



Sustainable Secure Alternate Aviation Fueling

R.C. Hendricks

NASA GRC

Cleveland, OH 44135

Drivers

- **Energy** source for aviation fuels and biodiesel
- Conservation of fresh**water**
- Sustainable **food** source
- Positive global **climate** benefit

2007 NASA Seal/Secondary Air System Workshop

November 13-14, 2007

Ohio Aerospace Institute (OAI) Cleveland Ohio 44142



Sustainable Secure Alternate Fuels Workshop

www.atlanticgreenfuels.com

World Aviation 85 B gallons/yr

101 (20 Million bbl storage facilities)

About 12% of Transportation Industry



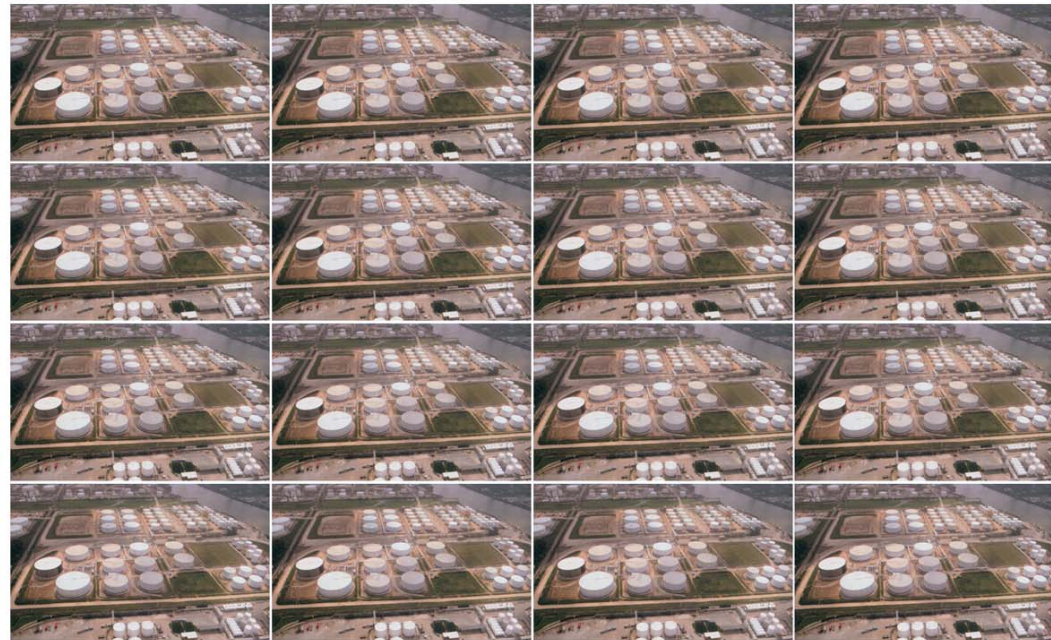
US fleet used 13.6B gallons

US Domestic
Commercial
Aviation



13.6 B gallons/yr

16 (20 Million bbl
storage facilities)



16 (20 Million bbl storage facilities)

<http://tonto.eia.doe.gov/ftproot/international/edexfiles/nepal.ppt#285>,
1, World Energy Outlook: Near and Mid Term Projections

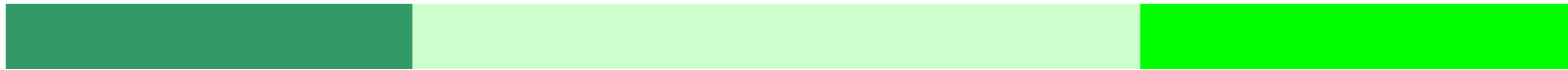


Synthetic and Biomass Aviation Fueling ¹

Before	1859 →	1939-1941	1943	WWII	1944
1860	Titusville	Jet	64 yrs ago	1944	US synfuel Program
Synfuels	Cheap Oil	Engine	Nov-43	25 German	
		VonOham	Congrsman	Synfuel plants	
		1939	Jennings	124000 bbl/day	Whittle
		Gasoline	Randolph	95% Av Gas	Kerosene
		Whittle	Flight from	Patton	JP1 (-60C)
		1941	West Va	power tanks	Standard
		Kerosene	to DC	ersatz gasoline	availability
			Syn Fuel	(synfuel)	Naphtha
					Kerosene
					Mix



Synthetic and Biomass Aviation Fueling ²



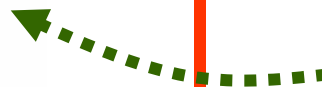
1970's Hsu [NASA]	1990	1997→	2004-2006
Biomass Fueling	Baylor	Sasol	NASA/Boeing
NASA Algae for O2	Beech	Synfuel	Fuels
	King Air	S. Africa	Initiative
1984	Turboprop	Domestic	Impact on
Embraer	Flights	International	Aviation and
biokerosene	Blend	Com.Flights	Global Climate
turbo--prop	20% bio	18%-25%	CAAFI-2006
Flight	80% kero	Blend	Seattle
São José to	25000ft	Synfuel	LM2500 / CF6
Brasília	60 hr total	+ Jet A	Cruise Ship
Prof. Parentee	PWC-PT6A	(max 50%)	Biodiesel



Several marine operators have been running biodiesel in their aero-derivative engines for about 2 years.

