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Concepts for, and Utility of, Future Space Central-Power Stations

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Abstract

THE rate of industrial development in space is largely dependent on the cost of transportation to, through, and from space and the cost of electrical power in space. The technological and economical impact of a large central-power station in Earth orbit on the cost and performance of future spacecraft and their orbital-transfer systems has been examined.[1] Analysis of the cost effectiveness of meeting Earth-orbiting spacecraft electrical power demands from a central-power station indicates that this application cannot justify the investment required for the central station. However, laser-thermal and laser-electric propulsion systems powered from a central-power station promise major cost savings when compared to orbital-transfer vehicles using advanced, conventional, chemical, and solar-electric propulsion—at least within the bounds of the assumptions made.

Contents

A preliminary evaluation of central-power stations in Earth orbit has been made considering two classes of users: 1) Earth-orbiting satellites requiring electrical power for routine operations to meet mission goals, and 2) orbital-transfer vehicles (OTV) requiring power for propulsion.

Three concepts for central, space-based power stations considered were: a photovoltaic array system representing proven technology with incremental improvements in costs, weight, and efficiency obtainable by the turn of the century; a direct nuclear-pumped laser system based on a rapidly evolving technology; and a direct solar-pumped laser system based on new technology that is emerging in the laboratory. Both microwave and laser transmission of energy from the central-power station to the user were considered. However, microwave systems were not competitive with laser systems for power transmission over geosynchronous distances.

Space-Based Central-Power Station Concepts

The three central-power station concepts located in GEO are shown in Figs. 1-3. For all concepts, the major systems and subsystems are sized for a total laser output of 100 MW_L at the transmitter.

Photovoltaic Array

The solar-powered, photovoltaic central-power station with laser-energy transmission systems is shown in Fig. 1. Gallium arsenide (GaAs) solar cell arrays with 20% efficiency (projected to be available in the 1990s) are based on conventional, existing technology. Efficiencies[2] of 18.6% have already been achieved for these solar cells in the laboratory. Two independent, high-energy, electric-discharge laser (EDL) systems, each about 15 m square and 40 m long[3] radiate power to 30 m diam laser transmitters. Passive heat-rejection

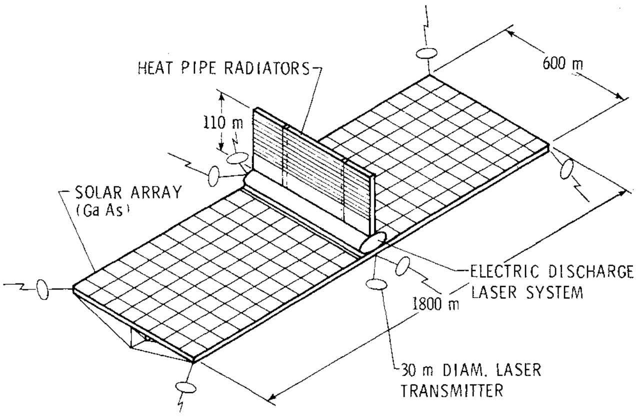

Fig. 1 Solar-powered, photovoltaic central-power station.

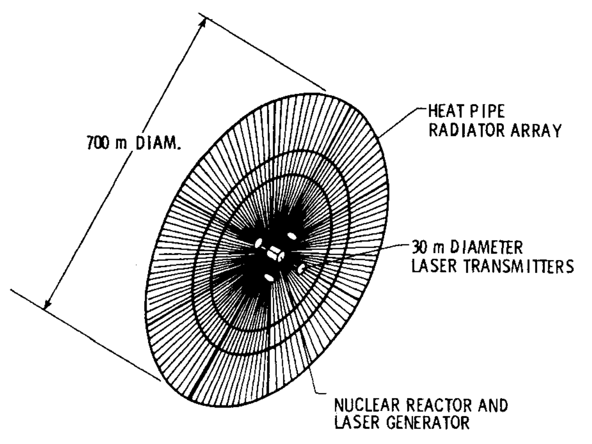

Fig. 2 Direct nuclear-pumped laser-power station (100 MW_L).

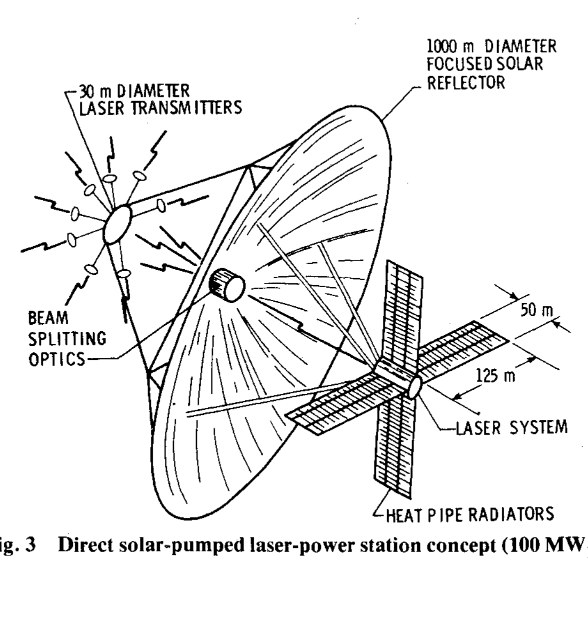

Fig. 3 Direct solar-pumped laser-power station concept (100 MW_L).

