ARPA-E Fusion Workshop General Overview, Objective and Theme A Description

Ahmed Diallo, Program Director, ARPA-E

Fusion New Program Development Workshop
March 7, 2023

ARPA-E New Fusion Program Development Team

ARPA-E

Ahmed Diallo
Program Director

Sam Wurzel
T2M Advisor

Anil Ganti
ARPA-E Fellow

Special Thanks to ARPA-E Directors and Fellows:

- Bob Ledoux – Program Director
- Laurent Pilon – Program Director
- Olga Spahn – Program Director
- Phil Kim – Program Director
- Katharine Greco – ARPA-E Fellow

Booz Allen SETAs

Edward Cruz

Cheng Xu

Pankaj Trivedi

Colin Gore

Sade Ruffin

- Christina Leggett
- Nancy Hicks

ARPA-E Mission

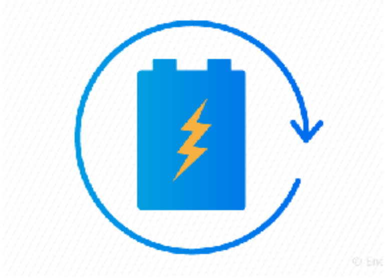
Goal 1: To enhance the economic and energy security of the U.S. through the development of energy technologies that—

- REDUCE IMPORTS
- IMPROVE EFFICIENCY
- REDUCE EMISSIONS
- IMPROVE THE MANAGEMENT, CLEAN-UP, AND DISPOSAL OF RADIOACTIVE WASTE AND SPENT NUCLEAR FUEL
- IMPROVE THE RESILIENCE, RELIABILITY, AND SECURITY OF ENERGY INFRASTRUCTURE

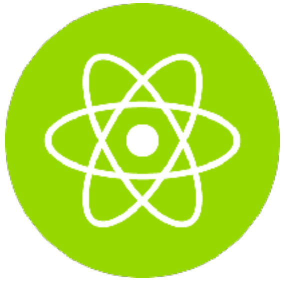
Goal 2: To ensure that the U.S. maintains a technological lead in developing and deploying advanced energy technologies.

Framing of fusion energy within ARPA-E’s portfolio

- Fusion samples the **highest-risk and highest-impact end of ARPA-E’s portfolio**

