Energy After Oil

Materials Challenges in Alternative and Renewable Energy Conference
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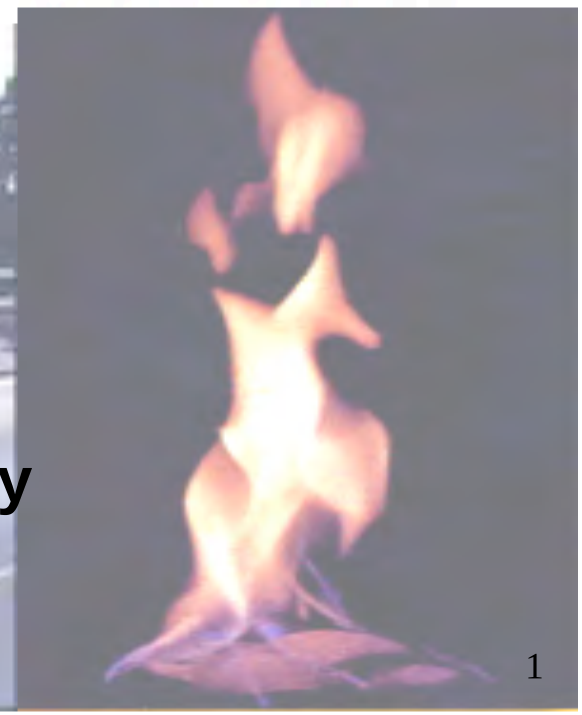


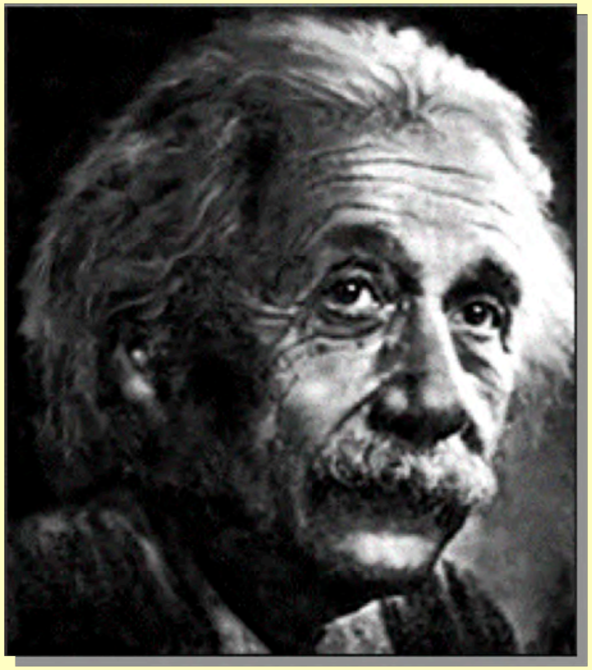
Global Issues

- Energy
- Water
- Environment

Our Generation's Challenge

When asked shortly after WWII:

"Prof Einstein, what do you see as the greatest threat to mankind?"

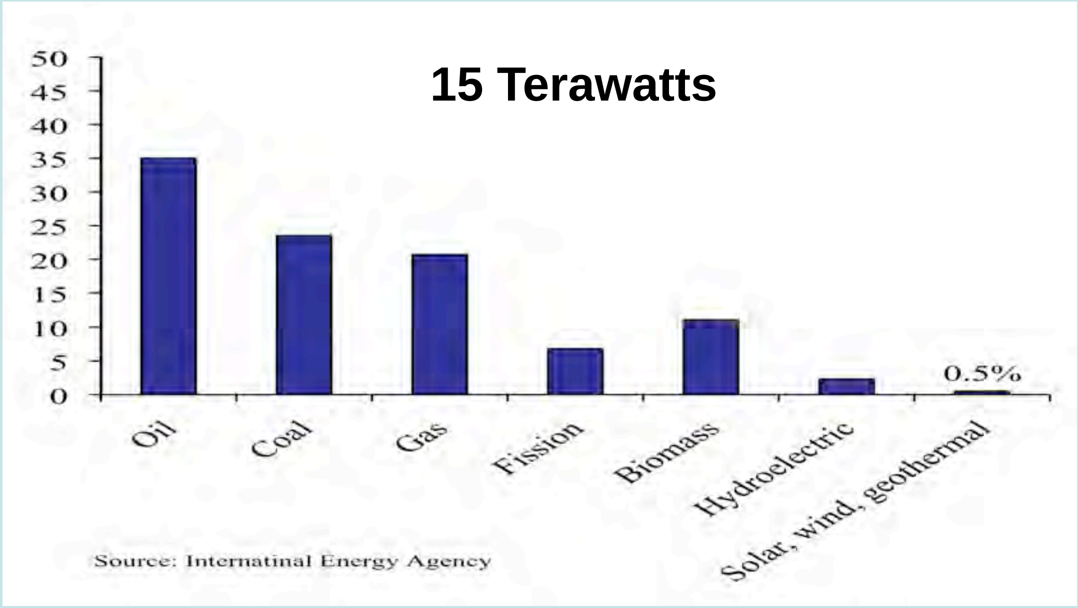


His prompt reply:

"Exponential growth."

The ENERGY REVOLUTION
(The Terawatt Challenge)

Sources of Energy Supply - Worldwide



Source: International Energy Agency

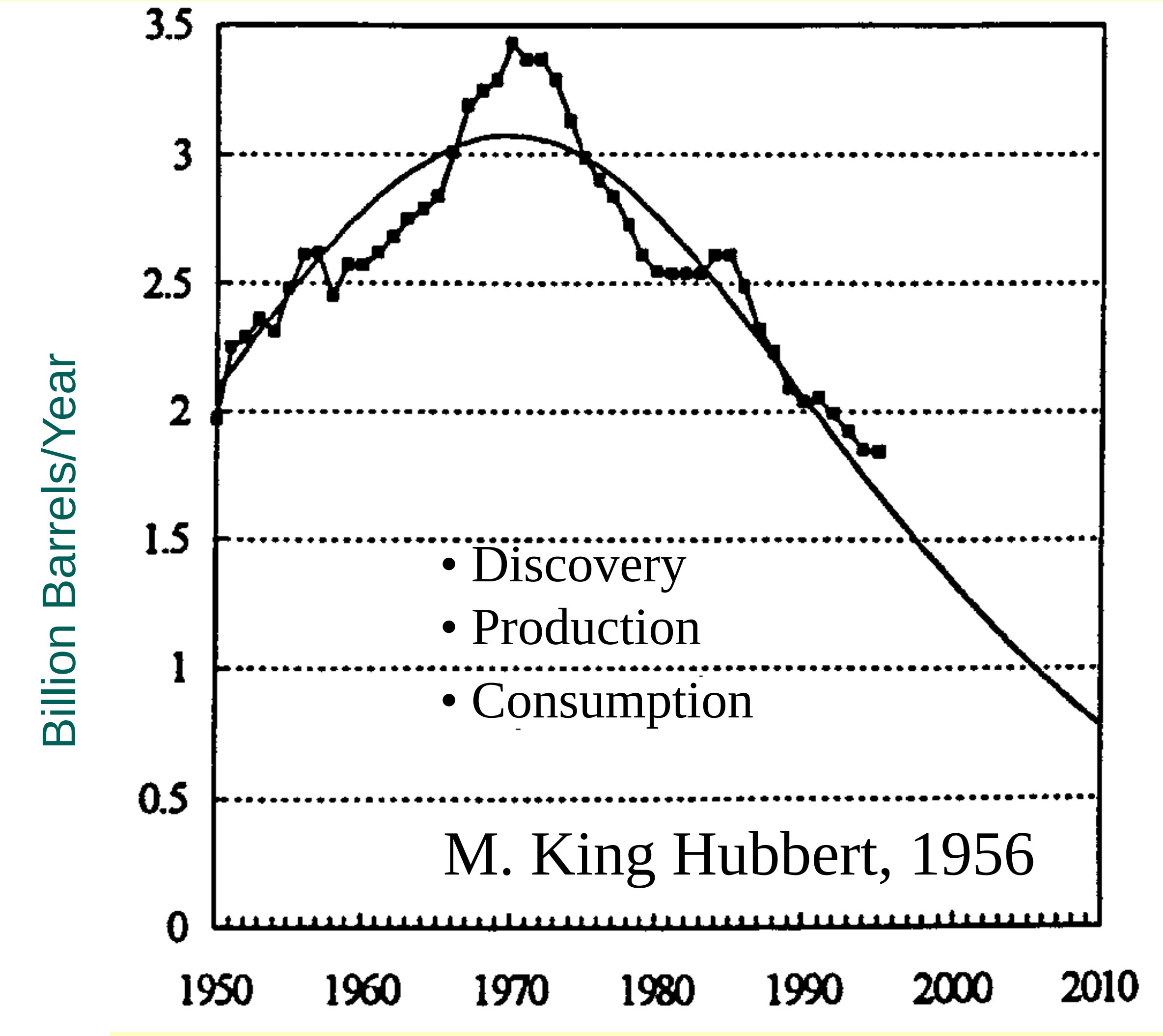
Setting the Stage: A Global Overview

- Consider in 1900 less than 1 million barrels of oil per day vs. today at ~87 million barrels per day

