**Energy 790.1 – Special Topics in Energy: Emerging Energy Technologies – From Lab to Market**

**Fall 2024**

**Duke University**

**Credit hours/meeting time:** 1.5 credit hours, 6:15-7:30 pm, Tuesdays

**Location:**  Gross Hall, Room 100C

**Course format:**  Lectures, discussion, interactive exercises, projects

**Instructors:**

[Eric Rohlfing](https://energy.duke.edu/leadership-staff/eric-rohlfing), Energy Executive in Residence, Duke University Energy Initiative, former acting Director of the Advanced Research Projects Agency – Energy (ARPA-E) (eric.rohlfing@duke.edu )

[David Henshall](https://www.src.org/about/management-team/henshall-david/), Director of Business Development for the Semiconductor Research Corporation, former Deputy Director for Commercialization, ARPA-E (dnhenshall@gmail.com )

**Possible Guest Lecturers:**

[Jenifer Shafer](https://arpa-e.energy.gov/about/team-directory/dr-jenifer-shafer), Associate Director for Technology and Program Director, ARPA-E (jenifer.shafer@hq.doe.gov )

[Josh Gould](https://www.linkedin.com/in/joshuagould/), Director of Innovation at Duquesne Light (former Tech-to-Market Advisor at ARPA-E) (jgould@duqlight.com )

[Scott Litzelman](https://www.linkedin.com/in/scott-litzelman/), Program Lead for Climate at Stripe (former Program Director at ARPA-E) (sjlitzel@gmail.com )

[Ann Xu](https://www.linkedin.com/in/yanzhi-ann-xu/), Co-Founder and CEO, [Electrotempo](https://www.electrotempo.com/) (former Senior Technical Advisor at ARPA-E) (yanzhi.xu@gmail.com )

[Ashwin Salvi](https://www.linkedin.com/search/results/all/?fetchDeterministicClustersOnly=false&heroEntityKey=urn%3Ali%3Afsd_profile%3AACoAAAcMq5sBLRGzj9jLBfu2Y8HUW6VqVtXYO9k&keywords=ashwin%20salvi&origin=RICH_QUERY_SUGGESTION&position=0&searchId=000f9f5f-4f7a-456e-adbd-57260a62f4bd&sid=6gi), Co-Founder and COO, AtmosZero (former Fellow at ARPA-E)

[Joe Manser](https://www.linkedin.com/in/jsmanser/), R&D Manager at Form Energy (former Fellow at ARPA-E)

#### **Aims and Objectives:**

This course will expand students’ knowledge of advanced energy R&D driving potentially transformative energy technologies. The course will also educate students on the economic, policy, funding, and communication challenges associated with transitioning energy technology from the laboratory to the real world, referred to as tech-to-market (T2M). The primary viewpoint for the class will be through the programs and projects of ARPA-E. Initial lectures will provide an introduction to the agency and cover the basic elements of the T2M program at ARPA-E – cost and scale-up assessments, market knowledge, effective communications with prospective investors. The course will cover a representative set of areas where advances in energy technology can make a significant impact on decarbonizing the energy system, including but not limited to stationary power generation, next generation electric grid, energy storage, energy efficiency, carbon capture, and mobility. The course will feature a series of lectures discussing the current state of technologies in these areas given by current and former ARPA-E program directors and T2M advisors who will also share their career experience and advice with students.

#### **Evaluation Criteria:**

Assignment 1: 25%

Assignment 2: 30%

Assignment 3: 35%

Class Participation: 10%

Ample time will be left for class discussion of the pros and cons of ARPA-E programs and projects and for more general discussion of the technology topic of the class. 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](https://arpa-e.energy.gov/) 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](https://itif.org/publications/2017/11/15/arpa-e-versatile-catalyst-us-energy-innovation)

The National Academy of Sciences [Review of ARPA-E](https://www.nap.edu/catalog/24778/an-assessment-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

For topical classes, the [ARPA-E Program Descriptions](https://arpa-e.energy.gov/?q=program-listing) listed for each class are the appropriate starting point for reading about the technical area. More specific readings will be suggested prior to the class by the guest lecturer.

#### **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 12 year lifespan. The current impact indicators for the agency will be discussed, as will the challenge of innovation in the energy technology space. 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 start to examine the key questions that need to be answered in order to successfully pitch a new program concept in ARPA-E.

Suggested reading:  [Article](https://itif.org/publications/2017/11/15/arpa-e-versatile-catalyst-us-energy-innovation) describing ARPA-E from Information Technology and Innovation Foundation. The ARPA-E website sections covering authorizing legislation and history. Survey some of the project impacts described in *ARPA-E Impacts: A Sample of Project Outcomes*, [Volume I](https://arpa-e.energy.gov/?q=publications/arpa-e-first-seven-years-sampling-project-outcomes), [Volume II](https://arpa-e.energy.gov/?q=publications/arpa-e-impacts-sample-project-outcomes-volume-ii), and [Volume III](https://arpa-e.energy.gov/?q=publications/arpa-e-impacts-sample-project-outcomes-volume-iii).