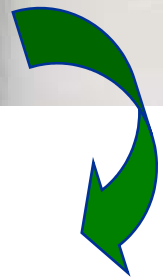


CF6 Aero Engine (core of LM2500 engine)



Aero-derivative LM2500 Cruise Ship Engine

Dave Daggett Boeing





Synthetic and Biomass Aviation Fueling ³

2007	2007	2008	2008	2009→	2011
Aug-07	Oct C17 flight	Virgin	NASA	Biofuels	USAF
B52H flight	50:50 blend	Quatar	plant/algae	Embraer	Fleet
50:50 blend	Turbofan	Air New	growth	Synfuels	Certi
JP8+Synfuel	AtlanticGreen	Zealand	saline + arid	DarpaBAA	
Turbojet	Fuels Wkshp.	747	ag.plant oils	cellulosic	
2007 2 Oct	CAAFI-2007	Flights	FT plant	Algae oils	
Green Flt.Int	CFM green	DarpaBAA	Sector tests	halophytes	
Czk L29	engine ME	NASA/PW	fuel blends	DOD	
Centrfg.Comprs	Alage Summit	Eng.Test	properties	Eng.Tests	
Veg. Oil	NASA Fuels	Life Cycle	handling	Flt.Tests	
Flight	Program	Issues	Combustion		



B52H & C17 Fight Testing [Synthetic + JP8 fueling]

Fueling the future



8 Aug 2007

B52H Certified
50:50 Blend
Synfuel + JP8

22 Oct 2007
C17 flight - all
engines 50:50
Blend





L- 29 Flight: Biodiesel Solutions Vegetable Oil

October 2, 2007, Green Flight Int. Chief Pilot Carol Sugars and Douglas Rodante



<http://www.greenflightinternational.com/index.htm>



Biojet fuel production process

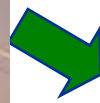


Biocrude Oil

DARPA BAA06-43 directed at low cost crop and weed biocrude Triglyceride oils conversion to JP8.

[UOP, Univ. N.Dakota, and GE processes remove Oxygen]

Scaling up for pilot plants



Refining Process



Biojet Fuel

Dave Daggett Boeing



Triangle of Conflicts : Energy Water Food

Global Climatic Change

Anthropogenic Energy Demands
CH₄ release (stranded and hydrates)
Freshwater depletion
Desertification rise
Sea Level rise

Population

6.6 B	2007
9B-10B	2050

Need 40% increase Earth arable land

Developing Countries

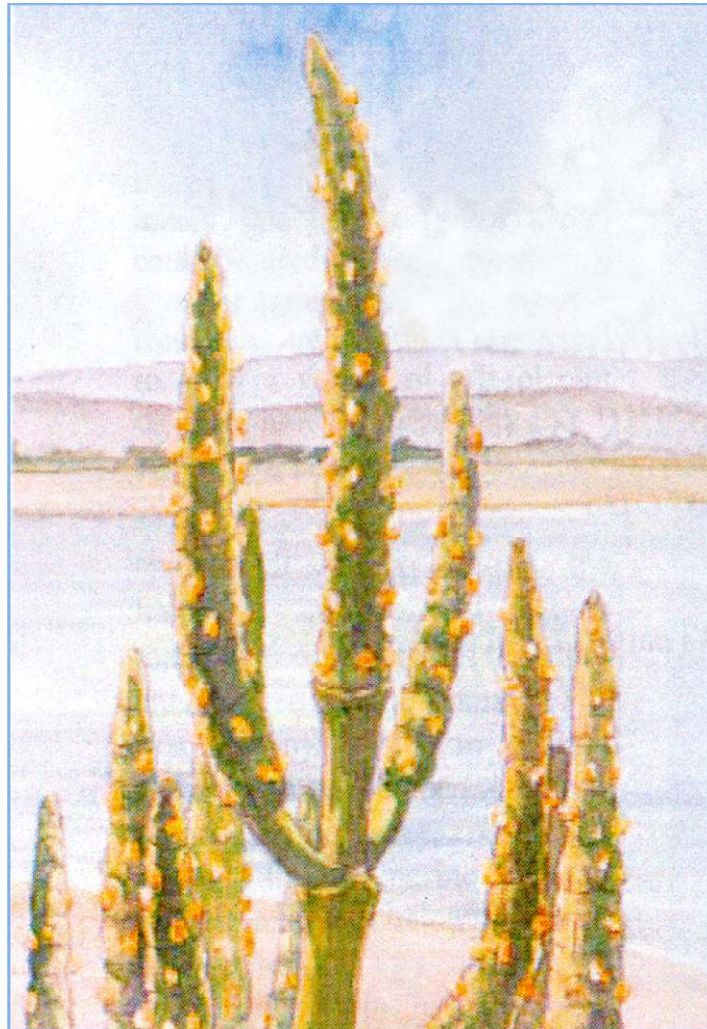
Major market growth
Energy Water Food demands



Halophytes are Salt Water Tolerant Plants

Typical Halophyte is Salicornia (glasswort)

