantages such as they pollute the environment throughout the obtaining and using process, are explosive, and will deplete one day. Specifically, oil will last 50 years, natural gas 53 years, and coal 114 years.[6,7]

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Clean energy used in the present:

Clean energy includes solar, wind, and hydrogen energy, among other more experimental sources.[8] While solar energy has the advantages that it costs little to operate and maintain and produces little carbon dioxide, it has the disadvantage that it highly depends on the weather.[9,10] Solar energy is produced when the sun shines onto a solar panel, and energy from sunlight is absorbed by the photovoltaic cells in the panel. This energy then creates electrical charges that move in response to an internal electrical field in the cell, producing an electric flow.[11]

Wind energy has the advantage of low operating cost; however, the disadvantages include the turbines being visual pollution, producing noise, and being costly. Also, the location of wind turbines is limited.[12,13] The process of how electricity is produced by wind is that wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, generating electricity.[14]

Hydrogen fuel cells produce electricity by combining hydrogen and oxygen atoms and reacting across an electrochemical cell to produce electricity, resulting in water and small amounts of heat.[15] While other renewable energy sources exist, this paper will limit the discussion to these three because they are currently the most proliferated and promising.

Linear generator:

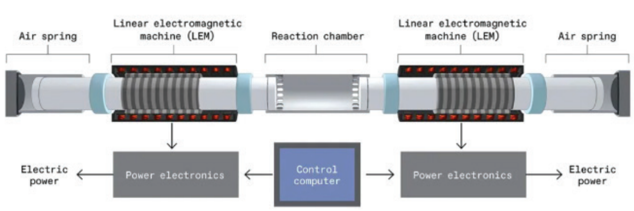

Figure 2: Linear generator (Svrek, 2023).[16]

The linear generator is a newer and less well-known renewable energy technology that recently entered the market. Figure 2 is a diagram of the linear generator's components. Linear generators are a kind of generator whose oscillators, containing magnets, run in a linear direction with an air spring on both sides. This is in contrast to traditional generators that have turbines that spin in a circular motion.

First, fuel and air enter a closed chamber with movable end walls. Next, those end walls move toward each other, compressing the mixture of fuel and air. As this happens, the molecules within the mixture collide faster until they break apart and reform into different molecules, releasing the energy stored in their chemical bonds. That energy causes the new molecules to collide even faster and more often, not just with themselves but also with the chamber's walls, raising the pressure in the chamber.[16] The air springs on the two sides will be pressured after the first reaction, pushing the oscillator toward the middle and compressing the fuel entered from the ports. The oscillators, which have magnets attached to them, will then move back and forth with the help of air bearings that reduce friction. The horizontal copper coil surrounding the container to the oscillator will generate electricity while the oscillators move back and forth due to magnetic induction. Outside of this chamber, the control computer controls the input of fuel to allow linear generators to work optimally.[1]

Linear generators, compared to traditional generators, have a lot of advantages. First, linear generators can run on various fuels, including green hydrogen, green ammonia, biogas, etc. This versatility means that cleaner, more affordable options can be easily swapped in depending on market conditions. Second, when running on zero-carbon fuels, they do not produce carbon emissions and nearly zero nitrogen oxides. Third, their efficiency is relatively high. Fourth, linear generators do not burn fuels as they work in a flameless environment, thus avoiding the creation of significant nitrogen dioxide. Fifth, because of their low emissions, small size, and ease of portability, they do not have the typical location dependency of other power generators. Linear generators are also different from other equipment for renewable energy like solar panels and wind turbines. Instead of turning natural energy sources like the sun or wind into electricity, linear generators consume fuels and turn them into electricity. As a result, they have the advantage of being stable as they are not weather-dependent.[1]

