SPIKE: Empower the Powerless

Summary: The new SPIKE initiative aims to spur the required expertise and facilitate the means of providing clean, affordable, and reliable electrical energy to empower the powerless in underprivileged areas of the world. The SPIKE initiative leverages IIT's multi-disciplinary strength in renewable energy and smart grid technology research, development, demonstration, and deployment. The SPIKE initiative will be supported by an Advisory Board composed of renowned members from industry, government, academia, and national laboratories.

1. The Complex Societal Problem

Energy is an essential component of a modern society, not only in terms of economic development but also for the survival of individual human beings across the globe. The government challenges in global societies often pertain to providing local citizens with affordable and reliable energy especially in impoverished nations where the individuals' prosperity and healthcare depend on affordable energy supplies. Today, over 1.4 billion people in the world do not have any access to electricity supply for cooking, lighting, heating and refrigeration. In fact in many remote areas of the world, lives are routinely lost due to the absence of local refrigeration that is so vital to preserving life-saving medications.

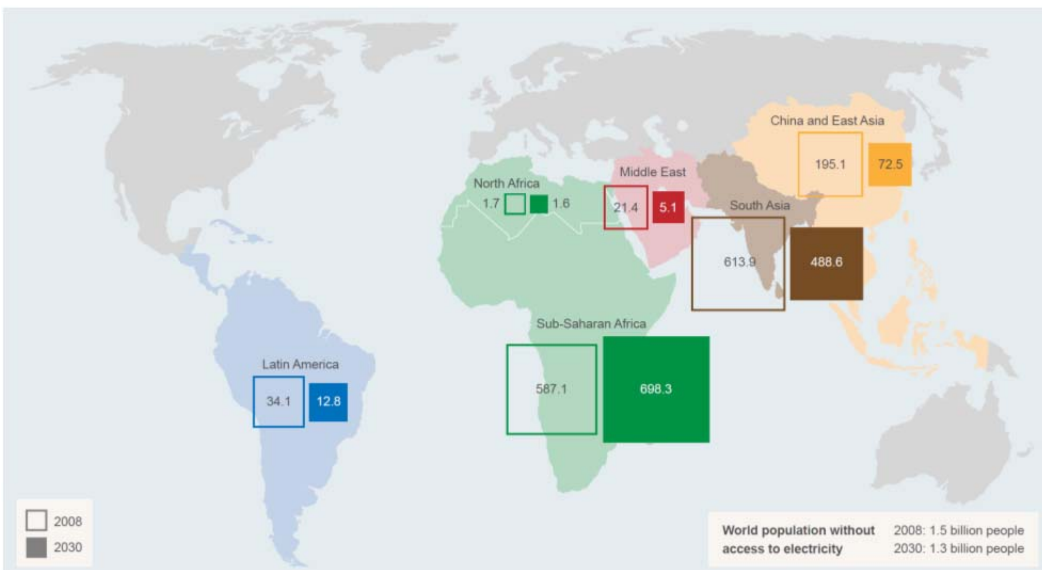


Figure 1: Number of people (in millions) without any access to electricity (IEA, 2010)

In the United Statas, the DOE Tribal Energy Program, which covers a small portion of the tribal lands, is deemed to be deficient in all respects. One fundamental reason for the insufficiency of the program is that it relies routinely on utility grid-connected energy installations that might be applicable to other developed areas but not to the tribal lands with an ailing supporting infrastructure. Another reason is the lack of accompanying education that can sustain the infrastructure development. People in the tribes do not have the know-how on operating such infrastructures, nor do they have sufficient resources for maintaining the infrastructure.

Consider the Pine Ridge Indian Reservation in South Dakota. Allen, South Dakota, a community of the Pine Ridge Reservation, is the poorest place in the United States, with a per-capita income of $1,539. According to the Department of the Interior data, about 10% of tribal members were employed in 2010 (i.e. 90% are unemployed); most tribal homes are in poor repair conditions, lacking indoor toilets, working furnaces, and electricity; with overcrowding, many tribal children share a bed with siblings, or do not have a bed at all; life expectancy was estimated to be 48 for males and 52 for females in 2009, the lowest life expectancy of any group in America and lowest in the Western Hemisphere outside of Haiti (USDA rural development data). The critical lack of electricity and heating fuel in reservations often result in death from exposure to high temperatures in the summer and freezing during harsh winters. The only alternative in the winter is expensive propane and firewood.

