Proposed: Massachusetts Energy R&D Innovation Package

$50M over 3 years

How Can Massachusetts Decarbonize Itself *and* Others?

The state of Massachusetts (MA) emits 1/500th of the world's CO_2. Subsequently, if MA reduces emissions to zero, the world's 499/500th will still harm MA, and others, with things like sea level rise, which is costly.

What can MA do to encourage others to reduce, without spending much money, relative to large decarbonization infrastructure projects? It turns out, a great deal, due to one of her greatest strengths: universities.

It is proposed that the great state of Massachusetts fund the development of technology that reduces *worldwide* carbon emissions with the stipulation that the money is used to develop things *not* already being developed by others. This includes technology being developed by the federal gov't, universities, and corporations.

As the world decarbonizes, it will install new low-carbon energy infrastructure (e.g. solar). The proposed effort develops the mechanical, electrical, and communications standards that define how this new infrastructure connects together. Plug-and-play dramatically reduces both cost and risk, for a variety of reasons, as explained in below.

Standards

A mechanical or electrical standard is a document that describes interconnections between components and is accepted by multiple companies within an industry.

For example, the mechanical design of the 35mm analog film canister enabled makers of film, and makers of cameras, to coordinate. Without this, revenue would be low given multiple proprietary expensive options for film and cameras.

Standards facilitate interoperability between components sold by multiple companies, which reduces cost via increased competition and commoditization.

There is very little incentive for a company to develop a standard, since the world receives the total benefit, while they receive a small portion of that total. Companies can only afford to focus on activities where they receive most, if not all, benefit.

The federal gov't tends to not fund standards development either, since they delegate to industry to solve this problem.

The proposed MA fund develops standards that are free and open, which means they are not owned by anyone, which facilitates worldwide collaboration and adoption. The world's companies are not interested in being controlled by another entity; therefore, if one really wants to get this done, free and open is a requirement. This is consistent with our worldwide CO_2 reduction goal. MA profits by reducing the cost of large future infrastructure projects, which could easily entail hundreds of billions of dollars.

We are assuming the responsibility of setting up plug-and-play for low-carbon infrastructure, since no one else seems to be doing it.

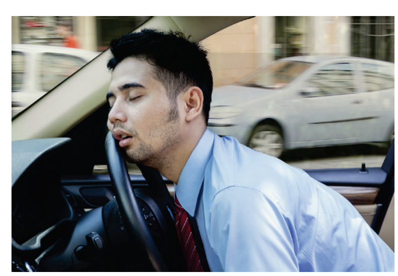
Below is a list of R&D Topics that we intend to fund.

Topic 1a) Develop Standard Electrical Vehicle Battery

Currently, the world has a mechanical and electrical standard that defines the 9V battery; and this enables one to power small appliances at low cost.

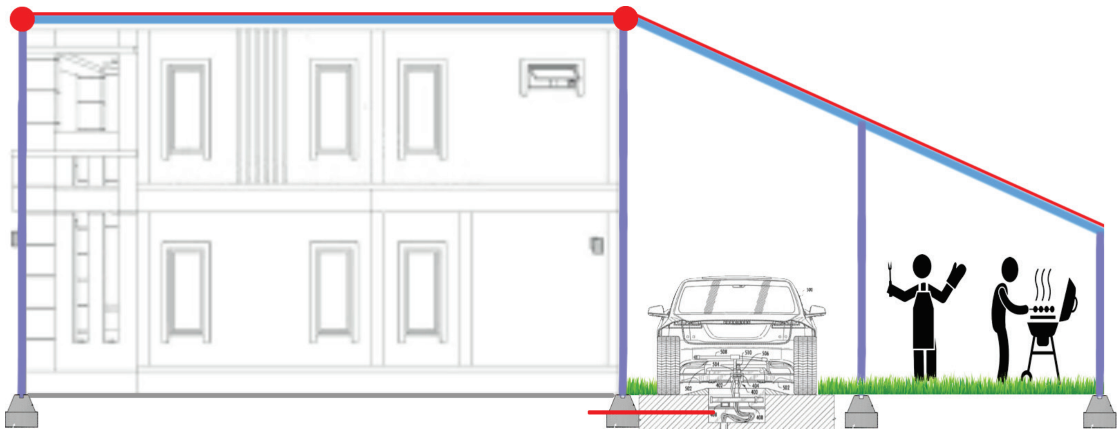
In theory, one could have a standardized car battery that looks similar to the Tesla battery, yet is used by all cars. The standard would define the mechanics (e.g. height, length, and width), electrical connections, and communication between battery and car. One could potentially swap out and replace with a fresh battery in under one minute.

What might the world do with such a standard?



- Create market for companies that manufacture standard EV batteries; which reduces cost through competition and commoditization.
- Driver visits ~~gas~~ swap station, swaps out battery, pays for electricity consumed and wear inflicted on battery, and goes -- instead of catching nap at charging station.
- Home includes chamber in driveway that houses standard batteries. One owns multiple batteries, solar charges during day, batteries power house at night, and one swaps with car as needed.

Researchers develop standard mechanical and electrical battery system, communication system between battery and charger, and communication system between car and battery swap station. Car companies are invited to participate with things like company-paid engineer on sabbatical who works side-by-side with MA funded engineers. All work is free and open, to support collaboration and adoption by multiple companies.



Budget: $1M/yr over 3 years

Topic 1b) Develop Standards that Better Coordinate the Charging of Electric Vehicles

Many world leaders are advocating we decarbonize over the next 20 to 40 years. This means we will probably need to power vehicles with electricity and/or hydrogen gas, instead of gasoline. A big challenge with electric vehicles is they consume much electricity when charging. The electrical grid might support charging a few cars at night on one street. However, it will not support simultaneously charging a car at each house. Electrical wires on the street telephone pole, and those that route to the neighborhood, are not large enough. Subsequently, converting transportation from gas to electric involves a costly upgrade of the electrical grid.

In theory, it is possible to position charging stations throughout a community -- to places like office parking lots, street parking meters, and homeowner's property edge.

Researchers propose standard electrical connectors, communication systems between car and charger, communication systems between grid and car display panel (tell me where I can charge and give me price), browser/smart phone user interface, and payment system interface.

Researchers might propose a new electrical connector that is potentially used by all manufacturers, with adaptors that affix to existing hardware.

Researchers might also propose standards that support radio communication between a common server and each car, and between that server and each charger. This would use very little radio spectrum since messages are short. Gov't or electric companies might be willing to pay for the server and radio spectrum, since it helps to distribute grid load.

