# COVER PAGE

**Title of Design:** Harvesting Kinetic Energy from Decelerating Aircraft to Improve Airport Energy Efficiency

**Design Challenge Addressed:** Airport Environment Interactions – Increasing Energy Efficiency


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FAA Design Competition for Universities
Airport Environmental Interactions

# Harvesting Kinetic Energy from Decelerating Aircraft to Improve Airport Energy Efficiency


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## Executive Summary

As the importance of reducing power consumption and increasing energy efficiency is becoming more prominent, the Federal Aviation Administration (FAA) has defined a goal to increase energy efficiency and sustainability at airports. While current methods for increasing energy efficiency usually involve powering a system through weather dependent devices such as solar panels or wind turbines, not all airports have the desired weather required to take advantage of such systems. Proposed herein by a team of undergraduate students from Binghamton University – State University of New York, is an energy harvesting system that provides a methodology for using energy captured when a plane decelerates during landing to effectively power airport utilities.

Kinetic energy is present when any object is in motion, and is dissipated when that object slows down or stops moving. Inspired by New Energy Technologies' MotionPower system of harvesting kinetic energy from decelerating road vehicles, this design involves installing an Embedded Kinetic Energy System (EKES) in airport runways to harvest dissipated kinetic energy from landing planes. The EKES will transfer a portion of the captured energy to batteries, from which airport utilities such as runway lights will be able to draw power, and send the rest directly to the power grid. This system effectively uses plane landings, one of the primary operations of airports, to power airport utilities and improve airport energy efficiency.

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## I. Problem Statement and Background

### *a. FAA Goals*

There is a focus within the aviation industry to combat the increasing cost of energy by improving airport energy efficiency and sustainability. Energy often accounts for up to 25% of an airport's total operating expenses [1], and the cost of energy is continuing to rise. The Federal Aviation Administration (FAA) has addressed the lack of energy efficiency as a problem, and has stated that becoming more energy efficient through new, innovative technologies is an important goal for the industry. One of the goals within the FAA's *Destination 2025*, a plan to provide the safest, most efficient aviation system in the world, is to develop and operate an aviation system that reduces aviation's energy impacts while simultaneously maintaining growth and sustainability within the aviation industry [2].

### *b. Current Methods for Meeting FAA Goals*

#### *i. Improving Energy Efficiency*

Over the last several years, the aviation industry has implemented a number of energy-saving techniques and technologies in order to increase energy efficiency. Airports such as the Honolulu International Airport have taken small steps to implement new technology in an attempt to combat the challenge of increasing energy costs. Some of these steps include replacing incandescent taxiway lamps with light-emitting diode (LED) lights [3], shown in Figure 1; however, these improvements only save an estimated 300,000 kilowatt hours (kWh) per year [3], so larger improvements need to be made.

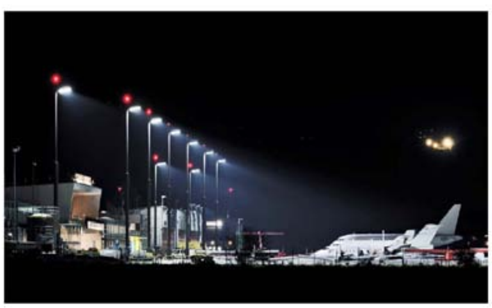

**Figure 1** – LED lights implemented at an airport [4]

*ii. Producing Renewable Sources of Energy*

Many airports hesitate to implement new technologies that produce renewable sources of energy, as those technologies are expensive to implement, require specific meteorological conditions to function, pose safety concerns, require large amounts of space, and don't yield large-scale amounts of power. Two sources of renewable energy that are increasing in prevalence at airports are solar panels and wind turbines.

**Figure 2** – Solar Panels on the roof of the Birmingham Airport [5]

Solar panels, shown in Figure 2, have been implemented at various airports to produce a renewable source of energy by capturing energy from sunlight. Despite producing renewable energy, solar panels are expensive to install and require sunlight to function, rendering them inefficient at airports with little to no access to sunlight. Additionally, solar panels are only capable of collecting small amounts of energy, as the Birmingham Airport was only able to generate 40,000 kWh of energy per year after installing 200 solar panels on the roof of its terminal building [5]. To increase the energy yielded from solar panels at airports, solar farms, or large clusters of solar panels, can be installed; however, these solar farms can require up to 75 acres of space as seen at Indianapolis Airport in Figure 3 [6], and many airports are unable to accommodate these extreme spatial requirements. Furthermore, some airports have seen these systems cause interference with air traffic control operations, such as the system at Manchester-Boston Regional Airport [7].


**Figure 3 –** Part of the 75 acre solar farm at Indianapolis Airport [6]

Similar to solar panels, specific conditions must be met for wind power to be a viable method of producing energy, as wind turbines, shown in Figure 4, would provide a very small impact in locations without a steady source of wind. The safety of these systems has also been questioned as noted in a study conducted at the University of Kansas in early 2014, which asserts that wind farms near airports pose safety hazards for small planes, as turbines can increase turbulence while creating circular vortexes and strong crosswinds. Additionally, the movement of turbine blades can mask the radar signature of airplanes, making them temporarily invisible to airport operators [9].

**Figure 4 –** An airplane flies near a wind turbine [8]

### *c. Moving the Industry Forward*

While systems that promote energy efficiency have already been implemented at airports, the improvements seen are incremental in nature. Airports are challenged with tremendous power requirements, which call for a solution that allows the aviation industry to make significant gains in the improvement of energy efficiency and sustainability. Developing a system that could allow an airport to safely and efficiently internalize its power supply would help the FAA solidify its position as an innovator and early adopter of forward-thinking technology with the goal of dramatically improving energy efficiency and sustainability at airports. The design proposal herein presents an innovative concept to significantly improve energy efficiency at airports.

## II. Summary of Literature Review

### *a. FAA Goals and Sustainability*

One of the goals of the FAA is to increase environmental responsibility and efficiency in American aerospace operations [10]. By 2025, the FAA hopes to make the U.S. aviation sector a model for viable growth through both environmentally and economically sound practices, and by simultaneously reducing aviation's carbon footprint and developing sustainable airport facilities [2]. The FAA is also subject to the National Environmental Policy Act (NEPA), which requires an airport to submit a document named an Environmental Impact Statement prior to making major changes to its design or infrastructure [11]. Executive Order 13123, a piece of legislation that mandates federal agencies to be accountable for their environmental impact, also provides federal oversight to airports [11]. This law pushes airports towards reducing emissions, improving energy efficiency, reducing energy consumption, and reducing the use of petroleum within its facilities [12].

In accordance with its goals, the FAA often invests in projects that promote environmental sustainability. Current examples include the 2004 Voluntary Airport Low Emission Program (VALE), which has provided grant money to purchase clean technology in polluted areas. This legislation has been overwhelmingly successful, as it has decreased airport emissions by about 466 tons per year [13]. The FAA is also involved in the Commercial Aviation Alternative Fuels Initiative (CAAFI), a collaborative effort to evaluate the fuels currently used in aviation, as well as research cleaner and more economically feasible alternatives. [14]. The Continuous Lower Energy, Emissions, and Noise (CLEEN) program, another environmental initiative, explores possible ways to reduce fuel burn and emissions. In addition, the FAA has introduced the NextGen program, a cash incentive for companies to research alternatives to petroleum including alcohols, sugars, biomass, and organic materials [15].

### *b. Airport Lighting*

According to a study conducted at the University of Texas A&M, energy use is the second largest operating cost at airports [16]. Airfield lighting accounts for 15% of the total energy consumption at an average airport, making it a sensible area to improve energy efficiency [3]. IT systems are continually evolving to meet the constant demands for making lighting systems quicker, simpler, and more reliable [17], and the implementation of cheaper sources of energy is crucial and necessary for the continual growth of the aviation industry.

The most modern airport lighting systems are taking advantage of new LED technology to improve efficiency. An LED can produce light equivalent to a conventional incandescent light for one sixth of the energy. LED lighting systems are an energy- and cost-efficient alternative that meet all FAA standards for runway and obstruction lighting, and can be easily integrated into taxiways and runways [18]. Producing electricity on the airfield to power these lights would be another significant step toward sustainability.

### *c. Alternative Energy at Airports*

Currently, a lucrative and pragmatic method of generating electricity from alternative sources is the use of solar energy. Over 15 airports in the country utilize solar power in their facilities, and this number is expanding rapidly as the technology improves and develops. Both the private and public sector offer a variety of incentives for carrying out solar projects, including tax credits [19]. Solar energy is becoming more reliable, though its use in airports can cause unforeseen issues, including communications interference and reflectivity, and the efficiency of these solar projects can vary widely due to climate and weather.

Additionally, airports across the country are beginning to implement wind turbines to harness alternative energy. In 2008, Boston Logan International Airport installed 20 roof turbines that produce enough energy to support 3% of the building's power requirements [20]. Minneapolis-St. Paul International Airport has also installed 10 wind powered 1 kW generators, which it uses to power electric utility vehicles that provide airport services [21]. Liverpool John Lennon Airport installed two 6 kW wind turbines, which provide enough energy to power a four bedroom house, to offset some of the airport's energy usage [22].

