Purdue Resource Series

Energy

能源产业

- **Solar power** 太阳能
- **Wind power** 风能
- **Biomass power** 生物能
- **Smart power grids** 智能电网
- **Other energy sources** 其他能源

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PURDUE UNIVERSITY

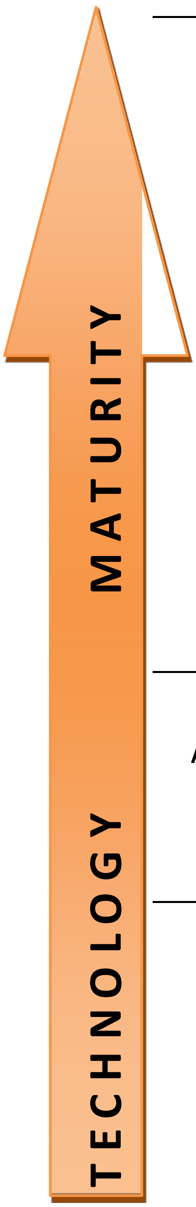
U.S.-CHINA ECOPARTNERSHIP FOR ENVIRONMENTAL SUSTAINABILITY

Contents

Section 1: Technologies

The following Purdue technologies are available for potential development, licensing or commercialization. Many of the technologies include a Technology Readiness Level (TRL) number which indicates how close each technology is to the market. The following chart describes these categories.

Definition of Technology Readiness Levels (source: NASA)



	TRL 9	**Actual system "mission proven" through successful mission operations** Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.
	TRL 8	**Actual system completed and "mission qualified" through test and demonstration in an operational environment:** End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios.
Applied	TRL 7	**System prototyping demonstration in an operational environment** System prototyping demonstration in operational environment. System is at or near scale of the operational system, with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.
	TRL 6	**System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space):** Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.
Advanced	TRL 5	**System/subsystem/component validation in relevant environment:** Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.
	TRL 4	**Component/subsystem validation in laboratory environment:** Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.
	TRL 3	**Analytical and experimental critical function and/or characteristic proof-of concept:** Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies.
Basic	TRL 2	**Technology concept and/or application formulated:** Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.
	TRL 1	**Basic principles observed and reported:** Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

Featured Technologies

PRF No. 64920 Method for Generating Hydrogen from Ammonia Borane

Major challenges exist to the commercialization of hydrogen fuelcells for wide-spread commercial use. Current methods of generation and on board storage are not safe or efficient and when combined with the fact that hydrogen technology is still too costly to be widely implemented, it is obvious that there are many roadblocks in the path of hydrogen fuel cell development.

Researchers at Purdue University have developed an innovative, new process for releasing hydrogen from ammonia borane. Ammonia borane has a high percentage of hydrogen and is a promising hydrogen storage material for fuel cells. This technology does not require the use of a catalyst and enables an increase in the amount of hydrogen released at specific temperatures than with pure thermolysis. This technology has the promise of being a major breakthrough in the area of fuel cell storage and efficiency.

Domain:
- Chemical Engineering

Advantages:
- Releases more hydrogen than current methods
- Required pressure can be easily created
- Cost effective

PRF No. 64923 Multiuse Coke Plant for Synthetic Fuel Production

Technology Readiness Level: 6

Although coke is an absolute essential part of iron making from ore and foundry processes, recently there was a shortfall of 5.5 million tons of coke per year in the United States. This shortfall resulted in increased imports, drastic increases in coke prices, and market volatility.

Purdue University researchers have developed an optimization algorithm for coke that could reduce annual coal fuel costs by up to 10 percent all-the-while allowing consideration for overlooked by-products that now have revenue potential. This cost reduction is obtained through the use of cheaper, lower heat content, high-sulfur coal from sources such as the Illinois Basin. Previously, the high-sulfur content was a detriment for coal users and almost made this coal unusable due to its undesirable trait of forming hydrogen sulfide during the pyrolysis process. This technology can place a value on this sulfur content, too. With modern technology and the current economic drivers for alternative energy, pyrolysis gas has a multitude of uses including the production of electricity, liquid transportation fuels, fertilizer, and hydrogen. The value of lower-grade coal alternatives can now be identified, and better yet, maximized.

Advantages:

- Reduced cost of coal through utilization of Illinois Basin coal
- Enhanced revenue streams

PRF No. 64940 Fast Hydropyrolysis for Hydrogen Bio-Oil

The transportation sector currently relies almost exclusively on liquid hydrocarbons as its energy source for good reasons. One of many reasons is that the high energy density of gasoline far exceeds that of proposed replacements like hydrogen or batteries. Additionally, the liquid hydrocarbon fuel distribution infrastructure is efficient and already in place. Production of liquid fuels from biomass can solve the problem of C02 emission from the transportation sector because C02 released from vehicle exhaust is captured during biomass growth.

Researchers from Purdue University have invented a process of “fast” pyrolysis, which is to be used on biomass. The process feeds H2 from a carbon-free source to a fluidized bed reactor. The H2 is mixed with a biomass in the reactor. The resulting mixture produces a biomass containing less oxygen atoms than normal due to the addition of the hydrogen. The mixture is then sent to a separator to remove the char, which is burned to create heat for the system, from the “bio-oil.” The bio-oil is further processed to create the hydrocarbon, which is then cooled to create the liquid hydrocarbon. The H2Bioil has all of the advantages of conventional Bio-Oil in addition to a greatly increased energy density all-the-while retaining compatibility with the conventional hydrocarbon fuel distribution, a truly carbon neutral solution to the Green transportation fuels concern.