Currently, there are several different systems and connectors that support charging and communication. Many are proprietary and are not recognized by multiple companies. For example, Tesla is not interested in talking to Ford, and vice versa. Researchers look at unifying suppliers and consumers with free and open software and standards.

An example project is a Website (server computer) that coordinates charging stations and cars. Owners of charging stations register, specify their location, and communicate their pricing model. Charging station constantly reports status (e.g. car is charging, solar electricity is available), price and source of electricity (e.g. solar, wind). Cars interact with website to identify reasonable charging options. System supports homeowners who charge cars at property edge. Researchers look at how to verify source of electricity and allow it to influence price (which might require standards that define how solar panels talk to charging hardware). Researchers do not implement the actual system, and instead create a prototype that demonstrates concepts and tests proposed standards. Deployment is a later step, which might involve a national gov't. All source code is given away for free, enabling others to build on the effort, and encouraging adoption by industry and gov't.

Budget: $700K/yr over 3 years

Topic 2a) Create website that Manages *Investments* in Solar Farms and Wind Farms

Researchers create a website that supports investors who fund portions of solar farms. Researchers propose standard ways for solar electronics to communicate with the common website (server computer). This allows the website to periodically receive information, including power generated, wind speed, and degradation of components. Energy output results in dividends to investors, degradation of components results in investment value reduction.

Hardware suppliers register at website and enter product prices and specifications. Installation and maintenance companies register and quote prices. Website coordinates the various parties, including routing dividend money to investors and trading of portions.

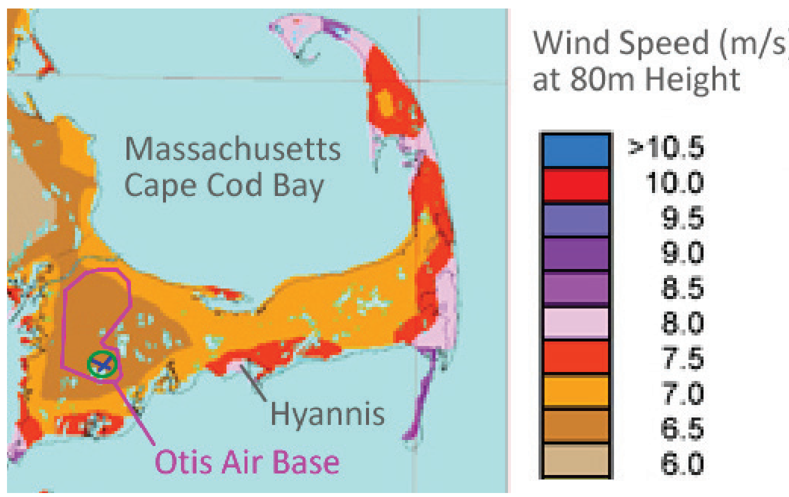
Tracking component degradation and faults creates incentive for suppliers to not reduce cost at a sacrifice to quality. This is a big problem for owners who are trying to get through multiple decades of ownership w/o premature failures.

Researchers do the same thing for wind farms.

Researchers do not implement the actual system, and instead create a prototype that demonstrates concepts and tests proposed communication standards. Deployment is a later step, which might involve a US Gov't agency. All source code is given away for free, enabling others to build on this work, and encouraging adoption by industry and gov't.

Budget: $500K/yr over 3 years

Topic 2b) Build Wind Farm Development Website



Researchers build an online website that designs and monitors wind farms. It supports any size, ranging from one small windmill to many large windmills in an array.

Owners of *existing* windmills and wind farms can register with the website (server computer), specify location, and specify size. Optionally, they maintain a constant connection and periodically report things like wind speed and energy output.

Manufacturers of wind products (e.g. turbines) register and enter product prices and specifications.

Organizations with wind data (e.g. NOAA) register and provide maps that show wind speeds at various locations. Also, developers of wind maps are given access to real-time wind and energy data from existing installations.

Researchers propose standard communication protocols between map makers and website, and between windmills and website.

Also, anyone can register and design a wind farm. Designers specify things like location, wind turbine hardware, height above ground and number of turbines; and the website responds with a report that estimates cost and energy production.

Researchers use Otis Air National Guard Base as a test case where they manually calculate Otis and then see how it compares with the automated website. Otis involves windy public land and therefore might be considered a candidate for deployment; however, people near Otis are not interested in windmill views. Alternatively, one might look at off-shore placement, yet this is more expensive and is also not popular with local residents. A large 20 square mile wind farm at Otis might supply ~1% of the state's electricity needs.

This project helps MA consider wind energy; yet more importantly, helps others consider wind.

Researchers do not implement the actual system, and instead create a prototype that demonstrates concepts and tests proposed communication standards. Deployment is a later step, which might involve a national gov't. All source code is given away for free, enabling others to build on this work, and encouraging adoption by industry and gov't.

Budget: $600K/yr over 3 years

Topic 2c) Develop Central Reporting Website That Implements Wind & Solar Project Transparency

Decarbonization is expensive and political support for spending vast sums does not exist. Therefore; now is a good time to develop, reduce cost, build and improve prototypes.

In theory, society might want to build a prototype, incur a variety of faults, make sure the engineering community is aware of the faults, have them fixed, produce a better prototype, and go through several cycles. However; suppliers, buyers, and owners tend to not want to openly discuss faults; for a variety of reasons. This reduces the improvement rate, since secrecy causes engineers to not learn from past experiences.

In this initiative, researchers create a website that controls technical and cost transparency for wind and solar farms. Technical transparency involves publically reporting technical performance (e.g. wind speed, electricity produced) and technical faults (e.g. turbine bearing failed). Cost transparency is when project cost components are made public.

Transparency is not always resisted. For example, gov't leaders, investors, and electric companies may at times desire transparency.

In the previous topic, researchers develop a website that communicates with wind and solar farms in a standardized manner. In this initiative, researchers add features that enable a higher authority to manage both cost and technical transparency. For example, the owner of a windmill might be required by the federal gov't to upload for public viewing PDF files describing each technical fault (e.g. bearing failure).

