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SOLAR PUMPED LASER AND ITS APPLICATION TO HYDROGEN PRODUCTION

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Outline

1.INTRODUCTION

2.SOLAR PUMPED LASER -HELIOS-

3.EXPERIMENTS ON HELIOS

4.FUTUR SYSTEM

5.HYDROGEN PRODUCTION & COST

6.SUMMARY

Solar pumped laser

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We have developed solar pumped laser for space power beaming,at first. During the development,we found

1 .Solar pumped laser is very efficient as 40%.Expected from experiments.

2 .Large area of solar energy can be concentrated.

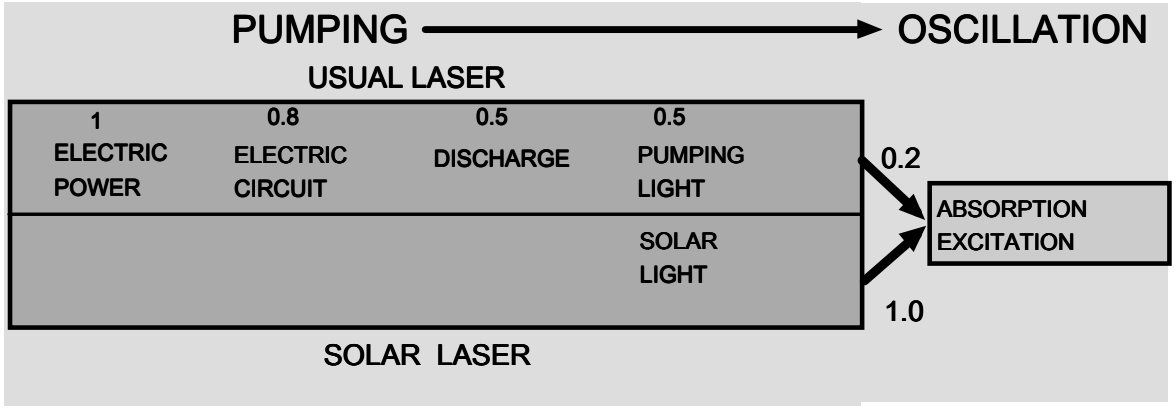
3 .High temperature is easily obtained.

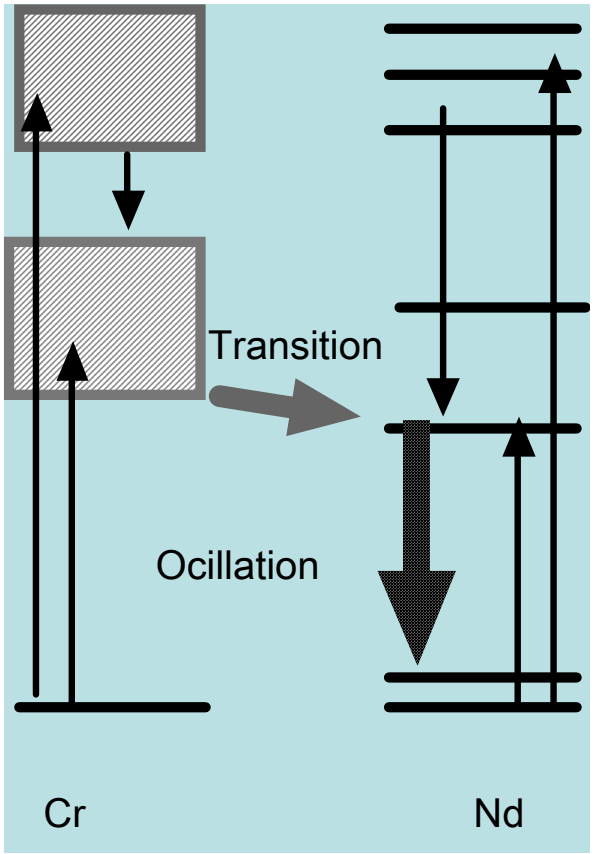
4.Low price laser is available.

Laser Space Solar Power Station (L-SSPS) (JAXA)

Hydrogen Production on surface is conceivable.

Why so efficient?





Direct Pumping

Wide Spectrum Absorption

Efficient Transition

from Cr^{3+} to Nd^{3+}

Concentration of wide spectrum

Cr^{3+} and Nd^{3+} ----> Nd^{3+}

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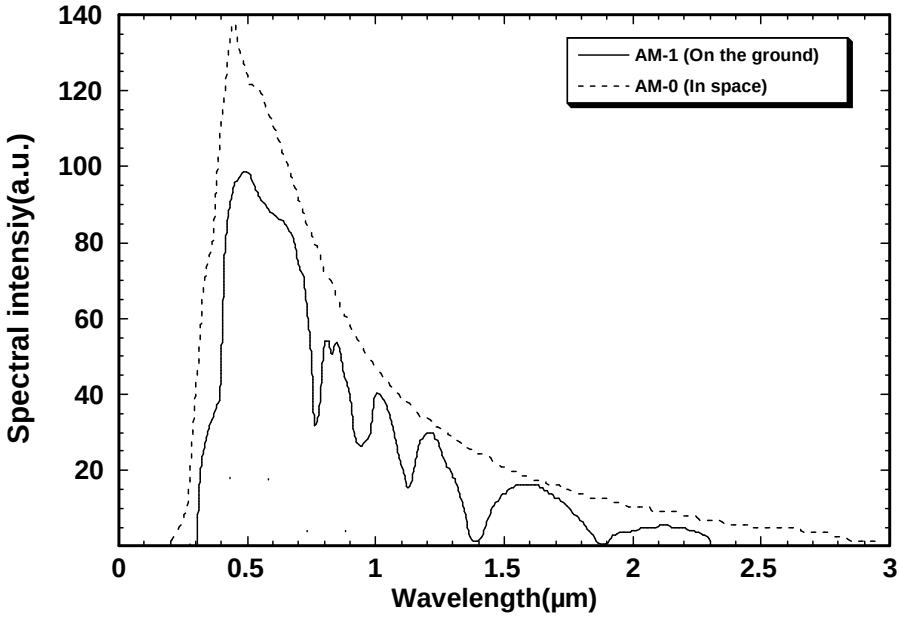

