HYDROGEN–BORON FUSION NETWORK

HBF Network

The intelligence layer for proton–boron-11 fusion research

A research-first platform for p-^{11}B fusion physics, alpha-particle diagnostics, AI & computer-vision detector analysis, robotics automation, and direct-energy-conversion modelling — every figure an open, reproducible model output.

- **FusionSim** · open physics
- **AlphaTrack AI** · CV diagnostics
- **RoboLab** · digital twins
- **DirectConvert** · energy modelling
- **Research Hub** · open data

Whitepaper v0.3.7 (revised) · July 2026 · Research & concept draft

READ FIRST

This document is **not** a reactor construction manual and makes **no** claim of a working fusion reactor. All quantitative figures are model outputs from the open `HBF FusionSim v0.3` code, with assumptions stated and uncertainty acknowledged. Nothing here is financial advice or an offer of securities.

CONTENTS

Table of contents

01

Executive Summary

HBF Network is a research-first technology platform focused on proton–boron-11 (p-^{11}B) fusion: the physics, the alpha-particle diagnostics that prove it, the AI and computer-vision tools that read those diagnostics, the robotics that automate them, and the direct energy conversion concepts that could one day turn charged fusion products into electricity without a steam cycle.

The long-term scientific motivation is the reaction **$p + {}^{11}B \rightarrow 3\alpha + 8.68$ MeV**. Its products are charged helium nuclei rather than neutrons, which opens the theoretical possibility of converting fusion energy directly into high-voltage DC electricity. Our own power-balance modelling (Section 4) confirms why this is one of the hardest problems in energy: in a thermal plasma with equal ion and electron temperatures, X-ray (bremsstrahlung) losses exceed fusion output in our model, and even aggressive hot-ion scenarios only approach break-even against radiation alone. We *show* these results rather than hide them.

HBF Network therefore does not sell a reactor. It builds the enabling intelligence layer that p-^{11}B research needs regardless of which confinement concept eventually wins: **HBF FusionSim** (open physics simulation), **HBF AlphaTrack AI** (computer-vision analysis of nuclear track detectors), **HBF RoboLab** (robotic diagnostic automation and digital twins), **HBF DirectConvert** (staged direct-conversion modelling), and the **HBF Research Hub** (transparent datasets, provenance, and open review).

CORE POSITIONING

HBF Network claims no working fusion reactor and no timeline to net power. The credible, investable claim is: HBF builds simulation, diagnostics, AI, robotics, and research infrastructure for long-term hydrogen–boron fusion research — with every step independently verifiable.

TL;DR FOR INVESTORS

- **What:** an intelligence layer — open simulation, alpha diagnostics, CV/AI, robotics — for p-^{11}B fusion research. Not a reactor.
- **Why now:** ≈$10B cumulative private fusion funding; every lab and company needs honest simulation and alpha diagnostics.
- **Wedge:** AlphaTrack AI (CV for detector images) + FusionSim (open, benchmarked physics) — demonstrable and salable today.
- **Honesty:** our own models show p-^{11}B thermal break-even is not reached — disclosed up front (§4), not discovered later.

- **Model:** research-tools SaaS + non-dilutive grants; grant-funded today with venture optionality if any p-^{11}B path advances.

TRACTION · WHAT EXISTS TODAY

We're already executing

This is not a slide-only concept. Every claim below exists now and is inspectable.

- **Live website & this reproducible whitepaper** — every quantitative figure is a model output from HBF FusionSim v0.3, shipped with a machine-readable `verification.json`.
- **HBF FusionSim v0.3** — working reactivity, power-balance, Lawson, and direct-conversion models; D-T benchmarked to Bosch–Hale within <2%, p-^{11}B to Nevins–Swain / Putvinski within ±25%.
- **HBF AlphaTrack AI (proof-of-concept)** — a real OpenCV pipeline reading synthetic CR-39 fields at precision 0.92 / recall 0.87 (synthetic ground truth).
- **Synthetic CR-39 generator** — safe, labelled training data (tracks + dust, scratches, uneven illumination) to develop CV before any licensed-lab plate exists.
- **DirectConvert v0.1** — exact stage-voltage optimization over the model alpha spectrum (Appendix B).

READ THIS AS MOMENTUM

The next milestones turn each of these from “built & synthetic” into “published & lab-validated” with partner labs.

02

Scientific Background: p-^{11}B Fusion

Fusion releases energy when light nuclei combine into more tightly bound products. Useful reaction rates require extreme ion temperature, density, and confinement time. The IAEA describes magnetic confinement fusion (MCF) and inertial confinement fusion (ICF) as the two major research families [1,2].

In deuterium–tritium (D-T) fusion, 80% of the energy leaves as 14 MeV neutrons. The primary p-^{11}B reaction instead produces three alpha particles carrying essentially all of the 8.68 MeV as charged-particle kinetic energy. This motivates interest in **aneutronic** fusion — although secondary reactions (e.g. ^{11}B(α,n)^{14}N) and impurities still produce some radiation, so “aneutronic” never means “radiation-free”. Model estimates put the secondary neutron output on the order of a few percent (or less) of the total energy — far below D-T’s ~80% — but still enough to require modest shielding and to be treated seriously in any real facility.

In 2023, researchers reported the first clear measurement of p-^{11}B fusion alphas in a magnetically confined plasma, using high-energy neutral beams and boron powder injection in the Large Helical Device [3]. The reaction is real and measurable in a plasma — but that was a diagnostic demonstration at negligible power, not a step toward net energy.

Term	Meaning for HBF Network
Proton	Hydrogen nucleus; one reactant in p-^{11}B fusion.
Boron-11	Stable boron isotope (80% of natural boron); the second reactant.
Alpha particle	Helium-4 nucleus, charge +2e. Emitted with a broad spectrum ~0–5.7 MeV, mean ≈ 2.9 MeV (8.68 ÷ 3). Not monoenergetic — a key engineering fact.
Bremsstrahlung	X-ray radiation from fast electrons deflected by ions. The central loss channel for p-^{11}B.
Direct conversion	Recovering charged-particle kinetic energy as DC electricity via retarding electric fields, without a full thermal cycle.
CR-39	Solid-state nuclear track detector; etched alpha pits are readable by microscope and computer vision.

03

Why Hydrogen–Boron Fusion Is Attractive

The appeal of p-^{11}B is the combination of abundant, stable, non-radioactive fuels and charged fusion products. Its promise is not that it is easy — it is that success would remove the neutron-damage, tritium-breeding, and activation burdens that dominate D-T reactor engineering.

