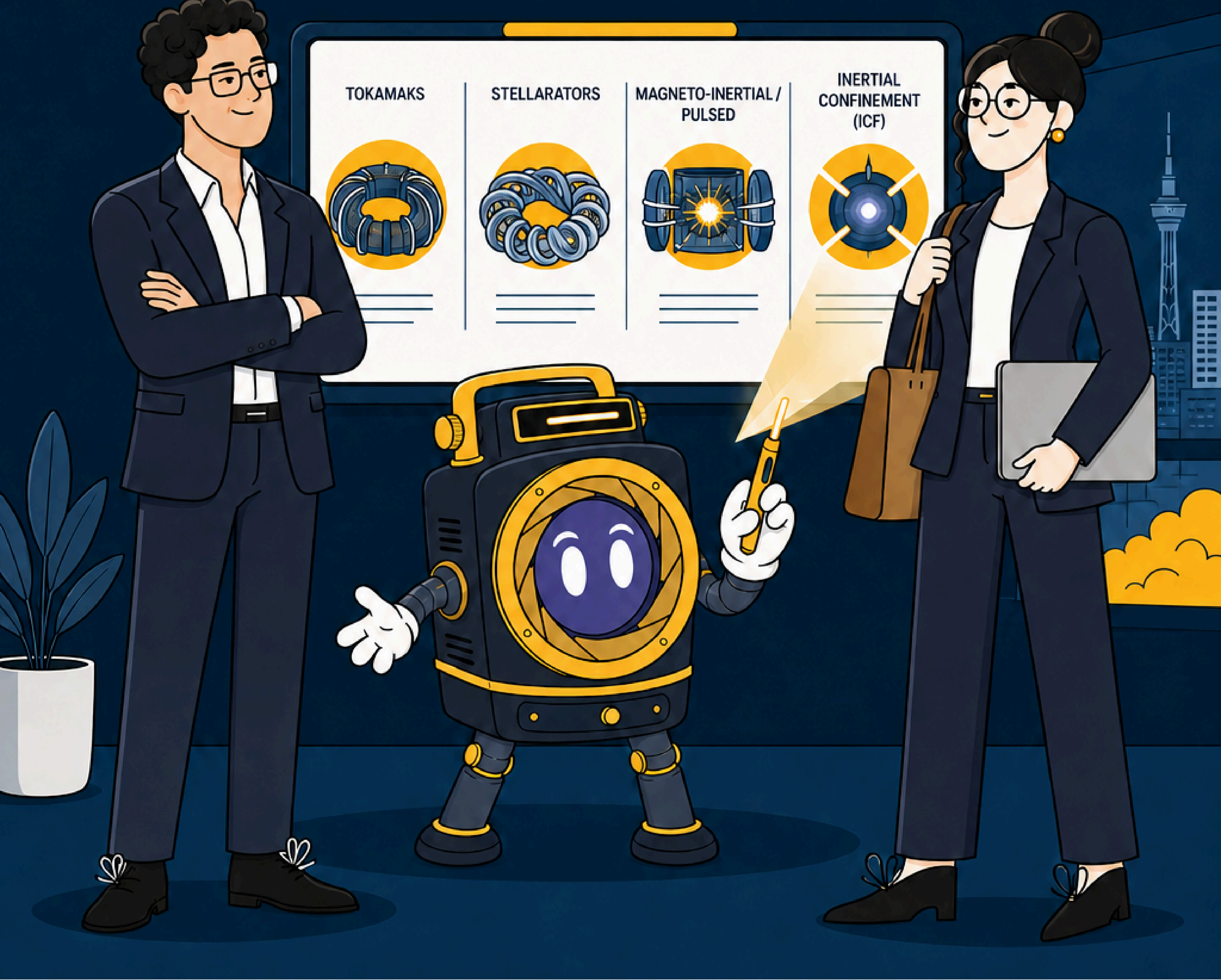
Four Fusion Confinement Technologies:

An Investor's Field Guide



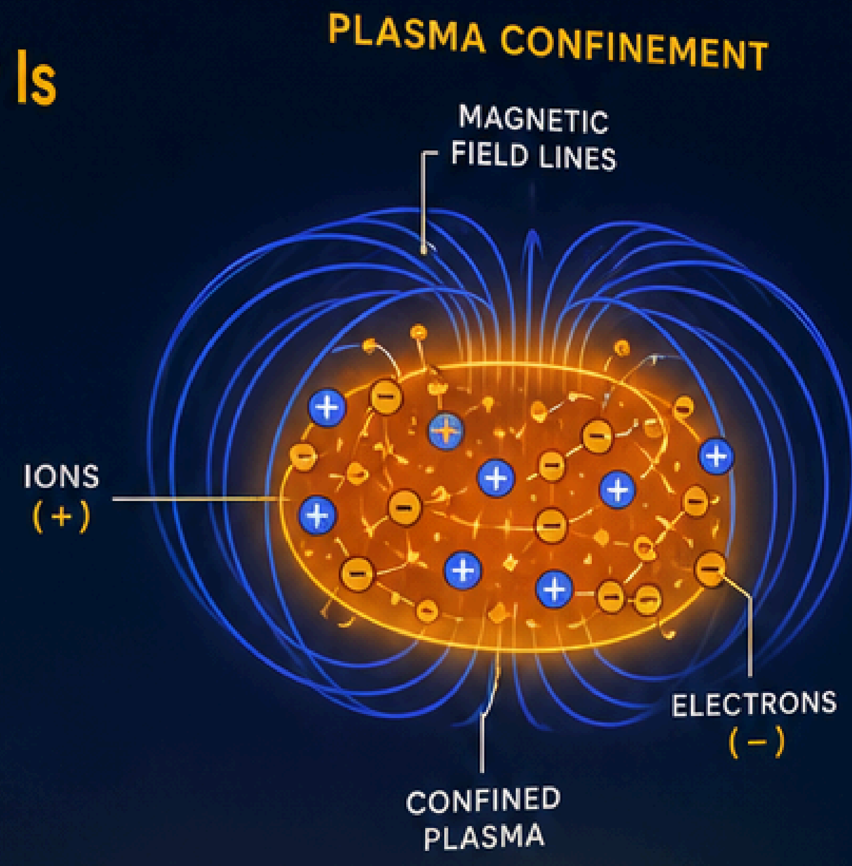
A Quick Primer:
What Fusion Confinement Actually Is

Fusion occurs when two light nuclei (typically deuterium and tritium, both isotopes of hydrogen) are forced together at extreme temperatures, around 100–150 million degrees Celsius. At those temperatures, the hydrogen fuel isn't a gas anymore. It's a plasma: a soup of free electrons and ions. The challenge is holding that plasma in place long enough and densely enough for fusion reactions to sustain themselves.