Ed Glenn U of Arizona
Hendricks and Bushnell,
ISROMAC12-2008-20241



Oil-seed yield
2000 kg/ha

Projected yield
20 000 kg/ha

Coastal
Seawater
Agriculture +
Aquaculture

Arid land
recovery

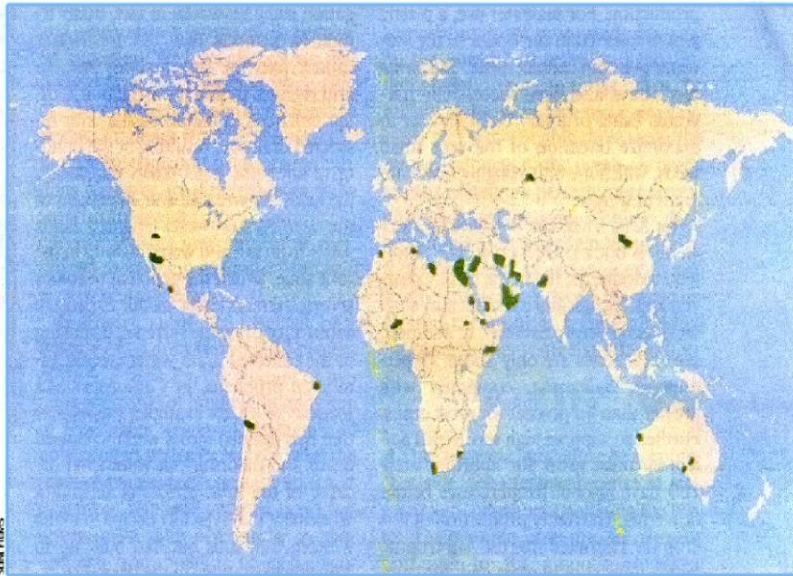


Potential Costal and Inland Halophyte & Algae Sites

43% Earth's land is arid or semi-arid

97% Earth's water is seawater

50% world population within 50km coastline



Hendricks and Bushnell,

ISROMAC12-2008-20241



Costal regions most suitable for halophyte agriculture and aquaculture

Ed Glenn (U of Arizona)

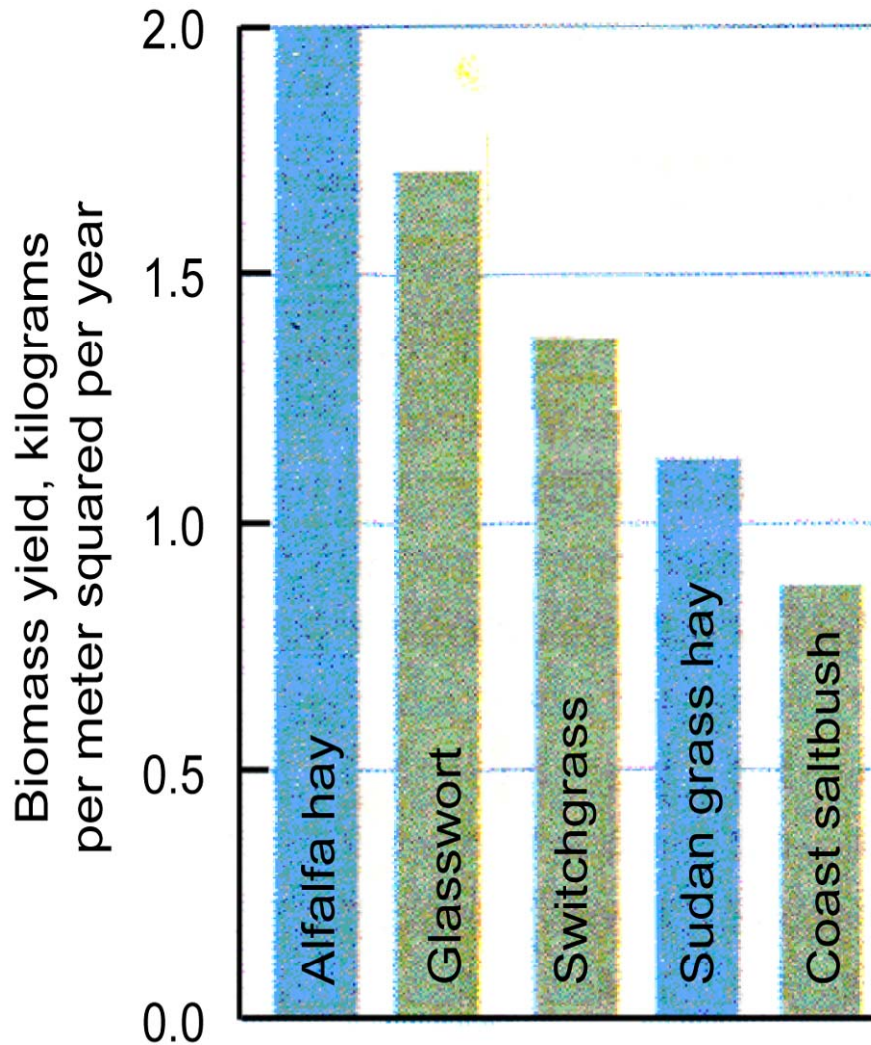
Inland regions abound and can be pumped from aquifers