### *d. Harvesting Kinetic Energy*

The law of conservation of energy states that energy cannot be created or destroyed, only transferred from one form to another [23]. An aircraft has both potential and kinetic energy while it is at cruising altitude. When the plane brakes, its kinetic energy is dissipated into heat, via friction, which could otherwise be harnessed [24]. Thus, implementing a safe, minimally invasive, and applicable method to harvest the energy of an airplane traveling on the runway would help to progress the FAA's goal of improving airport energy efficiency.

There are precedents for implementing devices that could slow down a plane and harvest the energy that would have otherwise been lost. A device of this style could be installed on a runway, embedded flush with its surroundings. This device would span the section of the runway where the most braking occurs, simultaneously slowing the plane and generating electricity.

### *e. Safety During Landing*

A design that involves heavily modifying the runway to embed a system could feasibly affect landing procedures, so potential safety impacts must be considered. Runway risk is gauged heavily on safety during taxiing, takeoff, and landing operations. The embedded system should not increase the risk of an accident during these procedures, or pilots will have to be briefed and trained on the effects of the device [25].

Knowing precisely how and where airplanes land is crucial for harvesting an optimal amount of kinetic energy and regulating safety. A typical landing process involves the plane decelerating in the air while running on minimal power at a target descent rate of 400 to 500 feet per minute. Pilots are required to maintain a certain airspeed, angle of descent, and power combination to achieve a precise landing [26]. Due to the specific nature of landing operations, the system would have to be placed in a specific, preferably standardized, location on the runway to avoid pilot confusion and landing mistakes while providing the optimal conditions for harvesting energy.

## III. Problem Solving Approach

### *a. Topic is Selected*

The project began when Professor William Ziegler discussed the idea of leading a team in the 2014 competition with Adam Rasefske, a student who was a member of a team that submitted a winning proposal in 2013. Adam developed several conceptual thoughts and ideas for a project and then met with Professor Ziegler, Professor Chad Nixon, and Carl Beardsley, Commissioner of Aviation at BGM, to discuss and refine potential projects. After discussing multiple topics, Adam chose to focus on improving energy efficiency at airports by harvesting kinetic energy from landing airplanes. Both Professor Ziegler and Professor Nixon embraced this idea as having merit and the potential for implementation.

### *b. Project Team is Assembled*

The entire project team was then assembled to discuss the project. The team was split into four sub-teams with unique responsibilities: Design, Engineering and Graphics, Risk Assessment and Research, and Strategies and Ethics. The Design team was responsible for analyzing the technical aspects and determining the projected impacts of the project. The

Engineering and Graphics team was responsible for identifying and describing the problem and photographing the entire design process. The Risk Assessment and Research team was responsible for compiling the literature review, as well as assessing any risk involved in the implementation of the project. The Strategies and Ethics team was tasked with recording the procedures involved with discovering a solution, as well as determining any ethical considerations that may arise with the installation of the proposed system.

Each sub-team consisted of two to three members, with a team leader responsible for ensuring that all work was completed correctly and on time. The sub-teams met weekly, both in and outside of class, to discuss weekly responsibilities. Each of the teams was responsible for creating its own schedule and determining how to best divide the assigned tasks between the members.

### *c. Refining the Concept*

The team began to brainstorm ideas related to the various ways in which energy can be harvested as planes decelerate, and several ideas were considered. One idea was to implement a system similar to those used to stop planes on aircraft carriers, shown in Figure 5. In this system, a hook located on the aircraft attaches to a cable on the landing surface as the plane lands. The kinetic energy from the plane would be transformed into mechanical energy through the cable, which in turn would be transformed into hydraulic energy to be used on the aircraft carrier [28]. This idea seemed intuitive and easy to implement, as the technique and technology are already utilized in military operations; however, concerns arose regarding whether this type of

**Figure 5** – An aircraft is stopped by an arresting cable [27]

system would affect the safety and flying experience of commercial passengers. Additionally, a system of this nature would require all commercial planes to be altered, which could be expensive and challenging from a regulatory perspective.

A new idea arose based on the way that Formula E racecars, shown in Figure 6, are charged through a wireless system that uses induction through a magnetic field to transfer energy from a charging pad on the ground to a pad located on the racecar [29]. This idea was deemed irrelevant because electricity is not the primary source of energy for airplanes, and the goal was not to power the plane itself. The students also suggested an idea in which the runway would resemble a treadmill, where the surface of the runway would move along with the plane to decelerate it, but this idea was deemed too difficult to execute and potentially dangerous.

**Figure 6 –** Formula E racecars are charged through the transfer of energy across a magnetic field [29]

Another idea the team discussed was the potential installation of hydraulic tiles into the runway. Pavegen manufactures a product, pictured in Figure 7, that captures energy whenever a footstep compresses a hydraulic tile system [30]. The major concerns involving this system related to the impact of weather on the tiles, as well as the uneven surface that this would create for landing aircraft. Additionally, questions arose about how much of the landing force of the plane is applied in the vertical direction to put pressure on the tiles. As most of the force

**Figure 7 –** Pavegen tiles capture energy from footsteps [30]

of a landing plane is exerted in the horizontal direction, a compression system would not be an efficient way to capture that energy.

The third major idea the students discussed was the use of some type of system to harvest the kinetic energy of the aircraft as it decelerates. New Energy Technologies is currently working to manufacture a type of energy harvesting system that is able to capture and convert the energy of decelerating cars and trucks into useful electrical energy, as pictured in Figure 8. These devices are designed for automobile traffic areas where braking occurs, such as parking lots, toll booths, and truck stops, where the harvested energy can be used to power lighting systems, appliances, or any number of devices that require electricity [31].

**Figure 8 –** The MotionPower system captures kinetic energy from vehicles and converts it to useable energy [31]

Despite some concerns regarding the durability and size of this system, the team officially decided to pursue the idea of an Embedded Kinetic Energy System (EKES), modeled after New Energy Technologies' MotionPower system, to improve the issue of airport energy efficiency by harvesting kinetic energy from decelerating aircraft.

*d. Interactions with Professionals at the Greater Binghamton Airport*

The team traveled to the Greater Binghamton Airport (BGM), pictured in Figure 9, to discuss these ideas with industry professionals. The students toured the runway and observed the area in which planes most frequently land, as well as the grooves built into the runway to shed water and increase friction between plane tires and the runway surface. The team asked a number of questions and left with several ideas as to how to most efficiently implement this system.

**Figure 9** – The entire team traveled to the Greater Binghamton Airport to meet with industry professionals

In order to develop a system that would harvest kinetic energy, the Design team contacted several industry experts and engineering professors to review the project, as discussed in detail in the Interaction with Airport Operators section of this proposal. The students decided that the EKES would harvest kinetic energy using a piezoelectric system, be embedded in the center of the runway, and transfer the harvested energy to batteries and the main airport power grid.

### *e. The Design Review*

The Design team prepared a presentation of the proposed EKES to share with industry professionals. The professionals provided the students with positive feedback regarding the use of harvested kinetic energy to power runway utilities, as well as the idea to store the harvested energy in batteries. Additionally, Charles Howe, an electrical engineer at McFarland Johnson, provided the students with information regarding a method of calculating how much power could be generated using the harvested energy, which the students were able to use to predict energy and cost savings from the implementation of the EKES.

## IV. Technical Aspects Addressed

### *a. Materials Used*

As New Energy Technologies has not released any information regarding the materials that the MotionPower system is made from, the Design team did extensive research on various types of materials to determine what to propose the EKES be made from. Based upon publicly available information regarding the MotionPower system and other similar systems, the EKES is proposed to be made from piezoelectric material contained in rubber, and will transfer the harvested energy to batteries and the airport electrical grid using a system of cables.

*i. Rubber*

The surface of the EKES will be made out of 100% recycled rubber, and will be 0.125 inches thick. This is the same surface material Pavegen uses for its tiles mentioned earlier in the proposal, so it is evident that this material can be successfully used in energy harvesting systems. The coefficient of static friction of rubber on rubber is 1.16, which is relatively high when compared to other materials, including the coefficient of 0.7 of rubber on concrete [32]. This means that friction between the plane tires and the landing surface will be greater as the plane decelerates over the EKES, implying that the EKES will actually lessen the amount of braking required to slow and stop the plane. The rubber surface will be grooved to match the existing grooves in runways, seen in Figure 10, in order to minimize the changes felt when aircraft decelerate over the surface of the EKES. A polyaspartic outer lining produced by Rhino Industrial will be applied to the rubber surface to increase the overall strength and durability of the system. This commercial grade lining is proven to be extremely durable as evidenced by its repeated use in emergency, aircraft, and heavy vehicle applications [33].

