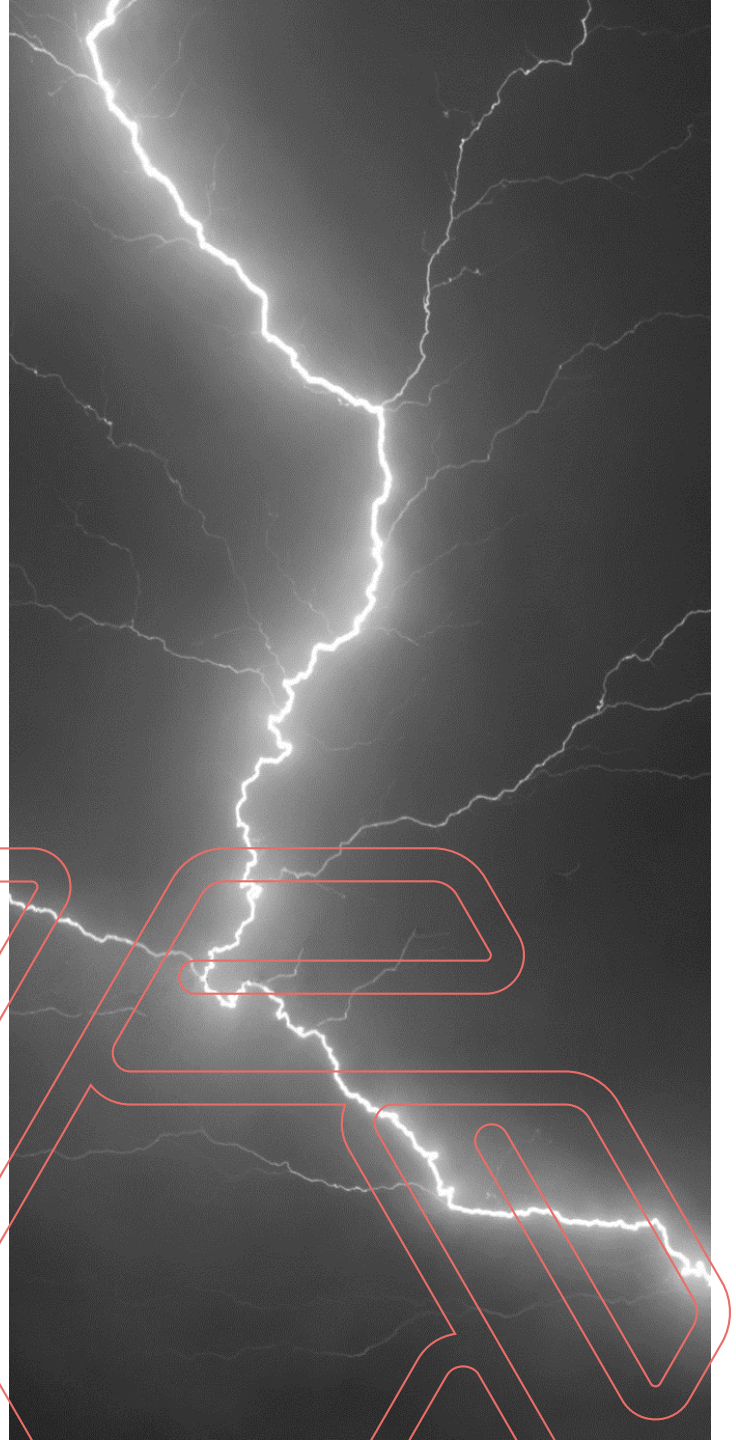

Creating Hardened and Durable Fusion First Wall Incorporating Centralized Knowledge (CHADWICK)

CHADWICK Kickoff Meeting

Dr. Ahmed Diallo
Program Director

March 27, 2025

CHADWICK Team

Ahmed Diallo
ARPA-E, Program Director

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BAH, Tech SETA

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Heather Jackson
ARPA-E, T2M Advisor

