The recent reconsideration of structural instabilities as a favorable mechanism instead of a route leading to failure, has brought increased attention across disciplines to extend their understanding of structural instabilities in both form and function. In biological systems, energy transduction is a concept that describes the conveyance of energy – the process to collect and store energy and then release it to perform work. Given the ingenious examples from nature, developing “smart” structures that can emulate biological ones has long been an engineering goal. Realizing energy transduction in mechanical systems offers many opportunities in the design of smart structural systems that can respond and react to their environment. Due to the ability of internal energy exchange within a structure or solid, the presence of elastic instabilities allows to drive dynamic reactions by releasing the system energy in a designed manner. Therefore, elastic instabilities can be harnessed to achieve energy transduction in a mechanical system. The research reported in this dissertation was aimed to address two challenges in mechanical energy transduction: (1) harvest electric energy from low frequency quasi-static mechanical deformations, and (2) dissipate energy in materials subject to cyclic shear deformations in a recoverable and rate-independent manner.

Novel structural concepts are proposed to address the noted challenges. Physical prototypes of both concepts were built through 3D multi-material polymer printing and tested experimentally to verify the expected behavior. For each structural system a theoretical model was developed based
on energy methods, and numerical simulations were carried out by finite element analyses (FEA) using the commercial program ABAQUS. The experimentally validated analytical and numerical models were used to predict system response and explore the design space for each concept.

In the energy harvesting concept, the strain energy accumulated in axially compressed bilaterally constrained columns under quasi-static deformations is released through multiple buckling instabilities in their elastic postbuckling response. The released strain energy is transformed into usable electric energy by coupling the dynamic response with the piezoelectric effect of mounted transducers. This proposed concept overcomes the poor performance of piezoelectric materials under low frequency excitations and it was shown to be effective in harvesting energy directly from quasi-static deformation sources. This work focused on enhancing this concept by maximizing the output through non-prismatic column designs for piezoelectric oscillators and integrated piezoelectric patches for geometric efficiency in energy harvesting devices. It was demonstrated that the resulting energy generation can adequately provide power supply for low-power budget devices with enhanced performance, which can be potentially used to power structural health monitoring systems and human wearable/implantable bio-sensors.

The energy-dissipative material concept, which proposes the use of elastic inclined beams in the microstructure of the material architecture, was shown to manage the strain energy generated due to cyclic shear deformations and dissipate it through sequential snapping instabilities. The periodic arrangement of the elastic inclined beams permits the generation of a ‘twinkling’ phenomenon under repeated in-plane deformations, which results in rate-independent energy dissipations and a fully recoverable response. This concept overcomes the disadvantages of permanent deformations and rate dependency in traditional energy dissipating mechanisms and materials. The developed material design concept can be deployed in diverse applications such as personal protection, packaging, and civil structures.