U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Technologies and Innovations Enabled by the U.S. Department of Energy Advanced Manufacturing and Materials Technologies Office via the LEEP Program

September 2024

Prepared by Pacific Northwest National Laboratory
for the U.S. Department of Advanced Manufacturing and Materials Technologies Office

Adavanced Manufacturing and Materials Technology Tracking through FY2024 and the LEEP Program

The one-page technology summaries contained here represent a small subset of the AMMTO R&D project portfolio of nearly 1,500 projects as of the end of FY2024. The LEEP program represents about 10% (155 projects) of AMMTO's portfolio, however, the LEEP follow-on funding numbers are very robust at over $3 billion for the entire program to date.

Information about the LEEP program can be found here: https://www.energy.gov/eere/ammto/lab-embedded-entrepreneurship-program

The technology articles here represent the some of the technology and project information that will be published on the PNNL lead technology tracking database website, sponsored by AMMTO, here: https://eere-techtrack.pnnl.gov/
Other information accessible via this webtool will be corresponding lead technology developers, project partners and other relevant background supporting information and documents, e.g. factsheets, presentations, publications and final reports to the AMMTO sponsor.

Pacific Northwest National Laboratory (PNNL) has performed technology tracking for AMMTO, formerly the Advanced Manufacturing Office (AMO) over several decades resulting in numerous annual "Impacts" reports. The goal of technology tracking is to discover which R&D projects or technologies will result in a commercialized or near market-ready technology (within 3-5 years).

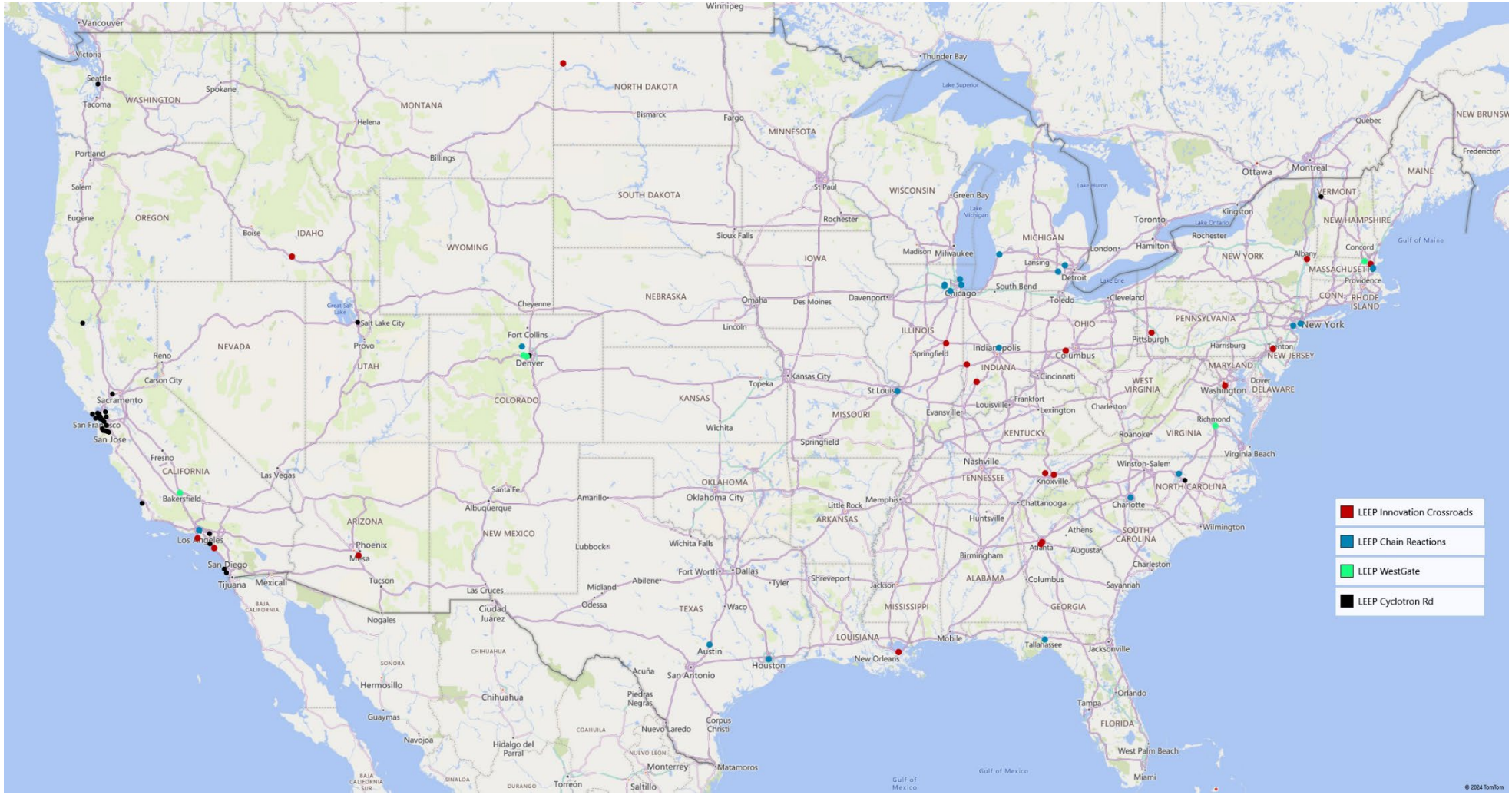
Since FY2019 the project/technology portfolio tracked by PNNL included R&D projects resulting from several funded consortia initiatives (CESMI, CMI, IACMI, MDF, Power America, RAPID, REMADE)[1]. In FY2024, four more consortia programs were added to the project portfolio, CYMANII, BOTTLE, HPC4MFG/HPC4EI and NAWI. Lastly, the LEEP program portfolios were also added between FY2020 and FY2024, Cyclotron Road (LBNL), West Gate (NREL), Chain Reaction Innovations (ANL) and Innovation Crossroads (ORNL). The net effect of the additional of these new project portfolios and the 2022 AMO reorganization resulted in the R&D funded project increasing 7-fold to approximately 2,300 projects.

Current trends in data access and acquisition have guided PNNL's technology tracking work away from old-fashioned paper files, management by spreadsheet towards the latest data and computing science techniques, deployment of database organizational tools and website access for our DOE sponsors and their industry stakeholders. Furthermore, AMMTO have expanded their research interests towards program impact metrics, return on investment (ROI), internation commercialization and sales, intellectual property, publications, company dynamics, partnership dynamics and community benefits such as DEIA.

To this end PNNL's technology tracking team have been constructing a database to provide access to all the technologies tracked over the past 5 decades (technologies date back to 1976). This paper to digital effort has been ongoing since approximatelyFY2014. Through FY2024, the database core consisting of 2,261 projects/technologies (over 20,000 database record fields) including multiple annual project updates. PNNL has accumulated over 2,000 AMO factsheets and other relevant information related to these projects/technologies which will be made accessible from within the website database. AMMTO staff have been granted access to the preliminary website rollout in late September 2024 with an anticipated public access in early 2025.

The remainder of this report consists of short technology summaries for several LEEP projects for publication on the database website mentioned above. These articles were approved for website publication by the technology developer organization's point of contact. We note here for the reader that a commercial technology is either commercialized or in-use (deployed) and that an emerging technology is expected to be market-ready or in-use within 3–5 years.

