LA-UR -78-1351

CONF-780801--16

TITLE: CO$_2$-LASER FUSION

AUTHOR(S): Eugene E. Stark, Jr.

SUBMITTED TO: 13th Intersociety Energy Conversion Engineering Conference, San Diego, CA, August 20-25, 1978

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

Form No. 836 R2
St. No. 2629
1/78

DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

CO_2-LASER FUSION

Eugene E. Stark, Jr.

Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

The basic concept of laser fusion is described, with a set of requirements on the laser system. Systems and applications concepts are presented and discussed. The CO_2 laser's characteristics and advantages for laser fusion are described. Finally, technological issues in the development of CO_2 laser systems for fusion applications are discussed.

FUSION OFFERS THE PROSPECT of virtually limitless energy for mankind, if we can solve the immense scientific problem of confining the reacting gases (deuterium and tritium) at their reaction temperature (50 million degrees C), as well as the engineering problems of translating scientific feasibility into commercial success. The fundamental idea in laser fusion is to heat a small sphere (~ 1 mm diameter) of DT gas with a short, few nanosecond (10^{-9} s) pulse of laser light. Absorption of the laser light on the outer layer of the sphere would cause a blowoff (ablation) of material, whose rocket reaction force would ideally compress the fuel to 10^4 x liquid density and heat it to the reaction ignition temperature. At this density, the thermonuclear reactions would proceed much more quickly than the kinetic disassembly of the fuel. The reaction energy, carried by neutrons and alpha particles, will be captured in a molten blanket for transfer to a steam generating plant or other energy-conversion system.

The requirements on lasers for inertial confinement fusion are summarized in Table 1. These requirements are based on very large extrapolations from present day laser-pellet interaction experiments (typically using up to 1 kJ of laser energy) to performance with $\sim$ 1 MJ of laser energy. The low pressure in the reactor chamber is required so that the very intense laser beams can reach the pellet without causing optical breakdown of the gas.

LASER FUSION POWER PLANT REQUIREMENTS

The basic elements of a laser fusion energy system would include the following, as shown in Fig. 1:

- A laser that produces short light pulses at high electricity-to-light conversion efficiency, ideally $\sim$ 5%, and that can operate at $\gtrsim$ 10 Hz.
- A beam transport system that delivers the laser light onto the pellets.
- An injection system for delivering the pellets into the reaction chamber.
- A reaction chamber to contain the pellet microexplosion, convert the reaction's energy release to heat, and produce new tritium through the reaction of neutrons with lithium.

Table 1 - Laser System Requirements

Pulse Energy	1-5 MJ
Pulse Length	1-10 ns
Efficiency	> 5%
Six or More Beams	
Each beam focusable to < 1 mm	
Repetition Rate	1-10Hz
Prepulse Limits	50 kW/beam
	1 mJ/beam
	10 mJ total

Interface to Reactor Chamber at $\leq$ 0.1 torr.

- An energy transfer and conversion system for the ultimate power application, whether it be electric power, the production of fissionable fuel for conventional nuclear reactors, or the production of hydrogen or industrial process heat.

Systems studies indicate that the product of the laser efficiency and the pellet gain (pellet thermonuclear energy output ÷ laser pulse energy) must exceed 10 for electric power applications if no more than 25% of the plant's power output should be recirculated to the laser system. The laser system must operate at $\sim$ 10 Hz with multiple reaction chambers pulsed at $\sim$ 1 Hz, with a 30 year system lifetime.

The impact of laser efficiency is illustrated in Fig. 2. The laser efficiency (wall plug to laser light output) is η ; Q is the pellet gain. The scientific feasibility of laser fusion is defined as achieving breakeven ($Q \gtrsim 1$) with a laser that can satisfy the fundamental efficiency and repetition-rate requirements for fusion power (Table 1). The importance of efficiency can be seen by comparing Fig. 1 and Fig. 2. Electricity from the power plant is required to operate the laser. The more efficient the laser, the less power is required to run it, and hence, more is available for sale to the consumer. Based on analyses of this issue from a total system viewpoint, higher laser efficiency will produce significant savings in both capital and operating costs.

eta

APPLICATIONS OF LASER FUSION

Figure 2 refers to the two major electrical applications, electricity from pure fusion and the breeding of fissile fuel to power conventional fission reactors.(1)* The fact that the latter application requires an $\sim Q$ of only 2 (allowing a smaller system because lower Q requires less laser energy) leads to the prediction that fissile fuel breeding will be the first commercial application of laser fusion.

