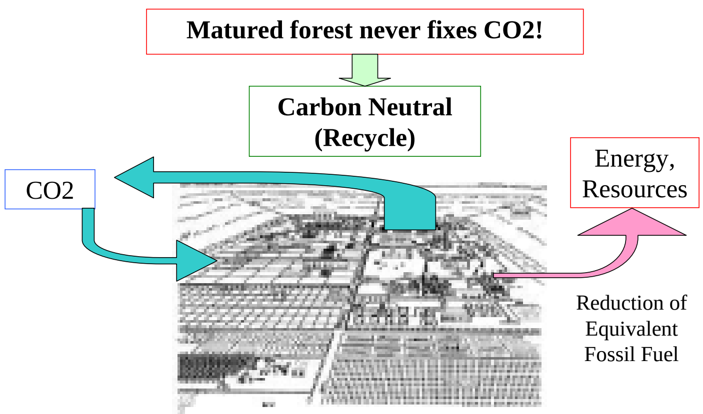
Biomass, Ocean Nourishment, Photobioreactor

Toru Sato

Technology for Reduction of CO_2

- Energy Saving
- Energy Conversion
- Sequestration/Recycle of CO_2
  - Geological Sequestration
  - Ocean Sequestration
  - Biological Sequestration
    - Afforestation
    - Microalgae
    - Ocean Nourishment

1. Afforestation



Biomass Plantation

Capacity and Problems (Global)

Total Amount : 2000GtC (62%Forest, 38%Soil)
Annual Timber Production : 3400Mt (364MtC/yr)
if carbonized (Charcoal) : 218MtC/yr Sequestration (Efficiency 60%)
(16% of CO_2 Emission from Fossil Fuel)

Eligible Area : 744Mha (Carbon Fixation : 2200MtC)

However,

Farm Area necessary for Population Explosion
Jeopardize Local Economy
Cost

Capacity and Problems (Japan)

Total Forestry Area : 25Mha (10Mha in Artificial, 2nd in World)
Annual Timber Increase : $69\times10^7m^3$ ($59\times10^7m^3$ in Artificial)
equivalent to 8% reduction of domestic CO2 emission
Therefore, $8.6\times10^7m^3$ / 1% reduction
or 2.2Mha / 1% reduction (cutting efficiency 70%)

However, most of them are burned at their last stage!!!

Electricity from Woody (xylem) Wastes

if on Flat Fallow Area : 1Mha / 1% reduction but impossible!

Wide Area Abroad

Electricity from Biomass

Sweden : Woody Biomass covers 19% of Primary Energy (9000GWh)
USA : 7000MW by 550 plants (1% of Electricity)
Japan : 160MW (Target 33MW in 2010)

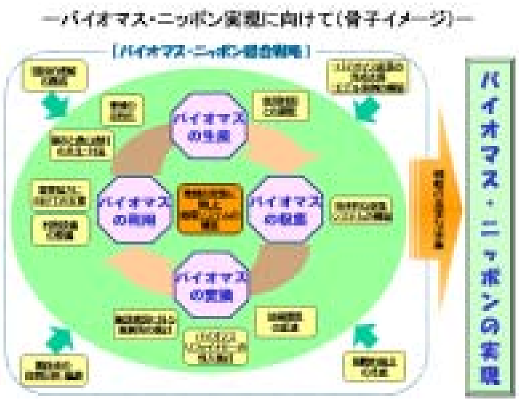
Electricity from Waste Woody Biomass
Capacity : 110Mt (6Mtoe=70000GWh in heat) (Oil Consumption : 217.5Mtoe)
Technology : Conventional Power Generation (efficiency 16%)
Gasification (efficiency 45%)
Gas → Methanol → Hydrogen
Cost : Collection + Transportation + Drying + Chipping + Gasification
10000JPY/t (35JPY/kWh in electricity)
13.86JPY/kWh (IGCC:Integrated Gasification Combined Cycle)

Economy of Biomass Power Plant

Chip Price: 1000-6000JPY/t (ave. 2500JPY/t)
1000JPY/t = 2.1JPY/kWh (Price to Grid is 2-3JPY/kWh)
to Obtain 10% Benefit,
Price to Grid : 12JPY/kWh (Wind Mill, TEPCO)→ 2000JPY/t
20JPY/kWh (more Government Support)→ 6000JPY/t
However, no one wants to sell the same timbers cheaper!!!

