Energy 790-1 – Special Topics in Energy: Emerging Energy Technologies – From Lab to Market

Fall 2020
Duke University

Credit hours/meeting time:	1.5 credit hours, 7:00 – 8:15 pm Tuesday
Location:	TBA
Course format:	Lectures, classroom discussion, interactive exercises, projects

Instructors:

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Teaching Assistant: Will Niver (will.niver@duke.edu)

Possible Guest Lecturers:

Chris Atkinson, Program Director at ARPA-E (chris.atkinson@hq.doe.gov)

Rachel Slaybaugh, Program Director at ARPA-E (Rachel.slaybaugh@hq.doe.gov)

Kory Hedman, Program Director at ARPA-E (kory.hedman@hq.doe.gov)

Marc von Keitz, Program Director at ARPA-E (Mark.vonkeitz@hq.doe.gov)

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Aims and Objectives:

The course will expand students' knowledge of advanced energy R&D and provide better understanding of the adoption challenges associated with new energy technologies. Students will gain a broader understanding of the types of potentially transformative energy technologies that might well be the technologies they work with in the future, either personally or professionally. The course will also educate students broadly on the economic, policy, funding, and communication challenges associated with transitioning technology from the laboratory into the real world, referred to as tech-to-market (T2M). The course will based upon Funding Opportunity Announcements (FOAs) issued by the Advanced Research Projects Agency – Energy (ARPA-E), supplemented by additional publications relevant to the FOA topic (journal articles, press coverage, project summaries, impact descriptions, etc.). A representative set of FOAs will be offered to students covering most of the key areas where advances in energy technology can make a significant impact on decarbonizing the energy system, including stationary power generation, next generation electric grid, energy storage, energy efficiency, and transportation. The course will feature a series of lectures discussing the current state of technologies

in these areas, featuring guest lectures from the original authors of the FOAs. Students will be asked to select areas for in-depth analysis, which may include development of their own ARPA-E program pitch. The basic elements of the T2M program at ARPA-E – cost and scale-up assessments, market knowledge, effective communications with prospective investors – will be used to provide students with some basic strategies for taking technology from the lab into the real world.

Evaluation Criteria:

Assignment 1: 25%
Assignment 2: 25%
Assignment 3: 30%
Class Participation: 20%
Students will be expected to come to class prepared to discuss the FOA/program or T2M topic chosen for the class. Ample time will be left for class discussion of the pros and cons of the chosen program and students will be expected to participate actively in the discussion. Particularly strong class participation will be required in critiquing the program pitches from fellow students at the end of the course. The objective here is to make the class culture as much like an ARPA-E meeting as possible – no ideas are off limits! Bring you craziest ideas! Think way outside the box!

Readings:

There is no textbook assigned for this class. The ARPA-E website contains a wealth of information and will be the main reading resource for the course. Other background sources include:

Article describing ARPA-E from Information Technology and Innovation Foundation

The National Academy of Sciences Review of ARPA-E.

For background on the role of the "state" (government) in innovation, see various interviews, podcasts, articles or books by Mariana Mazzucato:

https://marianamazzucato.com/

Harvard Business Review Podcast:

https://hbr.org/podcast/2019/04/the-innovation-economy

Book: *The Entrepreneurial State – Debunking Public vs Private Sector Myths* by Mariana Mazzucato.
Available on Amazon. Purchase not required.

Technology to Market:
Book: *Four Steps to the Epiphany* by Steve Blank
Available on Amazon. Purchase not required

Book: *Crossing the Chasm* by Geoffrey Moore
Available on Amazon. Purchase not required

Individual readings are suggested for each class session, as indicated below. For topical classes, the ARPA-E Program Descriptions listed for each class are the appropriate starting point for reading and a suggested minimum in order to be prepared for class. If the student wants more technical detail, then he/she should read the FOAs and/or the descriptions of projects within the program portfolios. Some projects have impact updates and links to those are provided within the project description.

Class 1: Introduction to ARPA-E (Eric Rohlfing)

This class will provide an overview of ARPA-E, covering the agency's authorizing legislation and history. Emphasis will be placed on the agency's authorizing statute that defines its mission but discussion will also include the policies and politics that have helped shape the agency over its 11 year lifespan. The current impact indicators for the agency will be discussed, as will the challenge of innovation in the energy technology space.

Suggested reading: Article describing ARPA-E from Information Technology and Innovation Foundation. The ARPA-E website sections covering authorizing legislation and history.