Domain:

- Energy

Advantages:

- Dramatically lower fuel cost
- Increased bio-oil energy density

PRF No. 65621 Low Lignin Second Generation BioEnergy Crops

In the quest for energy independence, production of biofuels, such as corn ethanol, has exploded. There has been a rapid increase in biorefinery construction, and tax credits encourage further production efforts. The majority of ethanol produced for transportation purposes is from corn, but this form of biofuel production is unsustainable. Transition from corn ethanol to cellulosic ethanol (derived from wood, grasses, or the non-edible parts of plants) is necessary, and federal support for this transition is evidenced by the substantial tax credits allotted for cellulosic-ethanol producers. Maximization of available biomass is necessary, however, to ensure the long-term success of cellulosic biofuels.

Researchers at Purdue University have developed a transgenic variety of poplar tree for use as feedstock for cellulosic-ethanol production. The transformed plant accumulates biomass faster than its non-transgenic counterpart. The biomass produced is more easily degradable, and the plant is sterile. These desirable traits are owed to multiple stem growth and low lignin production.

Domain:

- Energy

Advantages:

- Rapid accumulation of biomass (multi-stemmed)
- Biomass is easily degradable (low lignin)
- Sterility confines the altered genome and further increases biomass production

PRF No. 66109 A Shade Tolerant Panel Design for Thin Film Photovoltaics Technology

Technology Readiness Level: 6

Solar cells are becoming increasingly efficient at converting light into electricity but they still suffer from some reliability issues. One such issue is that if a cell of the solar panel is in the shade it will shut down and start absorbing excessive energy from the connected cells. The excess energy causes heating in the cell that can cause damage or even start a fire. This problem has usually been addressed by connecting diodes between segments of cells to prevent the current from flowing into a shaded panel section, but this does not work unless a large area is shaded. Researchers at Purdue University have developed a new solution to this problem by designing a radial layout for a solar panel. This design assures that a shadow will shade many cells at once, allowing those cells to distribute the reverse voltage across them. The design avoids reverse breakdown without need for external bypass diodes, simplifying the manufacturing process and alleviating shadow degradation.

Other Available Technologies

PRF No. 64629 Rapid Synthesis of Chalcogenide Nanoparticles

Technology Readiness Level: 5

Researchers at Purdue University have developed an innovative technology that is a fast and simple process for the synthesis of binary, ternary, and multinary nanoparticles of various combinations of Cu, In, Ga, and Se using commonly available precursors at moderate temperatures and atmosphere pressures.

The precursors that can be used in such processes may include various metal halides, elemental metals, elemental chalcogen, as well as chalcogen compounds. This new process is a low cost alternative that still maintains a high throughput synthesis of crystalline chalcogenide nanoparticles while providing a simpler method of production and integration than current technologies. Applications for this technology include thin-film solar panel devices.

Advantages:

- Cost effective
- Simple method
- High throughput method

PRF No. 65562 Tree Topology Charge Pump Design for Micro-Scale Energy Harvesting

Technology Readiness Level: 4

A key component of any energy harvesting system is the power converter, also known as a charge pump. A charge pump steps up the input voltage from a transducer to a higher voltage. Current micro-scale charge pumps see a sharp drop off in efficiency when input voltage from the transducers is very low (below 1 volt).

Purdue researchers have developed a new charge pump design for use in micro-scale energy harvesting. The power converter is configured to transfer electrical energy from an energy transducer to energy storage device. This new converter design is effective at very low input voltages, from near zero to 1 volt, where conventional charge pumps fail. It also increases harvested power by at least 20% over existing power converters.

Advantages:

- Significantly more harvested power
- Improved efficiency at very low voltages over current designs

PRF No. 65730 Lithium Ion Battery Cathode Optimization

Technology Readiness Level: 4

The development of lithium-ion batteries (LIBs) with high energy density and discharge/recharge rates are essential to their utilization in transportation, energy storage, and portable electronics applications. In addition, development of LIBs with dense, 3D architectures could enable micro-powered, micro-electromechanical systems, and independently powered 'smart dust' particles to enable highly distributed computing. Researchers at Purdue University have developed a low-cost, environmentally inert lithium-ion battery. This lithium-, iron-, phosphate-based battery has been fabricated with a high density microstructure for improved performance, maximized ion diffusivity, and maximized electronic conductivity.

Advantages:

- Low materials cost
- Environmentally benign components

PRF No. 64048 Ericsson Cycle Heat Pump

Technology Readiness Level: 8

A refrigeration machine, or heat pump, can be defined as any device that moves heat from a low temperature source to a high temperature sink. Depending on the specific need, the heat absorbed in the low temperature source can be utilized to provide cooling, the heat rejected to the sink can be used to provide heating, or both could be used simultaneously. However, current applications of refrigeration require the use of toxic refrigerants that are harmful to the environment or are flammable.

Inventors at Purdue University have created a heat pump system that is a practical application of the Ericsson cycle. It can be constructed primarily using existing equipment and technologies used by the HVACR industry. It has a high theoretical and attainable coefficient of performance, operates at pressures similar to existing heat pump equipment, and uses environmentally benign refrigerants.

The system is scalable and can be used for refrigeration, comfort cooling, and heating. Cryogenic applications are also possible. The machine can also be designed to operate as a heat engine using external combustion or virtually any other heat source.