[1] For more information: https://www.energy.gov/eere/amo/research-development-consortia



Geographic Locations of the LEEP Program nodes and projects as of May 2024

Technologies Resulting from LEEP Program – 5/20/24

cyclotronroad

Bio-Chemicals and Fuels

LEEP – Cyclotron Road **Emerging Technology**

Making Sustainable Manufacturing Scalable and Profitable

The modern world relies heavily on petroleum-based feedstocks to produce many essential products, such as plastics, rubber tires, soaps, clothing, cosmetics, and much more. Additionally, modern consumerism, and exponentially growing populations, create high demand for such products to be manufactured in massive quantities. Because of this, our demand for oil extraction, which is utilized to create petroleum products, is also high. Unfortunately, oil is not a renewable resource, and the process of extracting oil, as well as producing petroleum-derived materials, poses many threats to the environment, such as creating greenhouse gas emissions, accidental oil spills, and creating products (i.e., plastics) which do not biodegrade and end up in landfills and oceans. One potential solution to these problems, is to manufacture bio-based feedstocks, which can be used in place of petroleum-based feedstocks.

Visolis Inc, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), has developed new routes to producing key molecules which serve as chemical feedstocks for polymers, solvents, and resins. These bio-based feedstocks are manufactured and can be used in a range of specialty products, such as polymers, solvents, and resins. Other partners include Sumitomo Chemical, Nikko Chemicals, Biocat Polymers, Berkeley Lab, Bill & Melinda Gates Foundation, United States Department of Agriculture, National Science Foundation, and Horizon 2020.

Visolis integrates capabilities across synthetic biology, catalysis, and process development, supported by a high throughput screening and data analytics platform. Advanced data modeling is conducted via an AI powered engine. The goal is to create a circular economy and a more sustainable future though sustainable biomanufacturing. Currently, the production rate of bio-chemicals by Visolis is 100 ton per year, with a target scale up of 2000 ton per year (20x scale up). With their industry partners – Goodyear Tires – they will manufacture "Green" Rubber, which means reducing the CO_2 footprint of the rubber manufacturing process. The goal is to achieve a CO_2 reduction of 70-90%, in comparison with current production of synthetic and natural rubber which has a CO_2 output of 2.5 and 15 ton per ton respectiviey.

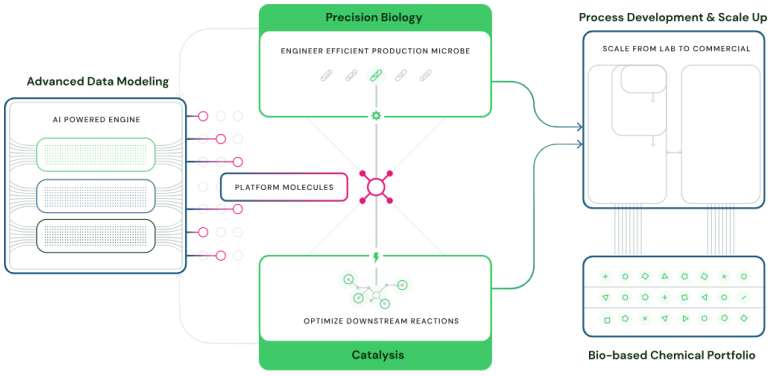


Diagram of High Throughput Screening & Data Analytics Platform

Overview

- Developed by Visolis Inc.
- Development began in 2015.
- Breakthrough Innovation winner at World Government Summit.

Applications

Can be used for production of bio-based specialty materials that can be utilized in a range of applications from cosmetics to cars.

Capabilities

- Currently produces 100 tonne of bio-chemicals per year, with potential to scale up by 20x.
- Can be used as an alternative to current manufacturing processes to reduce CO_2 outputs.
- Enables more sustainable manufacturing of various products, including RPI grade fuel for aviation.

Benefits

Diverse Applications

Visolis' platform can produce molecules with a wide array of applications, such as fuels, rubbers, cosmetics, and more.

High Performance

Production processes have 20-50% lower cost when compared to existing processes.

Sustainable Economic System

Creates the potential for a circular economy, meaning an economic system based on the reuse and regeneration of materials or products for continuing production in a sustainable way.

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Converting Ocean Waves Into Electricity

LEEP – Cyclotron Road **Emerging Technology**

Unlocking the Power of the Ocean

Clean and renewable energy sources are essential for a sustainable future. Fossil fuels are the largest sources of energy for electricity generation – at about 40% - in the United States as of 2022.[1] With these fossil fuels come many negative side effects, such as greenhouse gases, destruction of habitats, and toxic chemicals leeching into the surrounding ecosystems from extraction sites. One alternative to fossils fuels is wave power. Ocean waves pack the strongest degree of power in the water-world, ranking the greatest in terms of levels of marine energy resource potential in the U.S. Wave power has the technical feasible resource potential to meet 30% of the United States' electricity demand - equaling $120B in the total addressable market – yet this potential is currently unused.

CalWave, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), and in collaboration with multiple partners, is developing wave energy converters (WECs), which can convert ocean waves into electricity. By utilizing WECs to potentially satisfy 20-30% of global energy demands, an estimate of 1.38 gigatons of CO_2 could be sequestered annually. Additionally, CalWave has a target to displace 500 million tons of greenhouse gasses annually by 2050, should wave energy development follow a trajectory similar to offshore wind. CalWave plans to prepare for deployment of their x100™ unit, ranking 100kW of power, at the PacWave energy site (Newport, OR). This deployment follows their San Diego open-ocean pilot completed in 2021, which was California's first at-sea, long-duration wave energy pilot.

Wave energy is, essentially, a condensed form of solar power produced by wind action. The sun heats up air at different places around the globe, which creates wind that blows over the ocean's surface. Surface waves, such as those that crash on a beach, are created by this wind, and can travel thousands of miles before reaching land (with almost no energy lost). Once ocean waves come in contact with WECs, such as CalWave's x100™, the common approach is to extract the kinetic energy of a wave energy absorber via a suitable drivetrain, similar to a wind turbine's drivetrain. WECs can extract energy from incident ocean waves via a multitude of different motion patterns, wave characteristics, and directional influence by adjusting to the most ideal pattern for energy extraction.



CalWave's Wave Energy Converter

Overview

- Developed by CalWave Inc
- Development began in 2015
- Completed 2021 Open-Ocean Pilot in San Diego, California

Applications

Can be used to provide remote power for applications such as data centers, national security (defense), and remote monitoring applications where water waves are present.

Capabilities

- CalWave's x100™ achieves a minimum capacity of 40% capacity factor alone
- Devices are projected to be able to withstand over 20 years of use in open ocean
- Suitable for multiple applications, such as isolated microgrids and utility scale

Benefits

Capacity Factor

The xWave™ series achieves a minimum 40% capacity factor alone. When co-located with offshore wind, far greater capacity factor can be reached.

Environmental Impact

CalWave's technology ahs been deemed to have an acceptable level of environmental impact according to the latest State of Science report.

Resilience

The x100™ can operate in most weather conditions including storms and in extreme cases, shutdown automatically to survive intense storms which could be destructive to the system's infrastructure.

Scalability

CalWave's x100™ is scalable in both design and functionality. Energy farms that utilize the technology can supply coastal communities with anywhere from 100 kw to over 500 MW of local power.