"Confinement" is the word physicists use for this holding problem. Different approaches solve it with different tools: magnetic fields, inertia, mechanical compression, or some combination.

The key performance metric is the Lawson criterion (or its modern successor, the triple product), which combines three variables: plasma density (n), temperature (T), and energy confinement time (τ). When the product $\hbar \times T \times \tau$ exceeds a critical threshold, the plasma becomes self-heating, or "burning," and can sustain fusion without continuous external energy input.

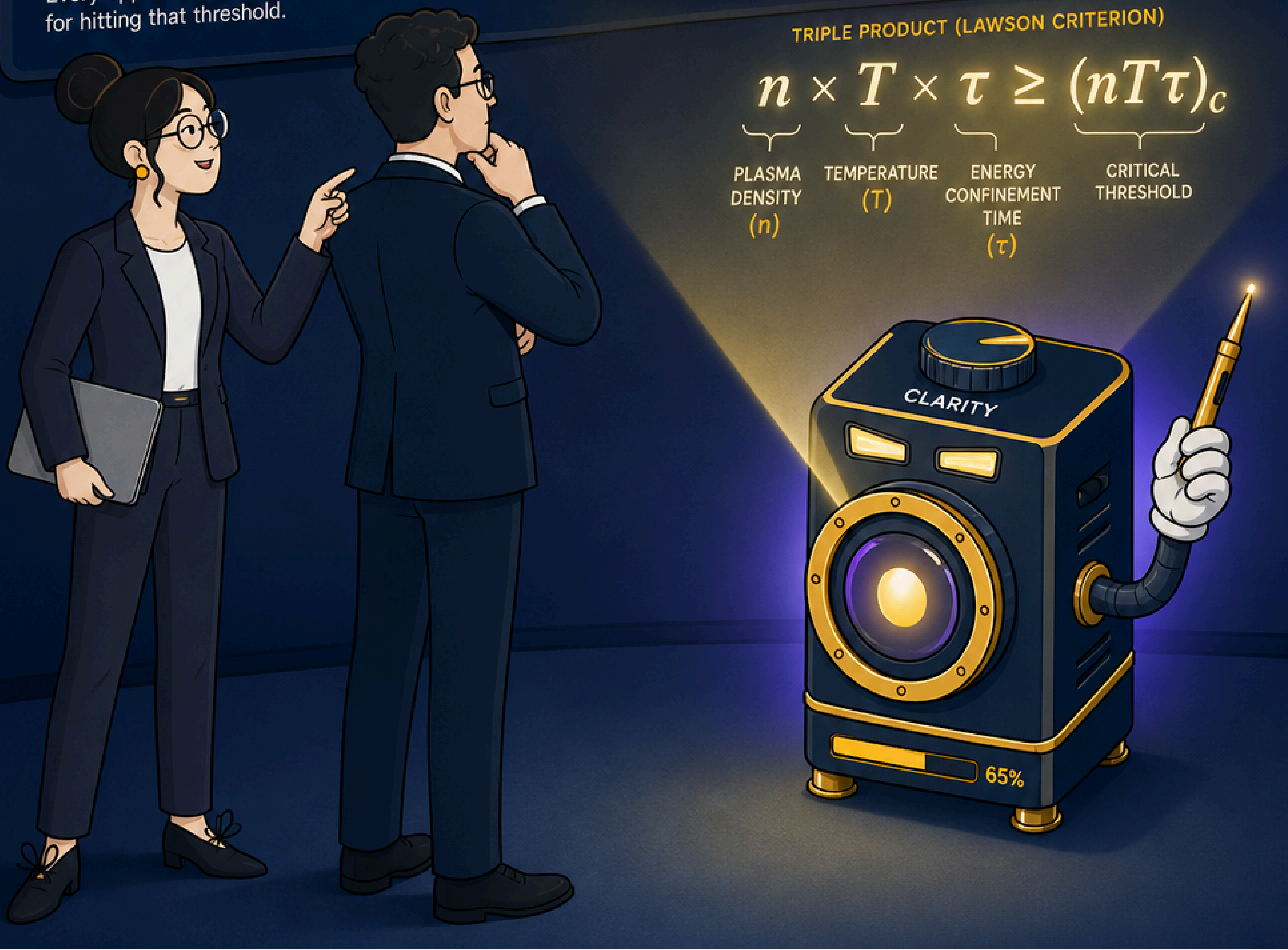
Every approach below is, at root, a different strategy for hitting that threshold.

