Fusion Update from the Advanced Research Projects Agency-Energy (ARPA-E)

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Fusion Power Associates 41st Annual Meeting (virtual)
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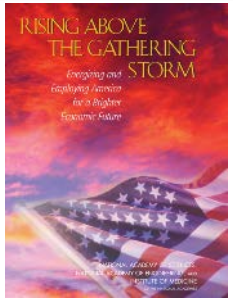
Outline

- Introduction
- Fusion portfolio and 2020 highlights
- Plans/opportunities

ARPA-E's history and mission



2007

American Recovery & Reinvestment Act **Signed** – ARPA-E's first appropriations of $400 million, which funded ARPA-E's first projects

2009

2020

850+ Awards
54 Programs

FY20 Funding:
$425M

Goal 1: Overcome long-term and high-risk technological barriers in the development of energy technologies that…

Goal 2: Ensure that the U.S. maintains a technological lead in developing and deploying advanced energy technologies.

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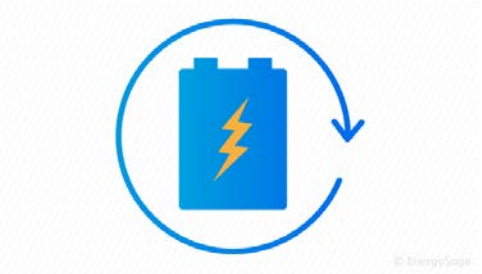
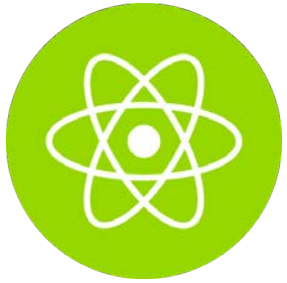
Framing of fusion energy within ARPA-E's program portfolio

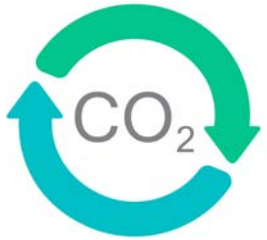
- Fusion energy sits at arguably the highest-risk, highest-impact end of ARPA-E's entire energy-technology portfolio
  - Fusion has the potential to be a high-power-density, firm, low-carbon energy source that can possibly be sited near dense population centers
  - Fusion can potentially disrupt the way humans generate and use energy
- Fusion is valuable risk mitigation for the world to achieve cost-effective "net-zero" GHG emissions while meeting growing energy demand and electrification
  - There are a limited number of low-carbon, primary-energy solutions, all with significant technical and/or socio-economic challenges:



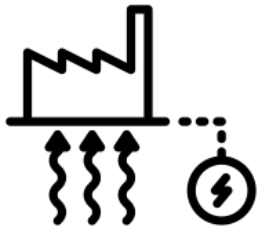
Renewables + long-duration storage



Advanced nuclear fission



Fossil fuels with carbon capture, utilization, sequestration (CCUS)



Enhanced geothermal

+ fusion?

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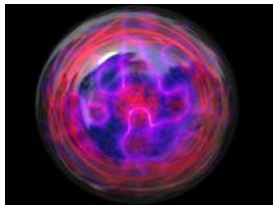
ARPA-E fusion timeline/programs

Program Director Dr. Pat McGrath decides to develop a fusion program

C. Nehl et al., ``Retrospective of the ARPA-E ALPHA Fusion Program,'' *J. Fusion Energy* **38**, 506 (2019).

ALPHA



2013 | 2015 | 2018 | 2019 | 2020

OPEN 2018

77 PROJECTS

Included three fusion projects

Diagnostic "capability teams"

joint with DOE Fusion Energy Sciences

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Thought process behind new ARPA-E fusion programs

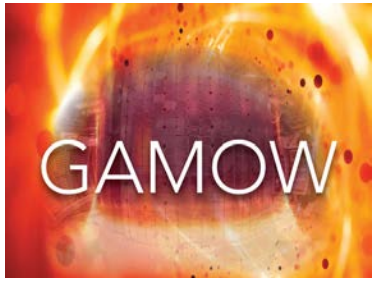
Aspiration: catalyze a new trajectory toward commercially viable DEMO on a two-decade time scale.