Nicholas P. Yensen



Halophyte and Glycophyte Crop Yields

Halophyte production similar to conventional crops



Hendricks and Bushnell,
ISROMAC12-2008-
20241

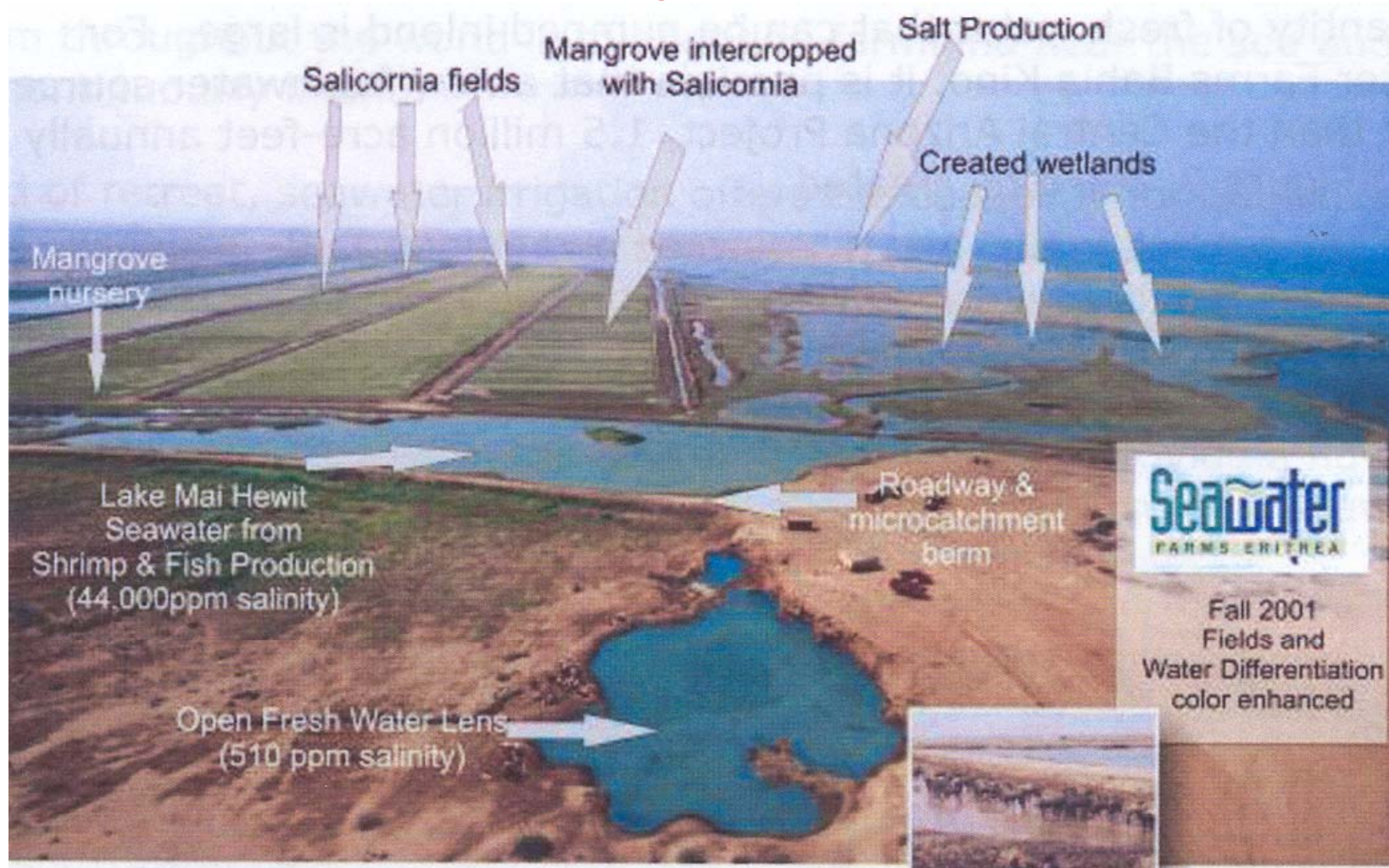
Salicornia
(glasswort)
Seed
31% Protein
28% oil
5% fiber
5% ash

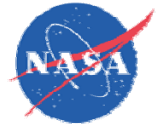


Seawater Agriculture + Aquaculture Farms

Eritrea Halophyte Project

www.atlanticgreenfuels.com

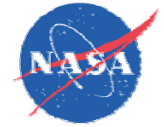




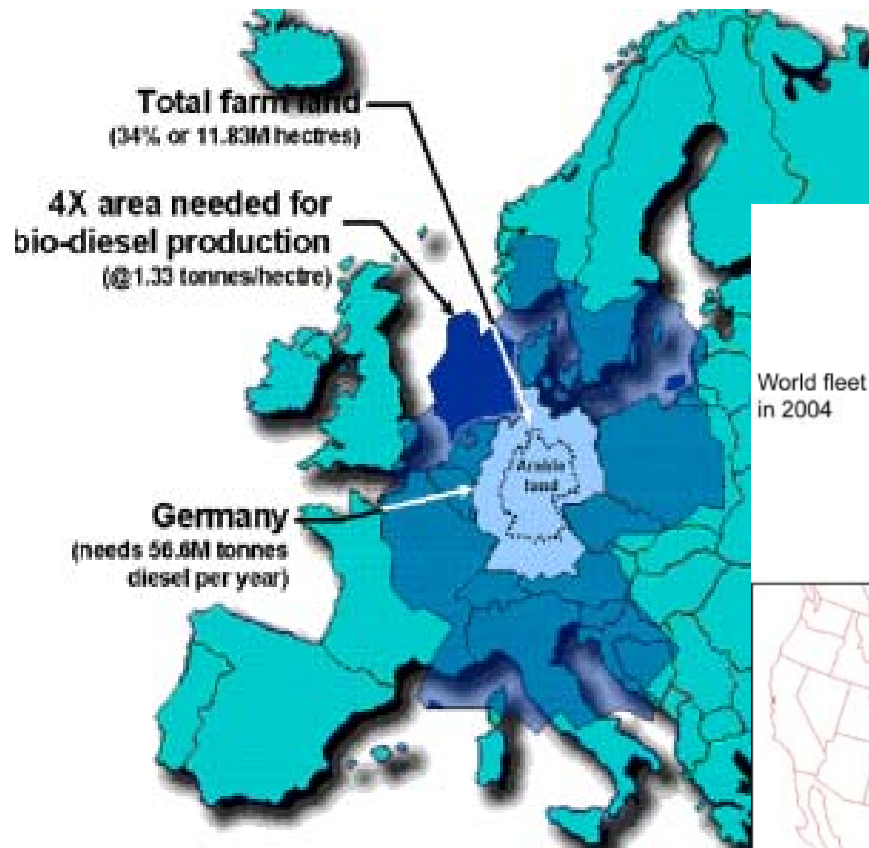
Some projected Alternate Fuel Feedstock Production