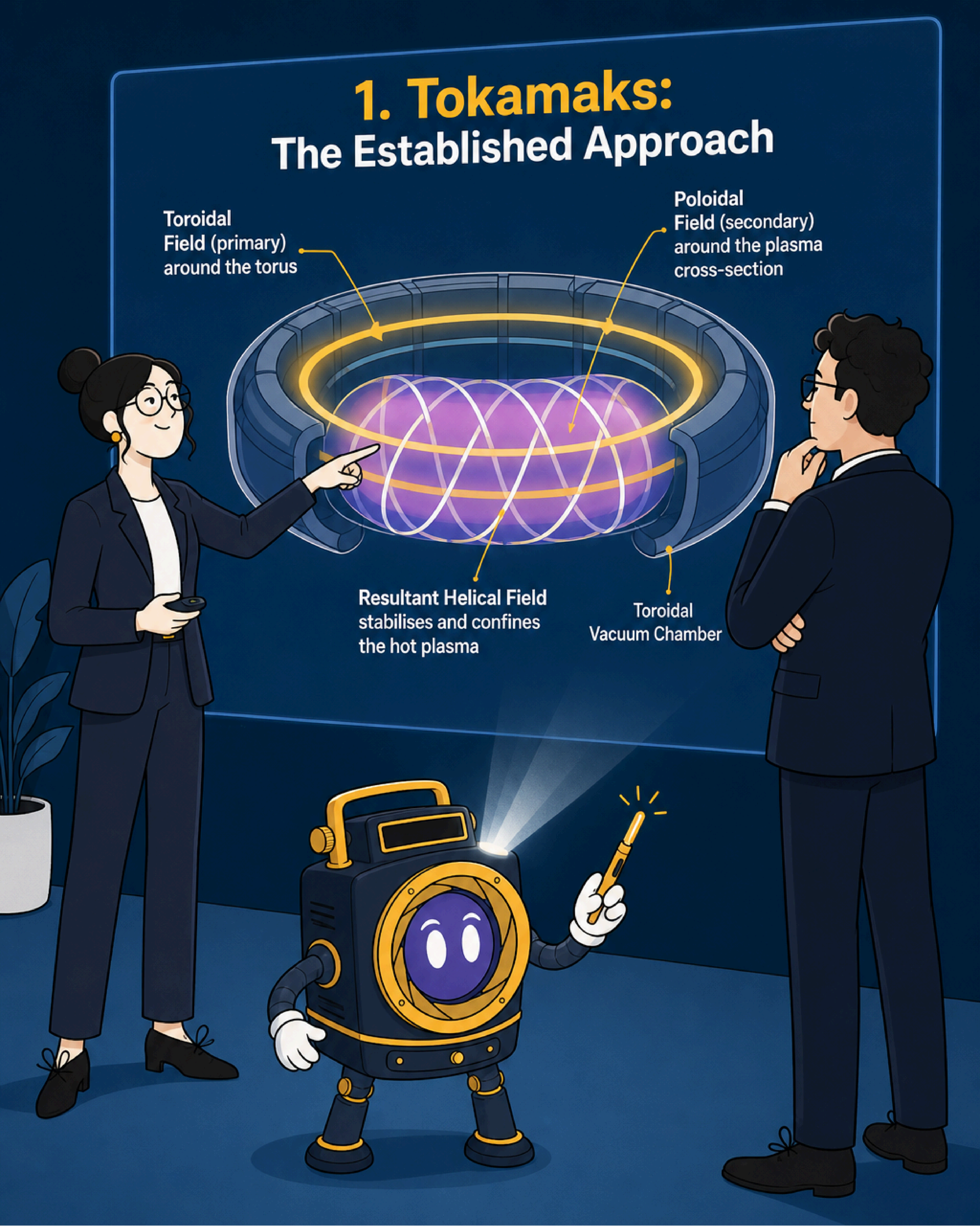


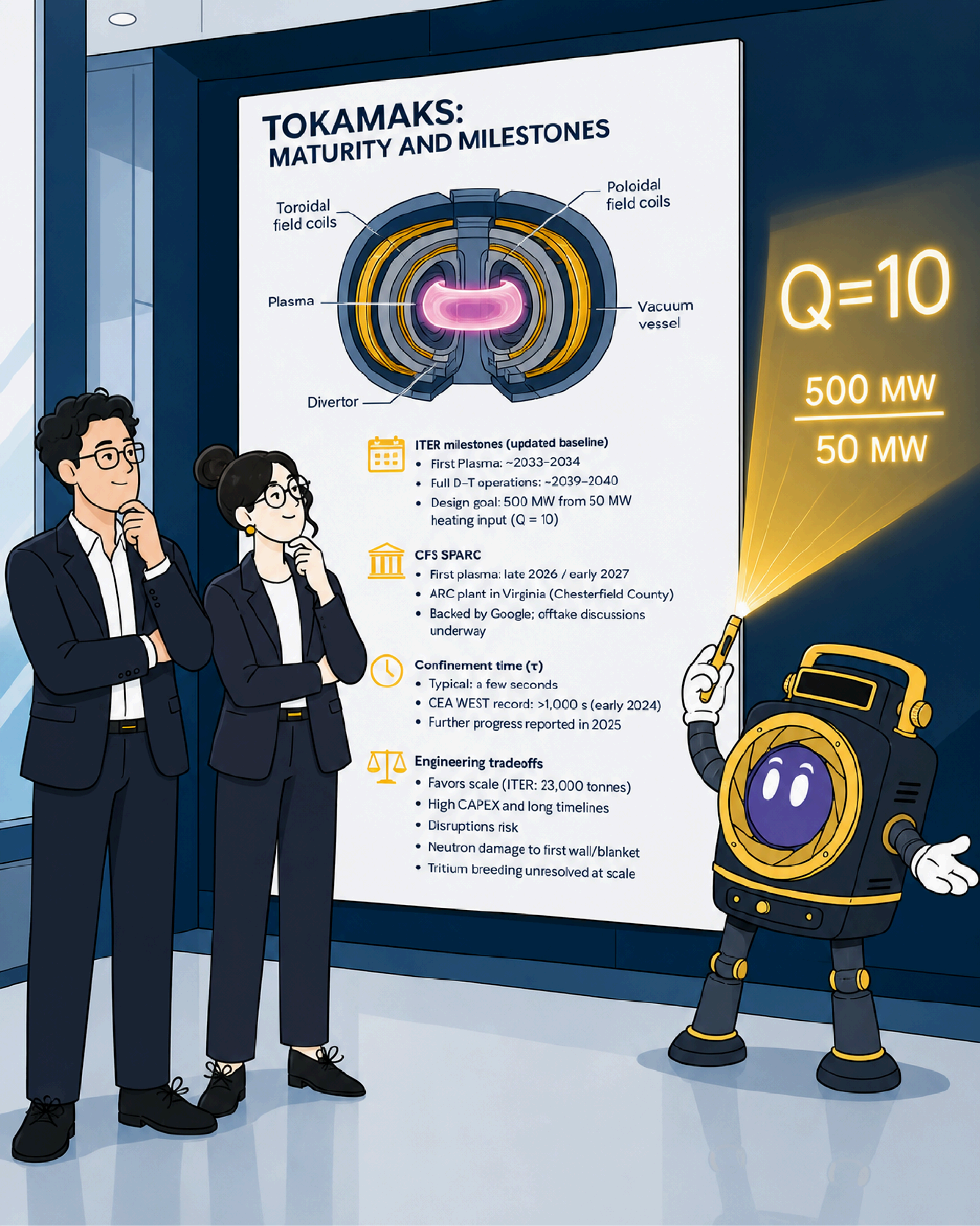
TRIPLE PRODUCT (LAWSON CRITERION)

