Developing a Triboelectric Wind Energy Generator

Constructing a Framework to Understand Innovations Effect on Climate Relief

A Thesis Prospectus

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

As sporadic weather intensifies and ocean levels surge, calls for electric generators alternate to oil and coal have surged. Wind energy is among the most promising proposed solutions, displaying some of the most explosive growth in market share of electricity produced worldwide (Our World in Data, 2024). While wind energy proves to be an invaluable tool, it experiences its own unique challenges—large turbines necessitate expansive land usage while demanding high wind speeds and creating noise pollution. In the energy sector, where the name of the game is spatial energy density, or how many watt-hours you can produce from a square kilometer, wind energy falls behind (Nøland et al., 2022). By integrating wind energy into already established structures such as buildings—small scale wind generators offer a promising opportunity to expand wind power into populated areas where electricity is most needed and massively expand usable land.

A small-scale wind generator that seeks to solve the issues facing turbines may now be possible through triboelectricity, a phenomenon in which a charge is deposited onto one surface by another through contact. These devices, deemed triboelectric nanogenerators (TENGs), allow one to collect energy from the interaction of two different materials—this interaction can be in the form of friction, where the rubbing of two materials against one another deposits a charge, and contact-separation, where the two materials (with no rubbing) leave a charge on one surface (Hasan et al., 2022). After the triboelectric effect takes place one surface is left with a surplus of charge, connecting these surfaces with a conductive material allows one to utilize the current traveling from one surface to the other, similar to a battery. By creating a device that converts the kinetic energy of the wind into repeated contacts—and therefore charge—we aim to create a form of TENG that can be integrated into populated areas to produce energy from low-speed winds.

With the apparent need for low-carbon power production, it is crucial that humanity begins to live within its means rather than waiting for some science-fiction technology to provide the perfect bail-out. Climate action is at an all-time high, and we are seeing global power consumption surge year-after-year (Enerdata, 2024). Spurred by technological hype cycles and excused by technological pipedreams, the march for scientific supremacy wages on. Humanity has a clear need for a methodological approach to determine which technologies should be pursued, and which should be abandoned.

By developing a strategy to compare a proposed innovation's potential value to a timeline for meaningful climate intervention, I seek to create a framework that can assess a technology's ability to intervene. This will then be used to critically analyze triboelectric nanogenerators, along with other technologies currently being developed. It is my hope that such a framework would create paths to fucus humanities limited resources and time to solutions that truly make a difference.

Developing a Wind Harvesting Triboelectric Nanogenerator

Wind energy has shown a promising trend in recent years, accounting for more than 10% of U.S. energy production and 12% of new electric capacity from 2023 to 2024 (Office of Energy Efficiency and Renewable Energy, 2024)—more than solar and hydropower (Our World in Data, 2024). These generators work when wind hits the turbine's blades, causing the rotor to spin, in turn supplying kinetic energy to power a generator that then provides electricity either to a grid or battery (Office of Energy Efficiency and Renewable Energy, n.d.). While wind energy claims many impressive accomplishments, it also faces many challenges. Currently, wind energy is stuck in rural areas—requiring large swaths of land with high wind speeds, modern turbines are restrained mostly to farmlands where early and even modern power grids face difficulties supplying electricity (Xiarchos & Sandborn, 2017).

Triboelectricity offers a promising solution to many of the problems facing traditional wind generators. Whereas turbines are typically bulky, land intensive, and require high wind speeds—our design seeks to minimize these requirements by implementing a small modular design. An array of alternating positive and negative materials modeled after blades of grass will blow in the wind, allowing for repeated contacts of the materials to occur. Each 'blade' will have a conductive core with all like blades connected (positive to positive and negative to negative), these grids will then be connected allowing charge to equalize, creating a current that can be harvested and supplied to the grid, see figure 1.

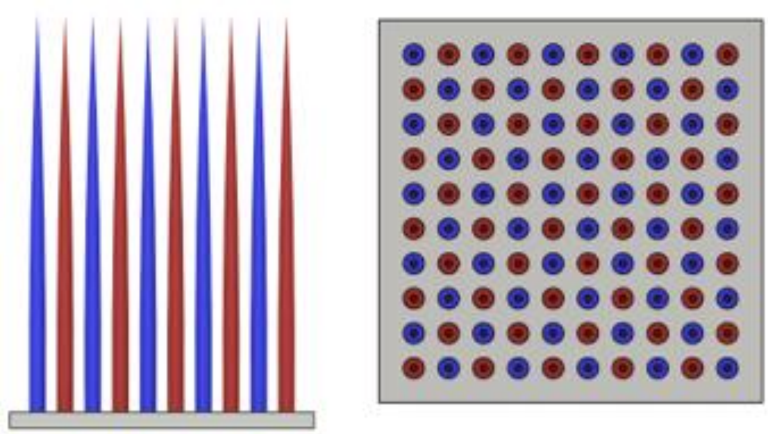

Figure 1. Wind Generator Side View (Left) and Bottom View (Right) Composed of Positive and Negative Blades

