A NEW PATHWAY FOR HARD TECHNOLOGY: SUPPORTING ENERGY INNOVATORS AT CYCLOTRON ROAD
ACKNOWLEDGMENTS

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Front Cover: Cyclotron Road project lead Etosha Cave sets up an electrochemical reactor for CO₂ reduction experiments.

Inside Back Cover: Cyclotron Road project lead Kendra Kuhl with a membrane electrode assembly for electrochemical CO₂ reduction.

Back Cover: Cyclotron Road project lead Deepak Dugar examines a cell culture for production of bio-based chemicals and fuels.
Built to support the nation’s leading energy innovators, Cyclotron Road has three core principles:

1. **Breakthroughs in hard technology will be critical to build a sustainable energy system.**
2. **When it comes to driving innovation, there is no substitute for top-notch people with an “all-in” commitment.**
3. **Innovators need the right environment to bridge the science-to-product gap.**

The science-to-product gap for hard technology is real. Our current innovation centers—within academia, corporate R&D, and startups—are not consistently translating promising science into commercially viable products with the potential for scalable impact. Academic research institutions are optimized for scientific discovery, but materials and manufacturing technologies can require years of system engineering and process development to mature. Industrial R&D labs reach well beyond discovery, but corporate innovations are highly constrained by near-term shareholder priorities and market dynamics. Startups are highly productive innovation engines, but the costly risks of hard technology development make it nearly impossible to raise startup capital in competition with digital technologies and market-ready consumer devices.

Given these issues, **Cyclotron Road is creating a new institutional home for innovators to bridge the science-to-product gap in hard energy technologies.** Our goal is to define a new innovation pathway—one bringing together the resources and partners needed to support our best and most-driven innovators, allowing them to develop cutting edge science into commercial products with sustained impact on our energy future.

Our approach:

1. **RECRUIT the best and most-driven hard tech innovators.**
2. **SELECT projects focused on commercial and scalable technical solutions to maximize energy market impact.**
3. **LEVERAGE existing R&D assets through a partnership with our national labs.**
4. **SUPPORT innovators with world-class mentors, education, and seed funding to get their projects off the ground.**
5. **CONNECT innovators with the right commercial partners at the right time.**

With the first cohort of projects admitted into the program in October 2014, we’re already seeing results. From the support of Lawrence Berkeley National Lab, to the incredible network of energy sector experts we’re building as mentors, to the milestones our innovators have already been able to achieve at relatively low cost, all indications are that Cyclotron Road is charting a compelling course.
1. Breakthroughs in hard technology will be critical to build a sustainable energy system. While we have made progress towards a more sustainable energy system with existing technologies, there are significant gaps in the technology portfolio that must be bridged by physical innovation based on hard science breakthroughs.

2. There is no substitute for top-notch people with an “all-in” commitment. People are the drivers of innovation. Transformational innovation requires our best innovators to pursue their goals with dedicated passion and singular focus.

3. Innovators need the right environment to bridge the science-to-product gap. Making progress on hard technology takes time and resources. Innovators need an environment that allows them to efficiently explore and validate technical opportunities, while aggressively searching for viable commercial pathways to bring their idea to scale.
Cyclotron Road project lead Raymond Weitekamp and postdoc Corinne Allen prepare reagents in a glove box at the Molecular Foundry.

“Innovation has nothing to do with how many R&D dollars you have. When Apple came up with the Mac, IBM was spending at least 100 times more on R&D. It’s not about the money. It’s about the people you have, how you’re led, and how much you get it.”

— Steve Jobs, tech visionary, Apple co-founder and former CEO

Steve Jobs shows off the iPhone 4 at the 2010 Worldwide Developers Conference. Photo credit: Matthew Yohe, CC BY-SA 3.0 Wikimedia Commons.
Technical innovations in chemistry, physics, and materials have driven the progress of modern civilization. While scientific inquiry has always pushed the boundaries of human knowledge, it is often that rare person or team—one with an uncommon mix of technical skills and entrepreneurial acumen—that makes the final leap from theory to commercial application and fundamentally changes the way we live.