Production of synthetic gas using heat, reaction products, or a combination of both may be another attractive application; the world's developed economies already have transmission, distribution and utilization systems for fossil fuels, and continue to depend on combustible fuels. A related application is the production of process heat for industrial applications.

CO_2 LASERS FOR FUSION

The CO_2 laser is the most attractive candidate laser-fusion driver because of its demonstrated operating characteristics. Efficiencies of 30% have been demonstrated in a long-pulse (μs) operation, and a method has been developed to achieve $\gtrsim$ 10% in repetitive short-pulse operation. Repetition rates as high as 750 Hz have been reported, far in excess of the requirement for laser fusion. (2)

Los Alamos is the only Laboratory in the United States engaged in CO_2 laser fusion research. Elsewhere, there are CO_2 laser fusion efforts in Japan, France, the Soviet Union and Canada. This widespread effort reflects the cost and efficiency advantages of CO_2 over Nd:glass lasers (a factor of $\sim$ 100 in efficiency, $\sim$2-4 in cost, depending on laser pulse length). Three major CO_2 laser systems have been built at Los Alamos for laser fusion experimentation and a fourth is under construction, as described in Table 2.

The Single-Beam-System began operation in 1973, providing the first experimental work on target interaction of 1 ns CO_2 laser pulses at energies of 10-100 J. The Two-Beam System began operation with targets in 1976 and demonstrated the first thermonuclear reactions ever induced by a CO_2 laser in early 1977. The Eight-Beam System reached a laser energy output of 8500 J, at a 16 TW power level, in April 1978, and is scheduled to begin target interaction experiments this summer. On the Antares laser, we plan to demonstrate the scientific feasibility of laser fusion in 1983.

CO_2 LASER TECHNOLOGY-In the context of fusion-qualified laser candidates, the technology of the CO_2 laser is the least complex. The gaseous medium is a mixture of carbon dioxide, nitrogen and sometimes helium at a total pressure of ~ 2.5 atmospheres.(3) An electron beam is injected in order to develop an appropriate gas conductivity, and main discharge electrodes excite the gas with an electric field of ~ 15 kV/cm, with a discharge current of ~ 10 A/cm^2 and a discharge pulse length of ~ 2-5 μs. The laser gas is at room temperature, is non-toxic, and does not undergo any significant chemical reactions within the discharge. NaCl windows provide an interface between the laser gas and ambient air, and ultimately to the reactor chamber. Directly micromachined mirrors (4) form the beam transport system, reflecting, enlarging, and finally focusing the laser pulses onto the fusion pellet.

For CO_2 laser fusion, as with any research phase program, there are significant technology improvements required to achieve commercial feasibility. These include the pulsed power system, the beam transport

Table 2 - CO_2 Laser Systems for ICF Research

System	Energy	Power	Achievement/Objective
Single-Beam	100 J	100 GW	Laser-target physics
Two-Beam	1000 J	1 TW	First demonstration of CO_2 laser-induced fusion reactions (1977)
Eight-Beam	10000 J	10-20 TW	Ablative compression scaling (1980)
Antares	10^5 J	100-200 TW	Demonstrate scientific breakeven (thermonuclear energy release > laser pulse energy)

system, the flow system for cooling the laser gas, as well as the electron-beam emitter and the foil window that is the interface between the evacuated e-beam source chamber and the high-pressure laser gas. These requirements are nearly identical with those of the advanced-laser candidate fusion drivers. (5) High reliability ($\sim$99%) and long life (30 years at 1-10 Hz) are the fundamental needs. A detailed analysis of the needs, prospects and timescale for the development of these technologies has been reported recently.(5)

WAVELENGTH SUITABILITY- In the past two years, serious questions on the suitability of the relatively long wavelength of the CO_2 laser have been substantially mitigated.(6, 7, 8) Previously, incomplete classical arguments predicted that the fractional absorption of 10 μm light, and the distance form the pellet center where the light is absorbed, would pose a severe disadvantage in comparison to visible wavelenths. These predictions ignored classically understood processes such as the ponderomotive force of electromagnetic waves and resonant absorption which theoretically remove most of the disadvantages. To date, experimental results have shown no important difference between pellet performance at 1 μm and 10.6 μm.(6, 7) but important experiments must still be done to show the suitability of either wavelength.