Class 2: ARPA-E – Programs and Projects (Eric Rohlfing)

ARPA-E is modeled closely after the Defense Advanced Research Projects Agency (DARPA) and emphasizes the freedom of program directors to develop, pitch, and manage their own programs and R&D portfolios. Using ARPA-E's adaptation of the Heilmeier catechism, the class will examine the key questions that need to be answered in order to successfully pitch a new program concept in ARPA-E. These include clear definitions of the problems the research will address, how success will be measured, and how technically successful projects will move toward market adoption. Perhaps most importantly, the class will cover the all-important exercise of "acronaming," e.g., devising incredibly clever acronyms for ARPA-E programs.

Suggested reading: Survey some of the project impacts described in *ARPA-E Impacts: A Sample of Project Outcomes*, Volume I, Volume II, and Volume III.

Class 3: Introduction to Technology to Market (T2M) (Dave Henshall)

There is a continuous flow of ideas and technology coming from research labs in academia, industry, and government, but understanding how to move these technologies onto a path of implementation to meet their environmental, economic, and social potential requires additional work beyond the science. The T2M component of ARPA-E was developed to address this by helping to answer the question: *If it works, will it matter?*

This class will discuss why the T2M organization was created within ARPA-E, what function it serves, and how it contributes to the mission of ARPA-E. We'll also talk about what T2M does and how it interacts with Program Directors during the formation and management of programs at ARPA-E.

Suggested reading: The Technology to Market section of the ARPA-E website.

Class 4: T2M Best Practices (Dave Henshall)

This class will discuss the role of the T2M Advisor at ARPA-E and how they interact with performers. The T2M Advisors supports performers in three ways: developing and managing performers to T2M milestones that are relevant and customized to their specific technology and business needs; advising performers to successfully execute their milestones; and helping performers strategize, network, and connect to resources that can help them achieve the project's business objective. This includes the application of such tools as techno-economic analysis, primary and secondary market research, and the development and testing of a product hypothesis and customer hypothesis. Throughout the execution of a project T2M Advisors advise performers both on an individual bases and across a program on their external outreach to maximize effectiveness of identifying and negotiating partnerships with potential vendors, customers, or financiers.

Suggested reading: *Four Steps to the Epiphany* by Steve Blank

Additional reading: *Crossing the Chasm* by Geoffrey Moore

Project #1 (written)

Select an ARPA-E FOA/program and write a short paper (5 pages) that presents an argument for why it should ***not*** have been run. Your argument must be based on technical reasons (e.g., it's not technically feasible), economics (e.g., it can never be done at a competitive cost), or other issues (e.g., the technology will never be adopted because of policy, regulatory, or social barriers).

Due: October ??

Topical Class Sessions:

The next set of classes will focus on specific energy technology areas. In each description, possible example FOAs/programs are listed, but not all of these may be covered in each class. Whenever possible, specific project examples with tangible T2M outcomes will be provided.

Class 5: Renewable Power Generation (Possible Guest Lecturer: Will Regan)

This class will introduce and discuss ARPA-E programs in renewable power generation, notably solar and wind energy. The challenge of innovation in the context of ever plummeting costs for solar PV and conventional wind energy will be discussed. Candidate ARPA-E solar programs include: **F**ull-**S**pectrum **O**ptimized **C**onversion and **U**tilization of **S**unlight (FOCUS) which sought to combine the best aspects of solar PV (high efficiency) with concentrated solar power (storage/dispatchability) and **M**icro-scale **O**ptimized **S**olar-cell **A**rrays with **I**ntegrated **C**oncentration (MOSAIC) which attempts to broaden the penetration of solar generation to regions of lower direct solar illumination through the use of novel, microscale optics and high-temperature PV. Wind energy will be represented by some individual projects and by the Aerodynamic **T**urbines **L**ighter and **A**float with **N**autical **T**echnologies and **I**ntegrated **S**ervo-control (ATLANTIS) program, which targets novel offshore wind technologies based on floating platforms requiring extremely advanced control systems.

Suggested reading: FOCUS program and project descriptions and FOA; MOSAIC program and project descriptions and FOA; ATLANTIS program description and FOA.

Class 6: Nuclear Power Generation (Possible Guest Lecturer: Rachel Slaybaugh)

This class will examine ARPA-E's programs in nuclear power generation – both fission and fusion. Possible programs include **M**odeling-**E**nhanced **I**nnovations **T**railblazing **N**uclear **E**nergy **R**einvigoration (MEITNER) and **G**enerating **E**lectricity **M**anaged by **I**ntelligent Nuclear **A**ssets (GEMINA), which seek to develop small-scale, automated fission reactors that are not based on light-water technology. The significant challenges associated with reducing the costs of nuclear reactor builds through mass manufacturing and operating costs through automation will be discussed, as will the even more significant challenge of public acceptance of widespread nuclear power.