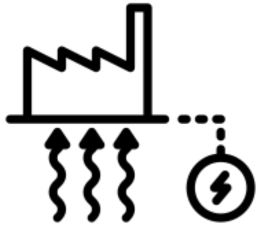


Renewables + long-duration storage



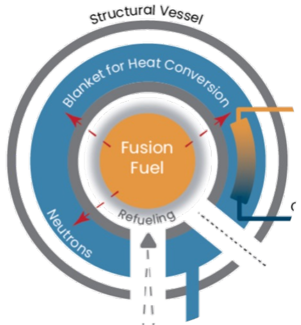
Advanced nuclear fission

Fossil w/CCUS



Enhanced geothermal

Biofuels



Fusion

Benefits

Zero carbon emissions

Dispatchable

Globally scalable

Beyond 2050 - risk-mitigation option for meeting net-zero targets

ARPA-E impact on commercial fusion R&D

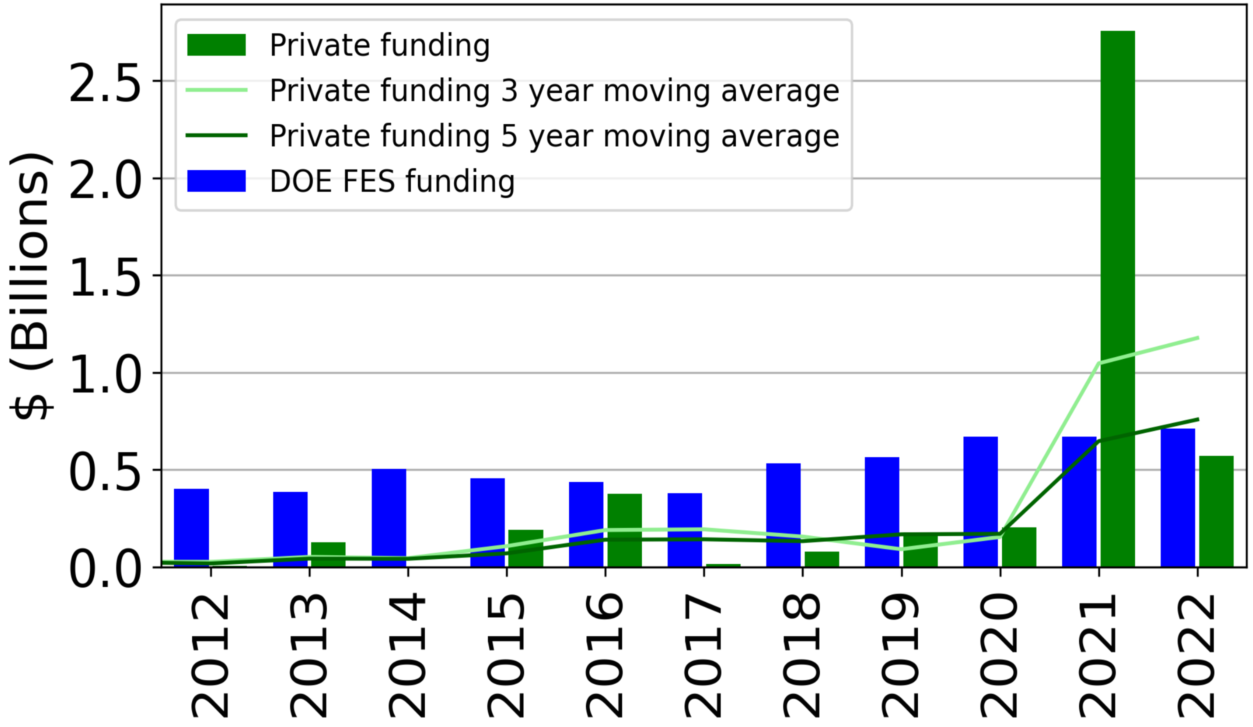
- ARPA-E's fusion programs changed fusion R&D landscape
  - ***$780M (and growing) of private funding as a result of ARPA-E fusion awards***
  - *Focus on capital cost and projected levelized cost of electricity (LCOE)*

- New (MIF) and renewed (MFE/IFE) investigations of promising fusion concepts
  - *Enabling materials & technologies R&D focused on multiple, commercially oriented concepts*

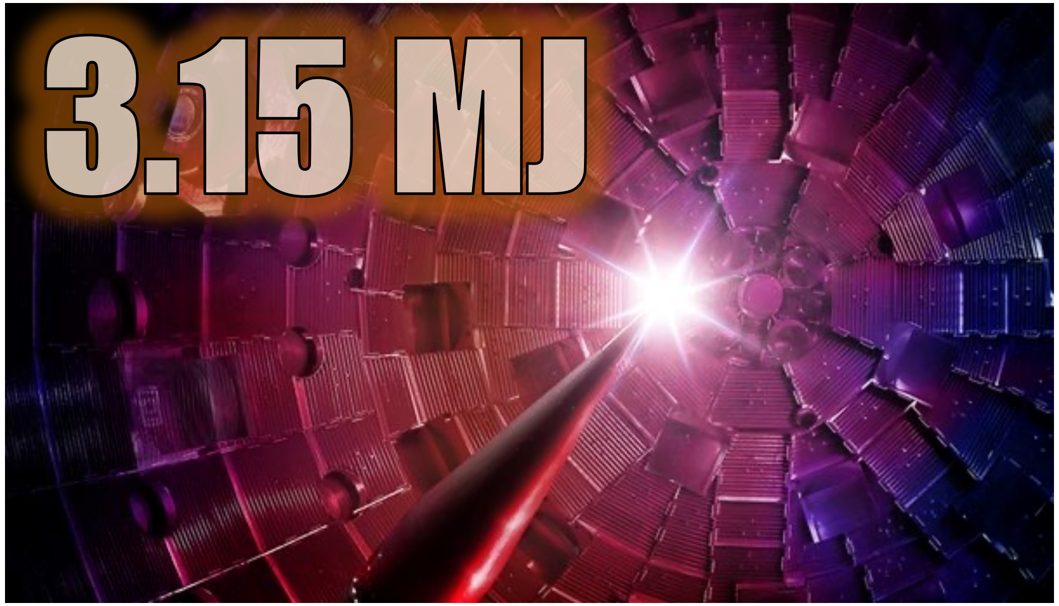
- From *one* (ITER) to multiple development paths (CFS, CTFusion, Helion, HyperJet, Realta, Type One, Zap, etc.)
  - 6 new fusion companies from ARPA-E programs so far