Potential advantage	Why it matters	Caution
Charged alpha products	Can be guided by electric/magnetic fields; enables direct conversion.	Requires particle-orbit control, MV-class insulation, loss management.
Low primary neutron output	Less activation and shielding; simpler maintenance.	Secondary reactions still produce some neutrons and gammas.
Stable, abundant fuel	No tritium breeding; boron is cheap and global.	Does not reduce plasma, X-ray, or high-voltage hazards.
Direct-conversion potential	Alpha kinetic energy → HV DC could beat ~33–40% thermal cycles (≈66% at 4 stages in our model, *under assumed engineering factors — modelled, not measured*).	Depends on the broad spectrum, geometry, and power electronics; unproven at system level.

04

Why p-^{11}B Is Hard — Quantified

This section is the scientific heart of the paper, and we deliberately present our own model results even where they are unfavorable. Three facts define the challenge.

Fact 1 — the reactivity gap

Boron's nuclear charge (Z=5) raises the Coulomb barrier, so p-^{11}B needs ion temperatures of **150–400 keV** — roughly ten times hotter than D-T's optimum — and even then its peak reactivity stays below D-T's. Our model integrates a resonance-based cross-section (dominant resonance ~600 keV c.m., σ ≈ 1.2 b) over a Maxwellian, benchmarked against Nevins–Swain (2000) and Putvinski (2019) [13,14,15].

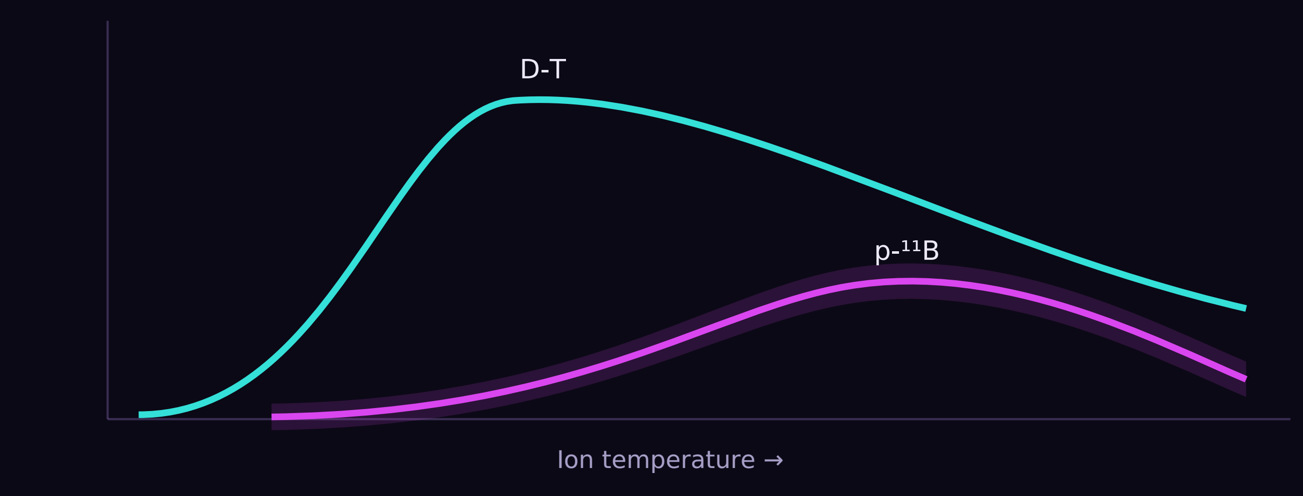

Figure 2 — Fusion reactivity vs ion temperature. p-^{11}B needs ~10× hotter ions and still reacts more slowly.

Fact 2 — bremsstrahlung

At those temperatures, plasma electrons radiate X-rays copiously. Using a relativistically-corrected model, our thermal power balance finds fusion output **never exceeds** X-ray losses at equal ion/electron temperature (peak ratio ≈ 0.40), and reaches only ≈ 0.88 even in an extreme hot-ion scenario (T_e = 0.5 T_i) — before transport, synchrotron, or impurity losses. Any credible concept must exploit non-thermal physics: beam-driven distributions, alpha channeling [6], X-ray recovery, or kinetic effects.

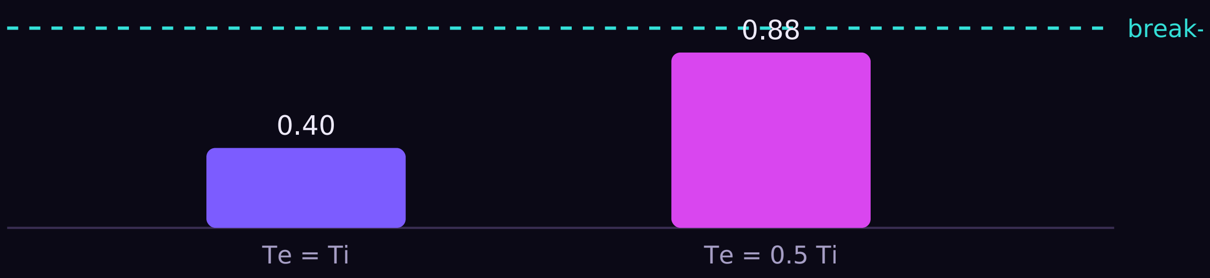

Figure 3 — Thermal power balance (FusionSim v0.3). Fusion-to-bremsstrahlung ratio stays below 1; hot-ion operation narrows but does not close the gap.

Fact 3 — the confinement gap

Even in the optimistic bound where all bremsstrahlung is recovered externally, our ignition-class Lawson triple product for p-^{11}B is **≈ 380× the D-T requirement** (min ≈ 1.1×10^{24} m^{-3}·keV·s near 185 keV, vs ≈ 3.0×10^{21} at 14 keV for D-T — the latter matching textbook values, validating the method). With bremsstrahlung as a true loss at $T_e = T_i$, no confinement time suffices.

