LASER ENERGY CONVERSION

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INTRODUCTION

The conversion of laser energy to other, more useful, forms is an important element of any space power transmission system employing lasers. In general the user, at the receiving sight, will require the energy in a form other than laser radiation. In particular, conversion to rocket power and electricity are considered to be two major areas where one must consider various conversion techniques.

REQUIREMENTS FOR A SPACE-BASED LASER ENERGY CONVERTER

The major requirements for a laser energy converter are listed below. These requirements are justified by the following:

High Conversion Efficiency - One wants to convert as much of the laser radiation as possible since laser energy not converted to useful energy will be converted to heat which must be rejected from the system by radiators.

Wavelength Independent - One does not know at this time which laser systems will be employed in a space-based power transmission system. One would like for the converter to be able to operate on any available laser.

High Power-to-Weight Ratio - Initial cost of launching the system into space may constitute a major portion of the mission cost.

High Reliability - Repair to space-based equipment is not only costly but also equipment failure could jeopardize a mission.

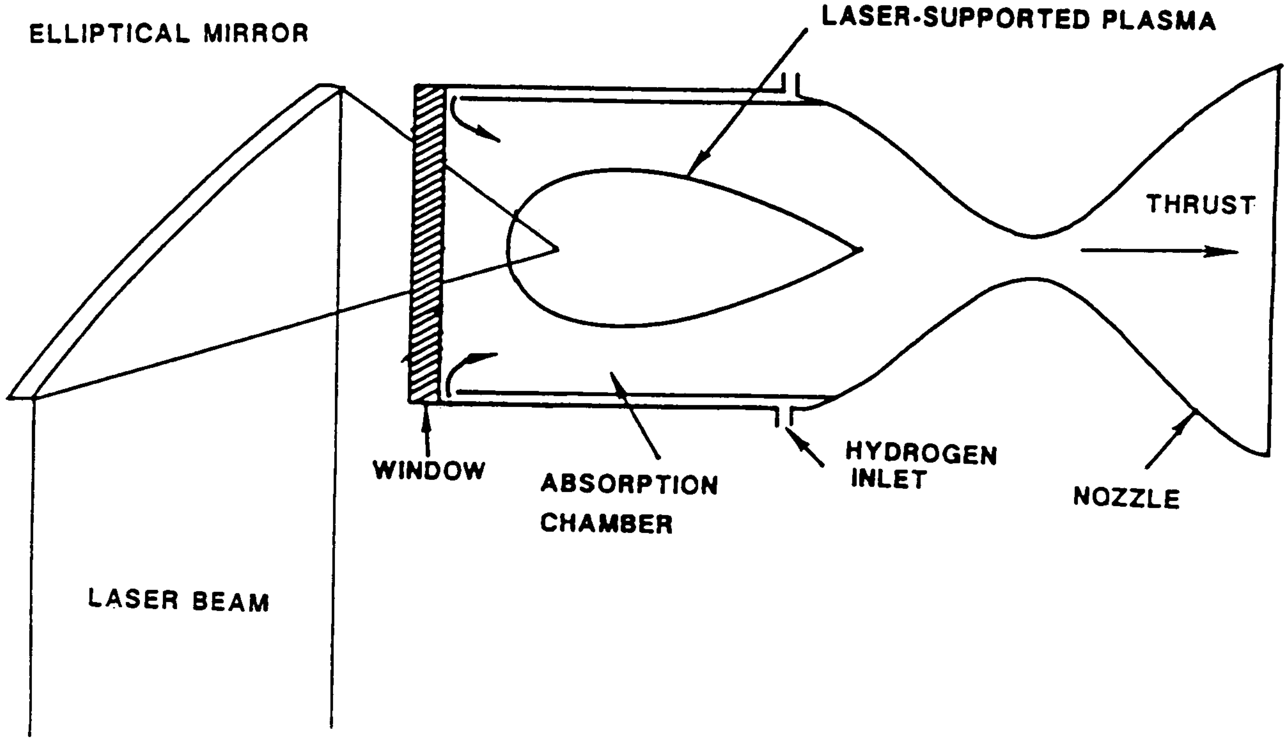
Minimum Maintenance - One does not want to spend a large portion of his time in space carrying out routine maintenance. It would appear that a static system might have an advantage in meeting this requirement.