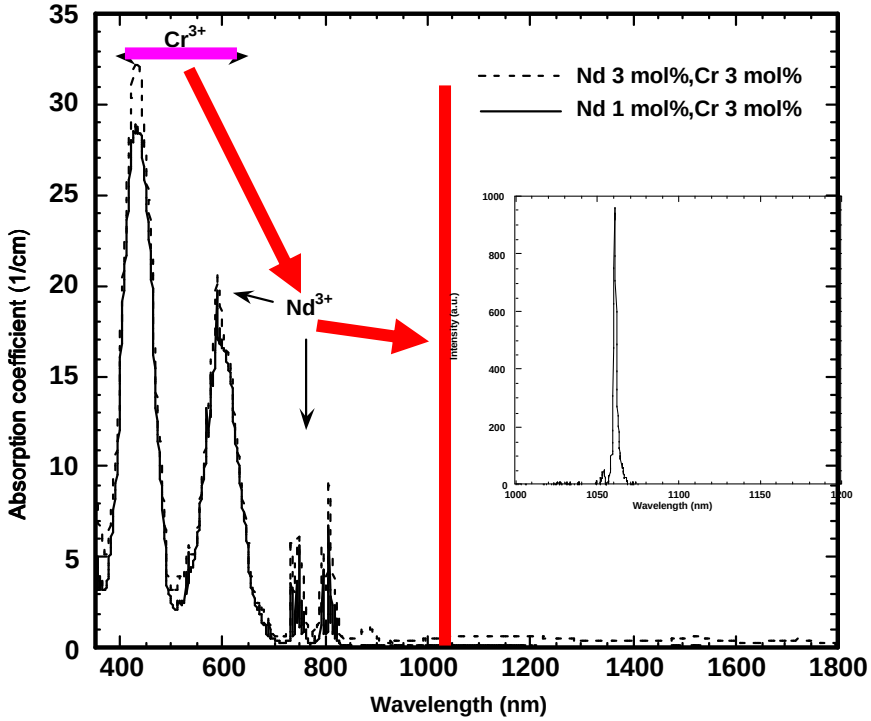

Solar light with wide spectrum is absorbed by Cr and Nd and is concentrated to Nd oscillation line of 1.06 micron meter.

Solar Pumped Laser

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Solar pumped laser has rather long history.

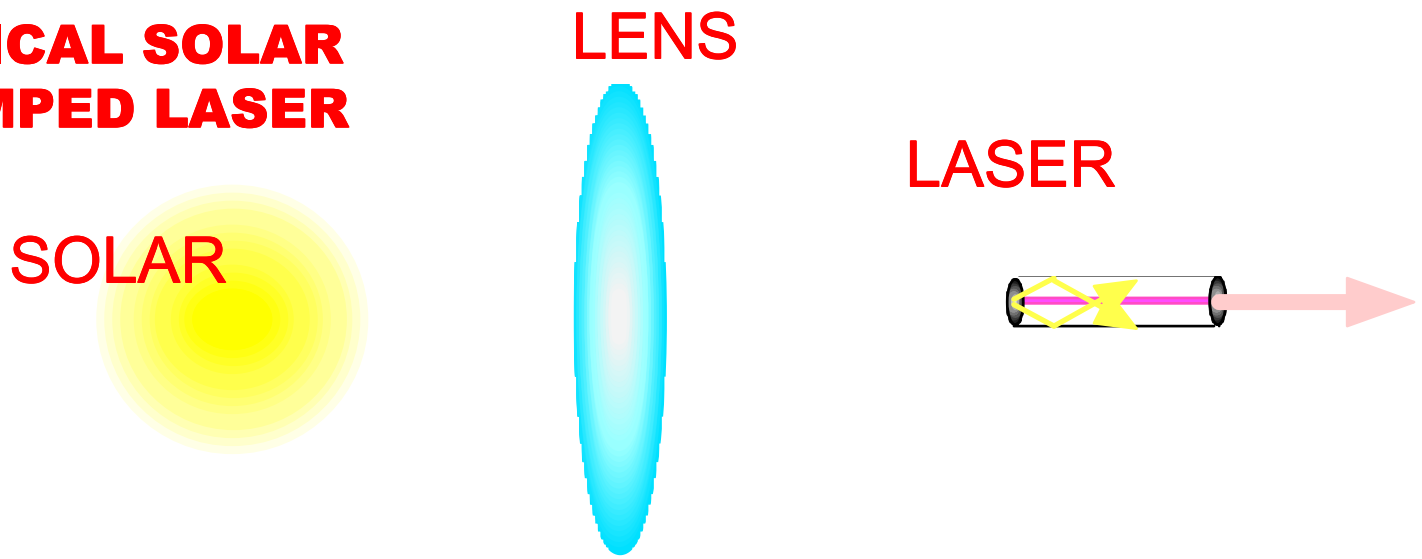
Crystal or Glass (USA,ISRAEL,JAPAN,RUSSIA et. al.)

Nd:YAG,Nd/Cr:GSGG,Cr:LiSaF

SEMI-CONDUCTOR. IODINE, and so on.

Ceramic laser has been developed in Japan for fusion laser.
It has many advantages for solar pumping as co-doping of multi materials with high density and high thermal conductivity.We can make sutable shape freely for solar pumping.