Figure 2 shows that there is much more that we can do as a nation by revitalizing these tribal communities and providing their residents with a more prosperous future that is supported by an affordable and reliable energy infrastructure. The smart microgrid potentials, however, are enormous in such locations. Less than 0.2% of the U.S. population lives in the American Indian tribal land, which comprises approximately 2% of U.S. land but contains an estimated 5% of all renewable energy resources in the North America.

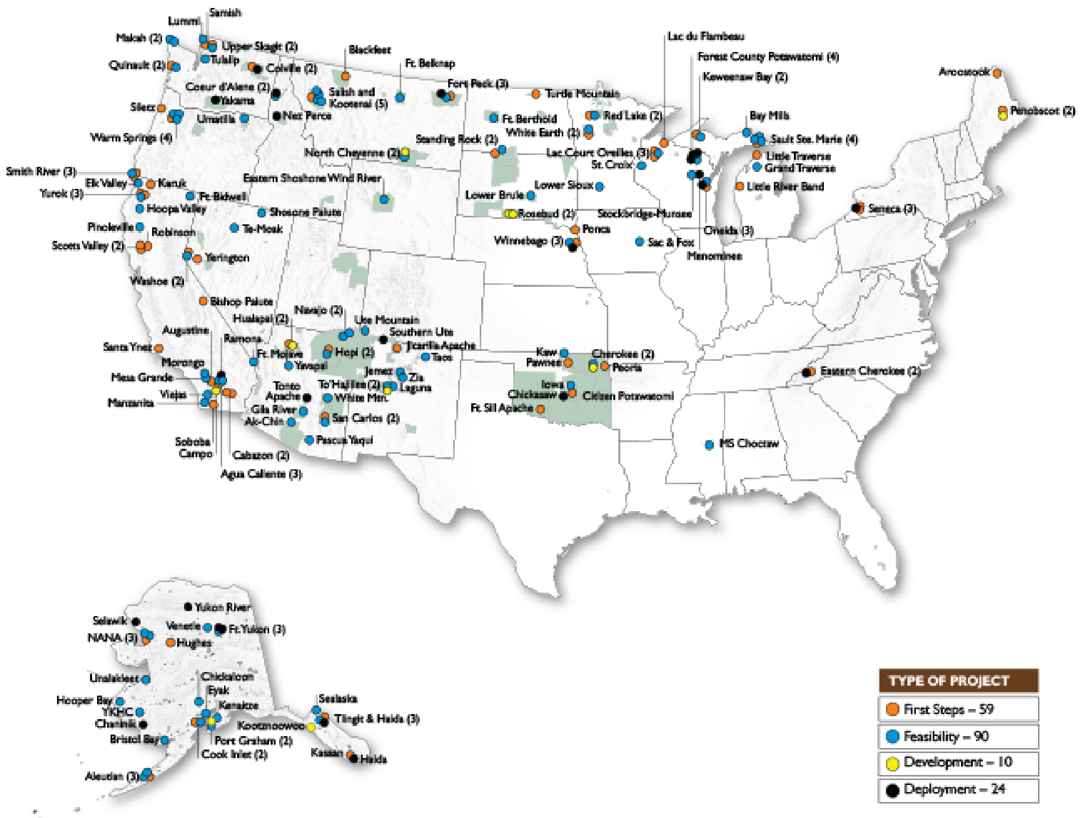


Figure 2: DOE Tribal Energy Program (DOE Office of Indian Energy, 2013)

Globally, energy poverty afflicts a large part of Africa, especially the Sub-Saharan area, the mountainous lands of Asia and the Andean zone of South America. These regions may register a per capita energy consumption ratio of to 1 to 20 with respect to developed countries. Low fuel availability and growing fuel prices would cost individual families additional hardship for making the ends meet. In some areas, individuals dedicate 2/3 of their annual income to energy-related expenses. In essence, shortages of energy services affect the productivity of the local population impeding, in a sort of vicious circle, the emancipation from the poverty state in which they live.