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[1] for more info: US Energy Information Administration

Enabling 1000X Improvements In Computing

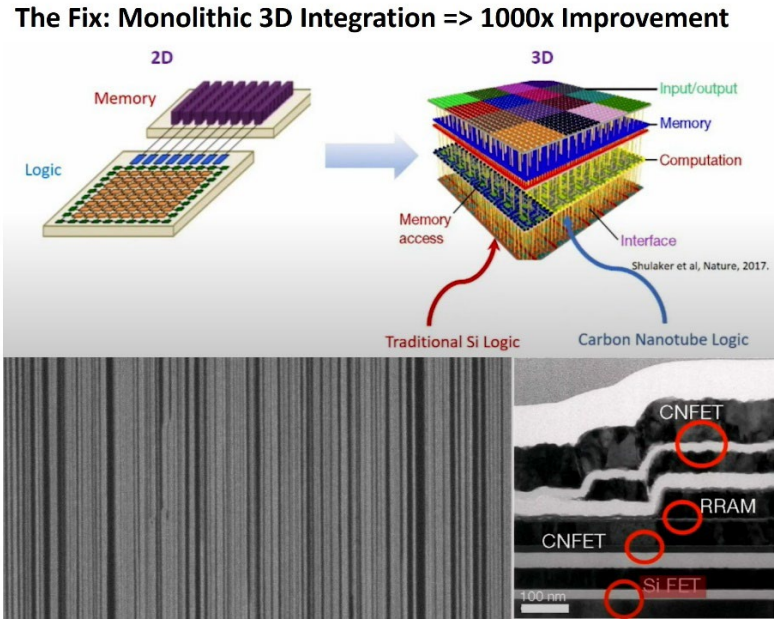
LEEP – Cyclotron Road **Emerging Technology**

Next-Generation Semiconductor Material that Takes the Industry Forward

While size reduction is still happening, doubling the components on semiconductor chips every two years (Moore's Law) is no longer a reality. Because of this, there are some setbacks in continuing to increase computing capacity today, which can lead to negative impacts on the environment due to the need for larger, more energy-consuming machines. Carbon nanotubes (CNTs) can transform the semiconductor industry and help put those issues to rest. However, for these benefits to be realized, CNTs must be manufactured in a way that can scale to the highest level.

Aligned Carbon Inc, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), has developed its proprietary Alcar wafer platform to transform the semiconductor industry and unlock 1000x power-performance in next-generation complementary metal-oxide semiconductor (CMOS) technology. Aligned Carbon's Alcar platform is built on three pillars of innovation: their CNTs are grown in a perfectly aligned fashion across a wafer-scale surface, their CNTs are semiconducting-pure, and their wafers are 100% CMOS fabrication-compatible.

To achieve the aligned CNT's, Aligned Carbon utilizes a unique wafer scale chemical vapor deposition (CVD) growth technique. This ensures that uniform density and effective scalability of all wafer sizes. Monolithic 3D integration is necessary to realize revolutionary new efficiency improvements, as well as brand new semiconductor use cases. Material must evolve from planar designs into 3D designs. To enable monolithic 3D, as well as multi-form integration, CNT transfer is performed from Aligned Carbon's growth wafer to any target water, meaning the process is scalable and deployable to essentially any substrate. When compared to Silicon, which is a traditional component of semiconductors with many constraints, CNTs demonstrate low resistivity for energy savings, high carrier mobility for enhanced clock speeds, high strength for stability, high thermal conductivity for efficient heat transfer, and radiation hardness.



Aligned Carbon's Nanotube Integration Solution

Overview

- Developed by Aligned Carbon Inc
- Development began in 2016, leveraging Stanford's 15 year history in CNT electronics research.
- Have made small batches of chips to demonstrate material capabilities

Applications

There are multiple applications that make CNTs valuable resources, such as improvements to semiconductors, analog/wireless technology, power electronics, sensors, quantum computers, and more.

Capabilities

- Aligned Carbon's CNTs hold promise for realizing higher frequency RF devices
- Aligned Carbon's CNTs will be key to improving computing performance by 1000x within the next 10-15 years
- Aligned CNTs possess low thermal budget and low film stress processing

Benefits

Alignment

Successfully aligning the carbon nanotubes and preventing them from crossing over each other is an important improvement, as density problems are no longer a concern and there is no longer interference with each other.

Manufacturable

All of Aligned Carbon's processes can meet manufacturing demands and standards, which includes CMOS compatibility, and meeting a low-temperature press transfer process rate of 100 wafers per hour.

Semiconductor Purification

Purified CNT material provides electrical properties that are all the same, so there is very little variation.

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From Atoms To Apparel

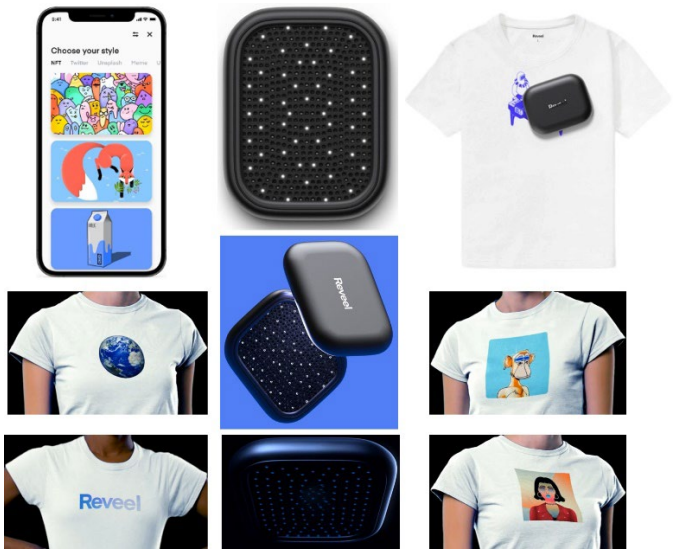
LEEP – Cyclotron Road **Emerging Technology**

Infinite Fashion Possibilities with One Canvas

Fast fashion poses many negative impacts on the planet. This is because fast fashion focuses on producing large volumes of new clothing products over short timeframes, as the name implies. Much of this clothing, which is often made up of synthetic materials such as polyester, eventually ends up being discarded by consumers, where it sits in landfills unable to fully decompose. Additionally, to keep up with manufacturing demands, large amounts of energy and water are consumed. This means inevitable carbon output and wasted materials. Customizable apparel is a unique concept which can help to mitigate the need for, and therefore the impacts of, fast fashion.

Reveel, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), has developed MagicInk™ technology to enable clothing personalization that can be printed, erased, and reprinted when desired. MagicInk™ is a type of electrochromic dye, which allows both the changing of color/design, as well as the erasure of the design, via contact with the light emitted from Reveel's image transfer lamps. In order to go through this process, Reveel is also working on connectivity and a mobile application (App) which will allow users to download or create and store their digital art, and/or Non-fungible token (NFT) art. Subsequently, these images can be used to image or pattern an article of clothing treated with MagicInk™ using Reveel's imaging lamps connected using either wireless, wifi, bluetooth or USB connection.

Specialized electrochromic inks that allow a single tee-shirt to essentially be "edited" over and over, has the benefit of reducing supply and demand factors, as there is no longer a need to purchase multiple different articles of clothing to acquire new designs. This also means, of course, that if clothing manufacturers have less demand for supply, the amount of materials utilized in the manufacturing process (such as fabrics, dyes, and water) are significantly reduced. By opting for an article of clothing that utilizes Reveel's MagicInk™ and lamp, a single individual can lower their carbon footprint and water footprint by significant amounts (12x lower carbon and 100x lower water).



Reveel's MagicInk™ and Lamp for Reuseable Fashion Image Transfers

Overview

- Developed by Reveel
- Development began in 2020
- Currently developing and beta testing 2nd generation electrochromic dyes

Applications

Can be used for changeable customization to create erasable and re-printable graphic tee-shirts, and eventually other types of clothing applications.

Capabilities

- Can print, erase, and reprint different designs by utilizing MagicInk™ and specialized lamp
- Images can be downloaded from the internet and printed/worn in minutes
- Makes personalized apparel accessible, scalable, and environmentally conscious.

Benefits

Environmental Impact

By using Reveel's patent pending MagicInk™ along with their Reveel lamp, individuals can lower their carbon footprint by 12x, and their water footprint by 100x, when compared to traditionally purchasing multiple different garments to obtain different graphic designs.

Monetary Savings

Costs on consumers can be dramatically reduced by eliminating the need to purchase multiple articles of clothing just to obtain new designs.

Sustainability

Reveel's (web application?) is built using the most sustainable web3 technologies to allow easy, instant design printing without heavy burden on the environment.