The linear generators discussed in this paper are made by Mainspring Energy, Inc. Mainspring is a company aiming to allow its commercial and industrial customers to use 100% renewable fuels with the ability to integrate onsite generation and grids by designing innovative products. Moreover, it has conducted and studied several environmentally friendly projects to speed up the process of reducing emissions and increasing resilience. According to a spokesperson of Mainspring, "The likely users are commercial and industrial businesses such as grocery stores, cold chain distribution centers, fleet EV charging facilities, biogas-producing facilities like wastewater plants, landfills, and dairies, as well as larger users like data centers and very large utilities."[17]

■ Methods

This paper aims to showcase the traits and data of several common generators and compare them to linear generators. Thus, the methodology used in this paper is reviewing, combining, and comparing existing documents from websites and literature. For fossil fuels, this research compared coal, natural gas, diesel, gasoline, and propane. For renewable energy, this research compared solar, wind, and hydrogen as they are the most commonly used fuel or source of clean energy. As for what metrics to compare, capital cost, efficiency, carbon emission, combustibility, and weather dependency are included. Capital cost affects the consumer's choice of purchase. Efficiency determines the level of emissions and can also affect the amount of fuel used and its overall cost. The efficiency discussed in this paper is fuel efficiency, which is the amount of electricity output theoretically divided by the electricity output in reality. Carbon emission is also considered since the world's trend is to become carbon neutral. When using each generator, it is necessary to indicate how harmful carbon emissions are to the environment. Combustibility correlates to safety concerns and carbon emissions, especially when using generators that run on traditional fossil fuels. Safety is always a priority, making it an indispensable factor to consider. Weather dependency could affect its effectiveness based on the region the generators are in and affect the amount of energy loss through transportation. The data used in this research was filtered from reliable websites. When there were two or more data from different websites, the one with a more detailed calculation process was chosen. When data were provided in different units, they were standardized wherever possible.

Some information was obtained by interviewing experts Sumedha Weerasuriya and a spokesperson of Mainspring for more detailed information. Weerasuriya joined Mainspring nine years ago as a mechanical engineer and is familiar with the workings of the linear generator. Findings are reported in Table 1 of the next section.

Result and Discussion

Table 1: Comparison of electricity generators.

Generator	Capital cost (USD)	Efficiency	Carbon emission (g/kWh)	Combustibility	Weather dependency
Linear[1,19-20]	Unknown	45%	0g/kWh	Non-combustible	Not dependent
Fossil Fuels					
Coal[21,23-24]	1.8m-4.5m	33%	388g/kWh	Combustible	Not dependent
Natural gas[22,24-27]	2200-25000	19%	177g/kWh	Combustible	Not dependent
Diesel[22,25-26,28]	3200-24000	27%	1270g/kWh	Combustible	Not dependent
Gasoline[22,24-27]	500-3200	19.3%	240g/kWh	Combustible	Not dependent
Propane[22,24-27]	2200-21000 (whole-house)	22.3%	211g/kWh	Combustible	Not dependent
Renewable Sources					
Solar panel[29-31]	3000-4000/kW	15-20%	50g/kWh (first year)	Non-combustible	Depends on sunlight
Wind turbine[32,33]	800-950/kW	30-50%	11g/kWh	Non-combustible	Depends on wind
Hydrogen fuel cell[18,34,35]	360-520/kW	40-60%	0g/kWh	Non-combustible	Not dependent

Table 1 shows how current electricity generators compare with each other. Coal plants are the most efficient among fossil fuel generators but still less efficient than linear generators. However, coal plants are carbon-intensive because they emit the second most carbon emissions every kilowatt hour. In contrast, natural gas generators are the least efficient. Nonetheless, they produce only 46% of the carbon emissions that coal plants produce every kilowatt hour. Solar panels are the least efficient among the renewable energy generators and have similar efficiency as natural gas and gasoline generators. This implies that solar panels can replace natural gas and gasoline generators while maintaining the electricity output in regions with sufficient sunlight. Hydrogen fuel cells have the highest efficiency among all electricity generators in the comparison and are almost two times more efficient than most fossil fuel generators. They are also more efficient than linear generators and do not produce carbon emissions as well. Hydrogen would be an optimal choice for a decarbonized world if storage systems and electricity transmission are not considered.

