Biomass and Biofuels Pathways

UCC501 Sustainable Energy, Fall 2014

Instructor: Dr. Alejandro Rios G.

Masdar Institute

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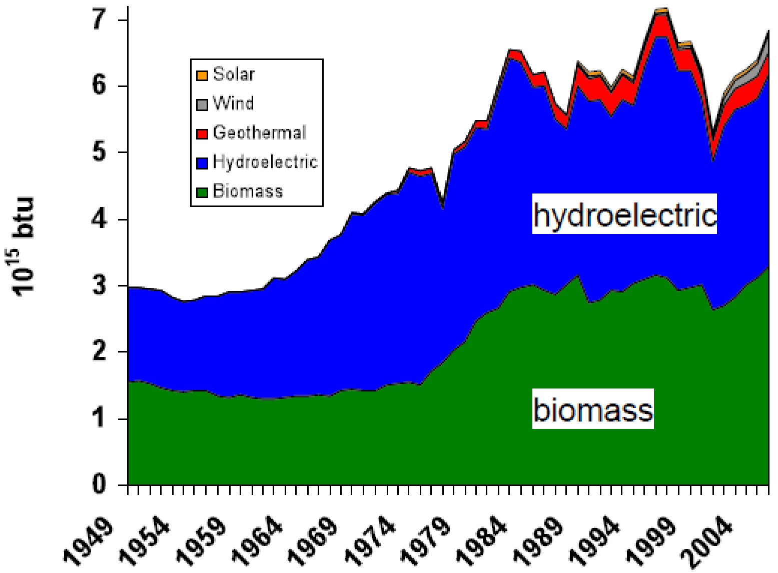
Contents

Biomass Attributes

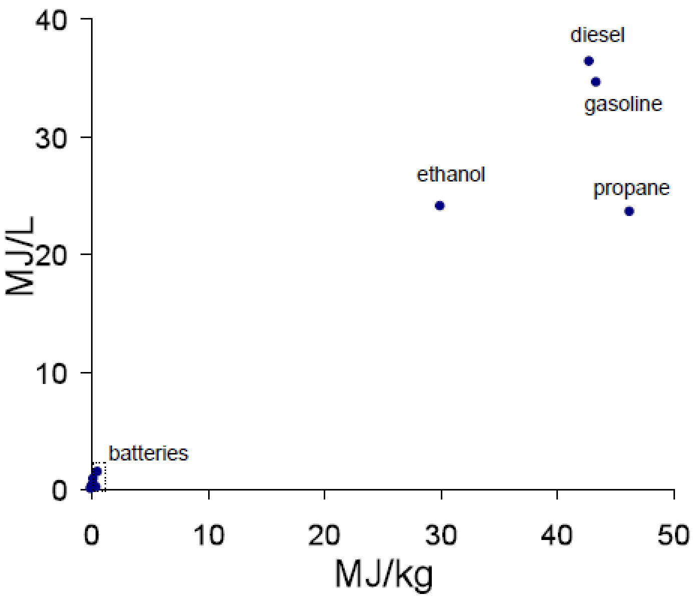
- Renewable
- Connected to farming and agriculture – employment
- Multiuse – food, shelter, energy, materials
- Environmental concerns include land and water use, fertilizer and other nutrient requirements
- Naturally diffuse and distributed – harvesting and transport and distribution are important