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Harvesting Value from Agricultural Waste

LEEP – Cyclotron Road **Emerging Technology**

Turning Crop and Forest Residues in Rural Communities into Carbon-Negative Bioproducts

Most crop and forest residues (biomass) are loose, wet, and bulky. This makes it expensive, and difficult, to collect and transport them. Consequentially, many rural, underserved communities are often shut out from the benefits of the bioeconomy, and their only means to dispose of these residues is through burning in open air. This results in a significant amount of pollution, and it increases risks of wildfires. One solution is to decentralize bio-product production using a combination of easy-to-use hardware and IoT-based control systems. Such hardware would be portable and could be carried from farm to farm to locally densify and upgrade small pockets of residues.

Takachar, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), has developed small scale, low-cost, portable equipment to upgrade waste agricultural and forest residues into a carbon-rich feedstock on-site, which in turn can be converted to higher-value bioproducts such as fertilizer blends, chemicals, and biofuels.

Takachar's small-scale systems can be latched onto the back of tractors and pick-up trucks, making them easily transportable. Because they do not require external energy input to upgrade and densify residues on-site into higher-value bio products, they enable rural communities to create a closed-loop bioeconomy locally. This, in turn, allows them to become more resilient and independent from the potentially vulnerable international supply chains for their key commodities and inputs. Additionally, by removing the need to burn biomass for removal, as is often done, the dangers of wildfires - and therefor air pollution - are reduced. These mobile bioreactors can take in agricultural waste, and forest waste, and produce customizable bioproducts which are then used in biopower, fertilizer, and biorefineries. Takachar's innovation in technology has earned them the "Clean our Air" prize; one of five Earthshot prizes presented by Prince William at a ceremony in London.



Takachar's Small Scale Portable Waste-Upgrading Equipment

Overview

- Developed by Takachar.
- Development began in 2018
- Currently, Takachar is receiving customer requests for quotes (ROQs) with customer interest in purchasing portable units.

Applications

Can be used for scaling the transformation of waste biomass into marketable bio-products for rural communities to combat air pollution, wildfires, and climate change.

Capabilities

- Low power requirements mean equipment can be operated in off-grid areas.
- Prevents air pollution from the open burning of crop and forest residues.
- Portable versions of the equipment can process hard-to-access biomass

Benefits

Reduced Air Pollution

Eliminates the need to dispose of biomass via open-air burning, thus reducing contributors to air pollution.

Portability

Small-scale units can be made which are easily transported to crop and forest residues by simply latching onto the back of tractors and pick-up trucks.

Economic Benefits

Enables rural communities to create a close-loop bioeconomy locally, which improves community resiliency and independency from international supply chains.

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Truly Compostable Plastics for a Circular Bioeconomy

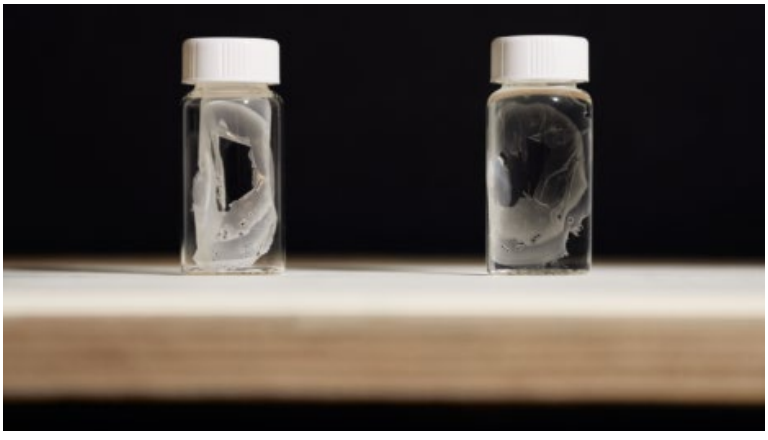
LEEP – Cyclotron Road **Emerging Technology**

Combining the Performance of Proteins with a Patented Stabilization Technology for Better Materials

Plastic is used as a material in almost everything we manufacture and use today, from clothing to electronics, and so much more. Even cosmetics and certain household supplies, such as dishwashing pods, utilize some forms of polymers. Plastics, however, are not truly compostable and, instead, continually break down into smaller and smaller pieces over many years. This has even led to rising issues with "micro-plastics", which end up in soils and waterways, and are extremely difficult to fully remove. Additionally, larger-sized plastics continually contribute to landfills, and often end up in our oceans, all of which can harm life on our planet. Enzymes, which are naturally created by many organisms, tend to struggle outside of their comfort zone (the cell), and high heats and pressures during plastic manufacturing can destroy them. One solution to this is the development of stabilized enzymes, which can be used to create plastics that can degrade rapidly, and completely.

Intropic Materials, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), has developed a patented enzyme stabilization technology, which can be added to plastics to make them completely self-degrading. To accomplish this, Intropic Materials has developed nano protectants that keep proteins stable and active in foreign environments. By doing so, these proteins can be used in a wider range of solvents, and thermal processing, to incorporate them into plastics.

To elaborate, inside the organisms, there are specialized molecules called chaperone proteins, which fit together with enzymes to "switch them on" or move them where they need to be. Intropic Materials has mimicked this process by having the chaperone proteins connect with enzymes inside of protected, biodegradable covers, which keep the enzymes from breaking when plastic is put under high temperatures and pressures to form shapes. These covers do not, however, stop the enzymes from doing their job to fully eat the plastics from the inside out, once placed in proper composting conditions. When these enzymes do their work, the plastic is not simply broken down into smaller pieces, but fully disintegrated into simpler molecules that can be reused to make new products or be broken down by microbes in soil or during water treatment.



Intropic Materials' Enzyme-Embedded Compostable Plastics

Overview

- Developed by Intropic Materials.
- Development began in 2021.
- Customer sample is in an ongoing test that will end in 2024.

Applications

Can be used for clean manufacturing of Polylactic Acid (PLA) and Polypropylene (PP) and polyethylene terephthalate (PET) bioplastics.

Capabilities

- Stabilized enzymes can break down polymer chains one at a time to quickly break down into small molecules.
- Currently capable of producing bench-scale quantities (1 – 2 grams).
- Give plastics the ability to degrade in compost or in warm-water baths.

Benefits

Circular Bioeconomy

This technology enables a circular bioeconomy, as plastics will now be able to be fully disintegrated, and the molecules will be reusable for either making new products, or be able to be broken down by microbes

Durability

The use of stabilized enzymes does not affect the integrity or durability of the plastics they are incorporated into; thus, plastics will still be as durable and lightweight as before, with the added benefit of being fully compostable once placed in proper conditions.

Waste Reduction

Developing and utilizing stable enzymes with chaperone proteins that can be used to create fully compostable plastics, will help to significantly cut down on plastic waste ending up in landfills and waterways permanently.

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ZeroTherm, A Scalable Breakthrough Aerogel Insulation Engineered to Meet the Growing Demand for High-Performance Insulation Materials

LEEP – Cyclotron Road **Emerging Technology**

A Gateway to the World of Zero Emissions and Low-Cost Aerogel

Aerogel has many useful applications, from aerospace to batteries, building envelopes, and more. There is even opportunity for aerogels to be useful in powering renewable energy. Often, however, there is a disconnect between what is developed by researchers, and what actually makes it into industry. Bridging this gap and bringing advanced aerogel technology to market would have global implications for green technologies and sustainability.

Westwood Aerogel, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), has developed an ambiently dried aerogel insulation; ZeroTherm™. The ambient drying process combines surface chemistry (low surface tension) with a solvent (low vapor pressure). The goal is to revolutionize sustainable technology by providing zero emissions, low-cost aerogel. Currently, Westwood Aerogel's advanced manufacturing process can make aerospace-grade aerogel materials at an with an estimated significant energy reduction over that used in traditional aerogel manufacturing. They can produce composite material (sheets), or it can be crushed to make a filler material.