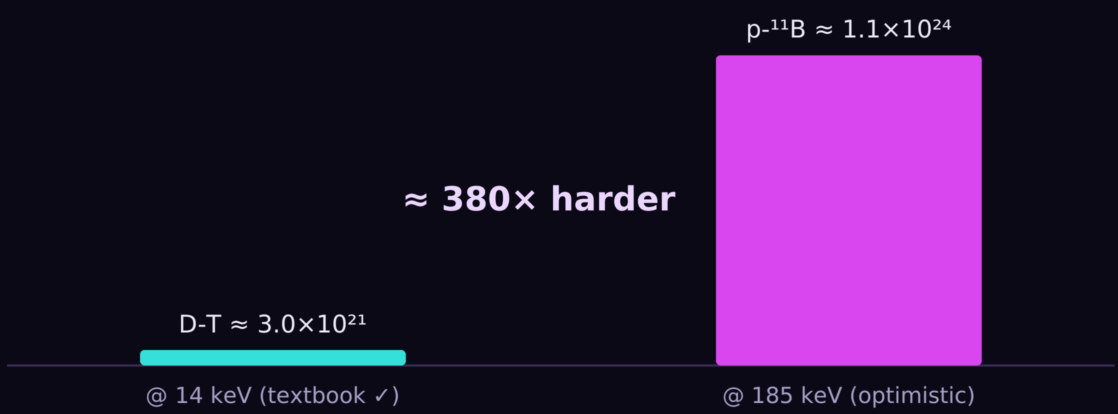

Figure 4 — Ignition-class Lawson requirement (FusionSim v0.3). The D-T minimum reproduces the textbook ~3×10^{21} m^{-3}·keV·s, validating the method; p-^{11}B is ~380× harder even under optimistic assumptions. *Reproducible: FusionSim v0.3 Lawson module.*

HONESTY RULE

These results are why HBF Network is structured as a diagnostics / AI / simulation platform first. If a future experiment or theory beats these baselines, our tools measure it. If not, our tools still have scientific and commercial value.

05

Technical Thesis & System Architecture

HBF Network builds enabling technologies around future $p\text{-}^{11}B$ research. This avoids unsupported reactor claims and produces useful outputs early: simulation tools, detector-analysis software, robotic diagnostics, curated datasets, and education infrastructure. The platform is modular — each module ships independently, and all write to a shared, provenance-tracked data layer consumed by university and licensed-lab partners.

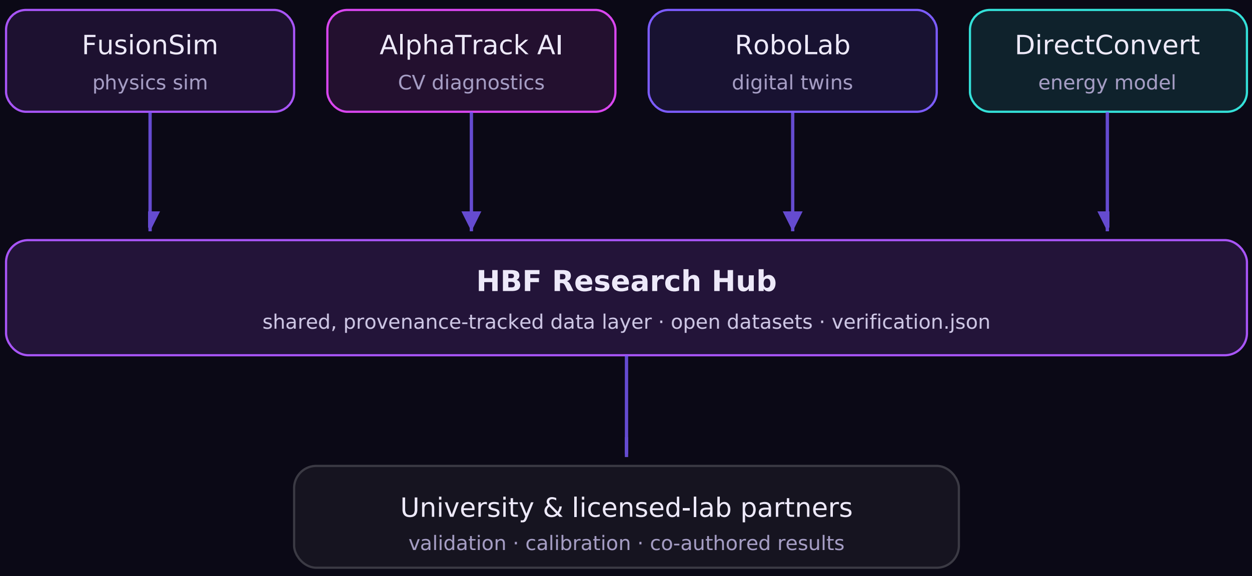

Figure 1 — HBF Network modular platform architecture. Each module ships independently and writes to a shared, provenance-tracked data layer.

STRATEGIC RULE

HBF never claims “we have working fusion energy” unless a validated, independently reviewed experiment demonstrates it. The claim is: HBF builds the intelligence layer for hydrogen–boron fusion research.

06

Alpha-Particle Diagnostics

Because p-^{11}B produces alphas, alpha detection is the proof layer for everything. A serious roadmap distinguishes four milestones — detecting alphas, estimating yield, measuring the energy spectrum, and generating useful electricity. Conflating them is how fusion projects lose credibility.

Alphas are stopped by centimetres of air and micrometres of solid material. Our stopping-range model (empirical Geiger / Bragg–Kleeman scaling) gives ≈ 1.7 cm in air, ≈ 14 μm in CR-39, and ≈ 12 μm in silicon for a 3 MeV alpha — matching published SRIM-class values. This is why real measurements need vacuum systems and thin-window detectors, and belong in licensed laboratories.

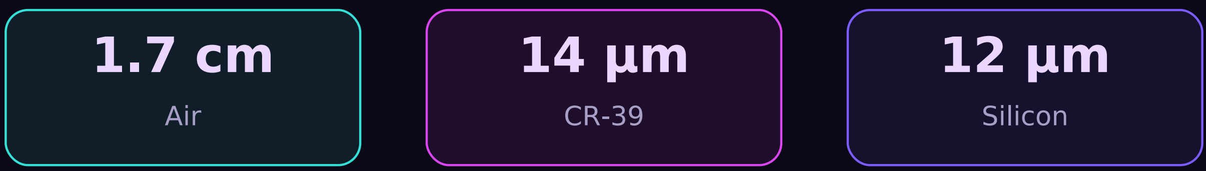

Figure 5 — 3 MeV alpha stopping ranges (empirical, validated vs published SRIM-class values). Depths differ by ~1000× across media — not to scale. Vacuum and thin-window detectors are mandatory.

Detector	Best use	CV / AI fit	Stage
CR-39 track detector	Post-shot charged-particle validation.	Excellent — microscope images suit OpenCV/YOLO.	Near-term (synthetic/ public data; calibration in licensed labs).
Scintillator + camera	Real-time spatial/ temporal hit visualization.	Strong — image/ video streams.	Medium-term lab partnership.
Silicon PIPS (passivated implanted planar silicon) detector	Electronic alpha spectroscopy.	High for signal ML, low for CV.	Lab-partnership only.
Magnetic / Thomson-parabola spectrometer	Species and energy separation.	Medium — image-plate readouts.	Advanced institutional stage.