Hendricks and Bushnell. ISROMAC12-2008-20241

Feedstock crop	Fuel	Production rate, kg/ha
Halophyte ^b	<u>biodiesel</u>	770
Projected		7500
Algae ^c	biodiesel	
Lower limit		43 090
Upper limit		172 360
Jatropha (India)	biodiesel	3 000
Palm oil (Malaysia)	biodiesel	5 000
Switchgrass ^d	ethanol	2 375
Sugarcane ^e	ethanol	2 790
Miscanthus giganteus ^f	ethanol	11 290
Seashore dropseed ^g	ethanol	6 970
Salt grass ^h	ethanol	6 020

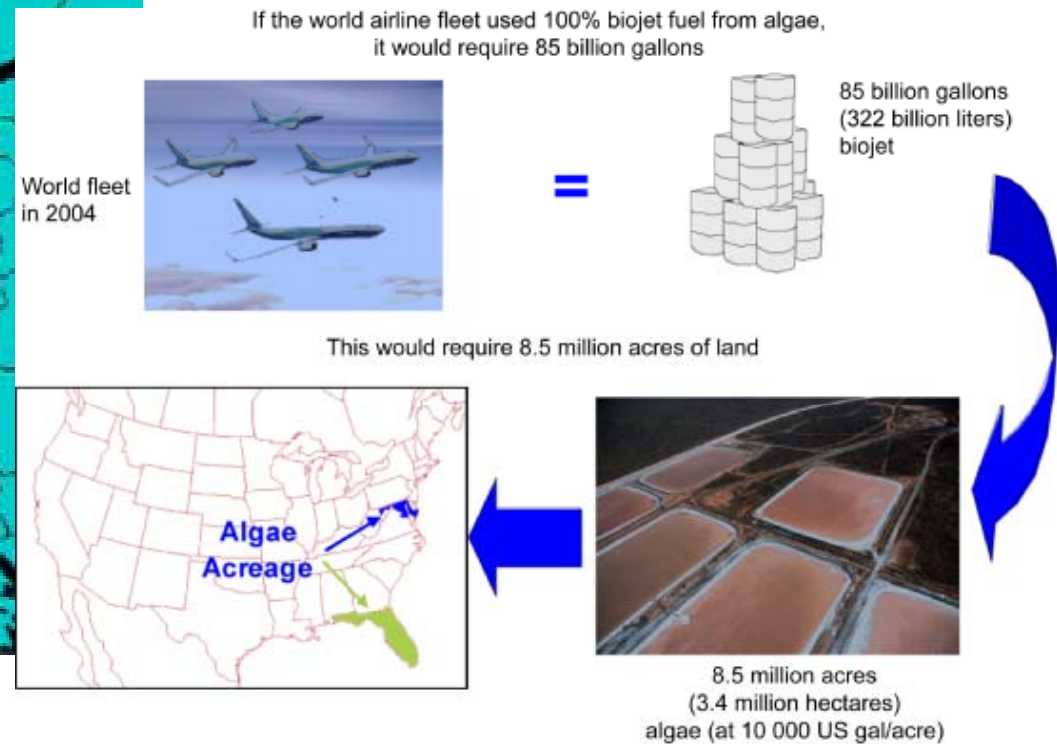


Food-Crop vs Algae biofuel Land Needs



Insufficient crop land to satisfy German Biofuel (rapeseed or soy) needs at 56.6Mmt/yr biodiesel

Algae biofuel production *potential* to 300 X soybeans



World Aviation needs US Algae Area about size of Maryland (optimistic) [Florida (more realistic)] to produce 85 B gal/yr (260Mmt/yr)



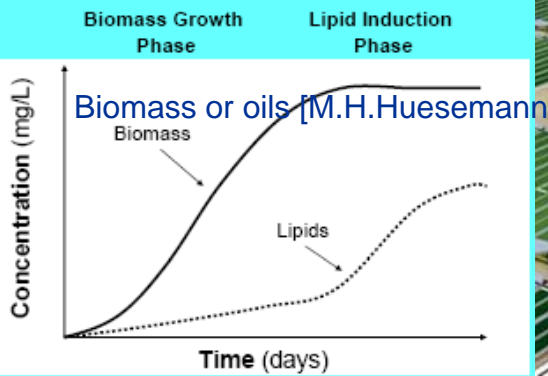
Algae Systems : Powerplant CO2 capture, bioreactors, circular and racetrack ponds, combined solar-bio