Advantages:

- Does not use toxic refrigerants
- Scalable
- High coefficient of performance

PRF No. 65459 Variable Regeneration from Hub Motors to Ultracapacitors for Auxiliary Batteries

Technology Readiness Level: 6

The global increase in energy prices has led to renewed interest in several fields of research. Increasing energy prices motivate scientists and technologists to invent new ways of harnessing energy to improve overall system efficiency. Because transportation is such a major consumer of energy, even small improvements in efficiency can have a large impact on overall energy consumption. Electric vehicles can be used to improve how we use energy for transportation.

Researchers at Purdue University have developed a regenerative braking system designed and implemented on an electric recumbent tricycle driven by a brushless DC hub motor. This electric vehicle (EV) can be used as a neighborhood electric vehicle (NEV) for short trips around town. The regenerated braking energy is captured using ultracapacitors and later transferred to the auxiliary battery; because ultracapacitors can absorb large amounts of energy very quickly, they offer significant efficiency advantages over battery only regenerative braking systems. When desired, the flow of energy can be reversed in order to power the vehicle, especially in situations where sudden acceleration is required. The system is also modular, by using a unique printed circuit board, similar to a mother board of a personal computer; users are able to add different functions by connecting auxiliary devices as needed.

Advantages:

- Faster acceleration than battery only
- Modular and customizable
- Stores captured energy to battery for use later

PRF No. 2013-NOF-66347 Failure Prevention and Repair for Energy Distributions

Technology Readiness Level: 4

The United States electricity grid is a complex system including numerous utility companies distributing power across large distances, with it often being bought by or sold to other companies before eventually reaching the consumer. This distributed system has many lines operating at near capacity on older equipment. These factors greatly increase the probability of a node failure in the system, which can easily damage other nodes causing a cascade of node failures. Repairs to these failures in the grid are currently completed in random order. This does nothing to minimize the further propagation of failures in the grid and increases the cost of the failures.

Purdue University researchers have developed a new method for selecting the nodes to repair in an electrical grid. The method analyzes the network topology to schedule repairs in a way to minimize the damage caused and prevent additional failure. The repairs can be done in a centralized or decentralized manner, depending on the resources available, providing a customized repair strategy for any failure. In a demonstration modeling daily activity in the Western United States power grid, the new model outperformed the current practice taking 50% less time to respond to and complete repairs, 80% less damage cost, and increased prevention of additional node failure by 300%.

Advantages:

- Customized repair strategy for any failure
- Outperforms current process

PRF No. 64045 Controlled Generation of Hydrogen from Sodium Borohydride and Efficient Regeneration

The pressure on today's society to be more mindful of carbon footprints, pollution, and emissions is pushing researchers to develop improved methods for fueling cars that are clean and efficient. Theoretically, hydrogen would be an excellent alternative fuel choice, but current processes for the generation of hydrogen are unstable and inefficient. The generation methods would be too slow to meet the demand that would occur if more vehicles were equipped with hydrogen fuel systems and most would produce excess heat.

Researchers at Purdue University have discovered an innovative method for the generation of hydrogen from sodium or lithium borohydride and aqueous ethylene glycol in the presence of trace amounts of Lewis or Bronsted acid catalyst. This protocol provides hydrogen in a controlled manner for application in fuel cells.

Domain:
- Chemical Analysis

Advantages:
- Stable, rapid process
- Effective Regeneration
- Cost effective

PRF No. 64251 Catalytic and Recyclable Hydrogen Production from Organic Silanes

Hydrogen has always been an attractive alternative fuel choice, but current methods are slow, expensive, and inefficient. In order to be used in a vehicle, the method for generation should be renewable, cost-effective, and have a practical set-up for onboard storage and delivery that does not include the need for high pressures or temperatures.

Researchers at Purdue University have developed an innovative strategy for hydrogen production on demand. In ambient conditions the reaction can be completed in a matter of minutes with the only organic by-product being disilane. However, disilane can be combined with a suitable hydrogenation catalyst and then be recycled as silane, resulting in a system without any waste by-products.

Domain:
- Chemical Analysis

Advantages:
- Low catalyst cost
- No waste by-products
- Reaction can operate at mild conditions

PRF No. 65166 Petroleum Crude Distillation

For the past 75 years the method for Petroleum crude distillation in industry has been a main column with side strippers. The side strippers are directly injected with steam which strips off all components into their individual compounds. This method requires a large amount of heat duty and only allows the least volatile to be stripped in the first column.

Purdue Researchers have found an improved method for the distillation of crude petroleum. The process for petroleum distillation uses distillation columns to separate the feed stream into five enriched product streams while reducing the heat duty required, which then reduces the energy needed to complete the distillation. Another feature of the new method is that it does not necessarily require the least volatile substance to leave in the first distillation column. This allows for an increase control in product streams with more flexibility for experiments and production. This also allows the choice of which product is stripped first allowing control over contamination of further product streams.

Domain: chemical Engineering

Advantages:

- Reduced energy consumption
- Decrease in heat duty
- Separates feed into enriched product streams
- Does not require that the least volatile substance be removed first

PRF No. 62062 Aqueous Bio-based Battery

Batteries have been around for quite some time. New advancements in science have led to the development of many different types of batteries ranging in size and power. Unfortunately, current batteries contain hazardous materials that are environmentally unfriendly. A new and popular alternative to conventional batteries are fuel cells. Fuel cells eliminate the use of hazardous materials; however, these fuel cells are rather large and some contain hydrogen which is very explosive, making this alternative unsafe. Purdue Researchers have developed a new battery that is both small and environmentally friendly.