07

Computer Vision & AI Detector Analysis

HBF AlphaTrack AI is the strongest near-term product: useful, demonstrable, and safe. The goal is to automate reading of detector images — especially CR-39 microscope fields — and convert them into quantitative, uncertainty-tagged reports.

We have already built a working proof-of-concept. On a synthetic CR-39 field (38 simulated etched tracks plus dust, a scratch, and uneven illumination), our real OpenCV pipeline (CLAHE → background flattening → Otsu → morphology → roundness filter) achieves **precision 0.92 / recall 0.87**. A YOLO-class deep detector is the planned upgrade — a 2025 study applying YOLOv8 to real CR-39 images reported >96% accuracy [10] — but we will publish our own benchmarks on real, lab-calibrated plates before any claim beyond synthetic data.

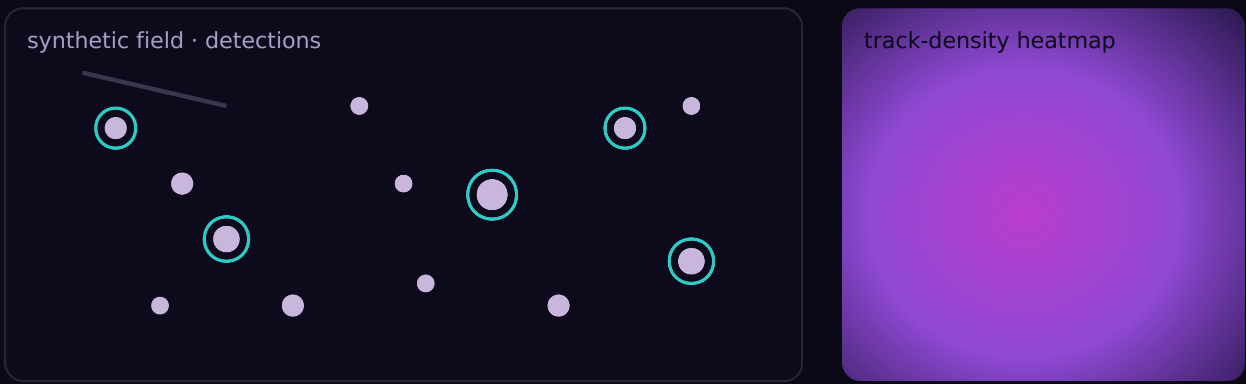

Figure 6 — AlphaTrack AI proof-of-concept on **synthetic** data (clearly labelled synthetic). Left: generated CR-39 field with OpenCV detections (cyan rings; precision 0.92 / recall 0.87). Right: track-density heatmap. *Reproducible: synthetic generator + OpenCV pipeline.*

Pipeline step	Purpose	Output
Image acquisition	Calibrated microscope tiles with metadata.	Raw images + metadata.
Pre-processing	Normalize contrast, denoise, flatten illumination.	Cleaned images.
Track detection	Classical CV baseline; YOLO-class upgrade.	Boxes / masks / points.
Feature extraction	Diameter, eccentricity, contrast, orientation, density.	Track feature table.
Classification	Separate real tracks from dust, scratches, artifacts.	Labels + confidence.

Reporting	Heatmaps, counts, uncertainty, dataset export.	PDF / CSV report.

08

Advanced Robotics & Digital Twin Lab

Robotics in HBF is diagnostic automation and safety infrastructure, not a reactor robot. ITER’s remote-handling systems show why robotics is central to any serious fusion environment [5]; HBF applies the same principle at research-tool scale.

Near-term goals: a robotic microscope scanner that tiles and stitches CR-39 plates reproducibly; a motorized XY stage; a 6-axis arm and mobile inspection rover in simulation; and a full digital twin in ROS 2 with Gazebo or NVIDIA Isaac Sim, so scanning workflows are validated before touching hardware.

`Stack: ROS 2 + Gazebo / Isaac Sim + MoveIt 2 + OpenCV + YOLO + Python dashboard + experiment database.`

09

Alpha-to-Electricity: Direct Energy Conversion

Because alphas are charged (+2e), decelerating them against a retarding electric field converts kinetic energy directly into electrical potential energy: an alpha of energy E can ideally be stopped by $V = E/2e$, i.e. ≈ 1.45 MV for the mean 2.89 MeV alpha. That single equation is the easy part; everything else is the hard part.

CORRECTION TO V0.2

p-^{11}B alphas are **not** a tidy monoenergetic 3 MeV beam. The reaction proceeds through ^{8}Be, producing one primary alpha (~4 MeV region) and two breakup alphas in a broad continuum — total spectrum ~0–5.7 MeV, mean ≈ 2.89 MeV — emitted nearly isotropically. Any real converter must handle this energy and angular spread; this single fact drives the entire multi-stage design.

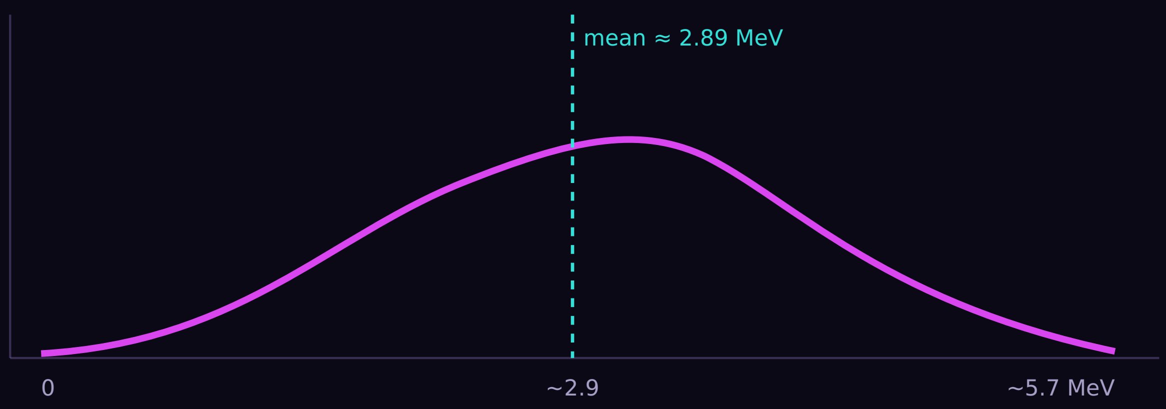

Figure 7 — Schematic p-^{11}B alpha spectrum (HBF model constrained to 8.68 MeV total). The broad spectrum — one primary alpha plus two ^{8}Be-breakup alphas — is why single-stage conversion is fundamentally limited.

