**SYNTHETIC AND BIOMASS ALTERNATE FUELING IN AVIATION**

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# Synthetic and Biomass Alternate Fueling in Aviation

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OAI-NASA Cleveland OH 44135

www.nasa.gov 1

# Hydrocarbon (HC) Addiction

- **Our planet is gripped by our addiction to hydrocarbon energy generation sources.**

  ***"Addiction is a terrible thing. It consumes and controls us, makes us deny important truths and blinds us to the consequences of our actions."***

  U.N. Secretary-General Ban Ki-Moon

- ***"We take pride in our clean, green identity as a nation and we are determined to take action to protect it. We appreciate that protecting the climate means behavior change by each and every one of us."*** Prime Minister Helen Clark, New Zealand

# Civil Aviation Alternate Fueling Progress

- Feb. 24, 2008, Virgin Atlantic 747–400 40-min. **biojet fueled flight**
  - One of four GE CF6-80C2B5F turbofan engines
  - London to Amsterdam (320 km) altitude to (7.6 km)
  - 80% Jet-A: 20% processed babassu nut-coconut oils (Parente)
  - Ground tests to 60JetA:40biojet no discernable problems
- February 1, 2008, Airbus A380 3-hr **GTL fueled flight**
  - One of four Rolls-Royce Trent 900 engines fueled
  - Bristol to Toulouse to assess environmental impact
  - GTL (gas-to-liquid) fueling 50% Jet-A: 50% Blend
  - Goal regulatory 50:50 blend (2009): 100% GTL (2013)
- Continental – GE plan CFM56–7B biofuel 737 test (2009)
- CAAFI Civil Aviation Alternate Fuels Initiative

  Research, Emissions, Business, Regulatory Groups

# Military Aviation Alternate Fueling Progress

- March 2008 B1B flew supersonic (50%JP8 : 50%SPK)
- **SPK** (Synthetic Paraffinic Kerosene) Standard

  **MIL-DTL-83133F** 11 April 2008

  Sperseeds MIL-DT-83133E 1 April 1999.
- SPK: CAAFI-ASTM modification for ASTM D1655.
- 17 Sept 2008 **50yr-old KC135 and F22 Raptor** Fueled 50:50 JP8-SPK

# Heat Engine Exhaust Emissions (HC)-Fueled Systems
## Health Hazards

- Particulate pollution : ***ultrafine particulates directly translocate to promote vascular system diseases.*** [Ultrafine: < 0.1 µm (< 100 nm)]

  Journal of America College of Cardiology (JACC) *.

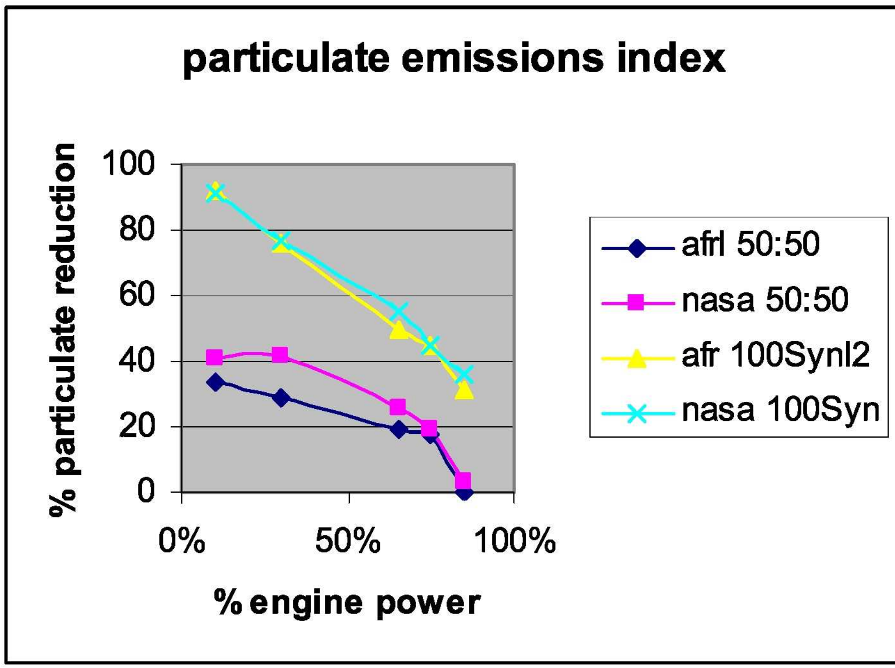
  chronic respiratory diseases due to particulates are better known **
- Exhaust (tailpipe) emissions (20-140 nm) includes aircraft, mobility/stationary systems

**•Simkhovich, B.Z, Kleinman, M.T., Kloner, R.A. (2008) Air Pollution and Cardiovascular Injury Epidemiology, Toxicology, and Mechanisms, Journal American College of Cardiology, 2008; 52:719-726, doi:10.1016/j.jacc.2008.05.029 (Published online 13 August 2008).**
http://content.onlinejacc.org/cgi/content/short/52/9/719
**** Schwartz, J.** (1993) Particulate Air Pollution and Chronic Respiratory Disease, Environmental Research, 62, pp. 7-13

# Civil-Military Engine Emissions Testing

- March 2008 PW-308 Engine Emissions FT- Jet A fuel test
- Fuels AFRL-FT, NASA-FT (Fischer-Tropsch), Jet A

Decreased particulate number with % power decrease for FT and Blends vs. Jet A.

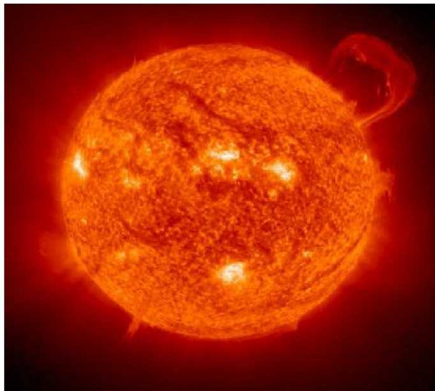



Exhaust Emissions Rake

# Aviation Ground Rules 2nd Generation Biomass Fueling

| Criteria | KLM | Virgin Atlantic. | Boeing | Airbus | Air Transport Association |
|---|---|---|---|---|---|
| **Water** | No use of drinking water | Should not divert water away form food agriculture or drinking water | Does not require freshwater irrigation | Does not compete with water use for food crops or with drinking water | |
| **Deforestation** | No deforestation or forced relocation of people | Should not lead to deforestation | Does not lead to deforestation directly or indirectly | Does not compete with natural carbon sinks such as rainforest | |
| **Soil** | No soil degradation | Should apply sustainable agronomy principles (e.g., equivalent of FSC) | Apply sustainable practices | Apply sustainable practices | |
| **Land and Food** | Not compete with food or make use of arable land | Should not conflict with staple food crops | Does not compete with food | Does not compete with land use for food crops | |
| **Emissions** | No negative influence on biodiversity | Should have lower life cycle carbon emissions | Reduce CO2 (ie on order of -50% from current Jet A fuel) | Beneficial on a life cycle basis both in terms of global warming and local air quality | Voluntary Emissions Reduction |
| **Supply** | | | Supply sufficient quantity of lipids that could be converted to biojet fuel [ 11.5B US gal (2026)] | Aspirational goal to have up to 30% of commercial aviation fuel being biofuel in 2030.<br>Set as a stretched goal to support scenarios discussion. | Reliable supply is critical; must be compatible with existing fueling infrastructure ; must meet regulatory and standards required by FAA |
| **Economic Feasibility** | | | Have some hope of becoming economic feasible (ie Processed biofuel costs no higher than today's Jet A fuel ( <$4/gal) | To be demonstrated | Beneficial to both suppliers and purchasers |
| **Feedstock** | | | Assume the raw oil from multiple feedstocks could be equally easily converted into biojet fuel | Multiple feedstock will have to be used | Feedstock neutral; fuel must satisfy Safety and Quality, Environmental benefits, Reliability of supply, and be Economically feasible |