- Broad engagement with commercialization stakeholders

Commercial Fusion Needs Accelerated Development



Growth of private-sector fusion investments
Figure credit: Sam Wurzel, ARPA-E

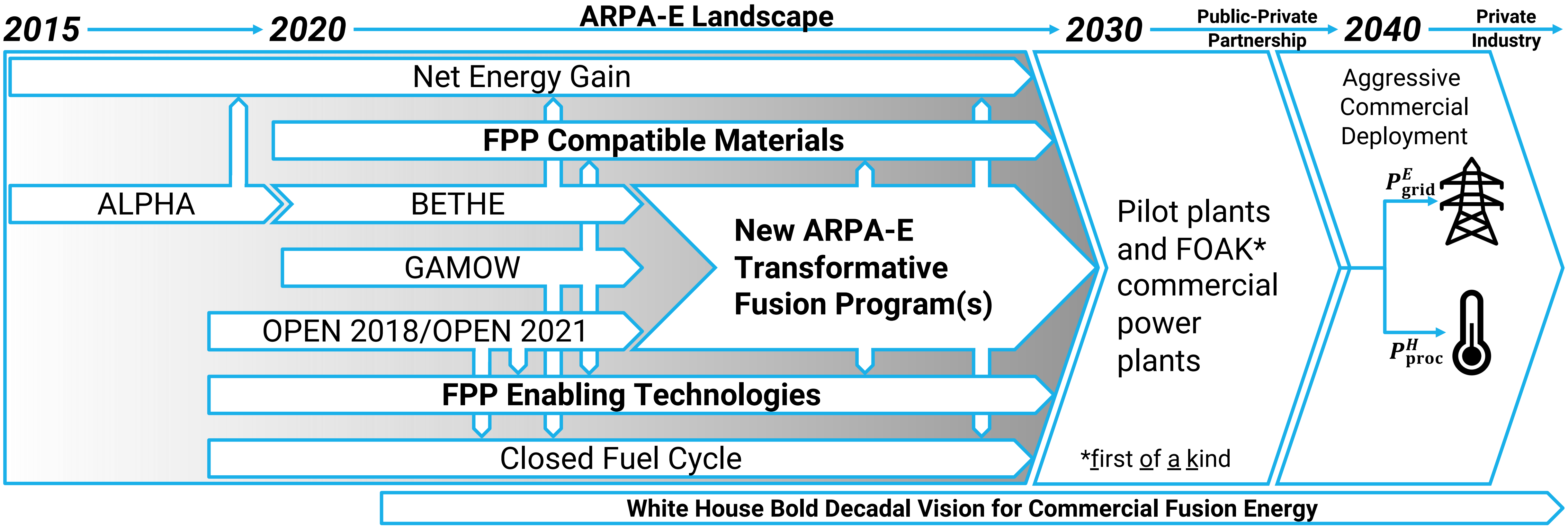


- Commercial investment in fusion energy has been steadily increasing
- Scientific feasibility of ignition has *finally* been demonstrated!
- White House bold decadal vision combined with recent breakthroughs provide a clear path to a Fusion Power Plant (FPP)

Still Unmet Requirements of a Fusion Power Plant (FPP)

- **FPP compatible materials**
  - *Robust materials are essential, needing a dedicated and FPP relevant neutron source for validation and development*
- **FPP enabling technologies**
  - *Increase attractiveness of FPPs by increasing plant efficiency and availability, reducing the cost and operational complexity*
- **Net energy gain**
  - *A high-performance plasma producing net energy is at the center of any potential FPP*
- **Closed fuel cycle**
  - *Tritium self-sufficiency is a key requirement for the first commercial FPPs*
  - *EPRI Fusion Fuel Cycles and Blankets Workshop 2023 to be held May 23rd – 25th, 2023 at EPRI's offices in Charlotte, NC.*

How ARPA-E Fusion Programs Align with FPP Requirements



arpa·e CHANGING WHAT'S POSSIBLE

Workshop Objective

- Refocus the conversation around the enabling technologies.
- Foster collaboration to tackle fusion related technology challenges.
- Support transformative R&D to enable a grid-ready, commercially viable fusion demonstration in decadal time frame.

Key Enabling Technologies for Low-Cost Fusion Energy

Low-cost commercial fusion energy

A **Improving performance with innovative heating schemes and high-performance targets**

Advanced driver technologies and target-driver architectures

Microwave heating (e.g., high-power, long-pulse microwave sources with electrical efficiency ≥ 55%)

Neutral particle beam heating challenges (e.g., novel neutral beam approaches; negative ion beam system with electrical efficiency > 60%)

- Low-cost scalable high rep-rate laser drivers for inertial fusion
- Reproducible target design and delivery systems at few Hz
- Optics technology with higher damage threshold tolerance to optics damage (gas optics, etc.)

