MatDB 4Fusion

MatDB4Fusion
International Working Group on the Material Database for Fusion

IAEA Technical Meeting on Tritium Breeding Blankets and Associated Neutronics

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CATF CLEAN AIR TASK FORCE

CATF Global Fusion Advocacy Programme

Fusion Energy Policy	De-Risking Strategies	Supply Chain Development	Awareness
▪ Support elected officials on policy formation ▪ Advise regulators ▪ Explore alternate fusion approaches ▪ Describe new and existing rule sets for neutron management ▪ Inform regional fusion strategies	▪ Harmonize global safety requirements ▪ Create materials catalogue to identify common challenges ▪ Provide generic techno-economic cost analysis ▪ Create tools for risk assessment	▪ Produce universal catalogue of material needs ▪ Maintain technology-agnostic view on workforce needs ▪ Evaluate technology enablers such as AI, HPC ▪ Codes and Standards development ▪ Identify priority materials for supply chain security ▪ Workforce development	▪ Increase fusion's visibility in energy sector ▪ Articulate fusion's role in the marketplace ▪ Support national, regional and international fusion commercialization efforts ▪ Demonstrate progress and set expectations for fusion expansion
Inform policies to harmonize global safety and regulatory frameworks.	Identify and mitigate the uncertainties in the deployment of fusion.	Inform reference tools to be able to integrate fusion into the net-zero energy mix.	Position fusion as "clean tech" and as part of the net zero solution.

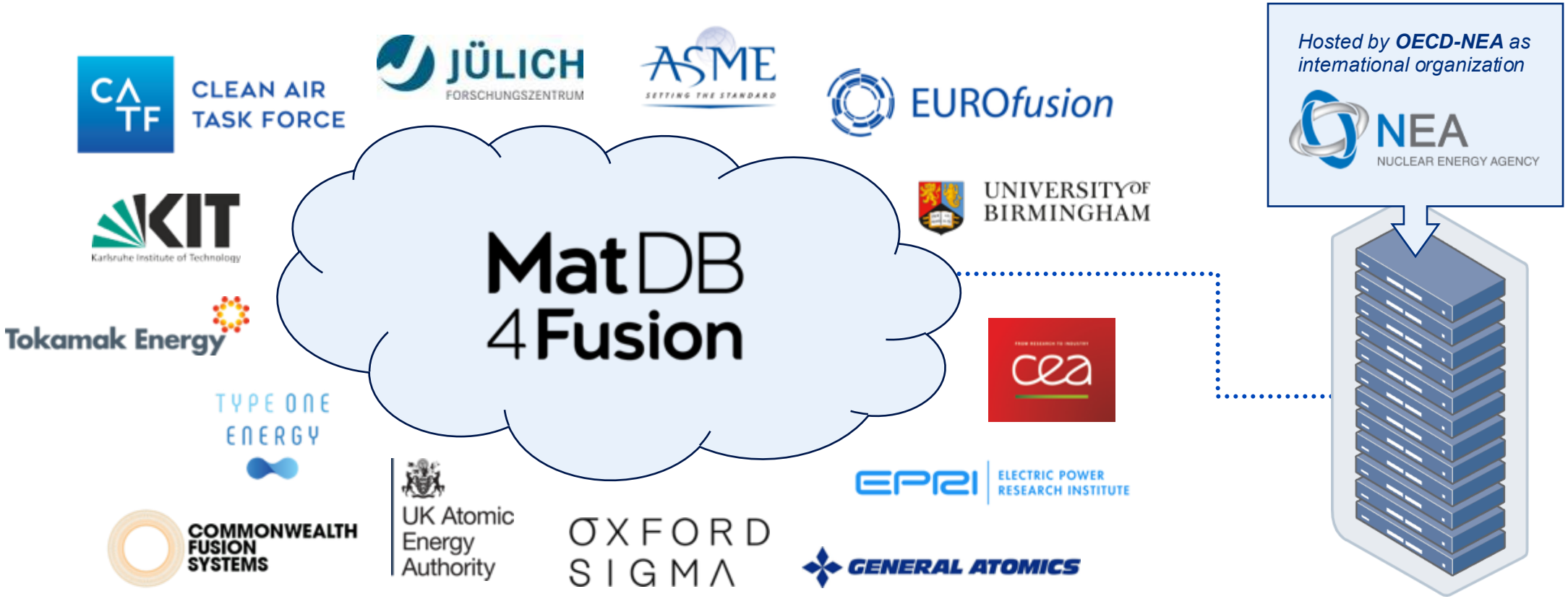
Introduction

The current situation for material science in fusion

- Recent breakthroughs in fusion technology
- Huge investments, also in private companies: Keen to accelerate development towards commercial fusion power, but relying on scientific data
- Development of basic materials suitable for fusion energy, qualified and validated in irradiation campaigns, is a matter of decades and consumes large budgets
- Scientific work of four decades created huge piles of data, however often not public
- Important material manufacturing details are often missing
- The rise of machine learning technology promises even more breakthroughs with enough data

► Urgent demand for a global database for fusion material properties

Formation of the International Working Group in 2023



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The Material Database for Fusion

Ultimate Vision

► ***Development started in 2024***

A database …

- covering all **materials, properties, supporting data** relevant to fusion device design,
- supplied by many entities from different countries,
- with **quality-controlled** data,
- contains open access data but also restricted data from different stakeholders,
- acts as a **single reference** for all fusion reactor design approaches to
  - ► access wealth of data that did not reach publication or attention
  - ► **assess data gaps** and / or reduce duplication of effort by improving focus of experimental campaigns
  - ► accelerate **creation of codes / standards** for qualification (data quality needed)
  - ► provide sufficient data for **Machine Learning** solutions (data quantity needed)