**Figure 10** – Runway grooves at the Greater Binghamton Airport

*ii. Piezoelectric Material*

Beneath the rubber surface of the EKES will be a piezoelectric system responsible for converting the kinetic energy of the plane into electrical energy through the use of piezoelectric crystals. As a mechanical force is applied to the system, the crystals deform, which creates an electric charge. When the force is removed, the crystals retake their original form, allowing them to be deformed again to create more electricity. Piezoelectric systems are known for producing relatively higher voltage and power density levels than similar systems such as electromagnetism [34], and the installation of piezoelectric systems into roadways has been proposed in California [35], so the use of such a system in a runway is plausible. A piezoelectric crystal is 0.7874 inches thick [35], so the thickness of the entire piezoelectric system will be 0.7874 inches. A second 0.125 inch rubber surface will be located directly underneath the piezoelectric system to contain it. The piezoelectric system contained in rubber can be seen in Figure 11.

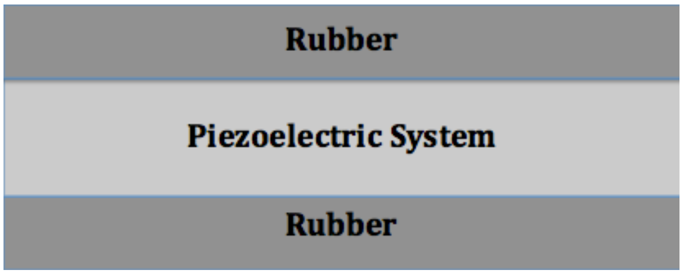


**Figure 11 –** The piezoelectric system is contained between two rubber surfaces (not drawn to scale)

*iii. Batteries*

The electrical system for the EKES will incorporate a battery bank that will serve as backup power for runway utilities. The battery bank will be comprised of two sets of four Trojan 12 Volt 27TMX Signature Line Flooded Deep Cycle batteries connected in series. This model is designed specifically for renewable energy systems and backup power applications [36], and is engineered to sustain high numbers of charge and discharge cycles without degrading over time [37]. Trojan specifically recommends its deep cycle batteries for off-grid lighting systems, noting the battery’s capability to provide consistent performance over a long period of time [38]. The 55 pound battery reaches 100% capacity near 80 degrees Fahrenheit, making it suitable for fair weather climates, and is able to provide an energy output of 1.4 kWh at a 100 hour rate [38].

*iv. Cables*

A system of underground cables is required to transfer the energy from the EKES to the batteries and the power grid. The cables used to transfer the energy will be the same type as those already installed at airports to transfer energy from the power grid to electrical utilities. In order to transfer the energy from the EKES without interfering with runway operations, the cables must be run through an underground trench. As underground cable systems already exist in many airports, implementation will not be difficult, thereby easily allowing kinetic energy harvested on the runway to be stored or immediately used where needed at the airport.

*b. Project Standardizations*

The EKES is initially proposed to be implemented at the Hartsfield-Jackson Atlanta International Airport (ATL), as it is the busiest airport in the world [39]. The large number of landings and the capability to land larger aircraft allow for the most available kinetic energy to be harvested at this location. Additionally, Atlanta is known as a city with fair weather and little to no extreme winter conditions, making it an ideal location to consider implementing the EKES.

If the EKES is to be implemented at a large airport such as ATL, it is logical to use an aircraft such as the Boeing 737-900, shown in Figure 12, when calculating the amount of energy available to harvest. The Boeing 737-900 is a widely used commercial aircraft that would be landing more frequently than other airplane models, and represents an average aircraft used across the country. Delta Airlines, which is based in Atlanta, has approximately 100 of the 737-900 aircraft in its current fleet mix. While each type of airplane will dissipate a different amount of kinetic energy, considering a common, standard airplane for calculations will allow for the most standardized results.

**Figure 12 –** A standard Boeing 737-900 landing on a runway [40]

*c. Location of Implementation*

*i. Landing Threshold*

In order to efficiently implement the EKES, it should be placed in an area that is exposed to a high amount of energy dissipation. To determine the proper location for implementation, there will be a focus on the landing threshold of the runway, which is defined as the point where planes aim to first make contact with the runway surface and begin decelerating. As the area directly beyond the landing threshold is where the most skidding between the tires of the plane and the runway surface occurs, the landing area is clearly seen on the runway as a collection of heavy black marks, shown in Figure 13. Applying the provided scale bar to an image of a runway at ATL on Google Maps [41], the distance of the landing area is approximately 2,000 feet long; however, the EKES should ideally be of a size that both harvests the maximum amount of energy while minimizing the cost of manufacturing, therefore a realistic length for the EKES to span is estimated to be 1,000 feet, starting near the landing threshold.

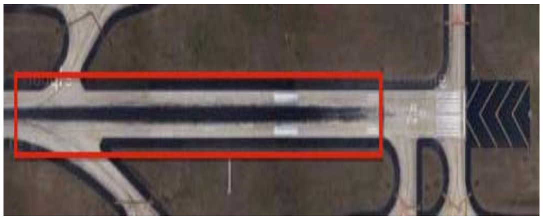

**Figure 13 –** An aerial view of a runway at Hartsfield-Jackson International Airport. The landing area is enclosed in red [41]

*ii. Runway Centerline*

The FAA has generalized the normal approach and landing procedures in the *Airplane Flying Handbook*. The handbook makes it clear that an approaching pilot will attempt to touch down at a specific, desired location. In a normal approach situation, the aircraft should be kept in line with the runway centerline throughout the duration of the approach and landing [26], indicating that a plane should touch down within a margin of the center of the runway during a normal landing. For this reason, it is ideal to install the EKES in the center of the runway, including a width that will allow for some margin of error in touchdown location. The rear landing gear spacing of an industry standard Boeing 737-900 is close to 19.69 feet [42] and will serve as the minimum practical width for the EKES. To minimize the cost of installation while allowing a margin of error to account for deviation from the centerline during landing, the width of the EKES will be 100 feet. This width will accommodate the landing gear spacing of the Boeing 737-900 as well as larger aircraft, while allowing up to 40 feet of landing precision error on either side of the runway centerline.

### *d. Runway Installation*

To avoid creating an uneven runway surface, the system should be embedded at an appropriate depth within the runway so that the surface of the system is flush with the surface of the runway. This will decrease the risk of an aircraft accident while landing on the EKES, as the runway surface will remain essentially uniform, allowing aircraft to fluently decelerate over the EKES and regular runway surface. As each rubber surface is 0.125 inches thick and the piezoelectric system is 0.7874 inches thick, the EKES will be embedded 1.0374 inches into the 20 inch deep runway at ATL. Embedding the EKES in the runway will also create a concrete encasement around the system, effectively holding it in place and maintaining its stability as aircraft decelerate over its surface.

An additional design consideration is that the EKES must be able to adapt to the cyclical changing temperatures during seasonal changes. As the temperature increases and decreases, the components of the EKES will expand and contract, respectively. To avoid damage from the EKES expanding into the surrounding concrete, open space will be left in the runway similar to the expansion gaps already present in runways. This open space will be sealed with a powerful epoxy to prevent any potential aircraft accidents resulting from gaps in the runway. Once the

EKES is installed into the runway, it will look similar to the rendering shown in Figure 14, which is exaggerated to show detail.

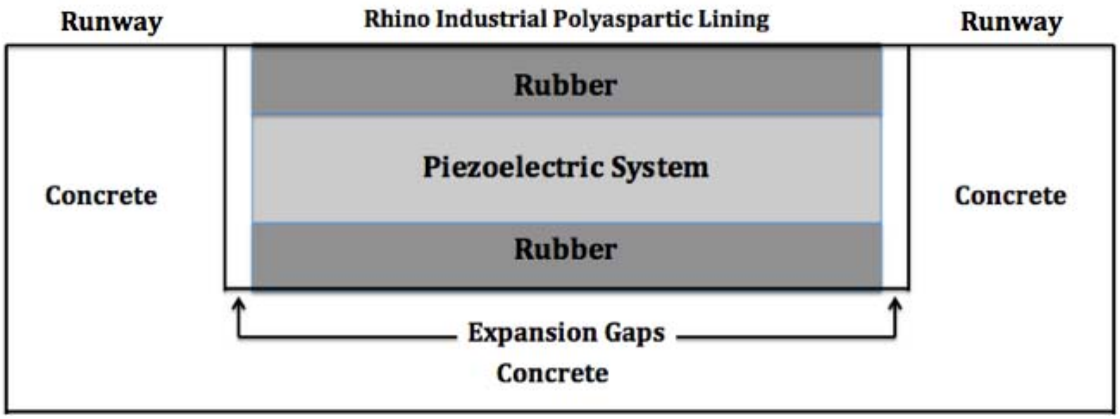


**Figure 14** – A cross-sectional view of the EKES embedded in the runway (not drawn to scale)

### *e. Harvesting Kinetic Energy*

Kinetic energy is the energy an object possesses while in motion, and calculating the change in kinetic energy will determine the amount of useable energy given off by a landing plane as it decelerates along the runway. Since most commercial aircraft have passengers and luggage, the maximum Boeing 737-900 mass of 66,360 kg will be considered for calculations [43]. The average initial velocity of a landing 737-900 is 72.5367 m/s [43], and the final velocity, after decelerating the length of the 1,000 foot system at an acceleration of -4.25 m/s$^2$, is 51.7 m/s according to Equation 1b. Using these variables in Equation 1a, the amount of energy available to be harvested from one Boeing 737-900 decelerating over the EKES is 85,892,496.86 joules, or 23.86 kWh by Equation 1c.