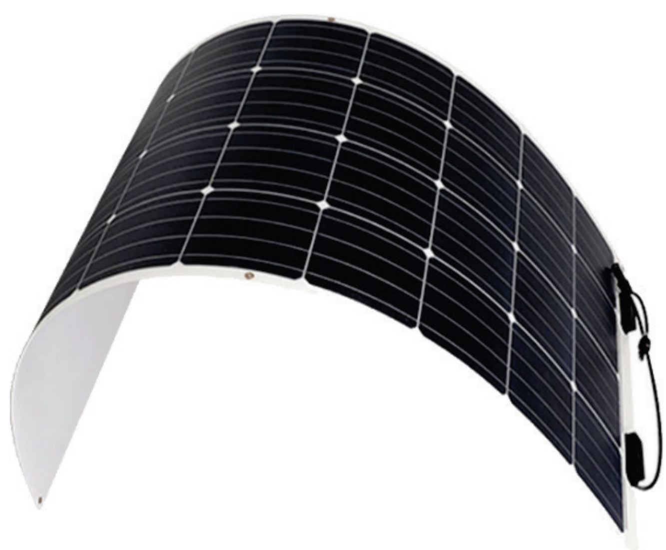
Requirements are stipulated either by government law or contract. For example, a federal gov't might require that wind turbines > 1MW publically report electricity production. This website provides a centralized place to report; and is therefore a tool used by higher authorities to manage transparency.

Researchers create control panels where Federal Gov't, State Gov't, and Electric Companies specify which information is made public; to help inforce their laws and contracts.

Researchers do not implement the actual system, and instead create a prototype that demonstrates concepts and tests proposed communication standards. Deployment is a later step, which might involve national governments. All source code is given away for free, enabling others to build on this work, and encouraging adoption by industry and governments.

Budget: $300K/yr over 3 years

Topic 3a) Develop Free & Open Electronics System Embedded in Rollable Solar Material



In theory, one could have an electrical and mechanical standard that defines a roll of solar material with embedded electronics.

This would be similar to the 35mm film canister, yet larger. A canister of rolled solar material might be 6 ft in diameter x 6 ft wide, and contain a piece of material that is 6 x 150 ft when flat. This approximate size fits into a shipping container or a large truck.

Small flexible solar products already exist, as pictured above (e.g. 5 x 2 ft). These are often made of plastic and silicon, and are approximately 0.1" thick. Big rolled solar does not exist since it would require specialized machines to handle it, these machines do not exists, and the material is useless without the machines. Researchers who develop the material, and standards that define it, in theory, could change this. This initiative focuses on packaging and installation, and therefore supports all forms of conversion material, including silicon and thin-film.

What could one do with this material? One could cut into smaller custom pieces and place them directly onto plywood roof and wall; or place directly onto land formed by specialized machines. If one does the math on energy, they can see we need to move beyond 3 x 5 ft panels handled by workers, and think about larger solar handled by machines.

Researchers develop embedded electronics, produce free and open reference designs, and propose communications protocols that support interoperability between electronics provided by different manufacturers. All produced materials are free and open, to support collaboration and enable others to build on this work.

For ideas on how researchers might tackle big rolled solar, click here.

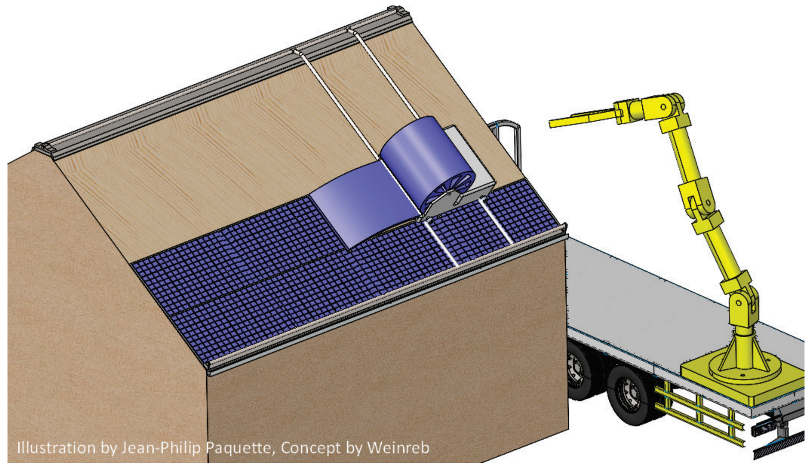
Budget: $1M/yr over 3 years

Topic 3b) Develop Mechanical System for Mounting Rollable Solar directly onto Building Roof and Wall Surfaces (BiPV)

This is similar to the previous topic, yet mechanical engineers devise a system for mounting rollable solar with embedded electronics directly onto building surfaces, such as plywood. This includes both roof and wall surfaces for commercial and residential buildings.

For example, if one has a plywood roof that is 40ft wide x 30ft high, they might place five overlapping strips of material directly onto plywood, where each strip is 40ft wide x ~6ft high. Horizontal metal rails might secure material at overlap positions, and vertical batons might help resist movement during high winds, as illustrated above.

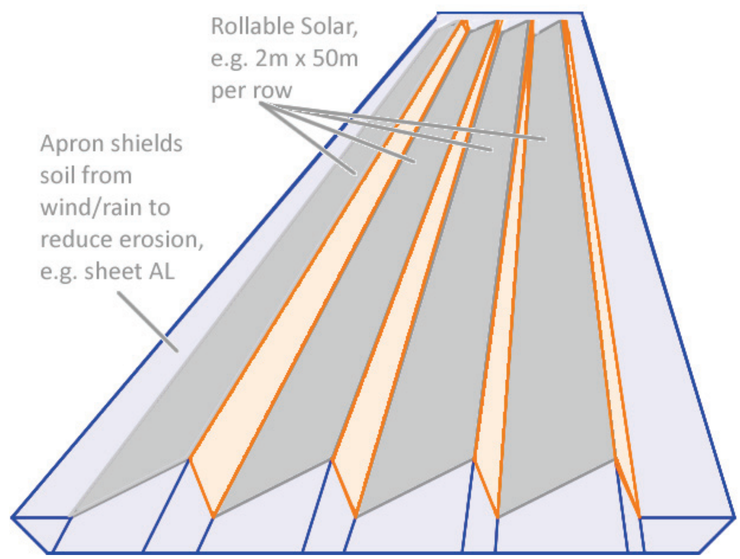
Researchers develop a durable mechanical system; design a canister that holds material during transportation; explore machines that transport, install, and clean; and propose mechanical standards that coordinate multiple suppliers. All produced materials are free and open, to support collaboration and enable others to build on this work.



Budget: $500K/yr over 3 years

Topic 3c) Develop Mechanical System for Mounting Rollable Solar Directly onto Land

Researchers develop a method for mounting rollable solar material with embedded electronics directly onto soil, on land, without framing, to create a cost-reduced method of high-volume installation via automated machinery.



For example, a road roller might prepare rows of soil at a 30° angle pointed toward the sun; while a different machine unrolls material onto soil, as illustrated here (e.g. 6 x 150 ft per strip).

One might have an anchoring layer (e.g. steel mesh on 1cm matrix) ~1 ft below ground that connects to top solar layer via steel rods. Engineers using software simulate how the system behaves over 30 years given wind, rain, erosion and other environmental conditions; and devise a system that works well.

