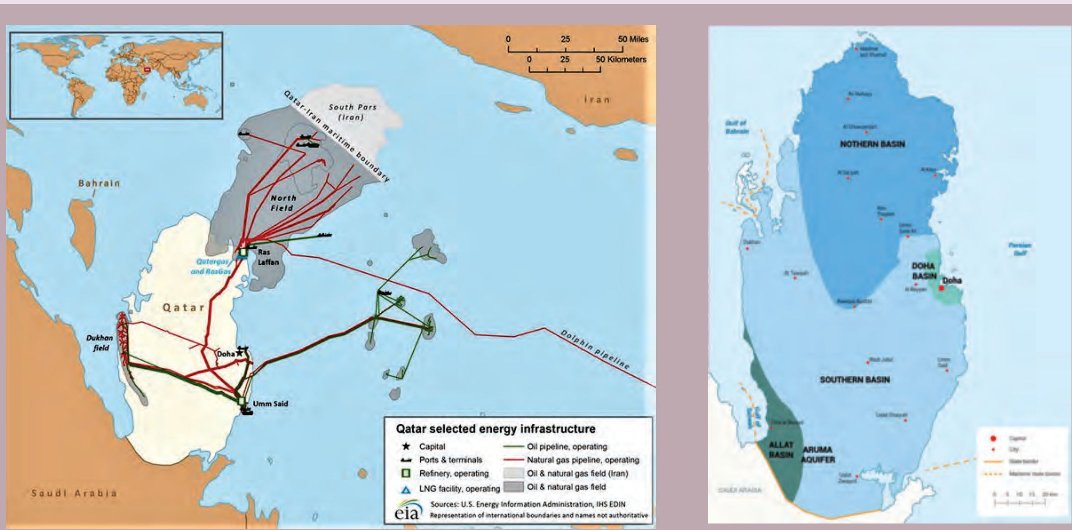
This research proposes and investigates a hybrid piezoelectric and electromagnetic hybrid vibration-based energy harvester (PEMHEH) that can power the smart sensors in condition monitoring applications and sustainably. The proposed harvester utilizes vortex-induced vibration (VIV) of moving fluid to convert kinetic energy into electrical energy. The Vortex-Induced Vibration Energy Harvester prototype is shown in Figure 2. This research is supported under Qatar University International Research Collaboration Co-Fund Grant (IRCC-2020-017). The research addresses issues related to energy sustainability while collaborating innovation between Qatar University and Sultan Qaboos University (SQU) of Oman. The collaboration oversees a strategic research study in both water and air transport mediums, where researchers in QU were responsible for the former and researchers in SQU for the latter. The Lead Principal Investigator from Qatar University was Dr. Asan G.A. Muthalif, alongside the project team members from the Mechanical and Industrial Engineering department.

Extensive research has demonstrated that prototyping and mass-producing self-powering systems is possible using additive manufacturing technologies. Additionally, the added novelty of a hybrid system overcomes the main difficulties presented in the current linear vibration energy harvesters that experience a performance drop due to changes in the environment.

This research highlighted that adding a circular bluff body has significantly increased flow-induced vibration energy harvesting performance output. Triangular, elliptical, and quadrilateral bluff body shapes were also investigated and optimized for galloping-based oscillating mechanisms. A

From left: Dr. Asan Muthalif (Lead Principal Investigator), Eng. Muhammad Hafizh, Dr. Jamil Renno, Dr. Roshun Paurobally.

PEMHEH system can harvest 23% more energy than a conventional piezoelectric energy harvester and is up to 52% more effective in dual-mass arrangement and is capable of functioning at different submergence depths. A heavier effective bluff body mass demonstrated better onset synchronization performance and can be optimized for lower-flow velocity in pipelines or water channels. Additional laboratory testing validated analytical models for synchronization with boundless and bounded boundary conditions that can help design a framework for VIV harvesters. A pipe submerged hybrid energy harvester decreased the overall performance output by 71% because of hydrodynamic-added mass effects. Furthermore, nonlinear magnetic coupling improved narrowband performance by increasing the bandwidth by up to 35% within a noticeable peak voltage reduction. Finally, a complete circular array of four tuned hybrid harvesters demonstrated a combined output of 9V with bandwidth enhancement properties from a central magnetic coupler for



(a) (b)

Figure 1. (a) Qatar energy pipeline infrastructure (EIA, 2015) (b) Qatar's water basin distribution (Fanack, 2021).