While IIT is undergoing an electric power renaissance, faculty, staff, and students at the Robert W. Galvin Center for Electricity Innovation are eager to share their expertise and spur greater energy innovations that can enhance impoverished communities nationally and globally. Dr. Shahidehpour has dedicated his time and energy to incentivize the energy initiative and “empower the powerless across the globe.” His recent trip was to Sierra Leone where he met with the country’s president, Dr. Ernest Bai Koroma, and his energy minister, the US ambassador, and others to find a reasonable solution for ending the misery of local residents who were also faced with the Ebola outbreak. Impoverished villagers in Sierra Leone drink water out of rivers where they bathe and wash their clothes. Figures 3-6 are taken in his visit. Dr. Shahidehpour demonstrated to the government officials that compact solar PV-based water pumps designed by IIT students and faculty can provide villagers with clean well-water. Also IIT-based microgrids tied to renewable sources of energy could provide the necessary supply of electricity for lighting, refrigeration, and other requisites that can save many lives.

Figure 3: A typical street in Freetown, Sierra Leone

Figure 4: Cell phones are collected and charged at a neighboring village 10 miles away that has electricity

Figure 5: Visit to Sierra Leon, Africa with Larry Morgan (left, President of Nation's Solar, Inc.) and the Sierra Leone's Minster of Energy (right)

Figure 6: Helping locals install a prototype solar system on the roof of a house in Ghana (photos are taken by Dr. Shahidehpour)

2. Project Objectives

The Galvin Center has launched a new initiative called SPIKE which stands for "Spearheading Poverty Inhibition through Klean Energy" for empowering the powerless. The SPIKE's key technology innovation is the Affordable Microgrid (AM) program. The SPIKE initiative leverages the IIT's strength in renewable energy and smart grid technology research, development, demonstration, and deployment. The SPIKE initiative is a joint effort of the IIT's Galvin Center for Electricity Innovation (led by Dr. Mohammad Shahidehpour) and Stuart Business School (led by Dr. Ghazale Haddadian). The initial focus areas of the SPIKE initiative encompass American Indian Tribes in the United States, and residents in the United States Virgin Islands (a U.S. territory), Sierra Leon, and Ghana (two sub-Saharan countries). These are the geographical areas that the IIT project team has visited over the last three years, signed cooperative agreements (Figure 7) and hosted the visit by their representatives to the Galvin Center and the IIT's Microgrid (Figure 8). In all such cases, the SPIKE project team apprehends that a simple microgrid design for extreme affordability, which is seldom available in designated locations, represents its ultimate objective.

Figure 7: Visit to the U.S. Virgin Islands (right)

Figure 8: Delegation from Ghana, Africa Visited IIT

3. Background and Significance

The Robert W. Galvin Center for Electricity Innovation is an IIT initiative which has established IIT as the leader in the smart grid revolution. The mission of the Galvin Center is to pursue groundbreaking work in the generation, transmission, distribution, management and consumption of electricity. This is in line with the IIT mission "to provide distinctive and relevant education in an environment of scientific, technological, and professional knowledge creation and innovation." Highlights of Galvin Center's achievements include the completion of the $14 million flagship IIT Microgrid project (Figure 9), the establishment of the $13 million world-class Smart Grid Education and Workforce Training Center.

Dr. Mohammad Shahidehpour is the Director of the Galvin Center who led the team of experts in 2008 to build the first-ever Perfect Power microgrid, an electric system that will never fail the consumers, on the IIT's Main Campus in Chicago. The IIT Microgrid was designed in a replicable form for off-grid communities, military bases, corporate parks, sports facilities, and other universities. Dr. Shahidehpour as the chief architect of the IIT Microgrid has recently won the Innovation Award from the Association of Electrical Engineering Department Heads, the Technologist of the Year Award from the Illinois Technology Association, and the Outstanding Engineer Award from the IEEE/PES.