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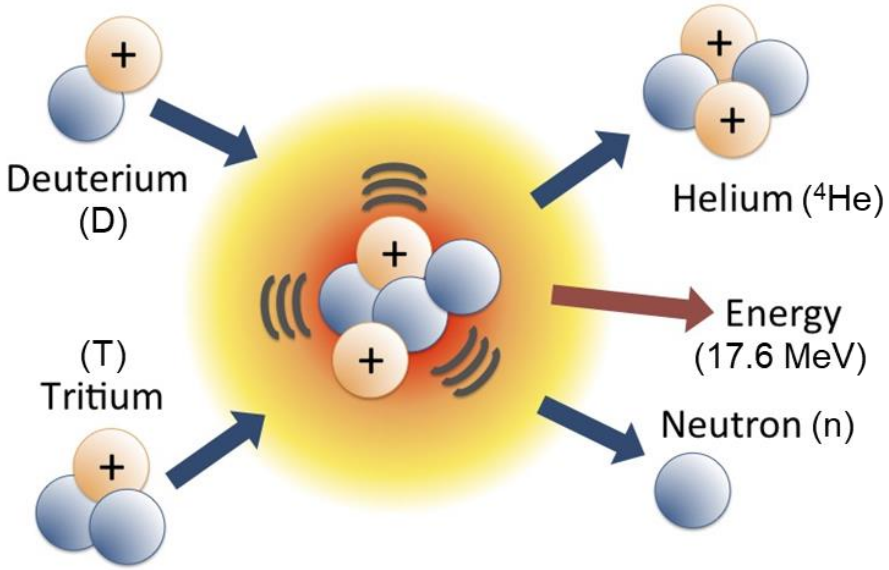
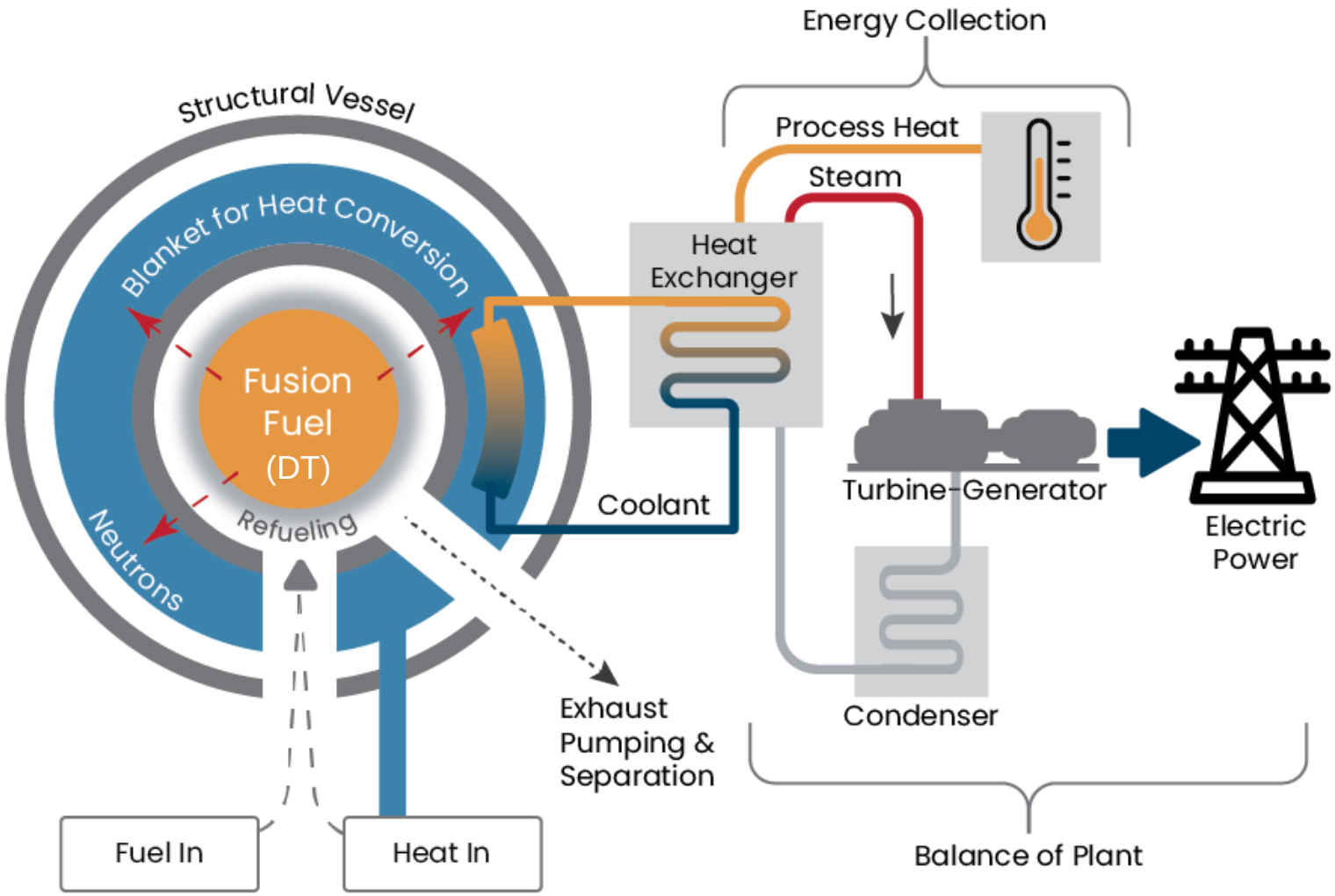
BAH, PM-SETA