**Equation 1** – Kinetic Energy

a. $\Delta K = .5m(v^2 - v_0{}^2)$

b. $v^2 = v_0{}^2 + 2ad$

c. $1\,Joule = 2.78 * 10^{-7}\,kWh$

- $\Delta K = Change\ in\ Kinetic\ Energy$
- $m = Mass$
- $v = Velocity$
- $v_0 = Initial\ Velocity$
- $a = Acceleration$
- $d = Distance$

According to a test of the MotionPower system conducted by New Energy Technologies, a loaded class 8 truck, shown in Figure 15, drove over the system while decelerating from 24.14 km/h to a complete stop, effectively dissipating 889,000 joules [44]. When compared to the amount of joules dissipated by the Boeing 737-900, the airplane dissipates over 96 times more energy than the loaded class 8 truck. This extreme difference in energy dissipation provides an insight into how beneficial adapting the MotionPower system to accommodate airplanes and installing the EKES at airports could be.

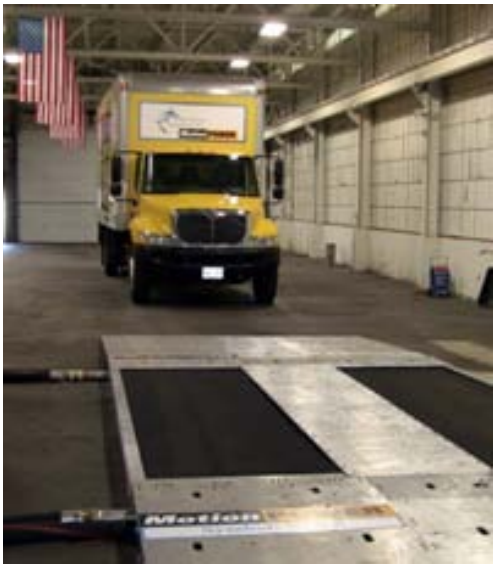

**Figure 15** – A loaded class 8 truck decelerating over the MotionPower system [44]

*f. System Integration*

When integrating the EKES, it is necessary to determine how energy harvested by the system will eventually become useful to some electrically driven component of the airport. It is optimal to separate the output generated by the EKES from the general power supply of the airport, allowing the system to provide immediate or stored backup power as an independent supply, as seen in Figure 16. Once the batteries have been filled to capacity, the remaining energy harvested by the EKES will be sent to the electrical grid, where it can be used in the same way that

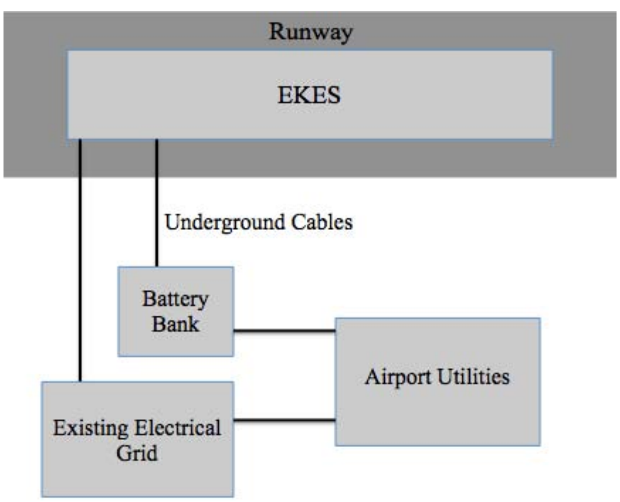


**Figure 16** – A schematic of the EKES transferring electricity

**Figure 17** – A typical runway lighting system [45]

electricity is regularly used to power airport utilities such as runway lights, shown in Figure 17.

The proposed energy harvesting system allows for a customizable and environmentally conscious integration, creating a simple and effective approach to routing the electricity generated by the system to airport utilities. As the system allows the regular airport operation of landing planes to provide airports with useable energy, this source of renewable energy will improve the overall energy efficiency of airports.

## V. Safety & Risk Assessment

It is the stated mission of the FAA to "provide the safest, most efficient aerospace system in the world," and in accordance with that goal, every new idea must undergo a safety evaluation [10]. The FAA Advisory Circular 150/5200-37 delineates the four pillars of an effective Safety Management System as Safety Policy, Safety Risk Management, Safety Assurance, and Safety Promotion. These four components outline the method for evaluating risk at airports [46].

In accordance with the Safety Risk Management policy, all aspects of an idea involving risk are evaluated on a predictive risk matrix, pictured in Figure 18. The biaxial matrix assesses a problem in terms of its severity and likelihood, from no safety effect to catastrophic, and from frequent to extremely improbable, respectively [47]. Based on where a potential risk falls, it is labeled as acceptable, moderate, or unacceptable risk [48]. A design that is calculated to have an unacceptable level of risk, pictured as red on the risk matrix, requires immediate attention and mitigation, and cannot be implemented. A design with moderate risk, pictured as yellow, may be implemented but requires monitoring. Ideally, the design will be categorized as an acceptably low level of risk, pictured in green, and may be implemented in its current state.

| Likelihood \ Severity | No Safety Effect A | Minor B | Major C | Hazardous D | Catastrophic E |
|---|---|---|---|---|---|
| Frequent 1 | Low | Medium | High | High | High |
| Probable 2 | Low | Medium | High | High | High |
| Remote 3 | Low | Low | Medium | High | High |
| Extremely Remote 4 | Low | Low | Low | Medium | High |
| Extremely Improbable 5 | Low | Low | Low | Low | Medium / High |

**Figure 18** – FAA Predictive Risk Matrix [48]

Installing an EKES into a stretch of runway involves construction activities and a new runway surface that must be considered from a risk and safety perspective. One potential issue could be a discrepancy between the normal runway surface and the EKES. If the EKES created an uneven or bumpy runway surface, passenger experience may be affected, and pilots would have to adjust landing and takeoff techniques. The EKES is designed to be embedded flush with the runway, so the surface should not differ enough to noticeably impact the landing process. While embedded in the runway, the EKES will be buffered by a small gap to accommodate expansion and contraction as the design heats and cools, respectively, which is standard in runway pavement design. This expansion gap will prevent the EKES from damaging itself by expanding into the surrounding concrete, and will be sealed with an epoxy to mitigate the issue of an unsmooth runway surface. Since there is no difference between landing on the EKES or on a normal runway surface, the event of a runway excursion as a result of the EKES is extremely improbable in likelihood and minor in severity, resulting in a low risk landing experience for pilots without requiring any major changes in aircraft operation.

An additional consideration is whether implementing the EKES would require any alterations to existing landing procedures. Pilots are already trained to land in the center of the runway, which is where the EKES will be implemented. Additionally, the surface of the EKES, which will be finished with a commercial-grade lining, is paintable, so any necessary runway markings could be painted over the system. No additional training is necessary for landing on the EKES, as existing procedures will remain intact. With a remote probability of likelihood and no safety effect, this aspect adds low risk to the system.

Further potential issues pertaining to the runway surface arise from weather considerations, specifically whether the EKES would be influenced by rain, snow, or ice. As the EKES surface texture is similar to that of a grooved runway, rain will run off in the same way as it would on the runway and not be an issue. As for snow and ice, the proposal suggests the EKES initially be implemented in Atlanta, where such conditions would be minimal. When these conditions do arise, standard runway deicing procedures will still function properly on the EKES. Ranked on the risk matrix, weather concerns are an extremely remote issue of minor severity, and thus a low risk scenario to an airport with existing deicing protocols.

Another safety concern is the potential adverse effect if the EKES fails to generate electricity. The EKES is new technology, so minor technological adjustments may be required. The EKES will supply electricity both by charging batteries and directly powering the grid, so there is no specific airport facility that will be without power if the EKES malfunctions. A problem of this nature would be mechanical and would have no impact on the runway surface, so planes could continue landing on the runway as usual until the next instance of runway maintenance. Another scenario in which the EKES will not generate electricity is when planes drive over it during takeoff. As no deceleration is occurring, no energy will be harvested and no electricity will be produced; however, as previously mentioned, the runway surface will not be impacted so no problems will arise. On the risk matrix, the issue of the EKES not generating electricity is of remote frequency with no safety effect, rendering it a low risk scenario.

None of the outlined safety concerns, including runway excursions, weather, or technical failure, exceed either a remote likelihood or minor severity. Accordingly, the risk assessment for the entirety of the EKES, in terms of the guidelines set forth by the FAA risk matrix, concludes that there is low risk, and that it would be prudent to proceed with implementation [48].