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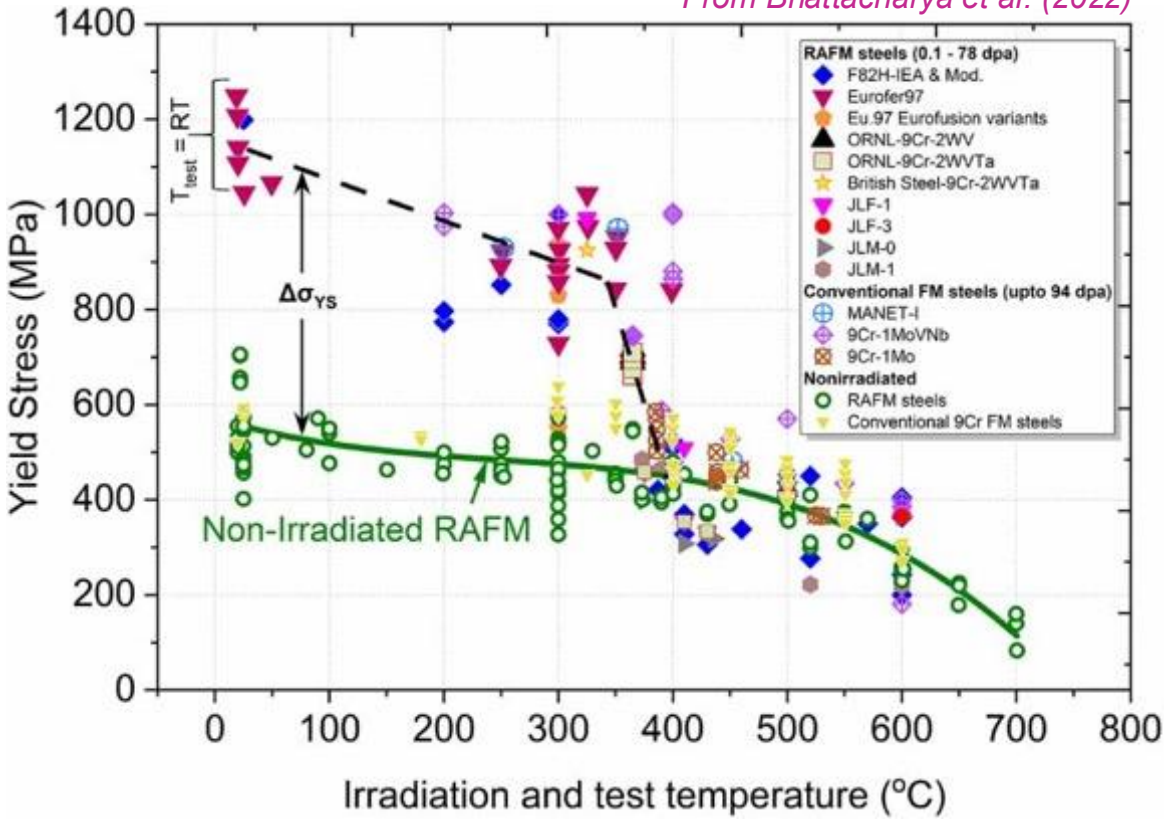
Database Content and Structure

Database Content and Structure

What should be a single entry in the Database?

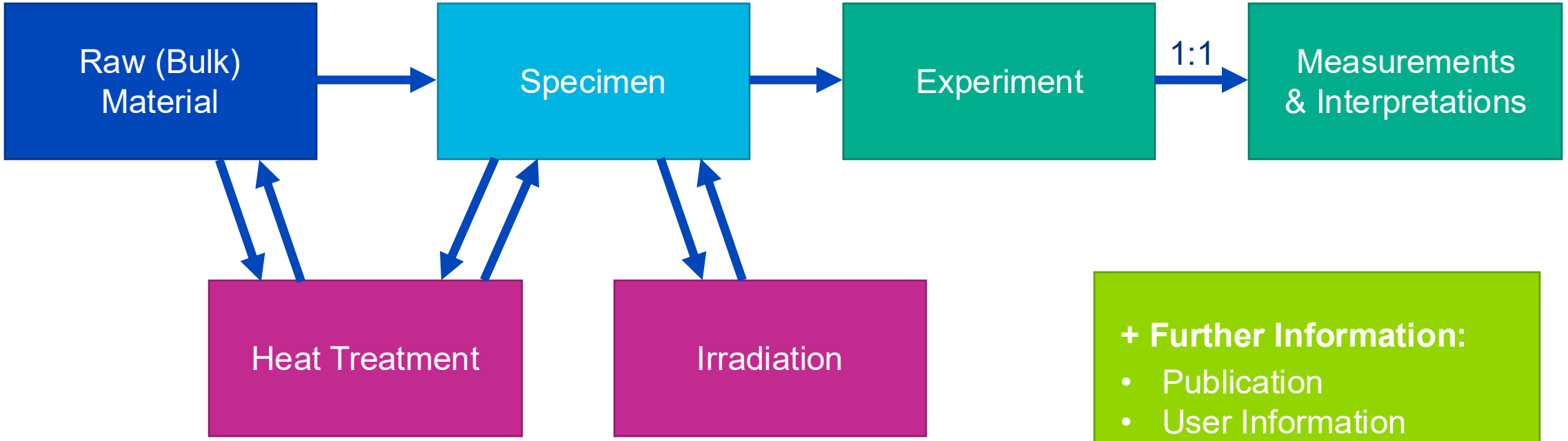
From Bhattacharya et al. (2022)



- Each data point represents a single experiment!
- … What is an “experiment”?

Database Content and Structure

What should be a single entry in the Database?