# What are Our Abundant Resources ?



- Arid Land (43% Earth's Lands)

- Sun
- Seawater (97% Earth's Water)

- Brackish / Waste Waters

- Biomass

**Halophytes are saltwater/brackish-water tolerant plants**

NASA/CP—2009-215677

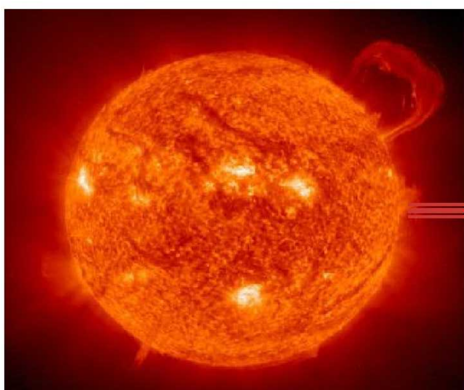




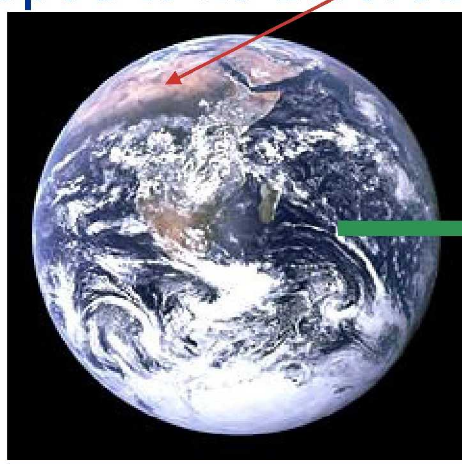
# Applying Abundant Resources and Halophyte Agriculture

## Assumptions

- **Sun**: solar incident radiation at 230 W/m2 daily
- **Seawater** (brackish water) irrigation
- **Arid Lands** : Total size of the Sahara Dessert (8.6x10$^8$ ha,13.6% of world arid or semi-arid lands)
- **Biomass**: Developed to its theoretical limits [ 10% ]



Sun: Hans De Keulenaer



**Halophyte Agriculture Could Produce 7.126 kQ/yr 16× the World Q (2004)**

National Aeronautics and Space Administration

# Why Our Interests are Halophytes Algae Bacteria Weeds and Seeds

**In a nut shell, here is the basis for our interest in Halophytes and derivatives**


- 97% earth's water is seawater
- 80% (or more) plant nutrients are in seawater
- 43% earth's land is arid or semiarid
- 40% population growth in next 40-50 yrs.
- Global warming threatens methane hydrates in permafrost and ocean ($CH_4$ release, 20X worse than $CO_2$ as GHG)
- Ample solar energy available
  ( to 16X total World Q in terms of biomass)
- Projected dearth: food supply, freshwater supply, energy supply
  current and projected environmental disasters + famines … by 2050 cities consume 50% world's freshwater…soil losses 5-10M ha-arable/yr …50% applied farm nutrients lost in runoff, leaching or erosion; worst is Gulf of Mexico
- Projected rise in ultrafine particulate health hazards impacts all living matter
- Inaction will lead to demise of humanity

**This is an existential matter**

# Raw Biomass Costs for $4/gal-biofuel

- Raw-Biomass conversion to fuel at 20%

  5 kg-raw-biomass = 1kg-biofuel

- Non-biomass costs (ROI, marketing, personnel, transport etc…) 30% of fuel cost

- Maximum allowable raw-biomass cost

  $4/gal x ¾ x gal/3.4kg-fuel

  = about $1/kg-fuel

  1000 kg/ton / 5 kg-raw biomass

  Less than **$200/ton-raw-biomass**

  Coal Spot (Sept.-Nov. 2008) $150 - $130 /ton (Volatility)

# Common plants, weeds and seeds address (Food, Energy, Water)

## Camelina

- Camelina looks like wild mustard plants.
- Can prosper on marginal (near arid) lands. Fast growing (85-105 days)
- Can survive winters of Montana and Dakota's. Banned in some states
- Oil-Seed yields to 3.2 mt/ha (1.4 t/a) with (35-45%) oils ; High Omega-3
- General purpose food-fuel feedstock

Camelina

http://en.wikipedia.org/wiki/Camelina_sativa

https://www.camelinacompany.com/Marketing/GrowerInformation.aspx

http://www.hort.purdue.edu/newcrop/proceedings1996/v3-357.html

http://aginfo.psu.edu/news/2008/6/camelinaforbiofuel.html

NASA/CP—2009-215677



# Common plants, weeds and seeds addresses (Food, Energy, Water)

## Castor plant

Castor plant member of the economically important Euphorbia family.

Ricin laced seeds a potent poison, One milligram can kill an adult.

Grows rapidly in arable soils, yet cannot tolerate frost. Its tolerance to arid soils and saline conditions needs assessment.

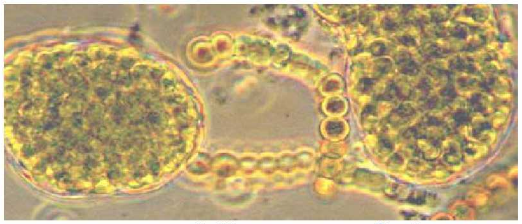
Colorless to pale yellow liquid, one of the world's most useful and economically important natural plant oils.  Yields to 1400L/ha 1.25mt/ha (0.5t/a)

http://en.wikipedia.org/wiki/Castor_oil_plant

http://www.castoroil.in/uses/fuel/castor_oil_fuel.html

# **Bacteria** Address (Energy, Food, Water)

- Cyanobacteria: oldest forms and found almost any habitat
- The chloroplast facilitates endosymbiotic relation between cyanobacteria living in plant or algae cells.
- Bacterial genomes easier to modify (maybe)
- Can fix either nitrogen or carbon
- Bacteria are prolific and reproduce rapidly. With proper conditioning can be harvested daily
- Natural blends or modified bacteria can absorb solar energy at different wavelengths,
- Some can tolerate extremes in temperature such in the hot springs at Yellowstone National Park.
- Bacterial biomass potential achieve or exceed 100 g/m2-day theoretical biomass limits set by Weismann (2007)



Nitrogen fixing

Genetic modeling

**Weissman, Joseph C**. (2007) From Laboratory to Pilot Plant – Lessons Learned from a Microalgae Biofuels Project Algae Biomass Summit, Nov. 15-16, Grand-Hyatt Hotel, San Francisco, CA, USA. http://www.wsgr.com/WSGR/Display.aspx?SectionName=news/emailer/Event141/info.htm

