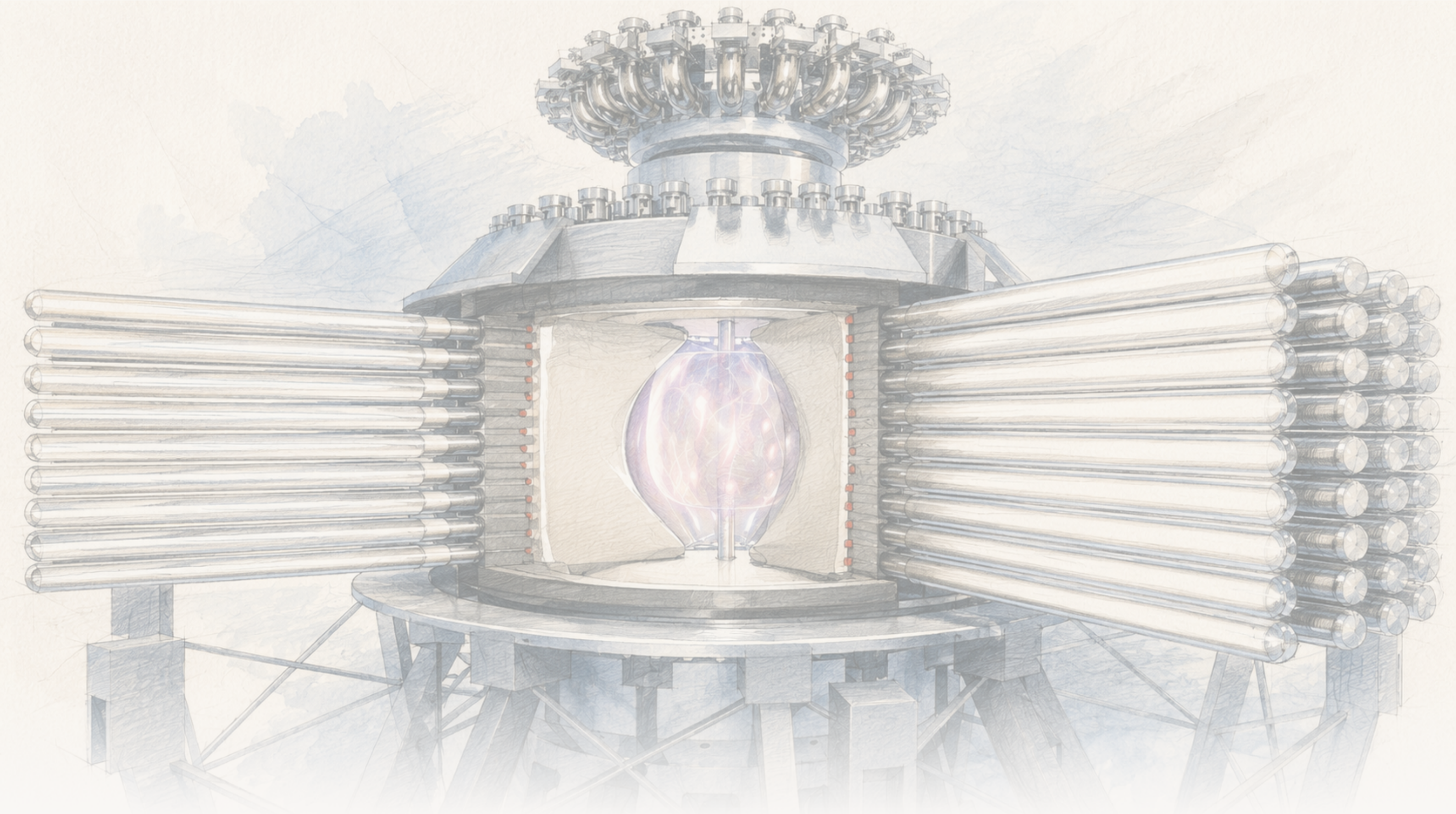

The Clean Paper

WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

Mashine ya fusion ilipasha plasma kwa kuikandamiza — hatua halisi, na power plant ambayo bado siyo

LM26 ya General Fusion ilikandamiza magnetized deuterium plasma kwa imploding lithium liner na kuona temperature ya electrons ikiongezeka zaidi ya mara tatu hadi peak ya takribani 0.72 keV (718 ± 80 eV, karibu 8 million °C), huku heating nyingi iki-attribuishwa kwa compression yenyewe, mechanism ambayo magnetized-target-fusion approach yake inategemea. Ni engineering checkpoint halisi. Pia ni shots 11 za kwanza kwenye machine moja, katika company preprint ambayo haijafanyiwa peer review, kwa temperature bado takribani mara kumi chini ya burning plasma — bila net energy, breakeven au electricity. Mechanism imeonyeshwa, si power plant kujengwa.