- "By 2015 we need to find, develop and produce new oil that is equal to 8 out of 10 bbl being produced today." President Exxon Mobil 2003

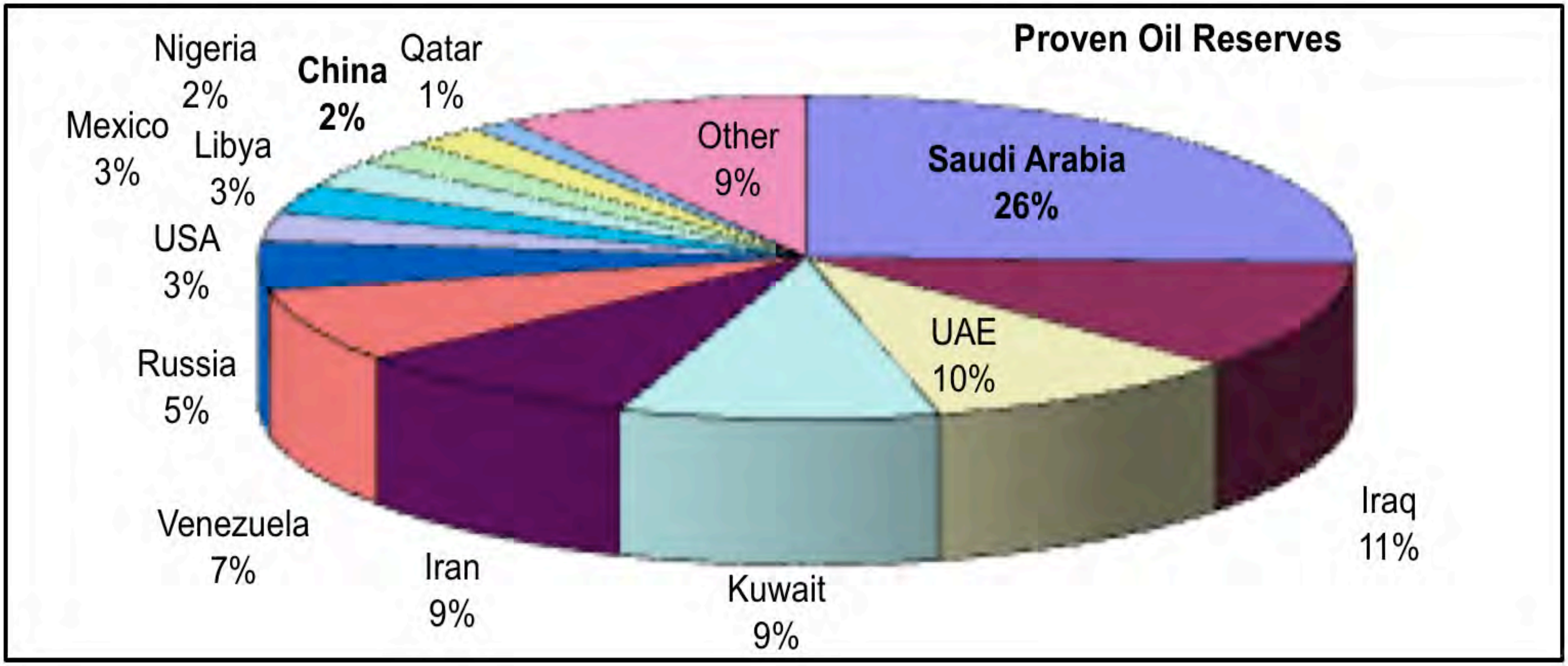
Tapped Out, Paul Roberts, National Geographic, June 2008

Crude Oil Production in the Lower 48

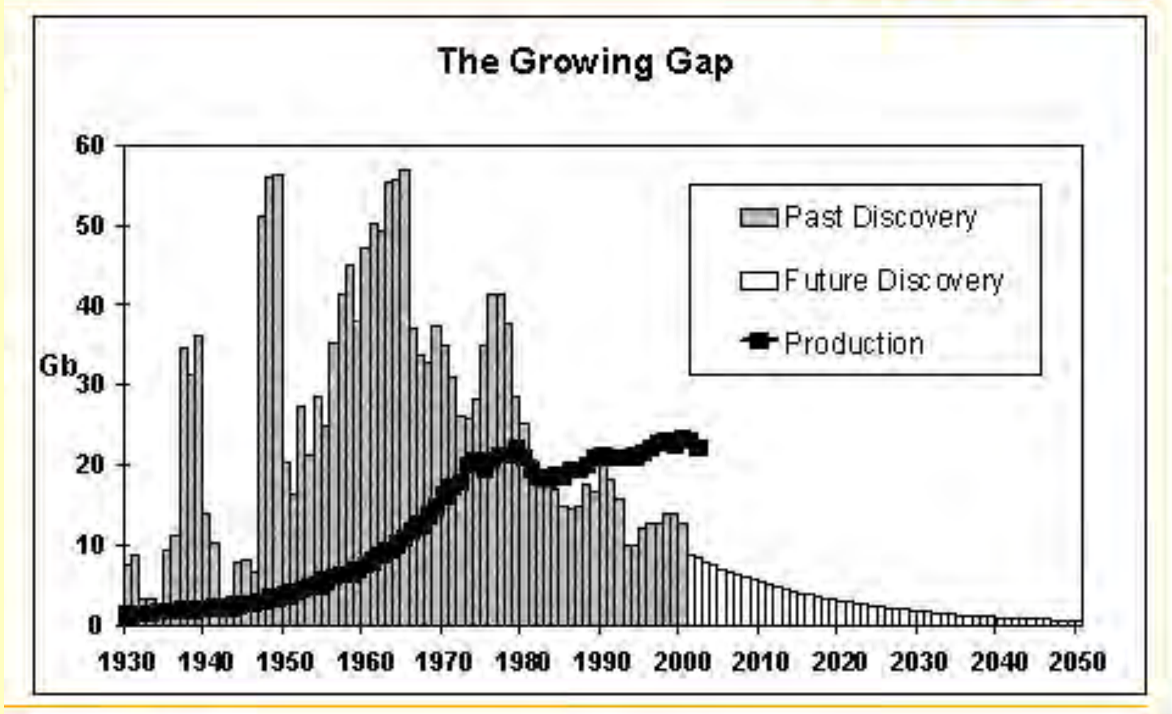


World Proven Oil Reserves

2000



Depletion of Oil Reserves



World oil reserves accumulated since 1930 are now being depleted. Industrial growth in Asia will accelerate the depletion

The Coming Oil Crisis, Colin J. Campbell

Alternatives (Renewables & Non-renewables)

Conservation / Efficiency -- not enough

Renewables

- Biomass -- large land mass, cost?, aviation?
- Hydrogen -- cost? safety? Beyond horizon for large scale use
- Wind -- commercial, not enough
- Nuclear Fusion -- technology challenges, cost? Beyond horizon
- Solar terrestrial -- commercial, large land mass, cost?
- Geothermal -- not enough
- Waves / Tides / Currents -- not enough, coastal issues
- Ocean thermal -- confined to tropical / equatorial regions, cost?
- Hydroelectric -- not enough
- Synthetic fuel -- technology challenges