TYPICAL SOLAR PUMPED LASER



Experiment by natural sun with rod ceramic laser

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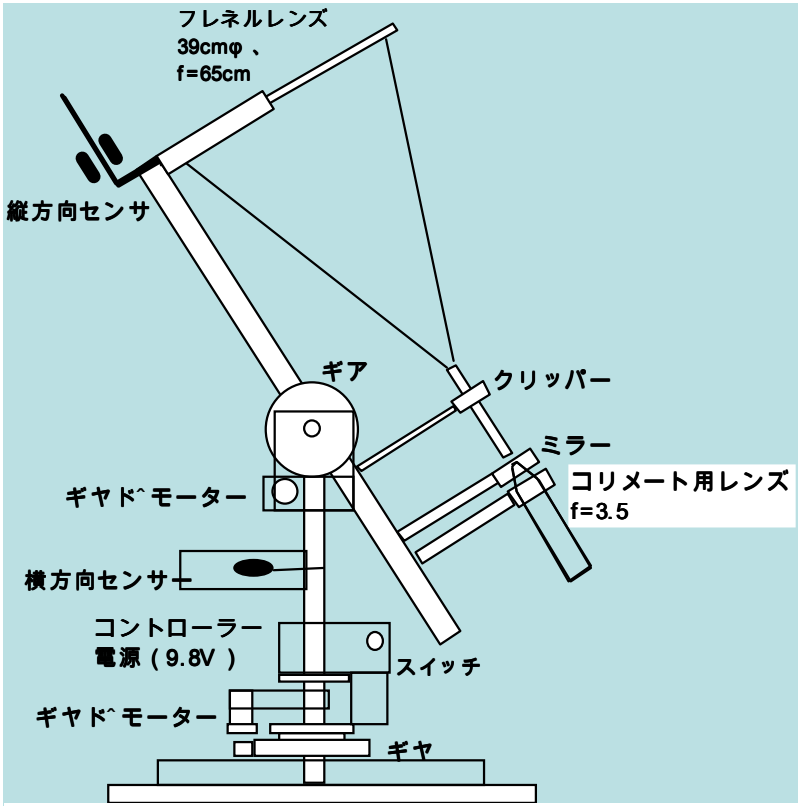
We observed oscillation by this simple system in natural sunshine.



It is hard to get a precise characteristics for solar perturbation on ground.

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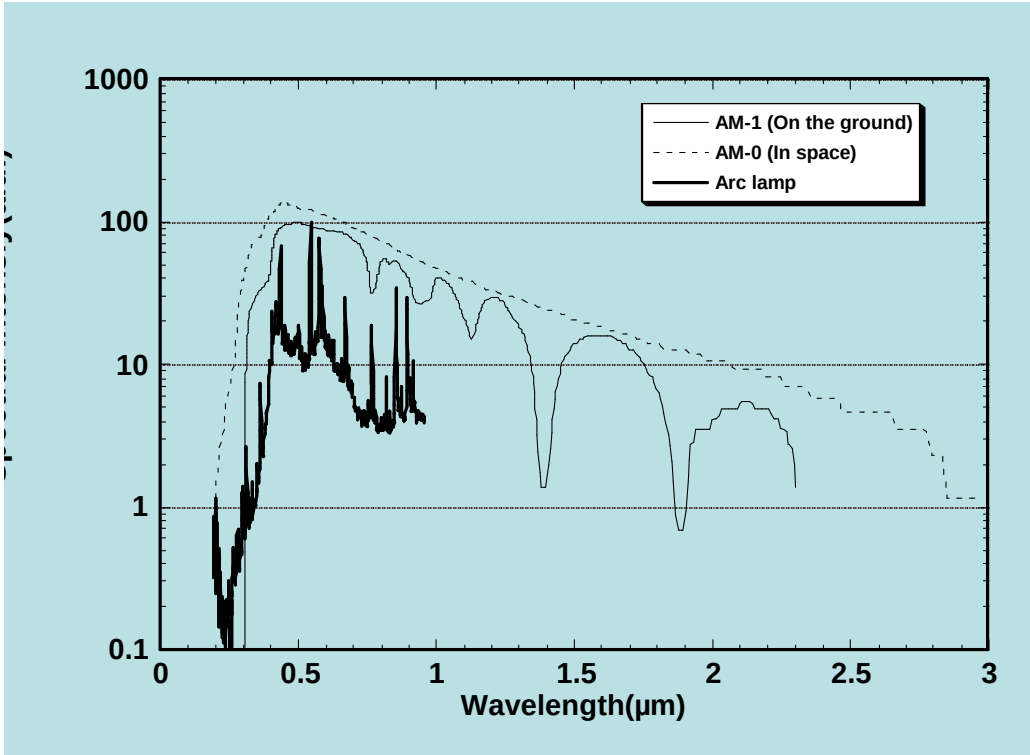
We used pseudo solar lamp for precise experiments on HELIOS



We needed precise experimental data to understand HELIOS laser characteristics, so we used pseudo solar lamp and performed detail experiments.

