The City College of New York
Office of Research

CCNY College-wide Research Vision (CRV) Initiative Concept White Paper

"Hygroscience" for Evaporation Energy Harvesting

Project Team:

Principal Investigator: Dr. Xi Chen, Assistant Professor
Department: Chemical Engineering | GSOE, The City College of New York
Other Key Personnel: Dr. Ahu Aydogan (Spitzer School of Architecture); Dr. Daniel DiSalvo (PoliSci/Colin Powell School); Dr. Raymond Tu (ChE/GSOE); Dr. Charles Vorosmarty (Civil/GSOE).

Project Concept Description:

Keywords: Renewable Energy, Power Generation, and Water-energy Nexus.

Objective: Drawing on expertise in multiple disciplines, we seek to consolidate a new research field of "Hygroscience," that contributes to using the ubiquitous, untapped energy source of water evaporation for energy generation/storage, desalination, locomotion, and green chemistry. This proposal primarily targets technical and marketing milestones that move our invention of evaporation energy harvesting technique from the lab to the real world.

In recent years, we invented a series of water-responsive (WR) materials that enable evaporation energy harvesting devices that run autonomously when placed at a suitable air-water vapor interface. We developed an electricity generator that floats on water and harvests evaporation to power a light source as well as a miniature car. While our technique is at an early stage, recent studies suggest that it is highly scalable, and could produce power comparable to current solar and wind farms, but at a much lower cost (~ 2 ¢/kWh). Despite its promise, our technique has yet to be fully tested for its power production potential or to be recognized by policymakers and the public. To meet these challenges, we have assembled a team with expertise in engineering, materials science, energy analysis, product design, and public policy. We request funding to (i) develop high-scalability WR materials; (ii) execute lab and meso-scale experiments to document their performance in a variety of physical conditions; (iii) assess scalability to determine evaporation energy harvesting technique's geospatial potential and cost-effectiveness; and (iv) develop marketing strategies for policymakers and the general public.

Approach: Work on this three-year project will be performed in the labs of the five collaborators, with each collaborator leading different sub-projects.

<u>Technical objective 1: Develop high-scalability WR materials (**Tu** and **Chen**).</u> Evaporation energy harvesting devices' performance relies on WR materials. Tu and Chen have developed various WR structures based on various low-cost biomaterials and polymers. Our goal is to reduce the enormous parameter space of potential materials by focusing on critical benchmarks of WR power density (>50 kW/m^3), efficiency (>10%) and scalability. We plan to use material processing to scale up our newly developed WR materials and define a series of polymer based films where a different degree of crosslinking or entanglements among polymer chains can define an 'operability window'.

<u>Technical objective 2: Develop and test laboratory- and meso-scale evaporation energy harvesting devices (**Chen** and **Aydogan**).</u> Chen has successfully developed in the lab small-scale, proof-of-concept energy harvesting device configurations that are ready for further development in terms of their performance metrics and system-level demonstration. To systematically test our technique and demonstrate its potential, Chen and Aydogan plan to build a series of testbeds from laboratory- (0.2 to 1 meter) to meso-scale (1 to 10 meters) that are easy to reconfigure for different WR materials and adjust for optimizing power output. Industrial design will be part of our device development for further exhibition and marketing purposes. The prototypes will also be integrated into the "plant-based air filtering system" to create a self-powered indoor purification system.

<u>Political/marketing objective 3: Feasibility studies: theoretical potential, intermittency, environmental impacts, cost-effectiveness, and scalability (**Vorosmarty**).</u> We intend to use computer models to test the behavior of evaporation energy harvesting devices in a wide variety of applications and assess the feasibility of deploying these devices under a wide range of climate and geographic conditions. The

simulations will be informed and driven by data from both laboratory- and meso-scale experiments, and will, in turn, guide subsequent device optimization, as well as establish the potential of the technique.

Political/marketing objective 4: Marketing strategies for policymakers and the general public (**DiSalvo** and **Chen**). To bring the enormous potential of evaporation energy harvesting to a wider audience, we will develop materials aimed at government policymakers, business leaders, and the informed public. These will include conference presentations, briefings for think tanks and policymakers, and articles for trade publications and major newspapers. In particular, we will target government agencies at the local, state, and federal levels along with legislative staff that work on energy and environmental issues. Finally, we will secure media coverage by science journalists.

Outcomes: Obj1 will lead to a series of scalable WR actuators. Obj 2 will test evaporation energy harvesting devices' capabilities and advance our existing prototypes towards system level demonstrations. Obj 3 will determine the theoretical potential of the system in a variety of environments. Obj 4 will lead to awareness of evaporation energy harvesting as well as the creation of contacts and materials to further market our innovations.

We expect that, with the support from the CRV, the proposed work will not only allow us to make the first transformative progress, but also position CCNY at the center of this emerging field of "Hygroscience." The integration of these efforts will also inform the scientific community, policymakers, and the general public about the potential of evaporation energy and dramatically enhances our applications for federal grant funding opportunities, which make this initiative sustainable after the initial three-year financial support from the CRV. We also expect that, in 5-10 years, the field will have made substantial progress such that the outcomes could find use in other fields of research and in new technologies. At that point, different funding sources can propel future progress of the field.

Expected Products: The team has highly-influential publications in relevant areas, including papers in *Nature*, *Science*, *Nature Materials*, *Nature Nanotechnology*, *Nature Communications*, and *Science Advances*. To maximize the visibility of our findings, we will aim to publish at broad readership journals as mentioned above. In addition, we will aim to publish a total of 3-5 papers per year in more specialized leading journals of the related disciplines. The project will also lead to proof-of-concept demonstrations of evaporation energy harvesting technique, videos, websites, and marketing materials.

Merits: The proposed evaporation energy harvesting devices can directly convert an untapped, ubiquitous source of energy—embodied within atmospheric water vapor—into mechanical energy and thereafter electricity. The metrics will include both physical aspects, such as power production and material efficiency, and techno-economic parameters to inform deployment challenges and opportunities across the nation.

Impact: We envision that, if successful, our invention could provide pioneering methods for humans to harness the ubiquitous, untapped energy source of natural evaporation for broad engineering applications, including actuation, energy conversion, water desalination, and environmental protection. Our evaporation energy harvesting technique will lead to a new clean energy whose power production is comparable to current solar and wind farms, but at a much lower economic and resource cost.

Milestones (Year 1):

Months 1-6: *Develop fabrication systems for WR materials; design and fabricate lab scale (~ 1m) rotary devices; develop models to simulate power output of rotary devices; collect and analyze information of existing renewable energy.* **Months 7-9:** *Fabricate polymer-based WR films and fibers; test performance of rotary devices; simulate energy/power output of rotary devices and compare to experimental results; develop materials to pitch evaporation energy.* **Months 9-12:** *Submission of annual technical report; discuss and submit proposals to program directors of funding agencies, including* ***DoE, DoD, NSF****, and* ***Sloan Foundation****.*

Budget ($200K):

Personnel Costs: $ 10k (Key Personnel); $ 160k (1 Postdoc, $ 68k; 2 PhDs, $78k; and 4 Undergrads, $14k).
OTPS Costs: $ 30k (Materials, supplies, conferences, and travel).