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Mashine ya fusion ilipasha plasma kwa kuikandamiza — hatua halisi, na power plant ambayo bado siyo

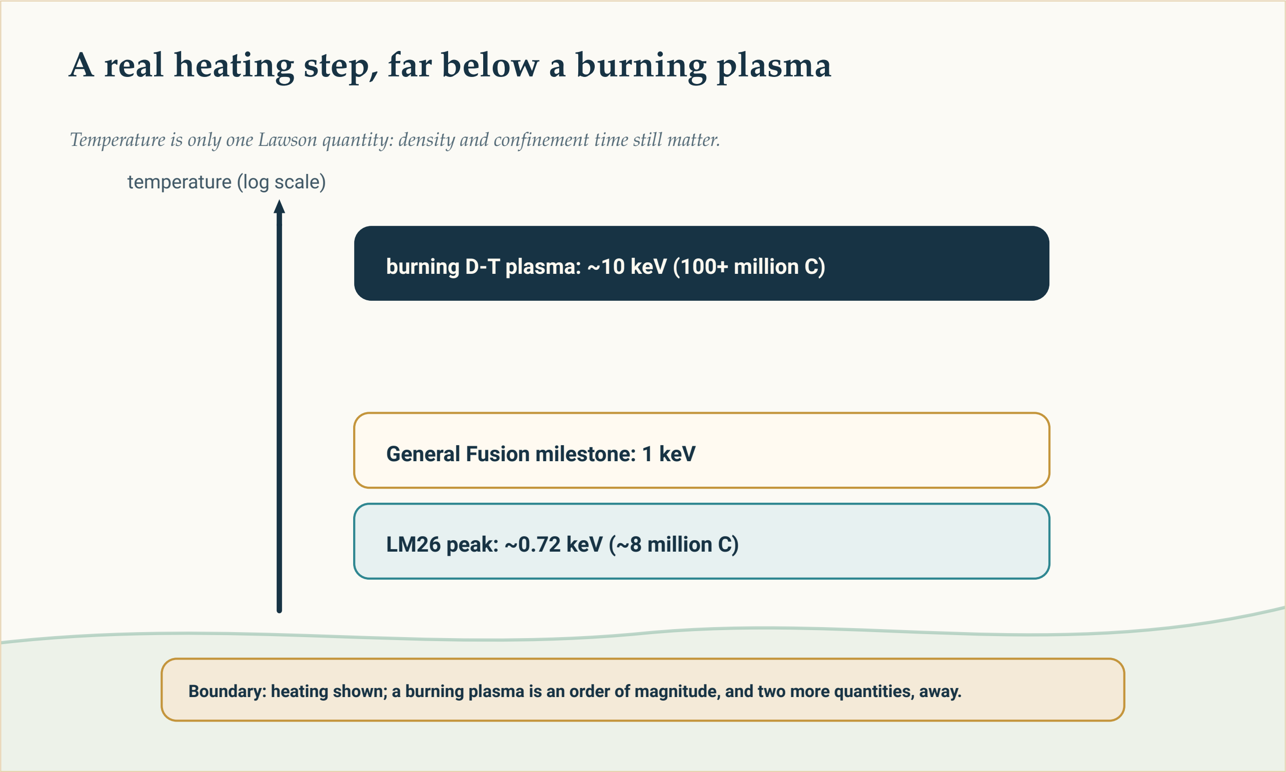
Ili fusion reactor irudishe energy zaidi kuliko inayotumia, fuel plasma lazima iwe kwa wakati mmoja moto vya kutosha, dense vya kutosha, na ishikiliwe pamoja kwa muda wa kutosha — quantities tatu zinazounganishwa katika kile physicists wanaita Lawson criterion. Sehemu kubwa ya uwanja hufuatilia hili kwa superconducting magnets kubwa sana (tokamaks kama ITER) au arrays za giant lasers (inertial confinement, kama US National Ignition Facility). Kampuni chache zaidi zinaweka dau kwenye njia ya tatu, **magnetized target fusion** (MTF): tengeneza plasma ya joto iliyo magnetized, halafu *ikandamize* mechanically na haraka, ili squeezing yenyewe ifanye heating — kama diesel engine inavyowasha fuel kwa compression badala ya spark.