Biomass: Major Renewable Source of Liquid and Gaseous Fuels

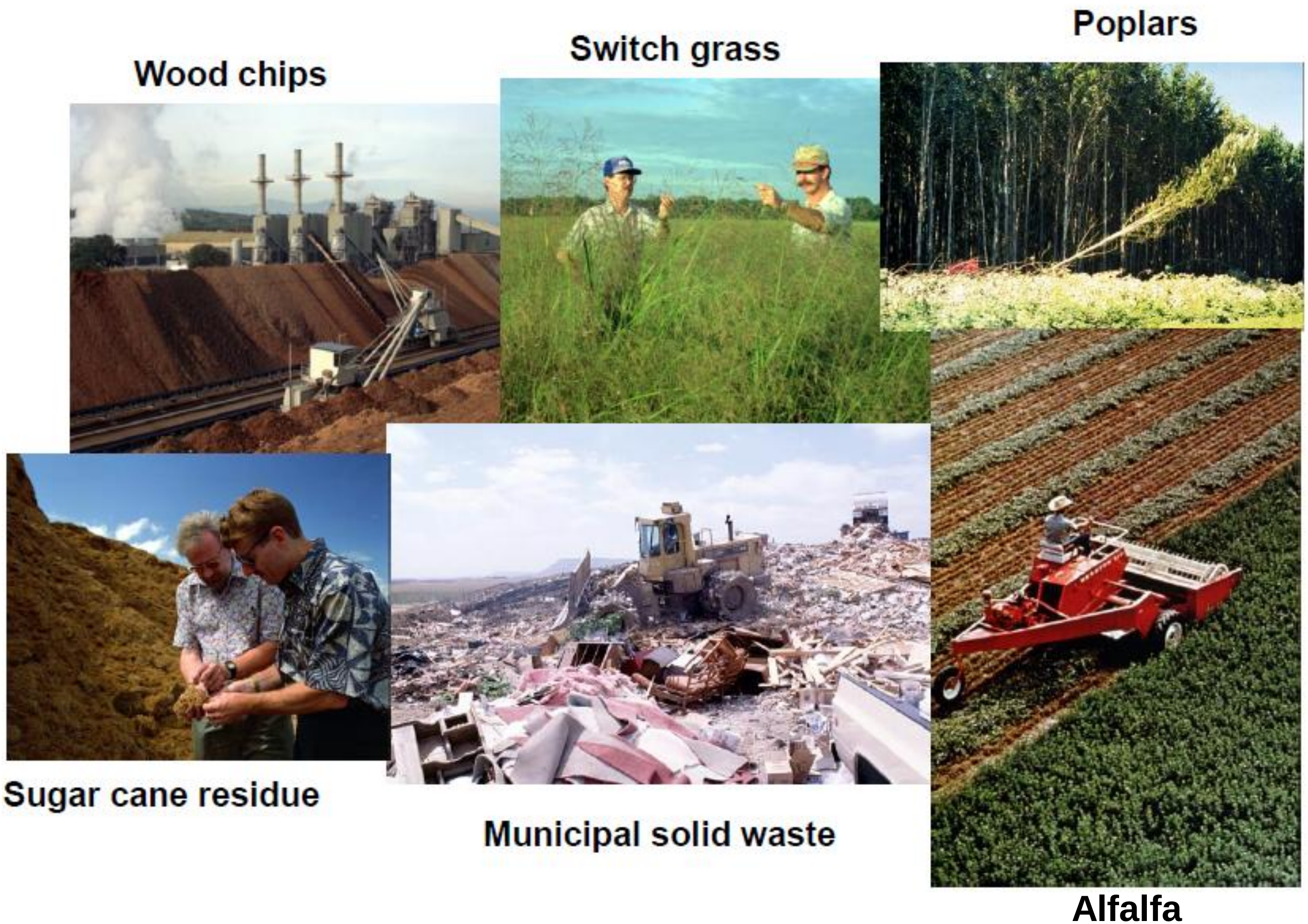


Biomass is currently the largest source of renewable energy in the US and the world, and the only renewable source capable of producing fuels with current technology.

Liquid fuels offer superior energy storage and transportability.



Biomass Feedstocks for Fuels and Energy are Diverse



Potential Opportunities for Biomass

1. Reducing CO_2 greenhouse gases by replacing/displacing fossil fuels

2. Improved management and utilization of forest resources

3. Rejuvenating agriculture industry

4. As a renewable carbon source in an long-term energy future dominated by non-carbon based electricity from nuclear, wind, hydro, geothermal, and solar, biomass becomes a significant raw material for: liquid hydrocarbon fuels, chemicals, and other high value products

But challenges are great too!