Berkely Ponds

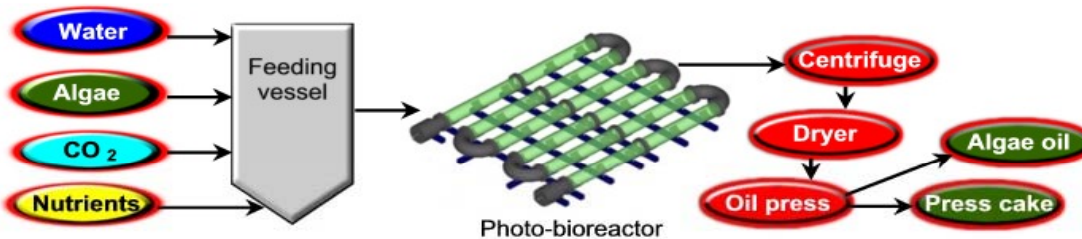
Maximization of Lipid Productivities

(Note: LP = BP · f_i)



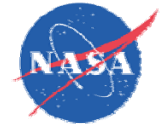
Solix ponds : <http://www.solixbiofuels.com/>

Process flow diagram of a photo-bioreactor plant



A. Ben-Amotz Israel

BioKing, BV (Algae Link): http://www.algaelink.com/algaelink_photo_bioreactors.htm



Algae Oil Extraction Process Need to Drive Costs Down

Algae Biomass Summit, Nov. 15-16, San Francisco, CA, USA.
[http://www.wsgr.com/WSGR/Display.aspx?SectionName=news/
emailer/Event141/info.htm](http://www.wsgr.com/WSGR/Display.aspx?SectionName=news/emailer/Event141/info.htm)

DARPA BAA08-07 directed at low cost cellulosic and algae based JP8.



Harvested Algae

Dave Daggett Boeing



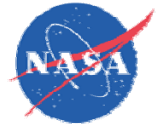
- Examples are:
- Expeller/Press
 - Hexane Extraction
 - Supercritical Fluid
 - Enzymatic
 - Ultrasonic
 - Etc.

**Oil Extraction
Process**



Biocrude Oil





Halophytes, Algal and Cellulosic Concerns

- Algal and Bacterial growth are rapid
- Lipids (oils) lag biomass production : which is needed?
- Cellulosic digesters EversTech process
(www.atlanticgreenfuels.com)
- Algae (open or covered) ponds and bioreactors
- Combined solar PV and bio systems
- **ISSUES**

Water source (sea, brakish, fresh)

Carbon Source CO₂ (coal, gas, hydrocarbon, sea, air)

Nutrients (fertilizer requirements)

Sunlight (capture and utilization)

Genetic Modifications (high lipid vs biomass ?)

Seawater Communities (synergistic approach)

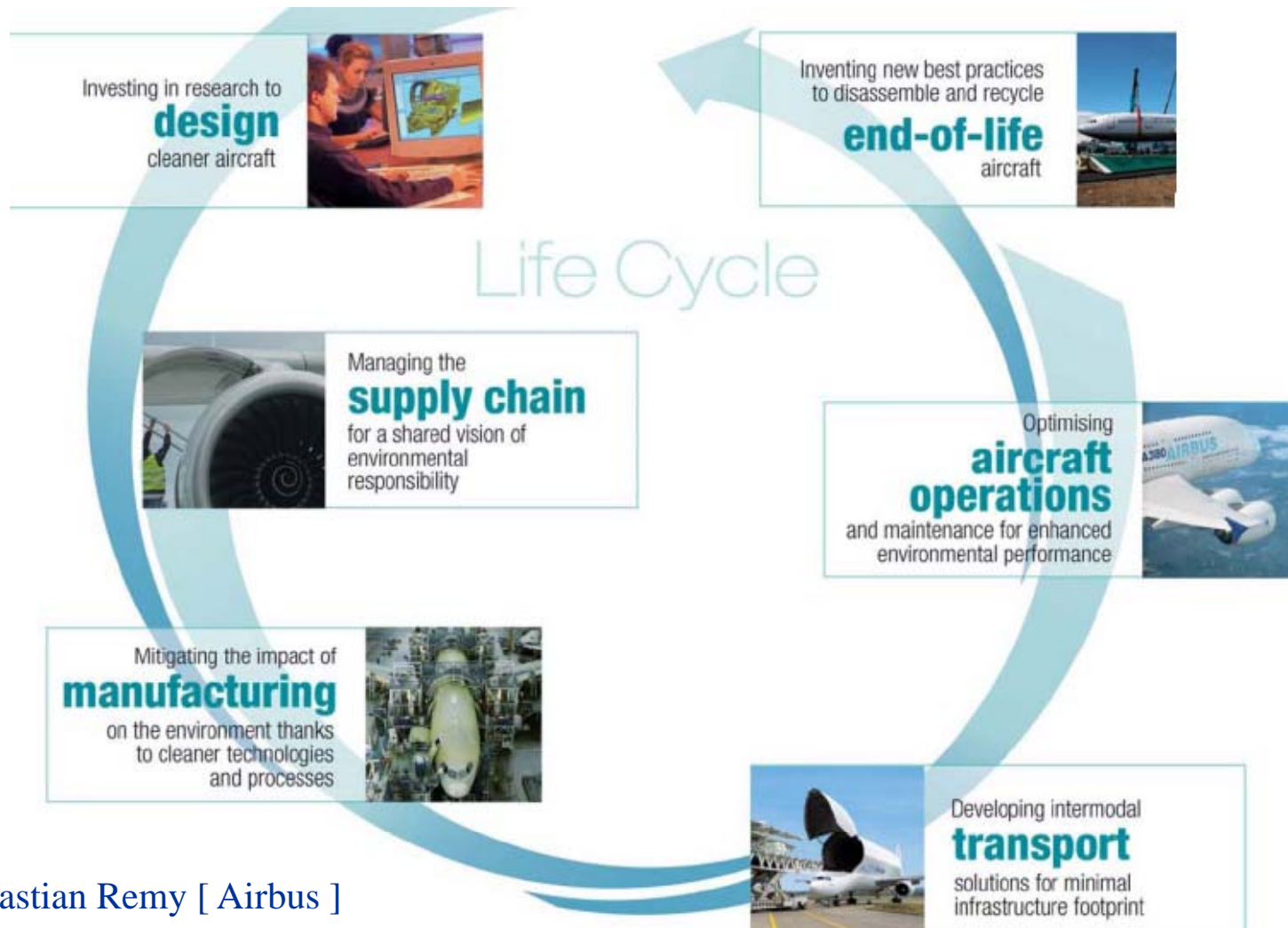
Imaging (site location and climatic changes)

