Jatropha to Biofuel

- Crop grows on marginal land but needs ample water supply
- Optimum yield 5x more fuel / acre / yr than corn
- Production: a) variable, depending on soil quality,
  b) highly labor intensive,
  c) depends on plant life,
  d) multiple harvests per year
- Leaves & seeds highly toxic
- Requires tropical climate: suitable in climates of Myanmar, India, China, Philippines, etc.

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **SEP 2010**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Jatropha to Biofuel**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory Washington, DC 20375**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADA560467. Indo-US Science and Technology Round Table Meeting (4th Annual) - Power Energy and Cognitive Science Held in Bangalore, India on September 21-23, 2010. U.S. Government or Federal Purpose Rights License

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**29**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Challenges for DoD Fuel from Algae

for 50% additive (2.4 B gal / yr)

•Need high solar flux, abundance of water, CO_2 and nutrients (N, P, etc.)

- Massive need for **wetlands and ponds**

  2500 gallons "oil" / acre / year requires 1600 square miles

- Use of **coal fired power plants** to sustain production

  233 coal power plants in south east US burn about 330 million tons of coal per year and produce about 860 million tons CO_2 per year

  2500 gallons "oil" / acre / year requires 20 million tons CO_2 per year (high CO_2 transportation cost if not adjacent)

- Massive **water requirements**

  2500 gallons "oil" / acre / year requires 1 trillion gallons of water per year (~ 1 / 120 of the volume of water in Lake Erie)

- 1 % S in coal will acidify the water to pH from ~ 5 to 3 (killing algae harvest)

- Costs of fuel could **(if the algae ponds and coal fired power plants are adjacent**) be as low as $ 2- 3 / gallon, excluding capital investment and SO_2 removal

Challenges for Navy Jet Fuel from Camelina (Montana project, excluding land cost) for 50% additive (~ .3 B gal / yr)

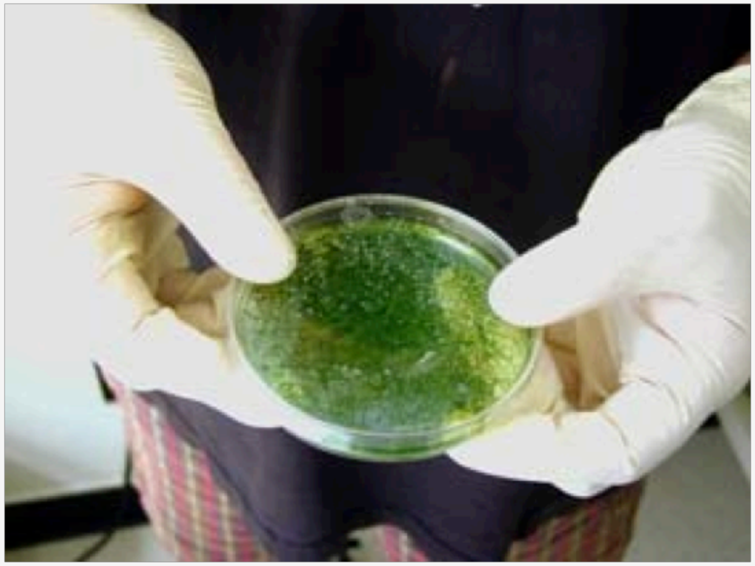
- Relies on massive arable (non-food) land use.
- Camelina at <100 gallons per acre per year would require 3 million acres or 1 / 20 of all pasture land in Montana
- Fertilization (~100×10^6 pounds per year) at a cost of $100 M / yr
- Requires planting & harvesting cost at ~$280 M / yr
- Processing costs to jet fuel ~ $3 B / yr ($ 10 / gal)
- Processing costs to bio diesel fuel ~ $ 1 / gal
- Market demands dictate diesel and not just jet fuel production
- Crop rotation with dry land wheat is under study

Pasture Land: 53 % of MT

Crop Land: 19 % of MT

Camelina for Navy 50 % Jet Fuel: 4 % of MT

Cyanobacteria: an incredible group of microbes



- Ethanol production in US / yr is ~ 4 B gal; 3 % of fuel consumption
- ~ 2 / 3 gal of oil used to produce 1 gal of ethanol

- Capture CO_2 and photons through photosynthesis (similar to plants and algae)
- Grow in fresh or saline water
- Fix nitrogen from atmosphere (eliminate nutrient additives)
- Produce sugars and polysaccharides
- Can easily be genetically modified for efficient production of sucrose, glucose, etc.
- Allow products to be extracted without harming the cells
- Are estimated to be able to produce > 700 gal of ethanol / acre / yr

R. M. Brown & D. R. Nobles, Jr., UT – Austin Report

Hydrogen: A Clean Energy Source

(From Oil To Hydrogen)

Massive R&D Challenges

Production	**Cost-effective hydrogen generators**
Distribution	**Much lower cost; reliability**
Fueling	**Standard fueling station and dispensing systems**
Storage	**High density storage; ease of release**
Conversion	**Hydrogen to electricity (fuel cells)**
Detection	**Compact and accurate hydrogen sensors (Typical leakage 1-3%)**

Hydrogen has high energy content, and is non-polluting. Why has it not been widely used as a fuel?

