

Consensus-Based Codes and Standards to Support and Enable a Robust Supply Chain for Commercial Fusion Energy



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IAEA TM on Experience in Codes and Standards for Fusion Technology
November 18, 2025

Establishing New Supply Chains Can Take Decades

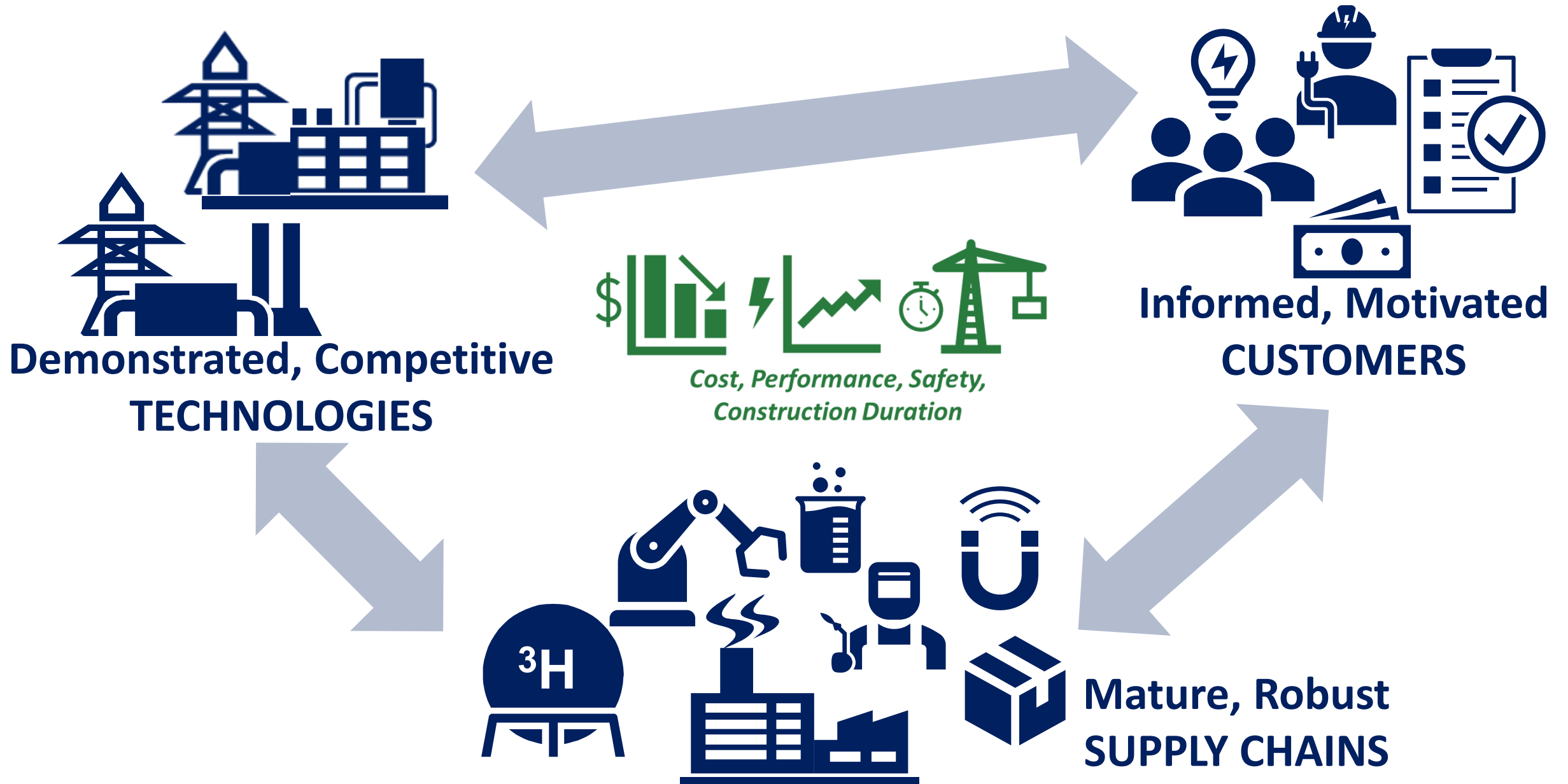
Example: Advanced Ultra-Supercritical (A-USC) Component Test Project (ComTest)

- Technology challenge: construction and operation of A-USC power plant for 760°C steam
- Approach: 20-year industrial consortium led by Energy Industries of Ohio and EPRI, supported by U.S. Department of Energy and Ohio Coal Development Office
- Outcome: development of a qualified supply chain to manufacture nickel superalloy components at commercial scale