The development of the Haber-Bosch process provides a salient example. At the turn of the 20th century, growing population meant food security was an increasingly dire issue for countries around the world. Atmospheric nitrogen fixation was considered a “holy grail” solution to this problem, with the potential to save millions of lives. But most believed it to be commercially infeasible because existing processes were prohibitively inefficient. Across the globe, scientists sought a solution.

The world-changing innovation finally came thanks to Fritz Haber and Carl Bosch, whose technical development effort combined the best of cutting-edge science with a focused drive for a commercially scalable process. Building on an academic breakthrough in high-pressure catalysis, their effort addressed critical technical challenges to make the leap from scientific demonstration to tabletop prototype, and eventually, to an economical industrial process. Their ability to commercialize these breakthroughs enabled the mass production of nitrogen fertilizer and a more secure food supply for the world.

Today the dire need for a more sustainable energy system poses a global threat to human society similar to that of the 20th century nitrogen crisis. Hard technology innovation will be critical to enabling and accelerating the breakthroughs needed for a sustainable energy future.

But these innovations won’t appear out of thin air. Like Haber-Bosch, people will drive them forward.

THE NEED FOR HARD TECHNOLOGY BREAKTHROUGHS

Many technologies with the potential to transform our energy system will require the commercialization of hard science breakthroughs to be feasible at scale. These include:

- Cheap, safe, and scalable energy storage for grid and mobility applications;
- Disruptively economic, next-gen renewable power generation;
- Technologies to capture, sequester, and utilize atmospheric greenhouse gases;
- Technologies to radically increase the efficiency of current power systems and production processes; and,
- Cheap, safe, and scalable nuclear power generation;
- Sustainably produced fuels and chemicals.
Today, skilled individuals looking to develop impactful energy technologies, and government agencies looking to fund them, typically choose among three pathways—academia, industrial R&D, or startups. Each is essential to the innovation ecosystem but none on its own is consistently enabling hard tech entrepreneurs to make rapid progress on the science-to-product gap.

ACADEMIA—TRAINING THE BEST AND BRIGHTEST

American universities have long been engines of scientific study, and excel at molding young scientists into skilled investigators—the U.S. is the leading source of Nobel Laureates in scientific disciplines. The national lab system is another major cornerstone of America’s scientific and technical prominence, performing basic research and providing cutting edge scientific facilities for the public’s benefit. For decades, this innovation ecosystem has advanced and built a strong foundation of technological discovery.

However, taking a scientific idea from the lab bench to a commercial product is difficult in the traditional academic environment and has remained an unmet opportunity for the national labs. The process of building a successful career within these institutions is generally constrained by a need to publish new scientific discoveries and build a broad research portfolio, limiting the ability to focus solely on translating and scaling these discoveries into impactful technologies.

GOVERNMENT—PROVIDING THE FUEL

In 2007, the National Academies Committee on Science, Engineering and Public Policy noted in its Rising Above the Gathering Storm report that “[America’s] competitive advantage, our success in global markets, our economic growth, and our standard of living all depend on maintaining a leadership position in science, technology, and innovation.” Aligned with this imperative, the U.S. Department of Energy and other government agencies provide critical financial and technical support for teams working on breakthrough energy research with commercial applications. Putting these resources into the hands of the right people within the most effective institutions is crucial to ignite the energy innovation process.
Daniel Riley and Jared Schwede met as graduate students in the physics department at Stanford University in 2008. In their Ph.D. work, they delved deeply into thermionic energy conversion (TEC)—a process that converts heat directly to electrical power—and discovered that the field had lain largely dormant since the 1960s. Recognizing the opportunity to apply modern materials and manufacturing techniques to foundational 1960s thermionics technology, Riley and Schwede began to think about how to bring their ideas to life and to the market.