# **Algae** addresses (Food, Energy, Water)

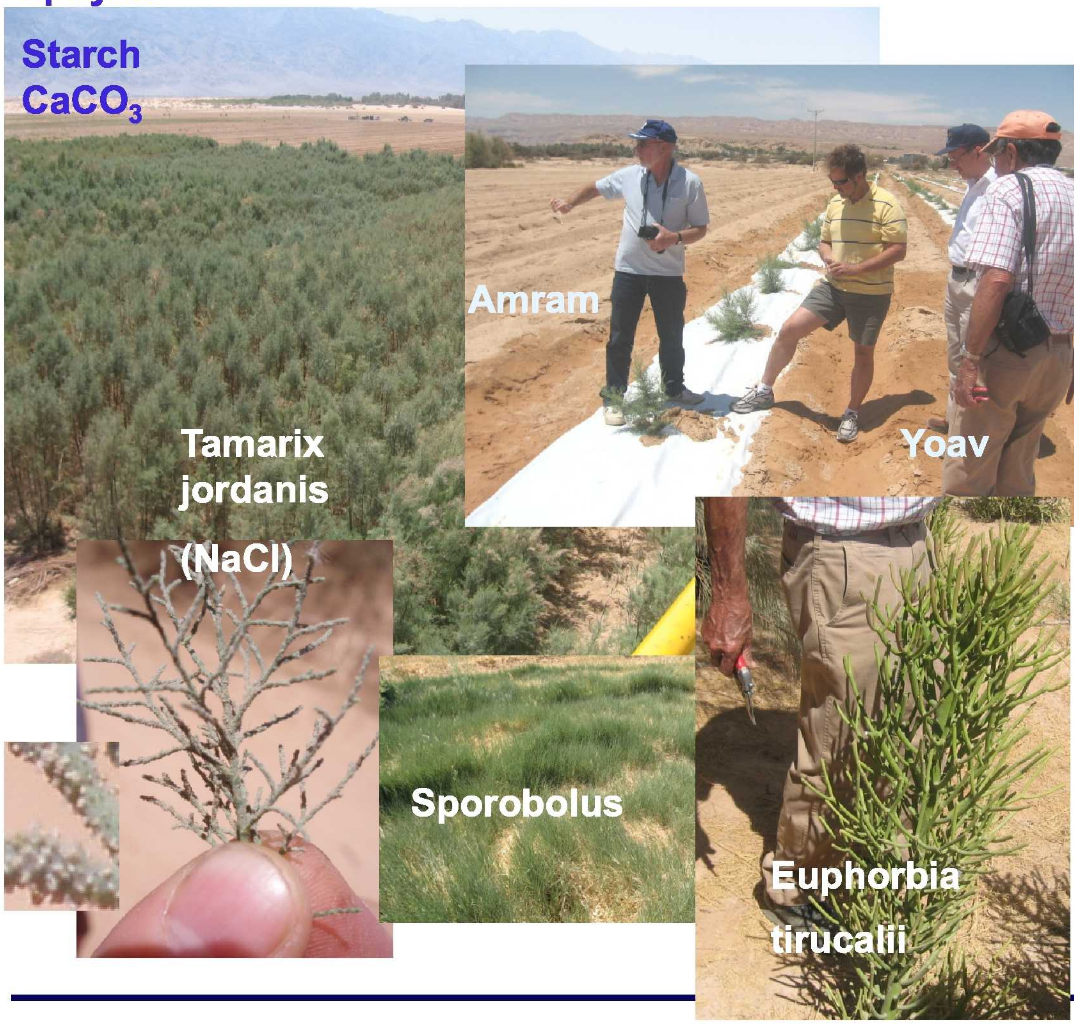
- Availability of solar, seawater, spent freshwater (eg livestock ) and arid land.
- “there is only 0.03% CO2 in our (lower) atmosphere and on this thin thread hangs our very existence” [Spoher, 1953]
- Increasing CO2 concentration increases biomass
- Force CO2 fed algae systems
- CO2 source ( about same productivity)
  - Pond (“pure” CO2) tanks or pipelines
  - Power Plant Desulphurized flue gas (FGD) CO2
- Bioreactors ( horizontal and vertical )

- Round numbers, 2 kg-biomass requires 1 kg-water and 3 kg-CO2 plus maybe up to 1 kg N (nitrogen) nutrient fertilizers (seawater irrigation provides some 80% of the nutrients needed for plant growth)

- Yields vary 2000-6000 gal/a

# Halophyte Fields Yotvata

Yoav Waisel [ YoavW@tauex.tau.ac.il ]
Amram Eshel [ AmramE@tauex.tau.ac.il ]

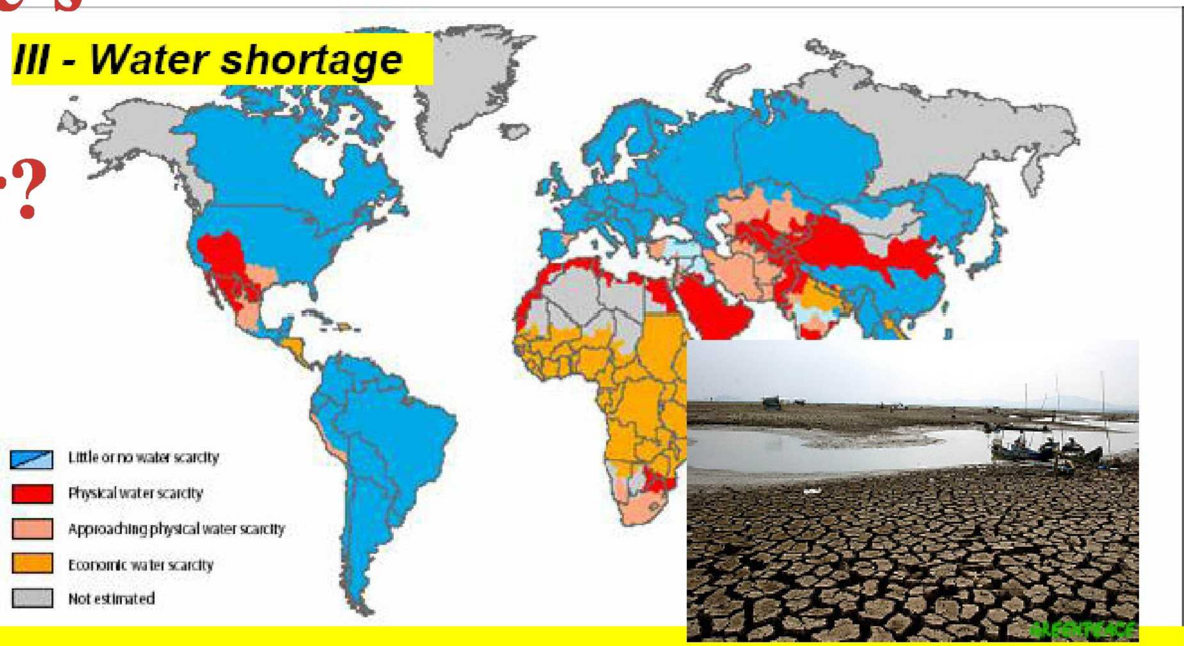



- Novel halophytes as well as classic ones.
- Biomass via invasive fir trees ( weeds ) Tamarix (Salt Cedar )
- 100 mt /(1.5yr) total biomass, 80mt/1.5yr carbon
- Branches and needles collect salts on surfaces
- Plant sap ( more viscous in salt water, less in fresh ) bleeds similar to milkweeds
- Collect research data base on potential halophytes for fuels and food
- Moving toward sustainable saline agriculture

National Aeronautics and Space Administration

# World Freshwater and Spent-water Issues

## Where's the Water?




**Groundwater is in decline everywhere**

**By 2050 cities will consume half the world's fresh water**

(Julian Cribb, FTSE, May 2008)

**Mario R. Tradici, Mario, R. (2008) Microalgae biofuels: potential and limitations. Algae Biomass Summit, Algae for Energy, Seattle Washington 23-24 October 2008 http://algalbiomass.org/, Department of Agricultural Biotechnology University of Florence, Italy**