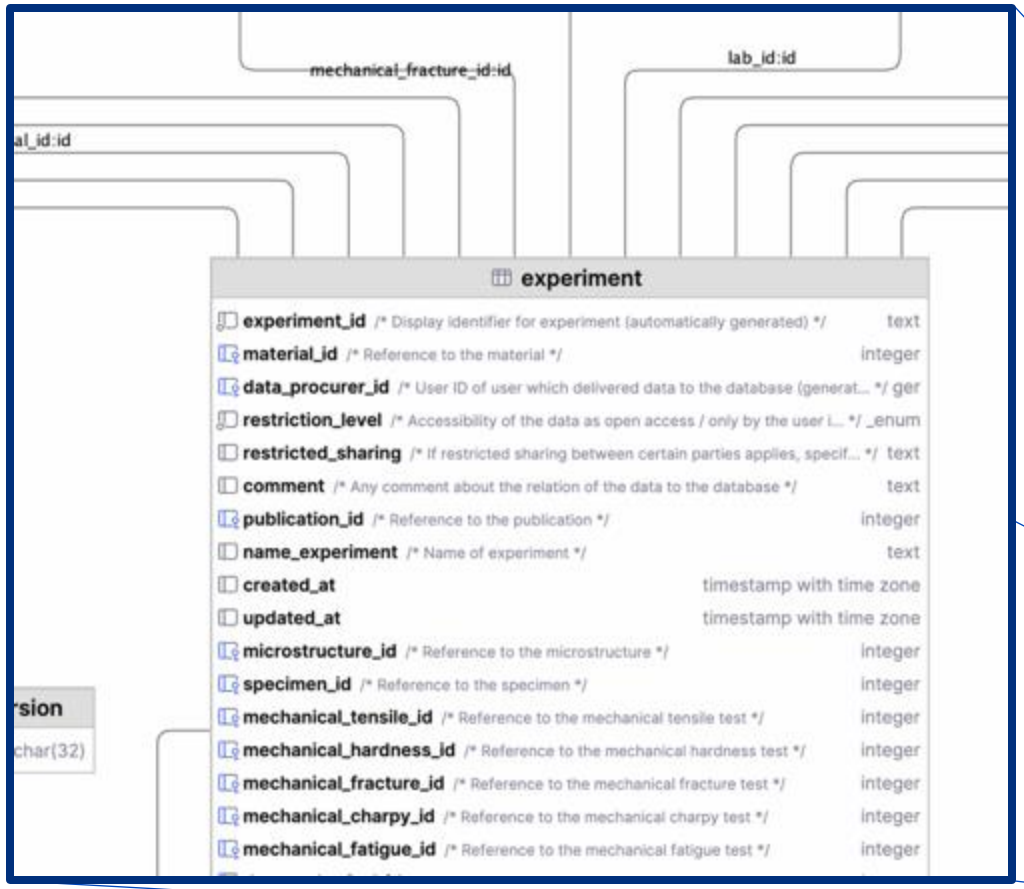


+ Further Information:

- Publication
- User Information
- Data Quality Evaluation

Database Content and Structure

Entity Relations



Database Content and Structure

Materials

High heat flux
Different W grades, W alloys, CuCrZr, ODS-Cu, Graphite, …

Structural
Steels (F82Hmod, EUROFER97, ODS-EUROFER, CNAs), Ti6Al4V, SiC, …

Blanket functional
Li, Li-ceramics, Be, beryllides, …

Optical & dielectric functional
Al2O3, MgAl2O4, α-SiO2, diamond …

×

Preconditions

Mechanical treatment
Type, temperature, degree of deformation, …

Thermal treatment
Annealing, aging, heating & cooling rate, …

Irradiation parameters
Type, spectrum, dose, temperature, …

Coating
Type, thickness, …

×

Properties

Microstructure
Grain size, particles, dislocations, …

Mechanical
Tensile, fracture toughness, charpy impact, fatigue, hardness, creep, …

Magnetic
Magnetic saturation, remnant magnetization, …

Recrystallization
Change in DBTT, hardness, …

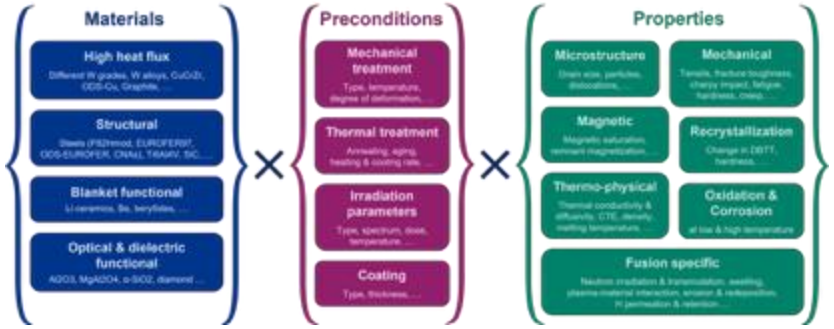
Thermo-physical
Thermal conductivity & diffusivity, CTE, density, melting temperature, …

Oxidation & Corrosion
at low & high temperature

Fusion specific
Neutron irradiation & transmutation, swelling, plasma-material interaction, erosion & redeposition, H permeation & retention …

Database Content and Structure

Analyzed Data



Linkage

Raw Data

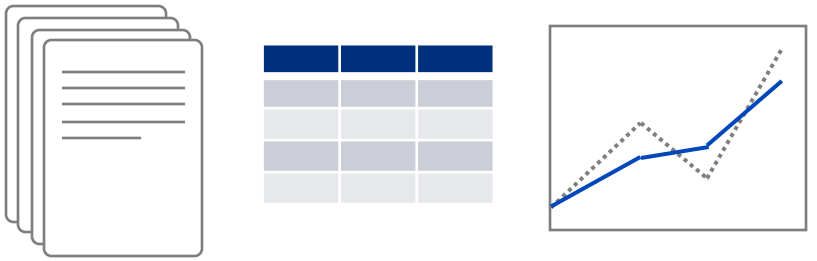
X-ray spectra | DSC curves | SEM / TEM images | EBSD data | Stress-strain curves | Protocols | Simulation data | Chemical analysis data | …

Calculation models

$$\frac{1}{n}\sum_{i=1}^{n} x_i$$

"Compendium"

Data in summarized format with mean values, average curves, …



Data Quality

Data Quality

Basic Considerations

Cherry picking data

Only "highest" quality available
Risk neglecting still valuable data (e.g. for ML)

vs.