- High Conversion Efficiency
- Wavelength Independent
- High Power-to-Weight Ratio
- High Reliability
- Minimum Maintenance

LASER PROPULSION

Conversion of laser energy to Rocket thrust can be achieved with the thruster shown below. The laser energy is absorbed by the plasma (T = 15,000 to 20,000K) and a portion of the energy is converted to heat. The heated plasma expands through the nozzle producing thrust. Such a device should have an efficiency in excess of 50%. The remaining energy is lost in molecular disassociation, ionization and excitation of molecular and atom. Heat and radiative losses to the wall may be partially recovered and used to preheat the incoming gas which should raise the overall efficiency and reduce the waste heat which must be removed from the sytem by radiators.

LASER ROCKET THRUSTER



PRINCIPAL ENERGY CONVERSION TECHNIQUE

The chart lists the principal technique for converting laser energy to electricity. Only those techniques which have a good technology base are considered.

Direct Conversion

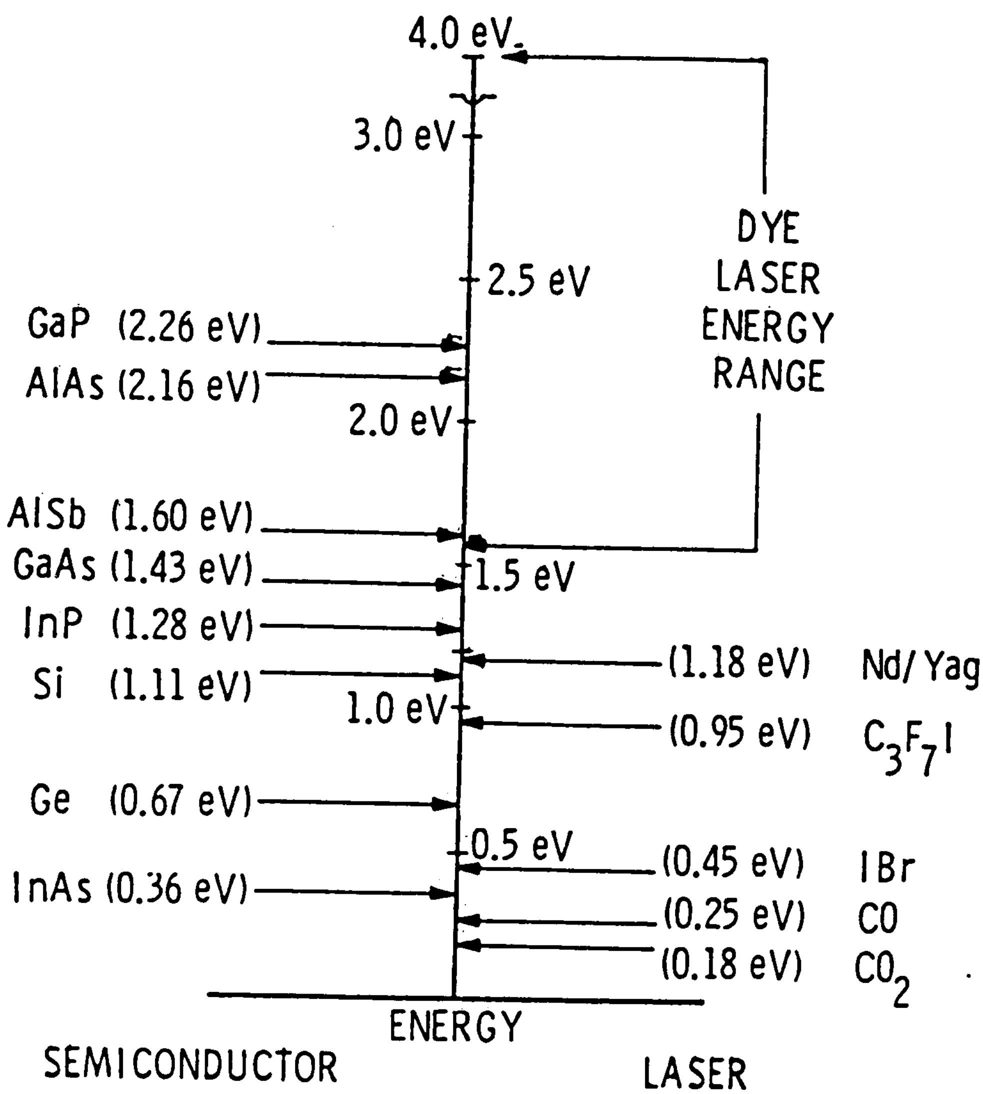
- Photovoltaic Cells

Dynamic Conversion

- Gas Turbine
- MHD Generators

LASER ENERGY-SEMICONDUCTOR BAND GAP ENERGY COMPARISON

The chart shows the energy band gap of various semiconductors and the photon energy for several different lasers. When the semiconductor absorbs photons from the laser, beam electrons are raised into the conduction band of the semiconductor allowing a conduct to flow. For a particular laser, one would choose the semiconductor having an energy band gap closest to the photon energy in the laser beam. The closer this match, the higher the efficiency.