Non-renewables

- Clean Coal / CTL -- sequestration?, cost?
- Nuclear Fission -- radioactive waste?, cost??
- Natural Gas -- not enough / resource limits
- Oil shale -- Technology? Environment? Cost?
- High energy density fuel -- research challenges
- Methane Hydrates -- clean and in abundance

(• DOE R&D Emphasis)
(• Active research at NRL)

Renewables

Biomass: A Potential Renewable Energy

Biomass: A Potential Energy Resource

- The oldest known energy source since the discovery of fire
- World's 4th largest energy source (47 quads/year; 13.6×10^{15} watt hr; 47×10^{15} BTU)
  - Domestic Biomass Source for Energy
  - Agricultural Waste
  - Forestry Waste
  - Municipal Solid and Industrial Waste
  - Energy Crops (Grown for Fuel)
- US Goals for Energy Contribution from Biomass by 2020 (NREL/DOE)
  - 10% Transportation Fuels
  - 5% Electric Power Production
  - 18% Chemicals and Materials

Robert Armstrong, NDU Report

Range in Biofuel Production (ethanol & diesel)

Feed Stock	Gallons of Oil / Acre / Year
Corn†	~350
Soybeans	48
Safflower	83
Sunflower	102
Rapeseed	127
Oil Palm	635
Algae*	1000-5000**
Jatropha*	125
Sugar Cane†	662
Cassava†	410
Sweet Sorghum†	374
Camelina*	75-100
Switchgrass*	low

† Production of ethanol
* Non food crops
** requires massive CO_2 injection for higher gallon number

Gasoline Gallon Equivalent

Fuel Type	BTUs/gal	Gallon Equivalent
Gasoline, regular unleaded	114,100	1.00
Diesel (typical)	129,800	0.88
Methanol	56,800	2.01
Ethanol	76,100	1.50

Ethanol from Biomass Controversy (Corn)

- Energy costs for corn production and conversion to one gallon of ethanol are 131,000 BTUs. Energy value of one gallon of ethanol is 76,000 BTUs (~70% more energy is needed than that derived from ethanol).
- Ethanol costs $ 1.83/gallon compared to $1.00/gallon for gasoline.
- An average car running 10,000 miles/year on ethanol fuel needs 850 gallons, grown on 11 acres of ground.
- $1.5+ Billion/year in subsidies are provided by federal and state governments for ethanol production

David Pimentel, Cornell U. (Encyclopedia of Phy. Sci. & Tech.)

Alternate renewable fuels (diesels & alcohols)

Feedstocks

Algae

Vegetable Oils

Animal Fat
(Conoco Philips and Tyson Foods)
(Neste Oil)

Multiple Biomass
(Neste Oil and Stora Enso)
(Sweden)

Corn/Sugar Cane

Processes	Products	Problems
Esterification (methanol, Strong Base) NaOH / KOH	**Biodiesel** Fatty Acid Methyl Ester (FAME)	**Stability** (microbial, emulsions, solvation, contaminants)
Hydro-treating (Hydrogen)	**Green diesel**	**Stability** (microbially-induced sulfate → sulfides)
Biomass to Gas (BTL Gasification) (formation of syngas)	**Fischer-Tropsch (FT) diesel**	**Need Evaluation**
Hydrolysis/ Fermentation	**Ethanol/C2+ Alcohols**	**Low Flash Point and Energy Density**

Biodiesel provides carbon source for microbial growth resulting in sulfide production and corrosion

No Sulfide Production | Sulfide Production | No Sulfide Production

Biodiesel

Persian Gulf SW

Carbon Steel Coupon

Sterilized Persian Gulf Seawater + Biodiesel | Natural Persian Gulf Seawater + Biodiesel | Natural Persian Gulf Seawater

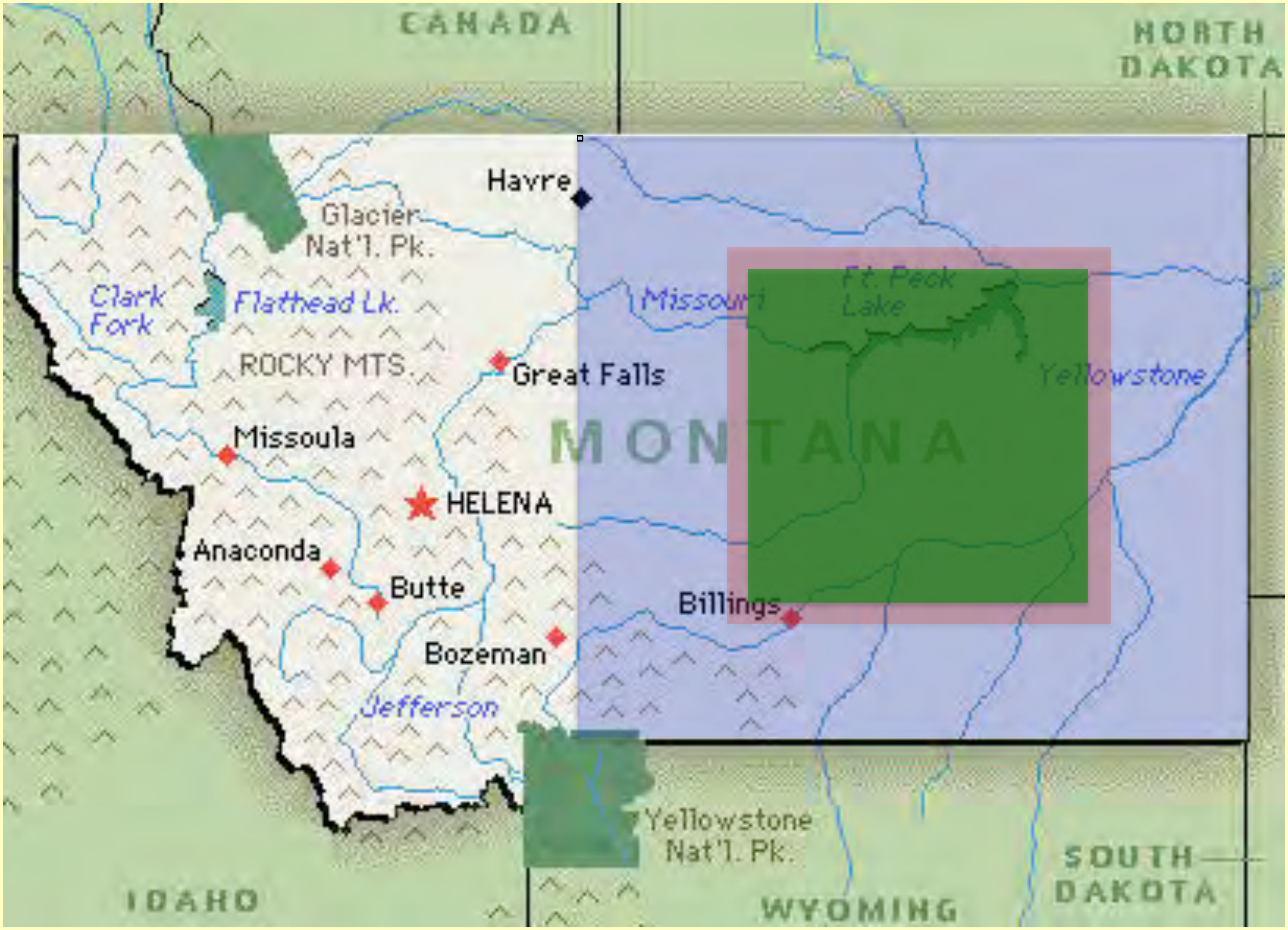
Algae to Jet Fuel (produce 5 x10^9 gal / yr from a yield of 1250 gal / acre / yr)

- **Need high solar flux, abundant water, CO_2 and nutrients** and **massive land areas**
- 1250 gallons "oil" / acre / year requires **6000 square miles**
- 233 **coal fired 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.
  5x10^9 gallons "oil" / yr requires 260 million tons CO_2 per year (high CO_2 transportation cost if not adjacent)
- Massive **water requirements**
  5x10^9 gallons "oil" / yr requires **4.5 trillion gallons of water** per year
- **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 ~ $ 2 / gallon, excluding capital investment **(if CO_2 is transported** the cost will be $ 35 – 40 / gallon)