Complete data with filtering

All data available, filtered by criteria for every use case

Multidimensional approach

Many criteria for filtering

Tag-system

vs.

One-dimensional approach

Single quality levels (e.g. silver, gold level)

Data Quality

Defining quality criteria

"Soft criterion"

Amount of metadata ("completeness")

Fabrication details, thermomechanical treatment of the material, semi-finished product type, location of the specimen, test conditions, description of data evaluation and analyses, …

Supplement of raw data

"Hard criterion"

Use of standards

Fabrication procedures, sample production, test equipment, test procedure, data evaluation & analysis, laboratory certification, ….

Hosting of the Database

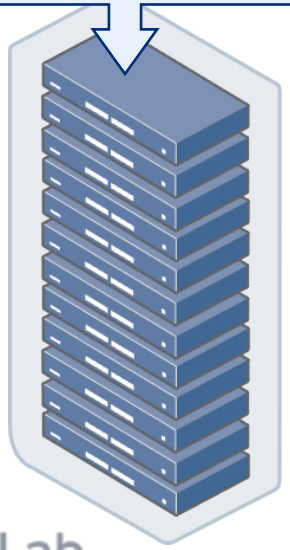
Hosting of the Database

Partnership with OECD-NEA

- International (as being part of OECD)
- Experienced and reliable:
  - Many databases currently hosted
  - Advanced tools for data compilation and access
  - Availability of secure long-term storage of DB
  - In-house backup solutions with regular snapshots (at least daily)
- Shows strong commitment, already active development with CATF
- Account management and regulations (member states)
- Hosting:
  - GitLab system (currently used for DB development)
  - Database & Backend API (Frontend to be discussed)

*Hosted by **OECD-NEA** as international organization*

NEA NUCLEAR ENERGY AGENCY



GitLab

FastAPI

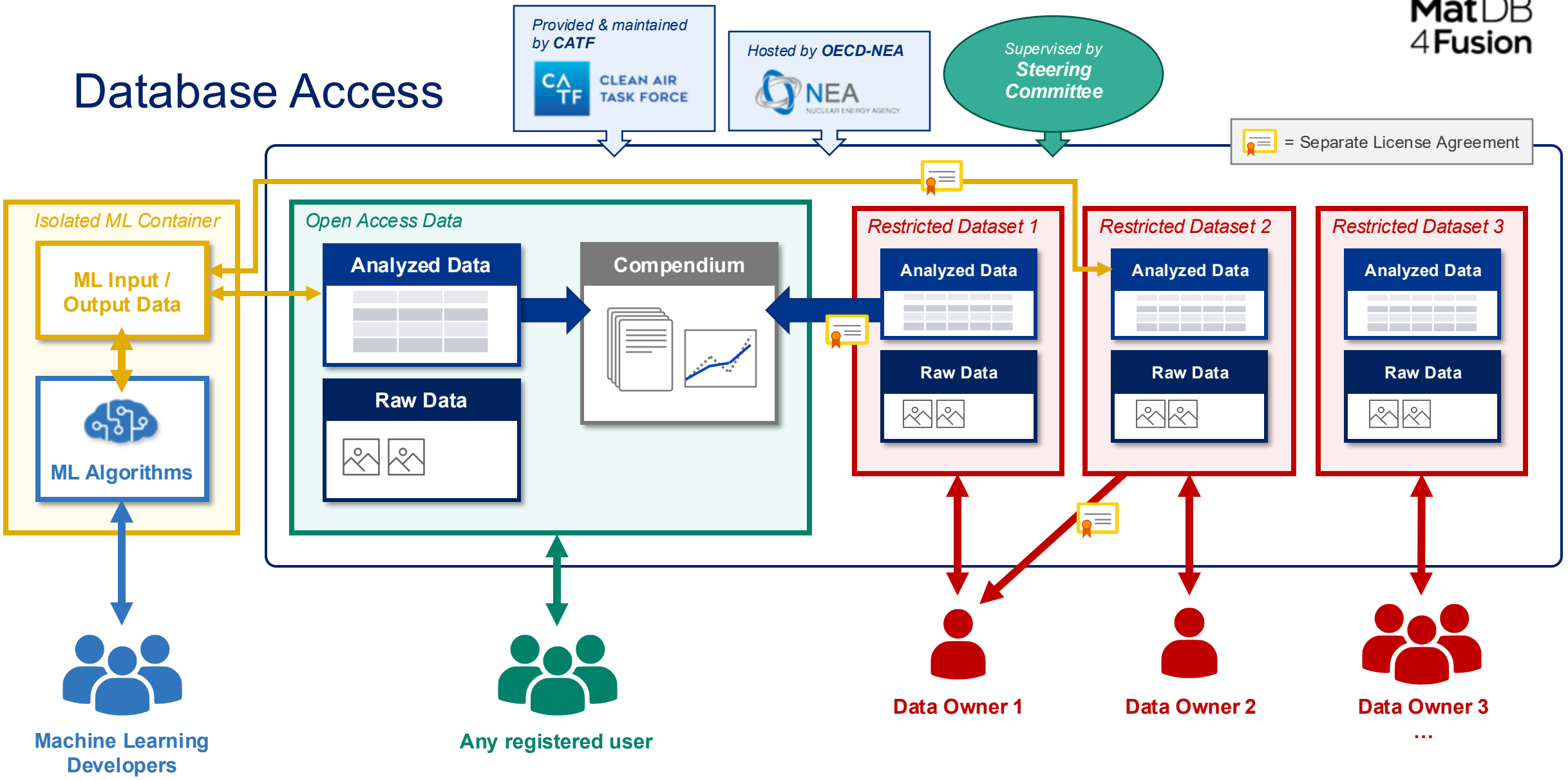
PostgreSQL

Frictionless Data

CATF

Access Models

Database Access



Machine Learning

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Machine Learning

Where it can make a difference

- Knowledge extraction (collaboration with Google started)
- Property prediction/interpolation to unknown regions of data in terms of important parameters such as irradiation damage and temperature
- Physics-informed models to constrain predictions
- Identification of important features in materials for different applications
- Anomaly identification
- Uncertainty quantification for component design
- Links well with optimization techniques as they can behave as surrogate models