Energy content of various fuels, referenced to gasoline.

Fuel	Energy /mass	Energy / volume	Temp.	Mass / volume
Gasoline	1.0	1.0	25 C	1.0
Methanol	0.44	0.51	25 C	1.1
Ethanol	0.61	0.69	25 C	1.1
Liquid Hydrogen	2.60	0.27	-253 C	0.1
Hydrogen Gas (@3,000 psi)	2.60	0.06	25 C	0.02
Hydrogen Gas (@ 10,000 psi)	2.60	0.20	25 C	0.08
Lithium Ion Battery	0.019	0.035	25 C	2.03

Other properties:
- wide limits of flammability
- low spark ignition energy
- nearly invisible flame

Storage:
- high pressure, or cryogenics (both have issues for the DoD, particularly combat situations)

Distribution:
- pipelines cost ~ $1M/mile
- would need to be newly laid

NOTE: Hydrogen has lowest heating value/ unit vol, w exception of Li battery.

Coffey et al, Defense Horizons, No. 36, 2003

Production

Steam reforming of methane

$CH_4 + 2H_2O + \text{energy} = 4H_2 + CO_2$

- To produce energy equivalent of oil consumed each year in the US, we would require 3×10^{14} gm of H_2 (300×10^6 tons); (from 6×10^{14} gms **(3×10^{13} ft^3)** of CH_4, 13.5×10^{14} gms of water with byproduct of 16.5×10^{14} gms of CO_2

(Current US use of CH_4 is 2.2×10^{13} ft^3/yr)

- Burning CH_4 for equivalent energy, we need 25% less CH_4 and produce 25% less CO_2

Electrolysis: Use of electricity to produce H_2 from H_2O

- Need 3.9 kW hr of electrical energy to produce 1 m^3 of H_2 with energy value of 3.2 kW hr (80% efficiency)
- 3.4×10^{12} m^3 of H_2 needed to replace US oil needs, requires **13.2×10^{12}** kW hr of electrical power

(US annual electrical production is 3.7×10^{12} kW hr)*

Energy from the Ocean

Tidal Energy

Variations in sea levels (twice daily) due to the gravitational effects of the sun and the moon turn immersed turbines

Advantages:
- **Large scale investment (100 MW+)**
- **Proven technology**
- **Protection from coastal flooding**

Disadvantages:
- **Specific sites (40 world wide)**
- **Intermittent operation (4 flows/day)**
- **High capital investment ($3-10K/kW)**
- **Environmental issues**
- **Navigation limits**

Wave Energy

Rise and fall of waves moves cylinder which drives electric generator

Advantages:
- **Single buoy (50 kW)**
- **Existing technology (tested at New Jersey by OPT)**
- **No environmental impact**

Disadvantages:
- **Coastal navigation**
- **High sea states**
- **Fisheries**
- **Capital investment**

Synthetic fuel from the Sea

Synthetic Fuel Production

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Objective:

Feasibility of producing sea-based synthesized hydrocarbon fuels

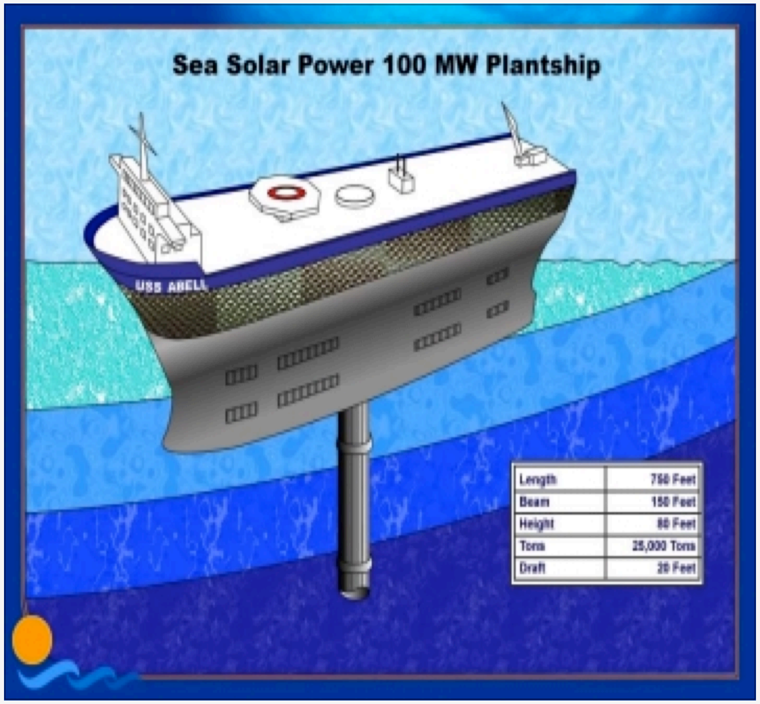
Benefits:

Synthetic Fuels: a "Game Changing" Proposition

- **Total independence from impending global oil crisis (price fluctuation, availability)**
- **Reduce vulnerabilities and storage**
- **Synthetic Jet fuels superior to petroleum based fuels (reduced engine maintenance and reduced aviation fuel exhaust)**
- **Assured source of jet fuel**
- **Zero net pollution to environment (CO_2 neutral)**

Fuel Where and When You Need It

Ocean Thermal: a renewable energy source



- Oceans are the largest solar energy collector on earth

- Stored energy in the equatorial / tropical oceans equals ~ 300 times the world’s energy consumption

- Energy conversion is 24 hours per day; not only when sun shines

- Energy extraction is environmentally neutral

Ocean Thermal Energy Conversion (OTEC)

- Efficient method to convert solar energy stored in tropical ocean waters to electricity

- 80^{o}F surface water boils working fluid (propylene) under pressure; expanded vapor to turbines to produce electricity

- < 40^{o}F cold water pumped from ~ 3000 ft to condense vapor back to liquid

- 100 MW plant needs 32 M gal water / day

- Power used to produce H_2 and CO_2; Fischer Tropsch process to produce JP-5, F-76

Synthetic Hydrocarbon Fuels

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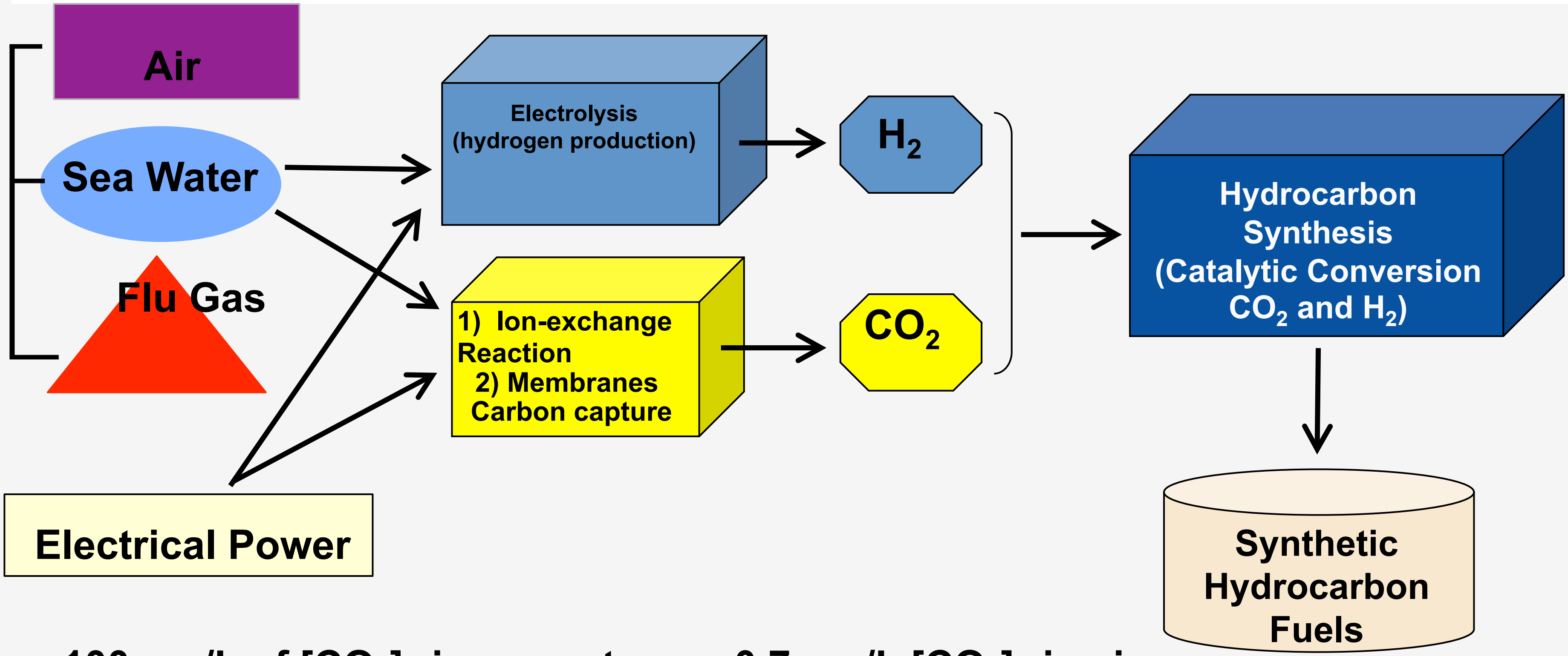
Approach: Synthesis of hydrocarbon fuels using CO_2 and H_2 and electricity