#### **Class 2: From Programs and Projects to Market (Eric Rohlfing & Dave Henshall)**

This class will complete the discussion of how ARPA-E Programs are developed and projects selected, including 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.

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: Suggested reading: The [Technology to Market](https://arpa-e.energy.gov/?q=site-page/tech-market-t2m) section of the ARPA-E website.

#### **Project #1 (written)**

Select an ARPA-E FOA/program and write a short paper (2-3 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).

#### **Class 3: 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

**Topical Class Sessions:**

The next set of classes will focus on specific energy technology areas. In each description, representative ARPA-E programs on that technology area are given. However, the exact subject matter covered in each topical lecture is at the sole discretion of the lecturer and may cover only a few ARPA-E programs or projects suggested as reading material below. Prior to each class, the guest lecturer will suggest additional background reading material that will be posted on the class Sakai website. The precise order of these lectures is subject to change, depending upon the availability of the guest lecturers.

#### **Class 4: Efficiency: Energy, Resources, GHG Emissions (Eric Rohlfing)**

After an overview of the U.S. energy system and a brief discussion of pathways to decarbonization, this lecture will focus on efficiency, defined broadly. Examples of ARPA-E programs that may be covered in this class include: **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; **M**odern **E**lectro/**T**hermochemical **A**dvances in **L**ight **M**etals **S**ystems (METALS) that sought energy efficient methods to process ore into lightweight metals and that developed innovative methods for recycling them; **A**dvanced **R**esearch **I**n **D**ry cooling (ARID) where the objective was to devise power plant cooling technologies that eliminated water waste; **M**ethane **O**bservation **N**etworks with **I**nnovative **T**echnology to **O**btain **R**eductions (MONITOR) that developed innovative ways of sensing and mitigating methane emissions in the natural gas system; and **R**hizosphere **O**bservations **O**ptimizing **T**errestrial **S**equestration (ROOTS) that seeks to breed plants with improved root structures to better sequester carbon in the soil.

Suggested reading: The [DELTA](https://arpa-e.energy.gov/?q=arpa-e-programs/delta) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?Search=delta&SearchType=); [METALS](https://arpa-e.energy.gov/technologies/programs/metals) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=7494c8b3-e88e-48f2-b4c8-e4c093bbe077); the [ARID](https://arpa-e.energy.gov/technologies/programs/arid) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=fba1c006-c1b0-4f5d-8522-3f814a217edd); the [MONITOR](https://arpa-e.energy.gov/technologies/programs/monitor) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=b5487723-6c6b-40d6-8336-4031b8423e66); the [ROOTS](https://arpa-e.energy.gov/?q=arpa-e-programs/roots) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=063b5038-d272-4caf-91d0-d104bb80569b).

#### **Class 5: Nuclear Power Generation (Possible Guest Lecturer: Jenifer Shafer)**

This class will examine nuclear (fission) power generation – in current form and using advanced technologies. Possible ARPA-E programs to be covered 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 **C**onverting **U**NF **R**adio**I**sotopes into **E**nergy (CURIE) program seeks innovative ways to reprocess used nuclear fuel. The **O**ptimizing **N**uclear **W**aste and **A**dvanced **R**eactor **D**isposal **S**ystems (ONWARDS) program aims to facilitate a tenfold reduction in volume or repository footprint for nuclear waste from advanced reactors. In addition, a number of projects on advanced materials for and fuels for fission reactors have been supported through OPEN solicitations. 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 and the issues of how to handle nuclear waste.

Suggested reading: The [MEITNER](https://arpa-e.energy.gov/?q=arpa-e-programs/meitner) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=9688fafc-3b63-42af-9786-77d930987b4a); the [GEMINA](https://arpa-e.energy.gov/?q=arpa-e-programs/gemina) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx#FoaId4f8d5ac3-267d-4849-ad63-80f858761a74); the [CURIE](https://arpa-e.energy.gov/technologies/programs/curie) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=49ab487d-8b8b-46cb-8f1f-9c57f44f744d); the [ONWARDS](https://arpa-e.energy.gov/technologies/programs/onwards) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=7912e4f9-4475-47d7-9a2c-2993e369c410).