B **Increasing FPP availability through accelerated discovery of novel fusion materials**

Materials “by design” for all aspects of FPP

Solid & self-healing materials with the following features

- minimize half-lives of materials
- reduce dust formation
- minimize fuel retention (e.g., hydrogen)
- minimize the displacement per atom due to neutron irradiations
- high heat resistant (> 600 C)
- corrosion resistant

Workshop Topics Break Down

- **Theme A (Day 1):** Improving fusion power plant (FPP) performance with innovative heating schemes, advanced drivers and high-performance targets and fueling

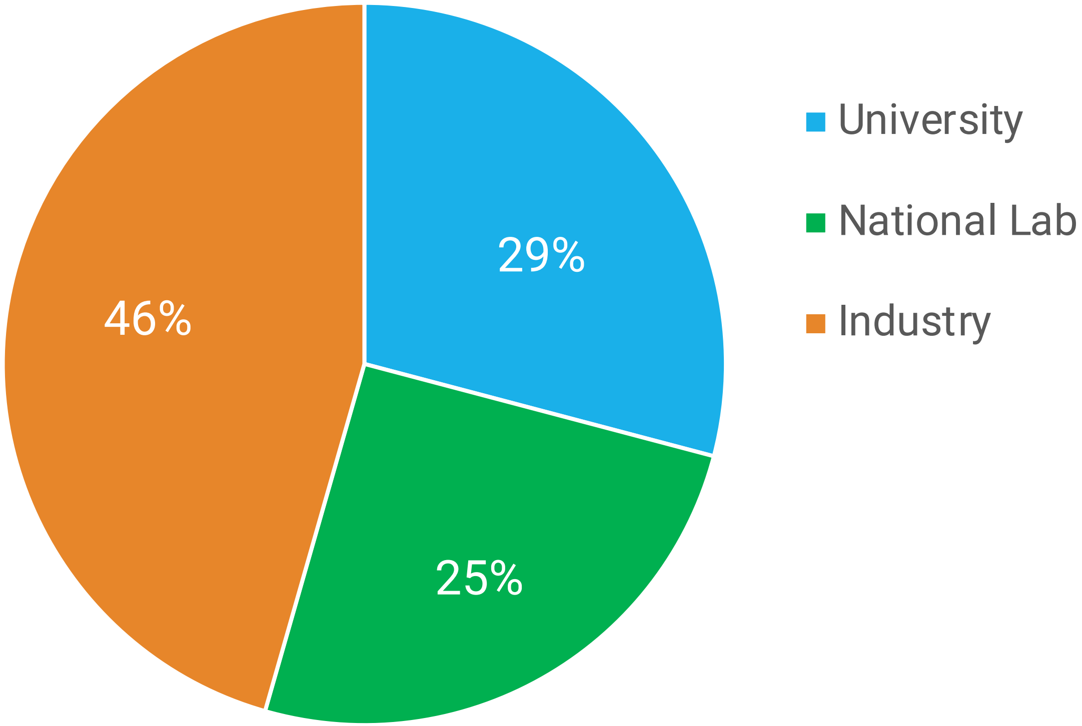
- **Theme B (Day 2):** Increasing FPP availability through accelerated discovery, synthesis, verification, implementation and scaling of novel fusion materials

- **Bonus:** Game-changing ideas are necessary to accelerate these technologies to a point suitable for low-cost commercial fusion energy

Breakdown of Workshop Attendees

- **95 total attendees, thank you all for coming!**
- **Problems ahead require major collaboration, please make connections and look forward towards working together**

Institutional Breakdown of Attendees:



- Attendees include:

Theme A: Heating systems for MFE

Technology	Objective(s)	Current SOTA	Possible targets
Gyrotrons for electron cyclotron resonance heating (ECH) and current drive	Increase power, frequency, efficiency and availability while reducing cost	• Up to 1 MW output power • Up to 200 GHz frequency • Up to 50% efficiency • Up to 300 s pulse width • Not all at once	• ~2 MW output power • >250 GHz frequency • >300 s pulse width • ~70% efficiency • 10x reduction in $/W of output power • 2x-5x increase in lifetime of high-current emitter materials • All at once
Neutral Beam Injection (NBI) systems for plasma heating and control and reactor fueling	Increase current density, efficiency, reliability and modularity while reducing size and complexity	• ~1 MeV output • ~60% neutralization efficiency • ~26% wall plug efficiency • ~200 A/m^2 peak negative ion (D-) current density	• ~1 MeV output • ≥90% neutralization efficiency • ≥70% wall plug efficiency • ≥600 A/m^2 peak negative ion (D-) current density • ≥50% source power per unit injected power • 10x reduction in $/W of output power • 3x improvement in up time between service intervals