Juni 2026, kampuni ya Canada **General Fusion** iliweka matokeo kutoka **Lawson Machine 26 (LM26)** yanayojaribu kama dau hilo kuu linafanya kazi: je, mechanically compressing magnetized plasma kweli huipasha kama modeli zinavyoahidi? Katika compression shots 11 za kwanza — ambapo spherical-tokamak deuterium plasma ilikandamizwa na *solid lithium liner* iliyokuwa ikiimplode — shots bora zilionyesha plasma ikiwa moto zaidi, dense zaidi na magnetized zaidi kadiri ilivyobanwa, na uchanganuzi ya kampuni inahusisha sehemu kubwa ya heating hiyo kwa compression yenyewe.

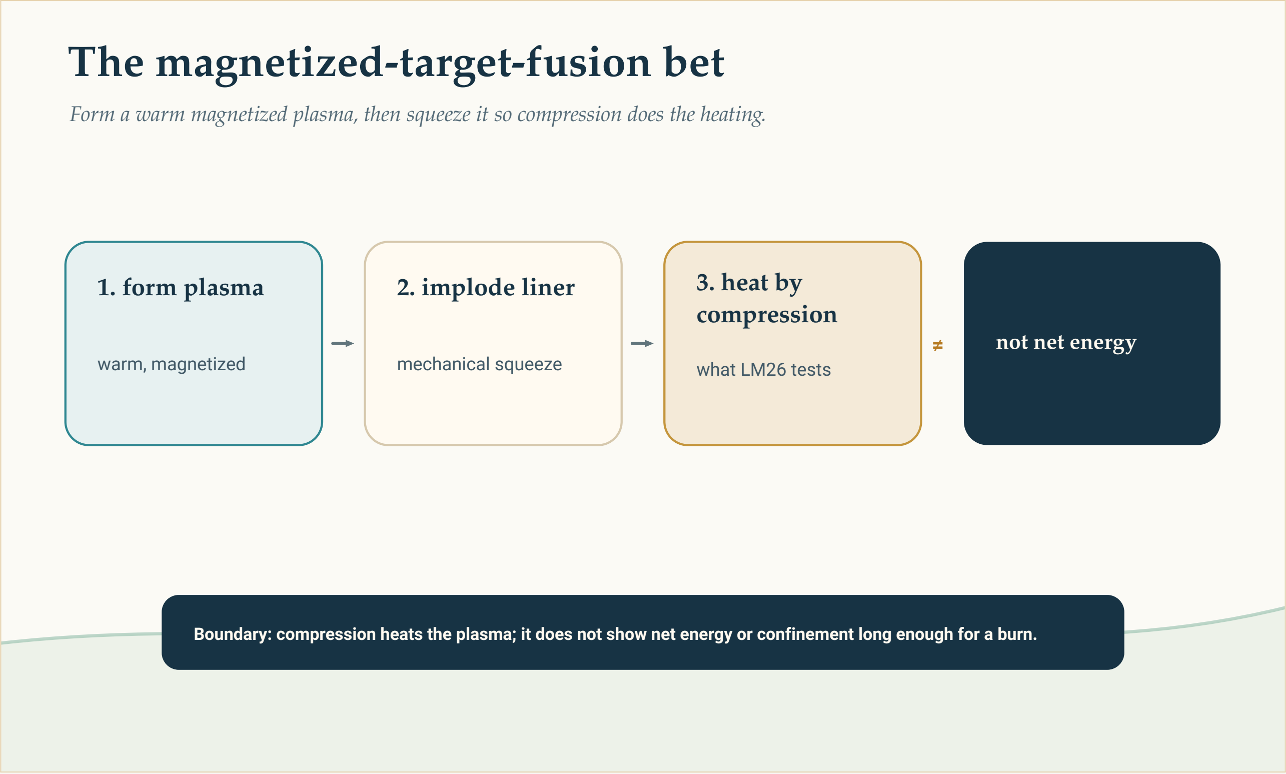
Hii ni engineering matokeo halisi na specific kwa njia ya MTF. Pia ni seti ya kwanza ya shots, iliyoelezwa katika **company preprint ambayo haijafanyiwa mapitio ya rika**, katika temperature bado mbali sana chini ya burning plasma — na si fusion energy, si breakeven, wala power plant.