Grace Brach
BAH, PM-SETA

Emma Guitar
BAH, PM-SETA

Fusion Energy

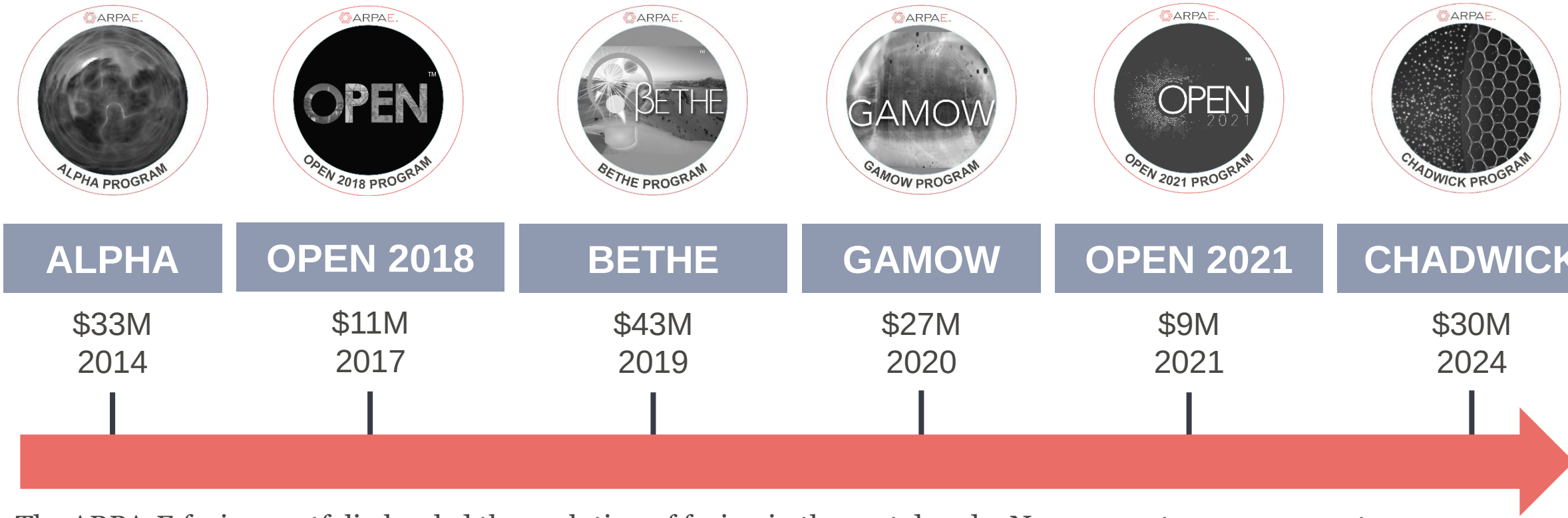




Potential benefits:

- Firm, zero carbon emissions
- Globally scalable
- Low land use
- Site in or near cities
- No high-level radioactive waste