## VI. Interaction with Airport Operators

### *a. Project Begins on Location at the Greater Binghamton Airport*

Adam Rasefske brainstormed a number of topics, including the problem of wasted energy during aircraft landings. He later visited BGM, as pictured in Figure 19, where he discussed this final idea with Professor Nixon and Carl Beardsley, who both deemed the idea very relevant. Adam learned that there is technology available that can harvest kinetic energy from automobiles during deceleration, and decided to attempt to modify the design to implement this technique at airports. Adam then analyzed the landing patterns of airplanes and observed that planes most frequently land in the first several hundred to thousand feet of runway, a fact integral to determining the area of installation of the system on the runway.


**Figure 19** – Team Leader Adam Rasefske meets with Carl Beardsley and Chad Nixon at the Greater Binghamton Airport

### *b. Team Visit to the Greater Binghamton Airport*

Early on in the process, the entire team visited BGM to discuss airport procedures and policies relevant to the design concept. The team met with Carl Beardsley, Doug Goodrich, a private pilot and owner of Goodrich Aviation, and Charles Howe. The team asked a number of questions regarding the precision and skill involved in landing a plane, where on the runway a plane would typically land, and several questions about the runway lights and other electrical devices located on or near the runway.

During this visit, the team also had the opportunity to tour and observe the runway. The team noticed the grooves in the pavement that shed water and increase friction between the runway and plane tires during landings. The students also had the opportunity to observe the landing threshold, the point on a runway where planes aim to touch down. One of the team members also had the additional opportunity to observe the use of the Tapley brake meter with Commissioner Beardsley. The Tapley brake meter, pictured in Figure 20, is a device that allows airport officials to measure the coefficient of static friction between the tires of a vehicle and the runway [49]. Measuring the coefficient of static friction was important in the development of the design, as braking is a major component of the proposal.

**Figure 20** – A team member had the opportunity to observe the use of the Tapley brake meter with Carl Beardsley

*c. Working with Airport Operators and Industry Professionals*

Discussion with Doug Goodrich revolved primarily around the specifics involved in landing a plane. The team asked several questions regarding how precisely a pilot is able to land an aircraft in a specific area of the runway. Goodrich, pictured in Figure 21, informed the team that there are various factors that can affect where a pilot lands on a runway, including weather, skill level of the pilot, and the type of aircraft that is being utilized. This caused the team to think about the best area of the runway in which to install the system. In order for the EKES to have the maximum cost efficiency, the system would be implemented in the smallest area possible while still harvesting the majority of the energy from the decelerating aircraft. Based on the information from Goodrich, the team learned that the majority of energy could be captured within the first 1,000 feet of runway where planes most frequently land, and the system would need to be wide enough to accommodate the differences in gear widths of various aircraft.

**Figure 21** – Private pilot Doug Goodrich worked with the team

When consulting with Charles Howe, the team had many questions regarding the electrical systems employed by the airport. The team initially thought the best utility to power with the EKES would be the runway lights. Charles Howe, seen in Figure 22, thought this was an excellent idea, and informed the students that the system could either feed directly into the existing electrical system or be used to charge batteries. The batteries would require space for storage, but would also prove useful in the event of an airport power outage. Additionally, Howe suggested the harvested energy could be used to power navigational aids for airplanes in addition to the runway lights. Howe also provided the students with detailed information regarding the mechanisms of

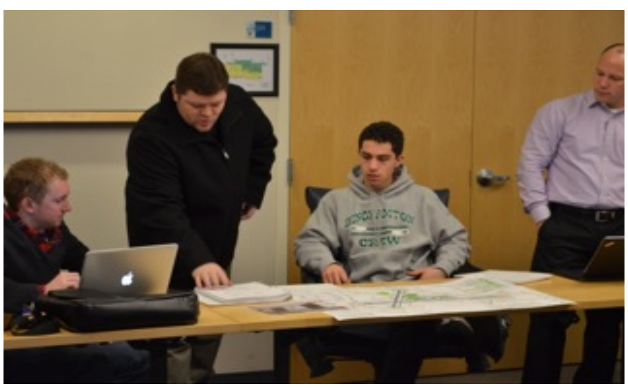

**Figure 22** – Charles Howe works with the students at BGM

airport lighting systems, which the team was able to use to assess the amount of energy required to power the lights.

Commissioner Beardsley, pictured in Figure 23, provided the team with several suggestions regarding the best place to implement the system. The team considered installing the system on the taxiway rather than on the runway; however, the edge lighting on the taxiway is LED and requires much less energy than the edge lighting of the runway. Additionally, planes on the taxiway are not decelerating, which decreases the potential for harvesting energy. Commissioner Beardsley also suggested that the system could be implemented at the terminal gates, as all planes pass over that area. As airplanes travel at a much slower speed around the terminal gates, there would be less risk involved with driving over the system, but there would be much less energy available to harvest.

**Figure 23** – Carl Beardsley talks to the students as they tour the runway

*d. Industry Officials Visited Binghamton University to Work with the Team*

As the project developed, the team prepared for another meeting with industry officials. A design review, shown in Figure 24, was scheduled with Harvey Stenger, President of Binghamton University, Professor Nixon, Professor Ziegler, Charles Howe, and Carl Beardsley. The finalized proposal was presented, and the team discussed questions that had arisen as the project developed.

**Figure 24** – The Design team presented the proposed EKES to industry professionals

The questions primarily revolved around the placement of the EKES on the runway, so the team explained that the system would be installed near the landing threshold. The industry experts also questioned whether the EKES would interfere with the safety of runway operations, including whether the system would make the runway surface uneven and how it would react to weather such as rain, snow, and ice.

After receiving the questions and advice from industry professionals, the team determined that the EKES should first be implemented in a warmer climate with little to no snow or ice. The team decided that Hartsfield-Jackson Atlanta International Airport would be a sufficient model airport to hypothesize the attributes of this system due to its location and high number of aircraft landings. The team also discussed how the EKES would respond to rain, and concluded that water would drain off the EKES in the same way that it drains from runways due to the similarities in grooves between the EKES and those already present in runways.

*e. Design Team Consults with Engineering Professors*

The Design team contacted and consulted with a number of different engineering professors at Binghamton University – State University of New York to discuss this project. The team members discussed the potential systems that the harvested energy could be used to power with Dr. Mike Elmore, director of the Engineering Design Division at the Watson School of Engineering. Dr. Elmore suggested that this energy could potentially be used to power luggage carts in airport terminals, conveyor belts in airports, ground carts that power planes, electrically powered jetways, or runway lighting systems. Based on the discussion with Dr. Elmore, the team determined that the harvested energy would be best used to power runway lighting systems due to the fact that a power outage involving the runway lighting system can lead to cost and safety problems. Additionally, the students learned that airports without traditional lighting systems could be prone to power losses.

Dr. Krishnaswami Srihari, dean of the Watson School of Engineering, advised the team about the best way to store the energy harvested in this process. Dr. Srihari suggested that the energy be stored in a battery away from the runway in order to ensure easy access to the energy. Dr. James Pitaressi, a distinguished professor in the mechanical engineering department, provided the Design team with a detailed description, shown in Figure 25, of how to implement the EKES into the runway. Additionally, Dr. Pitaressi assisted the team in performing some preliminary calculations as to how much energy could be harvested.

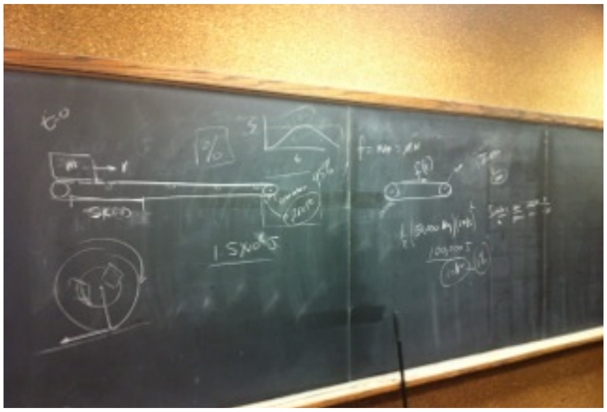

**Figure 25** – The Design team sketched potential ideas for the EKES with Dr. Pitaressi

*f. Correspondence with New Energy Technologies*

Adam Rasefske contacted New Energy Technologies, the company that makes the MotionPower system that the EKES is modeled after, several times to discuss this proposal. As New Energy Technologies is a publicly traded company attempting to patent a version of this technology for vehicles, it was restricted in the amount and type of information that could be provided, but was able to offer a limited amount of information including weather related safety concerns.