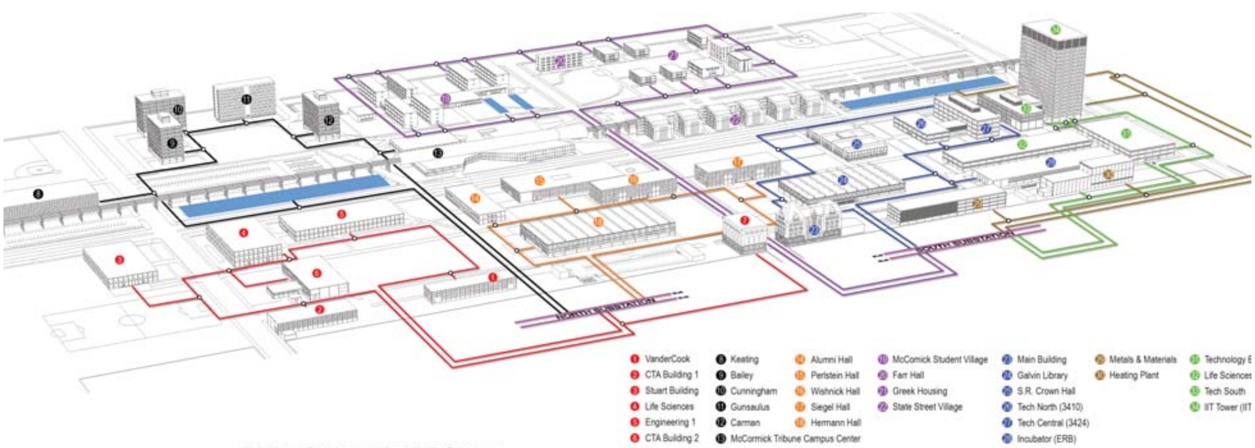


Figure 9: IIT's Flagship Microgrid: The World's First Perfect Power Microgrid

Overall, the Galvin Center has secured more than $50 million in project funding from the government and private sectors for the research and development in smart microgrids and sustainable energy. Currently the Center is working with the local utility for replicating the IIT Microgrid design in logistical Chicago locations, including in the neighboring Bronzeville, which will be directly tied to IIT for enhancing the neighborhood power system economics, resilience, security, and reliability.

The Galvin Center has been hosting two to three groups of visitors every week from K-12 students to senior citizens, from layman of smart grid to domestic and international experts of smart grid, from electrical engineers to venture capitalists, from general public to politicians.

4. Preliminary Work

Galvin Center has already collaborated with industry experts, non-profit organizations, and local partners to apply the IIT's expertise in renewable energy and smart grid to support residents in American Indian Tribes, U.S. Virgin Islands, and Sierra Leon, Africa get access to low-cost clean energy using less advanced technologies. The funding is extremely crucial for turning the adhoc SPIKE initiative to a concerted effort for empowering the powerless, and further expanding the edge of technology already developed and tested by the faculty and students at IIT.

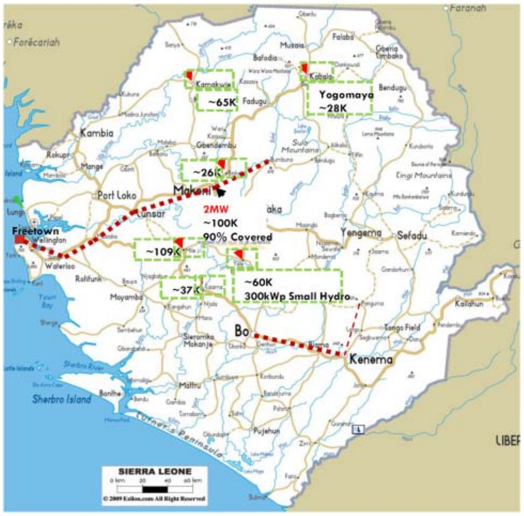
U.S. Virgin Islands: The U.S. Virgin Islands has a different yet telling story. The aggregate population of the U.S. Virgin Islands is 109,000. The median household income is approximately $32,000, which is well below the current U.S. average of about $50,000. The U.S. Census data indicate that 33% of the Islanders live below the poverty line. Similar to many island communities, the U.S. Virgin Islands is 100% dependent on imported fuel for electricity. Retail electricity rate is 56 cents/kWh which is almost 5 times higher than the average price in the United States. IIT has raised over $13 million to help build the first microgrid (Figure 10) in the Island which will reduce the cost of energy to about 30cents/kWh in this impoverished island. The avoided electricity cost is expected to be about $11 million for the first 8 years (39% reduction) and about $37 million for the first 25 years (52% reduction).

Figure 10: Micrigrid at the US Virgin Island

Figure 11: Visit to Pine Ridge Reservation, South Dakota

American Indian Tribe: IIT has teamed up with Re-Member, a non-profit organization located in the Pine Ridge Indian Reservation, South Dakota to improve the quality of life in the reservation. The solar panel construction training program introduced in the reservation utilizes imperfect, but usable solar cells to teach tribal people to build the low cost panels of various sizes from scratch which are used in light-boxes. Many tribal children live in houses where no lighting is available for studying at night. So, the team has taught the locals to build solar light-boxes with small battery-powered LED lights. They are delighted, both with the light and the fact that they built their own energy supply system (Figure 11).