When utilized in aerospace applications, Westwood Aerogel's ZeroTherm™ technology can enhance efficiency, reduce fuel consumption, and improve passenger comfort. Additionally, batteries can be improved to have enhanced performance, longer life, and be more environmentally friendly. Batteries and electronics work best in a very narrow temperature range. Aerogel insulation maintains a constant temperature, even in more intense weather conditions. Finally, the use of low-cost aerogel technology is beneficial for superior insulation, energy efficiency, and environmental responsibility when applied to building envelopes. This can be accomplished by utilizing aerogel insulation in glass units, which helps maintain mild temperatures in rooms, thus cutting down the need to run HVAC systems as heavily.



Westwood Aerogel's ZeroTherm™ Aerogel Technology

Overview

- Developed by Westwood Aerogel
- Development began in 2018
- Scaling process is currently lab scale at 10sf per month, with a target of 100x manufacturing process

Applications

Can be used for in multiple different applications, such as aerospace, battery, renewable energy, and building envelope.

Capabilities

- By insulating glass units, it is possible to improve comfort via room temperature, and reduce noise pollution
- Insulation maintains constant temperature to increase energy storage in batteries
- Battery lifetimes can be extended by improving efficiency for battery storage

Benefits

Government Incentives

There are potential government incentives that come with utilizing technologies such as ZeroTherm insulation. This includes tax credits or rebates and can be a driver for consumers to install energy-efficient technologies.

Monetary Savings

ZeroTherm offers significant energy savings and can help to reduce heating and cooling costs, which are major concerns for many consumers.

Reduced Caron Footprint

ZeroTherm™ can help to reduce the environmental impact of buildings and supports LEED certification. It is estimated that ZeroTherm™ has a 98% reduced energy cost of production compared to leading insulation materials.

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WEST
GATE

Compressed Earth Blocks

LEEP – West Gate **Emerging Technology**

Exceptionally Resilient and Energy Efficient

There is a critical need, due to continual high population-growth, for housing and other construction that will possess significant longevity, and reduce operational energy and related embodied carbon emissions. Buildings and homes constructed with traditional wood frames are, unfortunately, susceptible to mold and fire damage. Additionally, concrete (which is utilized in home construction) generates about 8% of global warming emissions. Compressed earth blocks, manufactured through the use of sand and clay by-products leftover from excavation operations, may prove a useful alternative building material which reduces and/or eliminates these problems.

Colorado Earth LLC, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), has developed their "EcoBlox" (lime-stabilized compressed earth blocks), manufactured using sand and clay fines from a nearby granite quarry. 6.5% hydrated lime (by weight) is added to the fines to increase the compressive strength of the blocks, add water protection, and to protect the blocks during construction. Once the masonry walls are protected with a suitable sealer or plaster finish, they will last indefinitely with little to no maintenance.

Colorado Earth is investigating the addition of phase change materials (PCMs) within the building envelope, which could provide additional energy savings benefits over traditional insulation materials. Homes, and other buildings that utilize earth block construction, have proven longevity and are likely to last 100's of years. Additionally, buildings constructed with EcoBlox are fire-resistant, possess a pH in which mold cannot grow, and are even earthquake resistant. This means utilizing EcoBlox for construction is a highly economical choice. The typical size of these compressed earth blocks can vary depending on the mold size, however Colorado Earth is currently producing 6″x 12″ x 3-1/2″ and 4″ x 12″ x 3-1/2″ blocks, with a height that can vary from 2″ to 5″. Weight is about 15.85 lbs. on average, and R-value is about 0.42/in or 2.52 for 6″ wide blocks.



Manufacturing of Colorado Earth's EcoBlox

Overview

- Developed by Colorado Earth LLC.
- Development began in the early 2000's.
- Established design and build business with multiple services and options.

Applications

Can be used for constructing high performance, resilient, and energy-efficient buildings utilizing natural local excavation waste stream materials.

Capabilities

- Regulates temperature, reducing energy consumption and shifting time when peak load occurs.
- Serves as a resilient, fireproof building material to protect homes and buildings from fire damage, as well as healthy interior finishes.
- Helps regulate home and building temperatures.

Benefits

Carbon Emissions Reduction

Potential to replace the need for concrete as a construction material, a material for which production leads to generating up to 8% of global warming emissions, thus reducing the overall carbon footprint.

Increased Durability

Durable (such as fire-resistance, mold-resistance, and earthquake resistance), and capable of lasting hundreds of years with little to no maintenance.

Fuel Savings

Raw materials for the production of compressed earth blocks are locally acquired, requiring less over the road transportation, and reducing fuel consumption and carbon emissions.

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UV Fluorescence Imaging of Defects in Solar Panels and Machine Learning for Automated Inspection

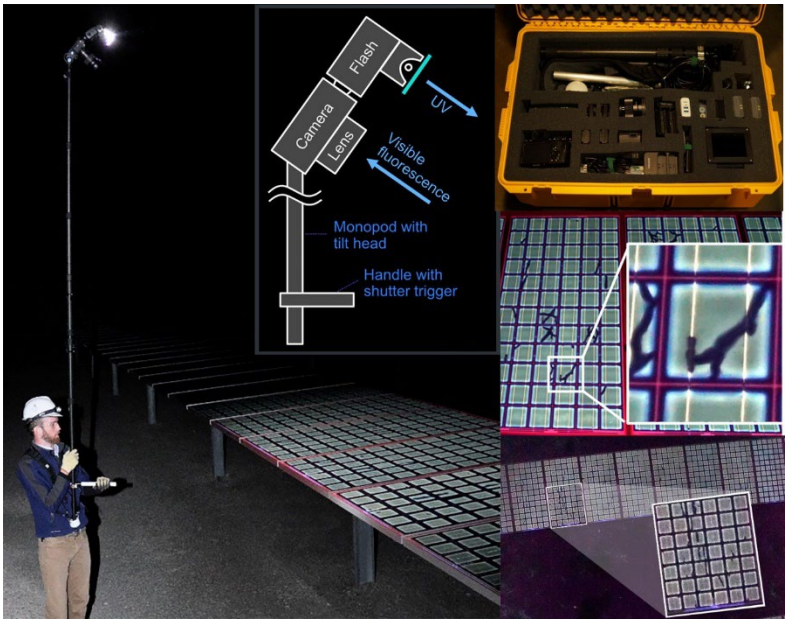
LEEP – West Gate **Emerging Technology**

Specialized Testing Equipment for Solar Cells and Panels

Soldering of interconnected wires into busbars of solar cells can cause thermal stresses, which in turn can too often lead to cracks in silicon solar cells. Often, these cracks end up branching outward from the busbar region and are thus easily seen in an electroluminescence (EL) image. However, the wires are often wider than the busbar metallization, so cracks can be located underneath or very close to the wires. This ends up causing the cracks to be "hidden" within the EL image. If cracks remain underneath the busbar metallization, they may not be a concern. However, if they propagate along the side of busbars and remain hidden under or next to the wires, they can prevent continuity of the gridlines to the busbars. Eventually, these cracks may even open up with thermal cycling and cyclic loading in the field over time. UV fluorescence (UVF) is proving to show great potential for low-cost, solar-panel characterization. It also provides complementary information to the common techniques of electroluminescent (EL) and thermal IR imaging.

BrightSpot Automation LLC, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), has developed UVF imaging of defects in solar panels, which utilizes AI and machine learning for automated inspection of UVF and EL defect images. UVF is a fast method to detect cell cracks and hot spots in aged modules. Through BrightSpot Automation, a low-cost handheld flashlight kit may be acquired for detection by eye, along with a high-throughput camera flash-based system which can image up to 1000 modules per hour.