## VII. Projected Impacts

### *a. Financial Analysis*

In order to determine the financial impact of implementing an EKES, the cost of materials, shown in Chart 1, must be computed. As the price of a 3 foot x 50 foot x 0.125 inch rubber sheet is $20.43, it would cost $13,620 per rubber surface to span the surface of the EKES [50]. The cost of the piezoelectric crystals was determined by considering the cost of the crystals researched in the piezoelectric road project in California. The dimensions for a single piezoelectric crystal used in the proposal are 14 cm x 14 cm x 2 cm [35]. The 1,000 foot length of the EKES requires 2,177 piezoelectric crystals, and the 100 foot width requires 69 crystals spaced 30 cm apart. The crystals cost $0.155 per cubic cm [35], invoking a cost of $9,126,941.88 for the piezoelectric system in the EKES. The team consulted with Professor Nixon and Charles Howe to accurately determine the prices for the underground cables, the polyaspartic lining, and the Trojan Deep Cycle batteries, which can be seen in Chart 1.

| Material | Unit Cost | Quantity | Total Cost |
|---|---|---|---|
| Grooved Rubber Surface | $13,620 | 2 | $27,240 |
| Polyaspartic Lining | $10,373.34 | 1 | $6,915.56 |
| Piezoelectric Crystals | $0.16 | 22,043,532 | $9,126,941.88 |
| Trojan 27TMX Signature Line Flooded Deep Cycle Battery: 12V, 105Ah | $163.21 | 8 | $1,305.68 |
| Battery/Inverter Cables | $27 | 1800 | $48,600 |
| Total Cost | | | $9,211,003.12 |

**Chart 1** – Cost of Materials

As seen in Chart 1, the total cost of materials for the proposed system is $9,211,003.12. To determine the total cost of implementing the system, the cost of installation and maintenance must also be considered. The installation of the EKES is recommended to occur during a time of major runway rehabilitation or reconstruction, so the runway will already be undergoing significant construction, and no additional cost will be required to create space to embed the system. Therefore, the installation cost will only consist of the labor necessary to implement the system, which, according to engineers from McFarland Johnson, will add an estimated $10,400, increasing the total cost of implementing an EKES to $9,221,403.12.

Once the EKES is embedded in the runway, it will remain stable and be able to function properly as aircraft decelerate over its surface. With the application of the polyaspartic lining, the EKES is projected to be a long lasting system [33], making the cost of maintenance negligible. According to the FAA Airport Improvement Program Handbook: Order 5100.38C, a pavement runway, or any system that is connected to a runway, is considered a permanent design with a life expectancy of 20 years [51]; however, the EKES is expected to maintain functionality beyond this period of time, with an estimated life expectancy well beyond 20 years.

### *b. Applications of Harvested Energy*

On average, there are approximately 1,250 landings per day at ATL. Since ATL has five runways in total, it is reasonable to assume that there are 250 landings per day on a single runway where the EKES will be installed. Multiplying the average daily number of landings on one runway by the power harvested from a single landing, the EKES will be able to harvest 5,965 kWh per day, and 2,177,225 kWh per year [52]. The energy harvested by the EKES can be utilized as an immediate or backup power supply wherever the airport deems necessary.

#### *i. Directly Powering Airport Utilities*

As ATL is the busiest airport in the world, its energy requirements are substantial. The amount of energy used at ATL has been steadily increasing over the past several years, and was listed as 292,236,533 kWh in 2011 for $32,438,255.16 [52]. To power airfield lighting and lighting vaults alone, ATL used 5,736,455 kWh for $636,746.51 [52]. As the EKES can generate 2,177,225 kWh per year at ATL, the energy from the system could account for nearly 40% of the yearly energy used to power the airfield lighting and lighting vaults. If additional Embedded Kinetic Energy Systems were installed in the remaining runways at ATL, the amount of energy harvested would be maximized, and could completely account for the energy requirements of the airfield lighting and lighting vaults while also contributing to other airport utilities.

To specifically address runway lights as a possible use for the power generated by the EKES, there are approximately 90 lights along a runway at ATL, each requiring a voltage of 240 volts and a constant current of 6.6 amps. According to Equation 2a, the runway lights require 142.56 kW to be powered at maximum intensity. As the EKES generates 5,965 kWh per day, according to Equation 2b, the energy generated by the EKES in one day can power the runway lights at maximum intensity for 41.8 hours, or 1.7 days.

**Equation 2** – Power

a. $P = I * V$

b. kWh = kW * h

- $P = Power$
- $I = Current$
- $V = Voltage$
- $h = time\ in\ hours$

*ii. Battery Storage*

A portion of the energy produced by the EKES will be stored in two banks of four 12 Volt 27TMX Signature Line Flooded Deep Cycle batteries. The batteries in each bank will be connected in series to achieve a constant voltage of 48 volts, and the two battery banks will be connected in parallel to maintain the voltage while doubling the amp hours (Ah). The two battery banks will be charged individually.

In the 4.908 seconds it takes a plane to decelerate over the length of the EKES, 175,000,508.73 watts of power will be generated by Equation 3a. According to Equation 2a, the

**Equation 3** – Charge

a. $1\,Watt = 1\,Joule/second$

b. $t = \frac{q}{I}$

- $t = Discharge\ Time$
- $q = Charge\ Capacity$
- $I = Current$

electrical current supplied to the batteries by the 240 volt constant current regulator is 72,918.79 amps. By Equation 3b, the amount of time required to charge one battery bank to 80% capacity is 16.59 seconds, therefore four planes decelerating over the EKES for 4.908 seconds each will charge one battery bank to 80% capacity.

Each battery has a current capacity of 105 Ah, indicating that it can supply 105 amps of current for 1 hour. Since the regulator that provides a constant current of 6.6 amps to the runway lighting system requires 8.85 amps to function, one battery bank at 80% capacity can power the lighting system for approximately 10 hours by Equation 3b.

An attractive feature of the EKES is its customizability and range of usages within an airport regarding the stored energy. The battery banks allow energy harvested by the EKES to be stored and used at any time for any airport utility powered by electricity, including runway lights, jetway lights, electric vehicles, and shuttle systems. Energy stored in batteries would also be useful in the event of an airport power outage. During a blackout, airports may be required to delay or cancel flights, and may experience security and baggage-handling delays [3], costing them revenue and passenger satisfaction. If an area of an airport experiences a blackout, the batteries could contribute power to the downed system to quicken the recovery process and minimize the decrease in airport throughput due to the power loss.

*c. Comparison to Existing Renewable Energy Sources*

It is important to compare the amount of energy harvested by the EKES to renewable energy sources already implemented at airports to gauge its effectiveness. Wind and solar power applications are increasing in prevalence at airports, and as seen in Figure 26, comprised nearly 50% of the renewable energy sources implemented in the United States in 2012 [53]. As such, it is suitable to compare the energy generated by the EKES to that generated by existing wind and solar power systems at airports.

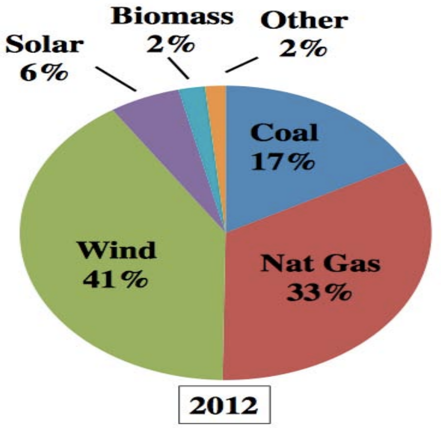


Figure 26– Renewable energy sources used by the U.S. in 2012 [53]

Martha's Vineyard Airport implemented a system of wind turbines that was only able to produce 120,450 kWh per year [54], 18 times less than the energy the EKES can produce at ATL. As previously mentioned, the Birmingham Airport could generate 40,000 kWh per year with its 200 solar panels, while the EKES can generate over 54 times more energy per year at ATL. In December of 2011, Chattanooga Metropolitan Airport (CHA) installed a 4.5 acre solar farm totaling $4.3 million to provide the airport with solar power. The system collected 90,000 kWh in the first two months of implementation, which can be projected to 540,000 Kwh per year [55]. Although the EKES is twice as expensive as this system, it can harvest more than four times as much energy. The solar farm also takes up a significant amount of space at CHA, while embedding an EKES in the runway will not require any extra space for implementation.

Although the technology inspiring the design for the EKES is still in the development stage, and the calculations for energy harvesting are estimates based upon other piezoelectric products, the EKES is proposed to be more efficient than current wind turbine and solar panel technology, and will be produced at a reasonable cost based on the publicly available material and technological information.

### *d. Assumptions and Considerations*

It is important to note that many assumptions were made when calculating the amount of energy dissipated by the aircraft and captured by the EKES. These assumptions include the type, mass, and velocity of the aircraft, the number of landings per runway per day at ATL specifically, and the cost of electricity in Atlanta. As such, the total amount of energy and cost savings that the EKES can provide will be different at each airport. Smaller airports land fewer and smaller aircraft, reducing the amount of energy available to be harvested, but presumably have smaller runways, requiring smaller EKES dimensions and a lower cost of implementation. As airports cannot save more money on energy than they spend, if the EKES harvests more energy than is needed, additional batteries or alternative storage methods may be required to successfully utilize all of the harvested energy, or the extra energy could potentially be turned into an extra source of revenue for the airport.