The technology is an aqueous based battery that generates power using a regenerable electron source derived from biological sources. The battery is renewable and environmentally compatible. It is also safer and lighter than current alternatives such as the H2 fuel cell or lead/acid batteries. This technology has been designed for field use and has many applications in areas where electronically powered sensors or devices, implanted in the human body are used.

Domain:

- Chemical Engineering

Advantages:

- Simplicity of design allows for economic development
- Safer and lighter than current portable energy sources
- Environmentally friendly
- Can be readily regenerated using bio-molecules or living cells

PRF No. 65367 Chemical liquid Deposition and Solution Phase Chalcogenization for the Formation of Multinary Metal Chalcogenide Thin Films

Researchers at Purdue University have recently discovered an innovative, low-cost deposition method of multinary metal chalcogenide films for applications in photovoltaic devices.

The films are formed by the reaction between a film of precursor(s) on a substrate and a precursor(s) dissolved in a liquid phase. The film of metallic precursors is converted to a multinary metal chalcogenide film by reacting it with chalcogen species dissolved in a liquid phase medium. The chalcogen is then exchanged in a multinary metal chacogenide film by a liquid phase reaction. A nanocrystalline or polycrystalline film of a multinary metal chalcogenide is sintered in a liquid phase medium containing chalcogen species. This method relates to photovoltaic devices containing the multinary metal chalcogenide films, as well as methods of preparing the photovoltaic devices.

Domain:
- Energy

Advantages:
- Cost-effective
- Ideal film for photovoltaic devices

PRF No. 64688 Process for Producing Synthetic Liquid Hydrocarbon

The transportation sector relies almost exclusively on liquid hydrocarbons as its energy source. The high energy density for gasoline far exceeds that of any proposed replacements and the distribution system is efficient and already inplace. But this energy source cannot be sustained forever and due to carbon dioxide emissions causes numerous environmental issues.

Purdue researchers have developed a method of synthesis for liquid hydrocarbon fuels using biomass and a carbon-free energy source. The process converts a larger amount of carbon in a biomass to hydrocarbon fuel. Because of the increased efficiency in the carbon conversion, less land area is needed to produce the fuel.

Domain:

- Chemical Engineering

Advantages:

- Significant decrease in land area required to support entire transportation sector
- Hydrogen storage in a very high density fuels
- Conversion of all carbon atoms to liquid fuels

PRF No. 65061 Synergistically Integrated Natural Gas Reforming Biomass Fast Hydropyrolysis Process

Researchers at Purdue University have developed a process to generate liquid hydrocarbons from biomass hydropyrolysis. For this process, liquid hydrocarbons (bio-oil) are generated from a fast hydropyrolysis process using a variety of biomass sources. The process ideally has a residence time of about two seconds. The hydrogen for the hydropyrolysis is provided from a syngas derived from a natural gas reforming process.

This invention provides a 1.6 times greater yield of liquid hydrocarbons and has better energy efficiency than cur-rent methods. The current design allows for a significantly smaller plant size resulting in low-cost, high-efficiency liquid hydrocarbon production.

Domain:
- Chemical Engineering

Advantages:
- Better yields than current methods
- Lower cost and higher efficiency

PRF No. 65460 Electronic Chain for Pedaling Recreational Electric Vehicles

The global increase in energy prices has led to renewed interest in several fields of research. Increasing energy prices motivate scientists and technologists to invent new ways of harnessing energy to improve overall system efficiency. Because the transportation industry is such a major consumer of energy, improving efficiency in this field can have a large impact on overall energy consumption. Electric vehicles can be used to improve how we use energy for transportation.

Researchers at Purdue University have developed an Electronic Chain for Pedaling Recreational Electric Vehicles. This electric vehicle (EV) can be used as a neighborhood electric vehicle (NEV) for short trips around town. In a NEV, such as an electric recumbent tricycle, pedals are mounted on a permanent generator which generates a varying DC voltage proportional to the pedaling speed. The generated energy is electronically controlled and absorbed in to a set of ultracapacitors. The energy is then used to drive the motor for vehicle propulsion based on throttle position. To further improve efficiency, regenerative braking is employed. The advantage of this system is that a rider can pedal constantly at a comfortable rate to provide power to the capacitors, while controlling the actual speed of the vehicle with the throttle position. Pedaling can even be done while the vehicle is not in motion. If the rider desires more physical exercise, or in the unlikely event that the capacitor fails, the motor can be directly powered by the generator much like a conventional mechanical system.

Domain:
- Mechanical Engineering

Advantages:
- No batteries
- Regenerative energy is captured
- Supercapacitors can provide sudden acceleration, reducing leg strain

PRF No. 66106 Production of Hydrogen Using an Anaerobic Biological Process

Technology Readiness Level: 6

As ethanol continues to become an integral part of the international energy future, it is critical to continue to increase the overall value and efficiency of ethanol production. Ethanol is an alcohol produced by yeast fermentation from sugars. The products of this biological reaction are carbon dioxide, ethanol, and waste products. Distillers dried grains with solubles (DDGS) are the nutrient by-products (i.e. protein, fiber, and oil) of ethanol production.

