

On the Time Scale for Developing Fusion Power

Daniel L. Jassby

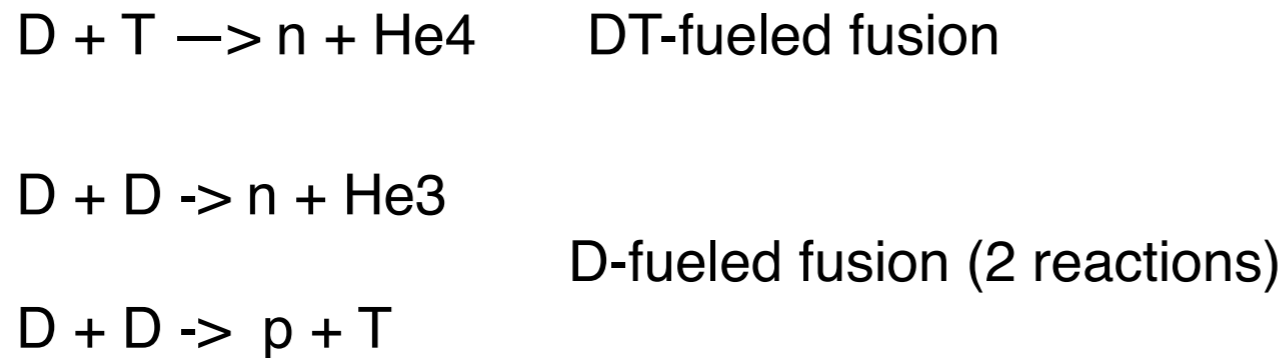
New Jersey, USA

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Email: dljenterp@aol.com

What is Fusion Energy?

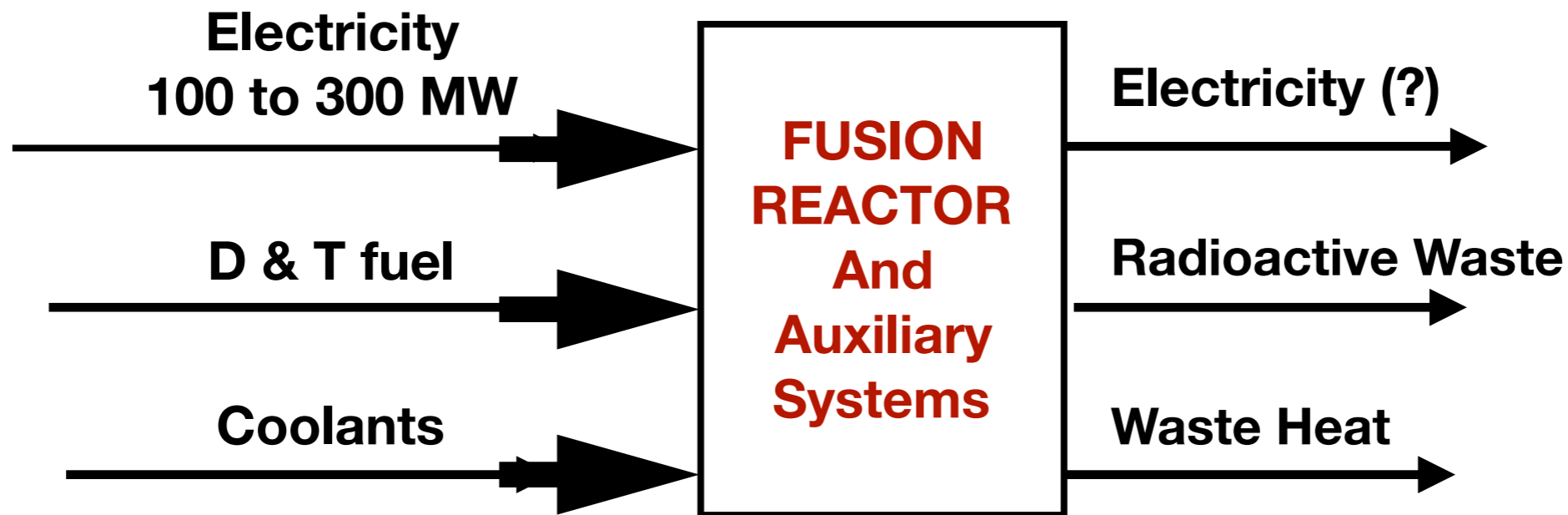
The nuclear fusion process in terrestrial systems combines the hydrogenic isotopes **deuterium and tritium** to release energy in the form of high-energy neutrons and helium ions. Deuterium fuel can also be used by itself, but is more difficult to ignite than D-T fuel.



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Reactor Input and Output

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- Auxiliary Systems include vacuum pumping, coolant pumping, cryogenic systems, tritium processing, computers, plasma diagnostics, HVAC.
- The **waste heat** is thermal pollution, and consists of the thermalized input electrical energy plus 2/3 of the fusion energy.