Key Aspects:

Knowledge Extraction

Data Analysis

LLM Search Function

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Web Interface

Web Interface

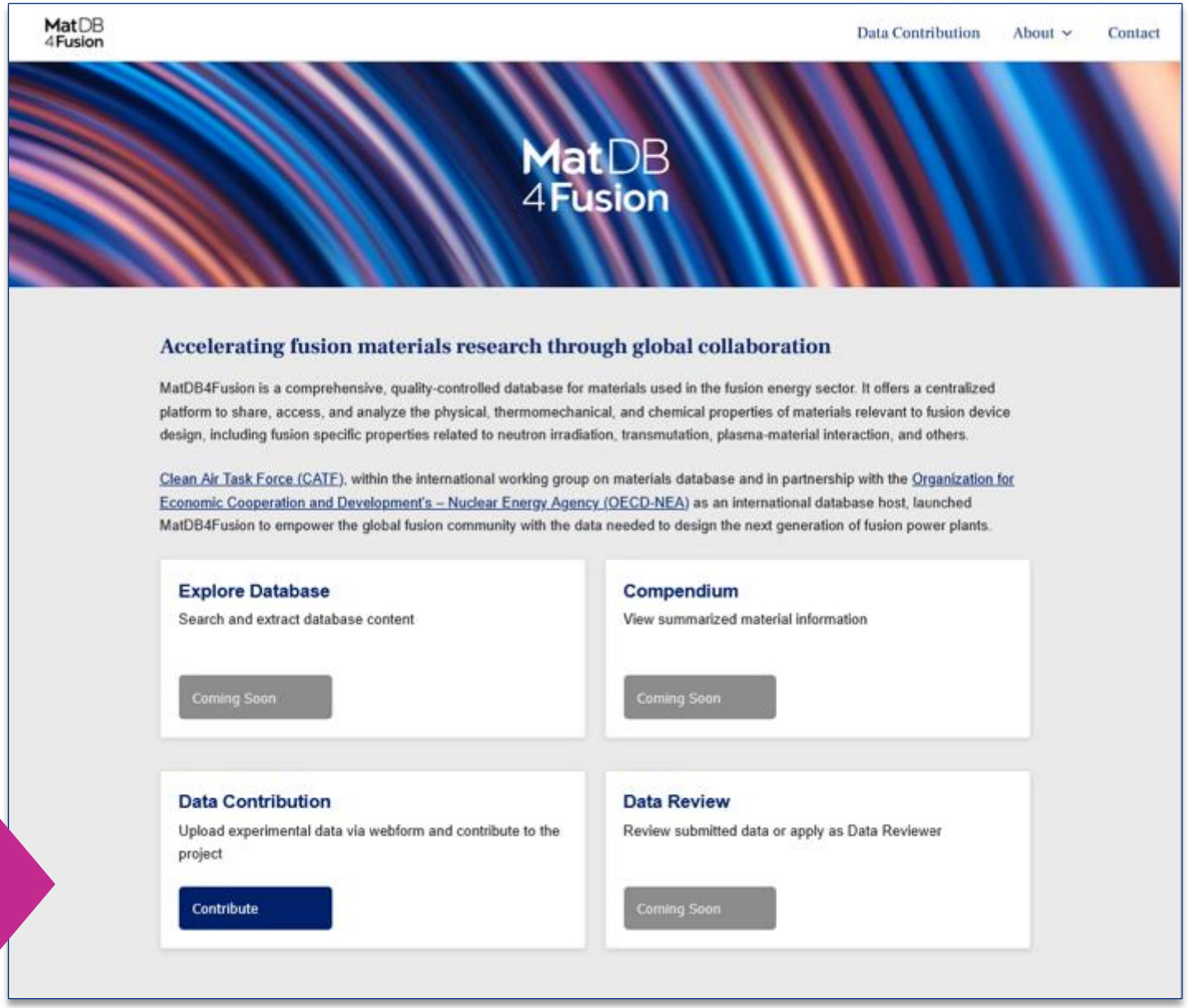
Features

- Data Explorer (Table)
  - Data Filtering
  - Data selection & export
  - Data plotting
- Compendium
- Tools for
  - Data contribution
  - Data review

Visit

www.MatDB4Fusion.app

… and subscribe for updates!



Fusion Codes and Standards

Harmonisation of Codes and Standards for an Emerging Industry

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Codes and Standards

Codes versus Standards

In engineering, "codes" and "standards" are two terms with distinct meanings:

Codes: Often referred to as safety codes, are a set of regulations, rules, and guidelines established by a recognized authority or government agency. The codes are designed to ensure the safety, integrity, and functionality of buildings, structures, systems, and processes. They typically define minimum requirements for design, construction, maintenance, and use of buildings or facilities. Compliance with Codes is mandatory, and failure to adhere to the codes may result in legal penalties or restrictions.

Standards: Standards are specifications developed by a recognized standard-setting organization. Standards are guidelines that establish a consistent and accepted approach to processes, products, services, or systems. Unlike codes, compliance with standards is not mandatory, but adherence to standards contributes to ensure quality, safety, certification and best practices.

Why Standardisation?