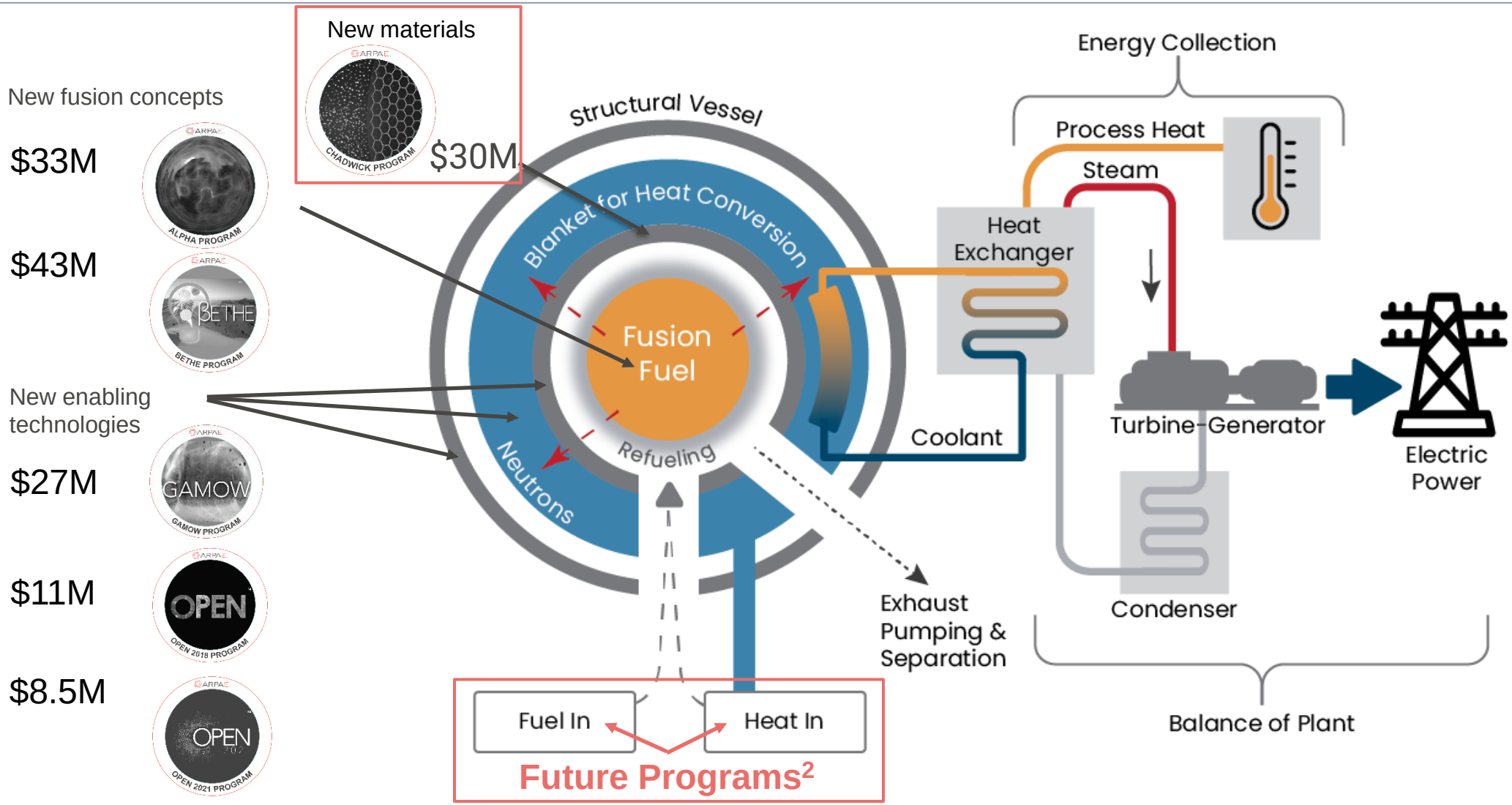
ARPA-E Fusion Programs: A Portfolio Approach



The ARPA-E fusion portfolio has led the evolution of fusion in the past decade: New concepts → component technology and teams → system simplification and cost reduction → technology for longer lasting powerplants

At each stage, ARPA-E has catalyzed significant investments from VC through strong thought leadership and sound technical diligence, leading to >$1.5B in private follow-on funding for fusion