Another factor that must be considered is that these calculations were based on the assumption that the EKES can successfully harvest and transfer 100% of the available energy from the decelerating aircraft. In reality, there is a margin of error that must be considered to account for dissipated energy lost through external forces, and not successfully harvested by the EKES. As New Energy Technologies furthers its development of the MotionPower system, and similar techniques for harvesting dissipated energy arise, more accurate estimations of energy harvesting efficiency can be established.

### *e. The Future of Kinetic Energy Harvesting*

Kinetic energy harvesting is a work in progress, as developments around this source of renewable energy are just beginning to be made. Companies such as Pavegen and New Energy Technologies are paving the way for kinetic energy harvesting systems to take rise as a prominent source of renewable energy. The proposed EKES is the first step toward unlocking the potential of an otherwise wasted source of renewable energy that will aid the FAA in its pursuit of improving airport energy efficiency.

### *i. Investing in Piezoelectricity*

As seen in Chart 1, the price of the piezoelectric system makes up the majority of the total material cost of the EKES. Despite the high initial cost of implementing piezoelectric materials, piezoelectric technology is still in an early stage of development. According to Kim Diamond, Vice Chair of the Carbon and Energy Trading and Finance Committee, "…investing in piezoelectric technology while it is still in its infancy could prove to be quite lucrative" [56]. Advancements in piezoelectric technology are continually being made, as researchers from the Korea Advanced Institute of Science and Technology have created a high-area, low-cost, environmentally friendly piezoelectric system [57]. According to Diamond, a breakthrough in piezoelectric technology could occur during the approval stage of a project and be implemented during the actual construction [56]. Additionally, Diamond asserts that entities that implement piezoelectric technology will "…garner positive press and enhance their reputation as being a leader in this futuristic clean technology…" [56].

### *ii. Additional Incentives*

The federal and state governments offer financial incentives to corporations for implementing renewable energy projects. The American Recovery and Reinvestment Act (ARRA), passed in 2009, allocates exponentially more funds for New Clean Renewable Energy

Bonds than were ever available in the past [58], allowing the federal government to provide large tax credits to facilities that employ methods of renewable energy generation. The IRS offers corporate credits and reductions for multiple renewable energy methods including solar and wind power [58]. Federal credit amounts differ based on the method of energy production and the size of the project. Currently, corporate solar, small wind, and fuel cell projects can earn tax credit up to 30% of the cost of investment [59]. Additional tax credits are provided for renewable energy producers, allowing corporations to earn tax credits on the development of their project as well as its operation.

State governments will offer similar credits for clean energy. According to the Database of State Incentives for Renewables & Efficiency, part of the U.S. Department of Energy, the Georgia state government offers up to 35% credit on renewables and $500,000 of incentives on wind, photovoltaic, and similar technology projects [60]. While kinetic energy harvesting does not currently fall in this highest level of tax credit, the rapidly developing technology will become an increasingly viable source of renewable energy, thereby driving similar credit options and incentivizing private companies to invest in kinetic energy harvesting technology.

### *f. Achieving FAA Goals*

The EKES will help the FAA achieve its goals for *Destination 2025* because it is designed to promote airport energy efficiency and sustainability while reducing reliance on outside energy providers. The concept driving the development of renewable energy technology is creating ways to generate energy from predictable and consistent occurrences [2]. Implementing the EKES will allow airports to generate electricity by simply continuing to land aircraft on the runway, a consistent and certain occurrence at an operational airport. This is an environmentally conscious and efficient method of replacing a quantity of electricity that would have otherwise been provided by an outside supplier.

Innovative energy technologies employed in the EKES allow the FAA to support research and development involved in progressing a new source of renewable energy technology. The impact of energy harvesting technology is unquantifiable given the immensity of its potential, as the overwhelming majority of energy involved in the deceleration of an object is simply dissipated and lost. While current applications of kinetic energy harvesting technology are limited, the possibilities are vast and provide a unique opportunity for the aviation industry to collaborate and advance. Airplanes possess enormous amounts of kinetic energy, and as there is currently no method for harvesting the energy dissipated during landing, all of that useable energy is wasted. The EKES is the first step in the direction toward making kinetic energy harvesting a prominent source of renewable energy, and is clearly a worthwhile and rational investment given the ways its implementation can advance the FAA's mission and goals of improving airport energy efficiency and sustainability outlined in *Destination 2025* [2].

## VIII. Summary and Conclusion

The FAA has outlined its expectations for airport management to reduce energy consumption while improving airport energy efficiency. As energy is the second largest airport expenditure, there is a need for airports to become more energy efficient to reduce the burdening costs of energy. The aviation industry has implemented a number of energy saving techniques and technologies in order to improve energy efficiency, but these implementations have only marginally helped the cause, and larger airports are still challenged to meet their personal energy efficiency goals. New technology is paramount in order to meet the goals set forth by the FAA and individual airports in their efforts to improve airport energy efficiency.

Whenever an airplane lands, a large amount of useable kinetic energy is lost due to the lack of a system that can harvest it. The team of students from Binghamton University – State University of New York has designed a method to harvest the kinetic energy dissipated when planes land on a runway by installing a system similar to the MotionPower system available at New Energy Technologies. Working with industry professionals from McFarland Johnson, Inc., professors from Binghamton University, and the Commissioner of Aviation at the Greater Binghamton Airport, the team was able to draw inspiration from the MotionPower system to design an Embedded Kinetic Energy System that would be installed near the landing threshold of airport runways. In addition to being able to harvest large amounts of energy that would otherwise be lost, the design is safe and not confined by any spatial or meteorological conditions. If implemented, the design will allow for a significant improvement in renewable energy technology at airports, effectively helping the FAA achieve its goal of improving airport energy efficiency and sustainability.

## Appendix A: List of Complete Contact Information

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## Appendix B. Description of Binghamton University – State University of New York

Binghamton University – State University of New York is located in Vestal, New York, a suburb of Binghamton, New York. It has an enrollment of 12,997 undergraduate and 3,080 graduate students. The university, pictured in Figure 27, consists of six different schools offering a wide range of majors and concentrations: Harpur College of Arts and Sciences, the College of Community and Public Affairs, the Decker School of Nursing, the Graduate School of Education, the School of Management, and the Thomas J. Watson School of Engineering and Applied Science [62]. Within these six schools, more than 130 academic programs are offered to undergraduates [63]. Additionally, Andrew Cuomo, the Governor of New York, stated that $10 million would be set aside for the foundation of a new school of Pharmaceutical Sciences and Pharmacy [64]. Binghamton University offers more than 30 doctoral programs, awarding more than 100 doctorates every year [62]. Binghamton University's student body is quite diverse, with students enrolled from 53 states and territories, as well as 116 countries around the world. Almost 30% of students at the university identify as students of color [65].

**Figure 27 –** Binghamton University [61]

Binghamton University is a member of the State University of New York (SUNY) System, which spans 64 campuses and currently enrolls 422,582 undergraduate and 40,116 graduate students [66]. SUNY's mission is to provide the people of New York with access to the best possible educational services and activities [67]. Binghamton University more specifically states its mission as enriching society through education and research. In the future, Binghamton University hopes to distinguish itself as a nationally recognized, premier public university [68]. In spring 2012, university president Harvey Stenger unveiled a “Road Map” for the university, setting strategic priorities for the university in the hopes of becoming the premier public university of the Northeast [64]. President Stenger also recently unveiled a new “20 by 2020’ initiative in his annual State of the University Address, stating his plans to increase enrollment to 14,000 undergraduate and 6,000 graduate students by 2020 [69].

Binghamton University was named one of the Top 10 Best Value Public Colleges for 2014 by the Princeton Review [70]. The university was also named the 15th best value public university for in-state students and the fourth best value public university for out-of-state students by Kiplinger in 2014 [71]. Binghamton University ranks 139th on the Forbes list of America’s Top Colleges [72], and is ranked 97th on the U.S. News and World Report’s List of National Universities [73]. Additionally, U.S. News and World Report ranks Binghamton University as the 44th Best Public School in the nation [74]. Binghamton University had an estimated economic impact of $965 million on the region and an estimated economic impact of $1.2 billion on New York State in 2011 [75].

Beyond the classroom, the Binghamton University campus spreads across 930 acres and features a 190 acre nature preserve with miles of hiking and biking trails. Students live in one of six residential learning communities, building strong bonds with their classmates. The Binghamton Bearcats offer 21 NCAA Division I varsity sports [62]. Additionally, there are over 250 clubs and organizations for students to join [76]. The Binghamton University Scholars Program is a selective honors program for students of exceptional merit. It combines academic opportunities, extracurricular activities, and community involvement to offer its students a holistic experience [77]. Binghamton University offers countless opportunities for students to grow and develop, both inside and outside of the classroom.

## Appendix C. Description of Non-University Partners

### *I. Greater Binghamton Airport*

Greater Binghamton Airport, shown in Figure 1, is a publicly owned, public-use commercial service airport located eight miles outside of Binghamton, NY [79]. BGM offers the choice of three major airlines: United Express, U.S. Airways, and Delta [80]. These three airlines offer daily flights to three major hub airports: Philadelphia, Detroit, and Washington D.C. From these three airports, travelers can access hundreds of destinations domestically and internationally [81].