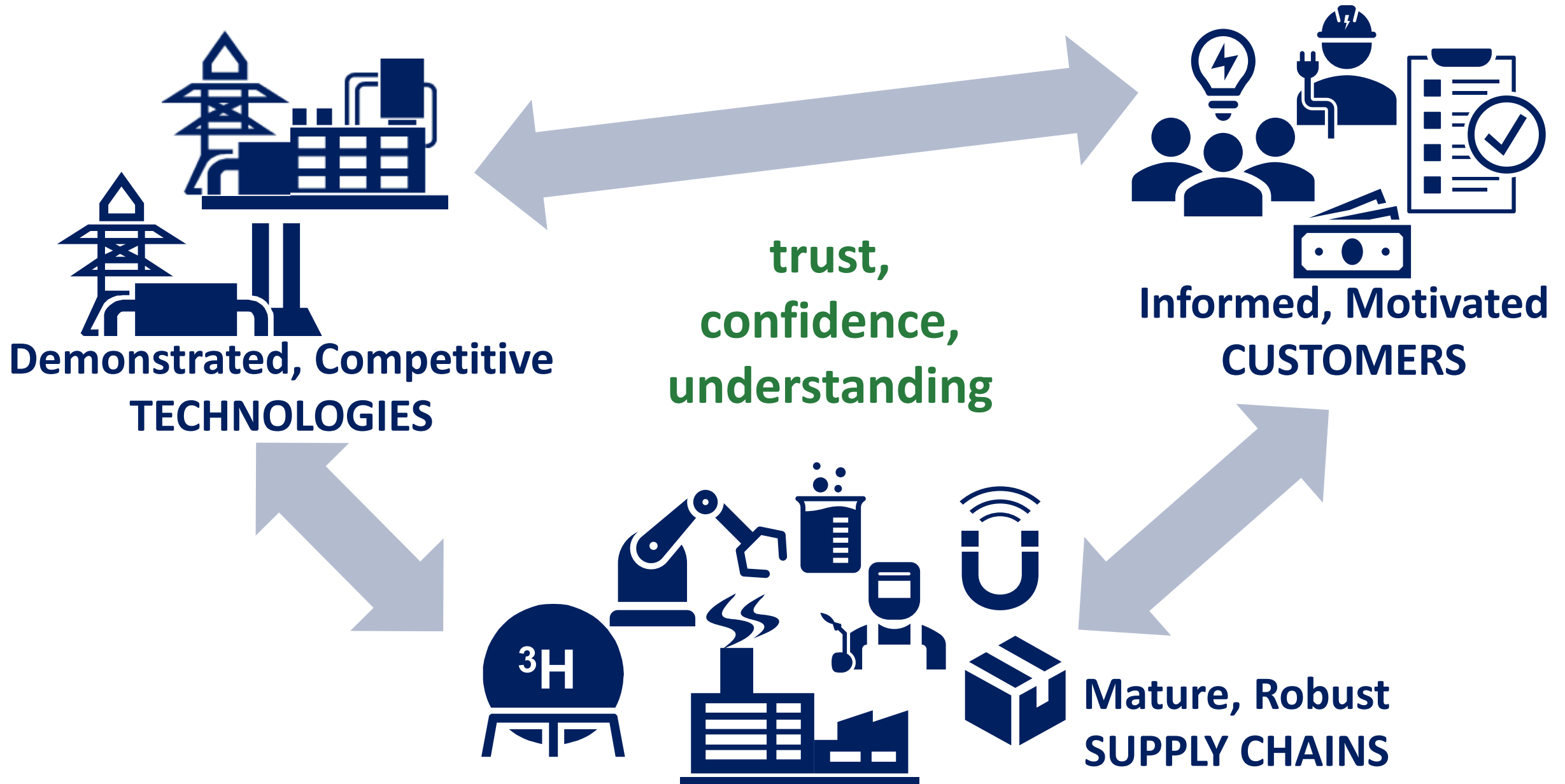


*DOE Contracts: DE-FG26-01NT41175, DE-FE0000234; OCDO Grants: CDO-D-05-02(A), CDO-D-05-02(B)

What will it take to commercialize fusion?



What will it take to commercialize fusion?



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What is code or standard?

- Standard (general usage): provides requirements, specifications, guidelines, or characteristics that can be used consistently to ensure that materials, products, processes, and services are fit for their purpose.
- Code vs. Standard (specific usage):
 - Code: What to do (minimum requirements)
 - Standard: How to do it (methods, best practices)
- **Voluntary Consensus Standard (VCS)**: developed or adopted through a process characterized by openness, balance, due process, consensus, and the right to appeals.*

*American National Standards Institute (ANSI), <https://www.ansi.org/standards-faqs>

When is a VCS not voluntary?