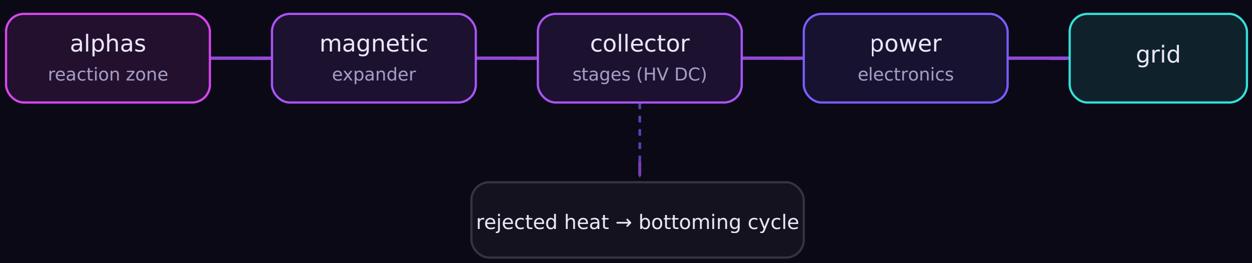

Figure 8 — HBF DirectConvert concept architecture (research model, not a build plan): expander → staged collectors → power electronics; rejected heat recovered by a conventional bottoming cycle.

We modelled staged electrostatic collection quantitatively. Optimizing stage voltages against the model spectrum gives an ideal collection limit of 53% (1 stage), 82% (4), and 93% (12); applying assumed engineering factors (85% geometric × 95% power electronics) yields ≈ 43%, 66%, and 75%. These are stated assumptions, not measurements; space charge, orbit losses, and voltage holding would reduce them further. Historical LLNL beam-direct-conversion experiments demonstrated staged collection works physically at high efficiency in idealized beam tests [12,16].

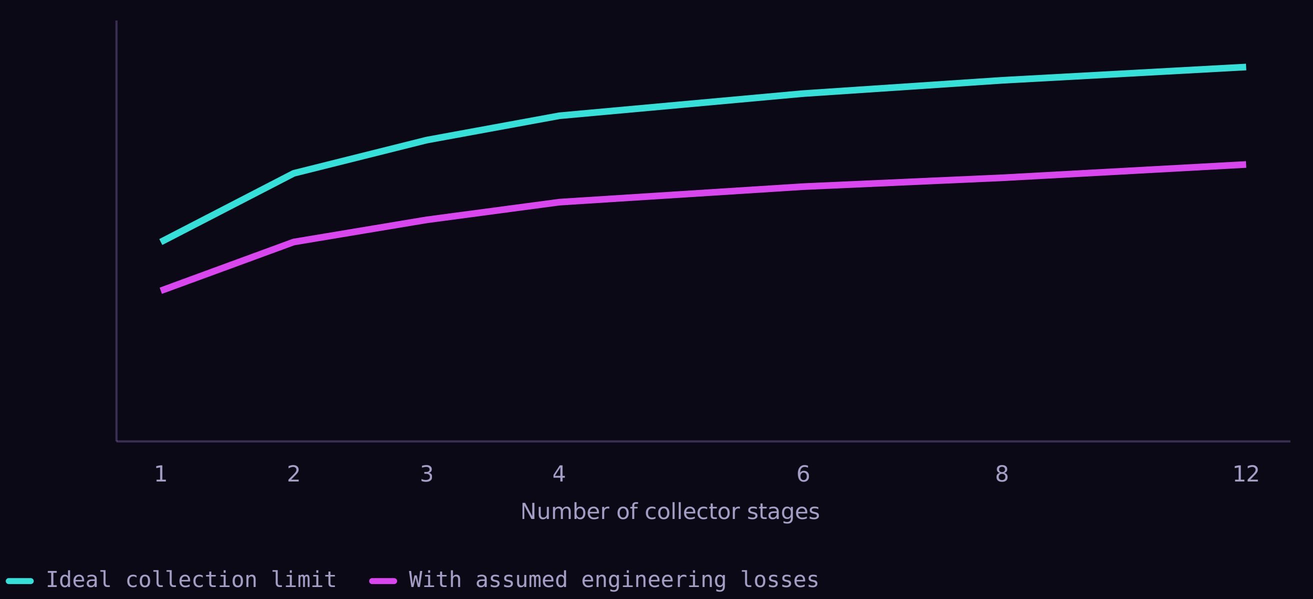

Figure 9 — DirectConvert v0.1: conversion efficiency vs collector stages (optimized stage voltages over the model spectrum). A hybrid layout (direct + bottoming cycle) reaches ≈ 78% of charged-particle energy as electricity in our accounting model.

Conversion method	Concept	HBF status
Electrostatic direct conversion	Retarding fields + collectors → HV DC.	Modelled in DirectConvert v0.1; no hardware claims.
Multi-stage collector	Different voltages capture different energy bands.	Stage-count trade study complete; sensitivity dashboard in Phase 5.
Inverse cyclotron / RF	Extract energy from spiralling ions.	Literature / model study; long-term.
Thermal bottoming cycle	Recover wall heat and X-rays conventionally.	Included in hybrid accounting.

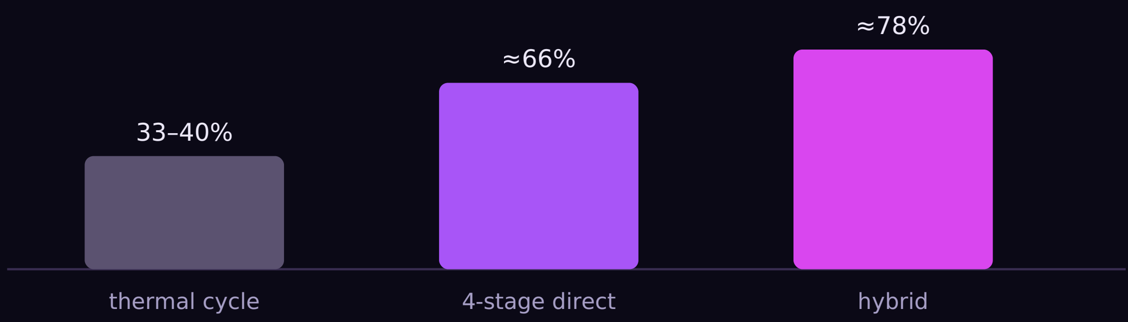

Figure 10 — Energy-recovery accounting for alpha kinetic energy under three pathways. Direct and hybrid values assume stated engineering factors — *modelled, not measured*; targets for partner-lab validation, not promises.

Energy scale (Appendix A): 8.68 MeV = 1.39×10^{-12} J; 1 W ≈ 7.2×10^{11} reactions/s; 1 MW ≈ 7.2×10^{17} reactions/s.