Typically used to create livestock feed, Purdue researchers have discovered that DDGS can produce large quantities of hydrogen with a low pressure anaerobic process. This method of hydrogen production could be implemented in the near term with minimal cost and impact upon existing operations because of minimal operation requirements and readily available off-the-shelf components. It is estimated this method can add 15% economic value to the DDGS. Additionally, the DDGS protein fraction increases, significantly increasing its use as a feed supplement.

Advantages:

- Produces large quantities of hydrogen
- Increases the DDGS use as a livestock feed supplement
- Increases the overall value to DDGS
- Can be implemented at minimal cost

PRF No. 65369 Synthesis of Multinary Chalcogenide Nanoparticles

Technology Readiness Level: 4

Among the various semiconductor nanomaterials investigated for photovoltaic applications, the most promising candidate for low cost solar cells is the I-III-VI2 family of chalcopyrite nanocrystals. However, due to the limited supply and ever increasing price of rare metals, such as indium and gallium, there is a need to find alternative materials with high abundance and low cost.

Researchers at Purdue University have discovered an innovative method that is related to the synthesis of multinary chalcogenide nanoparticles comprising of Cu, Zn, Sn, S, and Se. The main compound created is Cu2ZnSn(SySe1-y)4, whereby Cu/(Zn+Sn) can be substantially less than 1, but greater than 0.5; Zn/Sn can be greater than, equal to, or less than 1; and y can be between 0 and 1. This method would allow for improved thin films for photovoltaic applications because of tin and zinc's natural abundance in the earth's crust and the relatively low toxicity.

Advantages:

- Cost-effective
- Comparable Efficiency
- High abundance and low toxicity of inputs

PRF No. 65366 Fabricating Absorber Films with Nanoparticle Inks

Technology Readiness Level: 4

Semiconductor alloys based on copper, indium, gallium, sulfur, and selenium (CIGSSe) are some of the most promising candidates for photovoltaic applications due to their unique structural and electrical properties. The highest quality CIGSSe films have been traditionally fabricated using vacuum co-evaporation; however, production cost is high, which has limited its applicability for large scale fabrication. Recently, solar cells with CIGSSe absorber layers, fabricated by deposition of various alloys, have been developed using alternative approaches.

Among the various alternatives, coating technologies utilizing nanoparticle inks are a promising alternative for low cost and high throughput production of solar cells as compared to traditional vacuum-based deposition methods.

The optical and electrical properties of the CIGSSe absorber depend strongly on the composition. Thus, one of the major challenges to all deposition techniques is the ability to control and maintain the composition at the molecular level. To overcome this challenge, researchers at Purdue University have developed a method related to the fabrication and control of the composition profile along the depth Cu(In1-xGax(S1-ySey)2 absorber films where x and y are between 0 and 1, through the utilization of ink solutions containing Cu(In1-xGax(S1-ySey)2 nanoparticles where x and y are between 0 and 1. This method utilizes a precursor layer containing CIGSSe nanoparticles followed by selenization, which converts the nanoparticles into a densely packed absorber film that is fixed at the molecular level.

Advantages:

- Densely packed film where the composition is fixed
- More stable optoelectronic and electronic properties
- Cost effective

PRF No. 65257 Selenization of CIS Nanoparticles

Technology Readiness Level: 5

There are currently various challenges in the selenization of CuInS2 (CIS) films. There tends to be delamination of the film after selenization, where the film peels off from the substrates. Another method requires a high-temperature hydrogen reduction step to reduce the oxides, where substantial amounts of energy and time are necessary. This step is also potentially explosive and may require the use of highly toxic H2Se gas. Further, expensive, high-end equipment is needed for safety concerns when the gas is at high temperatures. The most challenging problem in previous art is the lack of control of the film composition. Because the electric properties of CIS depend strongly on its composition, there is a need where composition of the film can be controlled at the nanometer scale.

Researchers at Purdue University have developed a photovoltaic printing technology utilizing CuInS2 nanocrystal inks, allowing for the creation of CIGS at the molecular level. This is beneficial because smaller particles will lead to a more densely packed nanoparticle film, and it allows for the fabrication of the film with solely the CuInS2 nanoparticle or a mixture of the CuInS2 nanoparticle with other CIGS materials, such as CuIn(Sy,Se1-y)2, CuGaS2, CuGa(Sy,Se1-y)2, Cu(InGa1-x)S2, and Cu(InxGa1-x)(Sy,Se1-y)2. This process is also safe, less expensive, and has a high production yield.

Advantages:

- Safe
- Allows for creation of CIGS with the desired composition
- Inexpensive
- High production yields

PRF No. 65762 Thermoelectric Materials for High Temperature Applications

Technology Readiness Level: 3

Thermoelectric devices turn heat into electricity or vice versa. To work efficiently the particles that are used to construct the device need to be as one-dimensional as possible.

The best possible shape for these particles is a long, thin wire, which maximizes the electrical conductivity and minimizes the thermal conductivity of the device. Thermoelectric devices will allow waste heat to be captured and reused, greatly increasing efficiency. Purdue University researchers have developed several novel titanates for use in advanced thermoelectric devices. These new titanates could be used for harvesting electricity from the waste heat at high temperatures where a traditional Tellurium or Antimony-based compound will either oxidize or decompose. Alternative applications of this technology include use as energy storage devices such as in super capacitors.

Advantages:

- Can produce ultra-thin wires
- Thermal conductivity can be reduced

PRF No. 65806 Flexible Thermoelectric Materials on Fabrics

Technology Readiness Level: 4

Thermoelectric cooling uses a device that transfers heat through a cooling plate and releases the heat on the opposite, hot side of the device. Current thermoelectric devices use materials that limit the pliability so applications are limited.