Technical drivers

More low-cost approaches at higher levels of fusion performance

+ diagnostic teams

Innovative solutions from the first wall to the heat exchanger



joint with FES

Programmatic drivers

Engage larger portion of the fusion R&D community

Leverage SotA expertise/capabilities

Incentivize publicly and privately funded teams to work together

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BETHE* program: Catalyze R&D to deliver a larger number of lower-cost fusion concepts at higher performance levels

- Projected net-gain experiment for ≲ $100M
- Specify entry/exit milestones
- Funding ceiling commensurate w/ achieved performance
- Leverage capability teams
- Selected projects include mirrors, spheromak, MIF, Z pinch, μ-catalyzed fusion

Advance the performance of lower-cost concepts

- Concept development
- Capability teams

Lower the cost of more-mature concepts

- Component technology development

- Potentially enable overnight capital cost <$2B, <$5/W
- Selected projects include fast-ramping tokamak HTS central solenoid, new approaches to stellarator magnets, next-gen high-bandwidth lasers

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*Breakthroughs Enabling Thermonuclear-fusion Energy; click here for program overview

BETHE portfolio ($35M + $5M FES): 17 projects across 3 technical categories

Category A: Concept development

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

UMBC

ZAP ENERGY

NK

UNIVERSITY OF WASHINGTON
LVX · SIT
1861

Los Alamos
NATIONAL LABORATORY
EST. 1943

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Category B: Component technology development

Commonwealth Fusion Systems

PPPL

LABORATORY FOR LASER ENERGETICS
UNIVERSITY OF ROCHESTER

U.S. NAVAL RESEARCH LABORATORY

Jointly funded with FES

TYPE ONE ENERGY

Category C: Capability teams

VT

OAK RIDGE
National Laboratory

Los Alamos
NATIONAL LABORATORY
EST. 1943

LABORATORY FOR LASER ENERGETICS
UNIVERSITY OF ROCHESTER

SapientAI, LLC

Massachusetts Institute of Technology

Prime recipients: 7 universities, 5 private companies, 5 national labs; click here for full list of project teams.

GAMOW* program: Accelerate R&D in fusion enabling technologies to support commercially viable fusion concepts

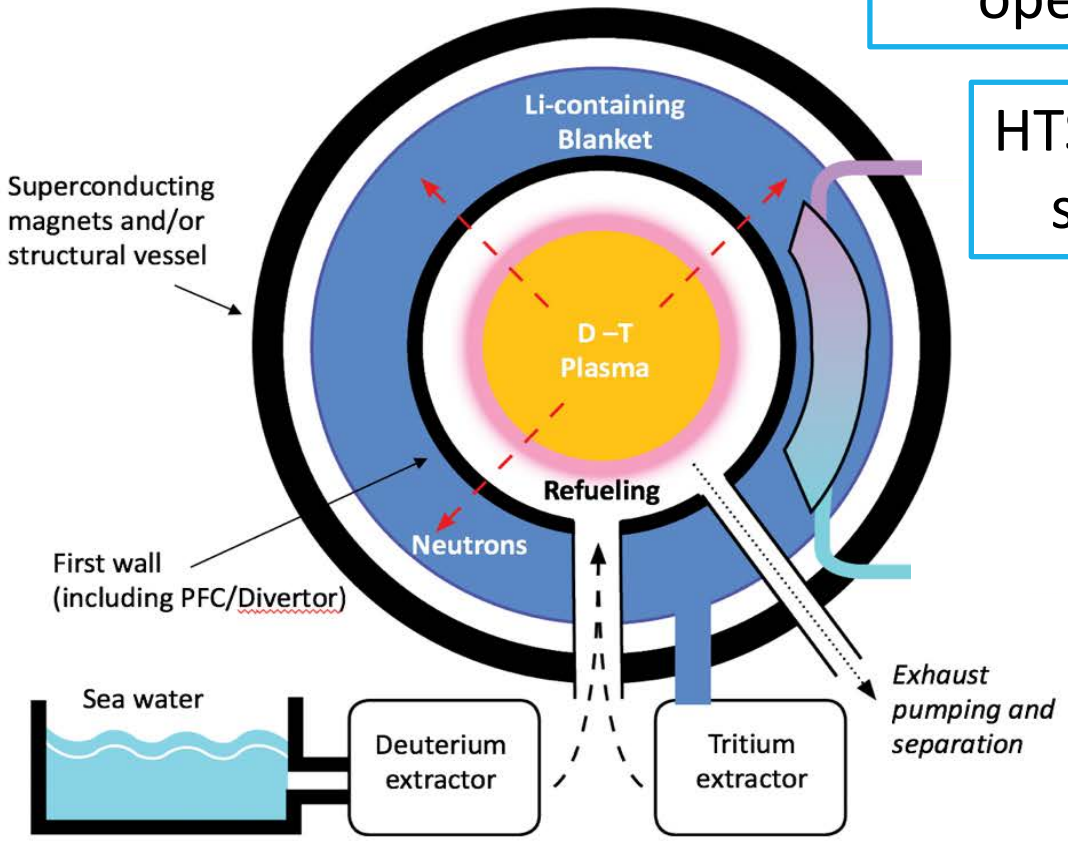
Deployable in experiments well within a decade

Device simplification or elimination of entire subsystems

Significant cost reduction

Improvements in RAMI, safety, sustainability

Joint program with FES



>900-K blanket operation

HTS tape <$10/kA-m, substrate >3 GPa

<1000-Ci (100-mg) T annual release

>10-MW/m^2 continuous power handling at 1st wall

<0.75-kG T inventory for 500-MW_{th} system

*Galvanizing Advances in Market-aligned fusion for an Overabundance of Watts; click here for program overview.