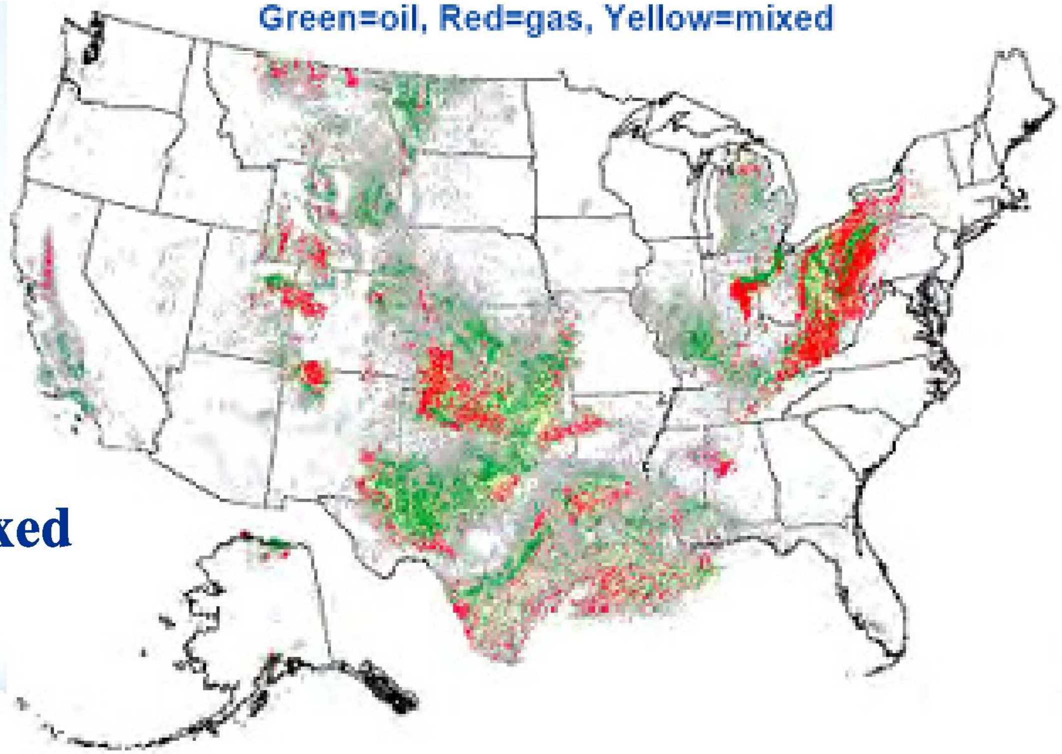
# **Water Issues** : Oil and Gas Wells Producing and Abandoned Potential Halophyte Algae Bacteria Water Sources

**Where's the Water?**

**Green =Oil**

**Red=Gas**

**Yellow=Mixed**



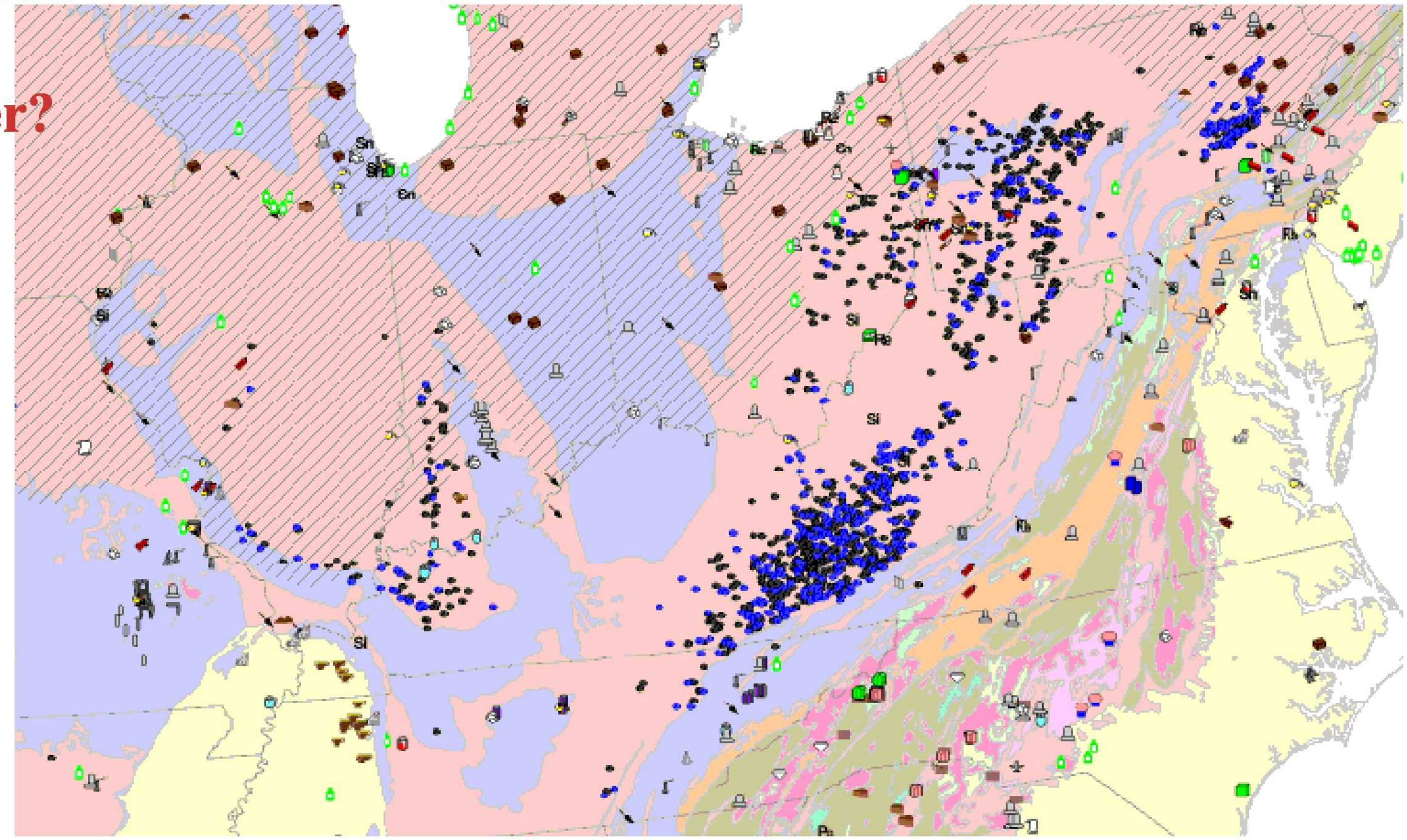

- 1. **[Pate, R. (2007)]** Sandia National Labs
- 2. http://wrri.nmsu.edu/conf/brackishworkshop/presentations/johnson.pdf

