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Testimony to the Energy Subcommittee,
Committee on Science, Space, and Technology
U.S. House of Representatives

Scheduled for Tuesday February 26.

Big Ideas, Small Companies, and ARPA-E innovation.

Otherlab and associated companies have been very successful leveraging ARPA-E funding to commercialize new energy technologies that are starting to have a major impact on the energy economy.

ARPA-E has a critical role in technology development in the US not only in the earliest stages of technology development (the first valley of death) but in assisting through pilot programs and manufacturing scale-up to get the most promising technologies over the second valley of death and into the market.

About Otherlab:

Otherlab is a small independent research lab whose business model is to invent and develop new technologies, find product-market fit, and spin out financeable start-up companies. Much of the reason to use this model is that it allows us to leverage early government investment and transition to other sources of capital such as angel investment and venture capital to grow successful companies.

This is a powerful model for commercializing technology, and reflects the recent analysis that small teams are more effective at early-stage technology disruption[1], while large teams are good at later-stage technology development, cost reduction, and improvement. At any one time Otherlab has 4-8 projects running with anything from 1-20 people on the teams. We have a focus on new energy technologies because of the importance of building a robust 21st-century energy infrastructure that will help us deal with climate change.

Otherlab is not a university, nor is it a federally funded or national lab, which puts it in a unique position. We have, however, partnered with both universities and national labs. We are known for being both inventive and effective, as evidenced by three companies growing out of ARPA-E funding and ARPA-E seeing the value in that research to the point of awarding follow-on funding for each. As well as being pioneers in new energy technologies, we are well known for our pioneering work in soft robotics, soft exoskeletons, and advanced manufacturing. Otherlab typically has 25-50

[1] https://www.nature.com/articles/s41586-019-0941-9

people on its payroll, and at any one time may have as many as 200-500 people employed by the various companies that have spun out.

However, because of our status as a for-profit independent research and development lab, we cannot apply for all categories of federal funding. I believe making more federal R&D money available to groups like ours will lead to a more innovative America.

Fortunately, ARPA-E and DARPA are agencies that will work with all categories of institutions. We have had a great deal of success working with both DARPA and ARPA-E, and we have also done research contract work for EERE, SOCOM, ONR, NASA, NSF, and NIH. We have had partnerships with universities including MIT, Stanford, Berkeley, Tulane, Purdue, and more. We have similarly partnered with major industrial concerns including Ford, Toyota, Facebook, Google, Adidas, Specialized, Nike, GE, Autodesk, OReilly Media, and more.

Otherlab and ARPA-E (Case Studies in Chronological order)

Makani Power, funded under ARPA-E Open 2009.

I founded the company Otherlab on April 22, 2009 (Earth day). I had previously been working as the CEO of Makani Power, which I founded in 2006. One of the last things I did at Makani was helping with their ARPA-E proposal for the inaugural funding round “Arpa Open 2009.” Makani was successful in obtaining an ARPA-E contract which was critical in the survival of the company in the depths of the global financial crisis of that period. I think it is reasonable to assume that the airborne wind energy technology Makani has pioneered would not have survived until today without the assistance of ARPA-E. Makani was later acquired by Google and absorbed into Google X. It has since partnered with Shell for its initial pilot commercial deployments. Makani has employed hundreds if not close to 1000 of the country’s best young engineers over the 10-plus years it has taken for the technology to move from equations on a sheet of paper and sketches in our imaginations to a powerful contender as a platform technology for high utility offshore wind energy. I estimate upwards of $200M has been invested in making this technology commercial, a successful example of the leverage of a relatively small ARPA-E investment (around $3M).

Sunfolding. Funded under ARPA-E Open 2012 with two “plus-up” awards

Sunfolding is on the cusp of becoming the next solar success story. We are redesigning solar trackers from the ground up -- these are the machines that move solar panels to follow the sun and are being installed in almost every utility-scale system today. Powered by air, Sunfolding’s tracker uses just three components while others use over twenty, making our solar plants easier, faster and cheaper to build and operate. Over the last 7 years, Sunfolding has gone from revolutionary concept with funding from ARPA-E to a 60MW portfolio being installed this quarter, including projects with one of the biggest solar developers and one of the largest utilities in the U.S.