GAMOW portfolio ($29M): 14 projects across 7 technical categories

Integrated First-Wall and Blanket Technology

- Fusion Energy Reactor Models Integrator (FERMI), *Oak Ridge National Laboratory*

Plasma-Facing Components (PFC) and Divertor

- Renewable low-Z wall for fusion reactors with built-in tritium recovery, *University of California: San Diego*

Tritium Fuel Cycle

- Interfacial-Engineered Membranes for Efficient Tritium Extraction, *Colorado School of Mines*
- Direct LiT Electrolysis Process Modeling & Scale up, *Savannah River National Laboratory*
- EM-Enhanced HyPOR Loop for Fast Fusion Fuel Cycles, *Savannah River National Laboratory*

Joint program with FES

Superconducting Magnets

- Advanced HTS Conductors Customized for Fusion, *University of Houston*

High-efficiency electrical-driver systems

- Wide Band Gap Semiconductor Amplifiers for Plasma Heating and Control, *Princeton Fusion Systems*
- AMPERE - Advanced Materials for Plasma-Exposed Robust Electrodes, *University of California: Los Angeles*
- High Efficiency, Megawatt Class Gyrotrons for Instability Control of Burning Plasma Machines, *Bridge 12 Technologies*

Novel Fusion Materials

- Advance Castable Nanostructured Alloys for First-Wall/Blanket Applications, *Oak Ridge National Laboratory*
- Ultra High Flux DT Neutron Source for Accelerated Testing of Fusion Materials and Subsystems to Reactor-relevant DPA Levels, *Phoenix LLC*
- ENHANCED Shield: A Critical Materials Technology Enabling Compact Superconducting Tokamaks, *Stony Brook University*

Advanced and Additive Manufacturing

- Plasma Facing Component Innovations by Advanced Manufacturing and Design, *Oak Ridge National Laboratory*
- Microstructure Optimization and Novel Processing Development of ODS Steels for Fusion Environments (MONDO-FE), *Pacific Northwest National Laboratory*

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Prime recipients: 5 universities, 3 private companies, 6 national labs; click here for full list of project teams.

Tech-to-Market (T2M) priorities for the ARPA-E fusion portfolio

- Investor engagement

- Market studies
- Updated reactor-costing tool, studies, and support of concept teams

WOODRUFF • SCIENTIFIC

- Engaging NGOs (who will be the advocates for the ultimate commercial adoption of fusion)
- Supporting/coaching our project teams (on development plan, team building, securing follow-on funding, etc.)

Summary of findings from ARPA-E report *Early Markets for Fusion Energy*

- Most-promising early markets are high-priced electricity markets around the world (up to $110/MWh, e.g., Singapore, Japan, California)
  - Eventually, fusion may need to cost <$50/MWh to access very large markets (to compete with natural gas w/CCS and $50/ton carbon tax)
- Load-following may not be economically feasible for fusion (it cannot afford to sit idle half the time due to large capital cost)
  - Integrated thermal storage may be needed so plant can run at high capacity factor
- Process-heat and hydrogen-production markets will be tough early markets (also, fusion may not be able to achieve the needed high temperatures)
- Desalination & direct air capture alongside power generation or retrofitting coal power plants may help make fusion more economically competitive

See Malcolm Handley's talk from BETHE kickoff, and read the report when it is released in the near future.

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Upcoming opportunities

- Teaming partner announcement posted for potential OPEN 2021 FOA (agency-wide)
  - Fusion energy
  - Energy/electrification applications of low-temperature plasmas (LTP)
  - Nuclear waste disposition

- Recruit my “successor” to start hopefully no later than mid-2022

Please contact me to discuss any of the above: scott.hsu at hq.doe.gov.

Check https://arpa-e-foa.energy.gov regularly for new FOAs.

Sign up for ARPA-E newsletter to receive updates.