They soon hit a dead end. Potential investors wanted to see a demonstration of this uncommon technology before committing capital to a potential startup. However, the highly applied work of developing a prototype could not be supported in the environment of their academic lab, and the two were encouraged to start their own company to build a prototype—landing them back at square one.

These two experts, members of a tiny community worldwide with the knowledge and skills to drive TEC innovation, gave up on pursuing a startup. Schwede began looking for academic postdocs in energy-related areas, while Riley took a consulting job. The pair then learned about Cyclotron Road. Riley and Schwede joined the program as members of its first cohort, where they have been working hard to develop and scale their core technology. Collaborations with Berkeley Lab scientists have proven particularly valuable for this team. Not long after joining Cyclotron Road, Riley and Schwede discovered that Berkeley Lab housed a custom-built microscope, one of a handful of its kind in the world. Serendipitously, this unique tool was ideally suited to conduct critical experiments needed to advance thermionic materials.

The lead research scientist on this microscope normally explores the basic properties of exotic materials, but after meeting Schwede and Riley, he was very excited by the prospect of working on a highly applied and potentially impactful project. They have been collaborating actively ever since.
Under constant competitive pressure, the enduring American materials and technology companies have had to become experts at bringing product improvements to scale. In 2013, private industry spent over $300 billion on R&D, accounting for about 70% of total U.S. R&D spending. Improvements to existing product lines and other current strategic interests drive most internal corporate R&D efforts. This bias is understandable: a 2014 Pricewaterhouse Coopers Analysis showed that “companies with more tightly aligned business and innovation strategies had 40 percent higher operating income growth over a three-year period, and 100 percent higher total shareholder returns, than industry peers.”

Engineers working in the small piece of the corporate R&D portfolio reserved for exploratory research are constrained by the same set of priorities. Technology breakthroughs must align with the strategic priorities of a business unit—driven by current products, specific market forces, and shareholder value—to gain traction within the company. Absent a serendipitous alignment between scientific discovery and market dynamics, a potentially transformative idea may never have the opportunity to scale.

Caught between the constraints of academia and the corporate world, many energy innovators start new ventures to advance their ideas. But entrepreneurs looking to develop hard technologies face unique challenges in getting their companies off the ground. The biggest early hurdle is securing and financing laboratory facilities and equipment. Setting up one’s own lab from scratch can take years and millions of dollars, and all this before an entrepreneur can even begin the applied R&D process. Early-career researchers with limited business experience and no lab space often struggle to secure federal applied research funding, no matter how promising their technologies are. Even if an entrepreneur is successful in securing a federal research grant, he or she must raise private sector matching funds to access the award or to cover expenses that aren’t allowable under the grant guidelines.

In search of private financing, most energy innovators end up trying to raise venture capital. While this has led to fruitful partnerships between VCs and entrepreneurs in “capital light” sectors, the compressed timeline to exit and return expectations that come with early-stage venture investment are often out of line with what hard technology innovations can achieve. Not surprisingly, a forthcoming DOE analysis of publicly available data shows that venture-backed cleantech companies had noticeably fewer high-multiple exits than medical and software startups over the past ten years. Seeking better returns, venture capital has cut back dramatically on early stage clean technology investment.

To change the culture so you can be a fast, short-cycle innovation-centric company requires a different type of R&D engine. The IT world showed us what type of R&D engine you need. It’s literally hiring millennials: hiring the entrepreneurs that normally would go to start-ups, and having a culture that resembles a start-up inside your company.”

— Andrew N. Liveris, Dow Chemical Company CEO

Source: Interview on the McKinsey website.
Photo credit: Media Gallery, dow.com.
In the summer of 2014, Steven Kaye set out to radically reduce the energy use and cost of chemical separations, industrial processes that account for about 10% of global energy consumption.