The proposed generator seeks to provide a modular option that can be easily connected in series, then placed onto rooftops, ships, and anywhere else that experiences moderate winds. The design aims to operate at lower speed winds, as opposed to small traditional wind turbines which require 14MPH winds to offset the typical home (Office of Energy Efficiency and Renewable Energy, n.d.). While moderate-to-high speed winds are typically required to supply the necessary inertia to a spinning rotor, the proposed TENG will create a charge from repeated impacts of components called blades as wind blows through them. These alterations allow a triboelectric generator to efficiently create power in conditions where wind may be sparse or blocked, such as urban environments.

The theory surrounding triboelectricity is somewhat sparse and continually being developed, but some basic models exist to quantify how it operates. The phenomenon occurs when two materials occupying different positions on the triboelectric series come into contact, causing electrons to transfer from the positive material to the negative. Although triboelectricity has been acknowledged for over 2000 years, many basics remain poorly understood (MRSEC Education Group, 2024), with some underdeveloped topics of research including how charge is transferred or what determines the triboelectric charge of a material (Lacks & Shinbrot, 2019). One generally accepted theory for solid-solid triboelectrification (as opposed to solid-liquid) proposes that as two atoms or molecules come into close enough proximity, their electron clouds 'overlap' allowing for the electron to tunnel between the two materials (Xu et al., 2018). When one connects the negative and positively charged materials, they act similar to the terminals of a battery, supplying a brief current of electricity that can be collected and used like any other source of electricity.

Triboelectric generators seek to supplement larger wind energy devices, allowing for the creation of power with fewer constraints. An effective small-scale wind generator may now be possible through the emerging field of triboelectricity. Such a device shows potential to provide a novel solution for mitigating climate change if deployed correctly.

Move Fast and Break Things—An Analysis of Futuristic Technologies

The importance of novel energy generation techniques cannot be understated. As humanity demands more power and fewer emissions, it has become clear that the current infrastructure is no longer serviceable. But while fantasies of sci-fi futuristic generators swooping us away from our problems are comforting, it denies us the necessary hardship of managing our own demands. While triboelectric nanogenerators may help transition to cleaner sources of energy, it's important that humanity remember its responsibility to the world and future generations. Climate scientists urge populations and governments to do all they can to slash carbon emissions as quickly as possible (Union of Concerned Scientists, 2024) but this is often undone by corporate pushes for new technologies and excused by futuristic solutions that have not yet come to fruition. Implementing Sarewitz and Nelson's *Three Rules for Technological Fixes* alongside Gartner's hype cycles, we can come to understand the shortcomings of these science-fiction contraptions.

Three rules can be used to asses the solution provided by a technology—the solution must embody the cause-effect relationship connecting problem to solution, the effects of the technological fix must be assessable using relatively unambiguous or uncontroversial criteria, and research and development is most likely to contribute decisively to solving a social problem when it focuses on improving a standardized technical core that already exists (Sarewitz &

Nelson, 2008). The first of these rules suggests that a valuable solution considers the cause of the problem it attempts to resolve. When considering climate change, a convenient cause to blame is fossil fuels, but this fails to question the root of the issue. A more apt explanation is a desire for technological supremacy—with electricity consumption bolstered by technologies like the blockchain (Clarke, 2023) and generative AI (Kneese & Young, 2024), we can see that emissions are often exacerbated by corporate pushes for supremacy over one another (Corefield, 2023). While climate scientists urge serious change in the next 7-8 years (Feigin et al., 2023), it is argued that technological solutions are too slow and we must instead focus on cultural/governmental change (Matos et al., 2022).

Sarewitz and Nelson's second rule states that a technological fix must be assessable by noncontroversial criteria. Desalination promises to produce clean water but produces greenhouse gases and water pollution (Elsaid et al., 2020) and AI companies say the technology will alleviate climate change while devouring water and electricity (Kneese & Young, 2024). These criteria for success clearly do not address the problem as they have yet to do so in any meaningful way, and with public opinion on technologies such as AI leaning towards disillusionment and distrust (Faverio, 2023) these future technologies can often court controversy. The final rule for technological fixes states that research and development are best focused on existing technologies. Perhaps the greatest fault in the solutions proposed to climate change is that they fail to operate within established solutions. Nuclear fusion may be possible but to rely on a technology whose greatest success to date is creating enough electricity to boil 6 kettles of water (Dunning & Gallagher, 2022), we must question where our resources are best allocated (Matos et al., 2022).