HELIOS experiments in laboratory to investigate the laser characteristics

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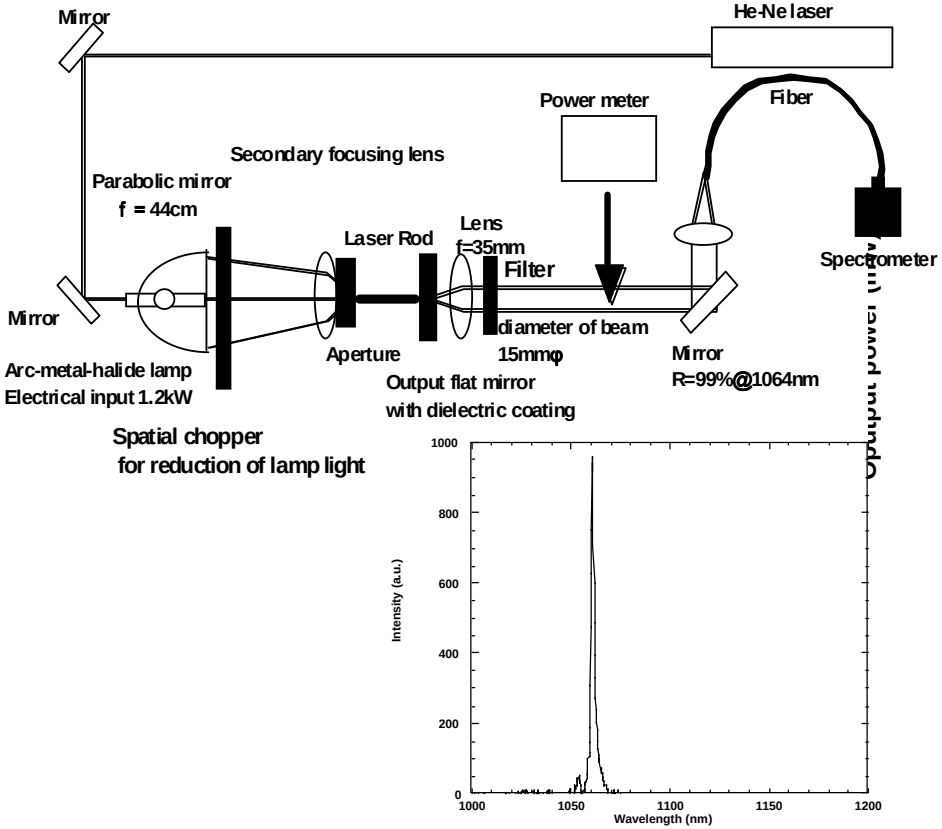
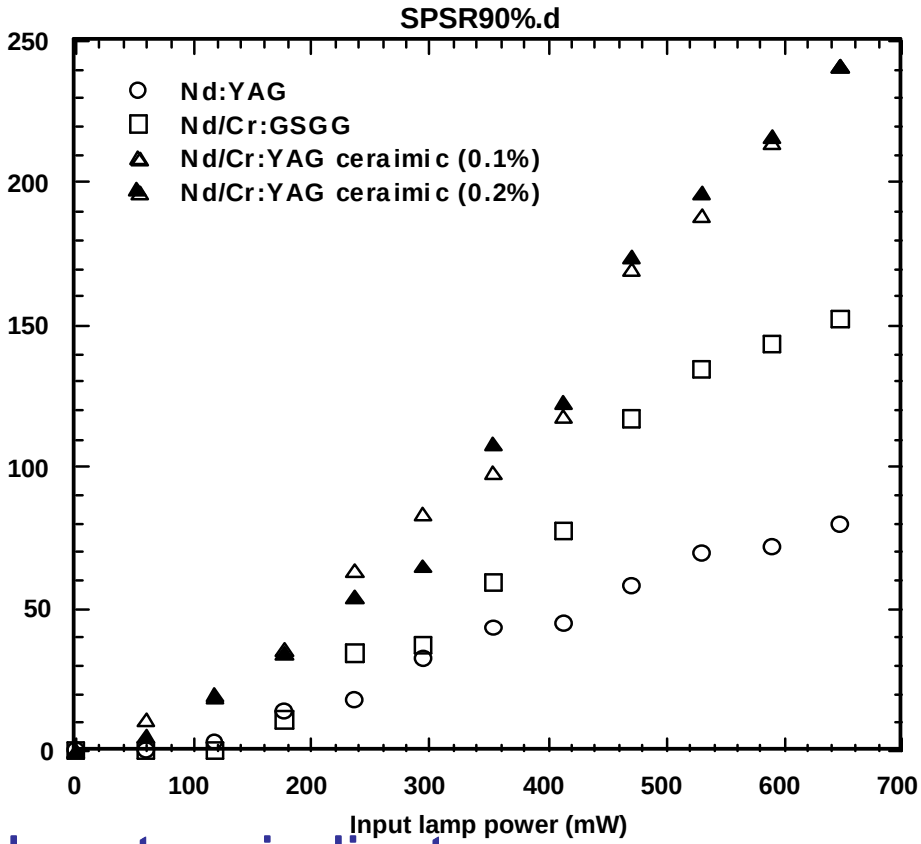
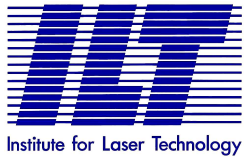




Small size experiments in the laboratory indicate extraction rate from solar power to laser power **42%**.

Research for ideal configuration for solar pumping



We performed experiments to find out suitable laser configuration for solar pumping as,

- Fiber: Bad coupling for solar power
- Rod : Coupling,problem of thermal conduction
- Disk:Good coupling and good thermal conduction.

We can not decide ideal laser configuration yet but disk shaped laser shows many advantages as coupling of focused sun, cooling and so on.

Disk-shaped Cr doped Nd:YAG ceramic for HELIOS

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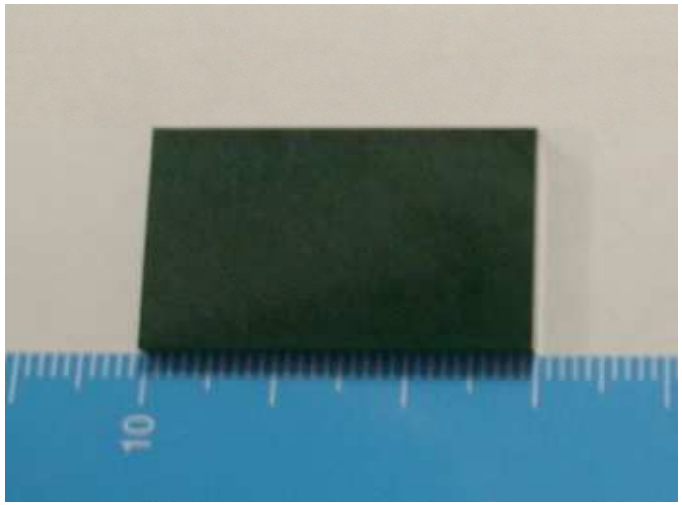

We need matching of laser size to focused sunlight of few mxm.

Size ; 20mmx30mmx3mmt
Nd=1%,Cr=3%
10cmSquerSheet is available
100cmlevel is tested