1. Achieve more **cost-effective** Fusion projects in terms of technical performance, life cycle cost-effectiveness, and on-time deliveries;

2. Improve the **quality and safety** of Fusion projects and products;

3. **Reduce risk** and guarantee interoperability and interface compatibility by applying proved and recognized requirements and methods;

4. Facilitate clear and unambiguous **communication** between all parties involved in Fusion systems development and operation;

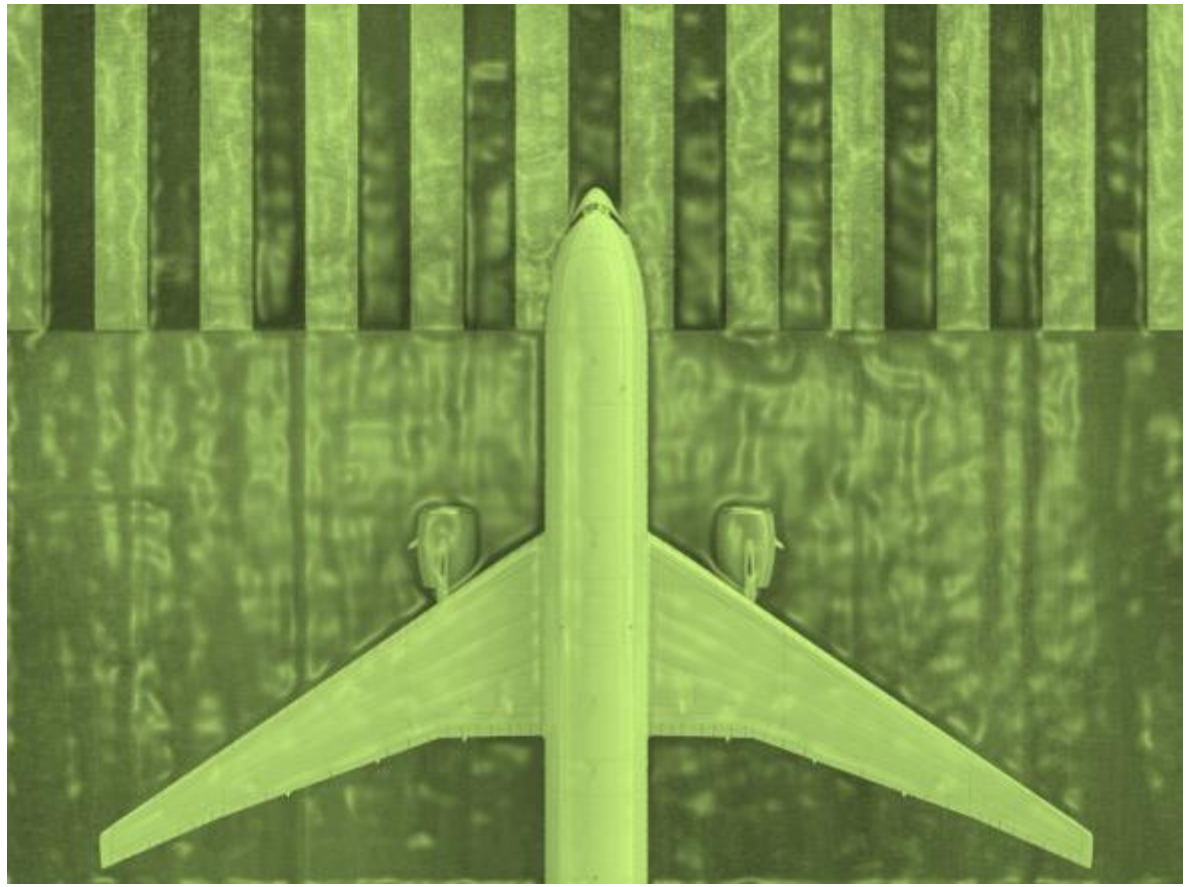
5. Reflect user needs and **feedback of experience** from projects and other appropriate sources to develop and improve Fusion Standards;

Codes and Standards: Learning from Other Sectors

Common Themes: Aviation Industry as a Precedent

International Civil Aviation Organization (ICAO)	Fusion
Formed on December 7, 1944, by 52 countries at the Chicago Convention. The purpose of ICAO is to "promote safe and orderly development of international civil aviation throughout the world".	Similar to the aviation sector, a safe and orderly development of fusion technology throughout the world is globally beneficial.
ICAO was formed for several reasons.	**Fusion Harmonization Roadmap**
First, the rapid growth of air travel in the early 20th century had created a need for international cooperation on air traffic control, safety, and other issues.	As fusion technologies mature and regulations are finalized in leading countries, specifics on safety, codes and standards, emergency preparedness, decommissioning and nonproliferation will be finalized. Harmonized policies and standards will ease the deployment of fusion technology and promote a more rapid deployment for the benefit of the environment.
Second, the advent of warplanes during World War II had shown the potential for air travel to be used for military purposes. ICAO was seen as a way to prevent the proliferation of military aircraft and to promote the use of air travel for peaceful purposes.	Globally accepted, established, and enforced policies on nonproliferation and security will ensure a peaceful deployment of fusion technologies.

Aviation Industry as a Precedent: ICAO Details



ICAO's members are the 193 countries that have ratified the Chicago Convention.

ICAO is funded by contributions from its member states. ICAO's management and operations are overseen by a number of bodies, including the Assembly, the Council, the Air Navigation Commission, and the Secretariat.

The Assembly is ICAO's supreme governing body. It is composed of representatives from all member states and meets every three years. The Assembly is responsible for setting ICAO's policies and budget.

The Council is ICAO's executive body. It is composed of 36 members, elected by the Assembly for three-year terms. The Council is responsible for implementing ICAO's policies and budget.