Camelina to Jet Fuel

(1.4 Billion gallons / year - Montana project)
(Excluding land acquisition cost)

- Grows on non-arable (non-food) land.
  (80 – 100 days for harvest)
- Camelina at <100 gal / acre / yr, requires 14 million acres (¼ of pasture land in Montana)
- Fertilizer (~100 x 10^6 lbs / yr), cost - $100 Million / yr
- Planting & harvesting cost at ~$280 Million / yr
- Processing costs to jet fuel ~ $3 Billion / yr
- Processing costs to bio diesel fuel ~ $ 300 Million / yr
- Market demand will favor FAME over jet fuel
- Crop rotation with dry land wheat is uncertain



Pasture Land: 53 % of MT

Crop Land: 19 % of MT

Camelina for Navy Fuel: 15 % of MT

Switchgrass to Ethanol

- A perennial grass native to the Great Plains
- Grows in marginal land
- Needs seeding once / decade
- Cultivation requires fertilizers (~ 100 lbs N_2 / acre) and irrigation
- 100 gal ethanol / acre / yr
- With higher cost enzymes for bioreactors, cost / gal about that for corn

Jatropha to Biofuel

- Crop grows on marginal land but needs ample water supply
- Claimed to produce more fuel / acre than corn
- Production: a) variable, depending on soil quality, b) highly labor intensive, c) depends on plant life
- Leaves & seeds highly toxic
- Requires tropical climate: (Myanmar, India, China, Philippines, etc.)

Hydrokinetic Energy from Ocean Currents

- **Most promising site in North Atlantic – Florida Straits**
  - **Incident energy flux: ~ 18 GW**
  - **Extracted energy: 3-4 GW**
- **Disadvantages:**
  - **Wake loss**
  - **Drag on supporting structures**
  - **Internal turbine and transmission losses**
  - **High cost**
  - **Usable energy transmitted to the grid: 1-2 GW**

Hydrokinetic Energy from Marine Environ.

Tides, Waves, Ocean/River Currents, and Ocean/Thermal

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

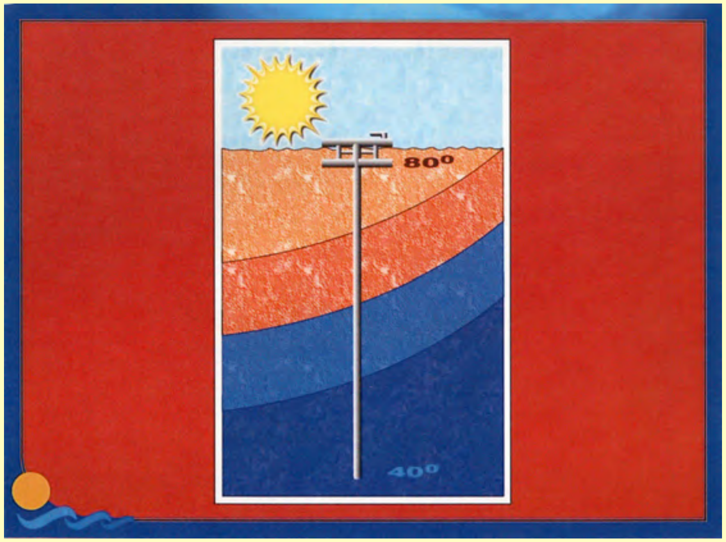
Advantages:

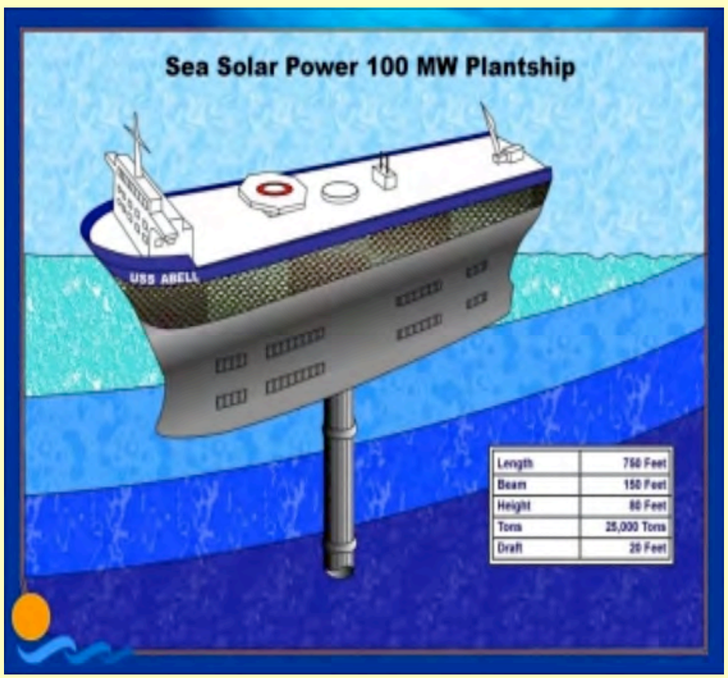
- **Single buoy (50 kW)**
- **Existing technology (tested at New Jersey by OPT)**
- **No environmental impact**

Disadvantages:

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

Ocean Thermal Energy Conversion (OTEC)





- **First proposed in 1881 – d'Arsonval**
- **Oceans are the largest solar energy collector on earth**
- **Stored energy in the equatorial / tropical oceans equals ~ 300 times the world's energy consumption (best operation for ΔT = 40 ºF)**
- **Energy conversion is 24 hours per day. Advantage over tides, solar & wind**
- **Energy extraction is environmentally neutral (tested in Hawaii: 50 kW in 1979, 1 MW in 1980)**

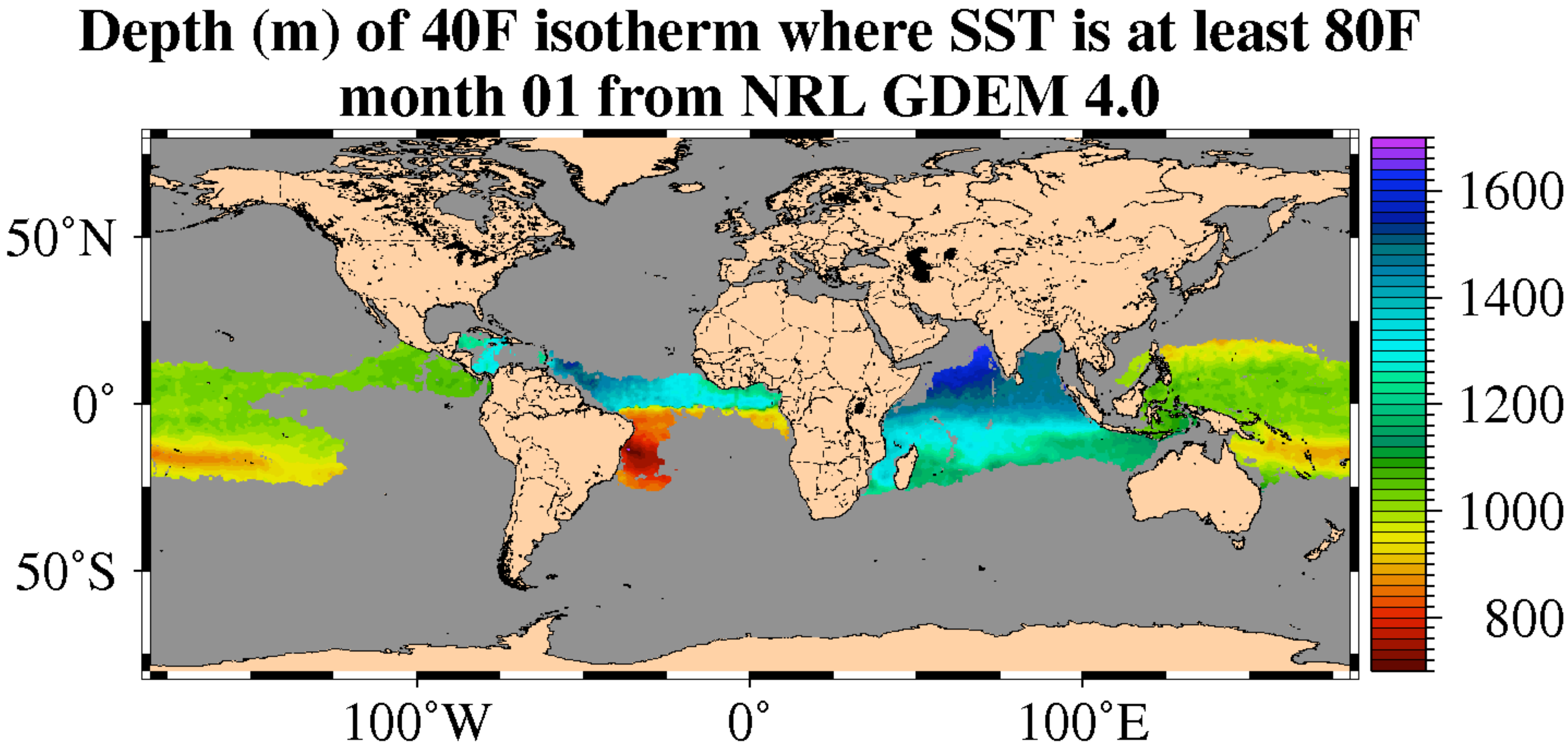
Technology Challenges for Ocean Thermal Energy Conversion