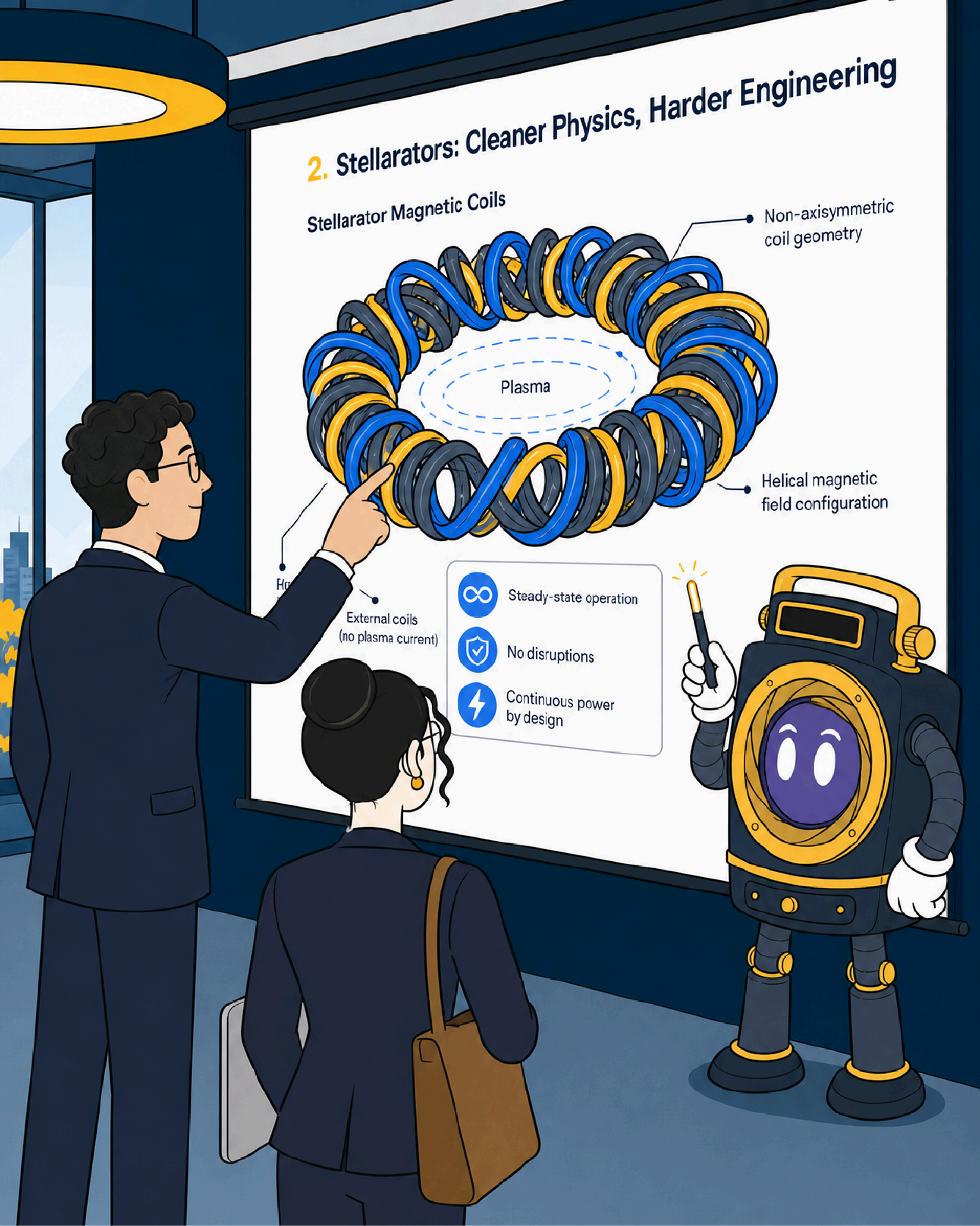
$$n \times T \times \tau \geq (nT\tau)_c$$

PLASMA DENSITY (n) · TEMPERATURE (T) · ENERGY CONFINEMENT TIME (τ) · CRITICAL THRESHOLD




1. Tokamaks:
The Established Approach
Toroidal Field (primary) around the torus
Poloidal Field (secondary) around the plasma cross-section
Resultant Helical Field stabilises and confines the hot plasma
Toroidal Vacuum Chamber


TOKAMAKS:
MATURITY AND MILESTONES
Toroidal field coils
Poloidal field coils
Plasma
Vacuum vessel
Divertor
ITER milestones (updated baseline)
• First Plasma: ~2033–2034
• Full D–T operations: ~2039–2040
• Design goal: 500 MW from 50 MW heating input (Q = 10)
CFS SPARC
• First plasma: late 2026 / early 2027
• ARC plant in Virginia (Chesterfield County)
• Backed by Google; offtake discussions underway
Confinement time (τ)
• Typical: a few seconds
• CEA WEST record: >1,000 s (early 2024)
• Further progress reported in 2025
Engineering tradeoffs
• Favors scale (ITER: 23,000 tonnes)
• High CAPEX and long timelines
• Disruptions risk
• Neutron damage to first wall/blanket
• Tritium breeding unresolved at scale
Q=10
500 MW
50 MW



2. Stellarators: Cleaner Physics, Harder Engineering
Stellarator Magnetic Coils
Non-axisymmetric coil geometry
Plasma
Helical magnetic field configuration
External coils (no plasma current)
Steady-state operation
No disruptions
Continuous power by design

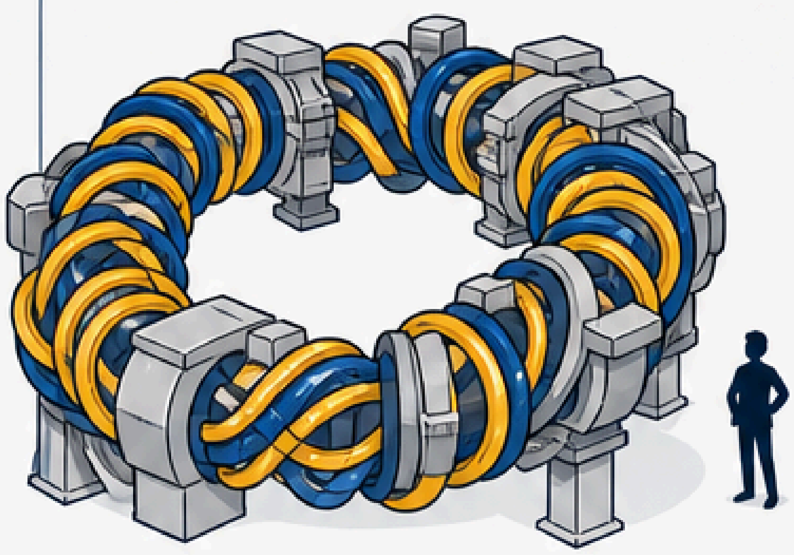
2. Stellarators: Maturity and milestones

Stellarators have historically lagged tokamaks on peak performance, partly because complex coil geometries made it difficult to optimise magnetic field quality. That gap has been closing.

Wendelstein 7-X (W7-X), operated by the Max Planck Institute for Plasma Physics in Greifswald, Germany, is the world's largest stellarator and the primary proving ground for the approach. W7-X has reported significant progress from its OP2 experimental campaigns, with results from 2024–2025 indicating advances in both triple product and long-duration plasma performance. Investors should consult the latest Max Planck IPP publications and press releases for confirmed figures, as specific performance claims from recent campaigns are still working through peer review.