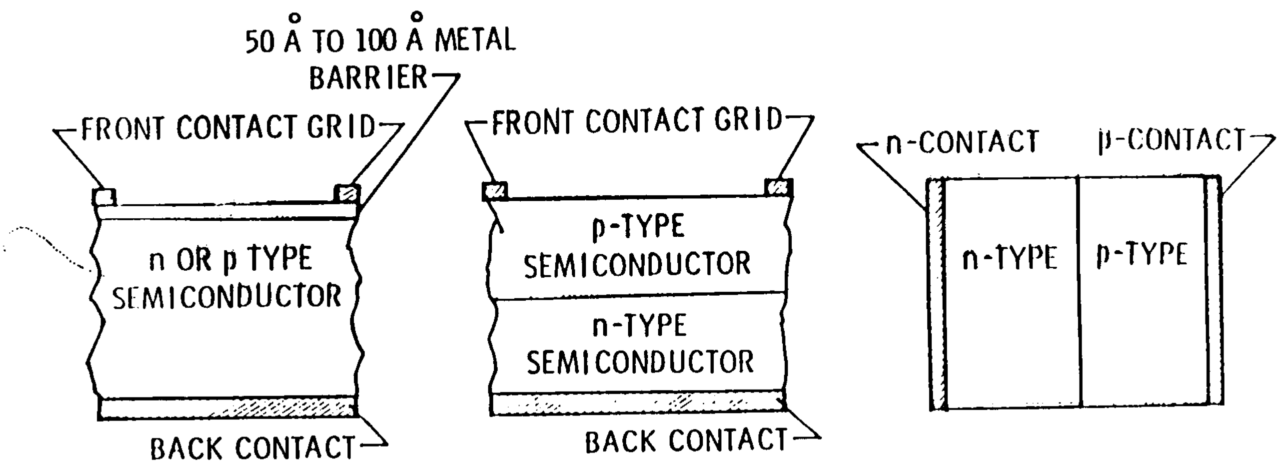


TYPES OF PHOTOVOLTAIC CONVERTERS

This figure shows the construction of three different types of photovoltaic converters. The Schottky Barrier converter uses a thin metal barrier which results in a large series resistance and has the lowest efficiency of the three.

The conventional p-m junction converter is the standard solar cell construction. A limiting feature of this type of cell is that charge carrier diffuse laterally resulting in a high series resistance.

The vertical p-m junction converter is best suited for high intensities and has the lowest series resistance. This converter has the highest efficiency of the three with efficiencies of about 50%.



