Renewable Energy and Carbon Capture with Thermomotive Biopolymer Textiles

By: Nicholas Witham

Project Background

Numerous renewable energy systems exist to decrease our dependence on fossil fuels. Hydroelectric, wind, and solar are most prevalent globally as they are often more cost efficient than their competitors. In recent years, solar and wind power have locally surpassed hydroelectric due to droughts, substantial maintenance costs, and concerns over its environmental impact. This points towards an emerging market need for renewable energy sources that don't depreciate in value, provide quick returns on investment, and are resilient to climate change.

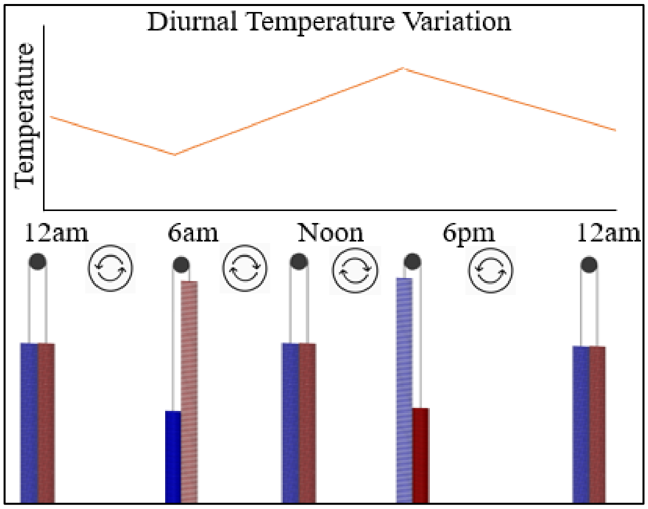


Figure 1. Thermomotive Energy Generation. Temperature changes TCPA length and turns the rotor of an electromechanical generator in different directions to produce power nearly continuously over 24-hours

What we propose is a novel renewable energy system that generates power via the daily heating and nightly cooling of the earth, known as the diurnal temperature variation. This can be accomplished using a type of artificial muscle known as a twisted coiled polymer actuator (TCPA), which can be designed to either contract or expand when heated. Our recent collaboration with TU Dresden has developed a manufacturing technique to inexpensively mass produce TCPAs with existing textile equipment.

While this research was aimed at creating biomimetic artificial muscles, we have expanded the academic understanding and utility of TCPAs significantly. Namely, we have improved the energy efficiency of our TCPAs by exploring different polymer resin compositions. We have also established a sample production and testing method to increase the reproducibility of TCPA research. Lastly, we have designed an inexpensive PCB to measure and control temperature, force, length, and speed.

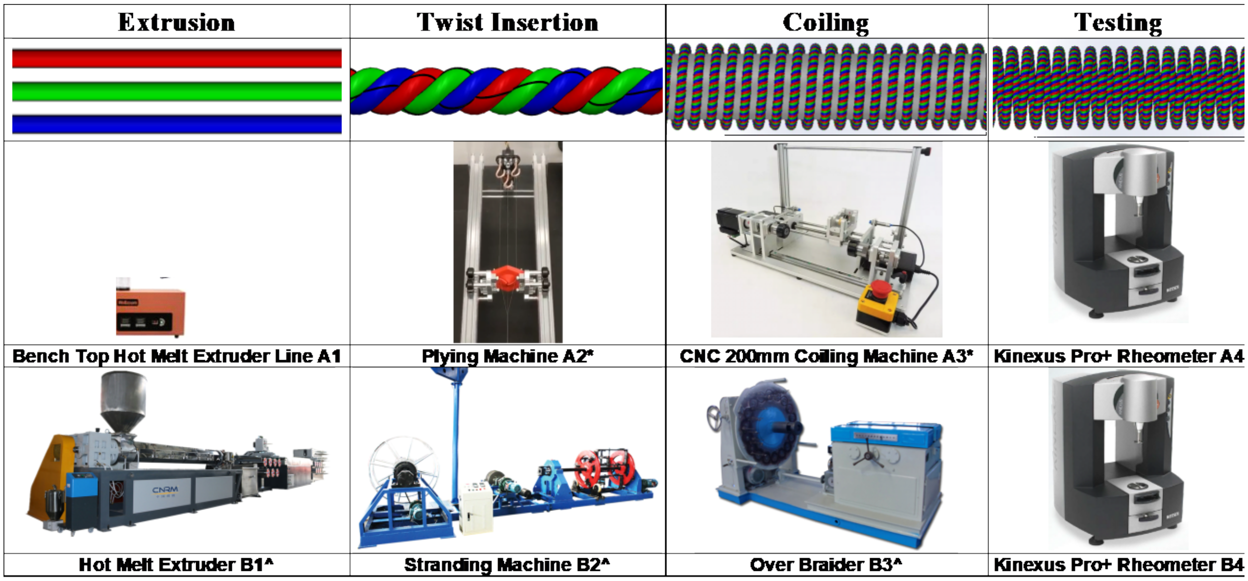


Figure 2. Manufacturing and Testing Equipment.