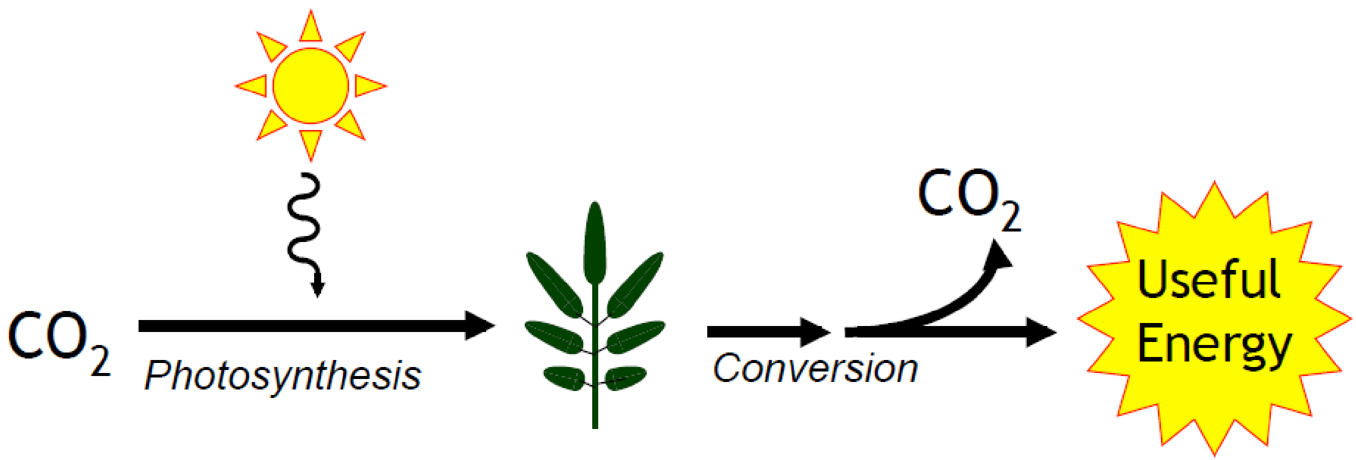
Environmental and Sustainability Issues

- Land use – for production, storage, conversion and distribution
- Water use
- Food versus biofuels and bioenergy -- 40%+ of world's population is undernourished
- Emissions from production, conversion, and end use – from commercial-scale combustors to wood stoves
- Nutrient requirements – fertilizer, etc.
- Herbicide and insecticide impacts
- Carbon and nitrogen balances in soils
- Biodiversity impacts of monoculture
- Employment and $ impacts
- Infrastructure impacts – for storage and T&D

Calls for a full life cycle analysis to quantify net energy balance, extent of CO_2 neutrality, and other environmental effects

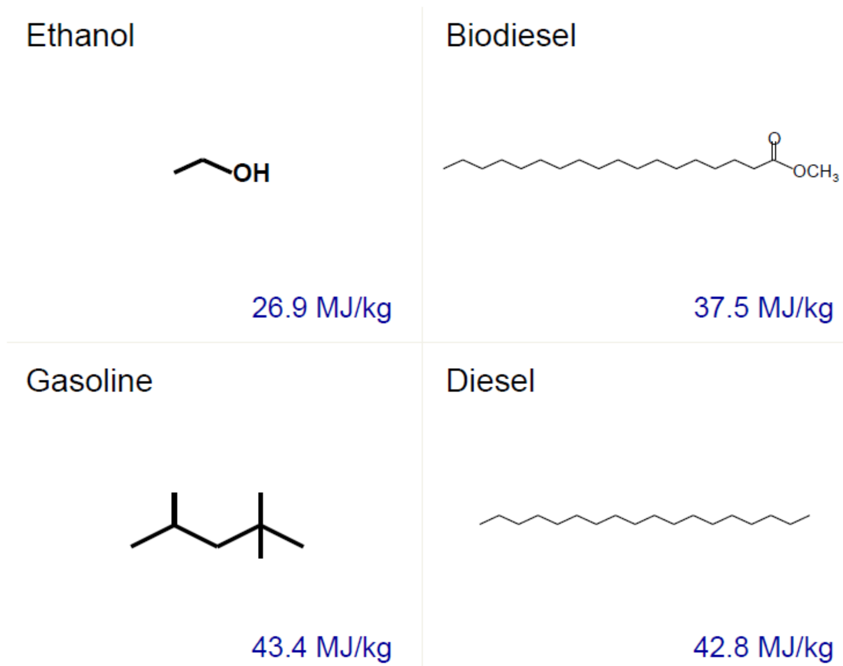
Biomass Characteristics

- Biomass energy is a form of solar energy
- Solar energy is captured via photosynthesis as carbon dioxide is incorporated as fixed carbon during the growth stage of all biomass
- Average solar incidence is about 1000 W/m^2
- Biomass solar capture efficiency is low – from 0.1 to 2 % (PV conversion efficiency is ~ 10-20% and solar thermal is 30% or more)