Nd/Cr:YAG Ceramic active-mirror laser experiments

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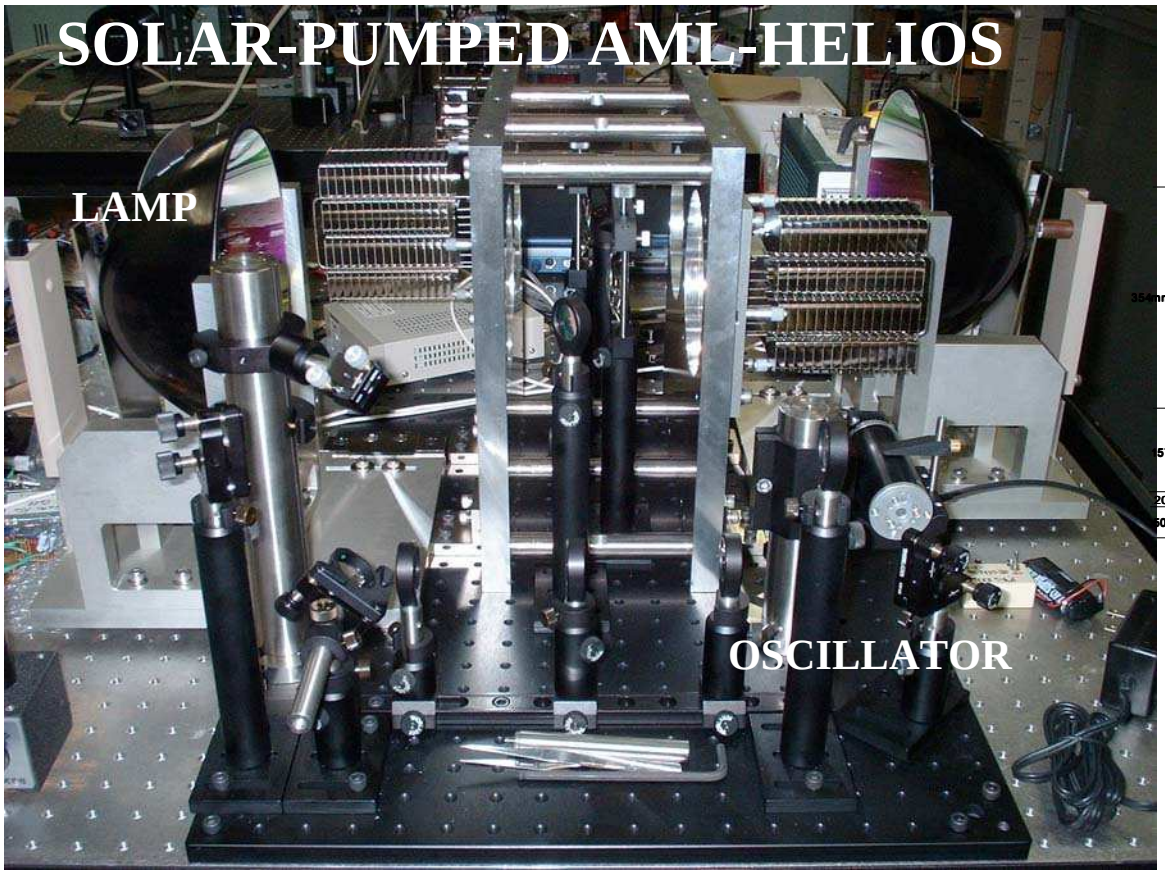
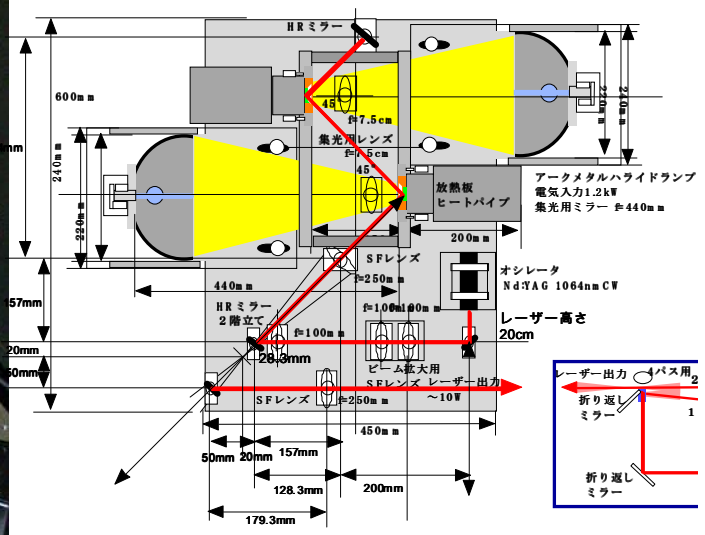
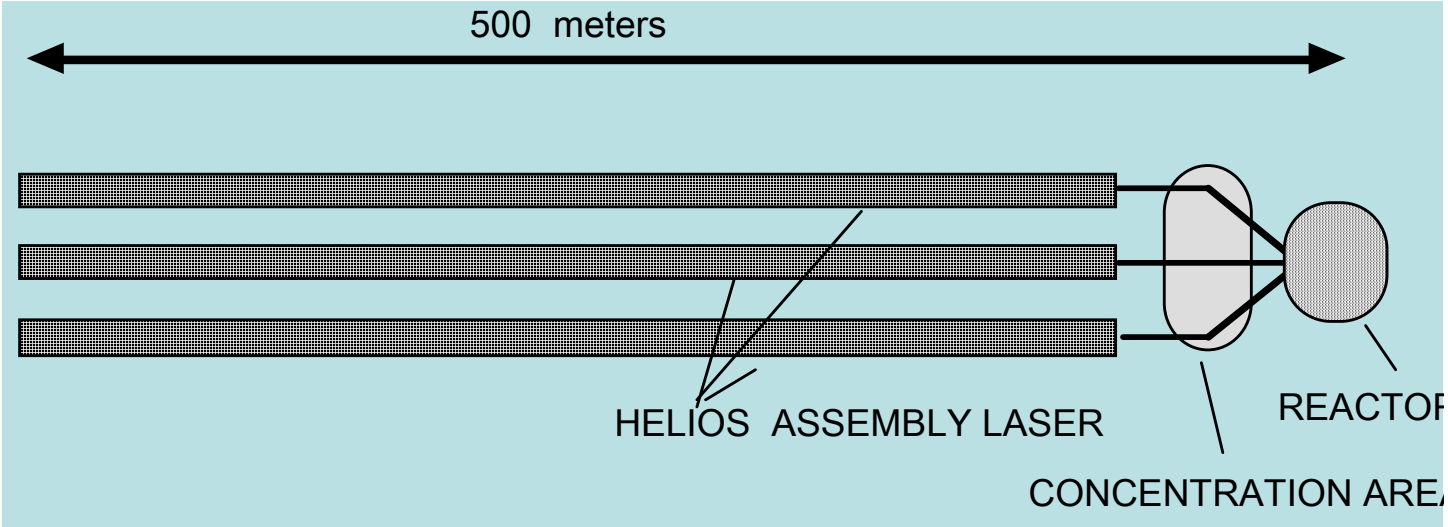