Proxima Fusion, a German startup spun out of Max Planck IPP's W7-X programme, has raised significant funding to advance its commercial stellarator power plant concept — investors should verify the latest confirmed round figures against Proxima's official announcements, as funding details have evolved through multiple rounds. W7-X has also become the reference point for several other private stellarator ventures globally.

W7-X: COMPLEX NON-PLANAR COIL ARRANGEMENT



- OP2 RESULTS (2024–2025): ADVANCES IN TRIPLE PRODUCT AND LONG-DURATION PLASMA PERFORMANCE
- GLOBAL REFERENCE POINT FOR PRIVATE STELLARATOR VENTURES
- COMMERCIAL PATHWAY BEING ADVANCED

Engineering tradeoffs

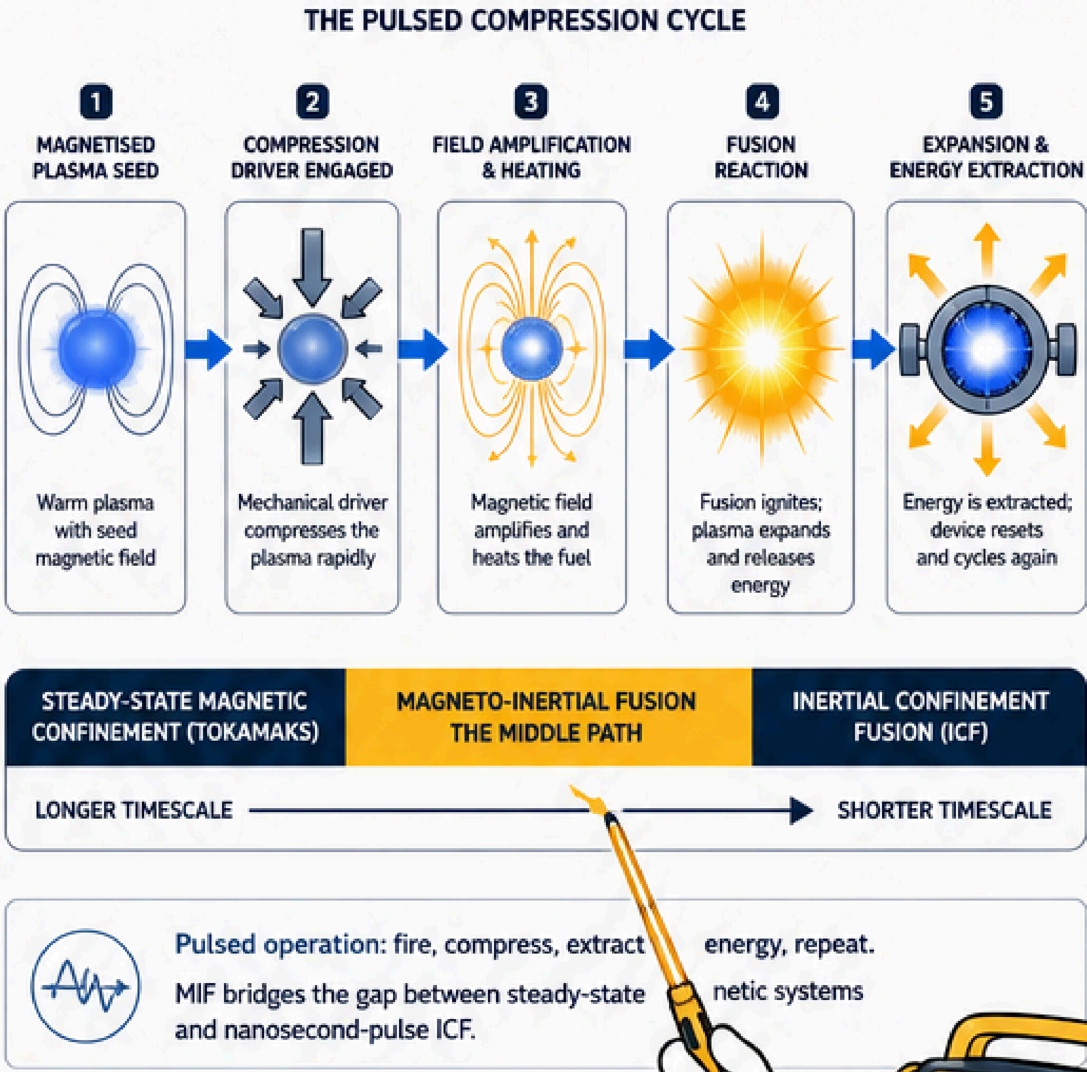
The coil fabrication challenge for stellarators is not trivial. W7-X has 50 non-planar superconducting coils, each with a unique and precisely calculated three-dimensional shape. The manufacturing tolerances are measured in tenths of millimetres across metre-scale structures. Modern computational optimisation and advances in high-temperature superconductor manufacturing are reducing this barrier, but it remains the principal cost risk for stellarator commercialisation. The offset: no disruptions, no plasma-current management, and a natural pathway to continuous operation make the steady-state power economics substantially easier to model than for tokamaks.

3. Magneto-Inertial and Pulsed Approaches: The Middle Path

The physics

Magneto-inertial fusion (MIF), sometimes called magnetised target fusion, sits between magnetic confinement and inertial confinement. The core idea: start with a magnetised plasma that is warm but not yet at fusion temperatures. Then compress it rapidly, using a mechanical driver (spinning liquid metal, plasma jets, or magnetic coils), on a timescale fast enough that inertia keeps the plasma together during compression, but slow enough that the embedded magnetic field suppresses heat loss and assists containment.

In practical terms, a "seed" magnetic field thermally insulates the plasma before the compression phase amplifies the internal field and heats the fuel to fusion conditions. The resulting reaction causes the plasma to expand and push back against the confining field. The device then cycles again. This pulsed operation — fire, compress, extract energy, repeat — distinguishes MIF from both the steady-state magnetic approaches above and from nanosecond-pulse ICF below.



3. Magneto-Inertial and Pulsed Approaches: Maturity and milestones

Helion Energy has a 2023 power purchase agreement with Microsoft targeting delivery of 50 MW by 2029 — a timeline widely regarded as highly ambitious and not publicly updated as of mid-2026.

Helion has reported that its seventh-generation prototype recovered electricity from fusion plasma interactions in 2025, a claimed milestone that has not been independently verified; investors should note the important distinction between electricity recovered from the process and net electricity generation.

General Fusion, a Canadian company, is preparing to demonstrate its liquid-metal-compression MIF machine (LM26) with the potential to reach engineering breakeven.