10

Sustaining the Burn

Fusion is not a fission-style chain reaction — no neutrons multiplying generation to generation, no criticality. The correct concept is a **self-sustained burn**: fusion-born alphas deposit energy back into the fuel, keeping it hot enough to continue without external heating. For p-^{11}B, closing this loop is the whole game.

- **Alpha self-heating** (established physics, unproven for p-^{11}B at scale): the 3 alphas carry all 8.68 MeV; if they thermalize they heat the fuel — but they preferentially heat electrons, which radiate the energy away as bremsstrahlung.
- **The "avalanche" hypothesis** (published but debated): some laser-driven schemes propose fusion alphas scatter fuel protons up to the ~600 keV window, breeding fast protons [11]. A self-sustaining avalanche has not been demonstrated; HBF treats it as a hypothesis to model, not a design basis.
- **Alpha channeling** (promising theory): wave–particle techniques could deliver alpha energy to fuel ions instead of electrons, directly attacking bremsstrahlung [6]. Strong pedigree, no integrated demonstration — ideal for HBF's open modelling.
- **Ash removal** (required either way): spent alphas dilute the fuel and must be extracted — conveniently, extraction and direct conversion can be the same hardware.

BOTTOM LINE

A p-^{11}B "complete chain" — reaction → alpha energy recycled to fuel ions → sustained burn → surplus alphas to direct conversion — is a coherent research program with published support for each link; but no link is demonstrated at reactor-relevant conditions. HBF builds the open models and diagnostics to test each link honestly.

11

Reactor Concepts at Research Level

Research pathway	Advantages	Hard problems
Magnetically confined p-^{11}B (beam-driven stellarator/tokamak)	Continuous research path; LHD result lives here [3].	Ti ≥ 150 keV, bremsstrahlung, confinement, impurities.
Beam-driven FRC	Compact; high beta; aligns with advanced fuels and direct conversion (TAE’s path).	Stability at scale, beam efficiency, alpha extraction, net power.
Laser-driven p-^{11}B	Highest alpha yields to date; strong diagnostics use case (HB11, Marvel).	Repetition rate, target gain, driver efficiency, energy recovery.
Alpha channeling concepts	Attacks the core electron-heating problem [6].	Wave–particle control unvalidated at relevant conditions.
Hybrid direct + thermal recovery	Most realistic power-plant accounting.	System complexity, MV insulation, materials, thermal management.

SAFETY BOUNDARY

This paper intentionally contains no operational parameters, hardware construction steps, or instructions for plasma, high-voltage, radiation, vacuum, or laser systems. Real experiments require licensed facilities, professional supervision, and regulatory approval.

HBF FusionSim: Design & Verification

HBF FusionSim is the first polished product, and this whitepaper doubles as its first output — every quantitative figure was generated by FusionSim v0.3 code. The MVP is educational but technically grounded, with visible assumptions and uncertainty ranges.

Verification so far

- D-T reactivity module reproduces published Bosch–Hale values to <2%.
- Computed D-T ignition triple-product minimum ($\approx 3.0\times10^{21}$ $m^{-3}\cdot$keV·s at 14 keV) matches textbook values.
- p-^{11}B reactivity benchmarked to Nevins–Swain / Putvinski within a stated ±25% band.
- Alpha stopping ranges match published SRIM-class values.

All source code and a machine-readable `verification.json` accompany the document. **Validation next** (Phase 1–2): independent replication of power-balance and collector-field models in COMSOL Multiphysics and an open-source code, with a published comparison; sensitivity analyses over cross-section uncertainty; and AlphaTrack benchmarking on real, lab-calibrated plates against expert counts. We publish disagreements, not just agreements.

`Version ladder: v1 simplified physics → v2 literature comparison + uncertainty → v3 calibrated partner-lab datasets → v4 ML surrogate models.`

REPRODUCIBILITY

Every quantitative figure in this paper (Figures 2–4, 7, 9, 10) is a direct output of HBF FusionSim v0.3. The source code and the machine-readable `verification.json` that re-generates each figure are available on request (and at the project repository once public) — the schematics shown here are for readability; the plots, axes, data points, and uncertainty bands live in the notebooks. Give them to any physicist to re-run.

13

Data Strategy & Benchmarks

Data is built in stages: synthetic first, public/partner second, calibrated lab data third. Every dataset ships with metadata, assumptions, acquisition settings, and validation notes.

Dataset stage	Examples	Purpose
Synthetic	Generated CR-39-like tracks, noise, artifacts.	Train early CV pipelines safely; publish generators.
Public / partner	Published detector images; partner non-sensitive samples.	Realism and generalization.
Calibration	Controlled alpha-source scans from licensed labs.	Validate morphology and detection accuracy.
Experiment metadata	Exposure, geometry, etching, microscope settings.	Reproducibility and audit.

14

Safety, Ethics & Compliance

The public-facing HBF project is software, simulation, education, and controlled research partnerships. Any real alpha source, detector calibration, plasma, laser, or high-voltage work happens only in licensed laboratories with trained professionals and institutional approval.

- No claim of a working reactor without peer-reviewed or independently validated evidence.
- No public instructions for hazardous plasma, radiation, high-voltage, vacuum, or laser systems.
- No energy-backed token claims and no guaranteed financial returns, ever.
- Clear separation: simulation → diagnostic proof → lab validation → net-energy claims.
- Transparent assumptions and uncertainty in every technical output — including the unfavorable ones.
- A scientific advisory board (plasma, detector, and radiation-safety expertise) holds **veto power** over any public claim of experimental results.
- Datasets and tools are screened for **export-control / dual-use** considerations; nuclear-adjacent data is handled accordingly.

15

Token Utility & DeSci Transparency

HBF's Web3 layer does two jobs: it is a **utility & coordination token** and a **scientific-transparency layer**. The token powers governance, grants, platform access, and contributor rewards; the transparency layer makes every dataset, model, and result verifiable. It is designed to coordinate an open research community — **not** as an investment, a security, or a claim on profits, and no returns are promised.

What the token is for

- **Governance** — vote on research priorities, grant allocation, and the roadmap.
- **Grants** — propose and fund open research from transparent, on-chain community & treasury pools.
- **Access** — unlock premium AI research tools, advanced simulations, curated datasets, and API access.
- **Contribute & earn** — rewards for verified contributions (data, code, review, lab calibration).
- **Stake for reputation** — stake to signal commitment and increase contributor / governance weight.