Air

Sea Water

Flu Gas

Electrical Power

Electrolysis
(hydrogen production)

1) Ion-exchange Reaction
2) Membranes
Carbon capture

H_2

CO_2

Hydrocarbon Synthesis
(Catalytic Conversion CO_2 and H_2)

Synthetic Hydrocarbon Fuels

100 mg/L of $[CO_2]_T$ in seawater vs. 0.7 mg/L $[CO_2]_T$ in air

Down-select Technologies to Convert Carbon Dioxide & Sea Water to Aviation Fuel

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Enhancement of Fuel Energy by High Energy Density Nanoparticulate Additives

An Intermediate Solution

- Provide greater enthalpy of fuels than currently available carbon based sources

- Develop highly energetic nanoparticles as additives to enhance energy density of diesel for gas turbine engines

Research Challenges

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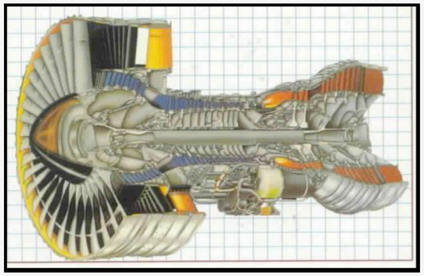
- Develop energetic nano-particle fuel additives for gas turbine engines.
- Enhance fuel combustion with catalysts.
- Surfactant coating for nanoparticle stability.
- Evaluation of combustion efficiency, acoustic signatures and coking
- Emission chemistry related to environmental and system impact



Non Renewables

Energy: Coal Production

Coal Production figures for year 2002
(x 10^6 tons)

Rank	Country	Amount
#1	China	1,956
#2	United States	1,008
#3	India	403
#4	Australia	365
#5	Russia	280

Liquid Fuel From Coal

- **Basic Equations:**
  - 2CH (Coal) + $2H_2O \rightarrow 2CO + 3H_2$ (1)

  $18C0 + 27H_2 + 4O_2 \rightarrow C_{12}H_{26}$(liquid fuel) + $14H_2O + 6CO_2$ + Heat (2)

  (Fischer - Tropsch process)
- 24 lbs of coal produces 1 gal of liquid fuel
- US annual consumption 7-9 B bbl of fuel/yr

8 B bbl x 42 gal/bbl = 3.4×10^{11} gal of fuel

x 24 lb of coal/gal = 4×10^{9} tons of coal

- US mines 10^9 tons of coal/yr (~ 6% for export)

To meet national needs: 4 x annual coal production

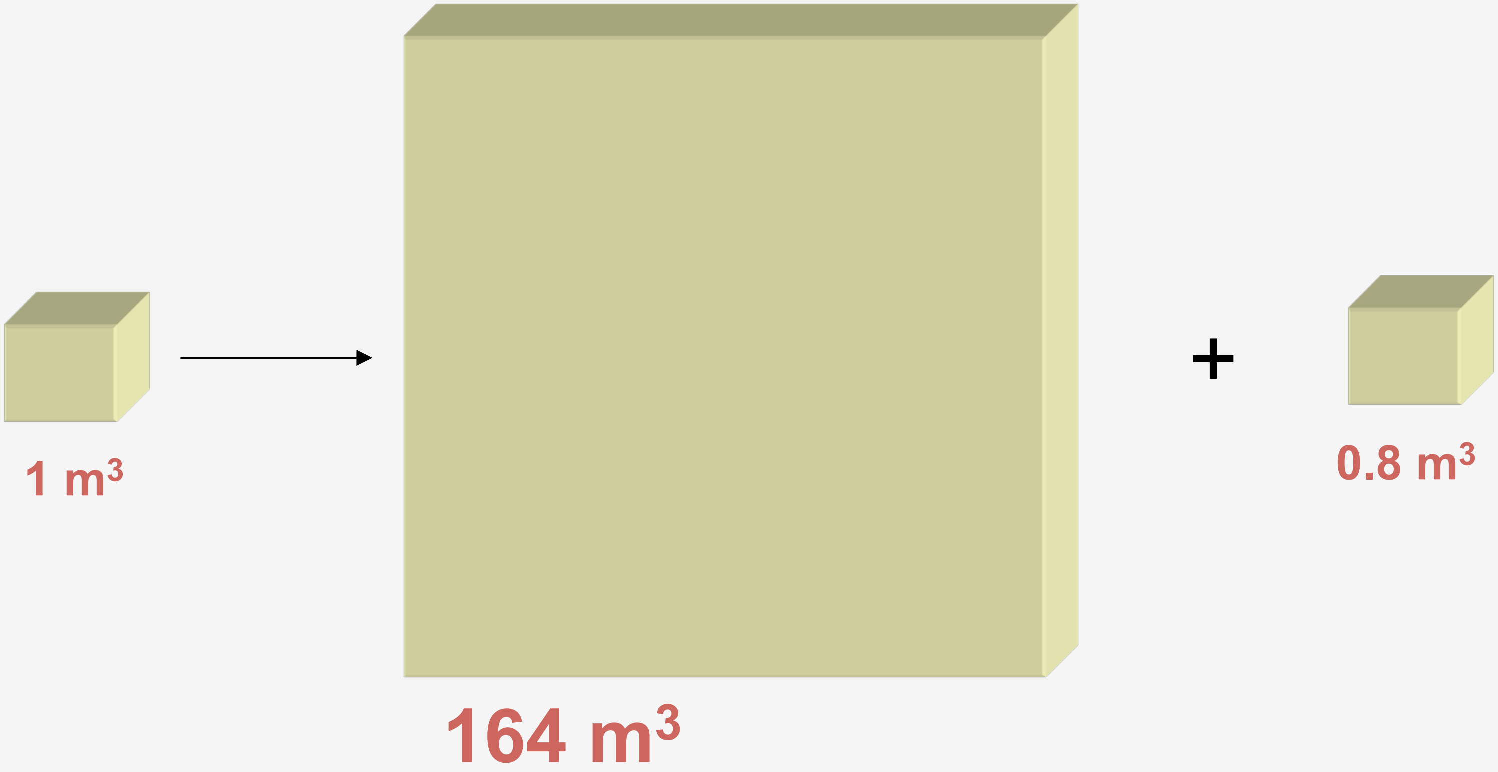
- **Issues:** (1) disposal of solid waste from coal
  (2) excess production of CO_2
  (3) requires water