- Incorporated by reference into law, regulation, or ordinance by national, state/provincial, or local government
- Incorporated into contractual agreements for procurement of goods or services

Endorsement of VCS by a regulator or other authority does not make them mandatory.

Private Sector Case for VCS

- Participation in the standards development provides the private sector some degree of self-determination otherwise lacking in public sector oversight and regulation
- Timely development of codes and standards supports/derisks/informs development of a supply chain that can meet customer requirements and expectations through:
 - preparation of an adequately trained workforce,
 - development of appropriate procedures,
 - informed, timely business investments, and
 - warranties on products and services

VCS allow you to tell your own story before someone else does.

Preference of VCS over government regulation in US law.

- The USNRC website (Standards Development) states*:

*Recognizing that participation in standards development improves the effectiveness and efficiency of the regulatory process, **Federal law stipulates that agencies ... use standards developed by a consensus body unless such use is inconsistent with applicable law or is otherwise impractical***

- Preferential use of VCS by Executive Branch departments and agencies established in Nuclear Technology Transfer and Advancement Act of 1985 (NTTAA) and OMB Circular A-119[†]
- Mandated use of VCS is common at the state/provincial and local levels in the U.S. and Canada via reference and incorporation in laws and ordinances

Government adoption of VCS provides for greater input into regulation by the private sector ... if companies choose to get involved in the process.

*<https://www.nrc.gov/about-nrc/regulatory/standards-dev.html>

[†]OMB Circular A-119. *Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities*

Fusion can leverage existing codes and standards

American National Standards Institute (ANSI) accredited standards for example:

- IEEE and IEC standards for instrumentation, controls, and cyber security
- ASME (non-nuclear) for piping, valves, pressure vessels, inspection, maintenance, design
- AWS for welding techniques and materials
- ASTM International standards for quality specifications for materials, products, and services
- NFPA standards for fire and electrical safety
- ASCE standards for safety, reliability, and efficiency in civil engineering, design
- ACI standards for concrete design codes and construction specifications, including reinforcement materials and methods
- AIChE standards for process safety assessment
- ...and many more

Technology-specific standards are useful, but limited in number

Example: American Nuclear Society (ANS)

- The ANS standards committee, established in 1957, maintains ANSI accredited standards across all applications of nuclear science and technology (except medical) for the commercial, academic, government sectors
- Standards are developed when needed according to a strict ANSI accredited consensus process, reviewed regularly, and revised or withdrawn as appropriate
- Only 92 current ANSI/ANS standards exist across all nuclear applications, for example:
 - ANS-2.6-2018 **Guidelines for Estimating Present & Projecting Future Population Distributions** Surrounding Nuclear Facility Sites
 - ANS-2.8-2019 **Probabilistic Evaluation of External Flood Hazards** for Nuclear Facilities
 - ANS-3.1-2014 (R2020) **Selection, Qualification and Training of Personnel** for Nuclear Power Plants
 - ANS-3.11-2015 (R2020) **Determining Meteorological Information** at Nuclear Facilities
 - ANS-5.1-2014 (R2019) **Decay Heat Power** in Light Water Reactors
 - ANS-6.3.1-1987 (R2020) **Program for Testing Radiation Shields** in Light Water Reactors (LWR)
 - ANS-6.4-2006 (R2016) **Nuclear Analysis and Design of Concrete Radiation Shielding** for Nuclear Power Plants
 - ANS-6.4.2-2006 (R2016) **Specification for Radiation Shielding Materials**
 - ANS-15.4-2016 **Selection and Training of Personnel** for Research Reactors
 - ANS-15.11-2016 **Radiation Protection** at Research Reactor Facilities