CHADWICK and Future Programs

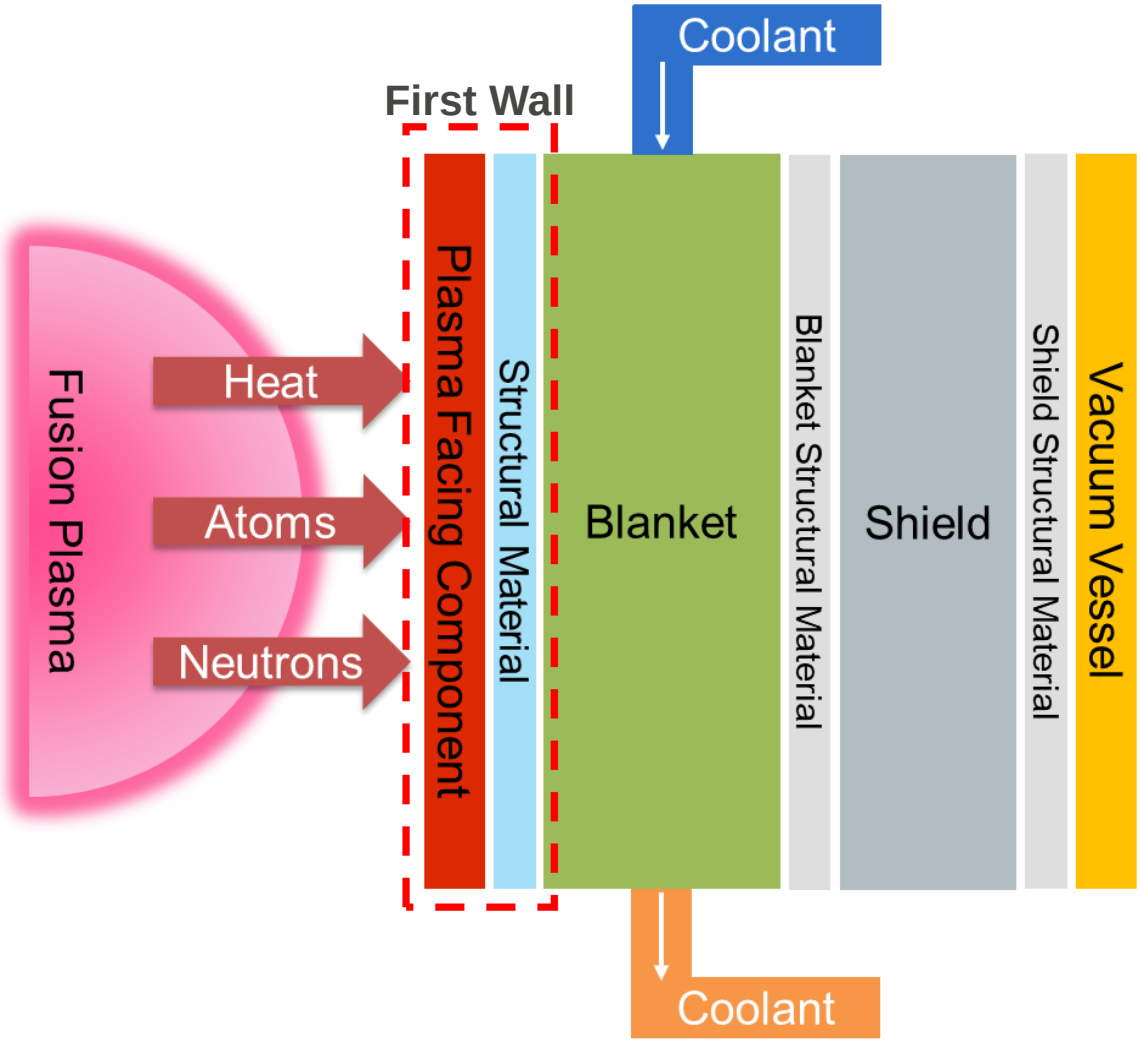


1. Selections Made
2. Programs under development

What Challenges Remain for Fusion Materials?

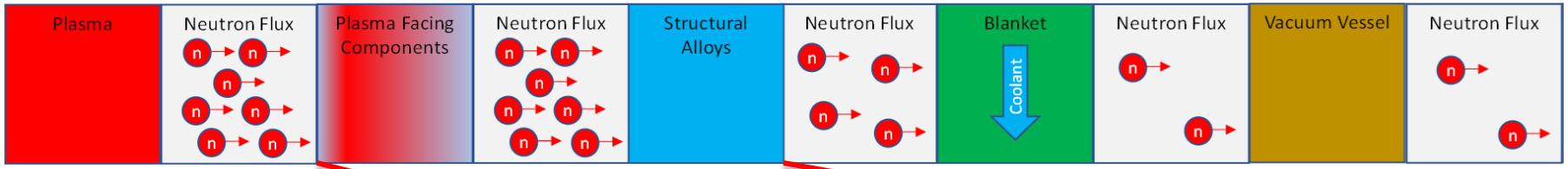
First wall materials remain a major challenge due to:

- High heat flux and temperature
- High energy neutron irradiation
- Direct hot plasma exposure
- High energy hydrogen and helium bombardment (ions and neutrals)



Existing materials are not expected to last more than 5 years

First Wall Material Technical Challenges by the Numbers



CHALLENGE	Estimated Range	Plasma Facing Components	Structural Alloys
Neutron Flux	5 x 10^{13} – 5 x 10^{14} (n/cm^2/s)	VERY HIGH	VERY HIGH
Temperature	600°C – 900°C	VERY HIGH	HIGH
Heat Flux	~ 10MW/m^2	HIGH	VARIED
Helium Generation	~10appm He/dpa	VARIED	VARIED
Plasma Erosion	0 – 50nm/day	HIGH	NO
Tritium Absorption	Not enough data	HIGH	VARIED

Recreated UKAEA, "UK Fusion Materials Roadmap 2021-2024"

CHADWICK Motivation

Performance

Existing materials can't last more than 5 years in a commercial fusion power plant