Researchers develop a durable mechanical design; design a canister that holds material during transportation; explore machines that transport, install, and clean; and propose mechanical standards that coordinate multiple suppliers. All produced materials are free and open, to support collaboration and enable others to build on this work.

Budget: $500K/yr over 3 years

Topic 3d) Develop Tools and Standards that Support Rollable Solar on Building Surfaces

Researchers develop architectural tools and propose standards that support rollable solar material mounted directly onto building surfaces.

Achieving building net-zero often requires high ratios of solar PV to floor space. A ratio of one square foot of solar for each square foot of floor space is illustrated here. Currently, this is expensive. In this initiative, we rethink solar installation and packaging, and work toward significant cost reduction. For ideas on how researchers might tackle this, click here.

Researchers develop architectural software modules that define PV shapes and placement, propose data standards that describe custom shapes for factory and installation machines, and propose changes to building codes.

All produced materials are free and open, to support collaboration and enable others to build on this work.

Budget: $400K/yr over 3 years

Topic 3e) Develop Standards That Supports Plug-in Modules under Large Angled Roofs

A high ratio of solar-to-floor-space might result in more indoor space under a large angled roof (e.g. 40 x 30 ft roof at 30° angle pointed toward the sun). Researchers design physical modules that install under angled roofs, including things like large deep drawers, deep cabinets that fit triangle shape, bathtub, bed with low headroom above feet, closet with triangle shape, and desk. Researchers assume each is a factory-made module that drops-in via crane, to reduce cost. Also, researchers propose mechanical standards that support fitting these together and securing to framing (e.g. standard widths and lengths affix to standard sized rails attached to framing). Electrical engineers propose standards that define ports which provide electricity and reliable wired communication to each module. This includes defining electrical power/data connectors, and communication protocols for a PCB within each module.

All produced materials are free and open, to support collaboration, adoption, and enable others to build on this work.

Budget: $300K/yr over 3 years

Topic 4a) Develop Residential Energy Core System

Let's make the following assumptions about a theoretical two story residential home with basement:

- A tank of water in the basement stores heat and/or cold. For example, one might heat water during the day via solar, and use that heat in the evening.
- A ground source supplies cold to the house via pipes that route to underground ~58°F soil. This significantly reduces both cooling *and* heating energy consumption via a Ground Source Heat Pump (GSHP).
- All energy intensive hardware is physically consolidated into 3 small utility rooms that are stacked on top of each other. One accesses each via a door.
- Energy intensive appliances back up against utility room wall. This includes oven, washer/dryer, dish washer, and refrigerator. Researchers consider standardized ports that integrate appliances with utility room. Interface includes things like electrical power, wired Ethernet, domestic hot/cold water, 58°F ground source water, thermal storage water, and heat pump airflow.
- Faucets, drains, air vents and HVAC radiators share wall with utility area.
- Stacked utility rooms contain: heat pump, water thermal storage tank, domestic hot water tank, ducts and pipes, electrical wiring, internet modem and Ethernet router. Air ducts and HVAC piping are kept short since they are consolidated into a small space; reducing energy loss.
- Fully loaded modular utility rooms, held together with metal or wood framing, drop in via crane.

We are increasing complexity, which typically increases costs. However, if modules are mass produced in a factory, additional cost is reduced. Yet by how much? Researchers explore the various possibilities, and their costs.

Researchers design examples of how Home Energy Cores might be implemented and propose mechanical, electrical, communications, and piping standards that define how the various pieces might fit together in a plug-and-play manner.

All communication is ≥99.999% reliable; which means no wireless and no power line communication.

All work is free and open, to support collaboration and adoption, and to assist others that want to build on this effort.

Budget: $500K/yr over 3 years

Topic 4b) Integrate Appliances with Heat Pump, Thermal Storage and Ground Source

In the previous initiative, architects connect energy intensive appliances (e.g. dish washer, refrigerator) with a Home Energy Core (i.e. utility rooms with heat pump, thermal storage water, ground source, etc.).

Researchers develop prototype appliances that integrate appliances with resources within the core. For example, one might interface refrigerator to 58°F ground source, or connect stored hot water to dish washer via heat exchanger; both of which would reduce CO_2 emissions.

All work is free and open, to support collaboration and adoption of standards, and to assist others who want to build on this effort, to reduce worldwide carbon emissions.

Budget: $1.1M/yr over 3 years

Topic 5a) Better Connect Federal Grant Applicants to Large Private Funds

There is a movement for large foundations to join the fight against climate change. An example is the $10B Bezos Earth Fund. Also, there exists a variety of USA Gov't offices that review, accept, fund and manage grants. For example, the US Dept. of Energy has both a Solar PV Research and Grid Modernization office.

Many of the newer private funds do not have the staff, the experience, or the computer systems that typically reside at a US Gov't office, many of which have been operating for decades. In some cases, gov't offices are comfortable sharing information with select individuals and organizations.

Massachusetts offers to pay gov't software developers to add a user interface to their computer systems that enables large private fund managers, of their choosing, to interact with existing proposals on file with their office. Added features include log in, viewing proposals, offering to fund proposals directly without gov't involvement, and offering to fund proposals managed by a gov't office augmented by a small management fee. We want Jeff Bezos to read a proposal on file, click a button, go to bed, and sleep well knowing it is being taken care of by the United States of America.

Budget: $250K over 1 year

Topic 5b) Develop Website that Manages a Decarbonization Research Fund

Researchers develop a website that manages research funds, such as what we have here. The website displays research topics and allows entities to donate money to each, with conditions. For example, a wealthy UCB alumni donates $1M to Topic 2b and specifies that 100% goes to UCB researchers. Or a state donates money toward various topics and specifies that ≥ 66% go toward in-state researchers.

The system might support both Large and Small donations. For example, Large might be ≥ $1M, maintain donation in an independent bank account, allow donor to view proposals before releasing funds, and allow donor to repatriate funds at any time. This additional control increases comfort, which encourages participation.

A management committee decides on the list of topics shown at the website, who reviews proposals for each topic, and who manages each grant.

Researchers register, upload their proposals, interact with reviewers, and interact with grant managers.

Other big funds (e.g. Bezos, Gates, etc.) are allowed to view proposals registered at the website, provided author specified they can be shared.

All produced materials and source code are free and open, to support collaboration, adoption, and enable others to build on this work.

This means that anyone can copy this website and deploy their own versions. For example, UCB might deploy a version with UCB professors on their management committee, control the topics, and use it to encourage alumni to support UCB researchers.