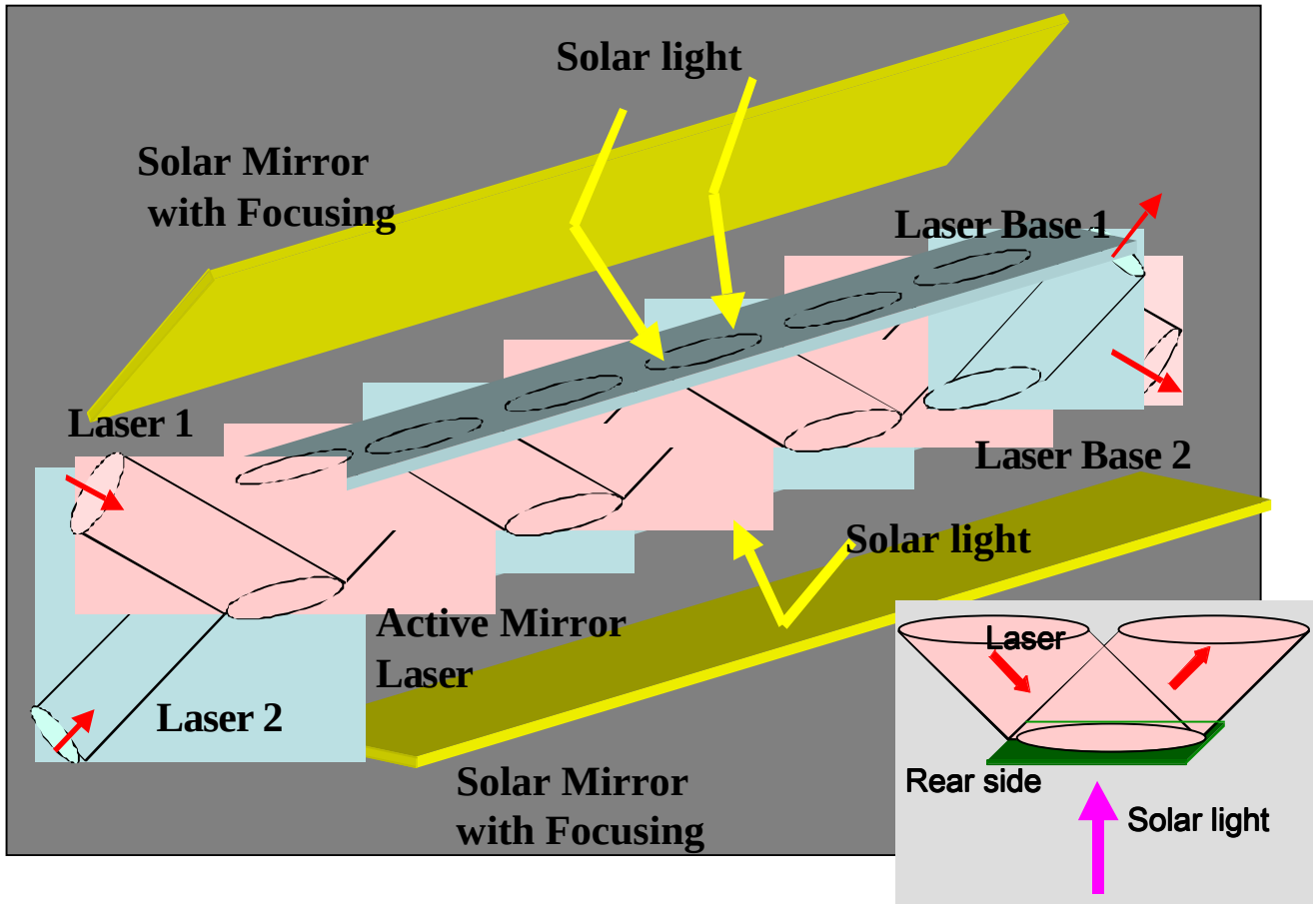


Practical system of HELIOS



1. We can converge 1kmx1km solar light to laser and laser can be propagate and can be focus to a small volume.
2. High temperature can be achieved by this for efficient hydrogen production.

Solar pumping laser Helios for 10MJ per line



Single mode laser can propagate in a long distance without loss

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Laser Propagation of 1km is not difficult.

----> To avoid them from thermal effect.

1. Power Propagation=Single Mode
---> Spatial Filter---> Higher order mode cut
2.Thermal Effect of Solar Irradiation=Air Cooling
---> Heat Pipe +Active Mirror Laser

These keep beam propagation and each output by solar laser is accumulated.