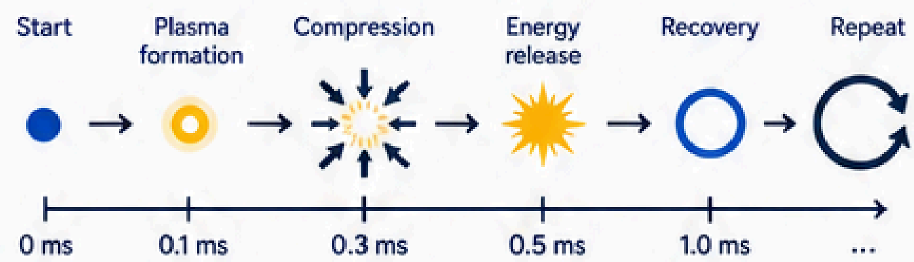
Zap Energy's Z-pinch approach, which uses a flowing plasma compressed by its own self-generated magnetic field, has also attracted significant investment.

GENERAL FUSION LM26

Truck-sized compression vessel vs. building-sized tokamak

The confinement time in MIF is inherently brief per pulse — microseconds to milliseconds — but the approach aims for high repetition rates (many pulses sustained average power output.

MIF PULSE CYCLE (EXAMPLE)



Engineering tradeoffs

- The engineering footprint for MIF devices is potentially much smaller and cheaper than large tokamaks.
- The key risks are durability (high-repetition mechanical or magnetic drivers must survive millions of cycles) and driver efficiency (compressing the plasma efficiently enough to achieve net electricity at the plant level, not just scientific Q).
- Direct electricity conversion, used by Helion, avoids traditional steam turbine losses but requires its own engineering development.
- The pulse-and-recovery power profile also demands thoughtful power conversion engineering to deliver smooth grid output.