On the fusion side, the **A**ccelerating **L**ow-Cost **P**lasma **H**eating and **A**ssembly (ALPHA) program seeks a cheaper, alternative path to fusion energy on the grid that lies between the two mainstream technological approaches to fusion – tokomak and inertial confinement. The challenges associated with the complex plasma physics will be briefly addressed, as will the agency's unique efforts to force plasma physicists to think about actually designing a power plant based on a fusion reactor.

Suggested reading: The MEITNER program and project descriptions and FOA; the GEMINA program description and FOA; the ALPHA program and project descriptions and FOA.

Class 7: Energy Storage (Possible Guest Lecturer: Joe Manser)

ARPA-E has funded a wide range of programs and projects to advance electrical energy storage for both vehicle and grid applications. This class will summarize some of the early work and specific types of technologies that might be impactful in both areas will be discussed. A recent program example is **I**ntegration and **O**ptimization of **N**ovel **I**on-**C**onducting **S**olids (IONICS) – a program that charts a path toward what could be a true revolution in lithium ion battery technology – an all solid-state battery. For grid applications, the game changing technology would be cheap, long-duration storage. The **D**uration **A**ddition to electricit**Y** **S**torage (DAYS) program is pushing toward storage of 100 hrs or more and the FOA contains some interesting techno-economic analysis that presents a subtle way of valuing energy storage. Interestingly, the program contains several projects using thermal energy storage that require conversion of input electricity to heat/cold and reconversion back to electricity, raising some interesting questions about efficiency versus cost.

Suggested reading (watching): A NOVA episode on the "Search for the Super Battery" provides an excellent introduction to solid state batteries and features several ARPA-E project teams. IONICS program and project descriptions and FOA; DAYS program and project descriptions and FOA.

Class 8: Transportation (Possible Guest Lecturer: Chris Atkinson)

This class will examine some of ARPA-E's programs aimed at improving the efficiency of transportation so as to reduce GHG emissions. The Next-Generation Energy Technologies for Connected and Automated On-Road Vehicles (NEXTCAR) program seeks to drive energy efficiency at the vehicle level by taking advantage of the rapid advance of connected and automated vehicles (CAVs). Most of the emphasis on CAVs has been on safety, e.g., either removing the human factor to make travel safer or, in the contrarian view, to put dangerous automated vehicles on our roadways. This program seeks to use

connectivity and automation to improve by 20% or more the energy efficiency of CAVs, whether they be powered by fuels or electricity. It has applications across all sectors, from passenger vehicles to freight transport. The **T**raveler **R**esponse **A**rchitecture using **N**ovel **S**ignaling for **N**etwork **E**fficiency in **T**ransportation (TRANSNET) program sought to optimize the energy efficiency of an urban, multi-modal transportation system (vehicles, mass transit, ride sharing, carpooling, scooters, bikes, walking, etc.) by providing the individual traveler with incentives through a smartphone app. Finally, if time permits, the class will discuss the Facsimile Appearance to Create Energy Savings (FACES) FOA, which was published but ultimately cancelled. FACES intended to completely displace business travel by creating digital representations of people (avatars) and enabling digital meetings that were so immersive they would accomplish all of the same objectives of a business meeting.

Suggested reading: The NEXTCAR program and project descriptions and FOA; the TRANSNET program and project descriptions and FOA; the FACES FOA.

Project #2 (written)

Prepare a T2M plan for a hypothetical startup company that has just won an ARPA-E award, using the standard template provided by ARPA-E. The details of the company and its technology will be provided.

Due: November ??

Class 9: Biofuels (Possible Guest Lecturer: Marc von Keitz)

The transportation sector is notoriously difficult to decarbonize because of the incredibly utility of liquid fuels and the infrastructure that exists for them. This class will examine some of the programs ARPA-E has initiated to enable the use of carbon neutral biofuels. **T**ransportation **E**nergy **R**esources from **R**enewable **A**griculture (TERRA) and **R**hizosphere **O**bservations **O**ptimizing **T**errestrial **S**equestration (ROOTS) are two programs that push the frontiers of precision agriculture, melding advanced sensing, robotics, and data analytics to advance the phenotyping of plants that can serve as either biofeedstocks or improved pathways to sequester carbon in the soil. The **M**acroalgae **R**esearch **I**nspiring **N**ovel **E**nergy **R**esources (MARINER) program seeks to develop cultivation and harvesting methods to turn the oceans into macroalgae (seaweed) farms to provide biofuels feedstocks.