Transparency mechanics

- **Provenance** — content-hash every dataset, model version, and figure so any published number traces to the exact code and inputs (the `verification.json` is the seed).
- **Contribution ledger** — an append-only record of who contributed what, for credit and audit.
- **Open peer review** — transparent, signed review of models and datasets; disagreements published, not hidden.

On-chain deployment

HBF is a real, fixed-supply ERC-20 on **BNB Smart Chain**. Two contracts back it: HBFToken — 1,000,000,000 HBF minted once, with **no mint function, no owner, no pause and no blacklist**, so supply can never grow and no one can freeze balances — and `HBFVesting`, the on-chain lock described below. Both are source-verifiable on BscScan.

Supply & allocation

Fixed supply: **1,000,000,000 HBF** (no inflation). The allocation is deliberately simple:

Allocation	Share	Amount	Status
Founder / company	60%	600,000,000	Time-locked 12 months in an on-chain vesting contract
Community distribution	40%	400,000,000	Community distribution, contributor rewards, grants & ecosystem liquidity

The founder/company allocation is **time-locked on-chain**: nothing can be moved for the first 12 months, and anyone can verify the locked balance and unlock date directly from the `HBFVesting` contract. This keeps long-term alignment while making the lock provable rather than a promise. The remaining 40% is available for community distribution, contributor rewards, grants, and ecosystem use.

Utility, not speculation

HBF exists solely to **coordinate the network** — governance, grants, access, and contributor rewards (as listed above) — and to make research verifiable on-chain. It is a **utility & coordination instrument**, not a security, an investment, or an energy-backed claim; it carries **no promise of profit or returns**, and its value can fall to zero. HBF is **not offered or promoted as a way to make money**, and nothing in this document is an offer, solicitation, or investment advice.

`Deployed contract addresses and the lock's unlock date are published on-chain and verifiable on BscScan before any public market opens.`

GUARDRAILS

The HBF token is a utility & coordination token — not an investment, a security, or an energy-backed claim, and no returns are promised. Crypto assets are volatile and can lose all value; regulatory treatment varies by jurisdiction. Fusion + crypto reads as hype by default, so every on-chain artifact must point to verifiable off-chain science.

16

Market Opportunity & Competitive Landscape

Fusion has become a real private market. The Fusion Industry Association reported **$2.64B** of new funding in the 12 months to July 2025 — cumulative industry funding ≈ **$10B** — and supplier spending is rising 24–27% year over year (≈$538M in 2025 → ≈$681M projected 2026) [17,18]. Capital flows not only to reactor builders but to the tooling, diagnostics, and software around them — exactly HBF's wedge.

Segment	Examples	HBF relationship
p-^{11}B reactor ventures	TAE, HB11 Energy, Marvel Fusion, LPP Fusion.	Potential customers/partners — not competitors.
Fusion software	Plasma codes (proprietary and academic).	HBF differentiates on open verification, detector CV, robotics.
Detector analysis	Manual microscope counting; scattered scripts.	Direct competition; HBF wins on automation & reproducibility.
Education / DeSci	Fusion courses, open-science platforms.	Adjacent revenue and community pipeline.

SIZING LOGIC

>50 private fusion companies and >100 university plasma groups. If HBF's diagnostics/simulation SaaS reaches 30 paying organizations at $20–80k/year within 4 years, that is a $1–2.5M ARR research-tools business — before grants, education revenue, or reactor-relevant IP upside.

Adjacent markets widen the wedge. The core assets — computer-vision analysis of charged-particle track detectors, robotic scanning, and open plasma/reaction simulation — are not p-^{11}B-specific. The same tools serve **deuterium–tritium and HEDP experiments**, and CR-39 / track-detector analysis is used well beyond fusion (radiation dosimetry, neutron metrology, space-radiation and medical-physics QA). That turns a niche p-^{11}B play into a broader charged-particle-diagnostics platform, and gives the business demand even if p-^{11}B never reaches net power.

Business Model & Funding Strategy

HBF creates value long before any reactor exists. Revenue starts with software, education, and research-collaboration tools; grants provide non-dilutive fuel; university partnerships provide validation and talent.

Revenue / funding path	Description	Credibility
Education platform	Courses, explainers, interactive FusionSim modules.	High near-term feasibility.
AlphaTrack AI SaaS	Detector-image analysis, reports, dashboards.	High once real-data benchmarks are published.
Robotics simulation kits	ROS 2 / Isaac / Gazebo lab-automation templates.	Strong fit with team’s robotics skills.
Research dashboard SaaS	Provenance, experiment logs, model reports.	Useful for student labs and research teams.
Grants	AI-for-science, clean energy, robotics, DeSci.	Good non-dilutive path.
University partnerships	Joint projects, datasets, preprints.	Essential for validation.

POSITIONING — GRANT-FUNDED, VENTURE-OPTIONAL

HBF is, first, a **grant-funded research-tools company**: SaaS + services + non-dilutive grants that stand on their own. The **venture** upside is optionality — if any p-^{11}B path advances, a validated diagnostics + conversion-modelling layer becomes strategically valuable. We do not ask investors to underwrite fusion physics; we ask them to back a research-tools business with asymmetric upside.

AlphaTrack AI — indicative pricing

Tier	For	Indicative price
Academic / single seat	Students, individual researchers.	\$6–12k / year
Lab / group	A research group or detector lab.	\$20–40k / year
Institution / enterprise	Department or fusion company; SSO, support, SLAs.	\$60–120k / year

Prices are illustrative planning assumptions, to be validated with early design partners.

Illustrative ARR ramp (conservative)

Year	Paying organizations	Blended ARR
1	3–5 (design partners, discounted)	~$0.1–0.2M
2	~10	~$0.4M
3	~20	~$1.0M
4	~30	~$1.5–2.5M

Grants (AI-for-science, clean-energy, robotics) run in parallel from month 1 to extend runway non-dilutively.

Pipeline & moat. Target design partners are university plasma groups and p-^{11}B ventures (TAE, HB11, Marvel, LPP) plus new academic entrants after the LHD result; signed letters of intent are a near-term deliverable (none are claimed yet). The moat compounds: proprietary calibrated detector datasets, benchmarked CV models, reproducible scanning workflows, and the direct-conversion model library — assets competitors cannot copy without the same partner-lab access.

Milestones

HBF ships value in verifiable steps. Each milestone below is a **published, independently checkable deliverable** — anyone can re-run or inspect it — not a status update.

Milestone	Target	Verifiable deliverable
M1 — Simulation live	~Month 6	FusionSim published with a verification notebook; anyone can re-run Figures 2–4.
M2 — Diagnostics benchmark	~Month 12	AlphaTrack benchmark report: precision/recall on synthetic + first real plates, vs human counts.
M3 — Lab validation	~Month 22	Lab-validated CR-39 dataset + a joint preprint with a university partner.