SCHOTTKY BARRIER CONVERTERS

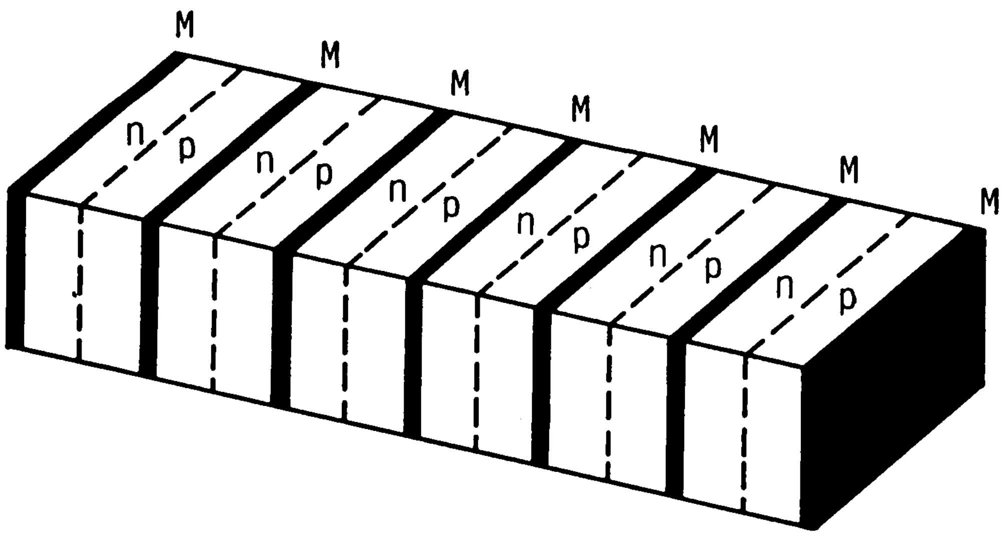
CONVENTIONAL p-n JUNCTION CONVERTERS

VERTICAL p-n JUNCTION CONVERTERS

SERIES-CONNECTED, VERTICAL-MULTIJUNCTION PHOTOVOLTAIC CONVERTER

This figure shows the construction of the series-connected, vertical-multijunction photovoltaic converter. This is just a stack of vertical p-n junction converters. As constructed, the device has a low series resistance and high efficiency.

M - metal
n - n-type semiconductor
p - p-type semiconductor



PHOTOVOLTAIC CELLS

This table lists the advantages and disadvantages of photovoltaic cells as space-based laser energy converters.

Advantages

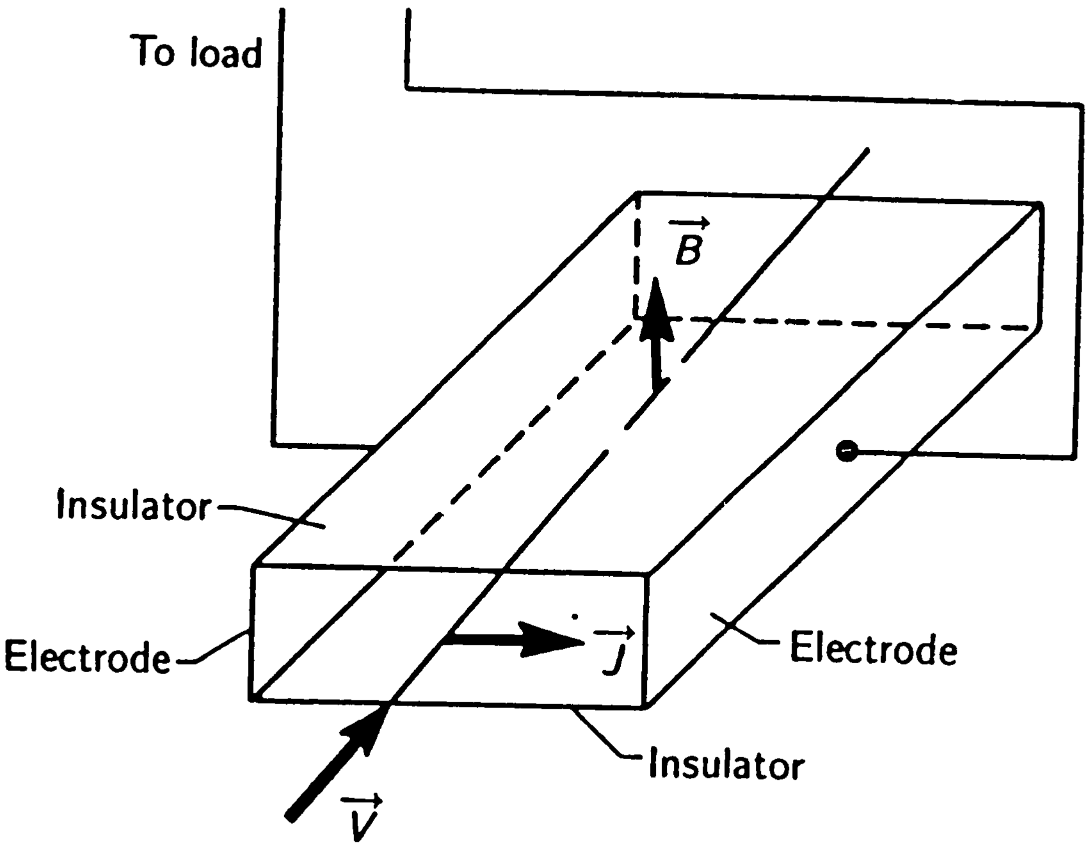
- Proven Technology
- High Conversion Efficiency > 40%
- High Power Density
- Low Maintenance

Disadvantages

- Low Temperature Operation
- High Intensity Effects Not Well Understood
- Restricted Wavelength Coverage