Biomass Characteristics

- Biomass contains more oxygen and is structurally different from fuels
- Most first-generation biofuels are imperfect fuel replacements



Biomass to Energy

Conversion Technologies

Biopower
- IGCC
- Combustion
- Cofiring
- Waste to energy
- Landfill gas
- Sewage or digester gas

Biofuels
- Ethanol
- Pyrolysis oil
- Hydrogen
- Methanol
- FT Liquids
- Biodiesel

Bioproducts
- Lactic acid
- Succinic acid
- Butanol
- Lipids
- Phenolics
- Propanediol

Processes for Conversion of Biomass

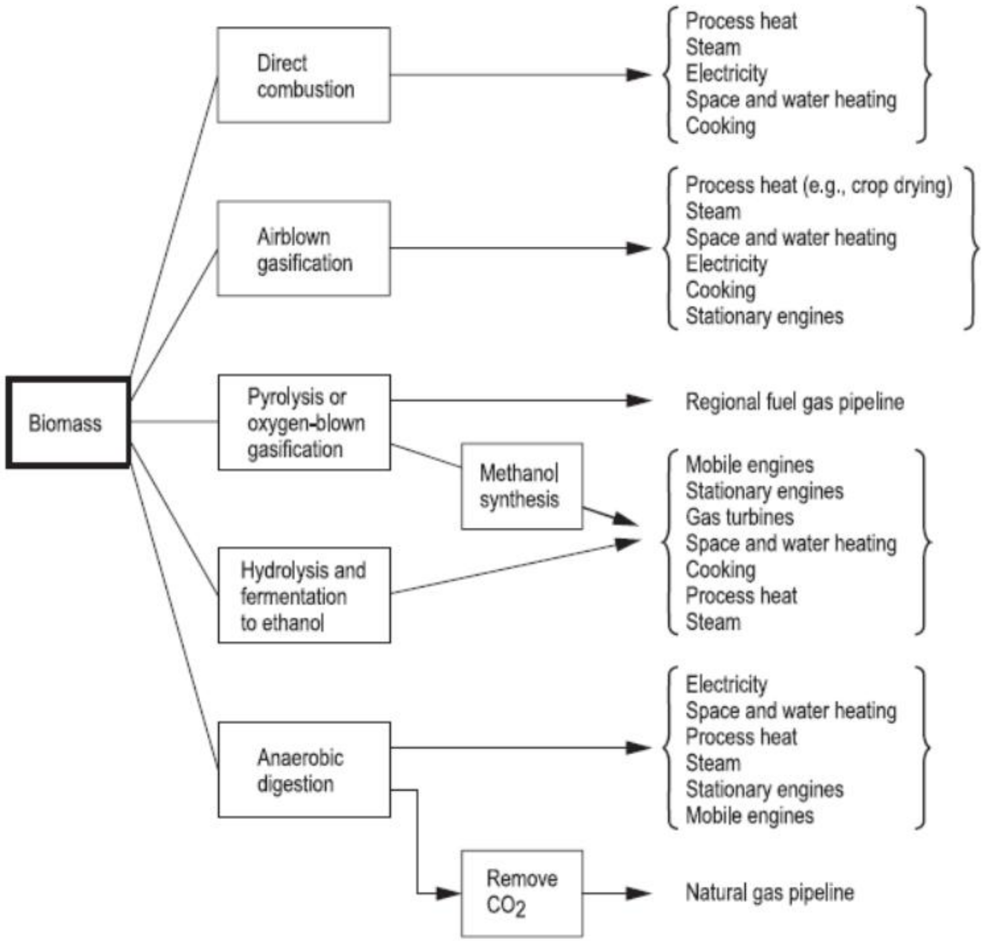


Figure 10.2. Processes for conversion of biomass to fuels, chemicals, and heat from various applications. Source: OTA (1980).