Sierra Leon, Africa: Galvin Center has teamed up with the industry to develop a microgrid roadmap for Sierra Leon to address the nation's energy shortage. Sierra Leon has an electrification rate of 2% and the government is targeting a moderate increase to 6% by 2017. IIT in collaboration with the Energy Ministry of Sierra Leon has identified six off-grid locations for building microgrids (Figure 12) in local villages. IIT has also conducted preliminary design for the microgrid development (Figure 13).



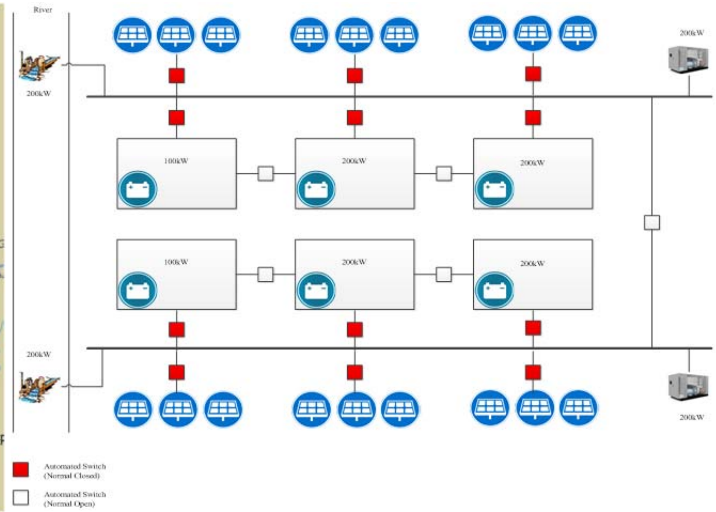


Figure 12: Six Microgrid Locations Proposed by IIT and Sierra Leone

Figure 13: Preliminary Microgrid Design for Sierra Leone Proposed by IIT

5. Proposed Approach

This project labeled as the SPIKE aims to provide clean, affordable, and reliable electrical energy to empower the underprivileged areas of the world. The key technology innovation is the Affordable Microgrid (AM). The initial focus areas of the SPIKE project include American Indian Tribes in the U.S. mainland, U.S. Virgin Islands (a U.S. territory), and Sierra Leon and Ghana (two sub-Saharan countries). These are the areas the project team at IIT has visited over the last three years and, more importantly, representatives from those areas have also visited IIT recently.

SPIKE

The SPIKE's proposed objectives include:

- Phase I (Year 1) will focus on the development of a laboratory-based demonstration of the AM technology, development of training course materials, and visit with three potential demonstration sites globally.
- Phase II (Year 2) will focus on the experimental implementation of the AM technology at three demonstration sites and offering of training courses to stakeholders in the three sites.
- Phase III (Year 3) will focus on the fully-executed implementation of the AM technology at 10 demonstration sites and offering a complete set of training courses for educating the locals.

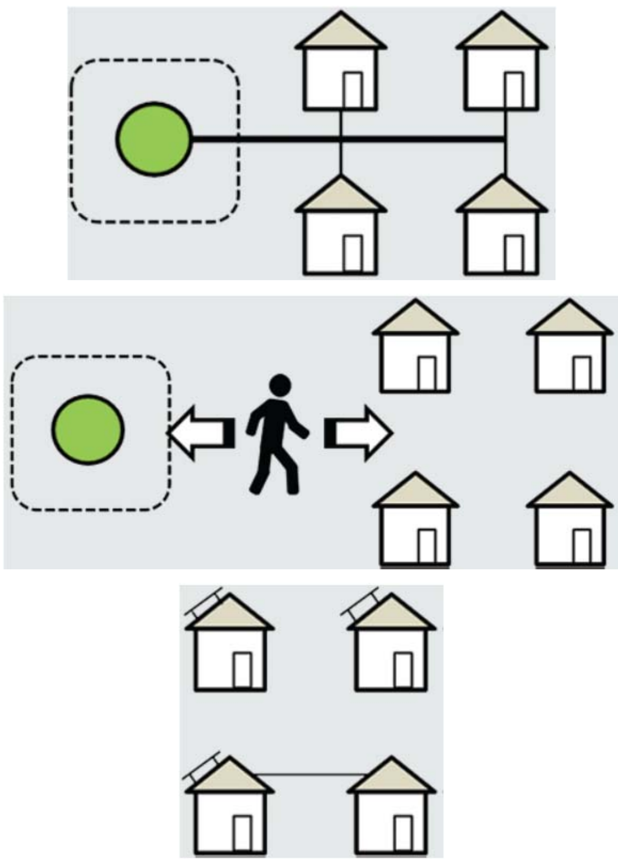
There are two elements of the Phase I activities of the SPIKE project: affordable technology development and engaging technology education. Past efforts by government agencies and non-profit organizations have not been sustainable. Most of the efforts remain on demonstration only when government grants or international aids are available. There are two fundamental issues with the government tribal energy initiatives. The first is that it relies too much on the utility-based technologies that might not be applicable to tribal lands. The second issue is the lack of accompanying education that can sustain the local development of the technology. The two elements of the Phase I of the SPIKE project are discussed as follows.