Sunfolding started with questions: What would a machine look like if it were specifically designed for solar? What problems could we solve by redesigning the fundamental building blocks of machines?What if we could use high volume manufacturing methods and advanced materials to create reliable, scalable solar trackers right here in the United States, rather than manually assembling these machines overseas, like nearly all existing tracker technologies today.

Back in 2011, we tried to get investors and corporate partners interested. Were it not for ARPA-E funding Sunfolding would not exist today. With ARPA-E funding we were able to do the fundamental R&D to determine whether or not the technology could work. Our progress was such that we received two “plus-up” awards from ARPA-E to continue the work. Both were critical to get the technology to the stage that it was investable by the private sector. There are still many hurdles to getting a new hardware out of the R&D lab and into the energy market. One challenge is proving that the the technology will survive in the field for 20-plus years before you have put them in the field for 20 years. A crucial part of this process are real world deployments and pilot projects. It is hard to find funds for this stage of development; often the developing entity of the technology has to finance these deployments and tests themselves, yet another difficult hurdle in bringing these projects to market.

Sunfolding was extremely fortunate at a critical moment to secure California Energy Commission funding for a pilot project. Without it, this promising technology may have withered in the lab without ever being tested in the real world. I cannot emphasize enough the importance of funds to do test deployments and pilot projects in de-risking new energy technologies. Without that de-risking, banks aren’t willing to finance projects with that energy technology, which is one of the final and biggest hurdles to entering the mainstream energy market.

Sunfolding has been able to leverage the investments of ARPA-E to raise investor funding, including Y-combinator. Sunfolding now employs 25 people and has manufacturing partnerships across the country, including Dupont. Our US-based supply chain partners are behind some of the most dependable material applications in the world typically employed in automotive, rail, marine, and industrial lift applications. We are partnering with them to bring their manufacturing methods, materials and quality standards to the solar industry. Sunfolding’s tracker technology is poised to install 100’s of MW of plants all over the US and internationally over the next 2 years. By all measures the company is succeeding greatly in lowering the cost of zero carbon renewable energy and keeping the US at the forefront of Solar.

FOCUS “Full-Spectrum Optimized Conversion and Utilization of Sunlight” 2014-2017.

Otherlab and Sunfolding became involved in another ARPA-E program in collaboration with Tulane University and Boeing’s Spectra lab. The program “FOCUS” targeted increasing the total system efficiency and even adding storage to solar energy through hybrid systems that captured more light and more heat and utilized both. Ultimately the technologies developed

under this program were not core to either Otherlab's or Sunfolding's mission, and we novated that award to the Sub Awardees to continue the good work in the University research setting which is now itself spinning up into a company.

Volute Inc. Funded under ARPA-E MOVE program. "Methane Opportunities for Vehicular Energy," 2012 and 2013-2015.

The MOVE program was designed to create technologies that supported Natural Gas Vehicles which can have lower operating costs and lower emissions than gasoline vehicles. Under that program, we developed a conformable tank technology exploiting some cunning mathematics and geometry. This technology improves the range, safety, and cost of natural gas vehicles. The program was initially funded with $250,000 to prove the concept, and upon successful proof we were granted a second contract of ~$4.1M of which we had to meet ~$870,000 in cost share.

Volute was able to leverage the $3.5M (federal share of the funding) to find another $10M in development revenue from major automakers in co-development programs.

The technology was licensed to Westport Fuel Systems (a natural gas vehicle company) for compressed natural gas vehicles.

Technology has been licensed to Linamar (a large supplier to major automotive OEMs) for hydrogen fuel cell vehicles. Linamar is continuing development and has hired several members of the core team that worked on the initial ARPA-E project.