# Water Issues : Coal Mine and Mineral Processing Plants

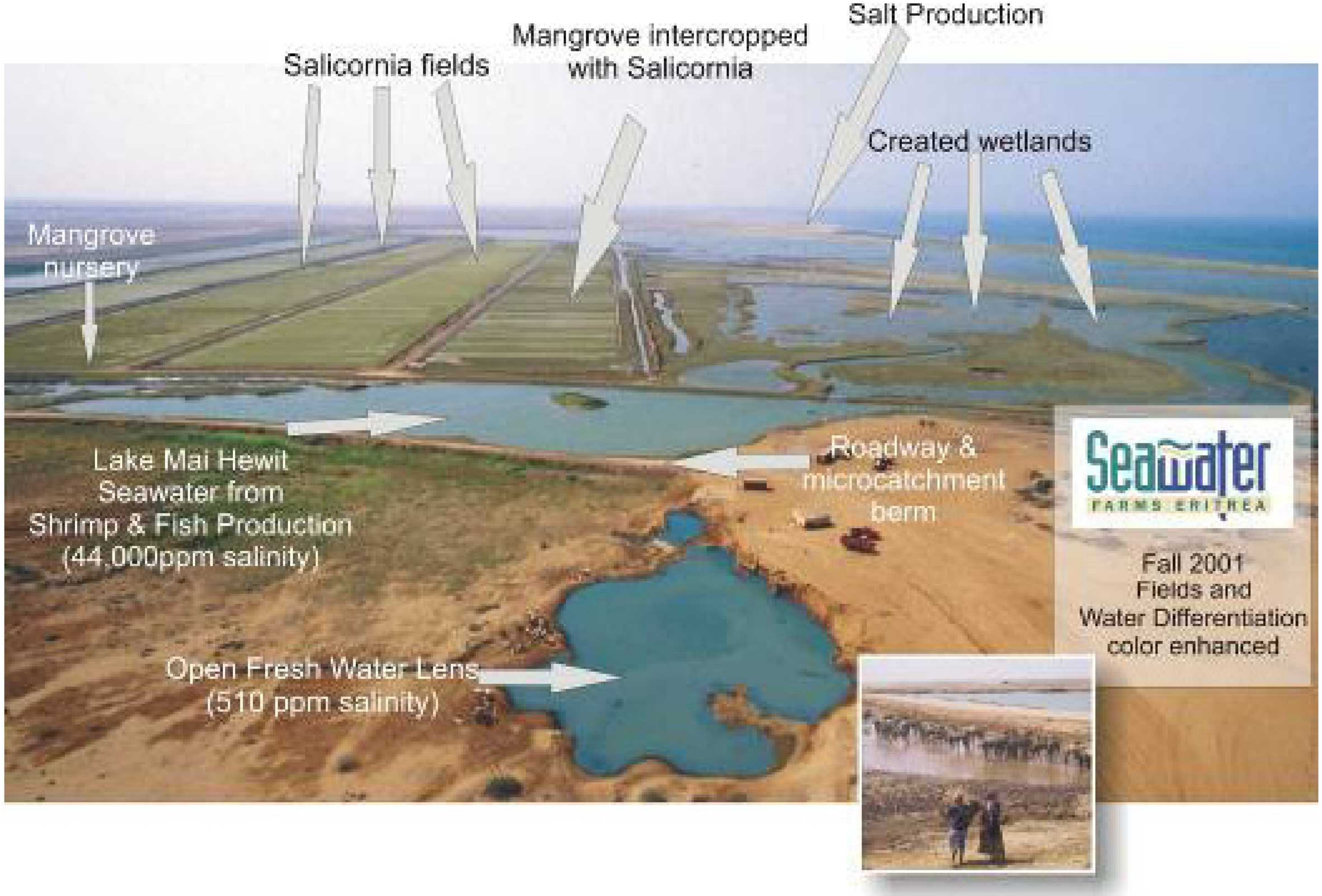
Producing and Abandoned, Impounded Brackish and Toxic Water, Waste Water, Spent-Freshwater : Potential Halophyte Algae Bacteria Water Sources

http://minerals.usgs.gov/minerals/pubs/mapdata/

Where's the Water?



# Live Cycle Systems



# ***Halophyte Production*** (salicornia)

- Salicornia [ Annual ] salt tolerant to 2X seawater
  optimum productivity to 1.3X seawater
- Over 6 years of field trials in Mexico ( others United Arab Emirates, Saudi Arabia, Eritrea, India)
- Total **Biomass** 2 kg/m2 ; **20 m-t/ha ( 8.1 t/a)**
- **Oilseed** 0.22 kg/m2 ; **2.2 m-t/ha ( 0.9 t/a)**

  Oil @35% 0.077 kg/m2 ; 0.77 m-$t_m$/ha ( 0.31 t/a)

  Sp.Gr. ~ 0.9 3.4kg/gal **226 gal/ha (92 gal/a)**

  *Aviation grade 76 gal/ha (31 gal/a)*
- Water requirements **1.35 X glycophyte irrigation**
  (prevents salt build-up at roots )
- SeawaterFoundation **Total Live Cycle System**

**Glenn et al. U Arizona, Scientific American Aug 1998; Hendricks & Bushnell ISROMAC12–2008–20241, Dr. Carl Hodges (2007,2008) http://www.seawaterfoundation.org/**

# Halophyte Production (seashore mallow)

- Seashore Mallow [ Perennial ] (salt tolerant to coastal seawater)
- Over 4 years of field trials in Delaware Coastal Plain ( others China, Egypt ) [ results for top-end harvest ; less for production fields]
- Total **Biomass** 1.8 kg/m2 ; **18 m-t/ha ( 7.3 t/a)**
- **Oilseed** 0.145 kg/m2 ; **1.45 m-t/ha ( 0.59 t/a)**

  Oil @20% 0.03 kg/m2 ; 0.29 m-t/ha ( 0.12 t/a)

  Sp.Gr. ~ 0.9 3.4kg/gal **85 gal/ha (35 gal/a)**

  **Aviation grade 29 gal/ha (12 gal/a)**
- Water requirements < **1.5 X glycophyte irrigation +**

  (prevents salt build-up at roots )

  \+ soil texture, drainage, natural rainfall, evapotransporation dependent
- Harvesting : Conventional Soybean Combine
- Soil remediator

Prof. John L. Gallagher, U. of Delaware
http://www.ocean.udel.edu/people/profile.aspx?jackg

# So, Why Alternate Fueling ?

Ostensibly, foreign control of US

energy

food or

freshwater

supplies, implies the US would be quite limited

politically,

commercially and

militarily

in the future

# What's the Problem Now ?

- We can make alternate Jet fuels
- CTL and GTL via FT processes
- Biomass fuels with conversion to Jet fuel

  Common crop oilseed [ soybean, palm, coconut etc)

  Algae

  Bacteria

  Halophyte

  Wastes [municipal, livestock, forestry etc )

- So what's the problem ?
- Why aren't we in control of our fueling sources ?

# The Problems

## How to make these Fuel Resources

Secure

Sustainable

Economically viable

Sufficient Supply

## And Satisfy the Ground Rules

# Beyond Drop-in Fueled Aviation

- Unmanned vehicles
- Solar powered
- Hydrogen fuel cell power
- Hybrid electric systems
- LH2 - Compressed Air propulsion systems
- Combined solar-hydrogen fuel cell systems
- Single seat aircraft demonstrators with and without battery-boost TO
- Holds promise of Clean Flight Systems

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# Solar-Electric ; LH2- Fuel Cell Electric

**http://www.avinc.com/**

Solar Powered Helios & Zephyr

http://news.bbc.co.uk/2/hi/science/nature/6916309.stm



**Stratospheric Persistent *UAS* (unmanned aircraft systems) : Global Observer**

**First Flight – June 2005**

**http://www.spacewar.com/reports/AeroVironment_Flies_Worlds_First_Liquid_Hydrogen_Powered_UAV.html**

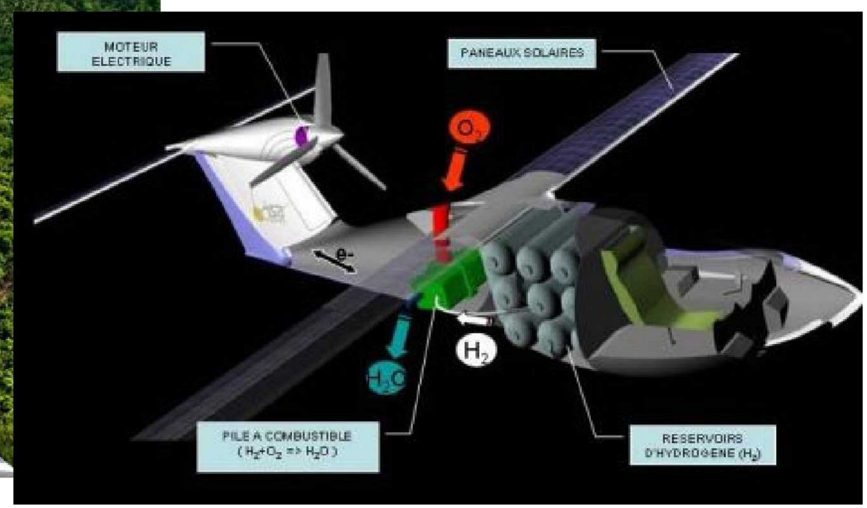
**Missions :** Communications Relay & Remote Sensing
**Features :** Stratospheric Global Persistence (all latitude)
**Endurance/Range :** Up to several days/global
**Payload :** Up to 400 lbs. for GO-1 & 1,000 lbs for GO-2
**Operating Altitude :** 65,000 feet
**Propulsion System :** Liquid hydrogen powered

# 2008 Battery Assist Hydrogen Fuel Cell-Electric

- Boeing 3 April 2008 : 3 test flights at 1 km.
- Battery boosted TO; fuel cells only at cruise
- http://news.bbc.co.uk/2/hi/technology/7330311.stm
- Potential for fly-back battery booster vehicle separation at cruise.