Energy Information Administration (2005)

Abundance of Frozen Clean Energy from the Sea

(Methane Hydrates)

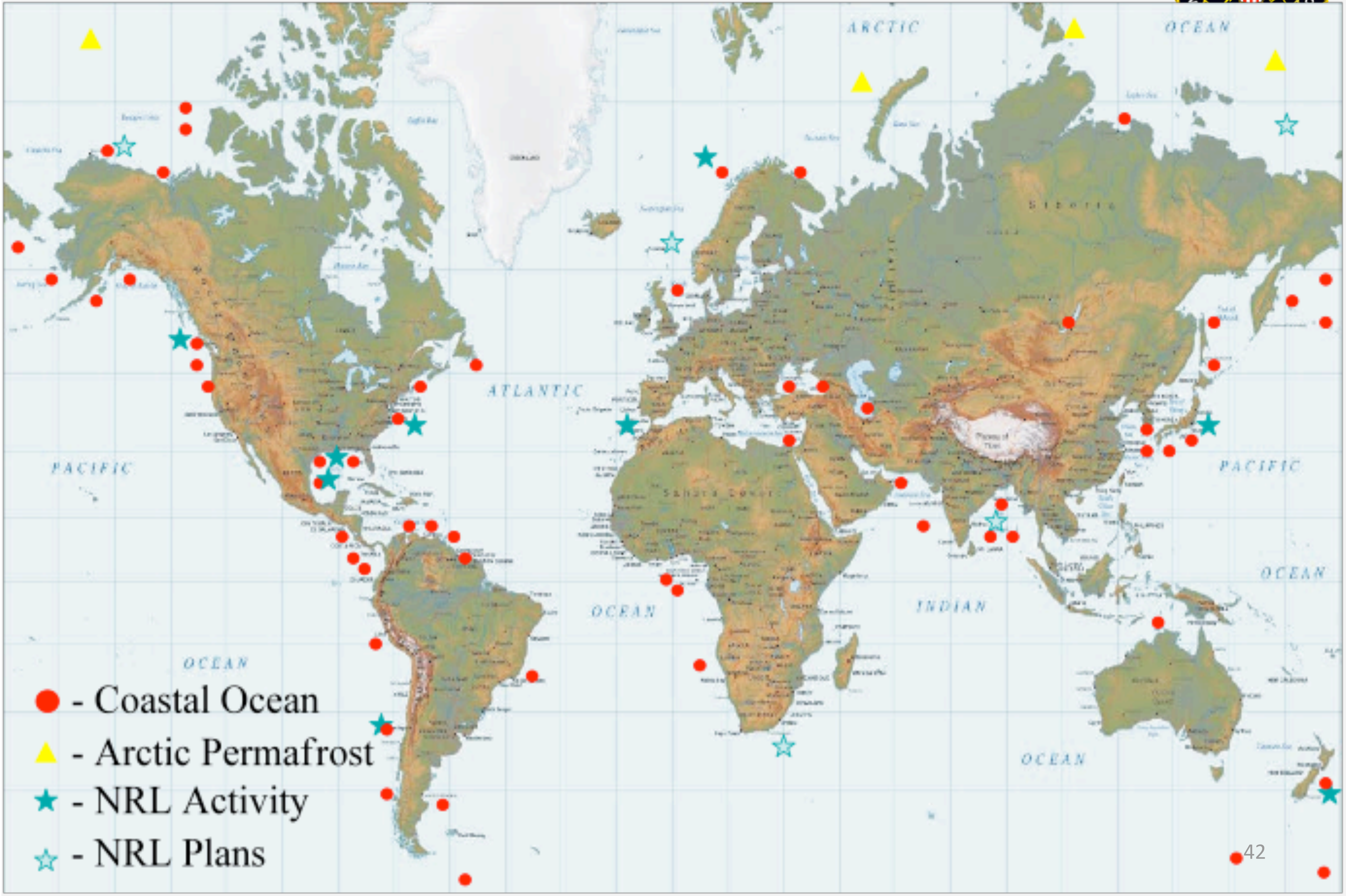
Volume of Gas Hydrate



$1\ m^3$ → $164\ m^3$ + $0.8\ m^3$

One cubic meter of gas hydrate yields 164 m^3 of gas and 0.8 m^3 of water at STP

World Methane Hydrate Distribution



● - Coastal Ocean

▲ - Arctic Permafrost

★ - NRL Activity

☆ - NRL Plans

Estimated Hydrate Concentrations

National/Regional Estimates of the Amount of Gas Within Hydrates

(cubic feet)

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United States	
$317{,}700 \times 10^{12}$	**Collett 1995**
Blake Ridge, USA	
635×10^{12}	**Dillon & others 1993**
2471×10^{12}	**Dickens & others 1997***
2844×10^{12}	**Holbrook & others 1996***
2012×10^{12}	**Collett 2000***
1331×10^{12}	**Collett 2000**
North Slope, Alaska	
590×10^{12}	**Collett 1997**
Nankai Trough	
1765×10^{12}	**MITI/JNOC 1998**
Andaman Sea, India	
4307×10^{12}	**ONGC 1997**