[video pending]

Hii ni promotional footage kutoka General Fusion, imejumuishwa kuonyesha LM26 inaonekanaje; si huru ushahidi kwamba machine itafikia future fusion milestones zake.



Temperature ladder: LM26 ~0.72 keV, milestone ya General Fusion ya 1 keV, na ~10 keV inayohitajika na burning deuterium–tritium plasma. Temperature ni moja tu ya quantities tatu za Lawson.



Magnetized target fusion: tengeneza warm magnetized plasma, kisha ikandamize kwa imploding liner ili squeeze ifanye heating — dau la diesel-style compression. LM26 ilijaribu kwamba compression huipasha plasma; haikujaribu net energy au confinement ya burn.

"Magnetized target fusion," "keV" na Lawson criterion vina maana gani

Plasma temperature katika fusion kawaida hutolewa kwa **kiloelectronvolts (keV)** badala ya degrees: 1 keV ni takribani **11.6 million °C**. Deuterium–tritium fuel inahitaji kufikia karibu **10 keV** (zaidi ya 100 million °C) ili kufuse kwa ufanisi — lakini temperature ni moja tu ya mambo matatu yanayopaswa kutimia pamoja. **Lawson criterion** inasema reactor pia inahitaji **density** ya kutosha na **confinement time** ya kutosha, mara nyingi zikiunganishwa kuwa "triple product" moja (temperature × density × confinement time). Kupasha plasma ni lazima, lakini peke yake hakukaribii kutosha.

Magnetized target fusion (MTF) ni njia ya kati kati ya mbinu mbili kuu za fusion. Badala ya kushikilia plasma moto kwa muda mrefu kwa sumaku kubwa, au kupasha shabaha ndogo sana karibu papo hapo kwa leza, MTF hutengeneza plasma yenye uga wa sumaku na kuikandamiza kimakanika ndani ya mikrosekunde. Ikiwa mbinu hiyo inafanya kazi, ukandamizaji huongeza joto na msongamano kwa wakati mmoja, kwa lengo la kufikia hali za fusion bila sumaku za ukubwa wa ITER au leza za ukubwa wa NIF. Swali ambalo majaribio kama LM26 yameundwa kujibu ni kama ukandamizaji huo kweli huleta ongezeko la joto linalotarajiwa katika mashine halisi.

Waandishi walifanya nini

- Walijenga na kufyatua **LM26**, magnetized-target-fusion machine ya General Fusion: spherical-tokamak deuterium plasma hutengenezwa, kisha hukandamizwa na **solid lithium liner** inayoporomoka kuelekea ndani — takribani **3×** **radial compression**.
- Waliendesha **compression shots 11 za kwanza** na kuweka diagnostics nyingi, wakireconstruct plasma temperature, density na magnetic field kwa muda na kurekodi emitted neutrons, X-rays, visible light na fast-camera images za plasma–wall interaction.
- Walijenga **integrated physics modeli** inayobalance heating kutoka compression dhidi ya Ohmic heating (kutokana na current ya plasma yenyewe) na energy losses kwenye boundary, kisha wakaifananisha na measured data kubaini heating ilitoka wapi.

Walichokuta

- **Plasma ilipata moto ilipobanwa.** Katika shots bora, electron temperature iliongezeka kwa **zaidi ya 3×**, electron density kwa takribani **10×**, na poloidal magnetic field kwa takribani **10×**, kutokana na 3× radial compression. Katika shot bora zaidi, makala inapima **peak electron temperature ya takribani 0.72 keV** (718 ± 80 eV, kwa Thomson scattering) — karibu 8 million °C.
- **Sehemu kubwa ya heating inahusishwa kwa compression.** Integrated modeli yao inahitimisha

kwamba *majority* ya temperature rise ilitoka kwa mechanical compression yenyewe — mechanism ambayo MTF yote inategemea — badala ya Ohmic heating.
- **Neutron emission iliongezeka wakati wa compression**, consistent na deuterium plasma moto na dense zaidi.