Regarding the linear generator, the following comparison section is divided into two sections: linear generators compared with fossil fuel generators and linear generators compared with renewable energy generators. This can better indicate whether linear generators are worth using before and after global decarbonization.

Compared with fossil fuel generators, linear generators have the highest efficiency, while natural gas generators have the lowest. This indicates that linear generators can produce more electricity with the same amount of fuel input. As for carbon emissions, linear generators have no carbon emissions when running zero-carbon fuels. Meanwhile, traditional fossil fuel generators emit various amounts of carbon dioxide, with diesel generators emitting the most. Linear generators work in a flameless, low-temperature condition while every other fossil fuel generator works in a condition that produces flame as they go through combustions when producing electricity. This indicates linear generators provide a safer working environment. To summarize, linear generators have many advantages over fossil fuel generators: high efficiency, zero carbon emission, a low-temperature, flameless reaction, and the ability to run and switch among multiple fuels, making it a better option than fossil fuel generators.

Compared with renewable energy generators, linear generators rank second in efficiency, while hydrogen fuel cells have the highest. As for carbon emissions, all produce either zero or a small amount of carbon emissions that could be ignorable compared to fossil fuel generators. Only hydrogen is flammable among the three renewable energies, causing more concern about its production process. To summarize, linear generators are not exceedingly prominent in their efficiency while having the merits of all other renewable energy generators. Additionally, they do not depend on the weather.

Based on the result, linear generators outcompete fossil fuel generators. They are on par with renewable energy generators on most metrics evaluated, showing their potential to replace existing generators after being introduced to the public. The only gap in this research is whether the capital cost of linear generators will hinder their wider use. According to a spokesperson of Mainspring, preliminary estimates show that the linear generator is similar in cost to a traditional generator. However, it is still too soon to have an accurate estimate because the pricing of linear generators is very new and changes across regions of the world, over scale, type of purchase, and over time. Still, this early indication implies that capital cost will not be a linear generator's future disadvantage. In summary, linear generators are the better option than fossil fuel generators in this paper as they are more efficient, environmentally friendly, and safer.

Next, how do linear generators compare with traditional renewable energy generators? Linear generators are not weather-reliant, unlike solar panels and wind turbines that

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only function effectively in areas with consistent sunlight and wind in moderate climates. However, linear generators are a highly viable complement to renewable energy generators rather than a competitor given the sheer amount of clean energy needed. They can track solar and wind power and instantly ramp up to generate the required power as other sources of power decrease, making them an optimal option to make up for the disadvantages of renewable energy generators.

The result seems to support the idea that hydrogen fuel cells are the better option. However, that would not be the case if electricity transportation and fuel storage were considered. Hydrogen fuel cells run on hydrogen, which requires a storage system with huge volumes to store hydrogen in gaseous form, and the storage system is expensive.[36] The storage system cost is 0.0042/kWh per day.[37] Though it may not sound like much, the global electricity usage in 2021 was 25343 billion kWh.[38] This means that if the world uses 100% hydrogen throughout 2021, approximately 29 million USD would have had to be spent a day to store hydrogen, making it unrealistic. Moreover, if hydrogen fuel cells are stored far from electricity-demanding areas, the electricity will decrease due to energy loss through transportation across transmission lines. To show that energy loss should not be underestimated, during a 100 km transmission, 0.7%-1% of energy is lost.[39] California, for example, lost about 1.97 x 10^{10} kilowatt hours of electrical energy (6.8% of the total amount of energy used in California the whole year, worth approximately 2.4 billion USD) through transmissions and distribution in 2008.[40] Linear generators, in contrast, are connected by fuel lines or tanks, allowing them to be installed where the electricity demands are. This not only saves the expense of the expensive storage that hydrogen needs, since linear generators run on many fuels other than hydrogen, but also minimizes the electricity loss through long-distance transportation. Added to its flameless safe working condition, linear generators could be a better option than hydrogen fuel cells.