"Biomass Nippon"

Dec. 2002 by MAFF, METI, ME



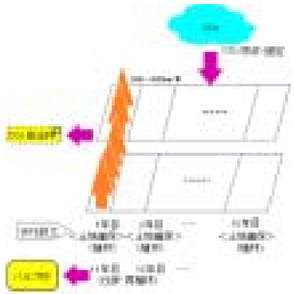
CDM : Afforestation Abroad

CDM (Clean Development Mechanism) :

Developed countries can count on investments in undeveloped countries.

Note: COP8(Oct 2002) did not come to conclusion on CDM regulation.

Afforestation in foreign countries!!!



Cost of Foreign Afforestation for Carbon Fixation

Organization	Site	Biomass	Investment (JPY)	Area (ha)	Carbon Fixation	Cost (JPY/tC)
Tokyo Electric Power	Australia, Tasmania	eucalyp-tus	1800mil. (total)	10000 /10yrs	3tC/ha	60000
Tohoku Electric Power	Australia, APFL Ltd.	eucaly-ptus	8000mil. (total)	26000 /10yrs	5tC/ha	61500
Kansai Electric power	Australia, Perth	eucaly-ptus	400mil. (total)	1000/ 20yrs	235KtC (total)	1700
Mitsubishi Paper Mills	Australia, Tasmania	eucaly-ptus	6300mil. (total)	25500 /15yrs	130KtC/ yr	3200
Japan Int. Forestry Center	Indonesia, Lombok Isl.	neem	-	3000/ 10yrs	4.5tC/ha	4000
Idemitsu Kosan	Australia, Ebenezer	eucaly-ptus	25mil. (total)	135/ 5yrs	6820tC (total)	3700

Coal with Carbon Credit

2. Microalgae

photosynthesis	-	CO_2 fixation
valuable products	-	business chance

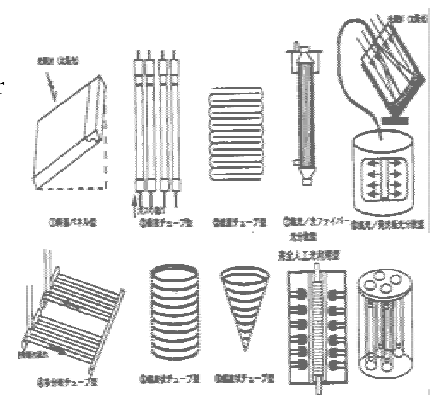
Microalgae	*usage*
Chlorella Sp.	healthy food
Nanno chloropsis	feed staff (DHA)
Botryococcus braunii	hydrocarbon
Hematococcus	Astaxithantin
Chlorococcum litorale	low pH

Photobiorector

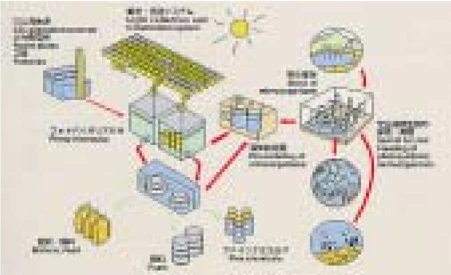
Efficiency of Photobiorector

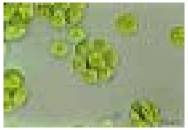
direct link

Efficiency of Sequestration



Bioreactor System in Power Plant Proposed by RITE





botyococcuss braunii → Heat Generation Equivalent to Heavy Fuel Oil C (with little N,S)

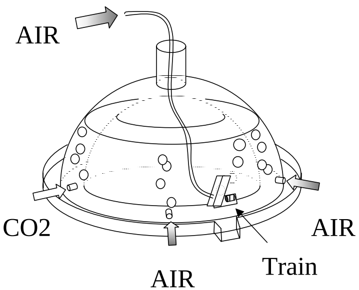
This System with Panel Area of 20km^2 in 1000MW LNG Power Plant fixes 7.4% of Exhausted CO_2, forms Solid Fuel, which generates electricity of 7.66×10^8kWh/yr (Reduction of 1.9% of LNG) →Total CO_2 Reduction is 5.5%

Invention Process of New Reactor

- Analysis of Existing Reactor + Past Patents
- ↓ Proposal of New Reactor
- ↓ FILTER 1: Sunlight Reception
- ↓ FILTER 2: Mixing Prediction by CFD
- ↓ FILTER 3: Cultivation Experiment
- ↓ Winner of Competition