Suggested reading: The TERRA program and project descriptions and FOA; the ROOTS program and project descriptions and FOA; the MARINER program and project descriptions and FOA.

Class 10: Energy Efficiency – Power Electronics (Dave Henshall)

ARPA-E has run a large number of programs seeking to improve energy efficiency. One particular area of emphasis has been power electronics, which are systems that convert one form of electricity to another based from generation through consumption requirements (for PV, wind energy, EVs, etc.). This class will examine the incredibly broad reach of power electronics and the progression of ARPA-E programs in this field, with an emphasis on wideband gap semiconductor materials. We'll discuss the **A**gile **D**elivery of **E**lectric **P**ower **T**echnology (ADEPT) program, which was the first program in this field and meant to be broad and exploratory, then move to **S**trategies for **W**ide Bandgap, **I**nexpensive

Transistors for **C**ontrolling **H**igh-**E**fficiency **S**ystems (SWITCHES), which focused on devices and materials, then conclude with **C**reating **I**nnovative and **R**eliable **C**ircuits **U**sing **I**nventive **T**opologies and **S**emiconductors (CIRCUITS) and **B**uilding **R**eliable **E**lectronics to **A**chieve **K**ilovolt **E**ffective **R**atings **S**afely (BREAKERS), which more systematically addressed the needs identified in preceding programs. Expect a dramatic collision of material science, market forces, utilities, and economics during this discussion.

Suggested reading: This ARPA-E authored survey article, Power electronic survey, is an excellent introduction. Also the ADEPT, SWITCHES, CIRCUITS, and BREAKERS program and project descriptions.

Class 11: Energy Efficiency – Consumer Facing (Eric Rohlfing)

Among the other ARPA-E programs focused on improving energy efficiency are several that are directed at the individual consumer as the ultimate adopter of the technology. Examples that may be covered in this class include three that focus on building energy efficiency: **D**elivering **E**fficient **L**ocal **T**hermal **A**menities (DELTA) that aimed to reduce building energy consumption by providing local thermal management systems (including wearable technologies) to occupants; **S**ingle-Pane **H**ighly **I**nsulating **E**fficient **L**ucid **D**esigns (SHIELD) that seeks novel coatings to dramatically improve the thermal insulating properties of single-pane windows; and **S**aving **E**nergy **N**ationwide in **S**tructures with **O**ccupancy **R**ecognition (SENSOR) that develops user-transparent sensor technology to reduce energy usage in residential and commercial buildings.

Suggested reading: The DELTA program and project descriptions and FOA; the SHIELD program and project descriptions and FOA; the SENSOR program and project descriptions and FOA

Project #3 (oral and written)

Select an energy R&D topic, develop your own ARPA-E style program pitch, present it to the class, and draft the technical section of your own FOA. The pitch must answer all of the ARPA-E version of the Heilmeier program framing questions. The FOA must provide technical and economic targets and must also contain a detailed discussion of how, if successful, the research funded under the FOA will get to market. Finished products: PPT presentation to class; written FOA.

Due: December ??

Class 12: Next Generation Grid (Possible Guest Lecturer: Kory Hedman)

The U.S. electric power grid is widely viewed as one of the most significant engineering feats of the 20th century. But it's not ready for massive decarbonization through high penetration of renewables, the use of storage, and the rapid advance of distributed energy resources (DERs) at the local and consumer level (e.g., rooftop solar). What will the future grid look like and how will it operate? This class will address those questions in the context of several programs run by ARPA-E. These may include the program, which seeks to use advanced algorithms to convert collections of DERs into synthetic reserves analogous to the conventional reserves currently employed on the grid. ARPA-E has developed new grid data sets in the Grid Data program for use in a Grid Optimization (GO) competition in which applied mathematicians have been asked to develop new algorithms for optimal power flow on the grid and this competition will be discussed. Finally, the new program is even more aggressive in seeking an entirely

new paradigm for allocating grid assets using risk-based algorithms derived from actuarial/financial science.

Suggested reading: The NODES program and project descriptions and FOA; the GRID DATA program and project descriptions and FOA; the GO competition description; the PERFORM program description and FOA.

Class 13: Student Program Pitches

This class will be devoted to student pitch presentations of their ARPA-E style programs. Each pitch must answer each question in the ARPA-E version of the Heilmeier catechism. Fellow students will be strongly encouraged to provide objective, unbiased criticism (technical, economic, societal) of program concepts, in the spirit of an ARPA!

Suggested reading: The PowerPoint pitch decks from the students who will be pitching in this class.