Conversion Techniques: 2 Main Camps

Biological

- Using microbes to convert biomass to fuels
- \+ Pros
  - Can make chemicals with high specificity
  - Works well in aqueous media at reasonable temperatures and pressures
- \- Cons
  - Requires specific chemical inputs (sugar)
  - Low throughput
- Examples:
  - Ethanol, CH_4, butanol

Thermochemical

- Using traditional chemical processing methods
- \+ Pros
  - Often doesn’t require chemical specificity of feedstocks
  - Higher throughput
- \- Cons
  - Extreme T, P may be needed
  - Subject to catalyst fouling, inorganic precipitation
- Examples
  - Biodiesel, syngas, CH_4, H_2, diesel, gasoline

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Chemical Conversion of Biomass to Useful Fuels

	Biomass	Conventional Fuels
State	• Generally solids	• Liquids or gases
Energy Density	• Low [Lignocellulose: ~10-20 MJ/kg]	• High [Gasoline: 43.4 MJ/kg]
Moisture Content	• High [Corn: 15% moisture delivered]	• No moisture content
Oxygen Content	• High [Often 10-40% oxygen]	• No oxygen content [<1% oxygen]
Compatibility	• Generally not compatible with existing engines, boilers, and turbines	• Combust efficiently in existing engines, boilers, and turbines

Biomass to Electricity

Examples of US installed capacity:

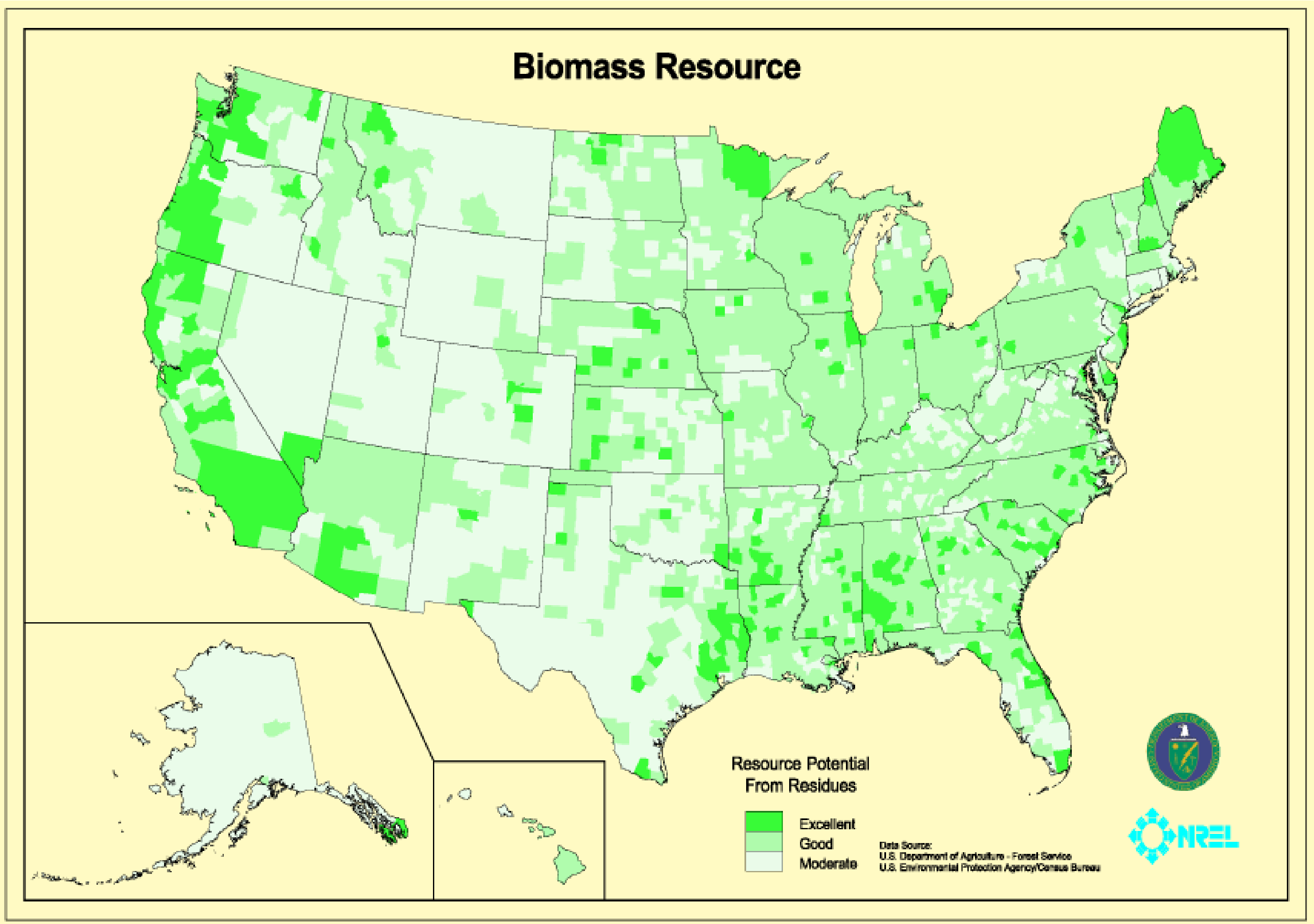
Type of Biomass	Number of Installations	Capacity, MW
Wood	259	5,332
Pulping Liquor	6	443
Bagasse and Other Ag Residues	39	669
Digester Gas	61	112
Landfill Gas	174	583
Tires	3	69
Total (Above + Other Sources)	678	10,006