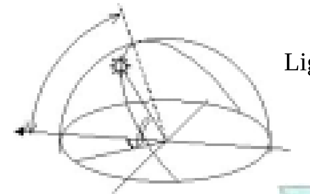
Existing Bioreactor

Biodome (Microgaia Co. Ltd)



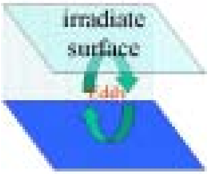
Microgaia Inc. in Hawaii

Functions of Photobioreactor



Light Reception

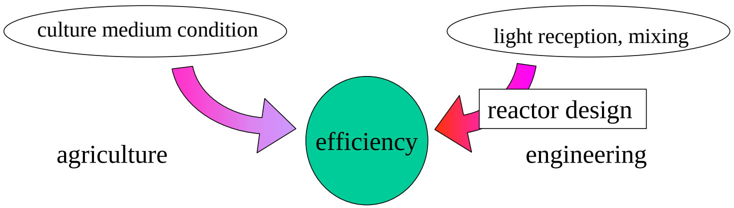
Global Mixing



Local Mixing

Elements associated with Efficiency

- sunlight reception
- mixing (global, local)
- culture medium condition (temperature, pH, salinity, etc)

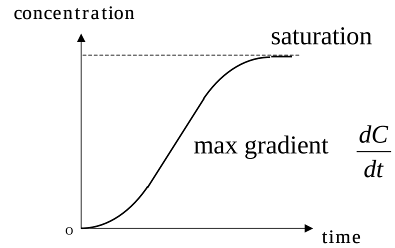


Growth Curve

Maximum Efficiency = Growth Rate

$$V\frac{dC}{dt}$$

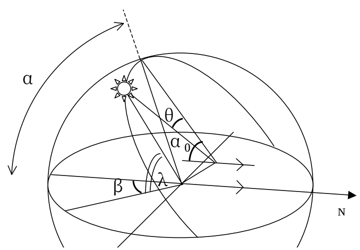
V : reactor capacity



general growth curve

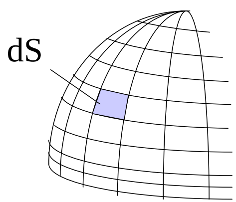
Light Reception

modelling of the movement of the sun with respect to season and daytime



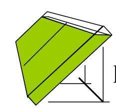
altitude of the sun **λ**

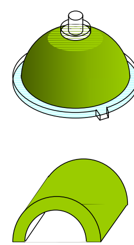
direction **β**

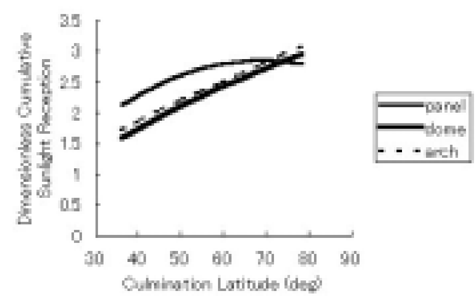


Comparison of Various Reactors in Reception in a Day

(at unit land area of **single reactor**, the north latitude 35 deg.)

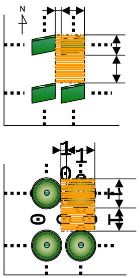






Comparison of Various Reactors in Reception in a Day

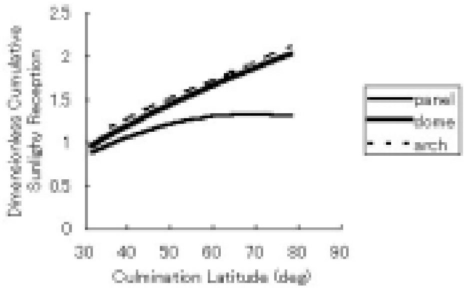
(at unit land area for **mass production**, the north latitude 35 deg.)