This technology is a system that is comprised of many different tools and equipment which vary depending on the clients' requirements. The PRO UVF Camera System, for example, comes with a hard travel case, UV Flashlight and goggles, drone interface components, GPS unit to enable orthomosaic placement of images on a digital twin, batteries, a harness with pole mount and tripod, and a camera with special flash and filters.



BrightSpot Automation's PRO UVF Camera Systems(Left) and UVF Imaging of Solar Panels from Pole-Mounted Camera (Top &Right)

Overview

- Developed by BrightSpot Automation LLC
- Development began in 2022
- Developing automatic detection methods via software which will utilize AI

Applications

Can be used for easy and rapid detection of cracks and hot spots in aged solar panel modules.

Capabilities

- Detects solar panel defects more easily and thoroughly than traditional methods
- See hotspots and EVA yellowing with the use of the kit
- Throughputs of about 1000 modules/hour via use of the pole and 5000 modules/hour via the drone

Benefits

Incentive

Providing better feedback to both investors and insurers alike can help to incentivize the more durable technologies.

Reliability

These defect detection techniques. and improved understanding. have the potential to lead to improved testing and feedback that accelerate product development and improve panel reliability.

Ease of use

With BrightSpot's specialized kit, there is no need to disconnect modules in order to conduct thorough inspection.

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CHAIN REACTION
INNOVATIONS
Entrepreneurship at Argonne

Graphene-Enhanced Electrodes

LEEP – Chain Reaction **Emerging Technology**

Next-Generation Lithium-Ion Batteries

Lithium-ion (Li-ion) batteries are currently the primary choice of energy storage for electric vehicles, as well as other machinery and tools that are beginning to adopt rechargeable batteries as their power source. While the adoption of electric vehicles and tools helps to reduce greenhouse gasses by eliminating the need to burn natural gasses in internal combustion engines, there are also some limitations to using batteries. Currently, there is a need for improved stability, and more effective systems for temperature change, as Li-ion batteries are prone to low-temperature performance challenges. These challenges can also negatively impact mileage in electric vehicles. One way to mitigate these issues is to incorporate a nanomaterial-based coating system.

Volexion Inc, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), is developing drop-in graphene encapsulation for Li-ion cathode materials. They have been refining their process at Argonne National Laboratory's Material Engineering Research Facility (MERF). This graphene-based technology takes advantage of the unique properties of graphene to enable the preparation of nanoscale composites to serve as advanced electrodes in Li-ion batteries. Graphene-enhanced electrodes can be used in specialty applications, such as power tools, drones, and cell phones, as well as electric vehicles.

By utilizing this graphene-based coating, Volexion can provide a comprehensive solution to improve the lifetime and power performance of Li-ion batteries, under both ambient and extreme temperature conditions. Their patented, straightforward methodology for coating batteries can be seamlessly integrated into existing battery manufacturing processes, as Volexion offers a drop-in technical solution that works in tandem with commercial Li-ion battery manufacturing technologies. Companies can simply send their active battery powder to Volexion for coating and then, once the coating is applied, Volexion returns the material for direct integration into the customer's production line. This proves useful in advancing the commercialization of next-generation Li-ion battery materials and technologies in the emerging markets from drones to electric vehicles.

Overview

- Developed by Volexion Inc
- Development began at Northwestern University in 2014
- Continuing to scale up process from 1kg to several kgs

Applications

Can be used to improve performance of next-generation Li-ion batteries, which can be used in electric vehicles and specialty applications such as power tools and drones.

Capabilities

- Reaches 30%+ energy density increase vs. today's state of the art battery technology

Benefits

Environmental Impact

The process by which the Li-ion batteries coating is created and used avoids dangerous chemicals and recycles their polymer and solvent precursors, making it environmentally friendly.

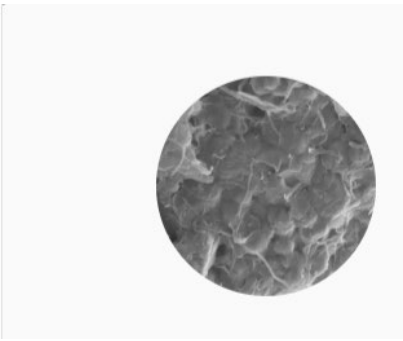
Integration

Volexion offers a drop-in technical solution that works in tandem with commercial Li-ion battery manufacturing technologies.

Performance

Comprehensive performance improvement and improved stability, as well as safety, of Low-Cobalt materials. Increased cycle life and power performance. Enhanced voltage range.





Volexion's Graphene Material for Encapsulation

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Organic Materials for Energy Storage

LEEP – Chain Reactions **Emerging Technology**

An All-Organic Solution for Grid-Scale Redox Flow Battery Storage

To meet aggressive climate change goals and regulations, the U.S. is rapidly adopting renewable generation while closing down dispatchable base load generation. However, with this focus on electrification of transportation, industrial equipment, and small engines, electricity demand is outpacing supply. There is a critical need for a scalable solution to grid energy storage, in order to continue development of renewable energy. This said, there are certain barriers that are prohibitive of development. This includes reliance on rare earth mining from foreign suppliers, costly Li-ion solutions, and dependencies on local topology and geology.

Jolt Energy, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), and in partnership with multiple organizations, is developing organic energy storage materials to be utilized in Redox Flow Batteries (RFBs). Jolt has discovered and patented a new class of over 50 compounds with unique and valuable properties. Some of the more powerful and beneficial properties of these materials include rapidly charging and discharging high amounts of energy, storing more electrons in a highly energy-dense solution, and robust multi-year performance. Additionally, these compounds can be reprocessed and placed back into use.

RFBs are currently commercial globally. However, these batteries typically rely on vanadium, a rare earth metal, which is largely imported for U.S. battery installations. Due to volatility of the market around vanadium, this material drives cost higher. Because of this, the market is not yet competitive enough for rapid deployment. Jolt Energy is partnering with technology companies, chemical manufacturers, and vanadium RFB companies, in order to replace the core energy storage material with an organic solution. This organic material will roughly double the energy storage capacity, and it can coexist (versus separation in ion exchange materials). Additionally, the use of this material will reduce the cost per kilowatt hour.

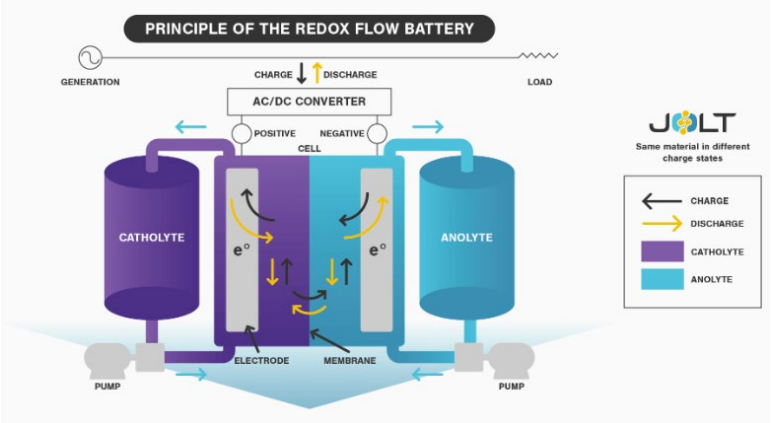


Diagram of Redox Flow Battery

Overview

- Developed by Jolt Energy
- Development began circa 2017 and subsequently Jolt Energy was founded in 2019.
- Has raised several seed rounds of funding for continued breakthroughs in R&D

Applications

Can be used as an alternative to rare earth metals for energy storage in batteries.