One drawback of the linear generator is that it currently exists only in commercial sizes. According to a spokesperson of Mainspring, “Mainspring's linear generator is not designed for individual residential use at a single home or a small store. However, it is conceivable that a smaller-scale linear generator could be designed for these smaller-scale uses. Some people have even theorized about using smaller scale versions for automotive uses like cars and trucks.” Perhaps in the future, with more technological advancement, the linear generator can be used individually, similar to the progress seen with solar energy technology. Another disadvantage of the linear generator is that it is as clean as the fuel it consumes. If the process of producing its fuels, such as pure hydrogen or ammonia, is carbon intensive, then the electricity produced by the linear generator is less environmentally friendly overall. Luckily, much progress is being made to produce cleaner fuels that the linear generator can consume, such as producing green hydrogen using electrolysis from renewable energy rather than burning fossil fuels.

Conclusion

In pursuit of producing less harm to the environment and maintaining the stability of electricity, linear generators have the potential to be broadly used. Linear generators have several advantages: high efficiency, produce zero carbon emission and nearly zero nitrogen oxide emission, have a flameless electricity generating process, are not weather dependent, and do not require a storage system. Based on the results, linear generators could be a potential solution toward a decarbonized world while ensuring a stable electricity source, which makes it worth being noticed by the public.

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References

1. Mainspring Energy. (2021). Mainspring Energy: Home. Retrieved September 18, 2023, from https://www.mainspringenergy.com/
2. Ember. (2023). Electricity Data Explorer | Open Source Global Electricity Data | Ember. Ember-climate.org. Retrieved September 24, 2023, from https://ember-climate.org/data/data-tools/data-explorer/
3. SaskPower. (2014, July 9). Using Coal to Generate Electricity. YouTube. Retrieved September 24, 2023, from https://www.youtube.com/watch?v=j6zBun7zZs0
4. University Of Calgary. (n.d.). Diesel generator. Energy Education. Retrieved September 24, 2023, from https://energyeducation.ca/encyclopedia/Diesel_generator
5. SOS Survival Products. (2022, February 6). Propane Power Generators - SOS Products - Voted Best Propane Power Generators Of 2022 - Popular, Top-Rated Power Generators - Find Cool, Free, Useful Information About Power Equipment, Fuel, Household Outlets, Engines, Portable Propane And ... SOS Survival Products. Retrieved September 24, 2023, from https://www.sosproducts.com/everything-you-need-to-know-about-propane-generators_a/367.htm
6. MET. (2020, July 6). Pros and cons of fossil fuels & why can fossil fuels be good? MET Group. Retrieved September 22, 2023, from https://group.met.com/en/mind-the-fyouture/mindthefyouture/pros-and-cons-of-fossil-fuels
7. MET. (2021, January 18). When will fossil fuels run out? MET Group. Retrieved September 24, 2023, from https://group.met.com/en/mind-the-fyouture/mindthefyouture/when-will-fossil-fuels-run-out
8. Office of Energy Efficiency & Renewable Energy. (n.d.). Clean Energy. Department of Energy. Retrieved September 25, 2023, from https://www.energy.gov/clean-energy
9. Minos, S. (2023, February 13). 5 Benefits of Residential Solar. Department of Energy. Retrieved September 24, 2023, from https://www.energy.gov/energysaver/articles/5-benefits-residential-solar
10. Vourvoulias, A. (2023). Advantages & Disadvantages of Solar Energy. GreenMatch. Retrieved September 24, 2023, from https://www.greenmatch.co.uk/blog/2014/08/5-advantages-and-5-disadvantages-of-solar-energy