panel

dome

arch



Invention Process of New Reactor

Analysis of Existing Reactor

Past Patents

Proposal of New Reactor

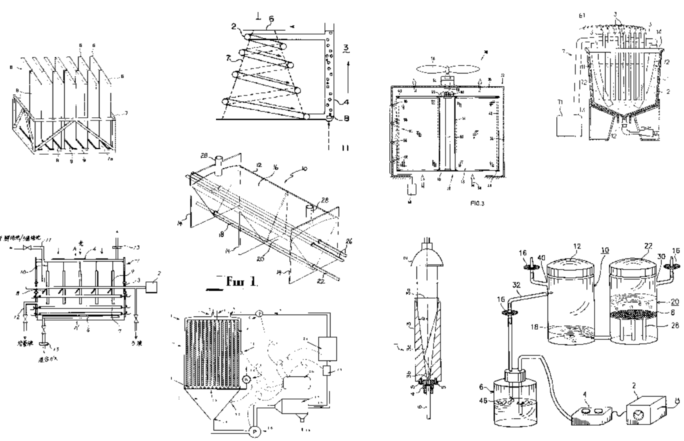
FILTER 1: Sunlight Reception

FILTER 2: Mixing Prediction by CFD

FILTER 3: Cultivation Experiment

Winner of Competition

Investigation of Past Patents



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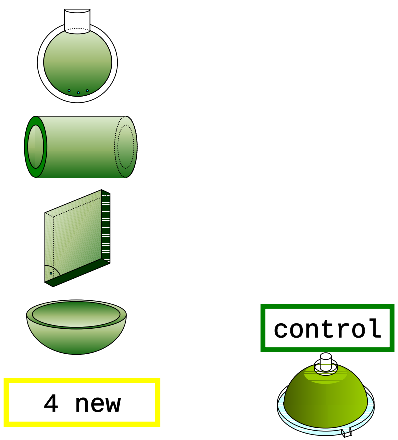

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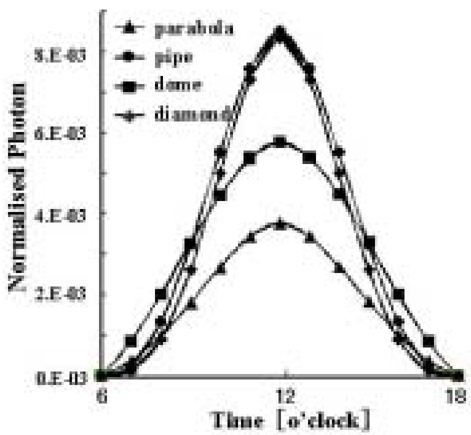
5. Winner of Competition

FILTER 1: Sunlight Reception



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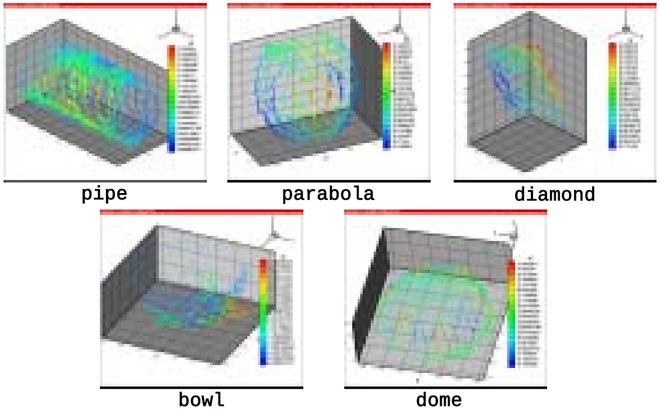
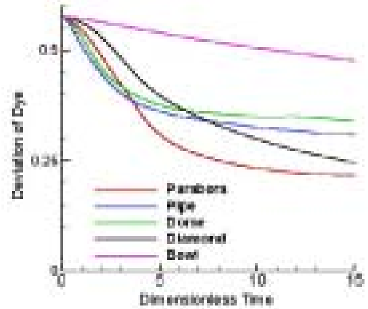
FILTER 2: Mixing Prediction by CFD



Assessment of Global Mixing by CFD: 1



diffusion equation:

$$\frac{\partial C}{\partial t} + u_j \frac{\partial C}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\nu_t}{S_{ct}} \frac{\partial C}{\partial x_j}\right) + \Gamma$$

$$C_0(L) = RandomNumber$$

$$\Gamma = 0$$

C:alga number

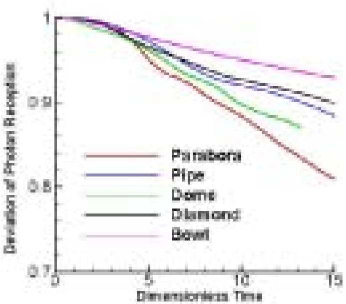
⇩

standard deviation

⇩

winner is **Parabola**

Assessment of Global Mixing by CFD: 2



diffusion equation:

$$\frac{\partial C}{\partial t} + u_j \frac{\partial C}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\nu_t}{S_{ct}} \frac{\partial C}{\partial x_j}\right) + \Gamma$$

$$C_0(L) = 0$$

$$\Gamma = I = I_0 \exp(-kcx)$$

C:integrated PFD

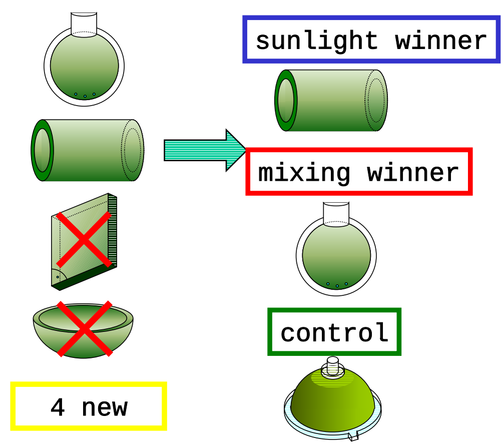
⇩

standard deviation

⇩

winner is **Parabola**

Result of FILTER 2



Invention Process of New Reactor

Analysis of Existing Reactor | Past Patents

↓

Proposal of New Reactor

↓

FILTER 1: Sunlight Reception

↓

FILTER 2: Mixing Prediction by CFD

↓

FILTER 3: Cultivation Experiment

↓

Winner of Competition

FILTER 3: Cultivation Experiment

Reactors：parabola・pipe・Biodome

date：12-24 January 2001

site：Yamaha Motor Co., Iwata City, Shizuoka

algae：*Chlorococum littorale*

by the courtesy of Marine Biotechnology Institute

FILTER 3: Cultivation Experiment

pipe

dome

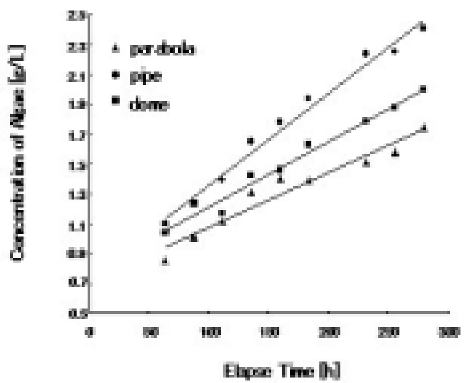
parabola

Dimensions and Conditions

	capacity (L)	occupation (m^2)	air flow rate (L/min)	temperature (deg)	pH
parabola	70	2.21	31	25	7.0-8.0
pipe	70	0.90	31		
Biodome	130	2.74	60		

- MC Culture Medium: artificial seawater
- Initial Alga Concentration：1．0g/L
- Align Direction: South (Axis: west-east)

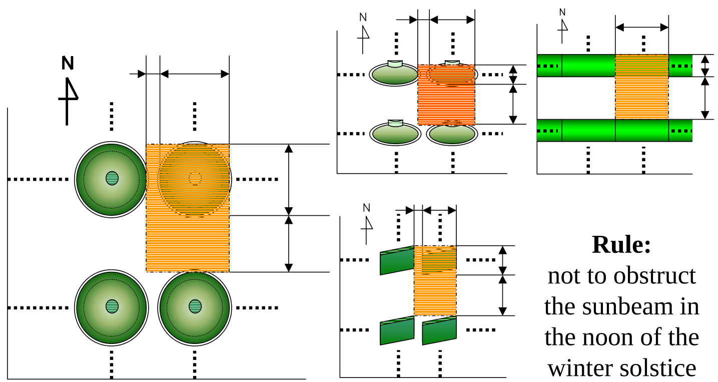
Results



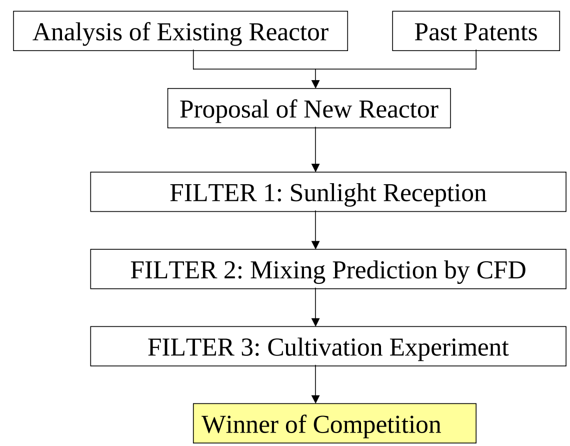
Assessment of Efficiency

	growth rate per apparatus (g/day)	growth rate per volume (g/L/day)	growth rate per land area (g/m^2/day)
parabola	6.05	0.086	2.73
pipe	10.25	0.146	11.39
Biodome	12.38	0.095	4.52