# 2009 Solar-Hydrogen-Electric

- Hydrogen fuel cells power Electric engine that is more efficient at altitude; Range about 1500 km.
- Hy-Bird PV cells provide cruise on-board power and hydrogen fuel cell TO peaking. [no battery boost cited]
- www.hy-bird.com or www.lisa-airplanes.com
- http://news.bbc.co.uk/2/hi/americas/4643575.stm AeroVironment



# Conclusions

- **Must use Earth's most abundant natural resources**

  **Biomass, Solar, Arid land (43%), Seawater (97%) with nutrients (80%) plus brackish waters and nutrients resolve environmental triangle of conflicts energy-food-freshwater and ultrafine particulate hazards**

- **Requires Paradigm Shift - Develop and Use Solar * for energy; Biomass for aviation and hybrid-electric-compressed air mobility fueling with transition to hydrogen long term.** * PV-Thermal-Wind (thermal includes geothermal)

# Consequences of Inaction

- Imperative (*existential*) humanity **Controls** and **Resolves**
  Triangle of Conflicts [ energy, food, freshwater]
  Emissions, in particular CO2, CH4, nano and ultrafine HC
    emissions peaking
    emissions levels
    emissions toxicity


- Current CO2 level and peaking have vivid similarities to Permian (~ 260 Mya) and dinosaur (~ 65Mya) periods
- Each of which led to **mass extinction** with multiple lesser extinctions over past 400 My.
- Known historical volcanic emissions, yet lack direct historical evidence to ultrafine particulate emissions.
- Ostensibly, **foreign control** of energy, food or freshwater supplies, implies **limited world influence**.

Energy

Food Thank You Water

ultrafine particulates

Environment

# Biomass Fueling Test Examples

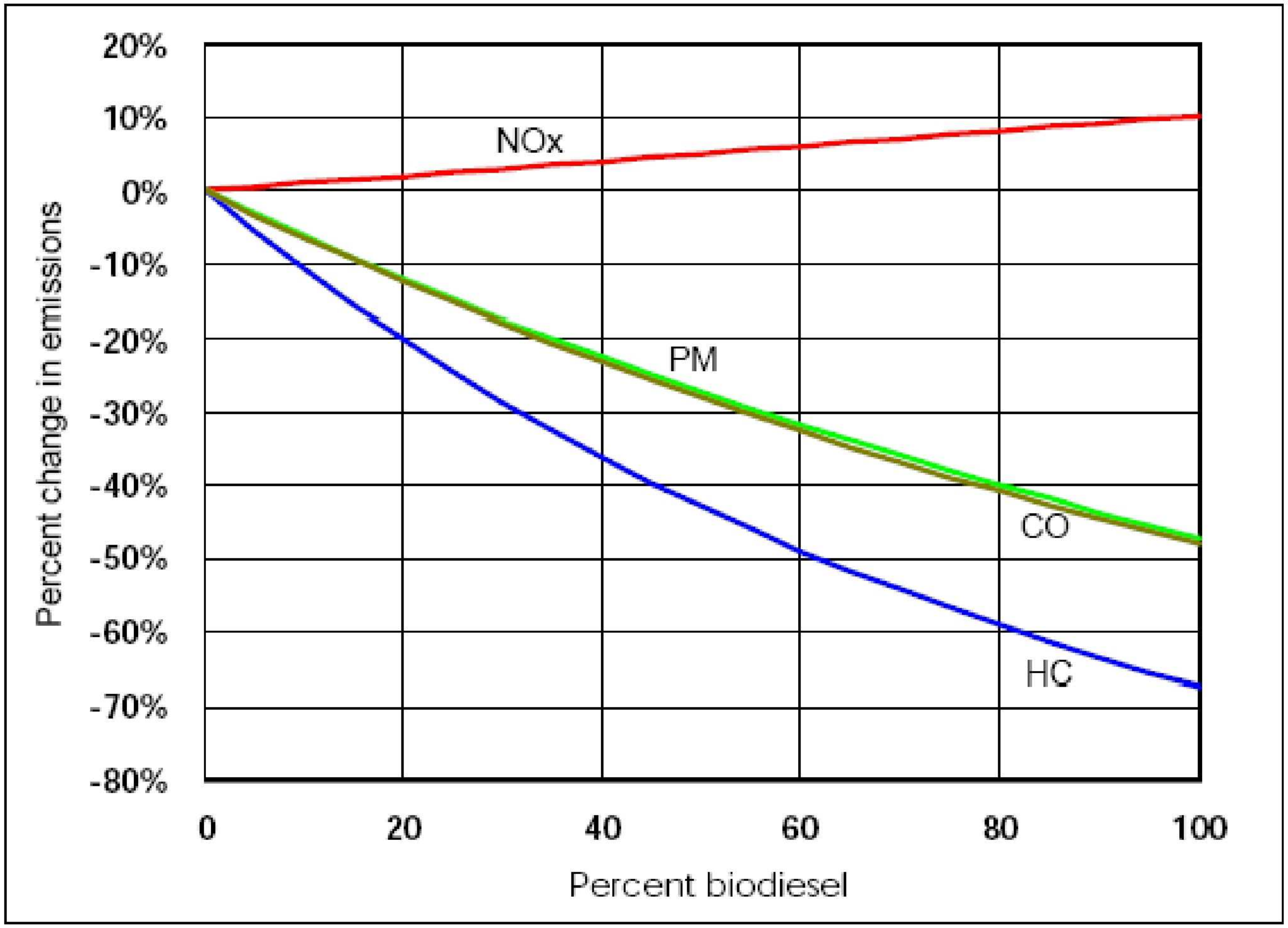
- ➢ Heavy Duty Diesel Engines Diesel-Biodiesel Blends
- Emissions decrease with % increase in blend
  - $CO_2$ formation
  - CO
  - particulates
  - unburned HC
  - SOx
- Increases in NOx (to 10%)
- Renewable, non toxic, feedstock diversity

- ➢ T-63 Small Gas Turbine Engine JP8-Biodiesel Blends
- Particle number density (PND) decrease with % increase in blend at cruise and take-off power (small decrease in size ), but PND increases at idle.
- Pyrene and fluoranthene found in soot data
- Typical turbine engine particulate size 30-70 nm

Effects of biomass burning: http://cat.inist.fr/?aModele=afficheN&cpsidt=14518203
Erie Ohio Biofuel producer: http://www.lakeeriebiofuels.com/