Bio Fuels Competitive Processes

Anthropogenetic Impact on planet



Alternate Fueling Life Cycle Issues Carbon Capture (Sequestration) System Climatic Carbon Benefits



Sebastian Remy [Airbus]



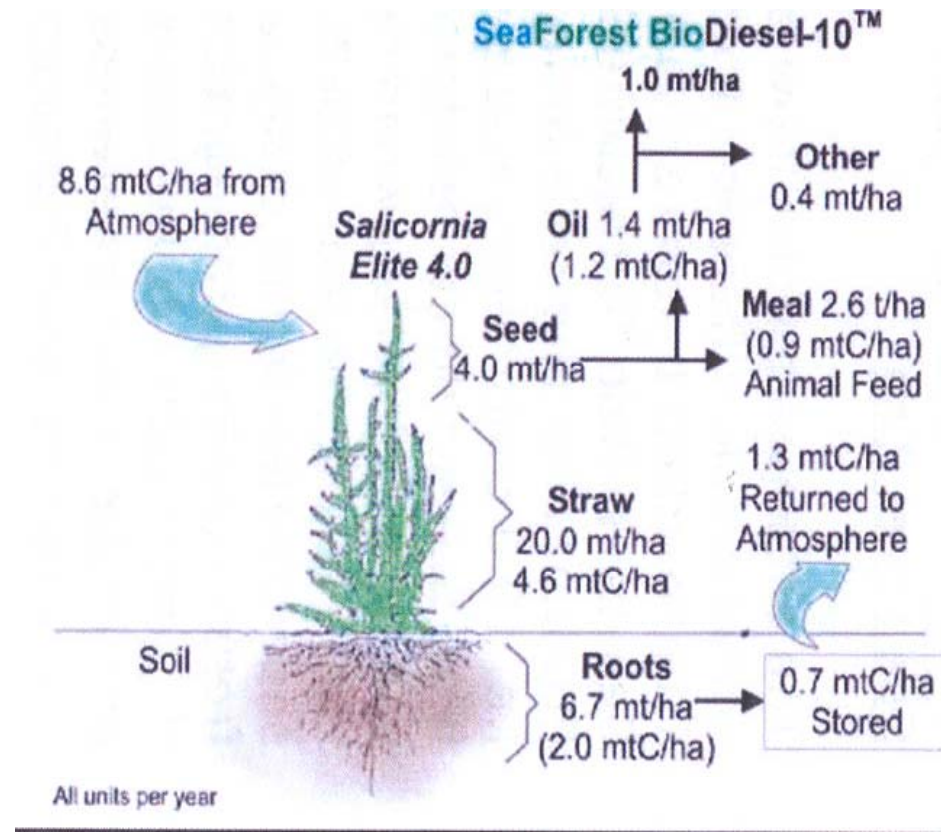
Halophyte Environmental Impact (Seawater Farms) Potential for Carbon-negative Aviation via Carbon Credits

Also, Hendricks ISROMAC12-2008-20242



Symbiotic Salicornia
and Mangroves
(Eritrea)