5.1 SPIKE's Affordable Technology Development

On the technology development front, the key technology of the SPIKE project is Affordable Microgrid (AM), an off-grid solution that uses generation resources locally available, including but not limited to solar PV and small hydro. Sample AM technologies that will be explored in Phase I are presented below.

Figure 14 shows three common standalone electrical system architectures that are distinguished by their energy delivery mode. Microgrids use wired connections to serve multiple customers in a limited geographic area. Energy kiosks, also known as "community charging stations," rely on the physical transportation of batteries to deliver the energy they produce. Solar home systems (SHSs) often serve a single household and may or may not have an explicit distribution system. One of the key issues of a solar powered system such as a microgrid or a solar home system is power quality including volatile frequency and voltage. The smart inverter technology developed at IIT can maintain constant frequency and voltage via robust droop control strategies.

System Architecture



Main Features

Microgrid
- Wired Distribution (Low-Voltage ac or dc)
- High Upfront Cost
- Continuous Power Consumption for Refrigeration and Lighting
- Can Be Remotely Operated
- Higher Energy Access Tier

Energy Kiosk
- Energy Transported by Battery
- Low/No Upfront Capital by Customer
- Mobile Phone, Electronic Device, or Dedicated Portable Battery Kit Recharging
- Operated by Staff
- Lower Energy Access Tier

Solar Home System
- Powered by PV
- Single or Small Number of Households Served
- Lower Energy Access Tier

Figure 14: Common stand-alone electricity system architectures

AM Technology 1: Microgrids. A microgrid is a small-scale independent electricity network that connects the domestic grids of neighboring houses (e.g. those of a village). Microgrids are a suitable solution for rural communities isolated from public distribution power networks and having a limited load demand; they can power both households and local businesses, with a higher power quality level and higher load factor compared to individual systems. Moreover, providing centralized electricity generation using a village distribution network, they are often more cost effective on a \$/kWh basis. Microgrids can be implemented in a variety of ways, with differing power generation technologies, voltage level and type (ac or dc), method of distribution, and metering systems. In renewable-based microgrid, solar PV or small hydropower plants are adopted usually with diesel generators as a back-up source. The most appropriate power generation technology for a microgrid depends heavily on the location and size of the grid. Hydro turbines are one of the lowest-cost options for grids of at least a few hundred kilowatts of capacity in areas that are near suitable rivers. The recent dramatic drop in photovoltaic (PV) prices has made PVs a more economical option in most areas. In general, the solar resources across the entire African continent are very strong. An installed kilowatt of PV panels will often yield more than 4 kWh per day. PV systems also have the advantages of flexibility in scale and location. Microgrids are an open and modular network that can easily be extended, in case of village growth, to accommodate new consumers or be integrated in the future through the national grid.

AM Technology 2: Energy Kiosk. Energy kiosks operate more like a retail store than a traditional utility. A typical energy kiosk serves walk-up customers and is equipped to recharge mobile phones, repurposed automobile batteries, and, in some cases, dedicated portable battery kits (PBKs). Energy kiosks bridge the gap between having no electricity at all and having wired electricity in a home. With the Energy Kiosk, the customer carries an 18 AH PBK back and forth to the energy kiosk. The customer typically recharges the PBK every 3 to 10 days. The PV panel capacity is around 1.5 kW with four 200 AH local house storage batteries. In the past an Energy kiosk with six 250 watt solar panels could typically support 100 to 200 homes, each with two 4 watt LED bulbs. The capital equipment total cost to power 100 homes including the assembled central charging station and 100 PBKs has been around $20,000. This does not include shipping, customs and delivery and installation at the LVE site. This translates to a cost per home of $200. The customer pays $6 to $10 per month.