# Fig. 3 Diesel Engine with Diesel-Biodiesel Fueling

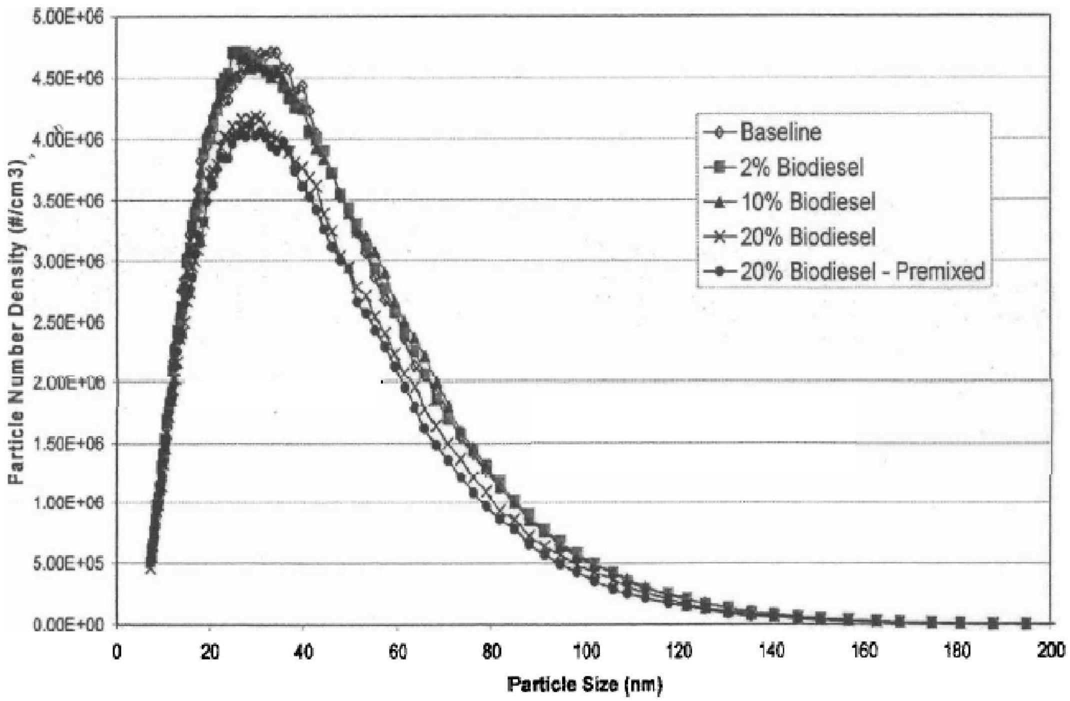
Average emission impacts of biodiesel for heavy-duty highway engines




http://www.epa.gov/otaq/models/analysis/biodsl/p02001.pdf

National Aeronautics and Space Administration

# Fig. 4 Gas Turbine Engine Particulate Distribution




Particle size distribution from T63 engine at cruise for JP-8 and JP-8/biodiesel blends.

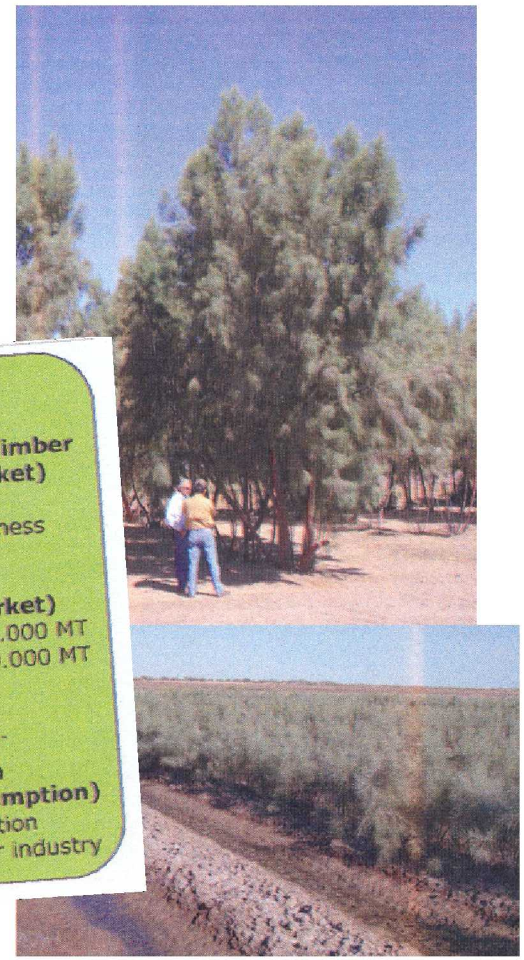
**Pyrene :** Toxic to kidneys and liver

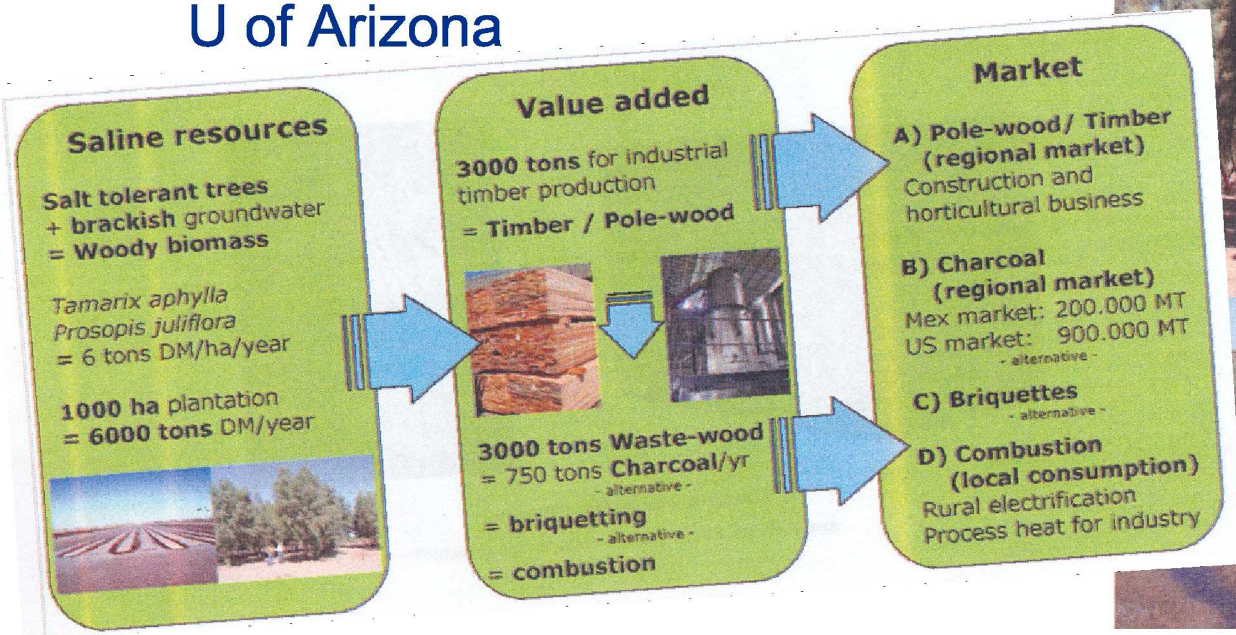
**Fluoranthene:** carcinogenic

Corporan et al. (2005) Impacts of Biodiesel on Pollutant Emissions of a JP-8-Fueled Turbine Engine, Air & Waste Management, Association, 55 pp.940-949.

# Colorado Delta Project
## www.oasefoundaion.eu/project 34

- Tamarix aphylla [similar to Yotvata]
- Value added marketing
- Prof. Ed Glenn Dr. Carlos Valdes
  U of Arizona





# Kibbutz Yotvata / Ketura – Advanced Technology

- **Biogas facility at Kibbutz Yotvata**
- **Solids separated and waters sent to fermenter with clean waste water but sent to fields for irrigation CH4 to gas generators and electric generators**
- **Cows milked on rotating platform life cycle is well regimented**
- **Bio reactor horizontal larger pipes and vertical (Kibbutz KETURA )**
- **Red algae for coloring pond fed salmon prior to serving are not pink ( rather gray in color) adding algae dies salmon pink**
- **Bio reactor fowled by foreign matter …shut down for 1.5 yr for cleanings ? Algae need to be protected against extremes in heat**

National Aeronautics and Space Administration

# Ocean and Bay Dead Zones [hypoxic – low oxygen ]
# Spent-freshwater treatment and algae recovery Systems

- Spinning mesh wheel develops an algal biofilm that feed on the suspended wastes (German Concept)