Fusion Energy Gain, Q

Fusion reactions are produced in hot deuterium or deuterium-tritium plasmas, The **fusion energy gain, Q** , of a reacting plasma configuration is the ratio of the fusion energy output released in a pulse to the external heating energy deposited in the plasma during that pulse.

Scientific feasibility, or **fusion energy breakeven**, is most often described as the demonstration of $Q = 1$ or greater.

Fusion energy can presumably be converted to electric energy with an efficiency of 30 to 40%, but that has never been done. Because of electric power consumption of the fusion device and its auxiliary support systems, a viable fusion power plant that could produce net electric power **requires Q of at least 10**.

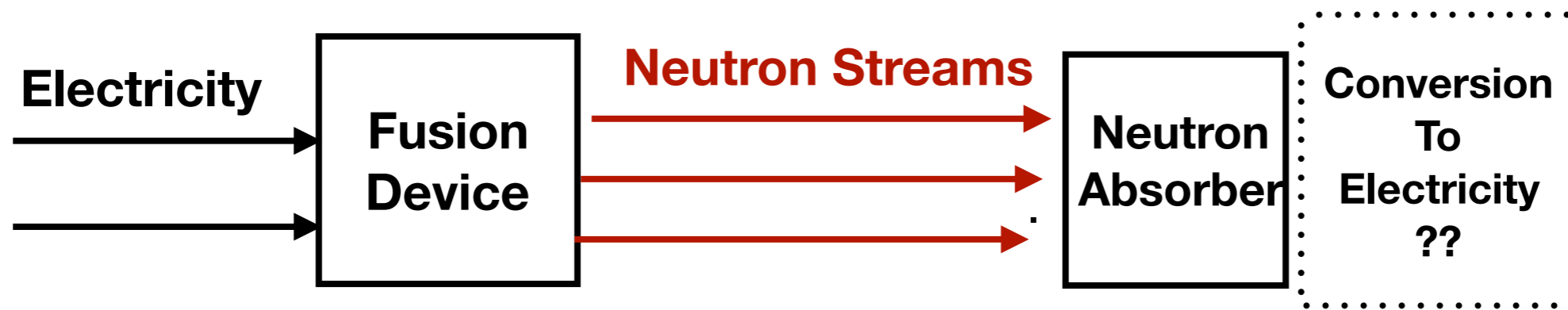
If you bombard a tritium target with a deuteron beam, you can get a Q up to 0.003. In 75 years of R&D, only 2 tokamaks and 2 laser-driven systems have achieved larger Q !

Only one fusion system (the laser-driven NIF at Livermore) has produced Q of 1 or greater. The successful method used radiatively-driven ablative implosion of the fusion fuel capsule, a concept that was actually first demonstrated in 1952 on a macroscopic scale.

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Fusion Devices are Electrical Appliances

Fusion devices, if they work at all, are **electrical appliances** that turn electrical energy into streams of high-energy neutrons, but they cannot convert fusion neutrons back into large amounts of electrical energy. They are most akin to electric heaters.



Nobody has ever produced electricity from streams of high-energy neutrons

No fusion device has ever produced even one watt of electricity.

Producing *net* electric power from any fusion facility may never be possible because of the colossal power consumption of any fusion device and its auxiliary systems.

Are Fusion Devices Capable of Producing Electricity?

Fusion-energy promoters claim that they will put fusion-derived electricity on the grid by the mid-2030's. But in 75 years of R&D, **no fusion device has produced one watt or one joule of electricity**, while its subsystems consume megajoules of electricity during each operating pulse.

Persistent low Q is no excuse for failure to make an electricity demonstration.

For example, if a facility produces 100 kW of fusion with 1 MW input power, it should be possible to produce at least **one watt** of electricity.

But nobody has ever done that. Why not?

There are two main reasons.

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Why Johnny Can't Read

In DT-fueled systems, four-fifths of the output of the D-T reaction comprises neutrons that stream out of the reacting plasma in every direction. Electricity production must come from converting the energy of those fusion-generated neutrons.

A. Today's **short-pulse facilities** such as Livermore's NIF that utilize the highly reactive D-T fuel have large instantaneous neutron outputs, but **minuscule duty factors**.

B. **Long-pulse systems** (multi-seconds) such as tokamaks rarely use D-T fuel and have zero or very small fusion reaction rates. **The neutron fluence per pulse is too small** to generate enough heat for conversion to electricity,

Far from promoters' assertions that their fusion reactors will each produce hundreds of megawatts of electricity for the grid in the early 2030's, it will be a miracle if anyone can produce *even one watt* of electrical power from any fusion device in the next 5 years, no matter the level of input energy.

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A Tale of Two Fusion Systems - Solar and Terrestrial - 75 Years in the Making

Solar Fusion. The first practical photovoltaic cell was made by AT&T Bell Labs in **1954** and produced about 5 watts.