High temperature achieved on high energy density materials

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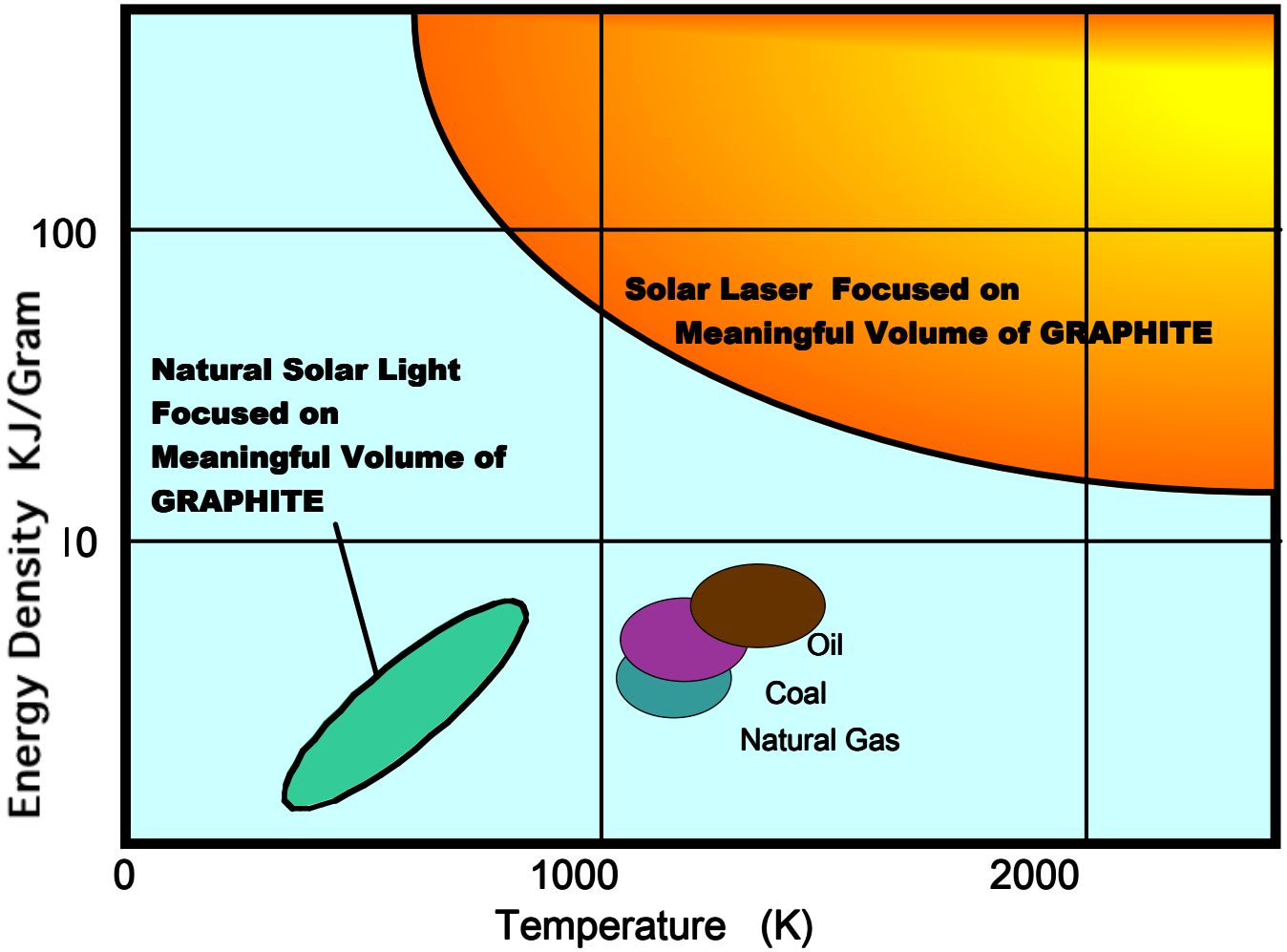

Meaningful volume for industrial application is required.

Hydrogen production-example

Hydrogen production processes has been proposed many cases. A typical hydrogen production is shown as,

$$xI_2 + SO_2 + 2H_2O \rightarrow H_2SO_4 + 2HIx \quad 500\sim700K$$
$$2HI \rightarrow H_2 + I_2 \quad 700\sim1100K$$
$$H_2SO_4 \rightarrow H_2O + SO_2 + 1/2\ O_2 \quad 1100\sim1600K.$$

Finally, a total of this is written as

$$H_2O \rightarrow H_2 + (1/2)O_2 .$$

Each process is a component of Carnot cycle and efficiency is given as

$$1- (Tmin / Tma) = 1100/1600 = 69\% ,$$

for ideal case.

Hydrogen production system by HELIOS

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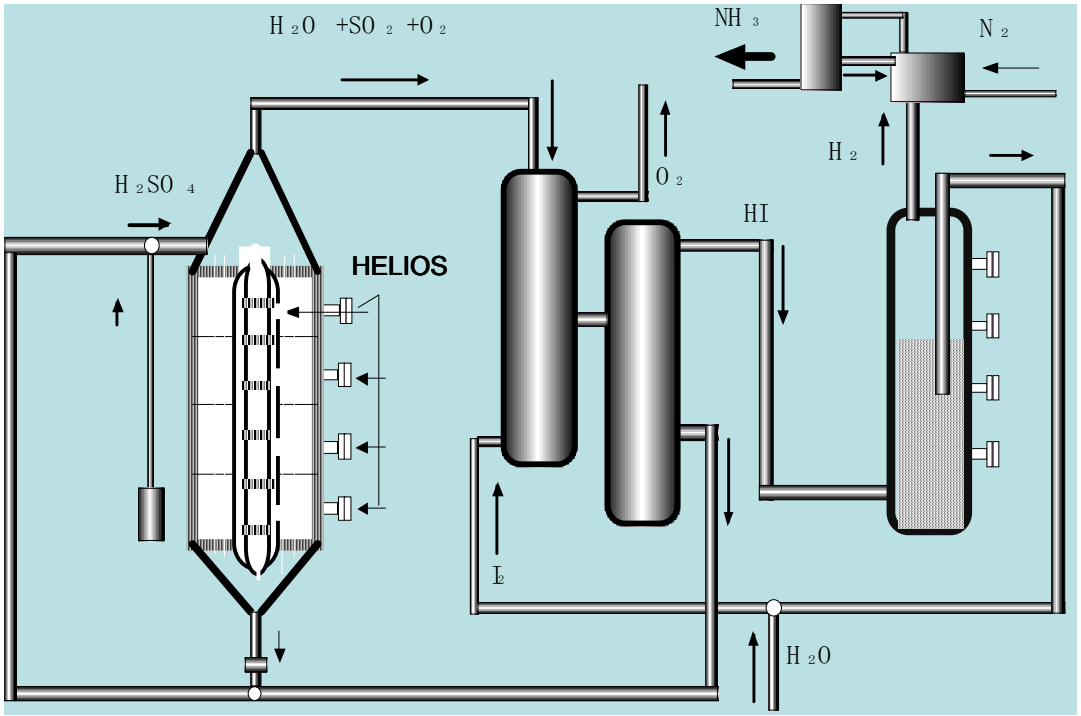