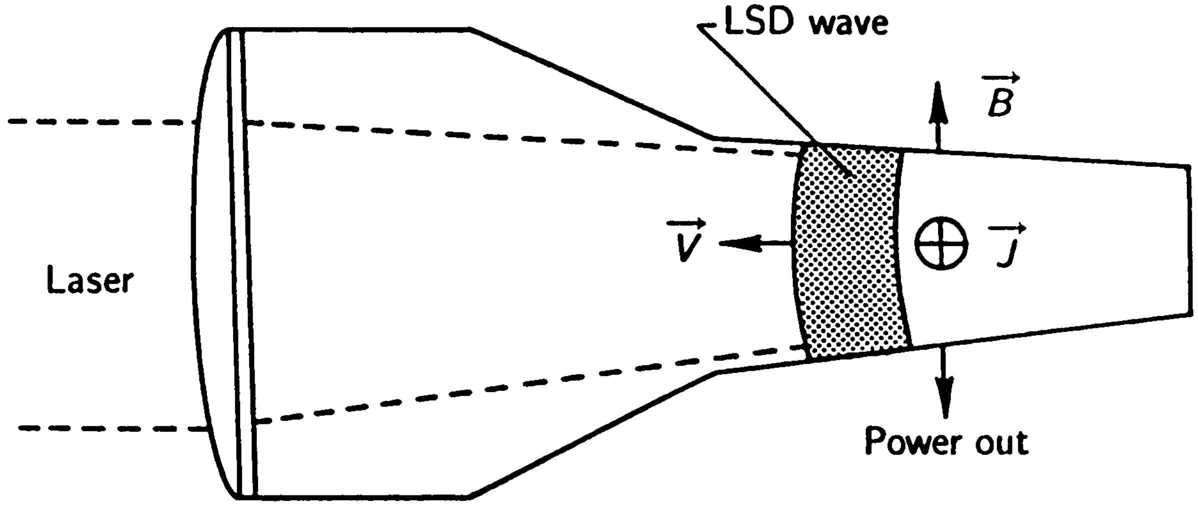
MHD GENERATOR

This figure shows a Schematic of a simple MHD generator. Power is generated when a plasma moves with velocity $\bar{\upsilon}$ through the magnetic field $\bar{B}$. The resulting $\bar{\upsilon} \times \bar{B}$ force causes a current to flow between the electrodes. To use this system for laser energy conversion, the laser energy either creates and heats the plasma which flows through the generator, or it may be used to heat an existing plasma prior to its introduction into the MHD generator.