Source: Adapted From Table 5-2 T.C. Schweizer, et al., EPRI Report No. TR-111893 (1998).

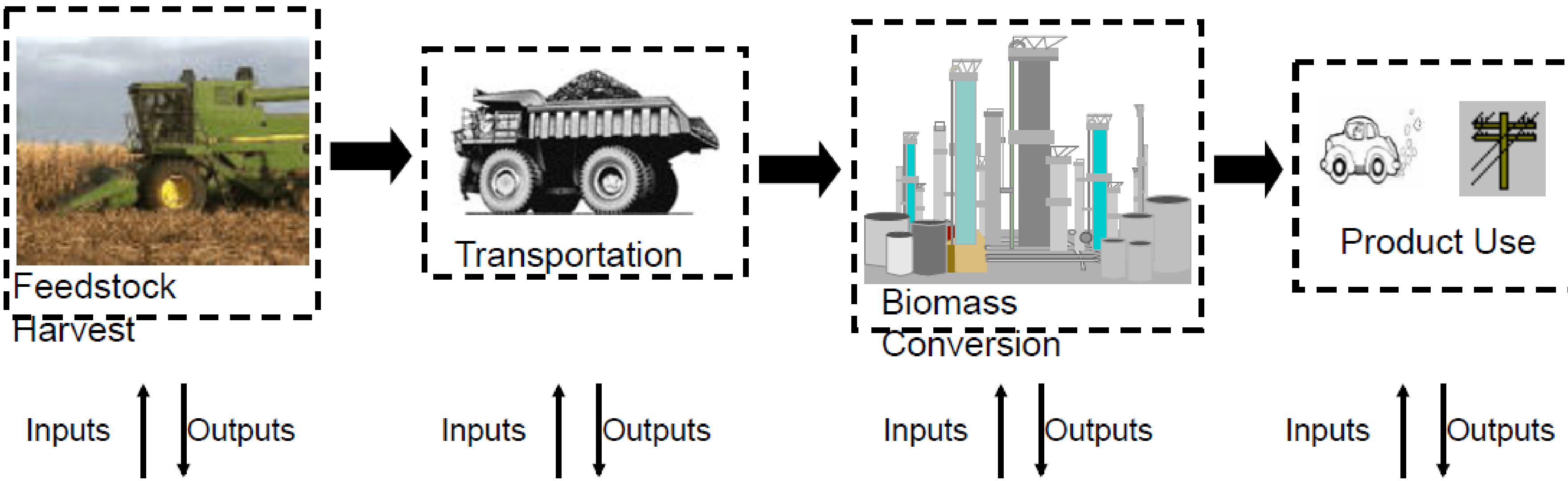
Challenges to a Broader Market Share: B to E