To answer why so many technologies, both promising and otherwise, seem to face such daunting hurdles in meeting the three rules, we may look to Gartner's exploration of hype cycles. Gartner categorizes and explains how technology grows and is adopted through its lifetime in five stages before it is ultimately accepted or discarded (Blosch & Fenn, 2018), see figure 2. Hype cycles are defined by five stages, the innovation trigger describes the breakthrough or launch of a technology, moving into a peak of inflated expectations, then the trough of disillusionment spurred by impatience around the technology's development, before experiencing a slope of enlightenment as the value of the technology comes to be realized and finally a plateau of productivity as the technology finds its place in the world.

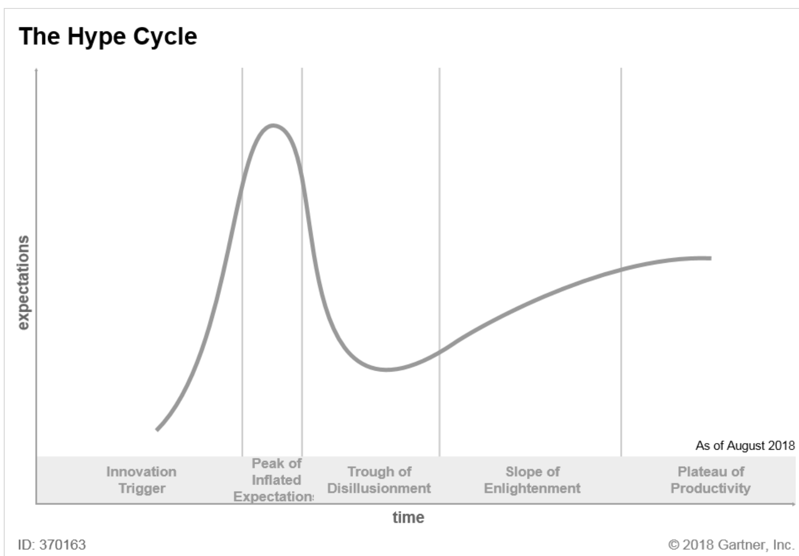

Figure 2. The Gartner Hype Cycle (Source: Blosch & Fenn, 2018)

The same factors that lead many innovations to fail Sarewitz and Nelson's rules can be explored through Gartner's hype cycles. Companies that fail to consider a problem's root cause and instead chase technological supremacy are likely victims of the peak of inflated expectations.

Corporations benefit from news of innovation in public perception and market growth, and are therefore willing to promise lofty, unrealistic aspirations for a product (Pratt, 2015). This can often come at the cost of initiatives like climate and sustainability goals. These embellished goals also introduce controversial criteria that stick with a technology, for instance, artificial intelligence is no longer judged on what it can accomplish, but how it can become artificial general intelligence (Siegel, 2023). If we come to understand where along the hype cycle a technology falls, we can forecast whether expectations are accurate and roughly when we can expect valuable results. Such a tool provides valuable metrics in determining if the terminus of a technology is worthy of the time and materials used to create it.

Research Question and Method

Technology often hailed as humanities saving grace appear to conflict with the immediate solutions demanded by climate change after years of focusing on proof-of-concept and last-ditch efforts instead of bolstering infrastructure around existing fixes. Under fast approaching time constraints one must ask: how do technological hype cycles and promises of futuristic technologies affect genuine progress towards meaningful climate solutions?

In investigating an answer to this question, I will use the frame of hype cycles established by Gartner to explore the impact and adoption of various proposed solutions. From the frequency with which various technologies impacting climate change, such as desalination and artificial intelligence, are mentioned across the Corpus of Contemporary American English, News on the Web Corpus, Google Trends, and Google N-Grams, I will assess which stage of adoption these technologies are in before using Gartner's hype cycle research as a framework to predict a timeline for said technologies to produce valuable outcomes (or potentially be abandoned). I will then compare this timeline to that of decarbonization set by climate researchers. This should yield valuable data concerning whether the expected results of these technologies can address climate change within a meaningful timeframe.

Conclusion

With the future of the earth's climate hanging in the balance, humanity must make strides to prevent ecological collapse and climate disaster. Failure to do so will result in massive losses of life and detrimental effects on health (USGCRP, 2016). By utilizing triboelectricity to address the shortcomings of wind energy, I will attempt to construct a proof-of-concept device that could one day be used to bolster an overstressed electricity grid. I will then analyze futuristic proposals such as my own through a lens of questions proposed by Sarewitz and Nelson's *Three Rules for Technological Fixes*, along with my own research on hype cycles to determine their impact on climate relief. It is my belief that the results of this research will provide a valuable framework for determining if a proposed solution can affect meaningful change in the time allotted by current climate conditions. This will allow us to determine which solutions should be pursued and which should be delayed or abandoned.

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