Purdue University researchers have developed a device that is thinner and more flexible than current thermoelectric devices. It can be coated onto fabric used to make clothing. Clothing that keeps the body cool will protect those in hot climates, such as battlefields in Iraq and Afghanistan, from heat related illnesses and can also reduce detection by infrared body heat detectors. This device can also be used to convert body heat into electricity and serve as a portable power source.

Advantages:

- Thin and flexible
- Can use body heat for electricity
- Portable power sources

PRF No. 64699 Self-Cleaning Anti-Fogging Materials

Technology Readiness Level: 8

It has been possible to separate small amounts of oil from water for quite some time. This was made possible through the use of nanoporous filters. Unfortunately, the minute size of the holes in a nanoporous filter requires the filtering process to be highly pressurized in order to function. In some situations, such as oil spill cleanup, this is not always practical. Purdue University researchers have devised a method of separating the small amounts of oil from water through the use of an advanced membrane coated glass micro filter. Micro filters don't have the same pressure requirements as nanoporous filters; therefore, water can flow freely through them. The membrane is composed of a patented hydrophilic layer of polyethylene glycol and each molecule is tipped with fluorine. The water is attracted by the polyethylene glycol flowing through both layers freely, and the oil is stopped at the fluorine barrier where it beads and can be easily removed through the use of cross flow filtration. Typical filters collect oil and must be changed out frequently when they have been rendered ineffective. This technology saves money by extending the life of the filter and making the oil easy to remove instead of exchanging the filter. This is done without the need for high pressure parts, thereby lowering system costs.

Advantages:

- High Pressure system is not necessary
- Longer life so filters do not need to be replaced as often

PRF No. 65614 Improved Crystallization of Solar Cells

Technology Readiness Level: 6

Thin-film photovoltaic solar cells work by absorbing solar energy into a layer of semiconducting material called the light absorbent layer. A process called Rapid Thermal Annealing (RTA) is currently used to crystallize this material after fabrication, but RTA leaves behind defects that degrade the efficiency of the solar cell. RTA also requires tight thermal control and a separate vacuum/inert gas system.

Purdue University researchers have developed a new technique for crystallization of photovoltaic material called High Speed Laser Crystallization (HSLC). This method uses a laser to rapidly crystallize material in the light absorbent layer. It can be targeted at specific layers or regions of material without damaging other parts of the solar cell, and the laser does not require a vacuum/inert gas system or other external equipment. HSLC is also faster and produces fewer defects than conventional techniques like RTA.

Advantages:

- Increases efficiency of solar cells
- Post-processing is faster, reducing manufacturing time
- Can be targeted at specific layers of material
- Lowers cost by removing the need for external vacuum/inert gas system

PRF No. 64581 Window That Improves Air Quality and Energy Use

Technology Readiness Level: 5

It has been reported that up to 90 percent of a typical American's time is spent indoors. Poor air quality often present indoors has been linked to respiratory illness, allergies, asthma, and sick building syndrome. Additionally, buildings in the United States account for one-third of the total primary energy consumption and two-thirds of the electricity consumption. Current window technology is limited in its ability to offer Improvement of Air Quality (IAQ). Windows that allow air flow within current airflow designs are inefficient and are constrained to a single air flow path.

Purdue University researchers have developed a more efficient window that improves air quality and conserves energy, exhausting the lesser quality air in a room and flowing in fresh, outdoor air by its two-way flow path. The air that flows into a room is appropriately tempered to conserve energy for heating or cooling a room throughout the year. On a calm, sunny day in the winter, tests have concluded that outdoor air can be preheated by up to 18Â°C (80 percent efficiency). Similarly, on a calm, cloudy day in the summer, outdoor air can be precooled by up to 3Â°C (24 percent efficiency).

Advantages:

- A more efficient window
- Improved air quality

PRF No. 66109 A Shade Tolerant Panel Design for Thin Film Photovoltaics

Technology Readiness Level: 5

Solar cells are becoming increasingly efficient at converting light into electricity, but they still suffer from some reliability issues. One such issue is that if a cell of the solar panel is in the shade it will shut down and start absorbing excessive energy from the connected cells.

The excess energy causes heating in the cell that can cause damage or even start a fire. This problem has usually been addressed by connecting diodes between segments of cells to prevent the current from flowing into a shaded panel section, but this does not work unless a large area is shaded.

Researchers at Purdue University have developed a new solution to this problem by designing a radial layout for a solar panel. This design assures that a shadow will shade many cells at once, allowing those cells to distribute the reverse voltage across them. The design avoids reverse breakdown without the need for external bypass diodes, simplifying the manufacturing process, and alleviating shadow degradation.

Advantages:
- Increased reliability of cells
- Less risk of damage

PRF No. 65763 Nanostructure-Based Thermoelectric Energy Conversion

Technology Readiness Level: 3

Thermoelectric materials directly convert temperature difference into electric voltage or vice versa. Therefore, thermoelectric materials can be used as an electric generator to recover waste heat into electricity or as a refrigerator.

Researchers at Purdue University have developed a new type of highly efficient, environmentally friendly thermoelectric material. These thermoelectric materials are based on a nanostructured Copper Zinc Tin Sulfide (CZTS), all of which are inexpensive, abundant, and non-toxic elements. In addition to being less costly and safer to produce, this technology works over a wider range of temperatures than most conventional thermoelectric materials.