Capabilities

- Designed to work within existing Vanadium flow batteries with cell modification
- Can roughly double the capacity of RFBs
- Quick overview of useful capabilities/stats

Benefits

Economic Security

Helps to eliminate reliance on foreign supply chain and rare earth mining by utilizing domestically supplied, all-organic materials.

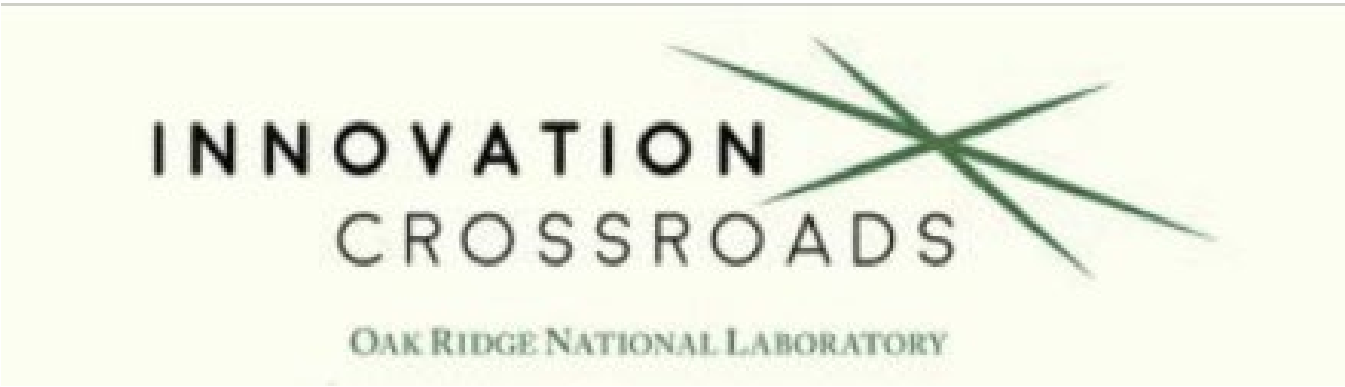
Higher Voltage

Organic chemistry allows for 2.8V potential, meaning more power, more energy, and small size.

Lower Costs

Jolt's organic materials are a very cost-competitive solution, as this technology can be scaled within existing industry positions.

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INNOVATION
CROSSROADS
OAK RIDGE NATIONAL LABORATORY

Advanced Air Pollution Control Technology

LEEP – Innovation Crossroads **Emerging Technology**

Emissions Control for Industrial Applications

Greenhouse gas emissions are a long-standing issue, in need of feasible solutions to reduce and even eliminate them completely. Typically, emissions control devices face problems such as needing to use tremendous amounts of energy (which in turn creates greenhouse gas emissions) and being expensive to operate. An alternative solution to traditional emissions control devices, is a Fluidized Bed Concentrator (FBC) with Bead Activated Carbon. The activated carbon is used to efficiently adsorb and recover emissions.

Captis Aire LLC, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), is developing an advanced air pollution control technology (the FBC) to capture air pollutants (extracting organic hydrocarbons) and convert them to high-value byproducts (such as terpene based hydrocarbons) which can be used to make sustainable aviation fuel. This technology can serve as a replacement, or be a retrofit, for existing plant equipment per clean air law requirements. A demo was performed at GP's Sandboard Mill plant for 1700 hours over 6 months, and it is projected that 200K gallons of turpentine can be produce on a medium-sized production site.

The FBC offers operational reliability, and safety, as it does not have any large, heavy moving parts that require replacement or repair. The only moving parts are the system exhaust fans. Additionally, the FBC is constructed with stainless-steel, which minimizes corrosion-related repairs. The FBC works by intaking process air that contains emissions from the influent gas blower. This air passes through a series of trays that contain activated charcoal, which cleans or scrubs the air by efficiently adsorbing the emissions. After the air is cleaned, it is released through the top of the adsorber. The carbon then falls to the bottom of the adsorber, where it is transported via the fans to the desorber, which heats the carbon beads to release the captured emissions for further processing to the liquid byproduct that is sold. The EPA Plywood and Composite Wood Products (PCWP) Maximum Achievable Control Technology (MACT) Standard requirement of over 90% reduction efficiency was met by the FBC during pilot trials in 2018.



Captis Aire's Fluidized Bed Concentrator

Overview

- Developed by Captis Aire LLC.
- Development began circa 2015.
- Received Environmental Protection Agency Chemistry Award in October of 2023.

Applications

Can be used in industrial applications with a very high volume of process air exhaust and low inlet emissions concentration.

Capabilities

- Operating temperature reduction of over 1000°F in adsorber vs. oxidizer, which reduces total fuel consumption.
- Expands installation site options, including rooftop mounting.
- Achieved over 90% emissions reductions during pilot trials.

Benefits

Economical

Allows the capability of transforming what would otherwise be pollutants, into valuable byproducts, such as terpenes. These byproducts can then serve many uses, such as producing fragrances, solvents, fuels, and more.

Efficiency

Reduces the energy usage required in emissions control by fluidizing the carbon and making it easier for fans to move through the device, versus packed carbon.

Reduction of Greenhouse Gases

Reduces greenhouse gas emissions by eliminating the need for using natural gas to heat the air in which emissions control is being performed on, and by eliminating the need to burn the same emissions being controlled.

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Advanced Ice-Thermal Storage

LEEP – Innovation Crossroads **Emerging Technology**

High Efficiency Heat Exchanger for Ice Thermal Energy Storage Systems

Cost-effective storage of energy is imperative for achieving a sustainable future. Air conditioning's meteoric uptake is fueling GHG emission growth. AC is responsible for 7% of GHG emissions today and is on track to double by 2050. One method that can reduce emissions is by ice-thermal energy storage. This process uses ice produced from a heat exchanger to provide cooling for buildings during warmer periods of the day, avoiding the use of chilling systems during peak operation hours. However, ice-thermal energy storage technology has large upfront costs, mostly due to the cooling coil in the heat exchanger used to produce the ice. Ice-on-coil heat exchangers grow ice radially outward from the coil's cooling surface. As the ice grows, the thermal resistance between the ice and the coil surface increases, requiring more energy to produce additional ice as it adheres to the surface of the coil.

In 2016, Shift Thermal (formerly Active Energy Systems), with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP) at Oak Ridge National Laboratory, began development on a pumped thermal energy storage system. However, a discovery made during development in 2018 led to a shift in focus to ice-thermal storage, leading to the evolution of an icephobic heat exchange (IHEX) system. Having frozen water droplets passively shed from the coil surface to avoid ice buildup can prevent the thermal resistance from increasing. To prevent droplets from adhering to the surface of the coil, the coil was completely coated with polytetrafluoroethylene (PTFE). Shift Thermal used their own phase change material (PCM), a mixture of water and an ice nucleating protein that freezes more easily than water to test the adherence of frozen droplets to the IHEX's cooling coil surface.

In 2019, Shift Thermal received follow-on SBIR funding to improve on the fundamentals of the IHEX, optimizing plate and tube-based cooling coil geometries as well as the formula of the oil coating to achieve repeatable ice removal. Results from these studies were used for the development and demonstration of a bench-scale prototype in 2020. The IHEX module features capabilities that improve bottom lines such as load shifting and optimized chiller fleet operation. Additionally, this cooling asset is efficient (+20% increase in efficiency) and is modular (enabling cooling system customizability), and can be integrated with existing systems.



Shift Thermal's IHEX Module

Overview

- Developed by Shift Thermal
- Development of ice-thermal storage began in 2018
- Follow-on NSF SBIR funding received in 2019
- Plans to achieve pilot-scale production by 2024

Applications

Can provide cost-effective air conditioning for buildings such as schools and hospitals.