For 100 MW Net Power

- Continental shelf closer to coastline
- Tropical ocean with minimum seastate fluctuation and currents
- Internal tides near islands (Hawaii)
- ~30 feet diameter pipeline extended ~ 3000 feet in ocean column
- Water pumping at a rate of ~ 13,000 cubic feet / sec
- ΔT equals ~ 40ºF for ammonia as a heat exchanging fluid

Power output α $(\Delta T)^2$

Generalized Digital Environmental Model (GDEM)



Synthetic Fuel from the Sea

Synthetic Hydrocarbon Fuel for Enhanced Operational Readiness and Logistics Independence

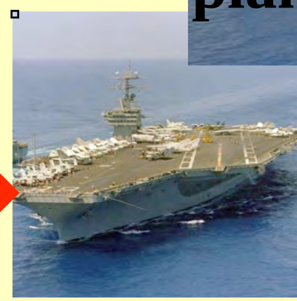
Objective

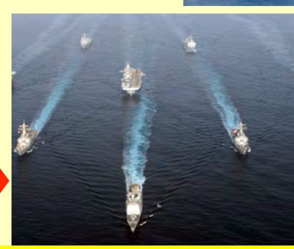
Fuel independence that is cost-effective and CO_2 neutral. Fuel synthesis using H_2 produced by electrolysis of seawater and CO_2 extraction from seawater.

1. Sea Based Application

Fuel production plant
Lily Pad

Energy Nuclear/OTEC





Rest of Battle Group
Cruiser, Destroyer, Frigate, Oiler, Amphibious

Hydrocarbon production

2. Fuel Ship Application

Rest of Battle Group
Cruiser, Destroyer, Frigate, Oiler, Amphibious

CO_2 from seawater:

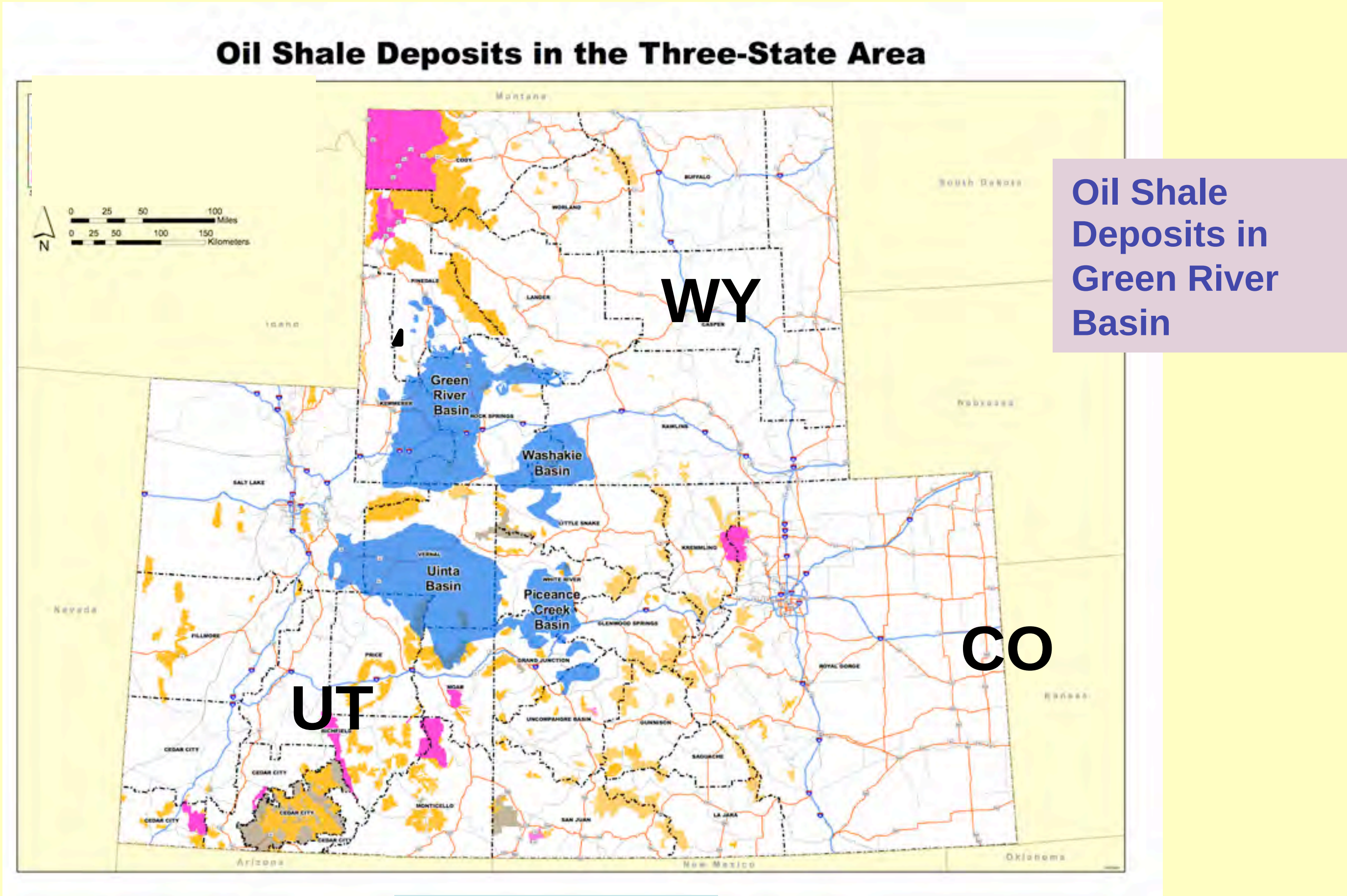
$H_2O \rightarrow H + O_2$
$H + H_2O + CaHCO_3 \rightarrow HCO_3 + CaOH$
$H_2CO_3 \rightarrow CO_2 + H_2O$