REFERENCES

1. L. M. Goldman, "The Impact of Laser Fusion Breeder on the Nuclear Economy," paper WC7, presented at the Topical Meeting on Inertial Confinement Fusion, San Diego, California, February 7-9, 1978.
2. J. D. Daugherty, "High Power CO_2 Laser Technology," Conference on Laser Engineering and Applications, Paper 17.1, Washington D. C., May

31-June 3, 1977.

3. T. F. Stratton, "CO_2 Short-Pulse Laser Technology," presented at the International College on Applied Physics Corso Italia 57, course on High Power Gas Lasers at Capri, Italy, September 22-October 4, 1975.

3. W. P. Barnes, Jr., Ed., "Design, Manufacture and Application of Metal Optics," Proceedings of the Society of Photo-Optical Instrumentation Engineers 65, August 19-20, 1975, pp. 19-20.

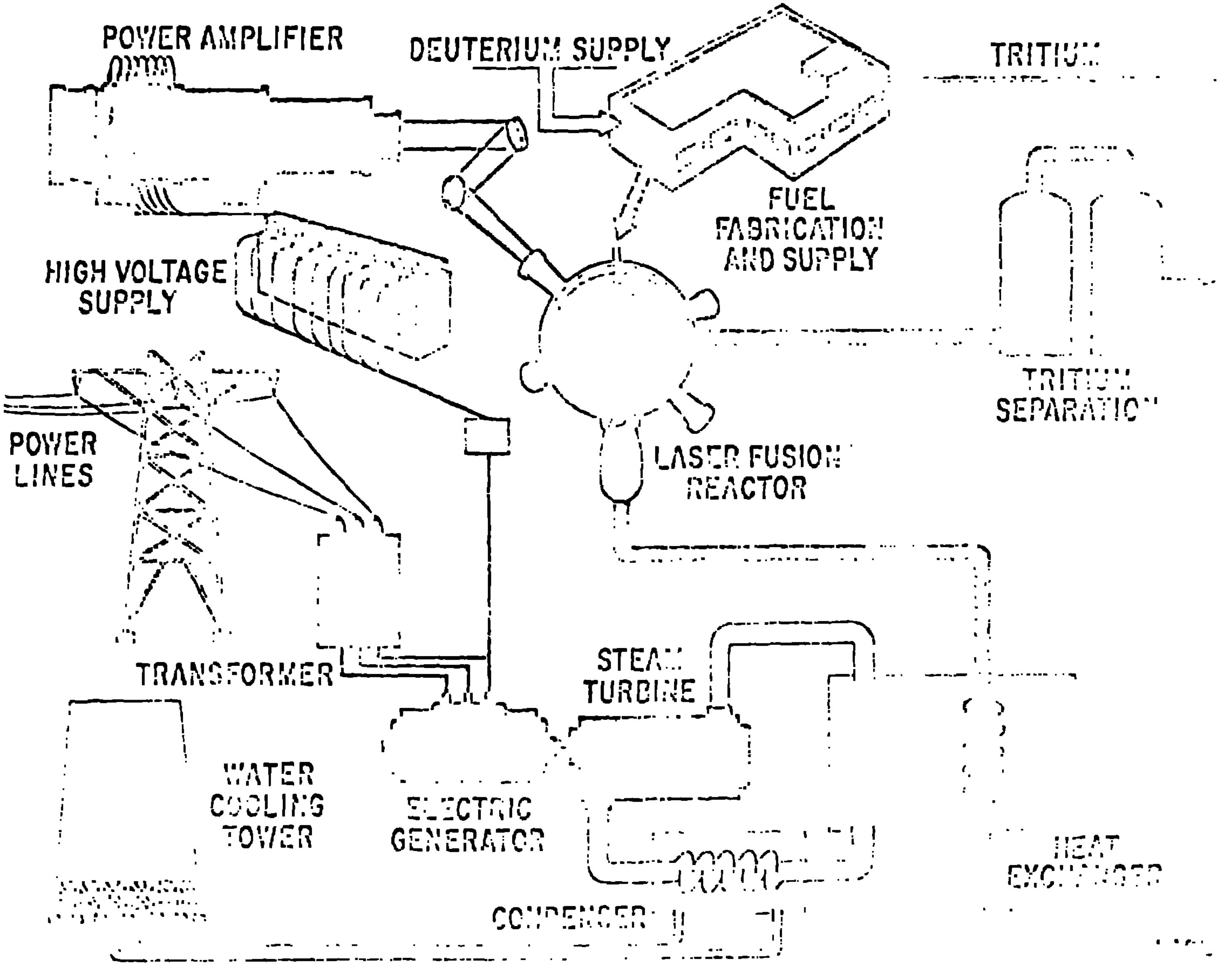
5. E. E. Stark, Jr., "Lasers and Power Systems for Inertial Confinement Fusion Reactors," presented at the American Nuclear Society Third Topical Meeting on Nuclear Fusion, Santa Fe, New Mexico, May 9-11, 1978.