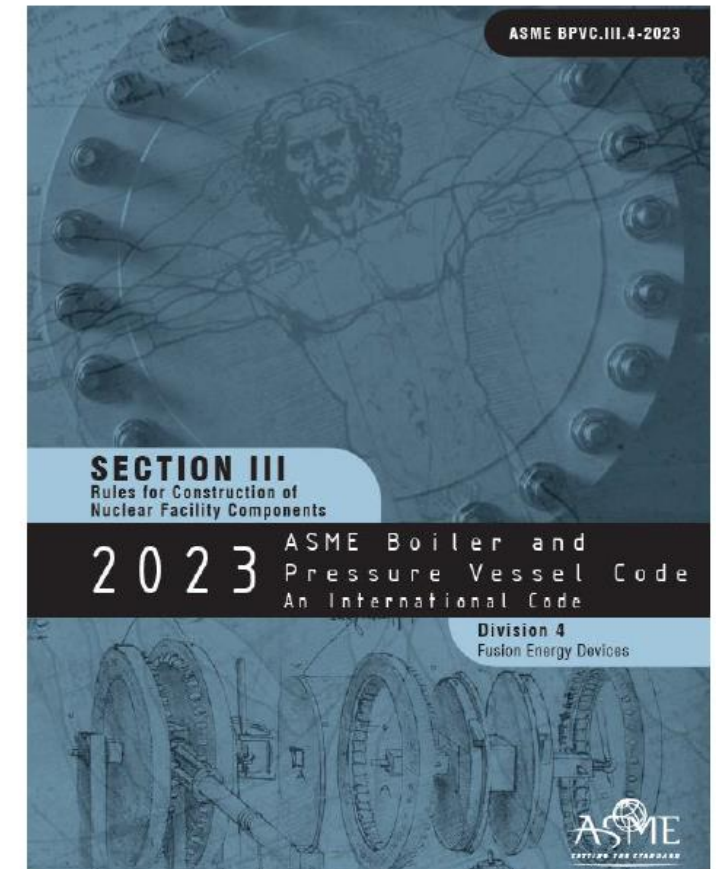
ISO Fusion Energy Standards Already Exist

- ISO 16646:2024. Fusion installations — Criteria for the design and operation of confinement and ventilation systems of tritium fusion facilities and fusion fuel handling facilities
- ISO/DIS 19991 [draft international standard]. Fusion technology — Experimental magnetic confinement fusion facilities — Supersonic molecular beam injection fueling technique for fusion devices
- ISO/DIS 18518 [draft international standard]. Magnetic fusion facilities — Requirements for the safety systems raised by the application of the superconducting technology
- ISO 4233:2023. Reactor technology — Nuclear fusion reactors — Hot helium leak testing method for high temperature pressure-bearing components in nuclear fusion reactors

ASME Section III Division 4 published (as of July 2023)

Section I	Power Boilers
Section II	Materials
Section III	Rules for Construction of Nuclear Facility Components
Section IV	Heating Boilers
Section V	Non-destructive Examination
Section VI	Recommended Rules for the Care and Operation of Heating Boilers
Section VII	Recommended Guidelines for the Care of Power Boilers
Section VIII	Pressure Vessels
Section IX	Welding and Brazing Qualifications
Section X	Fiber-Reinforced Plastic Pressure Vessels
Section XI	Rules for Inservice Inspection of Nuclear Power Plant Components
Section XII	Rules for the Construction and Continued Service of Transport Tanks
Section XIII	Over Pressure Protection

Division 1	Metallic vessels, heat exchangers, storage tanks, piping systems, pumps, valves, core support structures, supports, and similar items.
Division 2	Code for Concrete Containments
Division 3	Containment Systems for Transportation and Storage of Spent Nuclear Fuel and High-Level Radioactive Material
Division 4	Fusion Energy Devices
Division 5	High Temperature Reactors
Appendices	Section III Appendices
Section III Code Cases	Collection of Code Cases



Source: T. Davis. Advancements in pressure codes & standards for fusion power plants. SOFE 2025. Cambridge, MA. June 25, 2025.

Need for distinguishing “fusion quality” at some point?

- ISO 9001*
 - Internationally recognized and established
 - Holistic and generic; industry and technology agnostic
 - Process oriented, customer and product focused
 - Bottoms-up tailoring to fit application (add what you need)

- Technology- or industry- specific standards
 - Focused on technical requirements for products, not the process or system of production
 - Embedded assumptions and safety bases connected to technology and consequence avoidance
 - Adaptation via graded approach or “subtraction” does not address original or embedded assumptions

*<https://www.iso.org/quality-management/quality-assurance>

International Aerospace Quality Group (IAQG)

- IAQG: Membership-based organization that curates quality standards for the global aerospace supply chain and manages compliance certification of suppliers
 - ISO 9001: Provides the foundational framework for a quality management system focused on customer satisfaction and continuous improvement
 - AS 9100: Most common quality management system standard for the aerospace industry, incorporating all the requirements of ISO 9001 but tailored for enhanced aerospace requirements (e.g., risk management and product safety)
 - AS 9110: Quality standard for organizations that provide maintenance, repair, and overhaul (MRO) services
 - AS 9120: Quality standard for distributors of aerospace parts and products