**Figure 28 –** Greater Binghamton Airport [78]

BGM had a total budget of $4,109,241 in 2012, offering 7,232 airline operations, 401 military operations, and 96,943 boardings [82]. BGM also has a 21,000 square foot airport hangar with an additional 7,000 square feet of useable space [80].

The long-term goals of BGM are to meet the air travel needs of those in the airport's service area, maintain first-class airport facilities, and identify opportunities to increase the viability of the airport [79]. BGM is a forward-thinking facility that has made several industry-leading improvements over the last several years. These improvements include one of the first ten Engineered Material Arresting System (EMAS) installations in the world, as well as several significant energy efficiency improvements [83].

Carl Beardsley has been involved with many of these improvement projects. He has worked at the airport since 1998 and has held the title of commissioner since 2005 [84].

Commissioner Beardsley made himself available to answer many questions from the Binghamton University team.

### *II. McFarland Johnson, Inc.*

McFarland Johnson, Inc., founded in 1946, is a planning, engineering, and construction administration with a continuing focus on both clients and employees [85]. McFarland Johnson's corporate headquarters are located in Binghamton, NY, and the firm has seven branch offices located throughout the Northeast [86]. McFarland Johnson is fully employee-owned and serves the transportation, buildings, environmental, and land development markets [85]. The firm's core values are employee engagement, sustainability, client service, innovation, entrepreneurship, and company unity [87]. McFarland Johnson has several Leadership in Energy and Environmental Design (LEED) accredited professionals on staff and is a member of the U.S. Green Building Council [88].

McFarland Johnson's professionals have contributed to airport design, aviation planning, GIS capabilities, and environmental and sustainable services at a wide range of airports [89]. BGM selected McFarland Johnson as the firm best suited for completing their latest Master Plan, which emphasizes community involvement, utilities, financial strength, and airside development. While the plan was completed in 2008, the airport continues to work closely with McFarland Johnson on the plan's implementation. McFarland Johnson is currently working closely with Broome County officials to market airport-owned land

**Figure 19 –** Charles Howe works with Professor Nixon and Binghamton University students

to prospective businesses [78].

Charles Howe made himself available to answer many questions from the team as seen in Figure 29. Mr. Howe’s experience in airfield lighting, voltage regulators, and power conversion was especially helpful while considering the design for the EKES.

# Appendix E. Evaluation of the Education Experience

## Student Evaluation

**1. Did the FAA Design Competition provide a meaningful learning experience for you? Why or why not?**

Regardless of the outcome, the FAA Design Competition has been an invaluable educational experience for each team member. The structure of the project and the nature of the team's approach provided an extraordinary amount of experience with problem solving in a team setting, an important professional skill. The uniqueness of this project also gave many students their first management and leadership positions, especially relating to team-based problem solving. Students had practice using external resources and many improved their professional inter-personal skills. The knowledge and skills the students acquired through the FAA Design Competition can transcend the classroom and give the students an advantage in the professional world.

**2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?**

The main challenge faced by this team was the lack of available information regarding the specific products and ideas mentioned in the report. This led the students responsible for design aspects of the project to formulate ideas, plans, and calculations from scratch. New Energy Technologies, the company developing a product most similar to what the team envisioned, is restricted from providing revealing details about its design as it is still in the early stages of development. As the team lacked comprehensive product details from a professional source, those in charge of design researched similar technology, such as that developed by Pavegen Systems, in order to approximate the specifics of the product.

Students on this team faced other challenges throughout the course of this project, including meeting strict deadlines, agreeing on and finalizing design specifics, and submitting work that met the high standards expected of them. These aspects of the competition initially shocked many students that were not expecting to have to perform at such a high level; however, team members quickly adjusted and began producing more professional work. This development was a necessary step in the personal growth of the individual team members, as the experience introduced students to the rigor and veracity of the professional world as compared to the strictly educational scenario they were accustomed to.

**3. Describe the process you or your team used for developing your hypothesis.**

The process used to develop the hypothesis was mainly an intellectual one as opposed to a physical or pragmatic one. Since physical models of energy-collecting surfaces are not readily available to college students, the team started out with a general brainstorm of ideas. The team researched and deliberated the projected benefits and risk of each idea, and discussed the ideas with professional contacts in both the educational and aviation fields. The final hypothesis was selected for its powerful potential, unobtrusiveness, and innovative style as compared to the other possibilities explored by the team.

**4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?**

Industry input was extremely important to the decision making process during the development of the project. Various experts in the aviation industry gave advice related to the concept, as well as information related to potential problems and obstacles. Industry experts were able to provide professional viewpoints and insight on FAA operations as well as predict many indirect implications of proposed designs. Professional contacts, including an electrical engineer, engineering professor, and many aviation professionals, aided the team in selecting a design, determining its placement along the runway and its method of installation, and selecting a way to utilize the captured energy. The process of acquiring and utilizing external resources, especially in the form of professional contacts, was a new experience for many team members. This acquired skill will improve resourcefulness and ingenuity for many students in their future careers.

**5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?**

Overall, members of the team came away with a much greater knowledge of the problem-solving process in a team setting. Many members of the team had limited or no experience of this kind, and while struggling at first, are now much more comfortable working on large-scale group projects. This team also gained experience finding and using professional contacts and other resources to help accomplish a goal. Each team member practiced writing and revising reports, as well as accepting and responding to constructive criticism. The FAA Design Competition provided this group of students with invaluable experiences that will set them apart as they pursue professional careers.

## Faculty Response

**1. Describe the value of the educational experience for your student(s) participating in this Competition submission.**

As a lifetime student myself, I am a firm believer in continuing the educational process and doing so in a manner that has a lasting effect. While lecturing and laboratory time have great value they are limited in their ability to allow students a blank slate to work from. The FAA Design Competition provides the opportunity for students to take an idea, their idea, all the way from the brainstorming stage to a well-researched concept that has real potential for implementation. Creating their own solutions that do not currently exist for challenges facing an industry such as aviation allows the students to take true ownership in the educational experience.

Over the course of the design competition, a team of diverse students had to not only develop a sound proposal but also gain trust in each other by working in teams. Individually and collectively they had to deliver on milestones each week to ensure that the proposal stayed on track for meeting the submission deadline. This is a life skill that cannot be easily taught in class and the FAA Design Competition provides this critical educational opportunity.

**2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?**

The students involved in the design competition are not accustomed to working in a large group (20 students +/-). This opportunity required a high level of effective communication, management of schedule and assets in the form of smaller teams working on individual project components. Although this was new ground for most of the students, it pushed them to improve their communication and time management skills. This is a key element of the learning experience and one that will help the students as they complete their education and move into a career. Overall the experience was appropriate and effective.

**3. What challenges did the students face and overcome?**

The students had several challenges to overcome during the development of their proposal for the competition. Creating a design proposal from scratch is something that they have never undertaken before. They are similarly not familiar with working in a large team, which presented an additional challenge to the proposal development. Lastly, the competition deadline requires that they work quickly, with minimal rework and that time within the project team and external industry advisors is effective and efficient.

Regarding the development of the proposal from scratch; the team was able to overcome this challenge through the tireless efforts of the project leader. The project leader set the tempo and checked in frequently with the team to organize assignments and make sure that the groups involved in the proposal were working cohesively.

The challenge of working in such a large team was mitigated by using smaller groups of students to head up individual elements of the proposal. The course that was taught, which used the FAA Design Competition as the basis of semester's work, was Project Management. The students treated the competition as a project and the management of the proposal was handled exactly as a project manager would handle a large project.

The competition deadline, while challenging, was achieved through disciplined delegation of duties through the entire project team. The entire class was well aware that if any of the students or the teams did not perform at the highest level that the entire team would suffer. This created a camaraderie amongst the team that was evident during weekly check-ins where team members provided me assessments or 'grades' of how the other team members were performing within the group.

**4. Would you use this Competition as an educational vehicle in the future? Why or why not?**

I would highly recommend this competition to future students and faculty. As previously mentioned; this particular competition gives students a very different experience than they gain from typical courses and classroom activities. The significant collaborative effort that is required to develop a winning proposal is something that cannot be easily taught. This competition provides for an educational experience on communication, time management, team building and original writing that will serve the students well as they enter the workforce. I am confident that you will see Binghamton University participating in the competition again.

**5. Are there changes to the Competition that you would suggest for future years?**

New topics and categories have been added this past year to the competition. This is important to keep the competition interesting and relevant. The continued addition of new areas of focus would be my primary recommendation for future years. The FAA may also want to consider a research and development pipeline tied to winning proposals. Not all of the ideas are easily adopted; however certain proposals should be advanced to at least the prototype level and possibly beyond. Ultimately the competition serves as an important introduction to innovation in the aviation industry but could be more with additional federal funding and visibility to potential private investors. Overall, the competition is extremely well run and represents the type of educational opportunity that is critically needed in academia.

## Appendix F. Reference List in Full


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