As a Ph.D. student from 2003-2007, Kaye had worked on the design and synthesis of metal-organic frameworks (MOFs). One of the most exciting materials in chemistry today, MOFs are the most effective known material for separating gases. In particular, lab tests have shown that MOFs can cut in half the cost and energy required to separate carbon dioxide from other gases.

Taking a look at the field nearly a decade after his Ph.D. Kaye saw that the science-to-product gap had yet to be bridged: despite the discovery of thousands of MOFs over nearly two decades, there was not a single material in commercial use. Tiny powder samples were perfectly suited for scientific discovery and testing, but didn't match the needs of industrial customers. And few in the academic community had an interest in solving the scale-up and engineering challenges needed to make MOFs relevant to industry.

Seeing an opportunity, Kaye considered leaving his job to found a company focused on commercializing MOFs. Having worked as the chief scientific officer of a materials startup for seven years, he thought the technical challenges involved could be solved with a focused effort, and the opportunity for impact would be huge. But first, he would need money to build his own lab. Kaye contemplated fundraising from venture capital and angels, but knew that, even with solid experience managing a prior company, it would be difficult to sell investors on a hard technology startup with no commercially relevant results. At best, it would probably take a year to close a seed investment and start work in the lab.

Then Kaye learned of Cyclotron Road, which had just launched its pilot program. With seed funding and quick access to lab space, it seemed to be the ideal platform to start his project. Kaye applied for the program and was accepted. He was doing experiments at Berkeley Lab within weeks of joining the program last fall.

Since then, Kaye’s progress has been remarkable. Collaborating with Jeffrey Long, a staff scientist at Berkeley Lab and one of the world’s leading experts on MOFs, Kaye was quickly able to hire a scientist to help with R&D, allowing him to focus on understanding critical industry requirements. Within a few months, they had identified a promising first application and hit several key technical milestones toward scalable MOF processing. With this progress in hand, Kaye has since been able to secure grant money and raise aligned investment capital from specialized venture investors. After less than a year of focused effort within the program, Kaye has enough momentum to spin out of Cyclotron Road and scale up operations as an independent company.
The constraints of academia and corporate R&D today are misaligned with the goals of scientists and engineers with entrepreneurial mindsets and ambitions. At the same time, traditional venture backed startup companies are often untenable for hard technologies. Our best and brightest minds want to put their talents to use—but won’t wait around forever for the opportunity to have a positive impact and make a living pursuing their technology ideas. Without a clear pathway to develop their ideas, we risk losing these critical innovators.10

Nick Cizek, a former ARPA-E fellow with a Ph.D. in atomic physics from Stanford University, spent a year and a half trying to raise funds for a thermal energy storage startup while consulting part time; he eventually took a full time position before having a chance to pursue the idea in a laboratory.11 Before joining Cyclotron Road, Deepak Dugar had to take a day job as a management consultant to pay the bills while he put his project synthesizing chemicals from bio-based feedstock on hold.12

To keep top innovators working on hard technology breakthroughs, we need to create an environment that embodies the best aspects of academia, corporations, and startups, while minimizing their constraints on the innovation process.

BRIDGING THE INNOVATOR GAP

Today, our highly optimized, venture-capital-driven innovation system is simply not structured to support complex, slower-growing concepts that could end up being hugely significant—the kind that might lead to disruptive solutions to existential challenges in sustainable energy, water and food security, and health. . . . the United States needs a more systematic way to help its bottled-up new-science innovators deliver their ideas to the world.”

— L. Rafael Reif, President, Massachusetts Institute of Technology

Cyclotron Road is testing a new model to build this environment and bridge the critical science-to-product gap. To bring new energy technologies to scale, we'll need all stakeholders—both public and private—at the table. Our approach:

1. **Recruit the best and brightest innovators.**
   Top-notch innovation can't occur without top-notch people. We look for outstanding talent willing to go “all-in” to drive their energy technology from lab to market.