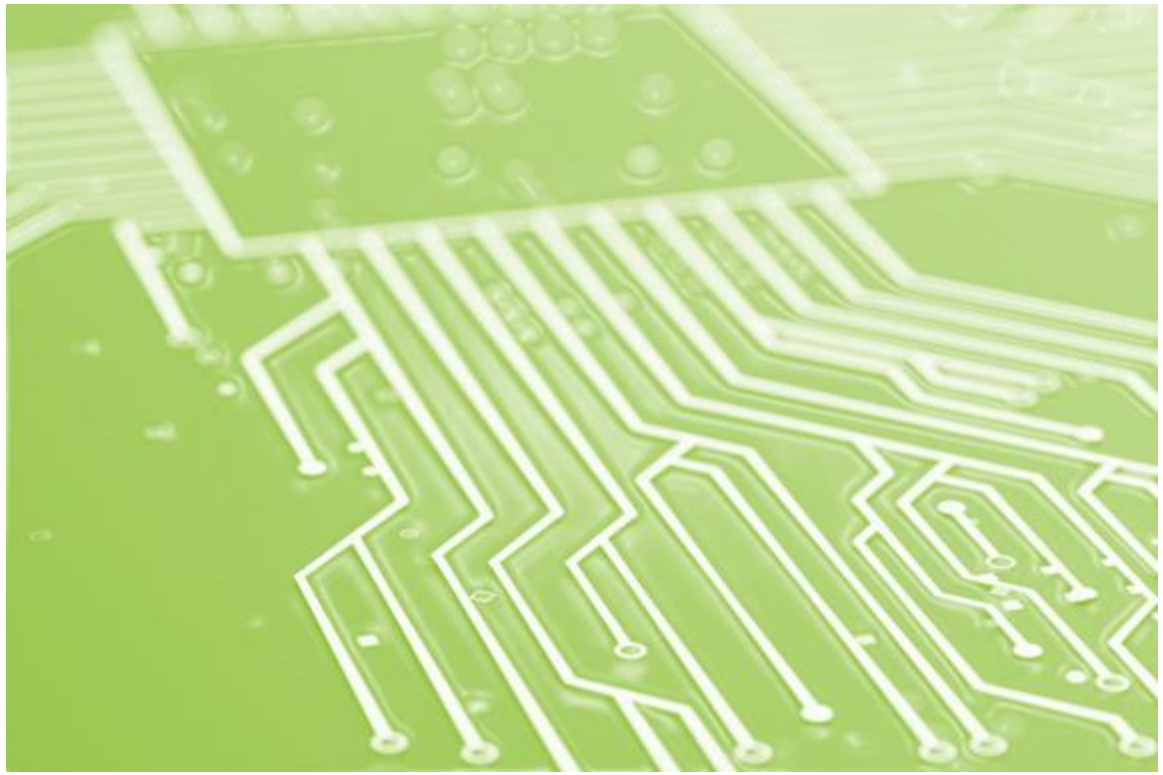
The Air Navigation Commission is ICAO's technical body. It is composed of experts from member states and is responsible for developing and updating ICAO's standards and recommended practices (SARPs).

The Secretariat is ICAO's administrative body. It is headed by the Secretary General, who is elected by the Assembly for a four-year term. The Secretariat is responsible for implementing ICAO's policies and budget, and for providing technical assistance to member states.

Common Themes: Semiconductor Industry as a Precedent

Industry Standards	Fusion
Industry Standards: Organizations like SEMI [SEMI Standards] develop international standards for chip manufacturing processes and materials. This fosters consistency and facilitates global trade.	Sector is in early stages of development and needs industry standards to be developed. Following examples like the development of SEMI over the last 50 years can facilitate a more rapid and smooth standards development effort.
Policy Advocacy	**Fusion Policy Advocacy**
Policy Advocacy: Industry associations like the Semiconductor Industry Association (SIA) [SIA - Semiconductor Industry Association] work with governments to promote policies that encourage innovation, competition, and responsible production practices.	Policy Advocacy: Industry associations like the Fusion Industry Association (FIA) work with governments to promote policies that encourage innovation, competition, and responsible production practices.
International Collaboration	**Fusion Harmonization Roadmap**
International Collaboration: Efforts are underway to establish international agreements on topics like export controls and intellectual property protection.	Globally accepted, established, and enforced codes and standards will ensure a peaceful deployment of fusion technologies. Evoking existing industry export control provisions where necessary, and not starting from scratch will shorten the time to commercial fusion.

Semiconductor Industry: Regulations Governing the Semiconductor Industry



Trade and Tariffs: Governments use tariffs and trade agreements to protect domestic chipmakers from foreign competition. This can make imported chips more expensive, impacting production costs.

Environmental Regulations: Semiconductor production can involve hazardous materials. Regulations like the Clean Air Act (US) ensure the industry operates responsibly and minimizes environmental impact.

Intellectual Property (IP): Strong IP protection, like patents, safeguards the innovative designs and technologies developed by semiconductor companies. This encourages continued research and development.

Export Controls: Some countries restrict the export of certain types of semiconductors due to national security concerns. These controls can limit market access for companies.

Worker Safety and Health: Regulations like OSHA standards (US) ensure safe working conditions in semiconductor fabrication facilities, which often involve hazardous materials and processes.

Learning from Other Sectors and Working with Industry

- Industries with huge societal benefits have established platforms to further a uniform commercialization of their technologies by aligning around common standards for the delivery of the technologies
- Independent international organizations, funded by government and private sector have been established to administer the standards
- Fusion is very similar in its potential for societal benefit and harmonization of standards supporting the most rapid commercialization of the technology is warranted
- The Clean Air Task Force is leading an effort to establish a first of a kind international working group on the development of standards for fusion technology.
    - Working with government, fusion technology developers, industry and international organizations today to get this important next step for fusion started
    - Working with Industry to meet the evolving needs of this developing technology
- The Clean Air Task Force is also on the ASME Division III Section 4 Special Working Group for Fusion Stakeholders

Global Efforts Focused on Codes and Standards for Fusion

Summary of Global Efforts by Organization

UK Atomic Energy Authority

Longest involvement in exploring codes and standards for commercialization of fusion engaging AFCEN, ASME, IAEA and SDC-IC

Fusion specific standards to include both Fusion reactor components and power generation process plant

Also engaging with regulator regarding off-site transportation of radioactive material and nuclear safeguards for Fusion plants.