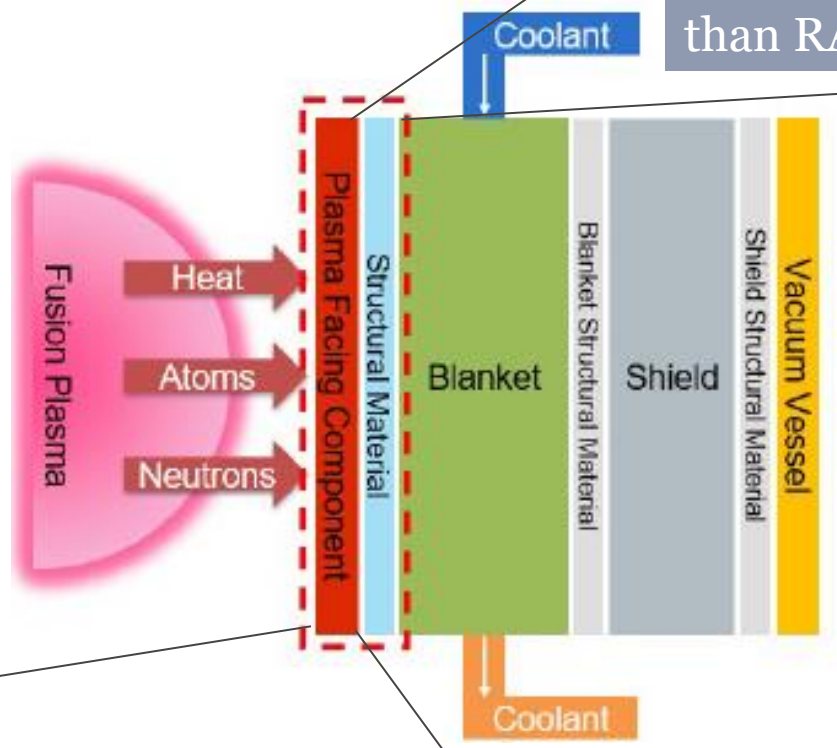
Speed

Existing material development pipeline takes too long to support fusion commercialization

Revolutionize how and what material is made for the extreme environment needed to enable commercial fusion power

CHADWICK Program Structure

Category B
Deliverable: Material product that performs better than RAFM steel as structural component



Data

Category A
Deliverable: Material product that performs better than tungsten as plasma facing component

Data

Category C
Deliverable: Database and technoeconomic analysis for novel materials

CHADWICK Metrics

ID	Metrics	Cat A: Constraints
A1	Thermal conductivity	> 170 W/m-K
A2	Plasma erosion	< 3.4 μm/hr
A3	Tritium solubility	< 5e20 T/√Pa-m^3
A4	Tritium diffusivity	>1.6e-8 m^2/s

ID	Metrics	Cat B: Constraints
B1	Thermal conductivity	> 33 W/m-K
B2	Yield strength	> 280MPa @ 650^{o}C tensile
B3	Tritium solubility	< 4e21 T/√Pa-m^3
B4	Tritium diffusivity	>8.2e-9 m^2/s