2. **Select projects focused on commercial and scalable technical solutions to maximize energy market impact.** At Cyclotron Road, we’re focused on commercial energy breakthroughs. This isn’t R&D for the sake of R&D—innovation can and should be informed by the real-world potential for impact at scale. At the same time, we help innovators identify crucial first markets for their products in order to demonstrate customer traction and technical feasibility as early as possible.

3. **Leverage existing R&D assets through a partnership with our national labs.** As a hard tech entrepreneur, the cost and time needed to set up a research lab, procure equipment, get equipment training, and set up safety protocols are significant. At Cyclotron Road, project leaders are working alongside experts at Berkeley Lab and using cutting edge equipment within weeks of joining the program. This immediate access to R&D facilities dramatically reduces the startup costs for a hard technology project, while providing innovators the opportunity to fail and pivot efficiently based on early results—substantially de-risking technologies while continuing to refine their business model.

4. **Support innovators with world-class mentors, education, and seed funding to get their projects off the ground.** We provide seed funding to enable our innovators to focus full time on their projects and help unlock federal research grant funding by meeting cost-sharing requirements. We recruit aligned hard-tech entrepreneurs, R&D executives, investors, and government researchers to mentor our innovators, giving them the technical and business advice necessary to take their projects to the next level.

5. **Connect innovators with the right commercial partners at the right time.** There is no one-size-fits-all business model for hard tech. Our goal is to maintain the viability of multiple pathways technologies to scale. Over the course of the Cyclotron Road program, we help innovators explore the best path and funding sources to position themselves for success with a variety of partners, including:
   - **Corporations.** Corporations can partner with entrepreneurs in a variety of ways, from joint development projects, to minority equity investment, to outright acquisition.
   - **Venture Firms.** Venture financing is appropriate for some early-stage hard technologies and often plays a crucial role at later stages. Venture can provide the leverage needed for non-dilutive grants and help innovators scale rapidly when the technology and market opportunity are sufficiently characterized.
   - **Family Offices.** Family offices are increasingly interested and creative in their ability to extend equity and debt financing to clean tech entrepreneurs.
   - **Non-profits.** Some innovations are most effectively brought to scale through non-profit or open source development models.
Cyclotron Road is designed to complement innovation efforts across the energy technology ecosystem, building a bridge between innovators and critical public and private sector institutions.

By aligning the interests of each of these stakeholder groups, our platform enables “win-win” collaborations that minimize constraints on the people driving hard technology innovation.

**INNOVATORS**

A custom-built home to pursue their applied R&D dreams with mentored support and a higher chance of success in commercializing breakthrough energy technologies

**NATIONAL LABS**

A new mode to drive impact, expose lab scientists to industry needs and entrepreneurial collaborations, and create an all-star alumni network in the private sector

**U.S. DEPARTMENT OF ENERGY**

A replicable model to support the best innovators and yield more mission-aligned commercial outcomes

**INVESTORS AND INDUSTRY PARTNERS**

A pipeline of top-notch people and technologies that will be the industry’s next breakthroughs and leaders
Brian Hardin and Craig Peters launched PLANT PV out of the material science department at Stanford University in 2010. “We had friends that raised $7 million from VCs, and spent a lot of money on equipment before they realized their original idea wasn’t going to work. By then it was too hard to pivot,” says Hardin. They knew they had to get scrappy to avoid the mistakes of their peers.

By chance, through a professional connection, Hardin learned of Berkeley Lab’s Molecular Foundry—a scientific user facility with six floors of state-of-the-art nanotechnology research equipment and experts. Lacking facilities of their own, they were able to work with Molecular Foundry scientists to demonstrate technical progress and publish results on breakthrough ideas, which eventually helped them secure federal research funding and raise a small venture round at an attractive valuation. They continue to collaborate with scientists at the Molecular Foundry today as they fully develop their technology. Once it’s ready, they plan to seek out strategic partners to scale up.