It took half a century of development for the cost of solar panels to become low enough that solar energy became a major source of electricity.

Terrestrial Fusion. Formal research programs to develop fusion power began in **1951**, but nobody has ever produced one watt or one joule of electricity from any terrestrial fusion device.

After 75 years of R&D, electric power from terrestrial fusion is in a primitive state even compared with solar panels circa 1954.

| The results of 75 years of R&D of Solar Fusion Power and Terrestrial Fusion Power. | | | |
|--|-------------------------|--------------------|---------------------------|
| | Solar Calculator | Solar Panel | Fusion Test Device |
| Cost | \$5 | \$200 | > \$2 billion |
| Input Electricity | ZERO | ZERO | > 100 megawatts |
| Output Electricity | 1 watt | 200 watts | ZERO |

Potential Demonstrations of Nominal Fusion-Derived Electricity

There are various stunts that in the 2030's could permit demonstrations of a few watts of electricity production (while still consuming megawatts):

- 1) Arrays of self-self-powered neutron detectors.
- 2) Radiovoltaics, that convert neutron-induced alphas (ions) to electric current.
- 3) Bombardment of scintillation screens by 100 kilowatts of fusion neutrons could generate 100 watts of light that would be converted by photovoltaic cells to watts of electric power.
- 4) Beam-target sources such as the SHINE facilities can generate up to 100 watts of continuous fusion power and could be candidates to attempt a watt-level electricity demo, if 10% of their output could be harnessed.

The best that anyone can realistically expect in the next two decades is that in the early to mid-2040's **the ITER tokamak project in the EU could produce tens of kilowatts of electricity** by converting the heat from numerous blanket modules around the plasma vessel that are bombarded by neutrons from fusion reactions. At the same time the ITER facility will be consuming 300 megawatts of electricity!

Timeline of Electricity Demonstrations

Every presentday fusion device **consumes** 10 to 300 MW of electricity.

Every conceptual fusion power facility would **consume** 100 to 300 MW of electricity.

| <u>Electrical Output*</u> | <u>Demonst'n Date</u> | <u>Demonst'n Method</u> |
|--|-----------------------|----------------------------------|
| 1 to 5 watts | 2030's | neutron scintil. or radiovoltaic |
| ten kilowatts | 2040's | ITER blanket modules (thermal) |
| 100 megawatts (zero net power) | 2070's or later | UNKNOWN |
| substantial net electric power | after 2100 | UNKNOWN |

* *While consuming 10 to 300 megawatts*

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Tritium Fuel Supply is Dubious

Deuterium is abundant in ordinary water, but tritium is radioactive with a short half-life and does not occur in nature. It must be manufactured.

After the challenge of net electricity production, the second most daunting hurdle for a fusion power plant is that the burned and lost **tritium fuel** must be replenished in the fusion device itself. No one has ever done a “tritium-breeding” experiment in an actual fusion device to investigate the predictions of neutronics codes.*

Tritium self-sufficiency may be unattainable, partly because of shortcomings in “breeding” tritium by fusion neutrons, but especially because inherently small burnup fractions result in unavoidable losses of some of the unburned tritium during the many cycles of reprocessing and re-injection.

For more discussion of this matter, see:

“The fuel supply quandary for fusion power reactors” – by Daniel Jassby, Nov. 2024.

<https://doi.org/10.1080/00963402.2024.2418708>

Only Reactors Fueled Solely by Deuterium are Practical

The only viable fusion fuel is deuterium alone, where tritium will be concurrently generated and burned in the fusing plasma. However, when compared with D-T fueling, the nuclear burning of deuterium requires order-of-magnitude more enhanced performance of the fusing plasma and supporting reactor equipment. It may be feasible with future laser-driven systems supplying 50 to 100 megajoules of laser energy per pulse.

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Conclusions

Fusion energy systems consume megawatts to hundreds of megawatts and are basically **electrical appliances**, not potential sources of electricity.

No fusion device has ever produced even one watt of electricity.

It's possible that in the next 5 years some fusion device might exhibit electrical output of a few watts, but a demonstration producing several kilowatts of electricity output (*while still consuming multi-megawatts*) is two decades away.

Because of irreducible on-site power drains, it's unlikely that any fusion facility based on any known fusion reactor concept could ever produce *net* electricity.

As for fuel supply, replenishing both the burned and lost tritium in DT-fueled systems is not feasible, so that only D-fueled reactors are practical. The difficulties 1) of achieving ignition in deuterium, 2) of developing adequate reactor technologies, and 3) of finding pathways to reduce electricity consumption of reactor subsystems, conspire to push the realization of a *prototype* fusion power plant at least half a century away.

Electricity derived from terrestrial fusion systems does not exist and will remain a fantasy for the indefinite future. It will not be an alternative source of electric energy in this century.