Category A: Plasma Facing Material

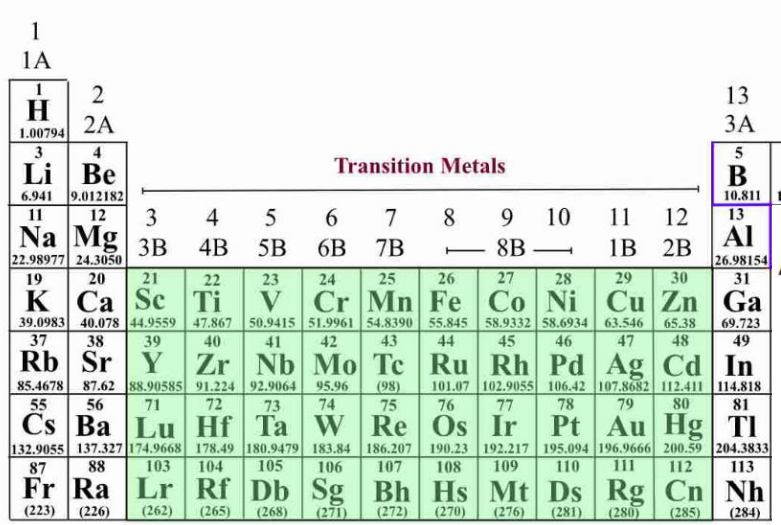
Category C: Capabilities

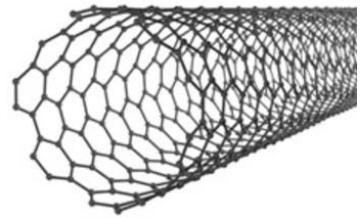
Category B: Structural Material

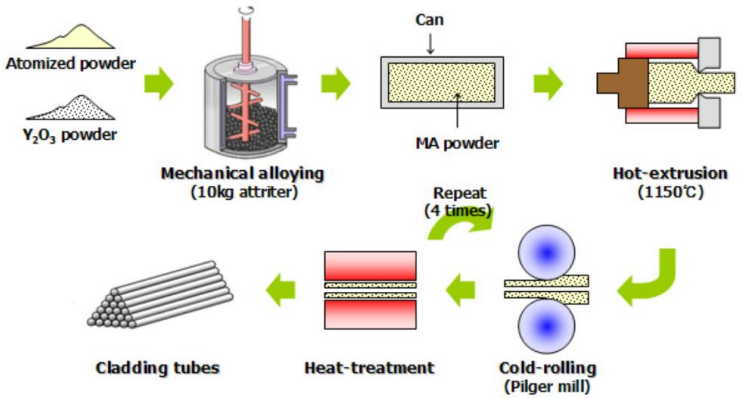
ID	Metrics	Cat A &B Targets	Capability
R1	Fracture toughness	> 30 MPa √m @ 20^{o}C	Irradiation, mechanical testing
R2	Irradiation swelling	< 1%	Irradiation, mechanical testing
R3	Neutron activation simulation	Contact dose <10,000 Sv/hr after 3 months decay	Activation analysis
M1	Total product amount	250mm x 250mm (tiled format)	N/A
M2	Minimum unit size	50mm x 50mm x 5mm	N/A
M3	Manufacturing tolerance	<0.25mm	N/A
M4	Manufacturing reliability	Rejection rate < 10%	Database
M5	Average raw material cost	<$1000/kg	Database

CHADWICK Portfolio ($30M): 13 Projects Across 3 Technical Categories

Fusion Material Innovation Categories







Class

- Amorphous glass
- Metal alloys
- Ceramics
- Liquids

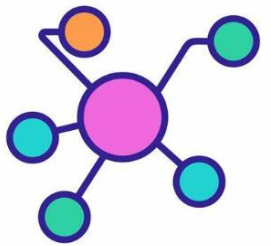
Composition

- Tungsten
- Vanadium
- Silicon
- Iron

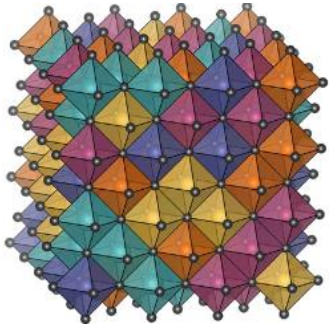
Microstructure

- Fiber reinforcements
- Dispersion strengthening
- Nano-particle strengthening
- Grain boundary engineering