Join the Team that is Transforming the Energy of Tomorrow

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- Techno-economic analyses
- Stakeholder outreach

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- Organizational support

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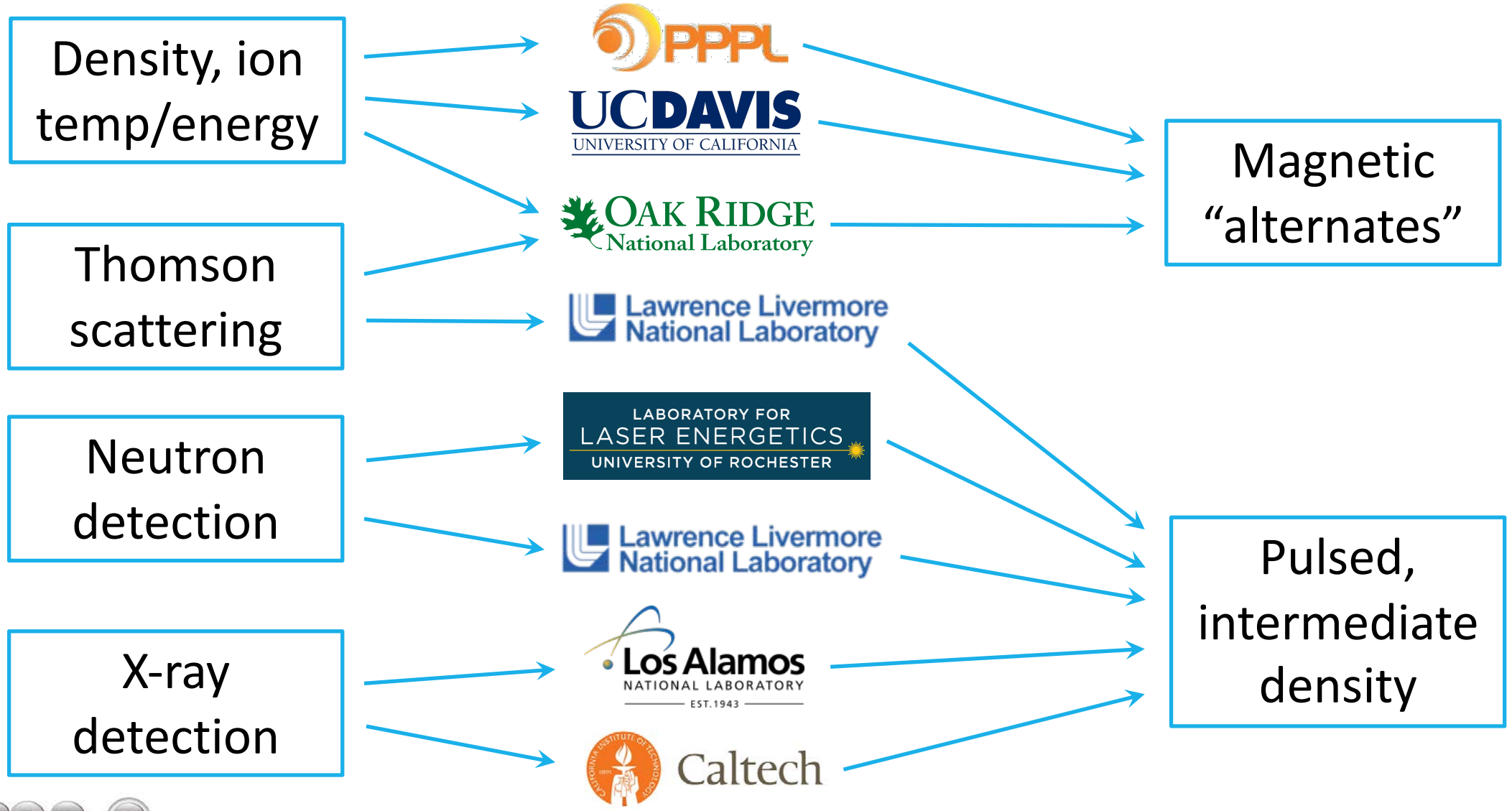
https://arpa-e.energy.gov

Diagnostic capability teams: "Transportable" diagnostics & expert diagnosticians to support ARPA-E fusion concept teams ($7.4M)



Click here for full list of project teams.

BETHE capability teams

Lead Institution	Primary Model/Codes or Diagnostic	Teams supported
VT	High-fidelity moment-kinetic models, Gkeyll	Wisconsin, LANL, UMBC, General Fusion
SapientAI, LLC	Data analytics, machine learning, AI	CTFusion, LANL, General Fusion
LABORATORY FOR LASER ENERGETICS UNIVERSITY OF ROCHESTER	Rad-MHD (FLASH), hybrid/kinetic (TriForce), kinetic PIC (OSIRIS)	MIFTI, PFS/PPPL, LANL, Compact Fusion Systems
Massachusetts Institute of Technology	RF modeling	Wisconsin, PFS/PPPL, UMBC
Los Alamos NATIONAL LABORATORY EST. 1943	Solid-state X-ray imager; multi-chord spectroscopy	tbd
OAK RIDGE National Laboratory	Doppler-free saturation spectroscopy (*B* and *E*)	PFS, TAE (via INFUSE)