Advantages:

- High efficiency
- Work over wide range of temperatures
- Non-toxic

PRF No. 65927 Novel Lignases and Aldo-Keto Reductases for Biomass Conversion

Technology Readiness Level: 2

Lignin, one of the most abundant natural polymers constituting onefourth to one-third of the total dry weight of physiologically mature plants, is currently a barrier to the production of second generation, non-food ethanol. Lignin limits access to plant cell wall sugars that can be fermented into bioethanol, and it has a negative impact on overall conversion efficiency.

Purdue University researchers have identified digestive enzymes from termites that target lignin and enable greater release of fermentable sugars. Utilization of these enzymes has the capacity to increase the yield and conversion efficiency of biomass to ethanol. These enzymes can also have applications in the production of value-added by products, as well as more sustainable plant based fossil fuel additives.

Domains:

- Energy
- Green Technologies
- Agrobioscience

Advantages:

- Breaks ligno-cellulose down into more accessible sugars for ethanol fuel production
- Increases efficiency of biomass to ethanol conversion

Section 2: Companies in Purdue's Research Park that may be interested in international collaboration

For more information on Research Park and its companies, see http://purdueresearchpark.com/

Genport North America Corp.
www.genport.it

Section 3: Purdue contract research facilities and services potentially available to external organizations

Center for Global Trade Analysis

The Global Trade Analysis Project (GTAP) is a global network of researchers and policy makers conducting quantitative analysis of international policy issues. GTAP's goal is to improve the quality of quantitative analysis of global economic issues within an economy-wide framework. GTAP offers a variety of products, including: data, models, and resources for multi-region, applied general equilibrium analysis of global economic issues. It also organizes courses and conferences and undertakes research projects. The Center for Global Trade Analysis employs staff members and graduate assistants, as well as coordinating with CGE modelers and trade economists, to support and further GTAP's missing.

https://www.gtap.agecon.purdue.edu/

Laboratory for Renewable Resources Engineering (LORRE)

The Laboratory of Renewable Resources Engineering, LORRE, was established in 1978 to carry out research on transforming renewable resources to liquid fuels. The role of the Laboratory in multidisciplinary research evolved over its 33-year history from biofuels research to its current function as an Integrative Center for Biotechnology and Engineering which carries out multi-disciplinary research in bioenergy, bioprocessing, bioproducts , bionanotechnology, and biorecovery. LORRE has capabilities ranging from fundamental studies on the molecular genetics of yeast and bacteria to bioreaction and bioprocess engineering, and biotechnology that uses organisms, tissues, cells, or their molecular components to: (1) act on living things, (2) intervene in the workings of cells, including their genetic material, (3) provide templates for advanced non-living systems that emulate specific biological functions, and (4) manufacture bioproducts.

https://engineering.purdue.edu/~lorre/16/overview/index.shtml

Hub Platform (virtual organizations)

HUBzero™ is an open source software platform for building powerful web sites that support scientific discovery, learning and collaboration. Originally created by researchers at Purdue University in conjunction with the NSF-sponsored Network for Computational Nanotechnology to support nanoHUB.org, the HUBzero platform now supports dozens of hubs across a variety of disciplines, including cancer research, pharmaceuticals, biofuels, microelectromechanical systems, climate modeling, water quality, volcanology, and more. Under the hood, powerful middleware serves up interactive simulation and modeling tools via your web browser. These tools connect you with rendering farms and powerful Grid computing resources.

http://hubzero.org/

Envision Center

The mission of Envision Center for Data Perceptualization is to serve, support, and collaborate with faculty, students, and industry to be a leader in scientific visualization through learning, discovery and engagement. Researchers in the Envision Center explore novel computer graphics, advanced visualization, and human computer interface technologies, such as auditory, haptic, and multimodal interaction. These technologies are integrated with state-of-the-art advanced computation and networking, and high-end immersive visualization environments to assist researchers and industry in their quest for new knowledge and innovative products. The Envision Center serves as a window into computational aspects of science and engineering, providing effective means to communicate complex research results to students, researchers, and the general public.

http://www.envision.purdue.edu/

Software Solutions

The Rosen Center for Advanced Computing provides access to leading-edge computational and data storage systems, as well as expertise in a broad range of high-performance computing activities. The RCAC evaluates, deploys and supports hardware and software for large-scale scientific computing. They also promote the effective use of our computing systems and application software through training and education, consultation, and documentation, contribute to the discovery process through algorithm design and the development of effective computing techniques, and partner with researchers to develop grant proposals by providing expertise in the assessment of hardware and software requirements. A partner in their collaborative efforts, the Scientific Solutions group works with Purdue faculty and staff to develop proposals and specific research solutions including computation- and data-intensive applications, science portals and other web services.

http://www.rcac.purdue.edu/projects/

Research Machining Services

Research Machining Services through Purdue's Discovery Park offers services and supplies in machining and welding, design and drafting, R&D prototyping to small production runs, and materials and hardware. A precision machine shop, open to all departments, provides both standard and CNC machining equipment, welding, and design services. Research Machining Services maintains a diverse inventory of the most common alloys of steel, stainless steel, aluminum, and brass in standard material sizes and structural shapes, plus offer special-ordering of exotic alloys and high-performance plastics. The Research Machining Services provides plating, anodizing, and water jetting services, along with many other services through vendors. They also specialize in one-of-a-kind research equipment and/or modifications.