A 100 MW power plant could produce 41,000 gal. of fuel / day

Non Renewables

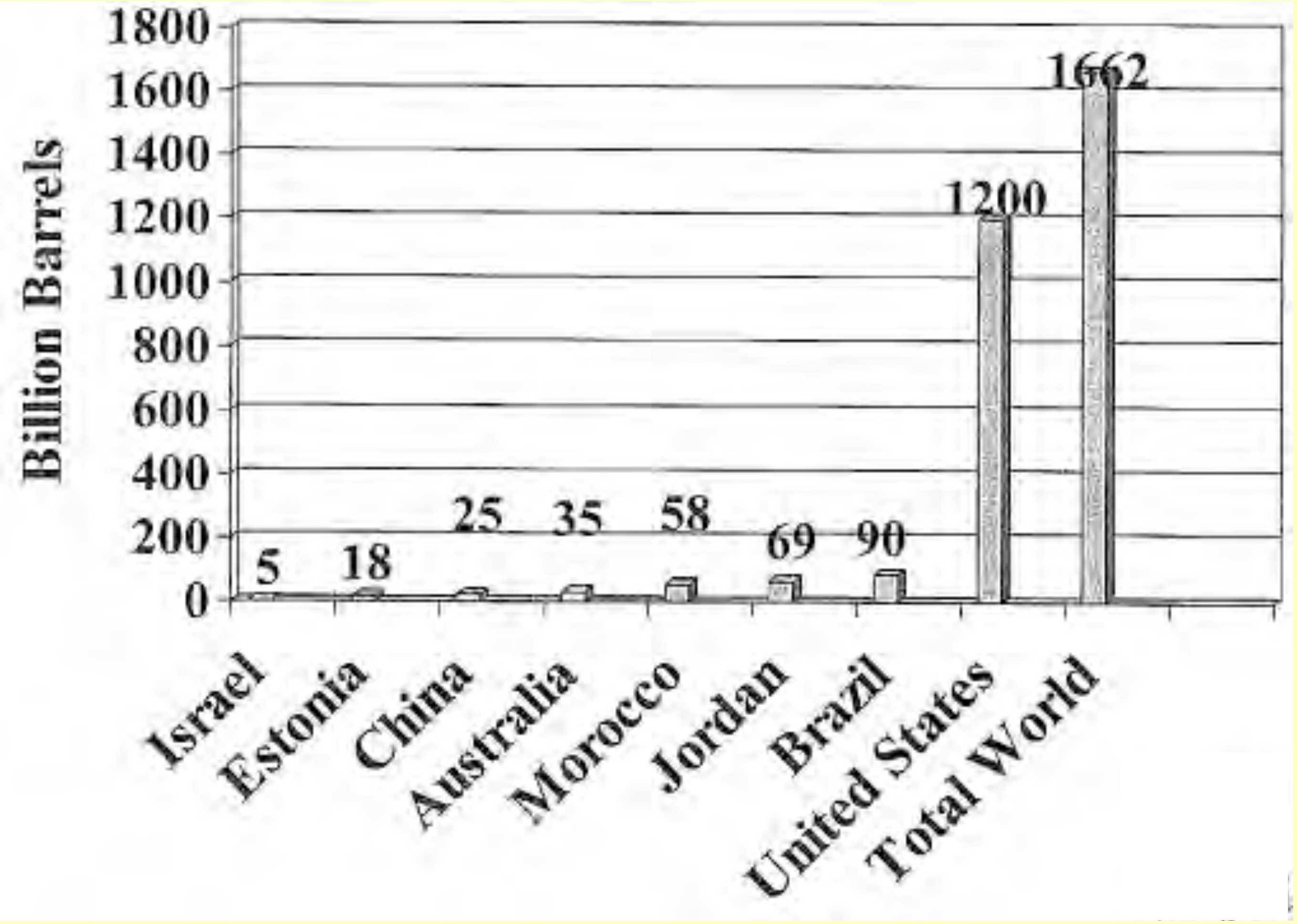
Petroleum from Domestic Oil Shale

CO, UT & WY



DOI, 2004

Major World Oil Shale Reserves



Tony Dammer, 2004

Comparison of Principal Factors Influencing the Economics of Producing Refinery Crude Oil

Characteristic	Athabasca Tar Sands (Canada)	Green River Oil Shale (US)
Reserves	More than 1 trillion bbl	More than 1 trillion bbl
Grade (Richness)	25 gallon bitumen/ton	25 gallon kerogen oil/ton
Hydrogen Content	10.5%	11.8%
N and S requiring removal	6.2 Wt%	4.0 Wt%
Loss to Coke	33 lb/ton-ore	nil (burned for energy)
Net yield of oil	0.50 bbl/ton mined	0.58 bbl/ton mined
Quality of oil	34°API	34°API 20

Tony Dammer, 2004

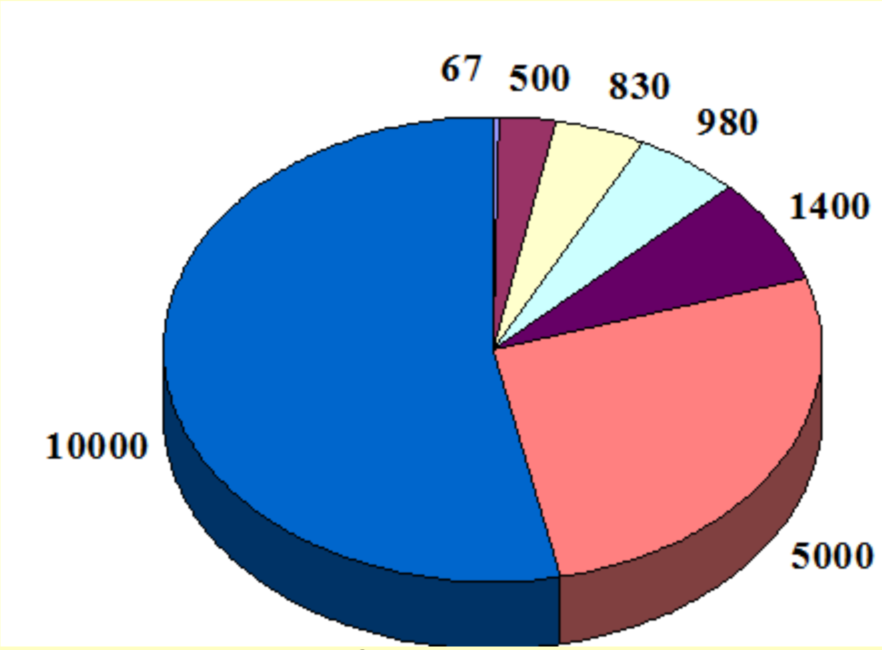
Petroleum From US Oil Shale

- Maximum deposits estimated at 1.5 x 10^{12} barrels (USGS 1965; DOE 2005; largest in the world)
- Recoverable oil: 1.0 to 17 x 10^{10} barrels (M. K. Hubbert 1969)
- Extraction technology: (mine and retort (old); in situ extraction (thermal energy, Shell Oil, 2000)
- Advantages
  - Large domestic deposits
  - Excellent finished product (JP-5)
- Issues
  - Disposal of spent shale
  - High levels of arsenic
  - High volumes of water for processing
  - Hydrogen upgrading
  - Meeting regulatory standards CO_2 emissions)
  - Cost?
  - (DoI, BLM estimates)

Abundance of Frozen Clean Energy from the Sea

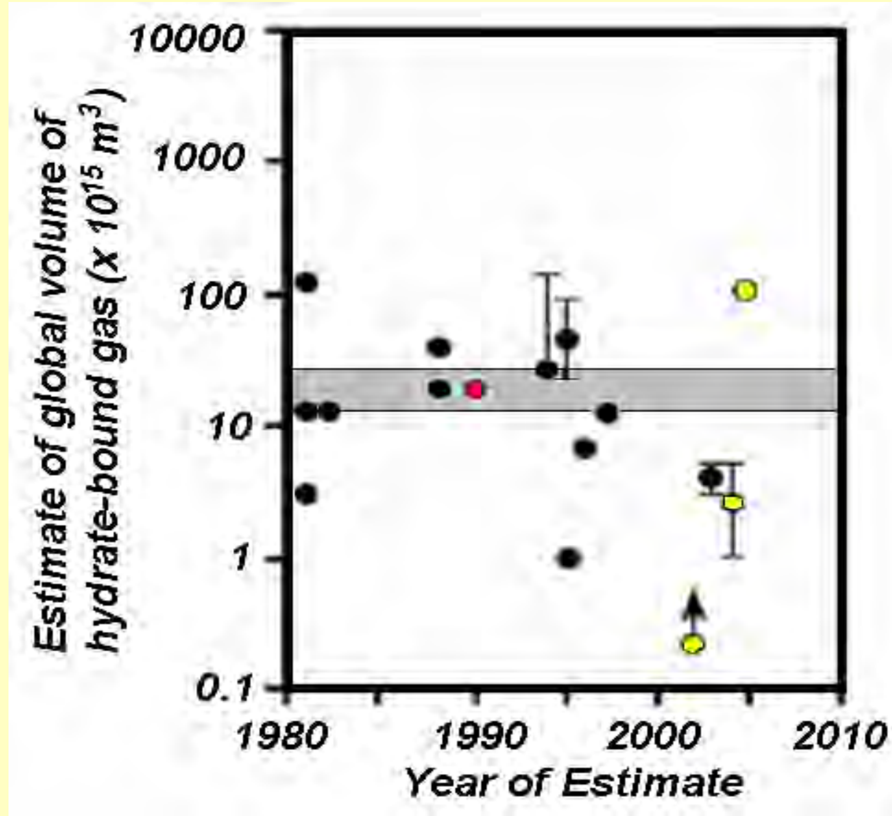
(Methane Hydrates)