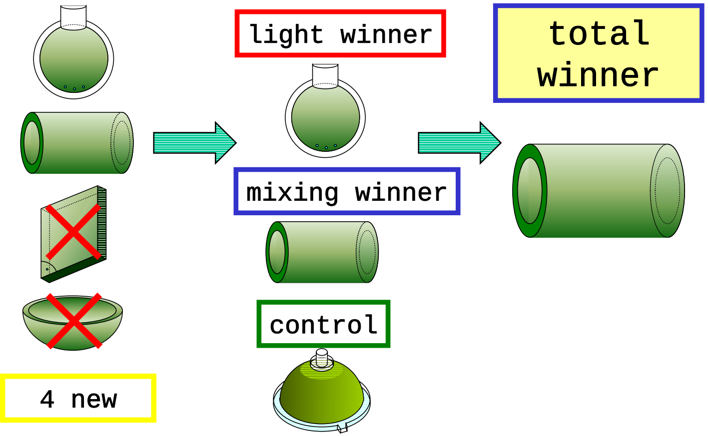
Land Occupation



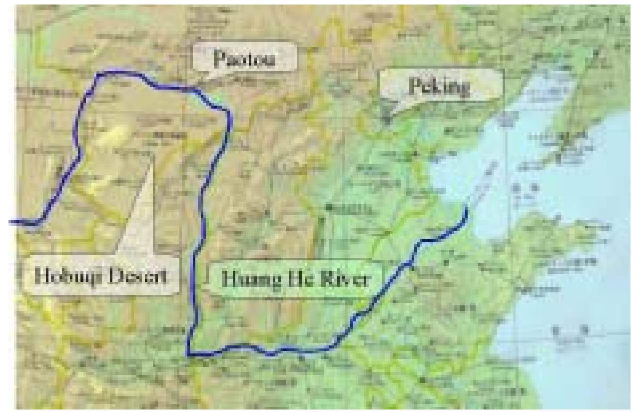
Invention Process of New Reactor



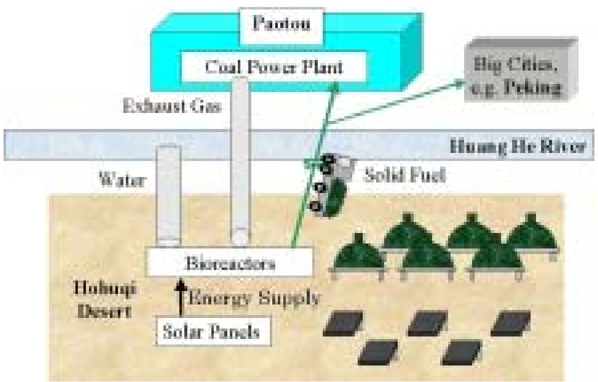
Winner of Competition



Design of CO2 Recycle System



Schematics of Proposed System



Botryococcus braunii.

Annual Energy Balance per 1km^2

MWh/km^2/year

A	Operation	20,000
B	CO2 Supply	240
C	Water Supply	15
D=A+B+C	(covered by solar energy)	20,255
E	Transportation of Algae	250
F	Gross Production	82,000
G=F-E	Net Production	81,750

Annual CO_2 Fixation per $1km^2$

H	Energy Production in Electricity ($MWh/km^2/year$)	19,800
I	CO_2 Emission per Unit Electricity (tCO_2/MWh)	14.7 Chinese Coal Power Plant
J=HI	CO_2 Fixation per Unit Area ($tCO_2/km^2/year$)	291,000