Kile ambacho hii haionyeshi

- **Si** fusion energy, breakeven au net gain. Hakuna hapa kilichozalisha energy zaidi kuliko kilichotumika kuendesha machine. matokeo ni kuhusu *kupasha plasma* — hatua moja katika fusion cycle — si energy balance ya reactor.
- Temperature bado **iko karibu mara kumi chini** ya burning plasma. Takribani 0.72 keV ni ~8 million °C; deuterium–tritium fuel inahitaji order ya **10 keV (zaidi ya 100 million °C)** *na* density × confinement time ya kutosha kudumisha burn. Milestone inayofuata ya General Fusion yenyewe ni **1 keV** — nayo bado mbali na ignition.
- "**Most of the heating is from compression**" ni **modeli-based conclusion**, si moja kwa moja reading. Inatoka integrated physics modeli iliyofitiwa kwa diagnostics; trust katika split kati ya compression, Ohmic heating na losses inategemea trust katika modeli hiyo.
- Ni **company preprint, si peer-reviewed**. Matokeo yameripotiwa na timu iliyojenga machine na imekusanya fedha juu ya promise yake; huru mapitio bado haijafanyika.
- Neutron increase **si energy-relevant fusion yield**. Neutrons kadhaa zinatarajiwa kutoka deuterium katika conditions hizi, mbali sana chini ya kitu muhimu kwa power.
- Haisemi chochote kuhusu separate company statement kwamba **future plant italeta electricity kwenye grid** — dai ambayo huru reporting imeitazama kwa tahadhari kubwa.

Ushahidi una nguvu kiasi gani

- **Core dai ni narrow na checkable.** "Tulicompress magnetized plasma na ikawa moto zaidi, kwa kiasi kikubwa kutokana na compression" ndiyo mechanism test ambayo MTF inahitaji kupita, na makala ina support kwa shots zilizo instrumented sana pamoja na explicit energy-balance modeli. Ikiwa itapita mapitio ya rika, ni validation ya mapema lakini halisi ya approach.
- **Caveats ni structural, si cosmetics.** Shots 11, machine moja, team moja, bado haijareviewiwa, na kichwa cha habari temperature order moja ya magnitude chini ya burning plasma. Load-bearing conclusion — *majority of heating from compression* — inategemea modeli, hivyo swali kuu la mapitio ya rika ni kama split hiyo ni robust.
- **Hali ya uaminifu ni mechanism imeonyeshwa, si milestone ya energy imedaiwa.** Inasukuma MTF kutoka "compression *inapaswa* kupasha plasma" kuelekea "compression *inaipasha* plasma," na si zaidi ya hapo.

Kwa nini ni muhimu

Kitu cha kuvutia kuhusu magnetized target fusion ni economics, si records. Kama mechanical compression inaweza kupasha plasma kuelekea fusion conditions, huenda ukafika bila ITER-scale magnets au NIF-scale lasers — njia ya bei nafuu na yenye iteration haraka zaidi, *ikiwa* inafanya kazi. “Ikiwa” hiyo ndiyo mchezo wote, na inategemea checkpoints zisizong’aa kama hii: je, compression inatoa heating ambayo modeli zinaahidi? Jibu la LM26 katika shots zake za kwanza ni ndiyo yenye masharti. Hilo linastahili kuandikwa precisely *kwa sababu* lina masharti — rung moja kwenye ladder ndefu, imeripotiwa na watu wanaoipanda, bado haijakaguliwa na wengine, na iko mbali chini ya kilele.

Muhtasari safi

LM26 ya General Fusion ilikandamiza plasma ya deuterium yenye uga wa sumaku kwa liner ya lithiamu iliyoporomoka kuelekea ndani na ikaonyesha plasma ikipata moto. Joto la elektroni liliongezeka zaidi ya mara tatu hadi kilele kilichopimwa cha takribani 0.72 keV (718 ± 80 eV, karibu °C milioni 8). Uchambuzi wa kampuni unahusisha sehemu kubwa ya ongezeko hilo la joto na ukandamizaji wenyewe, ambao ndio utaratibu msingi wa magnetized-target fusion. Hii ni hatua halisi ya uhandisi kwa njia hii ya fusion. Lakini ni majaribio 11 ya kwanza kwenye mashine moja, katika preprint ya kampuni ambayo haijapitia mapitio ya rika, na joto bado ni takribani mara kumi chini ya plasma inayowaka yenyewe. Hakukuwa na nishati ya ziada, breakeven au uzalishaji wa umeme. Utaratibu umeonyeshwa; mtambo wa nguvu bado haujajengwa.

Vyanzo

S. J. Howard et al. (General Fusion), The science of compressional heating on the LM26 magnetized target fusion experiment, arXiv:2606.23974 [physics.plasm-ph] (2026)
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https://generalfusion.com/post/general-fusion-achieves-compressional-plasma-heating-with-lm26-magnet

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https://www.nature.com/articles/d41586-026-01795-z