- Low heat to power efficiency of combustion steam turbines
  - 18--24% (14,000--19,000 Btu/kWh)
- Supply stability and economics
- Alkali and other trace metal deposits and emissions
- Particulate deposits and emissions
- NO_x emissions
- Cost of electricity
  - $0.065 – 0.08/kWh
- Lower energy density
  - Oxygen = 30-45 wt % dry basis
- Use of land, water, nutrients
- Displacement of higher value crops

Biomass Resource

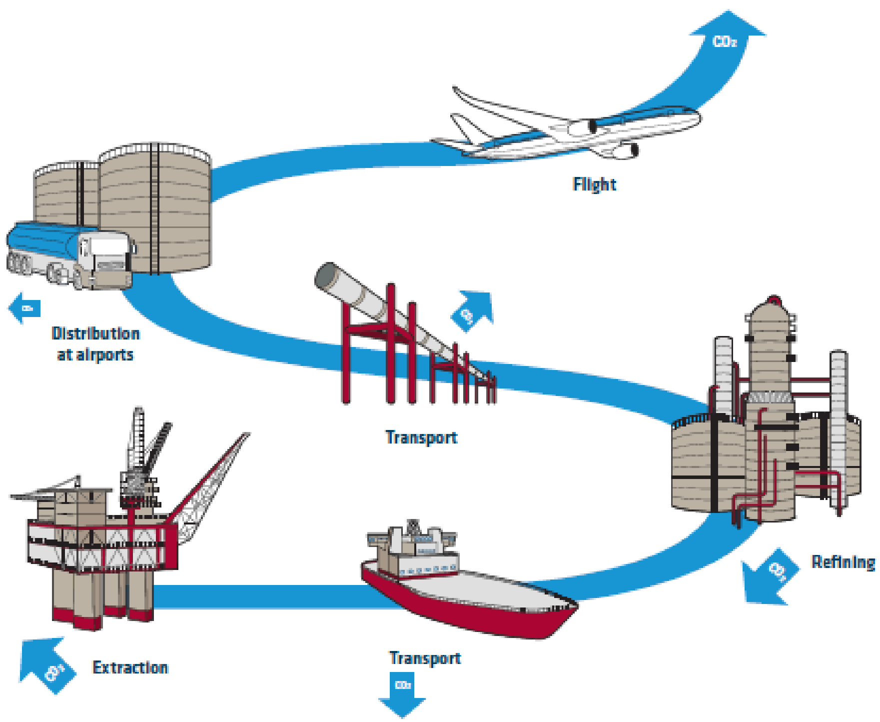


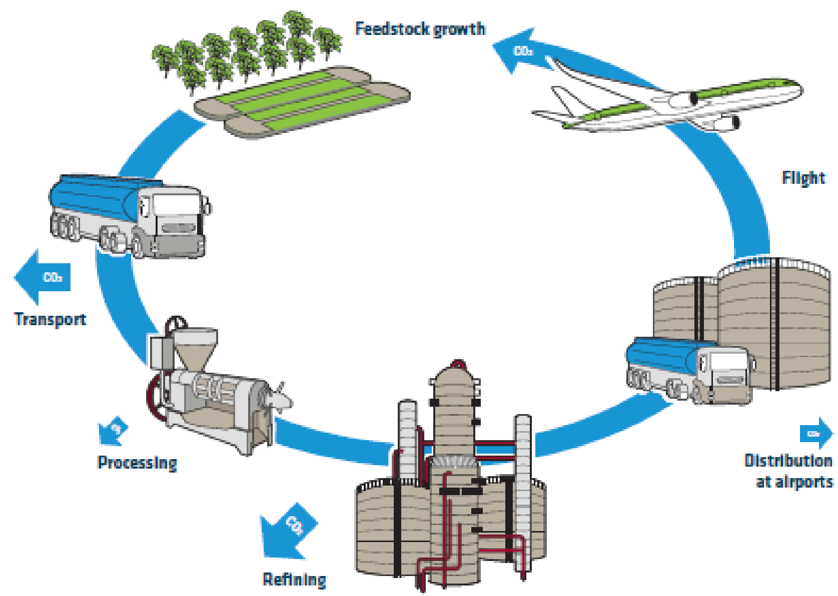
Biomass Process Evaluation



Biomass utilization contains energy inputs and emission outputs throughout the entire system – from farm to final use