Budget: $1.1M year 1, $800K year 2, $600K year 3

Topic 6a) Develop Standards that Support Motorized Windows

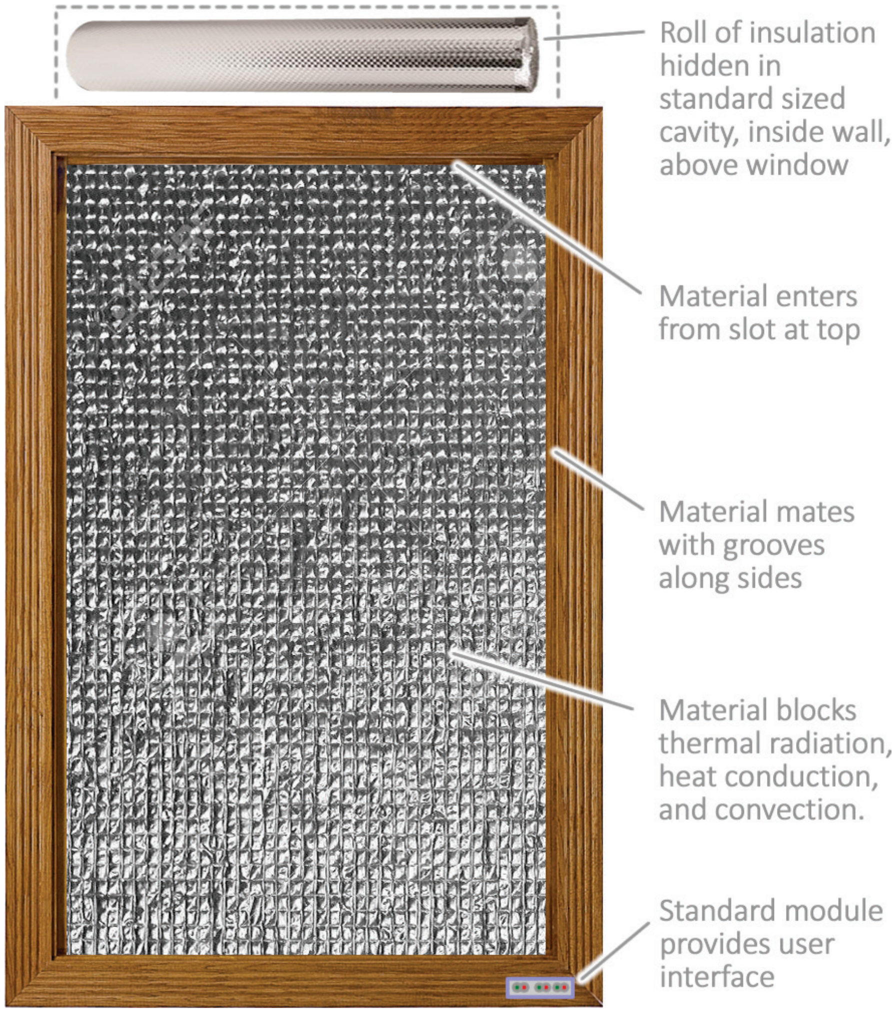
Much energy is lost through wall windows.

In theory, one could have motorized rolled thermal covers deploy over a window when the room is unoccupied. Products such as these *do* exist. Yet they do not sell well since there is no standard way to attach to a building, which dramatically increases cost.

Also, the components are not standardized modules, which means the building degrades over time when a module fails and a replacement is not available.

Much of this could be changed with standardized plug-and-play modules that support motorized windows.

There is a technique called "passive heating" which involves allowing the sun to enter the building and heat the floor. However, windows leak heat when the sun is not shinning.



Motorized thermal covers enable one to toggle between letting sun in and blocking heat loss; making passive heating much more feasible.

Lights saw a transformational improvement when we moved from incandescent to LED. We have not yet seen a transformational improvement with windows. Perhaps this is it?

All devices must be 99.999% reliable, which entails no wireless, no power line communication, and no batteries. For ideas on how researchers might tackle windows with motors, click here.

Budget: $1.2M/yr over 3 years

Topic 7a) Reduce cost of Installing a Ground Source

If one circulates ~58°F ground water through a heating/air conditioning heat pump, instead of outside air, they can reduce space heating/cooling energy consumption approximately 2 to 1. The problem is it is expensive to install underground piping through which one circulates water. The aim of this project is to reduce the cost of installing this pipe. Researchers design machines that utilize an independent drilling mechanism that worms its way into the ground instead of the traditional method of drilling (e.g. rotate heavy pipe that traverses entire length of drill hole with ~10,000 Kg of downward pressure). Researcher are not responsible for building the actual machine, and instead work with computer simulators to design a system "on paper" that works reasonably well. All designs, simulation files, reports and calculations are free and open; allowing others to build on this work. For ideas on how this might work, click here.

Budget: $1M/yr over 3 years

Topic 8a) Create CO_2-Reduction-Per-Dollar Website

There are many things that private individuals, small companies, large companies, power companies, state gov't and federal gov't can do to reduce CO_2 (six groups). Researchers produce lists for each of these groups that shows CO_2-reduction-per-dollar for a variety of activities, sorted, with highest reduction at the top.

This is based on past data, and not projections of future costs (which are sometimes later found to be inaccurate). For example, if MA built a solar farm last year for $1M, then one item on the list might be to build more of these, using this $1M value.

The list might show solar farms in rural areas with cheap land, low labor cost, and existing power wires to be more reduction per dollar than solar farms on expensive land near a large city and far from power wires. The natural inclination is for a city to focus on their own electricity, yet this list might show there is more reduction-per-dollar if they focus on someone else's electricity.

In another example, the data might show solar above parking lots as having relatively low reduction-per-dollar due to the cost of heavy structures that support high wind loads.

Researchers produce a website that displays the lists, and supports drilling down to receive more information. This provides an easy tool for decision makers who are not comfortable with dense technical reports. The website assumes the reader is not an engineer or scientist.

Communities are looking at spending money to reduce carbon emissions, and this tool would help them spend wisely.

Budget: $800K/yr over 3 years

Topic 8b) Publish Report on Massachusetts Decarbonization Options

There are multiple techniques that one can employ to decarbonize; each of which has their costs, advantages and disadvantages. Non-profit organization Energy Futures Initiative Inc. (EFI), for example, recently published a report on California's options (full report, summary, fact sheet). This organization is led by the former US Secretary of Energy Ernest Moniz, and he is considered to be an expert on this topic. In this initiate, we fund the development of a similar report, yet with respect to Massachusetts.

Budget: $350K/yr over 1 year

> The Massachusetts Decarbonization Handbook
> *Advantages, Disadvantages, and Costs of Decarbonization Options*
> By Energy Futures Initiative

Topic 9a) Study Methods for Increasing Safety at Existing Nuclear Power Plants

Researchers consider ways of making existing nuclear power plants safer; including proposing new safety standards.