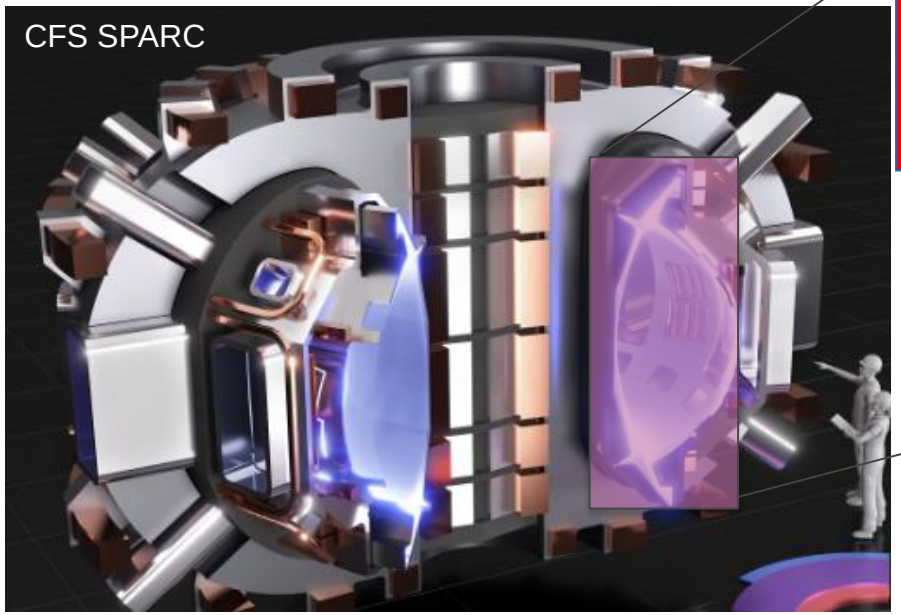
Project Innovations

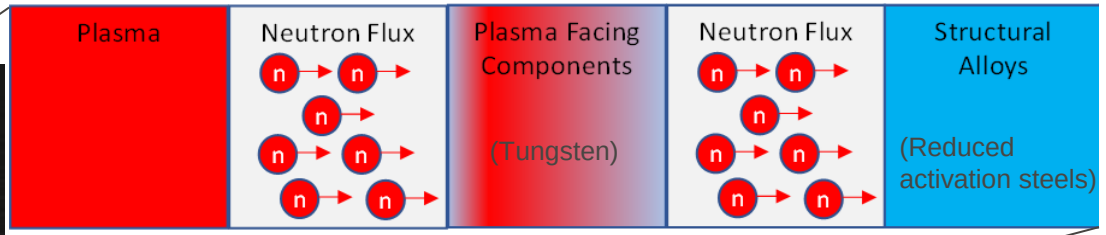


New composition

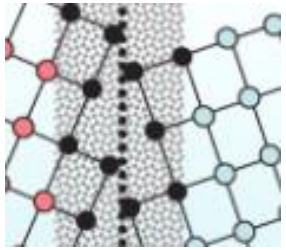


High entropy configuration

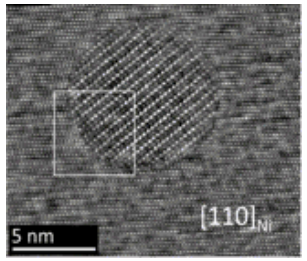




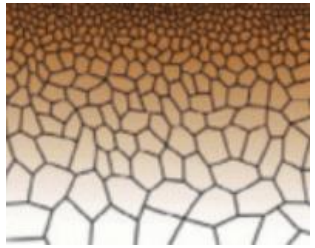
Liquid first wall



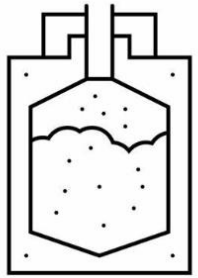
Grain boundary engineering



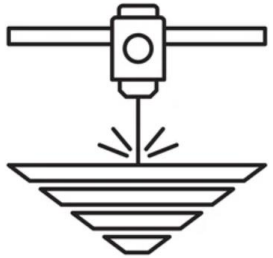
Secondary phase strengthening



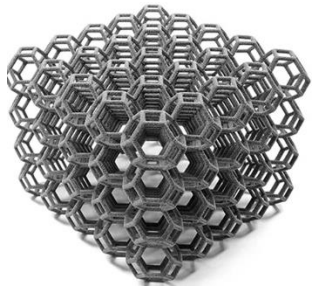
Functional grading



Powder metallurgy



Additive manufacturing



Volumetrically complexity

Project List

Project Title	Lead Organization
Batch-wise improvement in reduced design space using a holistic optimization technique for fusion environments (BIRDSHOT-FUSE)	Texas A&M Engineering Experiment Station
Refractory alloys with ductility and strength (RADS)	Ames Laboratory
Co-optimization of an integral, layered materials solution for compact tokamak vessels	Commonwealth Fusion Systems
Combinatorial modeling, screening and development of tungsten-ceramic composites with gradient microstructure for improved radiation-tolerant plasma facing materials	University of Kentucky Research Foundation
Ferritic and vanadium alloys with nanoparticle strengthening for fusion (FAVA-NSF)	Pacific Northwest National Laboratory
Parallel design of armor and structural materials	Lawrence Livermore National Laboratory
GRADED: gradient composites with radiation amorphization-enabled dimensional stability and energy dissipation	University of Illinois at Urbana-Champaign
Complexion engineered nanocrystalline tungsten alloy plasma facing materials for long-pulse tokamak operation	Johns Hopkins University
High flux plasma–materials interaction testing for rapid fusion materials development	U.C. San Diego
Machine learning for alloy discovery coupled with geometric optimization for functionally graded liquid metal first wall	Savannah River National Laboratory
Design and development of composited low-activation UHTC materials for very high temperature first wall application	SUNY University at Stony Brook
Centralized and on-demand radiation transport and techno-economics (CORTEX) for fusion material engineering	University of Illinois at Urbana-Champaign
Novel liquid metal plasma facing component alloys	Exofusion

Project Management

GREEN STATUS

- Meeting key **project milestones on time**
- Have a **clear project management structure** and dedicated personnel
- Maintain **regular communication with ARPA-E** Program Director and SETAs
- Identify and **engage additional help when needed** – internally and externally
- Are flexible enough to quickly redeploy personnel and adjust technical approaches when necessary
- Submitting succinct quarterly reports on time and with appropriate detail about milestone and project status

RED FLAGS

- **Consistently missing milestones**
- **Lack of a sense of urgency**
- **Disregard for the milestones or reinterpretation** of milestones without discussing with ARPA-E
- **Omission of key data/results**, avoiding detailed technical conversations on milestone challenges
- Challenges in hiring personnel or getting key pieces of equipment running
- Significantly behind on invoicing
- Project funds spent out of proportion without work accomplished

ARPA-E believes in active project management

ARPA·E™

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