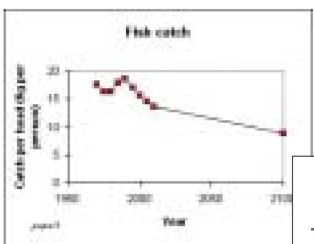
Cost of CO_2 Fixation

US$mill/$km^2$/year

K	Initial Cost (US$mill)	556.9
L	Annual Balance (US$mill)	-12.0
M=K/20-L	Annual Balance with Redemption (US$mill)	39.8
N=M/J	CO_2 Fixation Cost (US$/$tCO_2$)	137

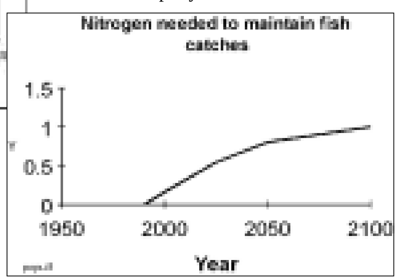
50000JPY/tC

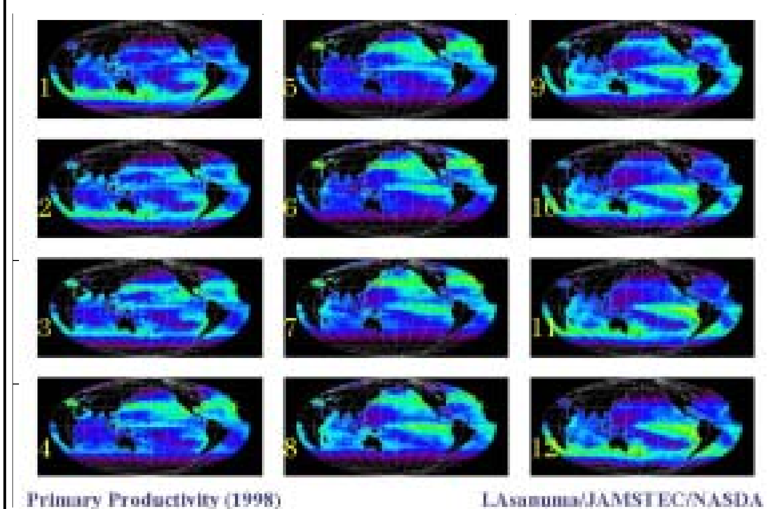
3. Ocean Nourishment

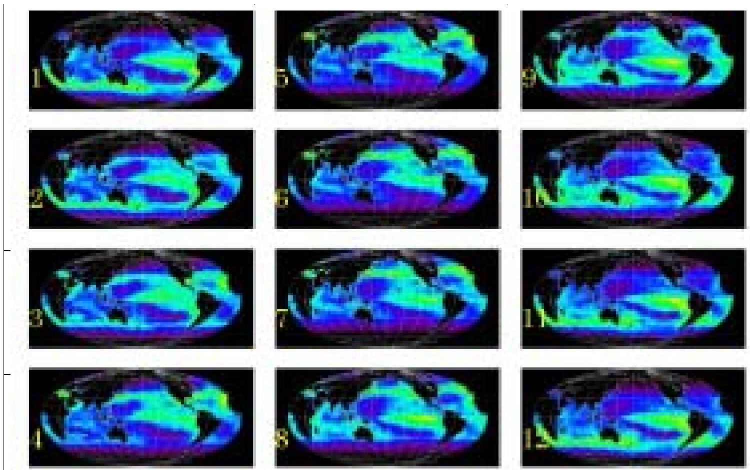


Fish catch (FAO 1994) per head of population. Predictions are based on an assumed constant catch after 1990

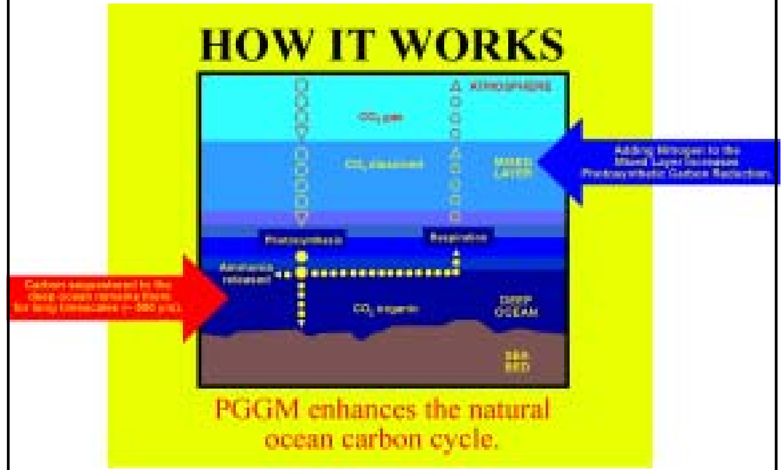
Additional nitrogen needed to keep fish catch per head of population constant, assuming new primary production in the ocean is 4.5 Gt C per year in 1990. The current level of nitrogen manufactured is about 80 Mt per year.