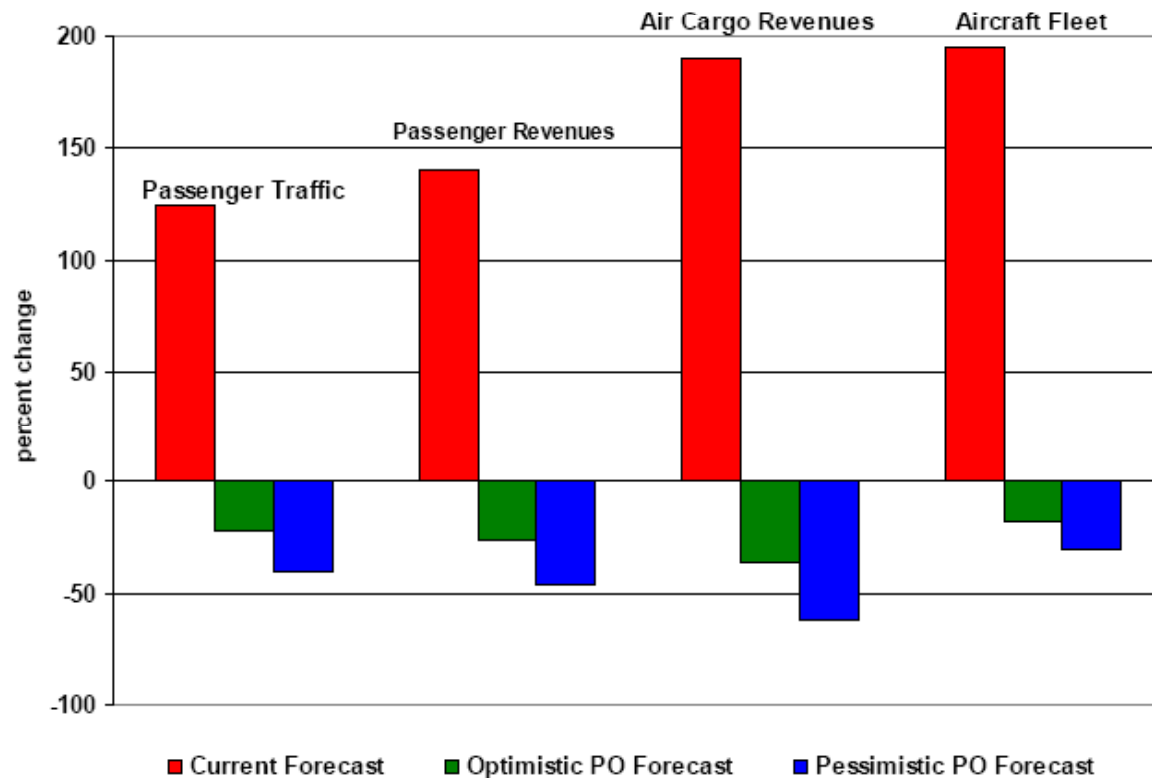
Carbon Balance





Peak-Petroleum Declining GDP Induced Impact = Our Major Concern

WORLD AVIATION FORECASTS, 2008 – 2026, UNDER THREE SCENARIOS



Industry
Projections = Red
(Unrealistic ?)
Assumes Peak in 2008
Not a Prediction

1% GDP
decline = Green

2% GDP
decline = Blue

Focus on GDP, not cost alone

Roger H. Bezdek [www.misi-net.com]



Sustainable Secure Alternate Aviation Fueling

Humanity Challenges: We live within a **Triangle of Conflicts made up of demands for **energy**, **water** and **food**.**

Sealing challenges abound

- Deep Water Drilling and Transfer Line Connections
- Synthetic and Biomass fuel lines, pumps, combustors
- Processing plants synfuel and biomass reactors
- Legacy aircraft fueling materials and fuel tank compatibility
- Biomass containment and Filtration
- Halophytes [plant and algae and cellulosic] processing
- 2008-2009 Synfuel and Biofuel Blend Flight Tests Commercial Airlines
- Economic Impact of “peak-oil” : watch GDP.

2007 NASA Seal/Secondary Air System Workshop
November 13-14, 2007
Ohio Aerospace Institute (OAI) Cleveland Ohio 44142



B52H Certification 50:50 Blend Synfuel+ JP8



1. The black ring represents the nation's huge coal reserves as a potential resource for synthetic fuel
2. The green branches represent biomass feedstock and environmental friendliness
3. The white letters represent the cleaner emissions from synthetic fuel
4. The B-52 represents the first aircraft in the certification process (and it's just "plane" cool)
5. The Latin is: "First in the Nation" representing the first aircraft to be certified to use synthetic fuel
6. The gold banner signifies the bright future and sovereign options this effort offers
7. The eight stars represent the primary implementation organizations
Secretary of The Air Force, Arnold Engineering Development Center, Air Force Research Laboratory,
Air Force Materiel Command, Air Combat Command, Oklahoma City ALC, Air Force Petroleum Office,
Air Force Flight Test Center
8. The blue sky represents the Air Force above the clouds, with a clear vision of the future, and on mission

BioFuels As An Alternative Energy Source For Aviation



by

Dr. Bilal Mark McDowell Bomani

Overview:

The use of BioFuels have been gaining in popularity over the past few years due to their ability to reduce the dependence on fossil fuels. Biofuels as a renewable energy source can be a viable option for sustaining long-term energy needs if they are managed efficiently. We are investigating past, present and possible future biofuel alternatives currently being research and applied around the world. The overall goal is to investigate the feasibility of using ethanol, cellulosic ethanol, biodiesel (biodiesel blends, e.g., palm oil, algae, halophytes), synthetic fuel, methane and Hydrogen that can potentially be used as fuels for aviation and non-aerospace applications, in a controlled environment.

Team Members:

Dr. Dan Bulzan – Project Manager (RTB0)

Mr. Robert C. Hendricks (ST – R)

Dr. Bilal Mark McDowell Bomani (REB)

Diana Centeno-Gomez (REB)

Technician (TBD)



Proposed Greenhouse to be built next to Building 333 next to the solar arrays.

Biofuels lab will also be in Building 333, rm 302



Chaetamorpha species

Chaetamorpha – a highly successful saltwater algae used in the saltwater aquarium industry. This species has proven to be very hardy and grows extremely fast.

(Also considered a halophyte)



Halophyte species

Halophytes– a seed plant that grows in habitats excessively rich in salts, such as salt marshes, sea coasts, and saline or alkaline semideserts and steppes. e.g, Salicornia, Seashore mallow

GRC BioFuel Research Goals :

To Build a Greenhouse (currently being purchased) investigating up to 6 biofuel plant species including but not limited to (Halophytes, Chaetamorpha, Jatropha, Mangroves, Salicornia). Each plant species will be evaluated for their use as an alternative fuel. More specifically, we plan to investigate the feasibility of using marine algae, halophytes as well as glycophytes for use as biofuels for the aviation industry that will provide some insight and guidance into the large-scale research and development of renewable energy sources in the future.