6. D. Giovanielli and C. Cranfill, "A Simple Model for Exploding-Pusher Targets," Los Alamos Scientific Laboratory report, LA-7218-MS, 1978.

7. R. B. Perkins, "The Potentialities of CO_2 Lasers for Fusion," presented at the International Scientific Forum on on Acceptable Nuclear Energy Future of the World, Fort Lauderdale, Florida, November 7-11, 1977.

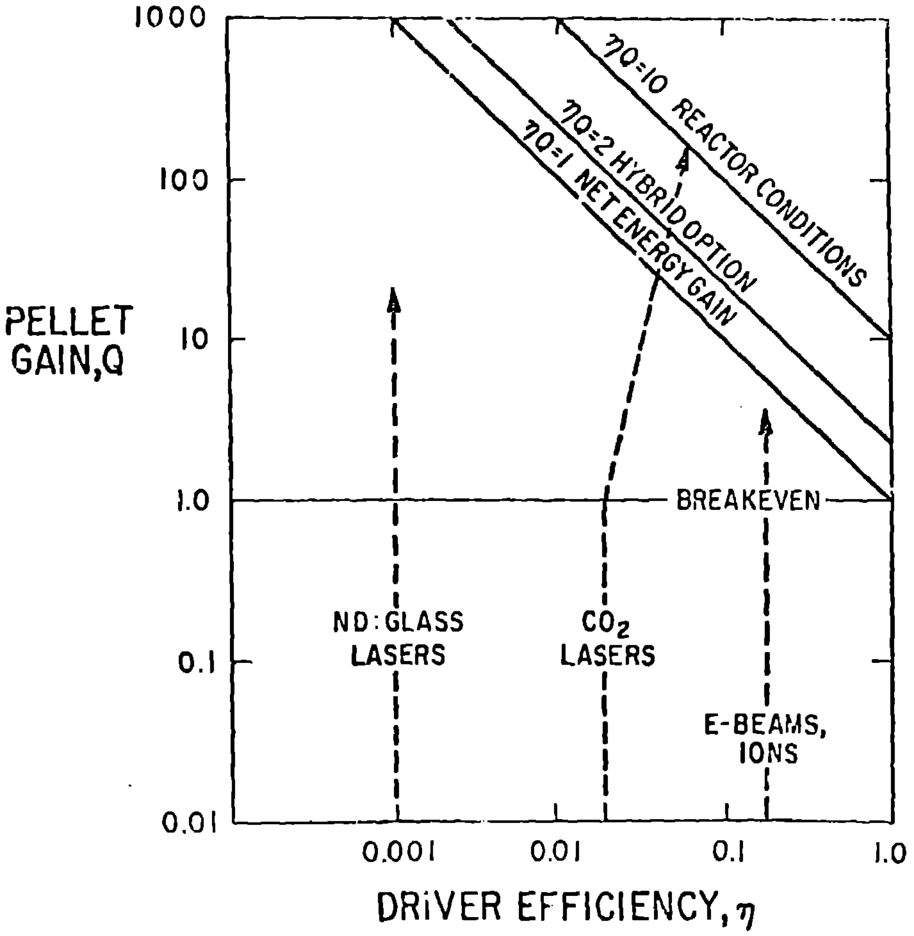
8. D. B. Henderson, "Laser Fusion Interactions in a Self-Consistent Classical Light," presented at the 11th International Symposium on Shock-Tubes and -Waves, Seattle, Washington, July 11-14, 1977.

ELECTRIC POWER GENERATION REQUIRES INTEGRATION OF UNIQUE ICF SUBSYSTEMS WITH CONVENTIONAL POWER PLANT TECHNOLOGY



[illegible]-78 LLK

APPROACHES TO INERTIAL FUSION ENERGY



LASL