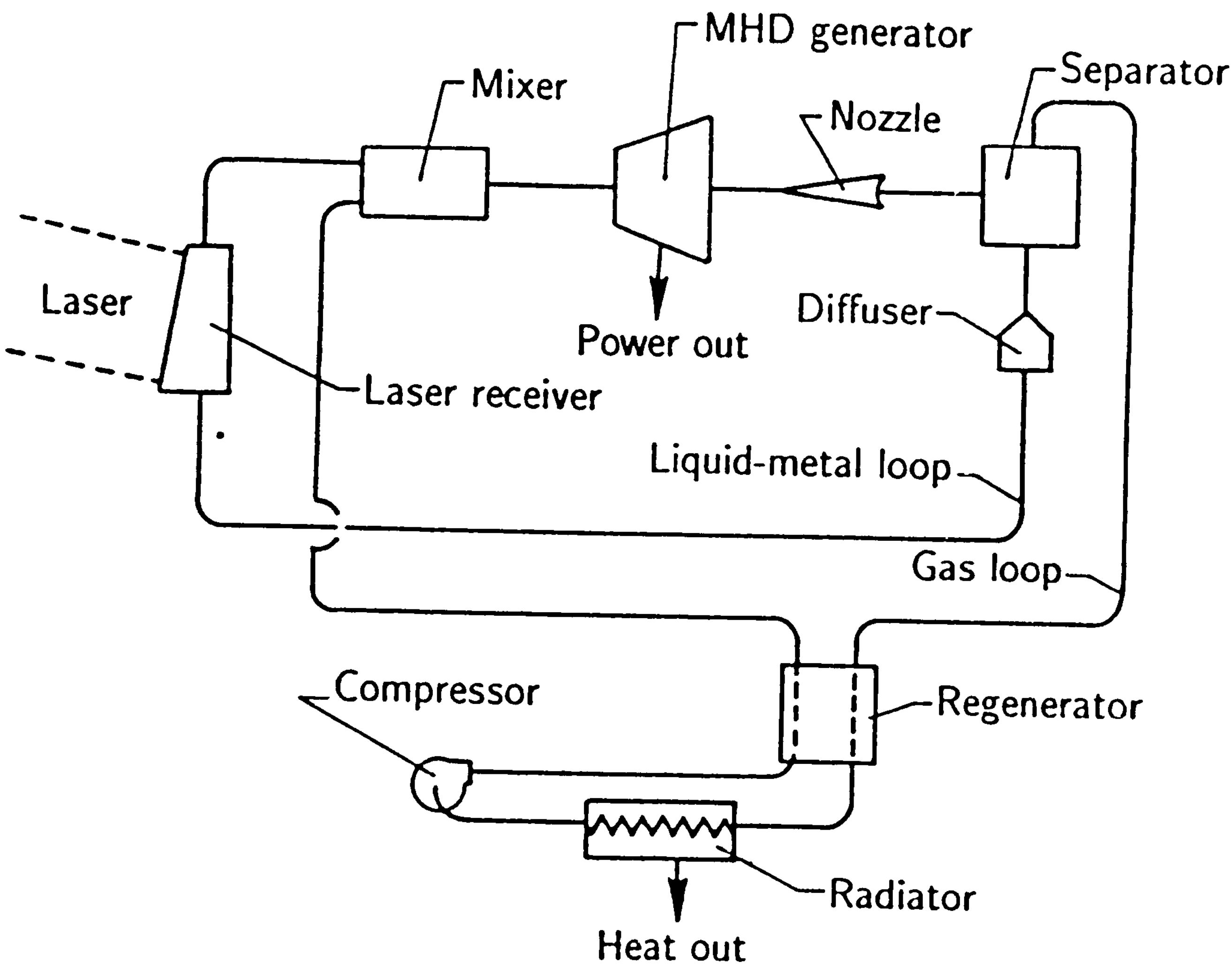
PULSED MHD SYSTEM

Focussing of the laser beam at the rear of the generator creates a breakdown in the gaseous medium resulting in a high temperature, dense plasma. As the plasma density increases the plasma becomes optically thick to the laser radiation (the laser cannot penetrate into the plasma) and a laser supported detonation wave is formed. The wave propagates to the left along the laser beam and as the wave passes through the MHD generator power is produced. Conversion efficiencies in excess of 50% are theoretically possible.



LIQUID-METAL MHD SYSTEM

A schematic of a liquid metal MHD, Brayton cycle space based system. The incoming laser radiation is used to heat the liquid-metal which is then mixed with the carrier gas. After passing through the MHD generator the flow is expanded through a nozzle into the separator where the liquid metal is separated from the carrier gas. Liquid metal and carrier gas are then recycled to the system. Conversion efficiencies of 70% are theoretically possible for the generator giving an overall system efficiency of 25-30%.



MHD GENERATORS

The table lists the advantages and disadvantages of MHD generators for space application.