Approximately 15 full-time jobs were created in the US; roughly 10 on the Volute team now at Linamar with a further 5 at contract manufacturers in the US.

Kestrel Materials, Funded under DELTA program. "Delivering Efficient Local Thermal Amenities." 2015-Ongoing.

Kestrel Materials was an idea that we developed at Otherlab to create textiles that use ambient temperature changes to change the loft (thickness) and hence the insulation (warmth) of fabrics. These can be used to make clothes that increase the comfortable temperature range of people within buildings and also outside. The idea was developed principally with Brent Ridley (PhD, MIT) who was originally hired to help with the materials science components of Sunfolding. It is important to recognize the importance of the role of ARPA-E in developing communities of experts and professionals not only across institutional boundaries but across disciplinary boundaries. Many of these people work together on multiple projects at different times. They are the institutional memory and skilled workforce of America's energy innovation ecosystem.

Otherlab secured a phase 1 award of $1.84M with a follow-on award of $3.6M after we proved the technology was on a successful pathway. Once again we have met the cost share of almost $1.5M with a combination of internal funds, angels, and professional venture capital. Kestrel

has secured more than $2.2M in venture funding and has advanced the technology to functional prototype articles of clothing and a scalable manufacturing process for producing bulk active textiles at affordable rates for inclusion in commodity clothing articles.

Kestrel employs 9 full time people and a number of contractors and has moved to Portland, Oregon to be closer to the epicenter of the apparel industry in the US. Kestrel will be releasing its first products in 2020 and anticipates raising a larger round of venture funding in mid 2019.

Super-Sankey, IDEAS program, "Innovative Development in Energy-Related Applied Science" 2017-2018.

In 2017 Otherlab secured close to $500K in funding from ARPA-E to build analysis tools and data visualizations to create the highest resolution mapping of US energy flows yet produced. The notion behind this project is that if we understand the flows and interactions of various energy sources in the US economy we can more effectively allocate federal research dollars and create greater professional and public understanding of the options for innovation and change in our energy economy.

This small project successfully highlighted problems with how we view energy flows born of historical legacies in how we defined and represented the data. This project has also enabled us to draw up scenarios for the US energy economy that enable us to think more clearly about the various pathways to decarbonization, or to american energy independence as examples of scenarios that can be looked at.

The Super Sankey project never had a commercial outcome in mind, but is a clear success in helping experts and the general public in understanding the energy flows of the American economy. ARPA-E's latest OPEN FOA even suggested that applicants cite this tool in their proposals to quantify their impact.

Near-Isothermal-Compression, OPEN 2018. 2019-ongoing.

Otherlab received a new award that started under contract only a few days ago, on February 20th, 2019. The award is to develop a near-isothermal compressor technology that will have profound implications for many applications where a gas needs to be compressed. It could be an enabling technology for the hydrogen economy, have huge implications for industrial efficiency in compression of air and other gases, potentially lower the huge energy cost of pumping natural gas, and enable new classes of refrigerators, air conditioners, and heat pumps. The award is only $500K and Otherlab has already been able to find a cost share partner (an angel investor) for the project. This project will employ 4 people in 2019 and will hopefully succeed and expand as we prove the viability of the design.

Closing Summary.

ARPA-E has been an excellent source of early stage funding for audacious and ambitious new energy technologies. The majority of the successful companies and projects discussed here would simply not exist if it were not for the early stage funding of ARPA-E.

ARPA-E has demonstrated an unbiased approach to funding non-traditional research entities. I think this is fantastic. In my experience (and backed up by recent research results) small teams, small companies and small start-ups are a vital national resource for high-risk transformative technologies.

Without exception, the challenge with bringing any of these technologies to market is the transition from a proof of concept—something that works—into a tested, validated, bankable, finance-able, product. ARPA-E currently does not provide funding for this stage of technology development. Again, in my experience, this phase of development always represents a cost of $1-10M (and sometimes much more) after the initial costs of technology development. This is due to the nature and expense of hardware development, and the timelines of development and proof of energy technologies. It would be in the national interest to increase ARPA-E funding in a manner that would enable it to help finance the very risky second valley of death: the proof by pilot or field testing of energy technologies.