For example, a researcher might propose that a nuclear reactor is to be capable of emergency shutdown to a cooled state (which might take 48hrs) with no human intervention under difficult conditions that include hurricane, tornado, 100m tsunami wave, 20m of floodwater, truck bomb explosion, light airplane attack, rogue operator, no operator, and armed insurgents. Also, it might state that all infrastructure within the hardened system is assumed to be intact (i.e. within 1m thick cement containment building).

Currently, reactor buildings utilize batteries that often do not contain enough power to circulate coolant for the required shut-down period. Subsequently, many reactors are dependent on infrastructure outside the 1m thick walls to turn off.

Given proposed safety standards, researchers look at what can be done to upgrade existing plants to meet new standard. For example, one might place 1m thick bunkers adjacent to the containment building with diesel generators to provide power for several days while the reactor cools. Researchers do rough designs and cost estimates of upgrades.

There are currently ~100 nuclear reactors in the USA and a radiation release might spread to MA. Subsequently, we would prefer they be a safer.

US nuclear power plants had many safety studies back in 1990s under the IPE (Individual Plant Examination) programs using Probabilistic Risk Assessment (PRA) methodology. First the PRA experts identified possible initiating events leading to nuclear accidents which include small and large Loss of Coolant Accident events (LOCA), Loss of Residual Heat Exchange, Loss of offsite power, earthquakes, and a few other events. Then PRA examined the plant safety system responses and failure probabilities to develop an event tree to fully understand the survivability of the plants and possible additional counter-measures. Researchers consider building on this work.

This is a paper-only exercise. All documentation, calculations and cost models are free and open; which enables others to build on this work.

Budget: $500K/yr over 3 years

Topic 9b) Create New Position -- Massachusetts Nuclear Energy *Research* Commissioner

MA funds the position of the "Massachusetts Nuclear Energy *Research* Commissioner" who has a Ph.D. in nuclear engineering or nuclear science. This individual writes articles and gives talks on research in *safer* nuclear power. They speak truth regarding costs and risks; explain prototypes under development; and review utility scale projects under construction. Their job is not to sell, yet instead to explain challenges faced by nuclear engineers in producing reliable, low cost and safer nuclear technology.

It is possible that *safer* nuclear will play a role in decarbonization, and this position allows the state to learn more about it without engaging in politically unpopular and expensive nuclear projects.

Budget: $300K/yr over 3 years

Topic 9c) Develop NRC Program That Maintains and Manages Standard Designs of Safer Nuclear Power Plants

The US Nuclear Regulatory Commission (NRC) regulates existing nuclear power plants, in addition to overseeing new construction. Currently, there exist little political support for building new plants; however, as the concern over climate change increases, and the cost of deep decarbonization becomes more apparent, we can expect interest in safer nuclear power to increase.

Currently, the cost of building a new plant is high due to an arduous design verification and approval process. In this initiative, we design on paper a new division of the NRC which develops standard *safer* nuclear power plants. Safer, in many cases, entails moderator molecules that are mixed into nuclear fuel and prevent melt-down. This division commissions firms to design reactors. Subsequently, the NRC owns and controls all IP, including software, mechanical designs, reports, test data, etc. When first utilized, these undergo the same verification and approval process as private firms. Yet after successful completion of one plant, the division makes the standard design available to others, to copy and deploy within a stream-lined approval process, reducing the time and cost associated with building a new safer nuclear power plant.

Researchers publish a report that describes this new NRC division. Researchers do not design power plants and do not create the actual NRC division. This is a paper-only exercise. All documentation, calculations and cost models are free and open; which enables others to build on this work.

Budget: $500K/yr over 3 years

Topic 10a) Design 10 TWhr/yr Solar PV Farm that Produces Hydrogen Gas

Instead of each state generating its own carbon-free energy, which is disruptive and confusing, one might look at a federal program that generates everyone's carbon-free energy. For example, one possible USA decarbonization path is to cover 25% of Nevada with solar PV (74K km^2 land, 37K km^2 PV) and then use the electricity to make H_2 gas. This gas could then be transported throughout America to power vehicles, heat homes, and generate more electricity. The electricity generated would be ~3 times more than what America currently generates since this system would be replacing energy we currently obtain from burning natural gas, coal, oil, and gasoline (10.4K vs 3.8K TWhr/yr). The solar parts and labor might cost ~$3.7T ($150B/yr over 25yrs, $0.50/Watt, 7.4TW capacity). However, this does not include the following costs: electrolysis to make H_2 (currently costly), transportation of H_2, maintenance of solar, and land. This solves the following problems: US decarbonization, energy storage (H_2 is storage), limited rare earth metals for many EV batteries (cars run on H_2), significant electrical grid expansion (no longer needed), and disruption to communities from locally based wind/solar/nuclear. The disadvantage is cost -- consumers might see a doubling of energy prices, which is politically unacceptable at this time. In order for this concept to be viable, researchers would need to reduce the cost of electrolysis. Mechanized rollable solar, direct to soil, described earlier in this document, could potentially play a key role in this effort.

In this initiative, researchers design a 10 TWhr/yr solar farm that produces hydrogen via electrolysis. Researchers produce drawings and spreadsheets that calculate a variety of issues, including energy production and costs. Researchers are not responsible for deployment. This is a paper-only exercise. All spreadsheets and documents are free and open, enabling others to build on this work.

Budget: $700K/yr over 3 years

Topic 11a) Design $100M/3yr Hydrogen Research Fund

Recipient designs a $100M fund that sponsors research in hydrogen gas (H_2) production, storage, transportation, deployment and consumption.

There are several methods of producing H_2, one of which is to convert natural gas to H_2 via SMR and store the CO_2 byproduct. Another is to convert clean electricity (e.g. from wind or solar) to H_2 via electrolysis. The former method is sensitive to natural gas prices, whereas the latter involves a currently costly conversion process. In summary, reducing the cost of H_2 production without emitting CO_2 is an important area of research.

Transportation involves moving gas in pipes, trains, ships, and/or trucks; either in liquid and gaseous form.

Fund designer does rough calculations to get a better sense of the issues, and specifies research topics (e.g. reduce cost of liquefying H_2, or reduce cost of converting electricity to H_2). Fund designer does not do the actual research. Instead, they write a proposed Funding Opportunities Announcement (FOA) that specifies research topics from which researchers would apply. Fund designer assumes $100M is spent over 3 years. This is a paper-only exercises. All spreadsheets and documents are free and open, enabling others to build on this work. Perhaps Jeff B, Bill G or Warren B will borrow proposed FOA, edit, fund, and pass to NREL for management?