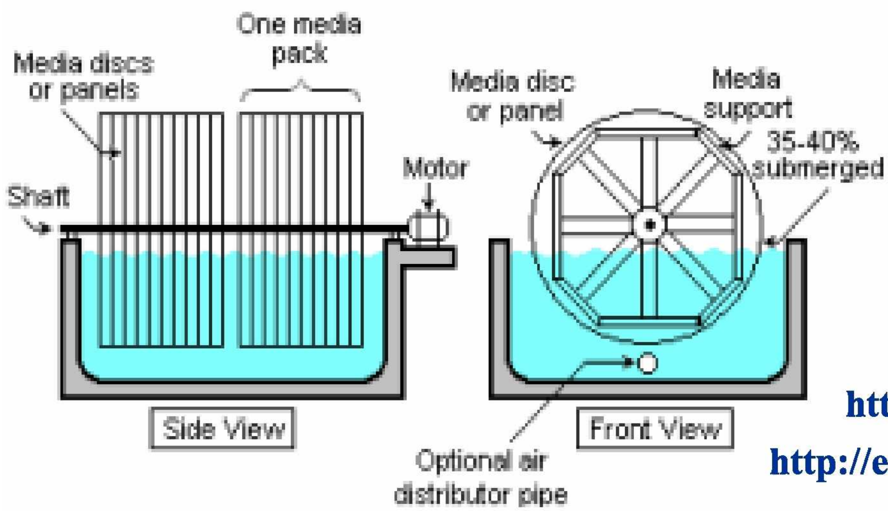
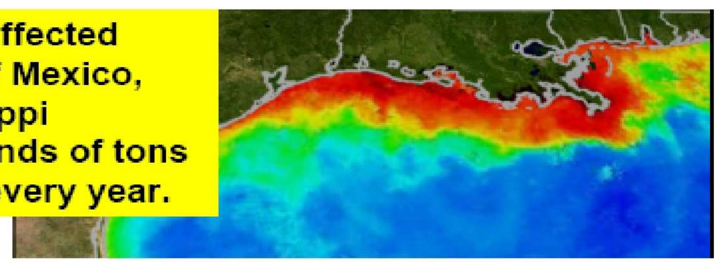



Photo: Kirsten Rodsgaard-Mathiesen©

**http://www.aquaflowgroup.com/pressroom.html**

**http://en.wikipedia.org/wiki/Sewage_treatment**

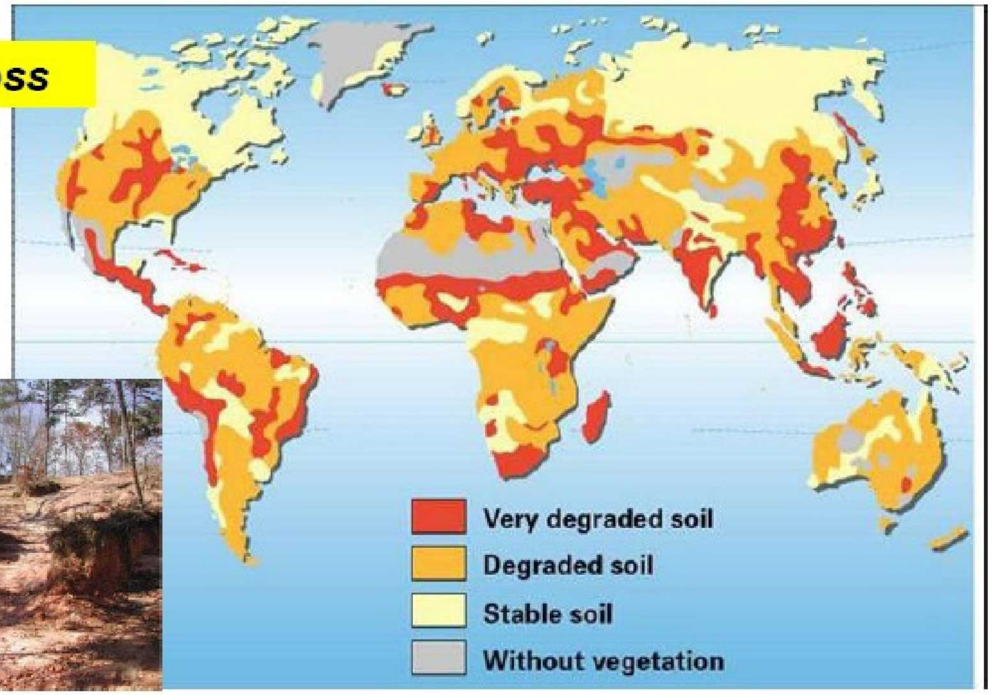
**Among the worst affected areas is the Gulf of Mexico, where the Mississippi discharges thousands of tons of agrochemicals every year.**



**Mario R. Tradici, Mario, R. (2008) Microalgae biofuels: potential and limitations. Algae Biomass Summit, Algae for Energy, Seattle Washington 23-24 October 2008 http://algalbiomass.org/, Department of Agricultural Biotechnology University of Florence, Italy**

# Soil Loss Issues

**IV - Soil loss**

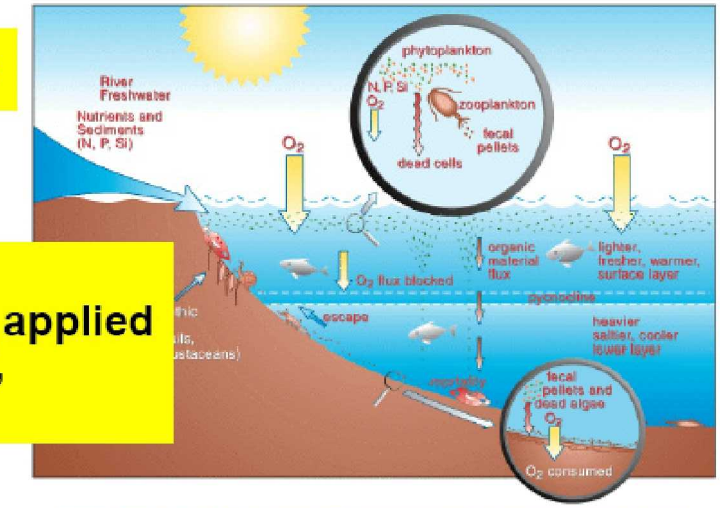



- there is a loss of about 5-10 million ha arable land a year.

**Mario R. Tradici, Mario, R. (2008) Microalgae biofuels: potential and limitations. Algae Biomass Summit, Algae for Energy, Seattle Washington 23-24 October 2008 http://algalbiomass.org/, Department of Agricultural Biotechnology University of Florence, Italy**

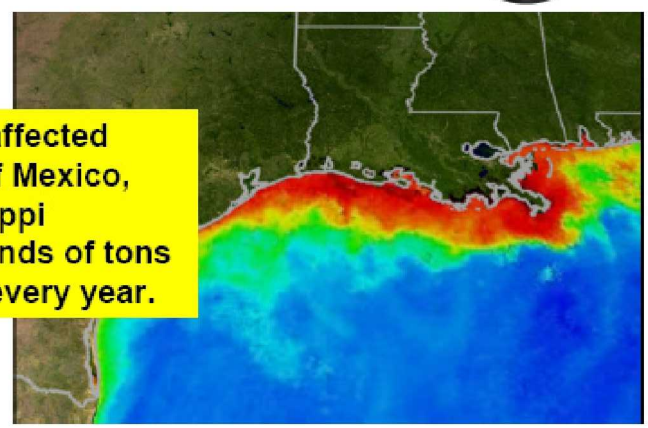
# Nutrient Runoff and Ocean/Bay Dead Zones (hypoxic)

***V - Ocean dead zones***




**Up to half of all nutrients applied on farm are lost in runoff, leaching or erosion.**

**Among the worst affected areas is the Gulf of Mexico, where the Mississippi discharges thousands of tons of agrochemicals every year.**



**Mario R. Tradici, Mario, R. (2008) Microalgae biofuels: potential and limitations. Algae Biomass Summit, Algae for Energy, Seattle Washington 23-24 October 2008 http://algalbiomass.org/, Department of Agricultural Biotechnology University of Florence, Italy**