Global Estimate of the Methane Hydrates



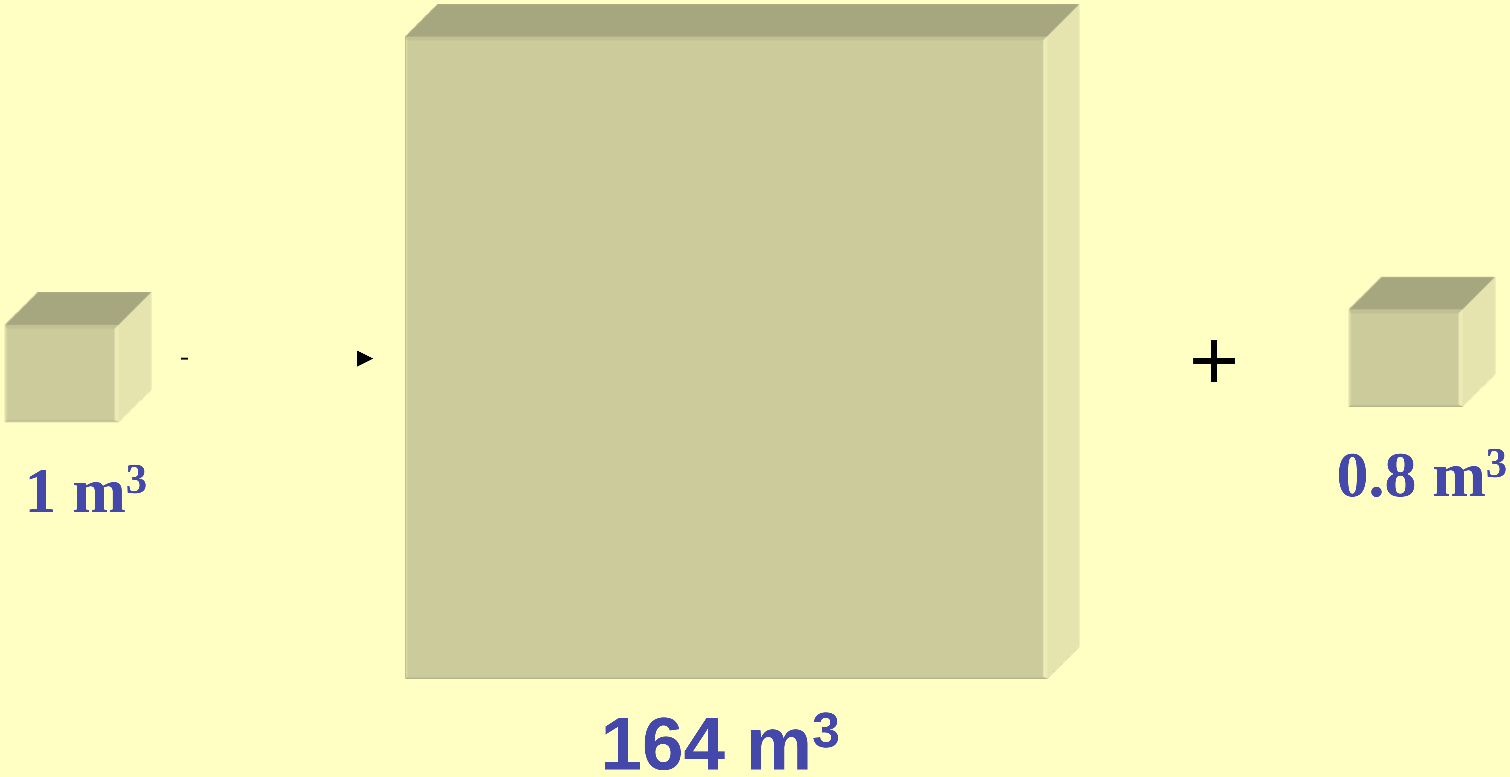
Gigatons (10^9 tons)

- Waste material
- Peat
- Land (animals and plants)
- Dissolved organic matter in water
- Soil
- **Total fossil fuels (gas, oil, coal)**
- **Methane hydrates**



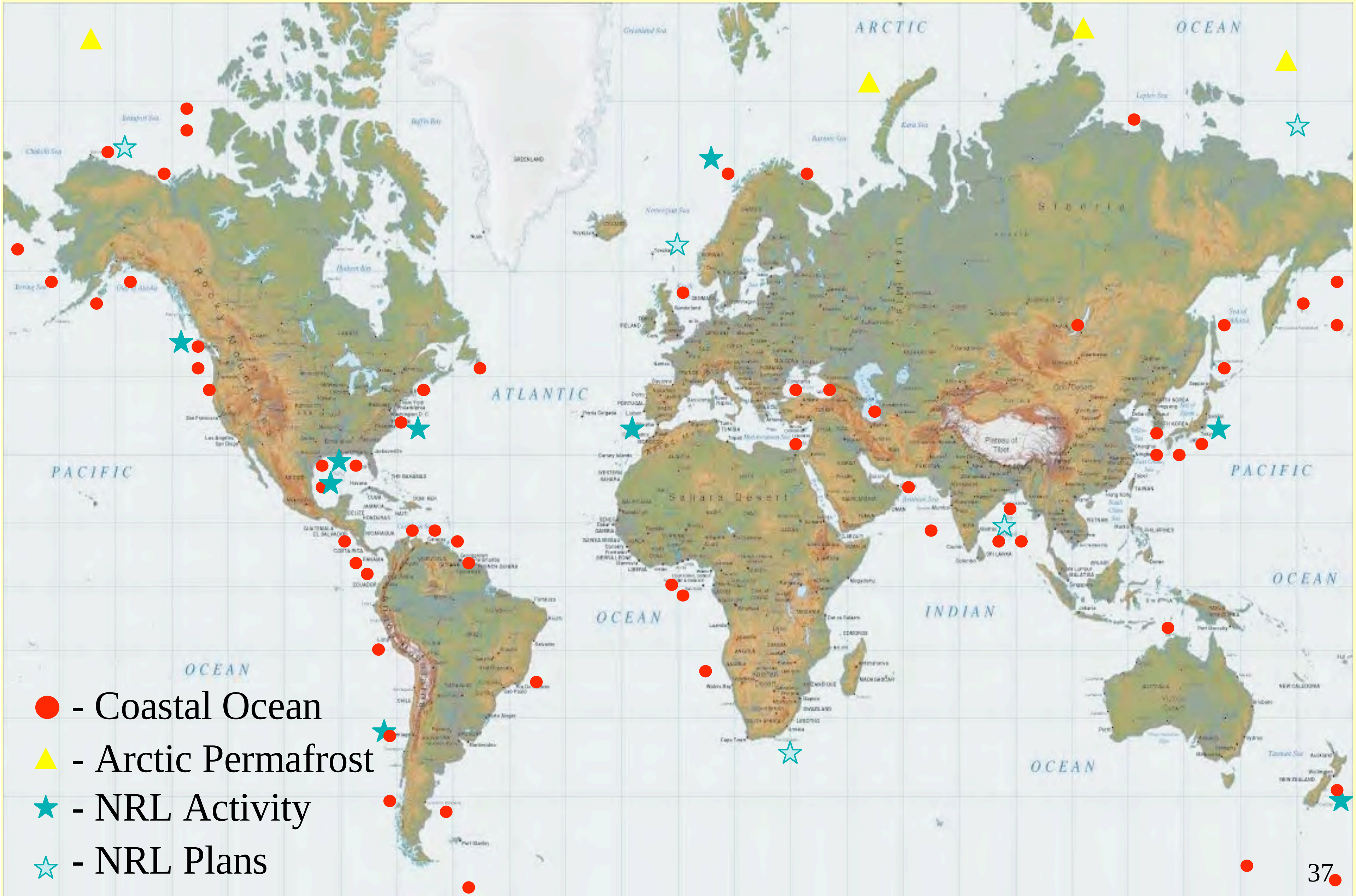
Global gas-in-place estimates vary but 700,000 tcf is most widely cited estimate