I would further suggest that like DARPA, the agency that ARPA-E is loosely modelled on, ARPA-E is one of the most effective and transformative technology development agencies in the country. DARPA's budget is around $3bN. It wouldn't be crazy were the US to similarly prioritize its energy infrastructure and technology development program to a similar level, something like 10X what it is today.

ARPA-E isn't perfect. The cost-share concept which I initially was in support of, I have found through experience to force the developers of technology to make poor partnerships or take ill-matched investments to meet, and it generally leads to bad outcomes of one kind or another, including the death of otherwise high-potential technology development projects.

ARPA-E could also improve on its billing cycle; small government contractors the nation over suffer enormous cash-flow problems in financing the receivables of government research contracts. On many occasions I had to take out extreme or egregious loans including home mortgages to cover the receivables on ARPA-E grants. On occasion, the federal government would pay more than 90 days after the work was completed. This may be absorbable by universities or National Labs, but it is fatal to small companies—the most innovative engine in the economy in bringing transformative technologies to market. I was on the brink of closing down on numerous occasions with more than half a million dollars in receivables to the government.

ARPA-E also has some egregious clauses in their contracts that do not ultimately benefit the US economy downstream despite the intention of those clauses. The worst perhaps is the "made in

the USA" clause which wants most of the technologies to be made in America. While a good goal, this is impractical in the global marketplace of energy technologies that have complicated supply chains. These clauses become issues when raising venture to commercialize the technology as Venture Capitalists appropriately don't want any unnecessary constraints on how they build successful US-based, globally operating companies.

There is absolutely no doubt in my mind that the American taxpayer and the American economy is benefiting greatly from investments that ARPA-E is making. In addition to the economic impact of the companies mentioned above themselves, the employees, Interns and contractors working on these projects have gone on to run dozens of related projects and have used skills learned on these projects to improve their careers, move to the top grad schools in the country, and launch new technology companies in every domain from electric aircraft to autonomous cars to advanced robotics to ag-tech.

We should find every possible way to help government research agencies fund and support the best work in the country, by the best people, no matter which lab or organization they work in. There are transformative technologies in garages that are finding it hard to escape because of biases in the federal funding system.

We should expand the funding and scope of ARPA-E in this moment of the international energy economy transition. The dominant energy technology players of the next century are being started and funded today.

The challenge of most hardware technologies, particularly in the energy industry, is proving that they will survive in the field for 20-plus years before you have put them in the field for 20 years. A lot of resources are spent testing this as it forms a critical component of the "bankability" of the technology—meaning the willingness of a bank to finance the projects that include the technology. A crucial part of this process are real-world deployments and pilot projects. Often the developing entity of the technology has to finance these deployments and tests themselves, yet another difficult hurdle in bringing these projects to market.

Government could choose to fill the different funding gaps for energy technologies. As we see it, there are 4.

The 1st is fundamental and exploratory research finding out what is possible and exploring new opportunities. This is obviously the traditional domain of government funding of the NSF variety.

The 2nd is development. This is applied research taking fundamental ideas and shaping it into a technology with the potential to have an impact. DARPA, ARPA-e and agencies like the California Energy Commission (CEC) have been fundamental in our experience in this phase.

Bankability (the 3rd) is using the proven elements of research and development and building a tested and piloted project or product sufficient to get first customers (the ones that will take risk)

and private investment (that wants to see that a customer will buy it). This is definitively the energy technology's most difficult valley of death and a giant opportunity for ARPA-e to help accelerate energy technology transition to market. This stage may also include assistance in funding the manufacturing innovations required to bring the technology to market.

The 4th category is commercialization and deployment. This is where government should not be involved, this is financeable by banks and late stage venture. This is where the market can pick the winners.

Thank you for your time and your interest in this topic that I have devoted my career to.

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