Advantages

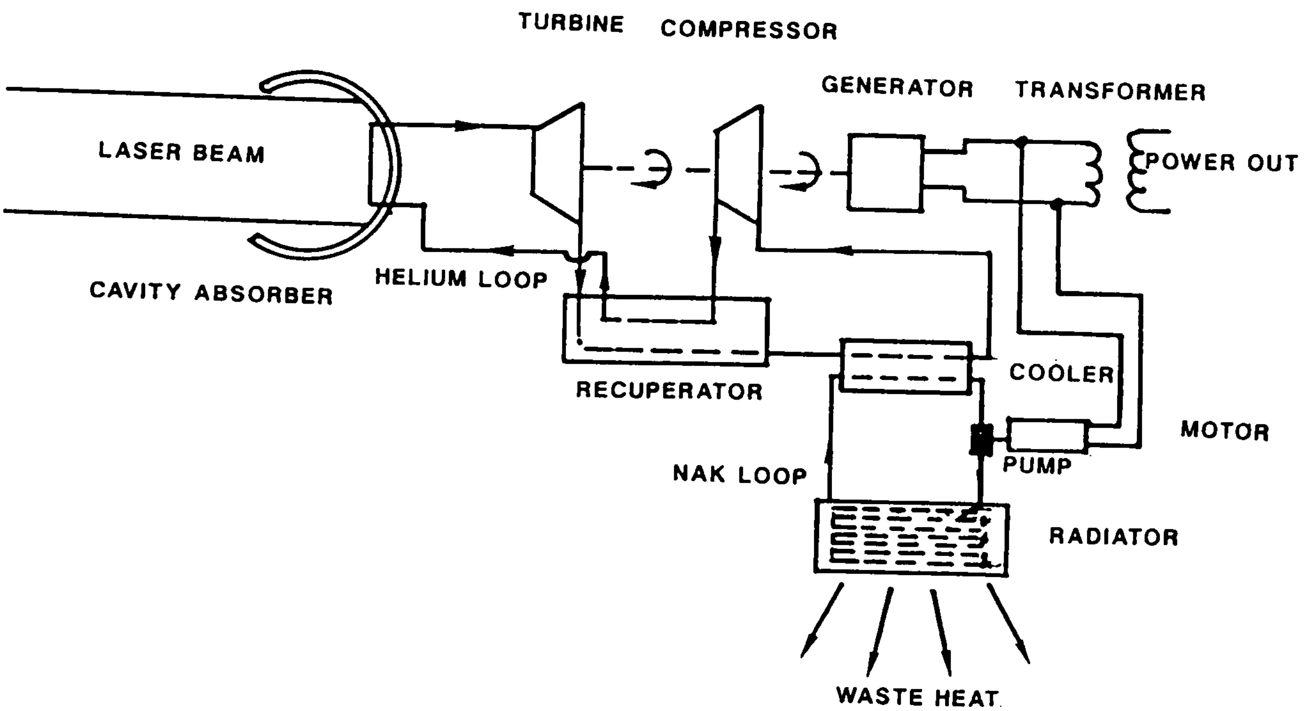
- Large Existing Technology Base from Terrestrial Applications
- Proven Technology
- High Overall System Efficiency
- High Power Density
- Closed Cycle Operation
- Low Maintenance (few or no moving parts)
- Operation Over a Broad Wavelength Range

Disadvantages

- Not Flight Proven
- Weight

LASER BRAYTON CYCLE TURBINE SYSTEM

Below is a schematic of a laser powered Brayton Cycle turbine system. The incoming laser energy is used to heat helium which is then expanded through a gas turbine. The turbine shaft drives a compressor to recycle the helium and a generator to produce electrical power. Overall efficiencies of 30% are predicted for this system.



GAS TURBINES

The table lists the advantages and disadvantages of gas turbines for space power application. Conversion of laser energy to heat in the helium loop should be very efficient.

Advantages

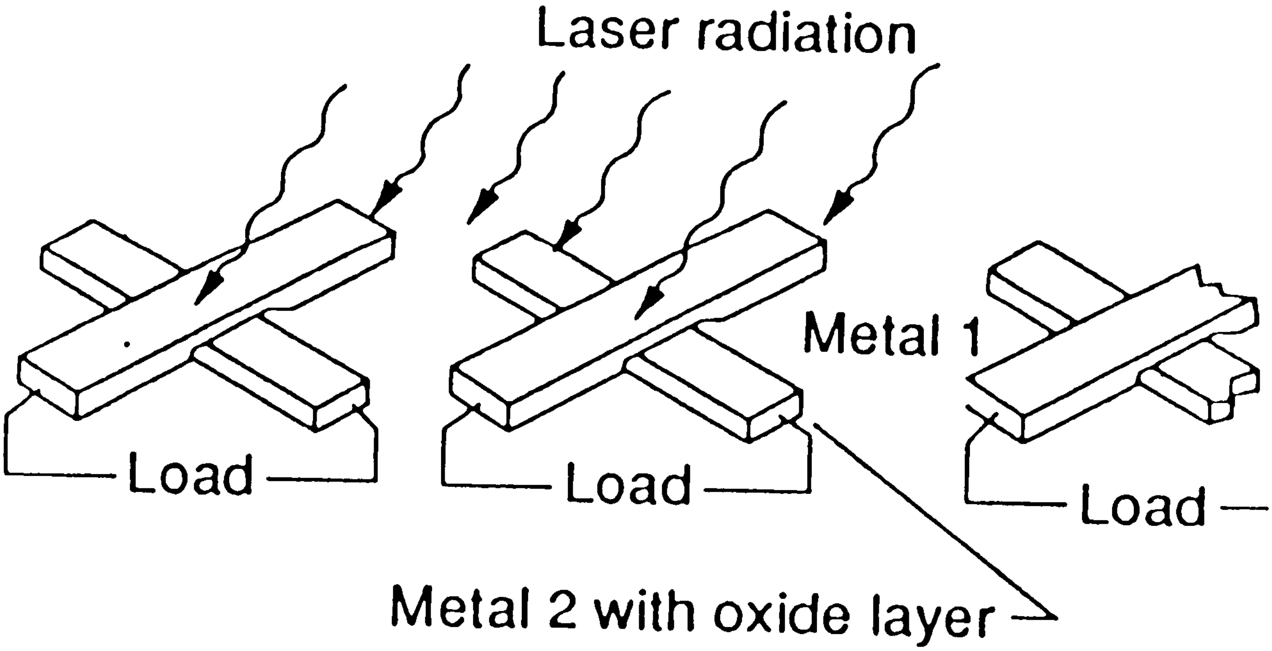
- Proven Technology
- High Reliability
- Good Efficiency (~ 30%)