Theme A: Laser Systems and fuel system

Technology	Objective(s)	SOTA	Possible targets
Electron beam pumped ArF excimer lasers and diode pumped solid-state lasers (DPSSL)	Increase rep rate and availability for ArF lasers; dramatically reduce cost of diode and improve lifetime of gain medium for solid-state lasers	• < 1 every 2 - 8 hrs rep-rate (NIF) • Sub 1% wall-plug efficiency at 3ω • Diode for DPSSL systems not cost competitive for commercial FPPs.	• ≥10 Hz shot rep-rate • ≥10% wall-plug efficiency at 3ω • ≥≥70 kV at >30 kA solid-state switch performance • >3-year lifetime of electron beam foil window for ArF • 10x reduction in cost of diode for DPSSL systems • 3x improvement in thermal shock resistance value of gain medium for DPSSL
IFE target delivery & manufacturing	Cheaply produce robust targets in mass quantities that can be rapidly delivered to the target chamber	• <10 targets per day • >$100 cost per target	• Production capacity of ~1M targets per day • <$0.05 cost per target
Final focusing optics	Increase lifetime and availability at 3ω		• >1 billion shot lifetime

CHANGING WHAT'S POSSIBLE

Day 1 Agenda – Theme A

Innovative Heating Schemes, Advanced Drivers and High-Performance Targets and Fueling

Time	Event
8:00 – 9:00 am	Registration, Coffee, Snacks, & Networking
9:00 - 9:05 am	Welcome & Introduction to ARPA-E Dr. David Tew – Acting Deputy Director Technology, ARPA-E
9:05 - 9:20 am	Workshop rationale and Theme A description Dr. Ahmed Diallo – Program Director, ARPA-E
9:20 – 9:25 am	ARPA-E Fusion T2M Overview Mr. Sam Wurzel – T2M Advisor, ARPA-E
9:25 – 10:25 am	Plenary: 2022 DOE Basic Research Needs for Inertial Fusion Energy (IFE) Dr. Tammy Ma – Advanced Photon Technologies (APT) Program Element Leader for High-Intensity Laser High Energy Density (HED) Science, LLNL
10:25 – 10:45 am	Coffee Break & Networking
10:45 – 11:10 am	Diode-pumped, solid-state laser (DPSSL) drivers for Inertial Fusion Energy (IFE) Dr. Jonathan Zuegel – Laser and Materials Technology Division Director, LLE
11:10 – 11:35 am	High-Energy Excimer-Raman-Brillouin IFE Laser Mr. Conner Galloway – CEO and Founder, Xcimer Energy
11:35 – 12:00 pm	ArF Repetition-Rate Laser and Pulse Power Technologies Enabling Smaller Lower Cost Fusion Power Plant Designs Dr. Matt Wolford – Head Electron Beam Science & Applications Section, NRL
12:00 – 1:00 pm	Lunch
1:00 – 1:25 pm	Fabrication, Verification, and Manufacturing of Fusion Targets Dr. Yongfeng Lu – Lott Distinguished Professor of Electrical and Computer Engineering, Mechanical and Materials Engineering, University of Nebraska
1:25 – 1:50 pm	Next Generation Gyrotron Sources for ECH Dr. Monica Blank – Senior Scientist in the Gyrotron Group, CPI
1:50 – 2:15 pm	Neutralized-Ion Beams Dr. Frank Wessel – Chief Scientist, SAFEnergy

2:15 – 2:30 pm	**Breakout Session 1: Introduction & Objectives** **Dr. Ahmed Diallo – Program Director, ARPA-E**
2:30 – 2:45 pm	Coffee Break; transition to breakout sessions
2:45 – 4:15 pm	Breakout Session 1: Metrics for Theme A w/ Focus on Cost Group 1: RF and Neutral Beam Heating Systems Group 2: Solid-State Laser Drivers and Optical Materials Group 3: Excimer Laser Drivers and Pulse Power Systems Group 4: Target Manufacturing and Fuel Delivery
4:15 – 4:45 pm	Break, Snacks & Networking
4:45 – 5:30 pm	Report out of breakout session 1
5:30 – 5:45 pm	Q & A
6:00 – 8:00 pm	Optional one-on-one meetings with PD
5:45 pm	Conclusion of Day 1