“In the 21st Century you can’t do material science in your garage… at Berkeley Lab you’ve got access to equipment, and can pivot a lot more easily than you could have if you took a Series A round,” says Peters. This model can be replicated through Cyclotron Road. “Materials startups face extreme hurdles,” adds Hardin. “Cyclotron Road can help turn A+ scientists into A+ entrepreneurs.”
It’s been an exciting year since we launched Cyclotron Road and we are seeing some early validation for our approach.

With only three weeks between the first public announcement of the program and the deadline to apply in August 2014, 150 hopeful teams signed up to throw their hats into the ring for the first cohort. The 20 finalists selected from this group had impressive technical backgrounds and hailed from a cross section of academia, industry, and startups. One applicant summarized what they found to be compelling: “Critically, […] I believe Cyclotron Road will reduce startup costs and enable lower risk development paths for energy and materials technologies while ensuring that these technologies are put into real-world use.” Clearly, the concept had struck a nerve.

Response from the broader hard tech innovation community has been strong as well. A committed group of experts in cutting-edge science, early-stage finance, government funded R&D, and industry participated in the project selection process, and has continued to donate their time and experience to support current cohort teams and advise the program. A number of public and private partners have stepped in to join Berkeley Lab in supporting the pilot phase, based on the opportunity to expand their impact in development and commercialization of new energy technologies. Cyclotron Road has also helped our first cohort of innovators secure additional capital to accelerate their progress.

Most importantly, our first cohort has already felt tangible benefits to their projects during the first six months at Cyclotron Road. In recent interviews, our innovators shared what has been most valuable to them.

Having the ability to focus on scaling and manufacturing challenges has been invaluable. “No one will talk to you about using your technology at scale until you’ve shown it to work at scale,” said Raymond Weitekamp, who is using a clean room facility at Berkeley Lab to demonstrate the viability of his technology in the context of actual industrial production processes. He hopes this early focus on manufacturing will facilitate industrial partnerships for his project.

Innovation can’t be done in a vacuum, and the program’s strong connection to industry has been key for validating assumptions and setting the right targets. “Cyclotron Road gives us a lot of opportunities and credibility to go and talk to external companies,” said Kendra Kuhl.

Finally, collaboration with Berkeley Lab experts has proved fruitful. By working with scientists at the national lab, Jared Schwede and Dan Riley have gained access to equipment and computational software “that we didn’t know existed…and would have been prohibitively time-consuming to develop on our own.” Rather than having to finance and build expensive vacuum chambers and test equipment from scratch, they are actively driving toward important technical milestones.

Riley seemed to speak for most of the cohort when he identified the most important benefit of joining Cyclotron Road: “Time. Time to develop thinking and ideas, time to apply for grants and talk with experts.”

(continued)
When Ernest O. Lawrence built the first cyclotron particle accelerator in the Berkeley hills in the 1930s, he ushered in a new era of scientific collaboration and invention. At Cyclotron Road, we're building on that legacy, creating a new home for best-in-class innovators to work on badly needed energy technology breakthroughs.

You can be a part of this movement. Whether you are a technical expert, investor, philanthropist, industry executive, or aspiring innovator—we need all the help we can get to build a new model for hard tech energy innovation.

THE TIME HAS COME. JOIN US.

ILAN GUR
DIRECTOR, CYCLOTRON ROAD
EXPERT INTERVIEWS AND ACKNOWLEDGEMENTS

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“People are THE most important thing in any organization. But that organization also needs to have the culture to bring the best out of them. That culture involves an ecosystem where they can interact openly and make each other better, as well as enlightened leadership to raise the bar, empower them to chart their course, and hold them accountable.”

—Arun Majumdar, former Director of the Advanced Research Projects Agency—Energy
FOOTNOTES:


6 Various interviews.

7. Interview with Colin Wessells, CEO and Founder at Alveo Energy.


10. Interview with Dane Boysen, former Program Director at Advanced Research Project Agency–Energy.

11. Interview with Nick Cizek, Senior Strategist at the Climate Corporation.

12. Interview with Deepak Dugar, Visolis.


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