4. Inertial Confinement Fusion (ICF): The Laser Path

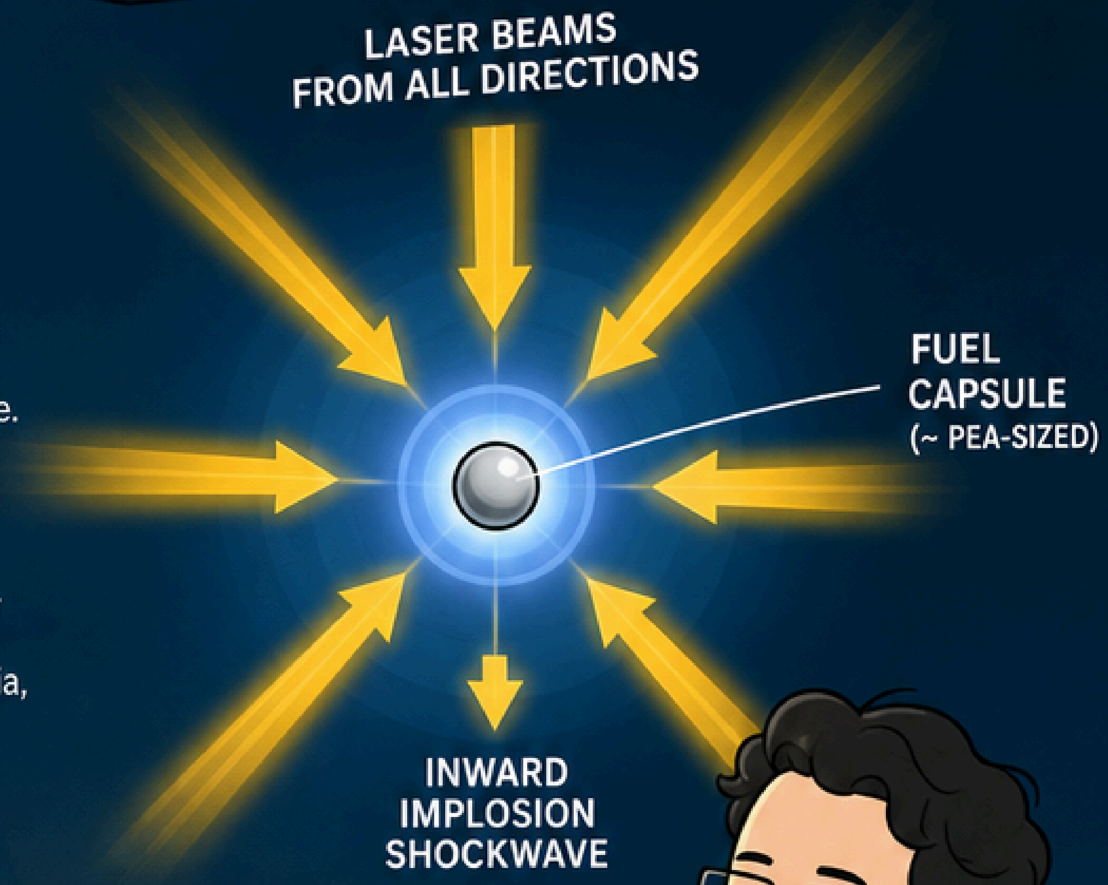
The physics

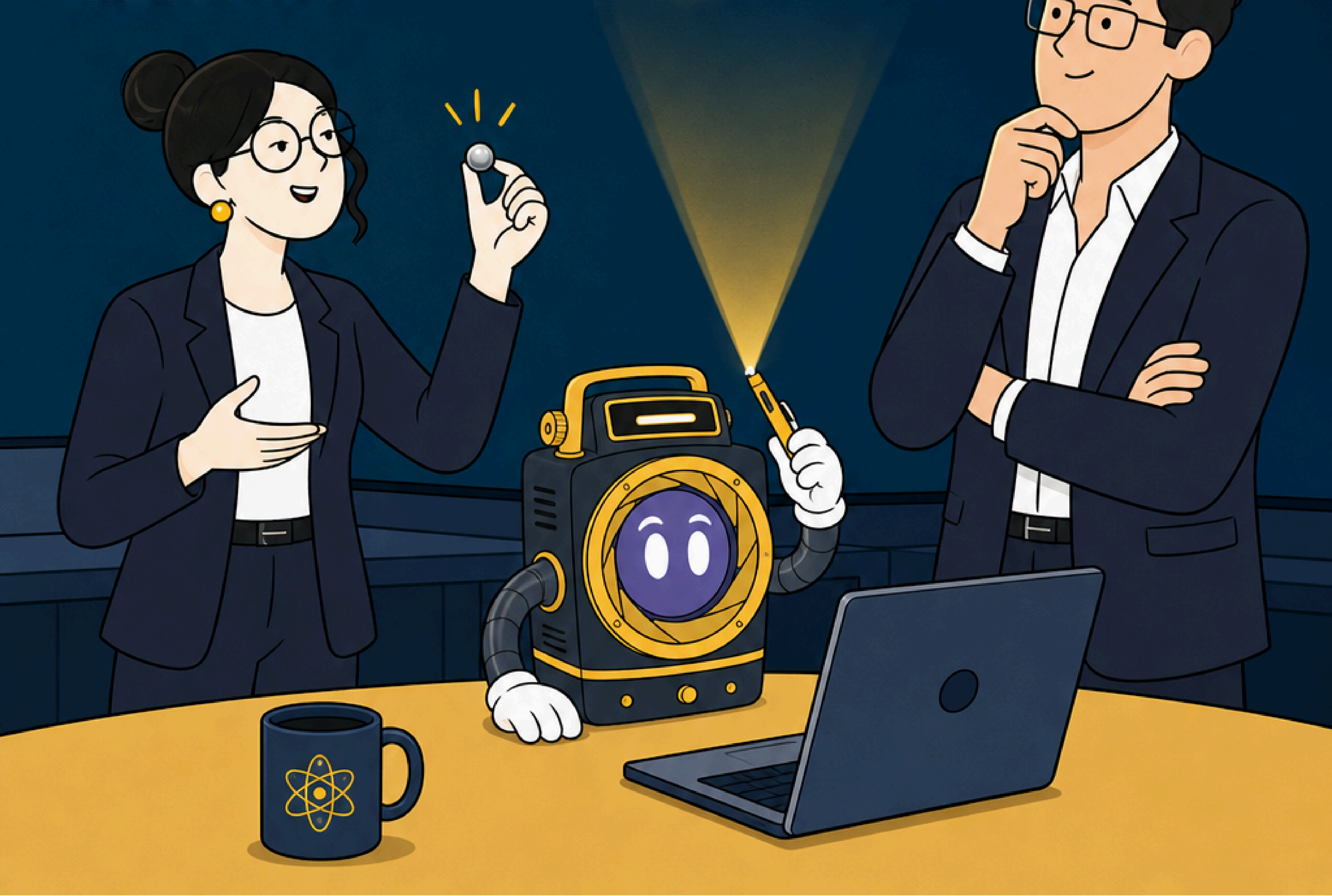
ICF takes a completely different approach. Instead of holding plasma in a magnetic bottle, it compresses a tiny fuel capsule so fast and so hard that the plasma's own inertia keeps it together long enough for fusion to ignite.

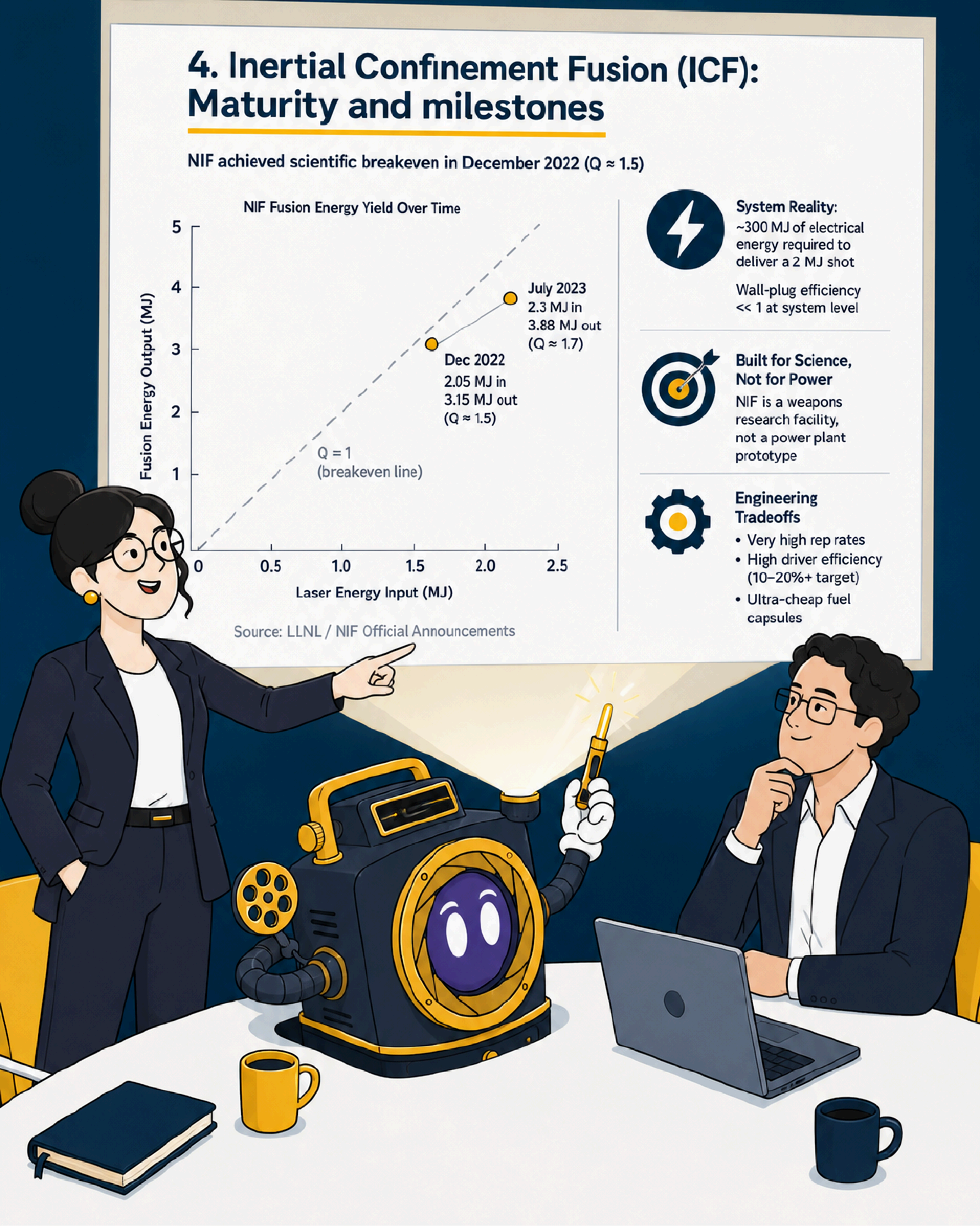
The process takes nanoseconds. A set of laser beams or particle beams simultaneously irradiate a small sphere (roughly the size of a pea) from all directions, ablating the outer layer and driving an inward implosion shockwave.

The core of the capsule reaches temperatures and densities sufficient for fusion. The compressed plasma ignites and releases energy before it has time to fly apart.