Volume of Gas Hydrate



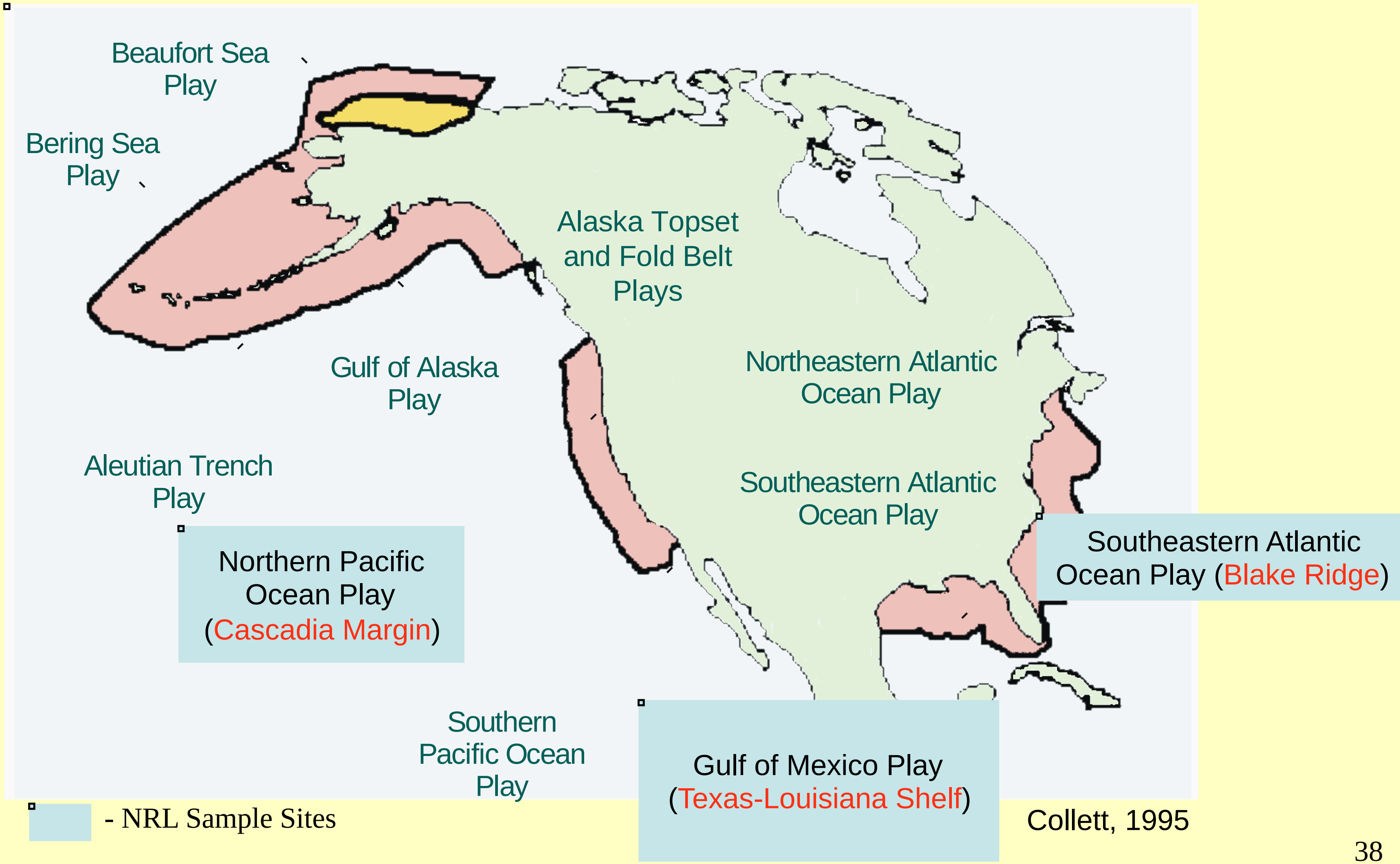
One cubic meter of gas hydrate yields 164 m^3 of gas and 0.8 m^3 of water at STP

World Methane Hydrate Distribution



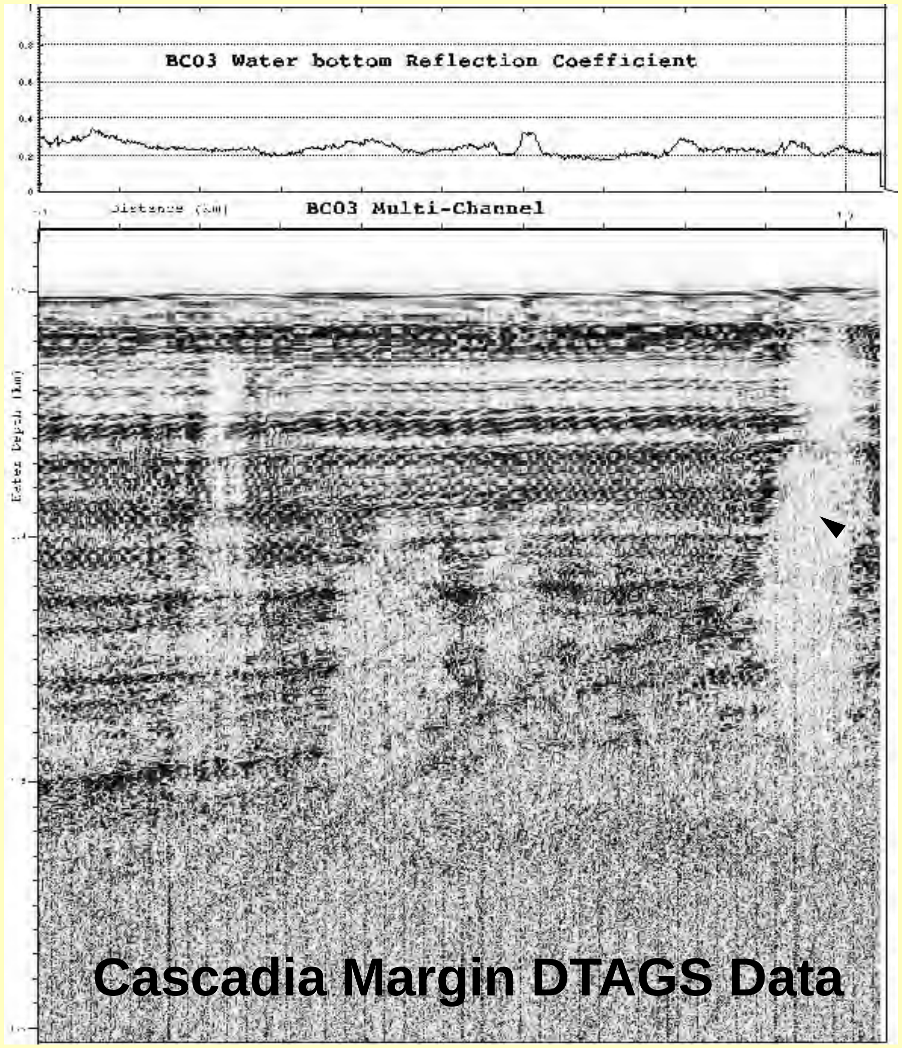
US Methane Hydrate Distribution

CH_4 deposit > 300 x 10^{15} Cu Ft
US annual consumption ~ 22 x 10^{12} Cu Ft



Collett, 1995

DTAGS Application on the Cascadia Margin



“Wipe Out” zones related to dissociation of hydrates


Coal Oil Point Anticlines
South Ellwood Anticlines

Materials Challenges in Alternative and Renewable Energy (needed for all technologies on alternate energy production)

- Corrosion / stress corrosion and corrosion fatigue resistance
- Materials for deeper ocean drilling
- Advanced catalysts and enzymes
- Environmentally friendly anti-fouling paints and coatings
- New low cost ferrous alloys for hydrogen transport
- Structural materials for OTEC application
- Hybrid plants with improved photosynthetic efficiency
- Genetic engineering to accelerate microbial processes

Energy for the 21st Century

"The crisis facing our nation would make the Depression years look like good times"

- Congressman Bartlett

Thank you

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