Disadvantages

- Rotating System (high maintenance)
- Materials (high temperature operation)

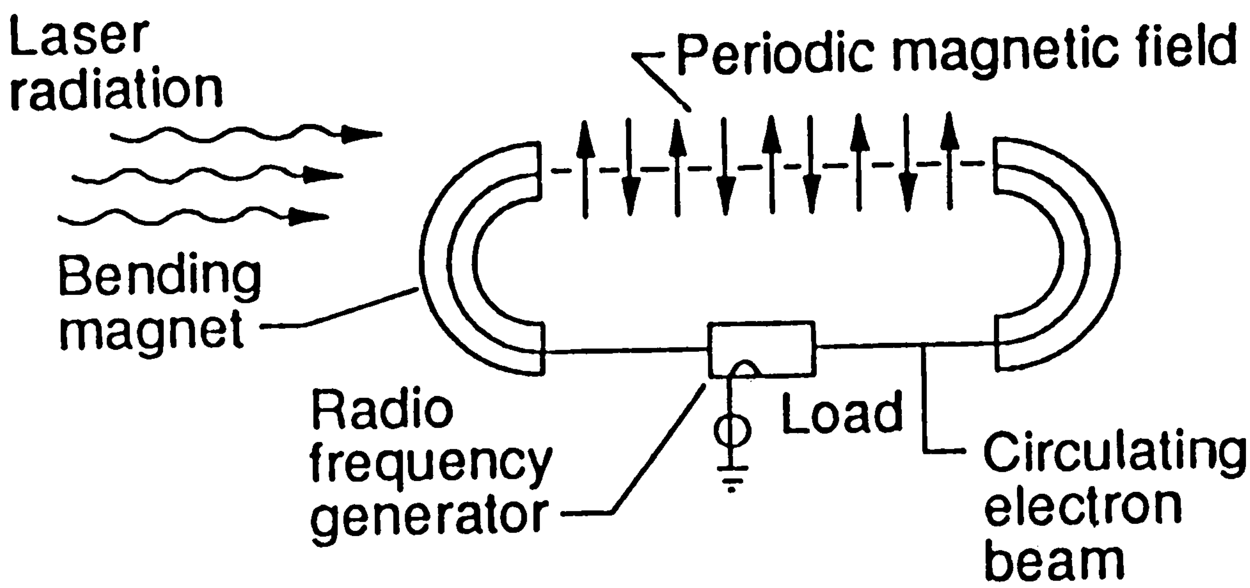
OPTICAL RECTIFICATION

The figure shows the concept of optical rectification as an energy converter. Not well developed, this method does, however, show much promise as an efficient laser energy converter with conversion efficiencies in excess of 50% being predicted. This system has not been developed to a point that all of its advantages and disadvantages are known.



REVERSE FREE-ELECTRON LASER

The free-electron laser may be used in a reverse cycle absorbing laser energy and producing electrical power. This concept is not well developed but theoretically is very promising due to its large theoretical conversion efficiency (> 50%).



SUMMARY AND CONCLUSIONS

Three systems (photovoltaic cells, MHD generators, and gas turbines) have been identified as the laser-to-electricity conversion systems that appear to meet most of the criteria for a space-based system. The laser thruster also shows considerable promise as a space propulsion system.

At this time one cannot predict which of the three laser-to-electric converters will be best suited to particular mission needs. All three systems have some particular advantages, as well as disadvantages. It would be prudent to continue research on all three systems, as well as the laser rocket thruster.

Research on novel energy conversion systems, such as the optical rectenna and the reverse free-electron laser, should continue due to their potential for high payoff.