Budget: $250K/yr over 3 years

Topic 11b) Design $100M/3yr Carbon Capture & Storage (CCS) Research Fund

This is similar to the above project, yet Recipient designs a $100M/3yr fund that supports research in CCS.

Budget: $250K/yr over 3 years

Topic 11c) Design $100M/3yr Mining Research Fund

This is similar to the above project, yet Recipient designs a $100M/3yr fund that supports research in mining of rare materials used in decarbonization (e.g. Cobalt, Nickel, Lithium). Mining for these might increase dramatically; subsequently, reducing mining cost is an important area of research.

Budget: $250K/yr over 3 years

Topic 11d) Design $100M/3yr Sea-Wall Research Fund

This is similar to the above project, yet Recipient designs a $100M/3yr fund that supports research in sea walls. This includes studying different designs, and developing technology that reduces sea walls construction cost.

Budget: $250K/yr over 3 years

Topic 11e) Design $100M/3yr Concentrated Solar Industrial Process Research Fund

This is similar to the above project, yet Recipient designs a $100M/3yr fund that supports research in concentrated solar that drives industrial processes. For example, one might use reflectors in the desert to provide heat for manufacturing cement, steel, aluminum, plastics, and other chemicals. Researcher's design factories driven by concentrated solar and develop cost models. Also, researchers look at transportation costs associated with moving production toward large deserts.

Budget: $250K/yr over 3 years

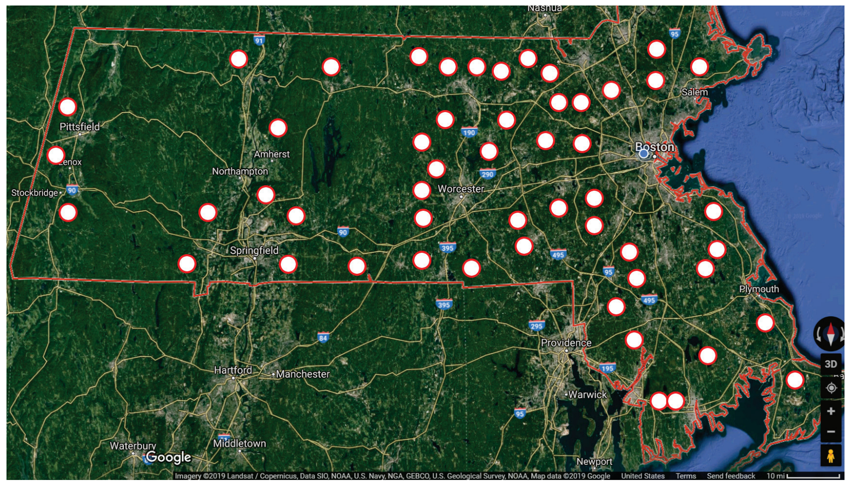
How Can Massachusetts Decarbonize?

MA consumes 55 TWh of electricity per year. If we replaced gasoline, natural gas, and coal with carbon-free electricity; this number could double (or triple depending on a variety of factors). Let's do a mental exercise and look at the numbers associated with 110 TWh/yr of wind, solar and safer nuclear.

Massachusetts Powered By Wind

One of the most advanced off-shore wind farms is the [London Array](#) (175 windmills, 47 square miles, $2B, 2.5 TWh/yr). MA would need 44 London Arrays to produce 110 TWh/yr, provided MA had their wind speed and water depth (110/2.5). This would cost ~$88B total and works out to $14K per MA citizen, or $600-per-person-per-year if spread out over 20 years (44*2, 88e9/20/7e6). This does not include maintenance costs. Currently, political support for these costs and windmill views is not available.

Massachusetts Powered By Solar



If solar farms generated 110 TWh/yr in electricity and we stored when the sun did not shine, MA would need to devote ~300 square miles to solar farms (~3% of the state). The picture to the right shows what this might look like if implemented with 36 farms, each 3.3miles in diameter. Parts and Installation Labor might cost ~$80B ($1/Watt). This does not include cost of land or maintenance. Currently, we do not have the technology to store this level of energy when the sun is down, and political support for this kind of project is not available.

Nuclear Fusion

Fusion involves nuclear energy yet without the risk of radiation release, nuclear waste, and bomb. Feasible fusion technology does not exist; however, researchers are working on it, and we might see it in ~15 years.

Nuclear Fission

Fission involves radioactive material that creates heat when positioned in a small cavity. Traditional fission reactors face three challenges: fuel can be refined further and made into a nuclear bomb, reactor can melt down and release radioactive particles, and nuclear waste lasts a long time.

Researchers are currently exploring ways of improving on these three areas, relative to traditional technology.

Traditional nuclear fuel is capable of melting, burning, creating pressure, and working its way into the environment ("melt down"). Currently, researchers are looking at adding substances to the fuel that cause the nuclear reaction to turn off in the event it gets too hot, before melting. This improves safety *dramatically*.

Many of the top MIT energy experts have concluded that *safer* nuclear is likely to play a significant role in decarbonization, due to cost and availability issues associated with alternate low carbon technologies.

For a list of electricity generation facilities in Massachusetts, for reference, click here.

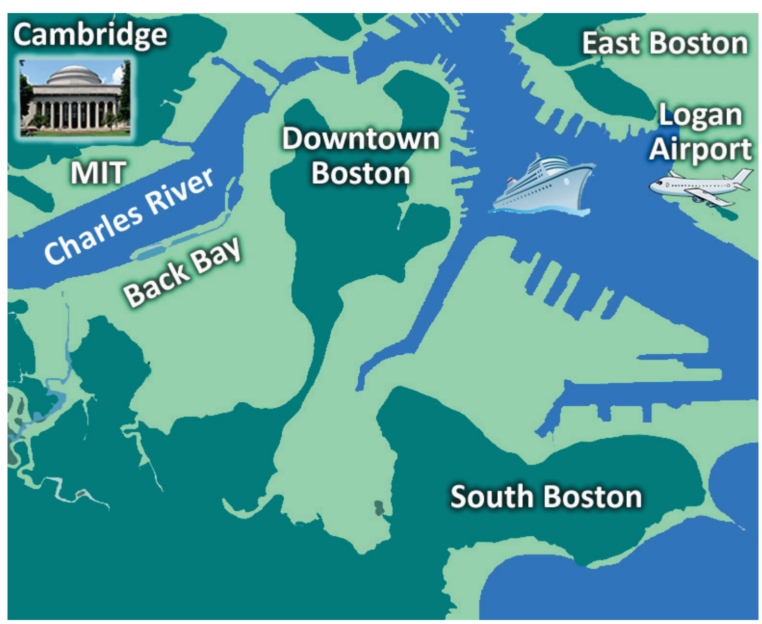
Energy Politics 2020

If there was a \$200/ton tax on $C0_2$, many low carbon technologies would become less costly than their $C0_2$ counterparts. For example, it might be less costly to power a car with hydrogen gas made in the Arizona desert with solar or with natural gas and carbon capture, than gasoline.