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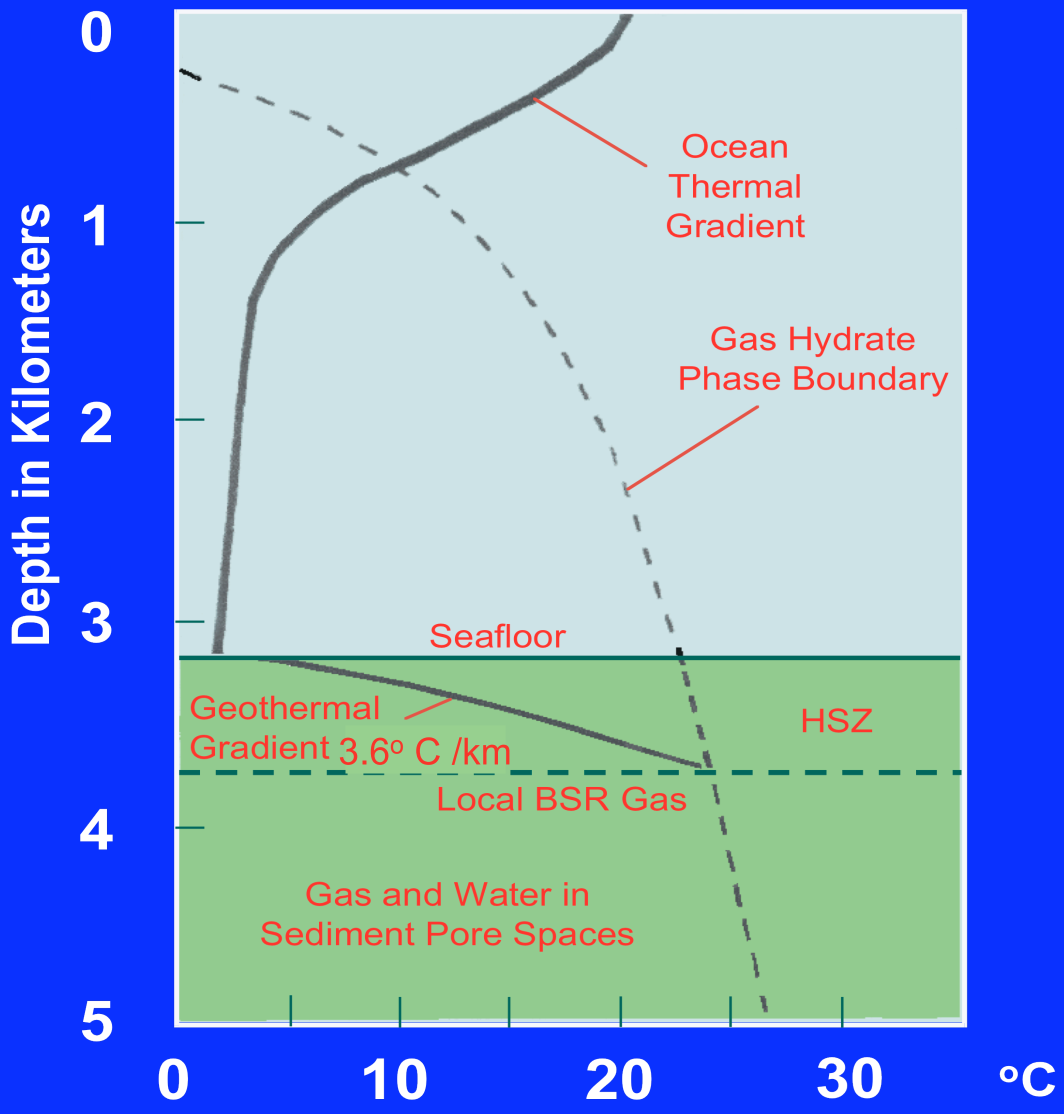