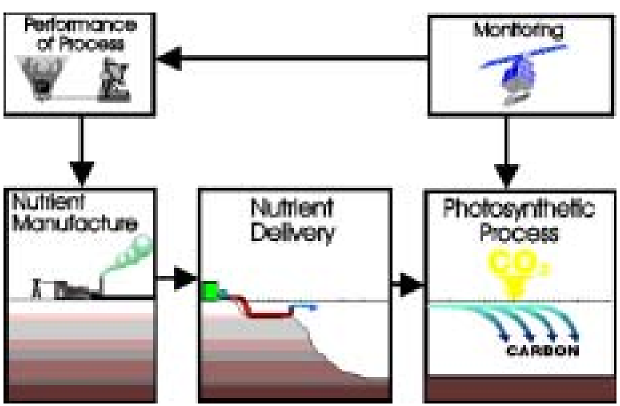


Primary Productivity (1999) I.Asanuma/JAMSTEC/NASDA



Jones and Otaegui (1997)

Design of Pilot Plant



Jones and Otaegui (1997)

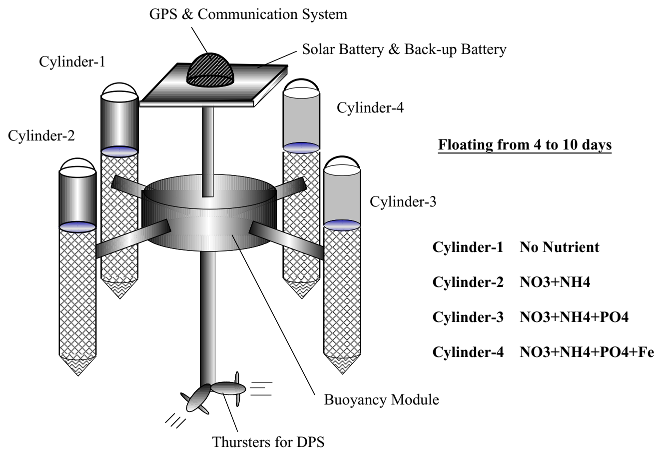
Research Project " Ocean Nourishment in Asia "

Objectives

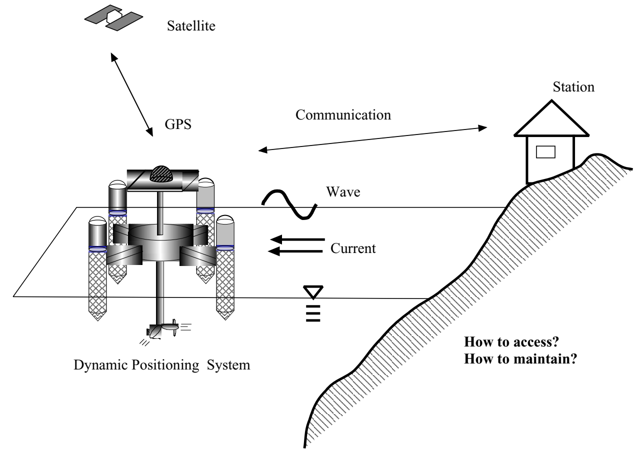
1. To Measure Carbon Flux Sinking to Deep Ocean and to Calculate Efficiency
2. To Estimate Benefits in Fish Catch via Food Web
3. To Assess Impacts to Ocean Ecosystem

Research Team

Ocean Biologists
Ocean Chemists
Ocean Physicians
Ocean Engineers



Offshore Mesocosm Experiment



Offshore Mesocosm Experiment

Capacity and Cost

- Amount of CO_2 sequestration per Ammonia 1ton
  - Redfield Ratio : 20t
  - CO_2 emission by operation : -2t
  - Deep-Sea Sequestration Efficiency 70% : 12.6t
- Cost : $19/tC (2200JPY/tC)
- Capacity : 5MtC/yr by 5 Pilot Plants