AM Technology 3: Solar Home System. Solar Home Systems (SHSs) typically consist of PV panel(s), battery, charge controller; and ports for lights, mobile phone charging, and other appliances. SHSs come in a wide range of capacities, typically fewer than several hundred watts, and most use battery chemistries similar to those in PBKs. In contrast to PBKs with PV panels, SHSs are designed to be stationary with larger capacities and may serve up to ten households. SHS needs a rechargeable battery, typically with three days storage capacity, to render power available at night and on cloudy days. The presence of batteries is important in order to regulate and stabilize the voltage of the grid. SHS is usually equipped with power electronic inverters to convert the dc electricity into ac compatible with household appliances.

5.2 SPIKE's Engaged Technology Transfer and Training

On the technology education front, the SPIKE project will address three key issues, including community participation and organization, building local capabilities, and financing technology deployment. The purpose is to empower the local community with the technology know-how so that they can operate and maintain the system after the system is completed.

Community Participation and Organization. Involving people at the point of conception of the project may reduce the risks of failure during and after the implementation stage. Clear and transparent information about the technological options that are applicable shall be provided at the early stages of the project. Community participation at the planning stage can also help reduce costs. Local labor can be used for the construction and installation of the technology. Local availability of some special skills (e.g. experienced masons, carpenters, etc.) may help the process.

Building Local Capabilities. Technical and managerial skills are a prerequisite for ensuring the continued operation of the system. Local technicians will be trained to be able to tackle failures of the installed systems. Training in bookkeeping and some managerial skills will also be conducted to run newly established energy businesses and/or community funds. The promotion of the productive use of electricity may include aspects such as training in entrepreneurship and support in accessing new markets.

Financing the Technology Deployment. This project will seek strategies to cover part of or the full amount of the initial costs of the technology implementation, as well as to secure the finance for the running costs and consequently the long-lasting operation of the solution. The initial approach is to establish a tariff scheme that allows the entrepreneur or the responsible organization to cover operation and maintenance costs, repay any loans and make a profit.

5.3 SPIKE's Tasks and Deliverables for Phase I

Phase I of the project will include four major tasks as presented below.

Task 1: SPIKE Strategic Plan Development (Lead: Shahidehpour, Arastoopour). This task will develop a more detailed plan for launching the SPIKE initiative including its technology development and training activities and the timeline for delivering the prototype. A draft plan will be presented at the

SPIKE Advisory Board meeting, which will be held at the second quarter. ***Deliverable***: SPIKE strategic plan and SPIKE Advisor Board meeting.

Task 2: SPIKE Technology Development (Lead: Li, Shahidehpour). This task will develop prototypes of the three AM technologies as described in Section 5.1 to the extent that they will be ready for demonstration at three potential sites. ***Deliverable***: prototypes of the three AM technologies.

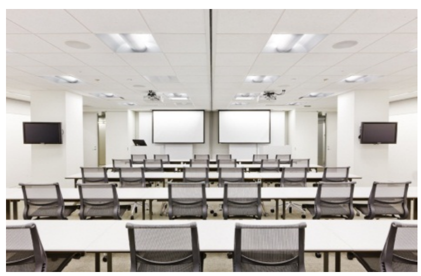
Task 3: SPIKE Training Course Development (Lead: Haddadian, Arastoopour). This task will develop the training course materials as described in Section 5.2 to the extent that they are ready for offering at three potential sites. Deliverable: SPIKE training course materials.

Task 4: Site Visits for SPIKE Technology Demonstration and Training Offering (Lead: Shahidehpour). This task will include site visits to three potential locations to engage the communities for SPIKE technology demonstration and training offering. ***Deliverable***: plans for technology demonstration and training offering in Phase II.

6. Resources, Facilities, and Collaborations

6.1 Resources and Facilities

The Galvin Center at IIT will provide the home base for the SPIKE project. The 16,000-square-foot center contains offices, exhibition rooms, classrooms and student workrooms, acting as a "Living Laboratory" and a training facility for smart grid, microgrid, and other energy technologies, engaging thousands of workers and students across the world. The Galvin Center will provide the education resources for the communities involved in the project.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