Capabilities

- Estimated cooling savings of up to 80%
- Can freeze a 50 µL drop of water with an average heat transfer coefficient of 520 $\pm$ 60 W/(m^{2}K)
- Reduces electric cooling energy consumption
- Can operate with a maximum adhesion stress of 5.21 Pa.

Benefits

Economical

The IHEX can maintain a constant heat transfer coefficient over the duration of the freezing process, reducing the required surface area of the cooling coil to make ice, thus reducing overall costs. Cooling bills may be cut by up to 70%, leading to payback in less than 2 years.

Flexibility

IHEX system can handle off-design conditions (e.g., record heat waves) and is easily integrated into existing chiller systems.

Increased Energy Efficiency

Can provide an estimated 15% improvement in energy efficiency upon existing technology through elimination of the heat exchange effect due to ice buildup. Meets ESG goals via reduced Tier 2 carbon emissions.

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Energy-efficient, carbon negative, bio-based insulation: HempWool

LEEP – Innovation Crossroads **Commercial Technology**

A Healthy, Non-Toxic Alternative to Traditional Insulation

Traditional fiberglass insulation, while beneficial for regulating building temperatures and reducing loss of indoor heating and cooling, can come with some negative drawbacks. Fiberglass insulation can be irritating to the skin, eyes, and lungs when coming into contact with it and releasing particles into the air. Too much contact can even lead to irritant contact dermatitis. Because fiberglass is considered a hazardous substance, it is not easily disposed of without professional help. Hemp-based thermal insulation has proven to provide insulation comparable to common forms used today, such as fiberglass, without the irritation and specialized handling. Additionally, hemp-based insulation is non-toxic, mold-resistant, pest-resistant, and more.

Hempitecture, with some assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP), has developed a thermal insulation product (HempWool©) which is made of 90% natural fibers. HempWool© is manufactured and sold in a batt-like form, and can it be incorporated anywhere in a home's thermal envelope. Additionally, HempWool© possesses a negative carbon footprint (offsetting and storing more carbon dioxide than is emitted from the manufacturing process).

The growth and production of hemp, which is utilized in Hempitecture's HempWool© batt insulation, is also highly sustainable, especially in comparison with traditional insulation materials in-use in the industry today. This is because hemp is a crop that is carbon-capturing, soil-regenerating, and requires little water and no pesticides or fertilizers. On the other hand, approximately 1.7 to 2.2 tonnes (or 1.9 to 2.4 tons) CO_2 emissions are produced for every 1 tonne of glass fibers.[1] Currently, Hempitecture has served over 1,500 projects with their clean, hemp-based insulation products. This has also equaled out to over 1,000,000 lbs. of CO_2 captured - and counting.



Hempitecture's HempWool© Batt Insulation

Overview

- Developed by Hempitecture.
- Development began in 2014.
- Commercialized in 2019.

Applications

Can be used for exterior and interior cavity thermo-acoustic insulation and excels in divers builds.

Capabilities

- Low energy to produce and easy to use.
- Carbon-capturing (over 1,000,000 lbs. to date).
- Suitable for multiple different environments, including humid, as it is vapor permeable and resistant to mold.

Benefits

High-Performance

Thermal value of about R-3.7/in. with high dimensional stability, and pressure fit system that keeps HempWool© in place with no slumping or sagging.

Reduced Carbon Emissions

The growth of hemp as a material sequesters 9 tons of CO_2 per acre during its growing season, meaning hemp-based insulation products can reduce carbon emissions via the initial step of production of the materials.

Sustainability

Very little resources, such as water and fertilizer, are needed to grow hemp, thus making hemp-based insulation a highly sustainable alternative to traditional insulation products used today.

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[1] For more information: Assessing the Environmental Impact of Fiberglass

Thermo-Mechanical, Flexible, And Future-Proof Long-Duration Energy Storage Using CO_2

LEEP – Innovation Crossroads **Emerging Technology**

Enabling Earth's Electrification through Renewable Energy

Efficient and advanced energy storage is necessary to ensure a realistic path to adopting and continuing renewable grids at a minimal price with maximal resilience. Current forms of energy storage, such as batteries, come with certain limitations, such as sensitivities to extreme temperatures which may lead to rapid loss of the energy stored, or even explosions. In addition to this, America's grid is under constant attack, and due to increasing changes in the climate, grid resiliency may continue to decrease. Using carbon dioxide (CO_2) based technology could provide flexible energy storage for 24/7 power, thus increasing grid resiliency and enabling a fully renewable grid.

EarthEn, with assistance from AMMTO through the Lab-Embedded Entrepreneurship Program (LEEP) and multiple partners, has developed flexible, future-proof, long-duration energy storage. This energy storage technology comes in the form of EarthEn's Pods, which use CO_2 in a closed loop to store 4 to 100+ hours of energy at a low cost, while being highly scalable and safe, for a 30-year shelf-life. Additionally, to ensure grid reliability and resiliency is optimized, AI-based software may be used to operate energy storage units with the grid.

EarthEn's Pods work by capturing CO_2 where compression-based energy storage takes place. This CO_2 compression is then depressurized through a turbine generator to produce electricity when needed. The capturing and use of CO_2 as a form of energy can be viewed as a part of a circular economy. The surplus electricity used for compressing the CO_2 can come from excess produced by solar or wind farms. EarthEn's energy storage technology is also compact and site-able, meaning it is small in size and can achieve significant energy density to enable a compact land footprint. This makes site integration much more feasible and seamless, and also helps to preserve land for other uses (such as solar or wind assets).

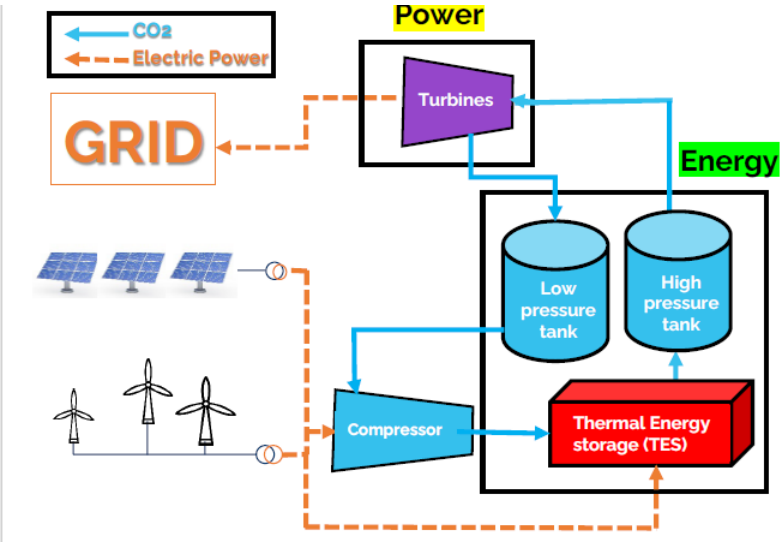


Diagram of EarthEn's Energy Storage and Output Process

Overview

- Developed by EarthEn
- Development began in 2021
- TRL 4 step completed and has led to winning funded pilot demonstrations

Applications

Can be used as a safer, more efficient, and cheaper alternative to traditional energy storage technologies such as batteries.

Capabilities

- Quick start up time to begin storing up cheap, clean electricity while it's available then dispatch when ready
- MW-scale building blocks can be seamlessly configured to meet any power load and energy demand
- Modular design to meet growing grid needs

Benefits

Flexible

Capable of storing anywhere from 4 to 100+ hours, as well as short, long, and multi-day storage.

Low Cost

Provides extremely cheap levelized cost of storage (LCOS) energy storage solutions, as materials used are from industrial-mature supply chains and existing manufacturing lines.

Safe

There is no thermal runaway, fire hazard, or reactive materials. EarthEn's systems are not susceptible to explosions from temperature increases, unlike traditional battery technology.

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