A \$200/ton tax would increase the cost of gasoline by ~\$2/gallon. Alternatively, one might look at a \$50/ton tax (\$0.50/gallon), with less influence on behavior.

Currently, there is not enough political support for a big tax on CO_2, both at the federal and state level. Recently, MA proposed a \$0.05/gallon tax, and this was met with discomfort by some lawmakers.

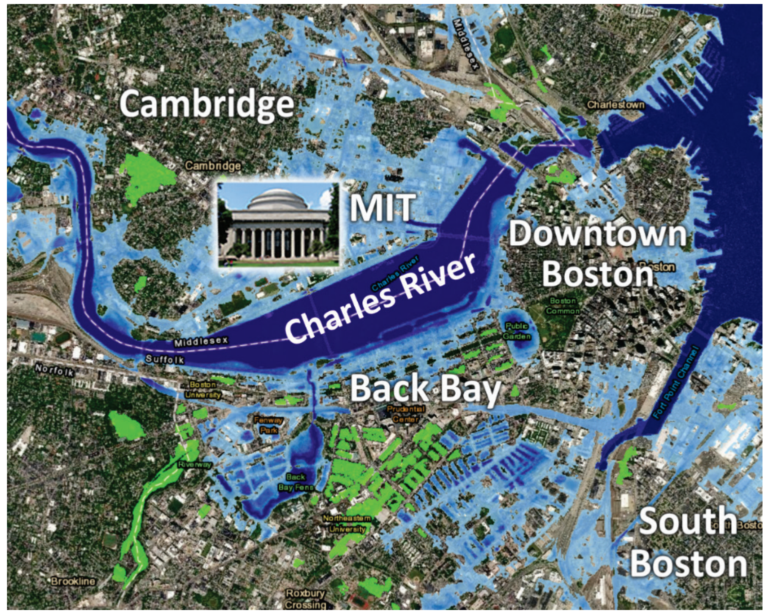
Also, the stress over climate change is growing. Perhaps geometrically. And the associated long term cost of climate change is becoming clearer. Here's an example.



Previously, landfill engineers only filled as required since adding "extra" soil is expensive. Therefore, if you add 5ft to sea level, for example, landfill is impacted. All landfill. Worldwide.

Boston was built on filled-in water over the last 400 years. The areas shown to the right in light green were covered in water in 1630, yet are now land. Expensive land.

The map to the right shows ocean water over developed land in light blue color after a 5ft sea level rise, according to the US Gov't NOAA [Sea Level Rise Viewer](). Notice how this corresponds to landfill.



US Gov't scientists predict 5ft will occur between 65 and 200 years from now, according to their Boston intermediate high (65yrs) and low (200yrs) models.

MA could build a sea wall between Boston and the Bay; however, a rising underground water table would eventually threaten basements and below-ground infrastructure.

As one might imagine, dealing with this is expensive. Subsequently, as this picture becomes clearer, a $200/ton tax might eventually become politically popular. One could possibly reduce other taxes by a similar amount to maintain constant tax revenue, and avoid a total net increase (called "tax shift"). States who add a big carbon tax risk having energy intensive businesses move across their border; and would therefore prefer a federal tax. Countries that add a big carbon tax risk having businesses move away; and would also prefer participation from others. Coordinating multiple countries might sound unrealistic today, and it is, yet as evidence of climate change increases, support for carbon tax increases.

We are probably in a pre-carbon tax era, and therefore might ask ourselves, "What can we do today to get ready for that day when a carbon tax makes low carbon alternatives less costly than their CO_2 counterparts?"

Junk is Bad

Many are concerned that new energy infrastructure such as wind or solar will fail prematurely and drive up costs. Due to competition, companies are under pressure to reduce price, and this sometimes leads to a non-obvious reduction in quality. In a sense, buyers would like to see two numbers, price and number-of-years-of-longevity. They could then consider trading dollars for years.

It might *seem* impossible to control quality and determine longevity before a life-time has elapsed. However, this is not the case. Multiple things can be done:

- Researchers can design products and make all drawings available to the public, free and open. Subsequently, any factory can copy and manufacture. Gov't funded researchers can do extensive stress testing and field testing, and make all data public. If gov't is buying billions of dollars of something, they might be inclined to spend a few million on engineering, and gain control over the cost vs quality tradeoff. Also, private companies can participate by improving on free and open designs.
- Components often degrade slowly over time. If their properties are measured in the field, one can predict failure rates after a relatively short period (e.g. Capacitors, MOSFETs, windmill bearings). If testing shows 30 year longevity, one might be inclined to scale up to larger volume. Otherwise, one might improve the design before scaling. Researchers propose standard communication systems for reporting component properties. If one wants wind and solar electronics to be durable, and therefore low cost, built-in field testing is crucial.

Ultimately, buyers of solar farms might utilize free and open designs of solar electronics due to additional testing with public data.

Now is the time for researchers to design and test new technology, to the extent that we can scale to larger volumes in the future with a reasonable understanding of how it wears over time. Junk is bad, and needs to be controlled.

Conclusion

The development of plug-and-play interconnection standards and technology, done now, is a great way to reduce costs and risks of future large projects.

Our initiative's goal is worldwide reduction of CO_2 emissions. Subsequently, some of this funding might go to researchers out of state, to encourage others to decarbonize. However, at least 2/3rd of funding stays in MA.

Research is inexpensive relative to infrastructure projects, provided it develops useful technology, which we encourage via our targeted topics.

Research is politically popular with both conservatives and liberals. For example, Federal Senator Alexander (R) responded to the Democrat's Green New Deal with a proposed Energy Research Initiative. The democrats then endorsed his proposal. Both sides agree research is good. Also, people who do not believe in climate change tend to be comfortable with university engineers who develop nifty gargets that reduce cost and/or increase comfort. They do not like expensive projects that increases prices; yet research is more about reducing costs.

Swedish 17yo Greta Thunberg became famous for scolding elders over climate change. This initiative, in a sense, is handing responsibility back to young people, at universities, handing them financial support, and saying "go fix it".

This Massachusetts Energy Research Initiative will help make this great state ground zero for developing the new low carbon society. This will help us, and others, as we head into an uncertain future.