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systems incorporated in the photovoltaic array radiate the unusable solar energy. Heat-pipe radiators arranged in a planar array are extended radially from the laser system to reject the unusable thermal energy in the laser. An electrical-to-laser energy conversion efficiency of 30%, based on the work of Monson,[4] is assumed. Thus, the GaAs solar array is sized to produce 330 MW_e of electrical power to yield laser power output of 100 MW_L.

Direct Nuclear-Pumped Laser

The direct nuclear-pumped laser (DNPL) power station shown in Fig. 2 is built around a gas-core reactor fueled with UF_6. The lasant is mixed with UF_6 so that the laser generation system is integral with the reactor. The physical dimensions are for a total reactor power of 100 MW_L. Boody et al.[5] note that experimental nuclear pumping of a CO lasant has yielded a 1% efficiency and nuclear-to-laser power conversion efficiency has been projected to reach 10%.[5,6] According to Rodgers,[6] a power-intensive nuclear reactor system capable of operating between 2 and 2000 MW can be enclosed in a 5 m diam and 6 m long pressure vessel. Heat-pipe thermal radiators reject excess heat from the nuclear-to-laser energy conversion process.

Direct Solar-Pumped Laser

Direct solar-pumped laser (DSPL) power stations and future performance estimates have been projected by Monson,[4] Rather,[7] and Taussig et al.[8] A conversion efficiency of 0.1% solar-to-laser energy was recently achieved[9] and although the technology for solar-pumped lasers is still in the earliest laboratory stages, it seems reasonable to project an overall, solar-to-laser energy conversion efficiency in the range of 1-20%.

A conceptual design of the solar-pumped laser power station is shown in Fig. 3. For this study, efficiencies of 10 and 1% are assumed requiring collector diameters of 1000 and 3000 m, respectively, to concentrate the low-level radiation (1.4 kW/m^2) on the transparent laser tubes. Assuming that a solar-filtering reflector material can be developed to reflect only the portion of the solar spectrum usable for lasing (20%) and that 50% of this reflected solar energy goes into lasing energy (for a 10% overall solar-to-laser energy conversion), then approximately 25,000 m^2 of heat-pipe thermal radiators are needed for the laser. High-emissivity materials on the back side of the solar concentrator could be used to passively radiate the unusable solar energy absorbed by the concentrator.

Comparative Cost Analysis

Comparative cost, mass, and performance data used in this study of onboard self-powered systems and remotely powered systems with several candidate central-power stations are developed in Ref. 1. Significant results are summarized for the two classes of users considered.

Earth-Orbiting Satellites

Comparative costs for solar-powered onboard photovoltaic arrays, operating at 20% efficiency, vs laser-powered remote photovoltaic arrays, operating at 50% efficiency and powered by the central DNPL or DSPL station, show that remotely powered satellites would be marginally competitive at best with onboard solar arrays in the cost range of \$100,000-\$300,000/kW_e and then only if each satellite required average continuous powers of 10-100 MW_e. If mass-produced solar array costs decline to optimistic solar-power-satellite estimates[10] of \$300-\$5000/kW_e, the costs of the central-power station could not be amortized, and thus the remotely powered satellites would not be cost competitive with onboard systems.

Orbital-Transfer Vehicles

The comparison of the cost advantages of remotely powered propulsion systems with onboard self-powered propulsion systems is based on an increasing rate of delivery of cargo from low-Earth to geosynchronous-Earth orbits and return. All OTVs were assumed to be space based. An advanced chemical system is compared with a remotely powered laser-thermal propulsion system (LTPS), and a solar-electric propulsion system (SEPS) is compared with a remotely powered laser-electric propulsion system (LEPS). As shown in Fig. 4, cumulative cost savings of the remotely powered over self-powered OTVs for annually increasing cargo mass can run in the tens to hundreds of billions of dollars over a 30 year period. The cost savings for remotely powered OTVs are derived by virtue of relatively lower propellant mass requirements and/or lighter, less costly receiver systems than for the self-powered OTVs (i.e., the remotely powered OTVs have higher specific impulse systems and smaller photovoltaic receivers than self-powered OTVs). The launch savings, with costs estimated at \$1000/kg, are the most significant contributor. Even with the development of a heavy-lift launch vehicle with a projected launch cost[11] of \$50/kg, the remotely powered OTVs would be most cost competitive with self-powered OTVs.

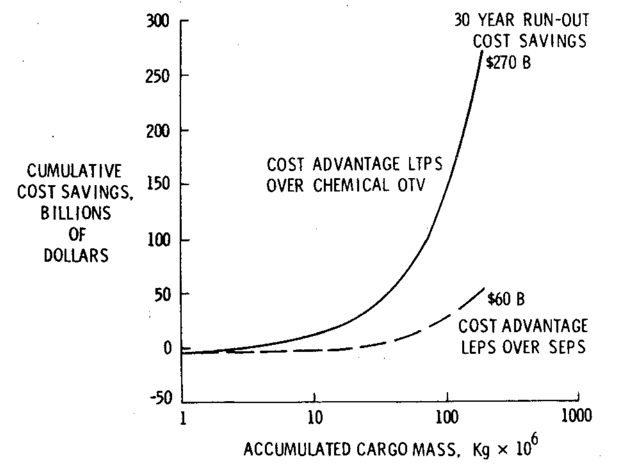

Fig. 4 Cumulative cost savings of remotely powered vs self-powered OTVs.

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