#### **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.

#### **Class 6: Carbon Capture (Possible Guest Lecturer: Scott Litzelman)**

Almost every scenario for decarbonizing the energy system includes carbon capture from fossil fuel generation sources at some level. In its early days, ARPA-E ran the **I**nnovative **M**aterials and **P**rocesses for **A**dvanced **C**arbon **C**apture **T**echnologies (IMPACCT) the sought innovative new materials and processes to remove CO2 from the exhaust streams of coal-fired power plants. For several years following, the agency struggled to find appropriate projects or programs in carbon capture. Recently, the agency has launched the **FLE**xible **C**arbon **C**apture and **S**torage (FLECCS) program that is much more relevant to realistic future applications of carbon capture technology. FLECCS seeks to develop CCS technologies that enable power generators to be responsive to grid conditions in an environment with a high penetration of renewables, e.g., a highly decarbonized system. Finally, ARPA-E has recently funded several direct air capture projects and the technical and economic feasibility of these projects will be discussed.

Suggested reading: The[IMPACCT](https://arpa-e.energy.gov/technologies/programs/impacct) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?Search=impacct&SearchType=); the [FLECCS](https://arpa-e.energy.gov/technologies/programs/fleccs) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?Search=fleccs&SearchType=).

#### **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”](https://www.pbs.org/wgbh/nova/video/search-for-the-super-battery/) provides an excellent introduction to solid state batteries and features several ARPA-E project teams. The [IONICS](https://arpa-e.energy.gov/?q=arpa-e-programs/ionics) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=d3b62d65-4754-4cb4-b879-d2e6cea654eb); the [DAYS](https://arpa-e.energy.gov/?q=arpa-e-programs/days) program and project descriptions and[FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=c931d71c-1e66-4fea-8a27-91860bcd781d).

#### **Class 8: Decarbonizing Industry (Possible Guest Lecturer: Ashwin Salvi)**

This class will cover approaches to the decarbonization of the industrial sector, thought to be one of the most significant challenges to achieving net-zero carbon emissions by mid-century. Industry makes widespread use of fossil fuels for the heat that drives chemical and materials processes, making all of the “stuff” that permeates our daily lives – concrete, steel, plastics, medicines, etc. ARPA-E has not run any programs on the specific topic of decarbonizing industrial process heat (but they should have and maybe they will). However, any program that deals with improved heat transfer properties or more efficient use of heat are relevant. One such program is HITEMMP, which aims to develop new approaches and technologies for the design and manufacture of high temperature, high pressure, efficient, and highly compact heat exchangers. In this lecture, the primary topic is likely to be using zero carbon electricity (from renewables or nuclear) to generate industrial process heat via heat pumps.

Suggested reading: The[HITEMMP](https://arpa-e.energy.gov/technologies/programs/hitemmp) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=a16ef45a-b2e3-4f40-b52d-e6ceebbf9e66).

#### **Project #3 (oral and written)**

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

#### **Class 9: Next Generation Grid (Possible Guest Lecturer: Josh Gould)**

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](https://www.arpa-e.energy.gov/?q=arpa-e-programs/nodes) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=c039dfd3-ae21-47e7-801c-fd13b2bf18ad)[;](https://arpa-e-foa.energy.gov/Default.aspx?Archive=1#FoaIdc039dfd3-ae21-47e7-801c-fd13b2bf18ad) the [GRID DATA](https://arpa-e.energy.gov/?q=arpa-e-programs/grid-data) program and project descriptions and[FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=986e4f22-e6af-4423-86ce-5632ce8dfafb); the [GO](https://arpa-e.energy.gov/?q=arpa-e-programs/go-competition) competition description; the [PERFORM](https://arpa-e.energy.gov/?q=arpa-e-programs/perform) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=cf23a62d-a269-4369-a408-bfb4ba014f8d).

#### **Class 10: Mobility (Possible Guest Lecturer: Ann Xu)**

This class will examine some of ARPA-E’s programs aimed at making mobility energy efficient. 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.

Suggested reading: The [NEXTCAR](https://arpa-e.energy.gov/?q=arpa-e-programs/nextcar) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=739efe2c-f3ec-4b2f-98b5-95f9aec9af02); the [TRANSNET](https://arpa-e.energy.gov/?q=arpa-e-programs/transnet) program and project descriptions and [FOA](https://arpa-e-foa.energy.gov/Default.aspx?foaId=a65ecb06-eb2c-43e5-8b96-bd902efff4e8).

#### **Class 11: 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 **T**ransistors 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](https://arpa-e.energy.gov/?q=publications/wide-band-gap-semiconductor-based-power-electronics-energy-efficiency), is an excellent introduction. Also the [ADEPT](https://arpa-e.energy.gov/?q=arpa-e-programs/adept), [SWITCHES](https://arpa-e.energy.gov/?q=arpa-e-programs/switches), [CIRCUITS](https://arpa-e.energy.gov/?q=arpa-e-programs/circuits), and [BREAKERS](https://arpa-e.energy.gov/?q=arpa-e-programs/breakers) program and project descriptions.

#### **Class 12 & 13: Student Program Pitches**

The last 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.