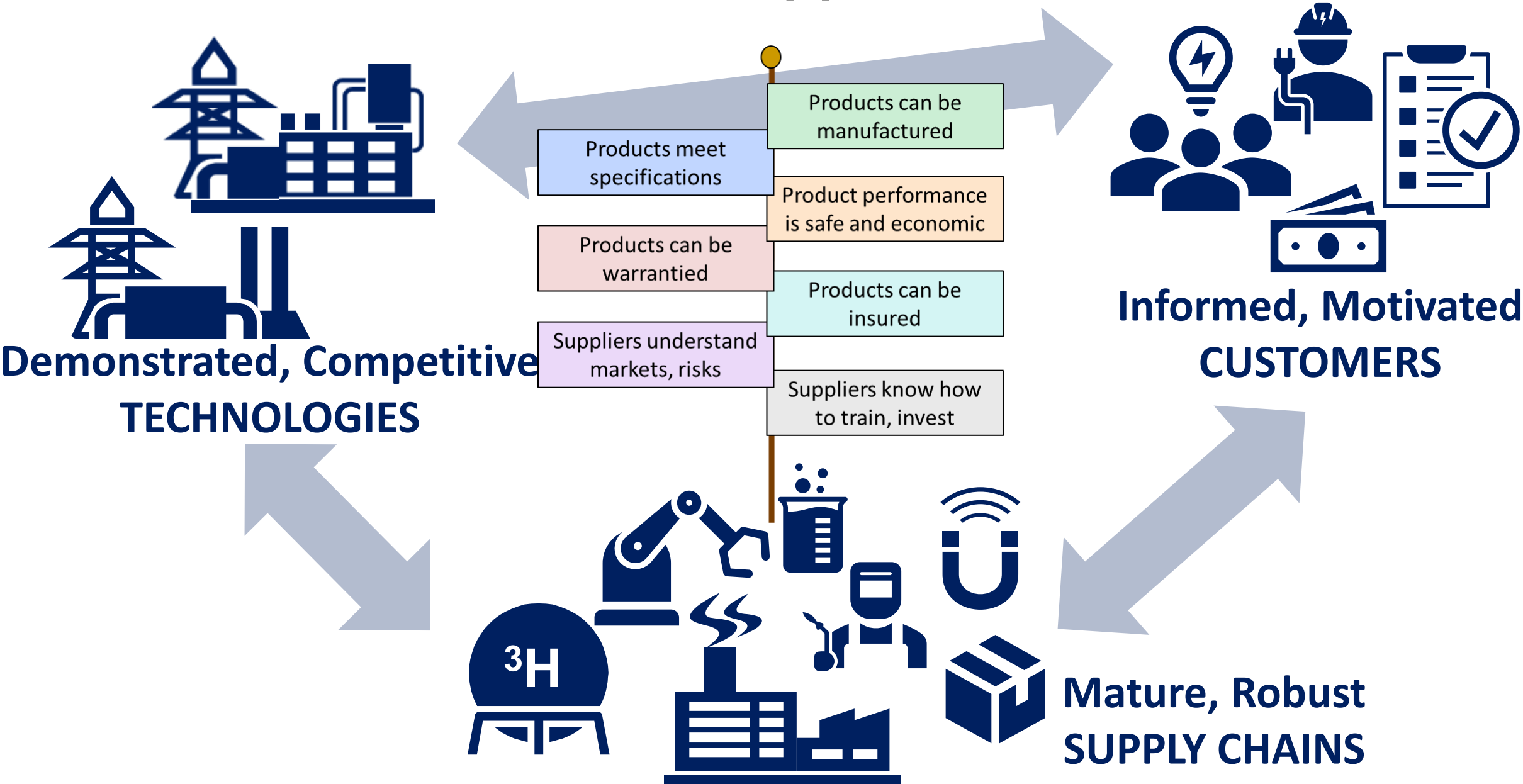
<https://iaqg.org/>

Other ISO Standards Adopting and Adapting 9001*

- ISO 13485 for medical devices
- ISO/TS 54001 for elections at all levels of government
- ISO 18091 for local government sector applications
- ISO 22163 for railway sector applications
- ISO 29001 for petroleum, petrochemical and natural gas-related products and services
- ISO/IEC/IEEE 90003 for computer software

*<https://www.iso.org/standard/62085.html>

Codes and standards can support commercial fusion.



The case for voluntary consensus standards (VCS)

- Participation in the standards development provides the private sector direct input into oversight and regulatory processes, increasing chances for fit-for-purpose, right-sized outcomes
- Timely development of Codes and Standards supports/derisks/informs development of a supply chain that can meet customer requirements and expectations through:
 - preparation of an adequately trained workforce,
 - development of appropriate procedures,
 - informed, timely business investments, and
 - warranties on products and services

It's November 18, 2025. Do you know who is writing your standards?