Feasibility

TCPAs in literature have energy density of 16 Wh/m^3/K, density of 720 kg/m^3, and a price around $0.7/kg. So for the western portion of the US where the diurnal temperature change is greater than 30 ℃ for 10 months of the year, a shipping container full (26 m^3) of our textile TCPAs (20 tons) could power an average Utah household year-round (9.2 MWh) at a price comparable to solar ($13,000).

The practical setup for our thermomotive generators would be very similar to wind power. Our TCPAs would pull a chain that turns a sprocket attached to a generator. Just as wind speed isn't constant the rate of heating and cooling fluctuates. This is can be combatted to some extent by a doubly fed induction generator, which can change it's ideal RPM. If necessary, a geothermal heat-pump HVAC system can further adjust the RPM by changing the rate of heating and cooling.

Just like there are methods to improve the performance of solar panels there are methods to improve the efficiency of our thermomotive generators. Other than optimizing the manufacturing settings of our TCPAs, one simple method to increase energy production would be to store our TCPAs in an enclosure painted black to absorb more thermal energy. Clouds and manmade pillars that cast shadow would also temporarily cool our TCPAs, increasing the total daily temperature change.

To fund this project, we plan to obtain grant funding after we have published our preliminary results for our textile actuators. Once funded, we will environmentally test our thermomotive generators first at small scale with conventional wind turbine generators. We will then progress to large scale tests with doubly-fed induction generators, heat-pump HVAC systems, and microgrids. After demonstrating financial viability and performing a market analysis, we will reach out to angel investors for funding to scale our production.

Co-benefits

The type of polymer we use in our textile TCPAs is linear low-density polyethylene (LLDPE) is resists degradation on a human timescale and our TCPAs can be thermally cycled a billion times without worsening. However, system maintenance and end-of-life situations could generate microplastics. For this reason, we designed our enclosure to contain any microplastics generated. We have also ensured that our TCPAs can also be recycled using existing methods.

Our thermomotive generators offer a path to combat the e-waste generated by solar power. Photovoltaic cells require semiconductors to produce and lithium batters to store excess power. While e-waste recycling exists, it isn't always cost effective or efficient. In the advent of smart phones and electric vehicles, our supply of these resources is growing more finite.

Additionally, the mining, refinement, and processing of these materials requires large quantities of water. The maintenance and cleaning of solar panels also requires water. Our thermomotive generators do not require water to manufacture, maintain, or recycle.

Finally solar panels cannot scale vertically, so when a company makes a solar farm its value naturally depreciates over time. The maintenance of our thermomotive generators is straight forward with our integrated measurement system. Furthermore, if a company wants to increase the energy production of a thermomotive generator farm, they can stack more vertically by connecting their heat-pump HVAC systems together.