http://www.purdue.edu/discoverypark/machineshop/

Machine Shop PHYS 39

The Physics Instrument Shop at Purdue University uses leading-edge computer-aided design and manufacturing software integrally linked to CNC machines, to produce precision parts and assemblies from a wide variety of materials. It specializes in small parts fabricated to precise tolerances. The machine shop extensively uses the (Autodesk) Inventor software to design parts and to make final assembly drawings. It offers a wide variety of equipment, including multiple mills and lathes, and raw materials, as well as an extensive stock of steel and stainless cap screws.

http://www.physics.purdue.edu/machineshop/

X-ray Crystallography

The x-ray crystallography laboratory provides data collection, structure analysis, and crystallography consultation services. Equipment available at the lab include (1) a Rigaku Rapid II image plate diffractometer equipped with a MicroMax002+ high intensity copper x-ray source, (2) a Nonius KappaCCD diffractometer on a sealed tube molybdenum source, (3) Oxford Cryosystems low temperature device capable of temperatures from 400 to 90K, and (4) LINUX PCs for structural calculations and the Cambridge Structural Database. (Other computers are available for collection and processing diffraction data.)

http://www.chem.purdue.edu/xray/default.asp

Amy Analytical Instrumentation Center

The Amy Analytical Instrumentation Center is a core facility in the Department of Chemistry that supports instruments and information technology and manages the shared departmental instrumentation. The center handles instrument design, fabrication, repairs and consulting as well as IT-related installation, networking and support. The long-established philosophy of the facility is to understand the experimental problem in depth such that the appropriate measurement of technology can be applied. The Amy Analytical Instrumentation Center houses a large range of instruments that can be accessed by both departmental and non-departmental users.

http://www.chem.purdue.edu/aaic/

Purdue Stable Isotope Facility

The Purdue Stable Isotope (PSI) facility is a state-of-the-art multi-user, stable isotope laboratory housed in the Earth and Atmospheric Sciences Department at Purdue University. The PSI group conducts research in a range of environmental and climate-related areas, including biogeochemistry, hydrology, ecology, and paleoclimatology. Analytical services currently offered include: (1) H and O isotope analysis of waters at natural abundance or high enrichment by TCEA-IRMS (precision < 1‰, 0.2‰), (2) H and O isotope analysis of organic solids by TCEA-IRMS (precision < 2‰, 0.3‰), (3) C and O isotope analysis of carbonates by GasBench-IRMS (precision < 0.1‰, 0.1‰), and (4) a range of chemical and physical sample preparation services. The facility houses three gas Isotope Ratio Mass Spectrometers (IRMS), each accompanied by peripheral devices for conversion of various compounds into analyzable gases.

http://www.eas.purdue.edu/psi/

PRIME Lab

The Purdue Rare Isotope Measurement Laboratory (PRIME Lab) is a dedicated research and service facility for accelerator mass spectrometry (AMS). AMS is an ultra-sensitive analytical technique for measuring low levels of long-lived radionuclides and rare trace elements. The accelerator is used to measure both man-made and cosmic-ray-produced radionuclides such as ^{10}Be (half-life 1,600,000 years), ^{14}C (5730 years), and ^{36}Cl (300,000 years) in natural samples having isotopic abundances down to one part in $1x10^{15}$.

http://www.physics.purdue.edu/primelab/

Interdepartmental NMR Facility

The Purdue Interdepartmental NMR Facility (PINMRF) is a university-wide resource dedicated to supporting NMR spectroscopy and to making this analytical technique available to researchers at Purdue and elsewhere in the scientific community. PINMRF currently has ten NMR spectrometers located in six laboratories in four buildings on the Purdue campus, with additional laboratory locations under consideration. PINMRF is set up to allow individual researchers direct access 24/7 to the spectrometers, after appropriate training and testing has been completed. However, we will gladly provide spectra of submitted samples, either on a service basis or as part of a collaborative research project.

http://www.pinmrf.purdue.edu/

Campus-wide Mass Spectrometry Center

The Campus-wide Mass Spectrometry Center (CWMSC) is a Purdue facility created to coordinate the operation and maintenance of and to provide research groups asses to mass spectrometers across campus. The facility insures a high level of quality control for the more routine types of analyses, and provides a collaborative analytical mass spectrometry capability to the Purdue research community. All major mass spectrometric ionization techniques and sample introduction methods are available, including gas chromatography, liquid chromatography, electron impact, chemical ionization, electrospray ionization, inductively coupled argon plasma, matrix-assisted laser desorption ionization, atmospheric pressure chemical ionization and high resolution mass measurements.

http://www.chem.purdue.edu/cwmsc

National Test Facility for Fuels and Propulsion

The National Test Facility for Fuels and Propulsion is funded with a $2.7 million grant from the U.S. Air Force and is housed in the Niswonger Aviation Technology Building at the Purdue Airport. The facility tests aerospace hardware in engines and aircraft and provides data related to fuel-sustainability and emissions goals and for economic assessments. Work of the facility focuses on jet engines but also includes some testing related to piston engines. The work will tackle four major bottlenecks to aerospace progress: access to hardware testing; development of control logic and systems permitting flex-fuel operation and realization of improved efficiencies; sustainability of biofuels related to crop productivity, as well as bio and synthetic fuels' ability to meet both near- and long-term aerospace requirements; and regulatory compliance.

http://www.tech.purdue.edu/at/NATEF/