11. Office of Energy Efficiency & Renewable Energy. (n.d.). How Does Solar Work? Department of Energy. Retrieved September 24, 2023, from https://www.energy.gov/eere/solar/how-does-solar-work
12. Just Energy. (2023). Wind Energy: The Pros and Cons. Just Energy. Retrieved September 24, 2023, from https://justenergy.com/blog/wind-energy-pros-and-cons/
13. EnergySage. Pros And Cons of Wind Energy. EnergySage. 2022, March 9. Retrieved September 24, 2023, from https://www.energysage.com/about-clean-energy/wind/pros-cons-wind-energy/.
14. EDF. (n.d.). All You Need To Know About Wind Power. EDF. Retrieved September 24, 2023, from https://www.edfenergy.com/energywise/all-you-need-to-know-about-wind-power
15. U.S. Energy Information Administration (EIA). Use of hydrogen. EIA. 2023, June 23. Retrieved September 25, 2023, from https://www.eia.gov/energyexplained/hydrogen/use-of-hydrogen.php.
16. Svrek, M. (2023, 2 18). IEEE Spectrum. THIS NEW BREED OF GENERATOR CAN RUN ON ALMOST ANY FUEL. Retrieved 9 24, 2023, from https://spectrum.ieee.org/mainspring-energy
17. Mainspring Spokesperson. (2024). Capital Cost of Linear Generators. Electronic Mail Message.
18. Kotowicz, J.; Uchman, W.; Jurczyk, M.; Robert, R. (2022, October 2) . . . - YouTube. Retrieved September 25, 2023, from https://www.sciencedirect.com/science/article/pii/S0306261923006335?ref=pdf_download&fr=RR-2&rr=80bc4825ddea4a33.
19. IndexBox. (2023). Liquid Ammonia Price Per Kg - Search. IndexBox. Retrieved September 19, 2023, from https://www.indexbox.io/search/liquid-ammonia-price-per-kg/
20. Jochen, F. (2018, 10). Ammonia - an ideal hydrogen storage medium. Bayern Innovativ. Retrieved September 19, 2023, from https://www.bayern-innovativ.de/en/page/ammonia-an-ideal-hydrogen-storage-medium
21. Budryk, Z. (2023, January 30). 99 percent of US coal plants are more expensive than new renewables would be: report. The Hill. Retrieved September 24, 2023, from https://thehill.com/policy/energy-environment/3836301-99-percent-of-u-s-coal-plants-are-more-expensive-than-new-renewables-would-be-report/
22. Ugov. (2022, October 2). . . - YouTube. Retrieved September 24, 2023, from https://ugov.net/Generator%20Efficiencies.pdf
23. Office of Fossil Energy and Carbon Management. (n.d.). Transformative Power Systems. Department of Energy. Retrieved September 24, 2023, from https://www.energy.gov/fecm/transformative-power-systems
24. EIA. (2022, November 25). Frequently Asked Questions (FAQs) - U.S. Energy Information Administration. Frequently Asked Questions (FAQs) - U.S. Energy Information Administration (EIA). Retrieved September 24, 2023, from https://www.eia.gov/tools/faqs/faq.php?id=74&t=11
25. Weimert, K.; Tynan, C. (2023, September 6). Average Generator Cost: By Type And Size – Forbes Home. Forbes. Retrieved September 24, 2023, from https://www.forbes.com/home-improvement/electrical/generator-cost-guide/
26. LearnMetrics. (2023). Generator Cost Per kWh: Diesel, Propane, Natural Gas, Gasoline. LearnMetrics. Retrieved September 24, 2023, from https://learnmetrics.com/generator-cost-per-kwh-diesel-propane-natural-gas-gasoline/
27. Shrink That Footprint. (2023). How Much Gas Does A Generator Use? Shrink That Footprint. Retrieved September 24, 2023, from https://shrinkthatfootprint.com/how-much-gas-does-a-generator-use/
28. instagrid. (2022). Choose clean energy – calculate your emission savings - instagrid. Instagrid Gmbh. Retrieved September 24, 2023, from https://instagrid.co/blog/choose-clean-energy-calculate-your-emission-savings
29. Solar Learning Center. (2023). Solar Panel Cost in 2023: How to Estimate The Cost of Solar. Solar.com. Retrieved September 24, 2023, from https://www.solar.com/learn/solar-panel-cost/