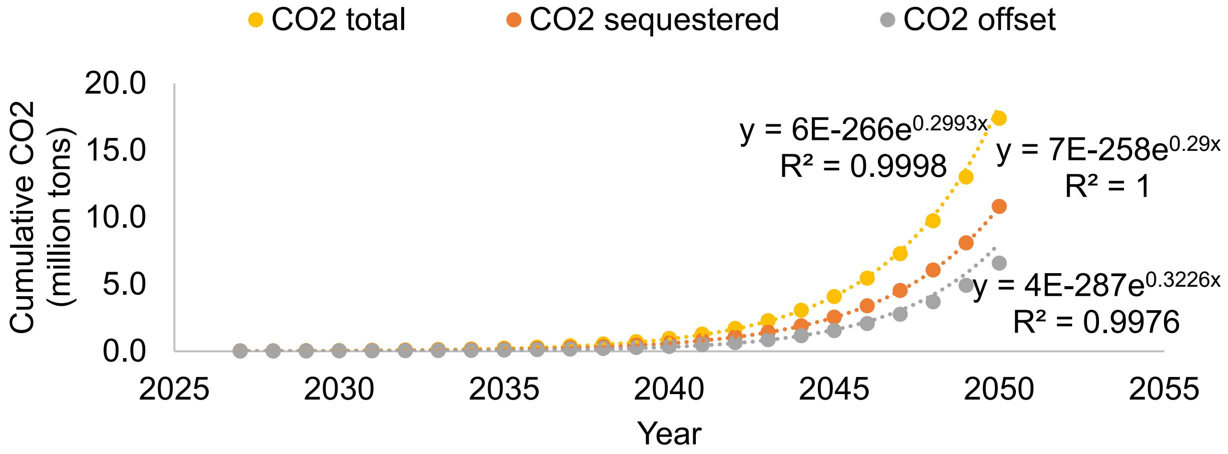
Scalable Impact

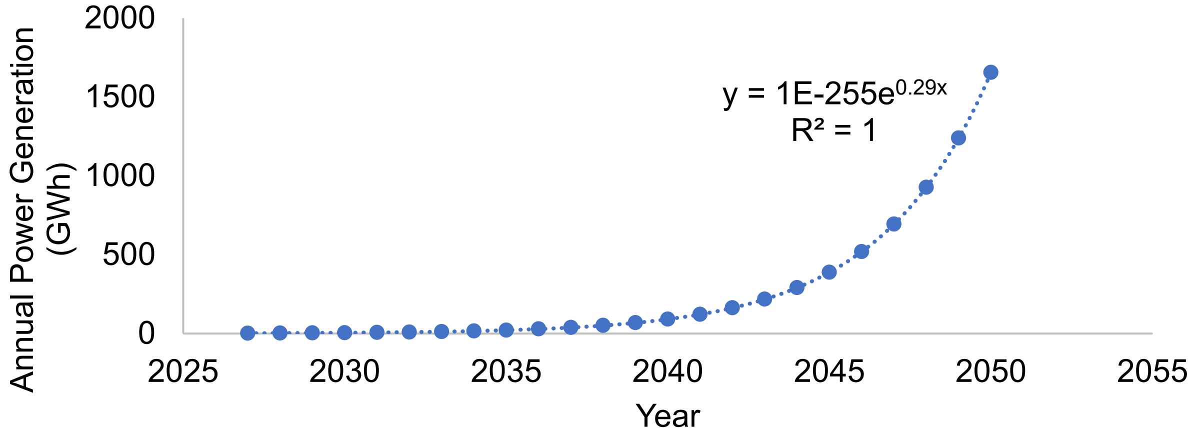
LLDPE isn't reliant on fossil fuels as it can be derived from plant-based sources as an extended form of CO_2 capture. Up to 86% of LLDPE mass is made up of carbon and 27% of CO_2 mass is made up of carbon. Therefore, each kg of LLDPE will prevent nearly 3 kg of CO_2 from returning to the atmosphere.

Coal, natural gas, and petroleum respectively create 1.0, 0.6, and 1.1 metric tons of CO_2 per MWh of electricity produced. We think it is feasible that we can create a full-scale version of our thermomotive generator in 2025. This generator would immediately sequester 60 metric tons of CO_2 from entering the atmosphere and will offset nearly 9.2 metric tons of CO_2 per year by producing nearly as many MWh of power.

Solar is expected to grow by 1.2 TWh or nearly triple from 2022 to 2027. Therefore, we think it is feasible to make a thermomotive generator farm equivalent to that of a 1 MW solar farm by 2027. This farm would produce around 2.1 GWh of power a year. This farm would immediately sequester nearly 14,000 tons of CO_2 and annually offset 2,100 tons of CO_2.

As the anticipated time for this investment to "break even" is comparable to solar at around 11 years, we believe that the natural doubling period of this technology would be similar at around 2.4 years. The graphs below are projections for this model. In this scenario, by 2050 our thermomotive generators would have sequestered nearly 11 million tons of CO_2 and would have cumulatively offset 6.6 million tons of CO_2.





Team Background

While Nicholas is the sole applicant, the proposed project relies on an existing team of industry experts in renewable energy, power systems, business, and textile manufacturing.

Responsibilities:

- University of Utah (UofU): thermomechanical actuator testing
- Technische Universität Dresden (TUD): textile artificial muscle fabrication
- Both: mechanical theory

Dr. Florian Solzbacher (Professor and Chair, Electrical and Computer Engineering, Bioengineering, Materials Science, Director Center for Engineering Innovation, University of Utah) Dr. Solzbacher is PI for the entire project and is responsible for the overall alignment of efforts and accomplishment of the project objectives. He will be responsible for testing overall device design, system integration, packaging, reliability and support regulatory efforts. He has 20 years of experience in Micro-electromechanical systems (MEMS) and implantable device development, translation and commercialization. Conflict of interest (COI) note: Dr. Solzbacher has financial interest in Blackrock Microsystems. COI is managed through University of Utah COI management.

Nicholas Witham (UofU) is a 5th year PhD student in Dr. Solzbacher's lab who researches and develops high performance sensors and actuators for rehabilitation devices, such as prosthetic limbs and exoskeletons. During his B.S. in Biomedical Engineering, he studied textile engineering methods at NCSU and biomechanics at UNC-CH. He is skilled at the design and rapid prototyping of advanced manufacturing equipment. More recently he completed a summer internship with Össur prosthetics. He also co-founded a prosthetic sensor company called Gaia Technologies.

Dr. Johannes Mersch (TUD) is a post-doctoral researcher working to establish new textile manufacturing methods for smart-actuators/artificial-muscles. Using the textile engineering equipment available to him, he established a continuous textile manufacturing method that can produce kilometers of our biomimetic artificial muscles at around $0.7 USD/kg.