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Establish a first of a kind international working group on the development of standards for fusion technology.

Work with government, fusion technology developers, industry and international organizations today to get this important next step for fusion started.

This position can lead to a new independent organization that will administer fusion standards.

IAEA

IAEA are collating a spreadsheet on the codes and standards for fusion development and deployment

Eventually converted into a database which will help to identify gaps in C&S which need to be developed by standards organizations or where existing C&S from other industries can be used

Open to all Member States involved or interested in the research and development of fusion technology, including government organizations (policymakers, analysts, regulators, and R&D agencies) and industry stakeholders (vendors, engineering companies, plant operators and technology developers).

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Other Groups for Consideration

ASTM INTERNATIONAL

ISO International Organization for Standardization

ANSI American National Standards Institute

IEEE

IEC International Electrotechnical Commission

LIA LASER INSTITUTE OF AMERICA

Fusion Technology and Regulation Development:
Landscape 2025 and Outlook

Blue Sky Nuclear
Advancing nuclear technology safely, simply, strategically.

2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032…

Technology Demonstrations
CFS (US) Helion (US)

HSE/EA Engagement

CNSC Engagement

Germany and Japan

US DOE Preliminary Plant Design (Cost Share Program)

Fusion Power Plant Construction

FOAK Fusion Plants

US NRC Limited Rule Making

Commission Decision

Application Guidance Fall 2024

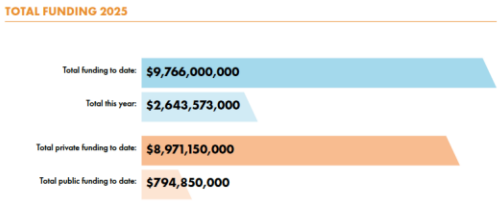
US Fusion Regulations Initialized

FOAK Fusion Plant

Technology Challenges/Power Plant Integration

Tritium Plasma Control Lithium Supply
Control Systems Waste Management
Codes and Standards Materials

Private Fusion Companies
(FIA 2025 Annual Report)



First Mover Safety Case Development | FPP Application Window | Execution

Submit License Applications | Regulation Initiation | Focus on Standardization

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Thank you!

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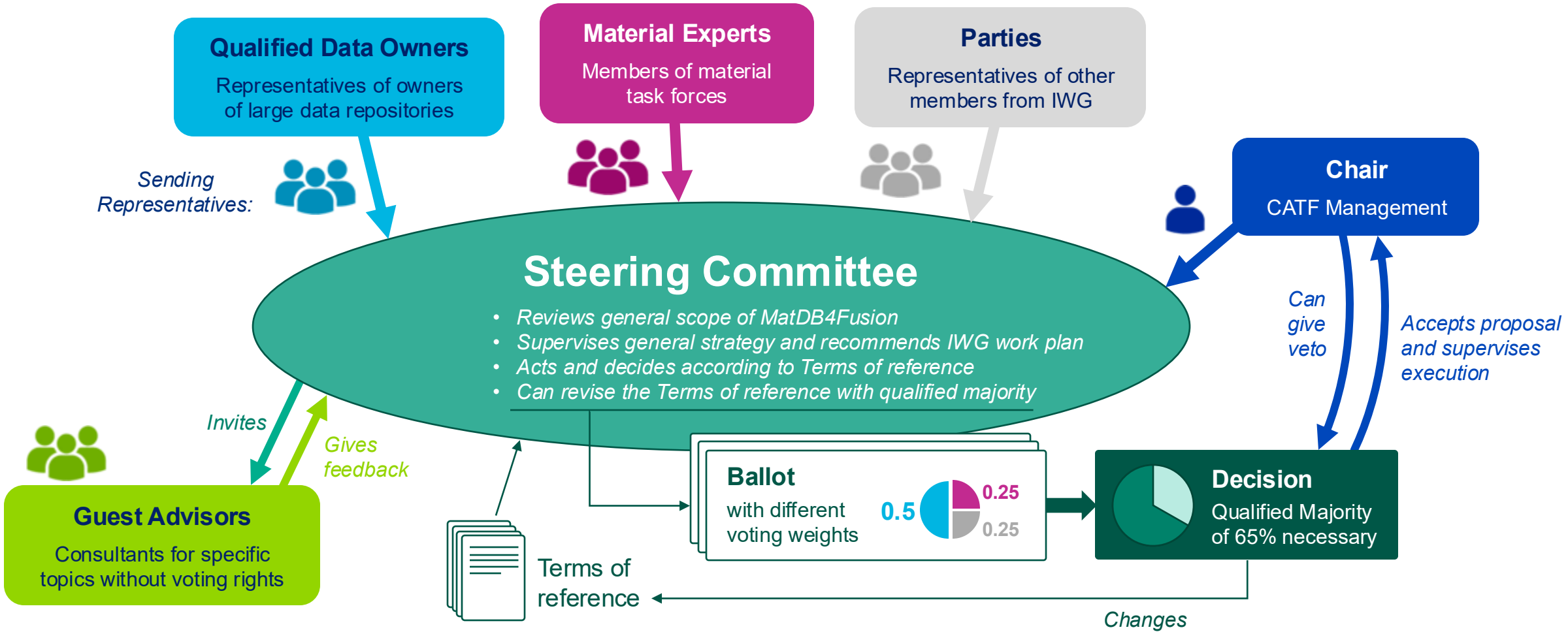
Role and Structure of the Steering Committee (SC)