Figure 11 — Staged milestones. Each is a published, independently verifiable deliverable.

What we're seeking. A small pre-seed to reach M1–M3. Use of funds is engineering (FusionSim + AlphaTrack), a partner-lab calibration dataset, and operations/compliance; grant applications run in parallel to extend runway non-dilutively. A detailed budget is available on request.

HOW TO EVALUATE US

The best diligence is technical — give §4 and our open code to any plasma physicist you trust. Every milestone is a published, independently verifiable deliverable, not a status update.

19

Risk Analysis

Risk	Impact	Mitigation
p-^{11}B net power may be physically out of reach.	Long-term reactor ambition never materializes.	Business is built on tools valuable regardless; physics risk disclosed up front.
Bremsstrahlung/ash results discourage the field.	Smaller customer base.	Diagnostics and CV tools serve D-T and D-^{3}He research too.
Synthetic-data models fail on real plates.	AlphaTrack credibility hit.	Real-plate benchmarks are required before any sales claim.
Perceived as crypto hype.	Loss of scientific and investor trust.	DeSci layer is subordinate, non-financial, provenance-only.
Regulatory / safety issues.	Blocked experiments.	All hardware work in licensed partner labs only.
Roadmap too broad for a small team.	Execution failure.	Strict gating: FusionSim + AlphaTrack first; robotics as demo; reactor research partner-led.
Key-person dependency.	Single-founder fragility.	Advisory board, open code, documented pipelines; first hires as the team grows.

20

Technical Appendices

Appendix A — Verified core numbers (FusionSim v0.3)

Quantity	Value	Check
Energy per p-^{11}B reaction	8.68 MeV = 1.39×10^{-12} J	verified in code ✓
Reactions/s for 1 W	7.19×10^{11}	1 / 1.39×10^{-12} ✓
Reactions/s for 1 MW / 1 GW	7.19×10^{17} / 7.19×10^{20}	scaling ✓
Mean alpha energy	2.89 MeV (0 – ~5.7 MeV, broad)	8.68 / 3
Ideal stopping potential (mean α)	≈ 1.45 MV	E = qV ✓
3 MeV alpha range: air / CR-39 / Si	≈ 1.7 cm / 14 µm / 12 µm	SRIM-class ✓
D-T triple-product minimum	≈ 3.0×10^{21} m^{-3}·keV·s @ 14 keV	matches textbook ✓
p-^{11}B / D-T requirement ratio	≈ 380× (optimistic bound)	diverges if brems is a loss at Te=Ti
Max P_{fus}/P_{brem} (Te=Ti / Te=0.5Ti)	≈ 0.40 / ≈ 0.88	model ±~40%

Appendix B — Direct-conversion efficiency vs stages

Stages	Ideal collection limit	With engineering losses (85% × 95%)
1	53%	43%
2	70%	57%
3	77%	62%
4	82%	66%
6	87%	70%
8	90%	72%

12	93%	75%

Appendix C — Simulation methodology

- D-T reactivity: Bosch–Hale (1992) analytic fit; verified <2% deviation.
- p-^{11}B reactivity: Maxwellian integration over a resonance-based cross-section (~600 keV c.m., $\sigma \approx 1.2$ b), benchmarked to Nevins–Swain / Putvinski; ±25% band.
- Bremsstrahlung: relativistically corrected, consistent with NRL formulary; ±~40% at Te > 100 keV.
- Direct conversion: exact stage-voltage optimization (dynamic programming) over the model spectrum; engineering factors labeled as assumptions.
- AlphaTrack CV: OpenCV pipeline (CLAHE → flatten → Otsu → morphology → roundness), metrics vs synthetic ground truth.
- Planned: independent replication in COMSOL and open-source codes (Phase 1). No COMSOL results are claimed here.

21
References

1. IAEA. Fusion background and controlled fusion overview.
2. IAEA Nucleus FUSE. Magnetic and Inertial Confinement Fusion overview.
3. Magee, R. M. et al. First measurements of p-^{11}B fusion in a magnetically confined plasma. *Nature Communications* 14, 955 (2023).
4. Gatu Johnson, M. et al. Charged particle diagnostics for ICF and HEDP. *Rev. Sci. Instrum.* 94 (2023).
5. ITER Organization. Remote handling systems.
6. Ochs, I. E. et al. Improving the feasibility of economical p-^{11}B fusion via alpha channeling. *Phys. Rev. E* 106, 055215 (2022).
7. Ochs, I. E. et al. Bremsstrahlung constraints on p-^{11}B inertial fusion. *Phys. Plasmas* 33, 012703 (2026).
8. Xie, H. S. Preliminary considerations and challenges of p-^{11}B fusion. *Plasma Sci. Technol.* (2025).
9. Liu, B. Progress of proton–boron research for fusion energy in China. IAEA FEC (2025).
10. Wang, Y. et al. D-D fusion charged-particle detection using CR-39 and deep learning. arXiv:2503.06932 (2025).
11. McKenzie, W. et al. HB11 — Understanding hydrogen–boron fusion. *J. Fusion Energy* (2023).
12. Patent WO2018208620A1. Direct conversion of charged particles from fusion reactions.
13. Bosch, H.-S. & Hale, G. M. Improved formulas for fusion cross-sections and reactivities. *Nucl. Fusion* 32, 611 (1992).
14. Putvinski, S. et al. Fusion reactivity of the pB11 plasma revisited. *Nucl. Fusion* 59, 076018 (2019).
15. Nevins, W. M. & Swain, R. The thermonuclear fusion rate coefficient for p-^{11}B. *Nucl. Fusion* 40, 865 (2000).
16. Moir, R. W. & Barr, W. L. Venetian-blind direct energy converter. *Nucl. Fusion* 13, 35 (1973).
17. Fusion Industry Association. The Global Fusion Industry in 2025; Supply Chain 2026.
18. Innovation News Network. Fusion energy supply-chain spending jumps 24% (2026).
19. TAE Technologies. TAE raises $150 million (June 2025).

All citations are to be confirmed against publisher DOIs before external distribution; recent (2025–2026) entries may be preprints or in press. Links available in the digital edition.

HBF Network — Hydrogen–Boron Fusion Network · Whitepaper v0.3.7 · July 2026

Not a reactor construction manual. All figures are model outputs from HBF FusionSim v0.3. This document is for information and discussion only and is **not** financial, investment, legal, or tax advice, nor an offer or solicitation to buy any asset or security. Forward-looking statements are uncertain. HBF Network operates