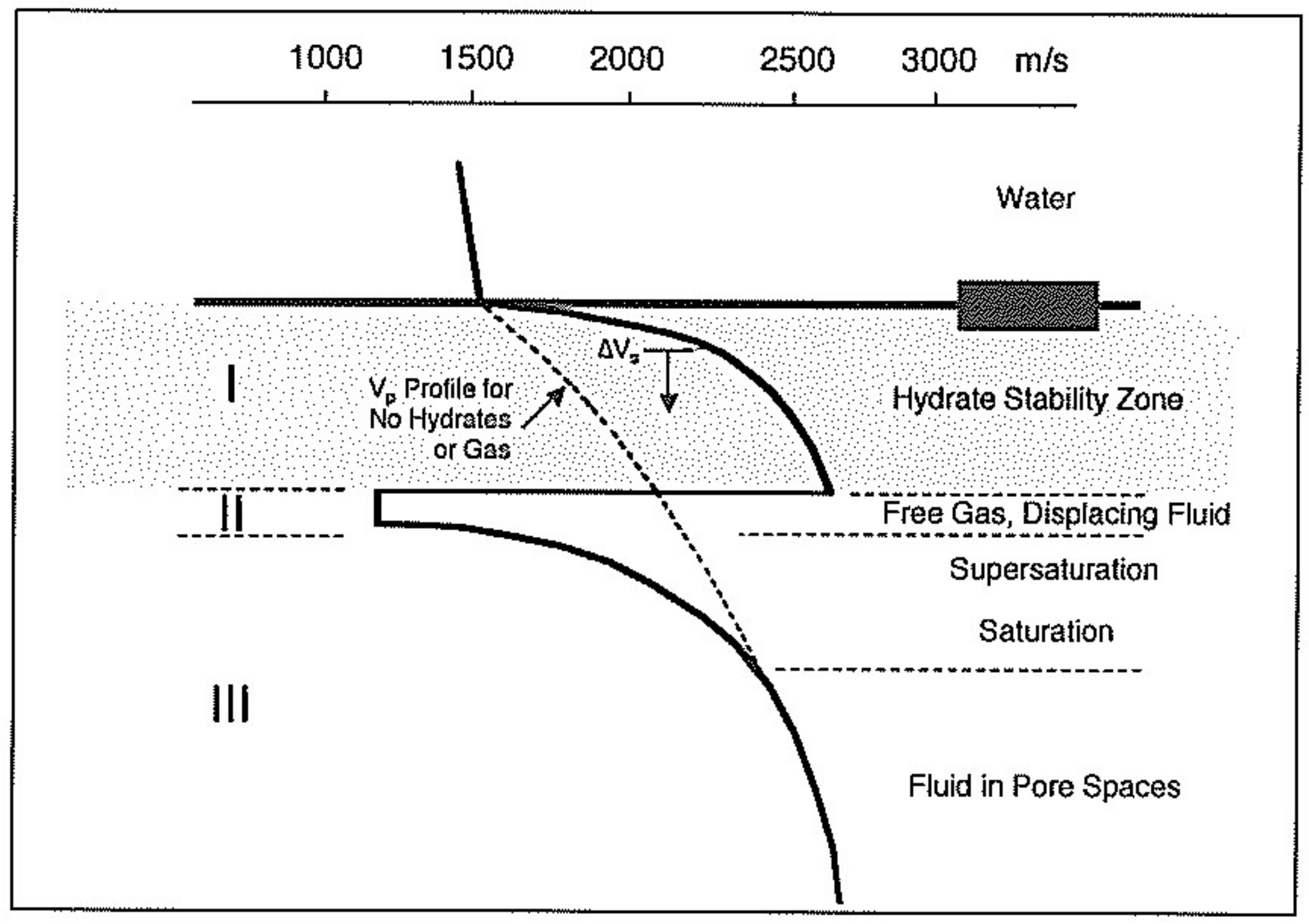
Methane Hydrate Stability Diagram