At the National Ignition Facility (NIF) in Livermore, California, the lasers heat the inside of a gold hohlraum (a small cylindrical enclosure), which converts laser energy into X-rays that then symmetrically implode the capsule. This is called indirect-drive ICF.






4. Inertial Confinement Fusion (ICF): Maturity and milestones
NIF achieved scientific breakeven in December 2022 (Q ≈ 1.5)
NIF Fusion Energy Yield Over Time
Fusion Energy Output (MJ)
5
4
3
2
1
0
0.5
1.0
1.5
2.0
2.5
Laser Energy Input (MJ)
July 2023
2.3 MJ in
3.88 MJ out
(Q ≈ 1.7)
Dec 2022
2.05 MJ in
3.15 MJ out
(Q ≈ 1.5)
Q = 1
(breakeven line)
Source: LLNL / NIF Official Announcements
System Reality:
~300 MJ of electrical energy required to deliver a 2 MJ shot
Wall-plug efficiency << 1 at system level
Built for Science, Not for Power
NIF is a weapons research facility, not a power plant prototype
Engineering Tradeoffs
• Very high rep rates
• High driver efficiency (10–20%+ target)
• Ultra-cheap fuel capsules


Investor Comparison: The Five Dimensions That Matter
1 Confinement time (τ)
2 Energy gain (Q)
3 Engineering complexity & materials durability (neutron flux)
4 Pulse vs. continuous operation implications
5 Realistic pilot-plant timelines
Tokamaks
Seconds to minutes
ITER: 400–600 s (target)
Extrapolated Q ≈ 1.1 (JT-60U, JET ~1998)
High
Disruption events + steady neutron bombardment
Continuous
Compatible with steam turbines and grid
Pilot plants: early 2030s
Commercial: late 2030s–2040s
Stellarators
Seconds to minutes
Steady-state operation
Extrapolated Q ≈ 1+ (W7-X improving)
High
Steady neutron exposure easier to manage
Continuous
Compatible with steam turbines and grid
Pilot plants: late 2030s
Commercial: 2040s+
MIF / Pulsed (Magneto-inertial)
Microseconds to milliseconds per pulse
High repetition target
Target Q > 1 (engineering level)
Helion: targeting > 1 next-gen
High
Neutron damage similar to tokamaks; pulsed mechanical stresses
Pulsed
Requires power smoothing or direct conversion (e.g., Helion DCE)
Pilot plants: 2030–2035
Helion: 50 MW target by 2029 (ambitious)
ICF (Inertial Confinement Fusion)
Nanoseconds per shot
Target Q > 1 (Dec 2022 achieved)
Wall-plug Q << 1 (current)
Very High
Chamber must survive millions of intense pulses
Pulsed
Requires extreme repetition rate & power smoothing
Pilot plants: 2035–2045
Driver efficiency & rep-rate need ~100x improvement
Q (Energy Gain) – Higher is Better
Scientific Breakeven (Q = 1)
0.01
0.1
1
10
100
Tokamaks
Stellarators
MIF / Pulsed
ICF
Confinement Time (τ) – Longer is Better
1 ns
1 μs
1 ms
1 s
100 s
1000 s

What This Means Before You Write the Cheque

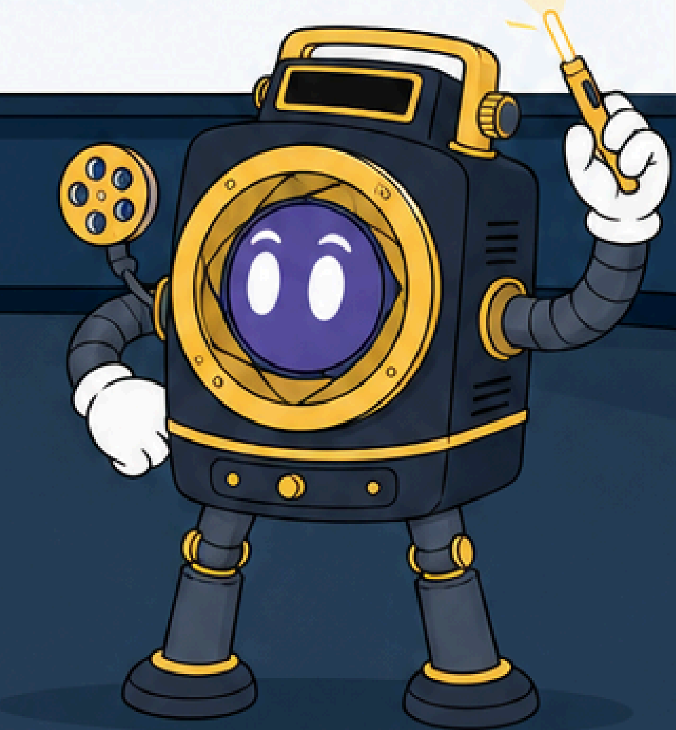
APPROACH	KEY STRENGTHS	KEY RISKS	EXAMPLE / SIGNAL	COMMERCIAL OUTLOOK
TOKAMAKS	• Deepest institutional knowledge base • Most mature supply chain	High cost and timeline risk ITER's repeated delays signal complexity	**ITER (public)** Private firms building smaller tokamaks with high-temperature superconducting magnets	One of the most credible near-term commercial paths, though unproven at pilot scale
STELLARATORS	• Cleaner physics (no disruptions) • Natural steady-state operation	Fabrication complexity of optimised coils limits commercial scalability	**W7-X (operational)** Advances in computational design tools improving feasibility	Increasingly credible to institutional investors
MAGNETO-INERTIAL	• Smaller device footprint • Potentially lower capital cost	Unproven durability and power conversion engineering	**Helion + Microsoft deal** 50 MW by 2029 timeline to watch closely	Commercially significant signal since NIF's 2022 ignition
ICF	• Scientific gains at NIF are real and improving	Large wall-plug efficiency gap Laser physics advances needed (not yet at commercial scale)	**NIF (ignition)** Companies exploring new driver architectures	Early-stage deep tech, not fusion-adjacent cleantech

All four approaches are worth tracking. None are guaranteed.

The most useful question to ask any fusion company is not "what's your Q?" but "what has to be true about your power conversion, materials durability, and driver efficiency for your pilot plant to generate dispatchable grid electricity at a competitive cost — and which of those has been demonstrated?"

That question will tell you more than the plasma physics slide will.

Infrairis helps deep tech and cleantech companies explain technically complex products to the audiences that matter. If your company is working in fusion, advanced energy, or any sector where comprehension is the bottleneck, start here.



infrairis

https://startups.infrairis.com