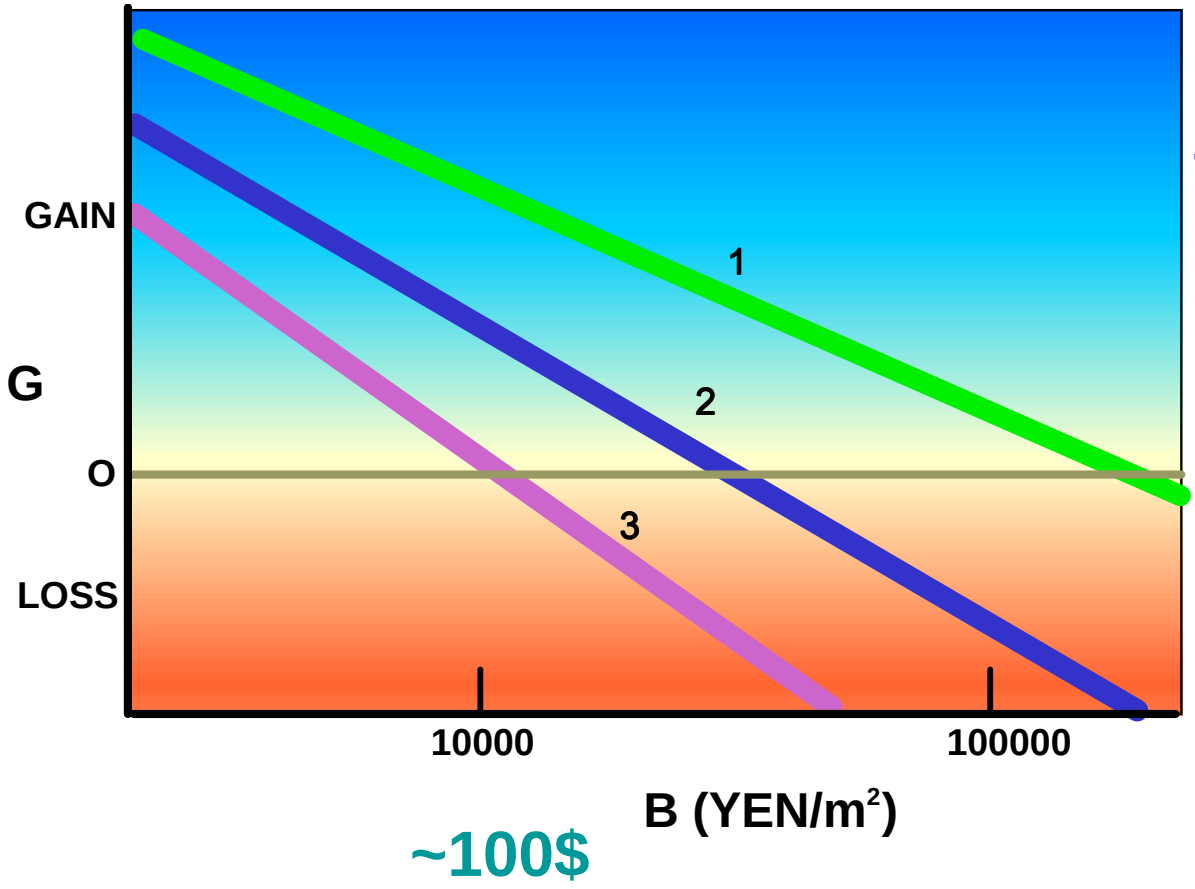
Suitable place to operate HELIOS is in desert of low latitude. To carry product to the place of consumer is important issue.

----> NH_3

Compound for Hydrogen Carrier

	Melting/Boiling point Mass	Hydrogen process	Byproduct
NH_3	-77℃ / -33℃ 0.64g/㎤	N_2+3H_2 → $2NH_3$	N_2 Atmosphere
CH_4	-183℃ / -162℃ 0.42g/㎤	$CO+3H_2$ → CH_4+H_2O	CO / CO_2
CH_2OH	-98℃ / -65℃ 0.79g/㎤	$CO+2H_2$ → CH_2OH	CO / CO_2

Gain can be expected in Hydrogen of 20¥/Nm^3



~100$

Ignoring b and c for large system, output product price can be estimated.

The ceramic laser unit price even today is low. The hard parts are main cost component of HELIOS.

CERAMIC laser is easy to make large number with meaningful size in a short duration at once. => very cheap

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POWDER
--> SHAPING
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SUMMARY

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1. SOLAR PUMPED LASER
   40% ---> 50%
2. LASER ENERGY TRANSPORT AND CONCENTRATION
   MODE /Graphite cavity ---> 100%
3. HIGH TEMPERATURE
   1600K 70% ---> Hydrogen production
4. HYDROGEN PRODUCTION COST -->NH_3
   ¥ 20/Nm^3 ---> Ceramic laser

This work is partially supported by Grant-in-Aid for Science Research in Japan and JAXA contract JX-PSPC-171176.

Disadvantage?

There is a disadvantage.

Solar power should be converted with expensive laser. ⇨ Efficiency! Cost!

But,

- **It is possible to concentrate solar power in a large area of 10kmx10km.**
- **Conversion efficiency would be 30% from solar power to hydrogen. High temperature is available.**
- **Laser with active mirror ceramic disk may give us an appropriate design by solar pumping.**

Ceramic laser seems to meet the economical requirements for hydrogen production.

COST

$$G = A\ R\ H\ S\ a - [\{S\ B/\ t\} + b + c],$$

The first term indicates the total gain by hydrogen production.

The second term is investment coefficient including an interest to install the system. The next two terms are kinds of maintenance cost.

COST

Typical parameters of system

Line No	1	2	3
A Yen / Nm^3	30	20	15
T Year	25	20	15
R-Operation rate	0.35	0.35	0.25
H %	35	30	25

A:hydrogen price in ¥ per Nm^3.

R:Operational rate per year.

H:Product of hydrogen and laser efficiency.

S:Solar receiving area in m^2

a: conversion rate of power to the hydrogen, $2.93x10^3$ Nm^3 per (year m^2)

B:Investment coefficient including an interest to install the system in ¥ /m^2

t : Duration of this system.

b:fixed cost

c : Liquid cost.

R is between 0.2 and 0.4.

Solar power is kW per m^2