30. Vourvoulias, A. (2023). How Efficient Solar Panels Are in 2023? GreenMatch. Retrieved September 24, 2023, from https://www.greenmatch.co.uk/blog/2014/11/how-efficient-are-solar-panels
31. Cool Effect. (2021, June 1). Carbon Footprint of Solar Panel Manufacturing. Cool Effect. Retrieved September 24, 2023, from https://www.cooleffect.org/solar-carbon-footprint/
32. Office of Energy Efficiency & Renewable Energy. (2022, August 16). Land-Based Wind Market Report: 2022 Edition. Department of Energy. Retrieved September 24, 2023, from https://www.energy.gov/eere/wind/articles/land-based-wind-market-report-2022-edition
33. Office of Energy Efficiency & Renewable Energy. (2023, August 24). How Wind Can Help Us Breathe Easier. Department of Energy. Retrieved September 24, 2023, from https://www.energy.gov/eere/wind/articles/how-wind-can-help-us-breathe-easier
34. Leo, T.; Hartvigsen, J.; Brisse, A.; Petri, R. (2020, September 29). DOE Hydrogen and Fuel Cells Program Record 20006: Hydrogen Production Cost from High Temperature Electrolysis - 2020. DOE Hydrogen Program. Retrieved September 25, 2023, from https://www.hydrogen.energy.gov/pdfs/20006-production-cost-high-temperature-electrolysis.pdf
35. Plug Power. (n.d.). Fuel Cell Power - Fuel Cell Benefits. Plug Power. Retrieved September 25, 2023, from https://www.plugpower.com/fuel-cell-power/fuel-cell-benefits/
36. U.S. Department of Energy. Hydrogen Storage. Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/eere/fuelcells/hydrogen-storage.
37. Abdin, Z.; Khalilpour, K.; Catchpole, K. (2022, October 2). . . - YouTube. Retrieved September 22, 2023, from https://www.sciencedirect.com/science/article/abs/pii/S0196890422010184?via%3Dihub
38. statista. (2023, September 19). Global electricity consumption 2022. Statista. Retrieved September 22, 2023, from https://www.statista.com/statistics/280704/world-power-consumption/
39. national grid. (2013). Factsheet. National Grid. Retrieved September 24, 2023, from https://www.nationalgrid.com/sites/default/files/documents/13784-High%20Voltage%20Direct%20Current%20Electricity%20%E2%80%93%20technical%20information.pdf
40. Harting, B. (2010). Physics 240: Energy Conversion, Large Scale. Stanford University. Retrieved [date], from http://large.stanford.edu/courses/2010/ph240/harting1/.
41. chrvoje engineering. (2017, October 2). Working Principle of DC Motor (animation of elementary model). YouTube. Retrieved September 25, 2023, from https://www.youtube.com/watch?v=j_F4limaHYI
42. Cooney, R. (2023, June 21). Green hydrogen could be a game changer by displacing fossil fuels – we just need the price to come down. The Conversation. Retrieved September 21, 2023, from https://theconversation.com/green-hydrogen-could-be-a-game-changer-by-displacing-fossil-fuels-we-just-need-the-price-to-come-down-205636/
43. Office of Energy Efficiency & Renewable Energy. (n.d.). Alternative Fuels Data Center: Hydrogen Benefits and Considerations. Alternative Fuels Data Center. Retrieved September 25, 2023, from https://afdc.energy.gov/fuels/hydrogen_benefits.html

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44. Owen, J. (2016, November 9). How AC Generator Produces Electricity? - Physics || Extramarks. YouTube. Retrieved September 25, 2023, from https://www.youtube.com/watch?v=MW1YUy3Yqpc
45. Weerasuriya, Sumedha. (2023, July 23). Interview on linear generators. Online interview.

Authors

The author of this paper is Yu-Che, Chou from Taiwan. Currently, he is a senior at Chien Kuo High School and is applying to be an engineering major. He is interested in the topics of robotics and renewable energy and decided to conduct research to familiarize himself with these topics with hopes of making contributions in these fields.