Geoacoustic Profile



Studies of Gas Hydrates in Ocean Sediments

- **Seismic**

  Structure of sediments and phase boundaries (BSR) from seismic reflections
- **Geochemistry**

  Geochemical parameters (sulfates, sulfides, chlorine, water, hydrate history, etc.)
- **Electromagnetics**

  Resistivity fluctuation in sediments
- **Heat Flow**

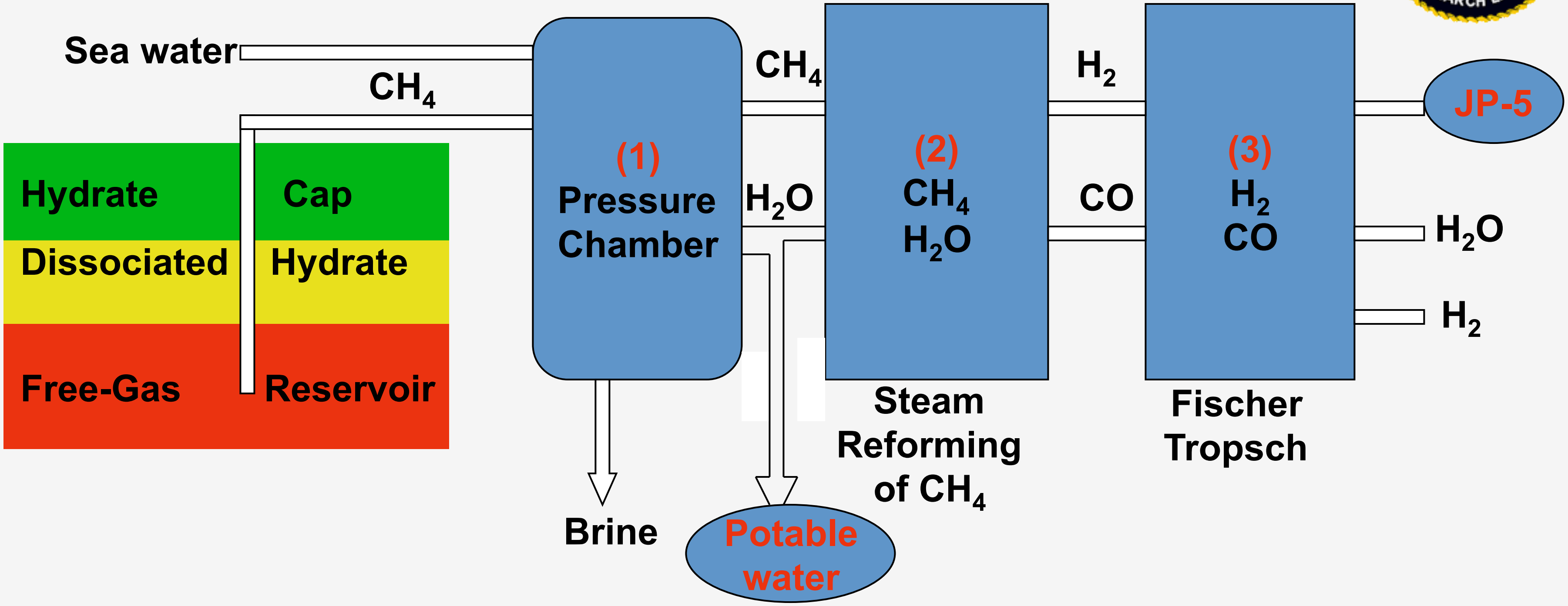
  Temperature and thermal conductivity profile, effects of hydrate dissociation on fluid flux
- **Micro- and Macro-biology**

  Role of bacteria and microbes on creation and dissociation of hydrates
- **Drilling**

  Establish ground truth against other measurements

Methane and Seawater from the Sea to JP-5 and Potable Water

Department of the Navy Naval Research Laboratory



Sea water

CH_4

Hydrate Cap

Dissociated Hydrate

Free-Gas Reservoir

(1) Pressure Chamber

Brine

Potable water

CH_4

H_2O

(2) CH_4 H_2O

Steam Reforming of CH_4

H_2

CO

(3) H_2 CO

Fischer Tropsch

JP-5

H_2O

H_2

1) $CH_4 + H_2O \overset{\text{pressure}}{\rightleftarrows}$ Clathrate (hydrate)

2) $13CH_4 + 13H_2O + \text{Energy} = 39H_2 + 13CO$

3) $39H_2 + 13CO = C_{13}H_{28}$ (JP-5) $+ 13H_2O + 12H_2 + \text{Energy}$

Energy for the 21st Century

“The crisis facing our civilization would make the World War II years look like good times”

Thank you

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