Life cycle comparison





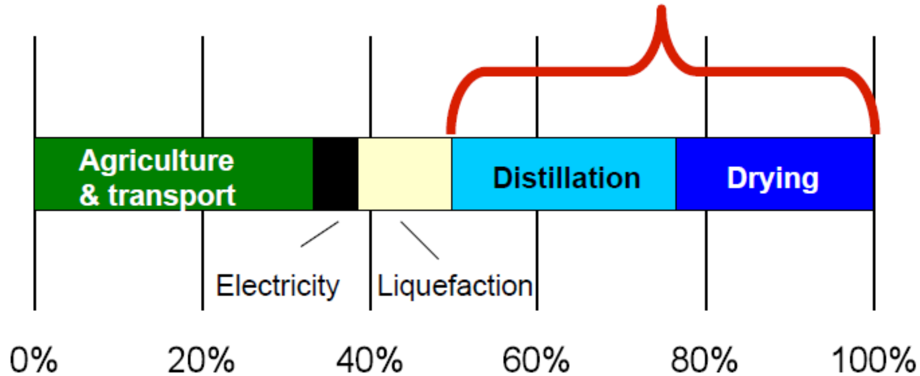
Fossil fuels

Biomass fuels

Source: Air Transport Action Group

Biomass to Biofuels

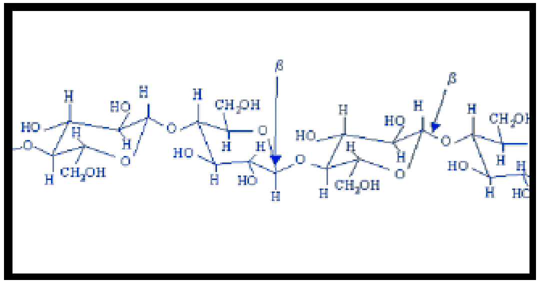
- Ethanol was the first fuel… Considered 1st generation – many problems
    - High-value feedstock (glucose / corn grain)
    - High energy penalty for production



Energy inputs in corn-grain ethanol production

Move to Lignocellulosic Ethanol

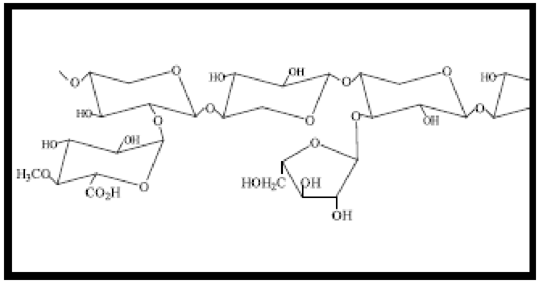
Cellulose



- Glucose units [fermentable]
- Structure:
  - β-(1-4)-glycosidic linkages
  - much hydrogen bonding
  - linear; crystalline

  [difficult to break down]
- ~17 MJ/kg

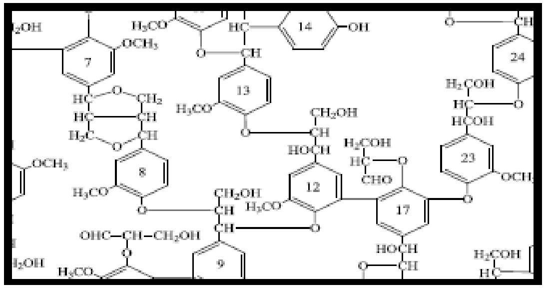
Hemicellulose



- Xylose, glucose, galactose, mannose, etc., units [not as easily fermentable]
- Structure:
  - branched; amorphous

  [easy to break down]
- ~17 MJ/kg

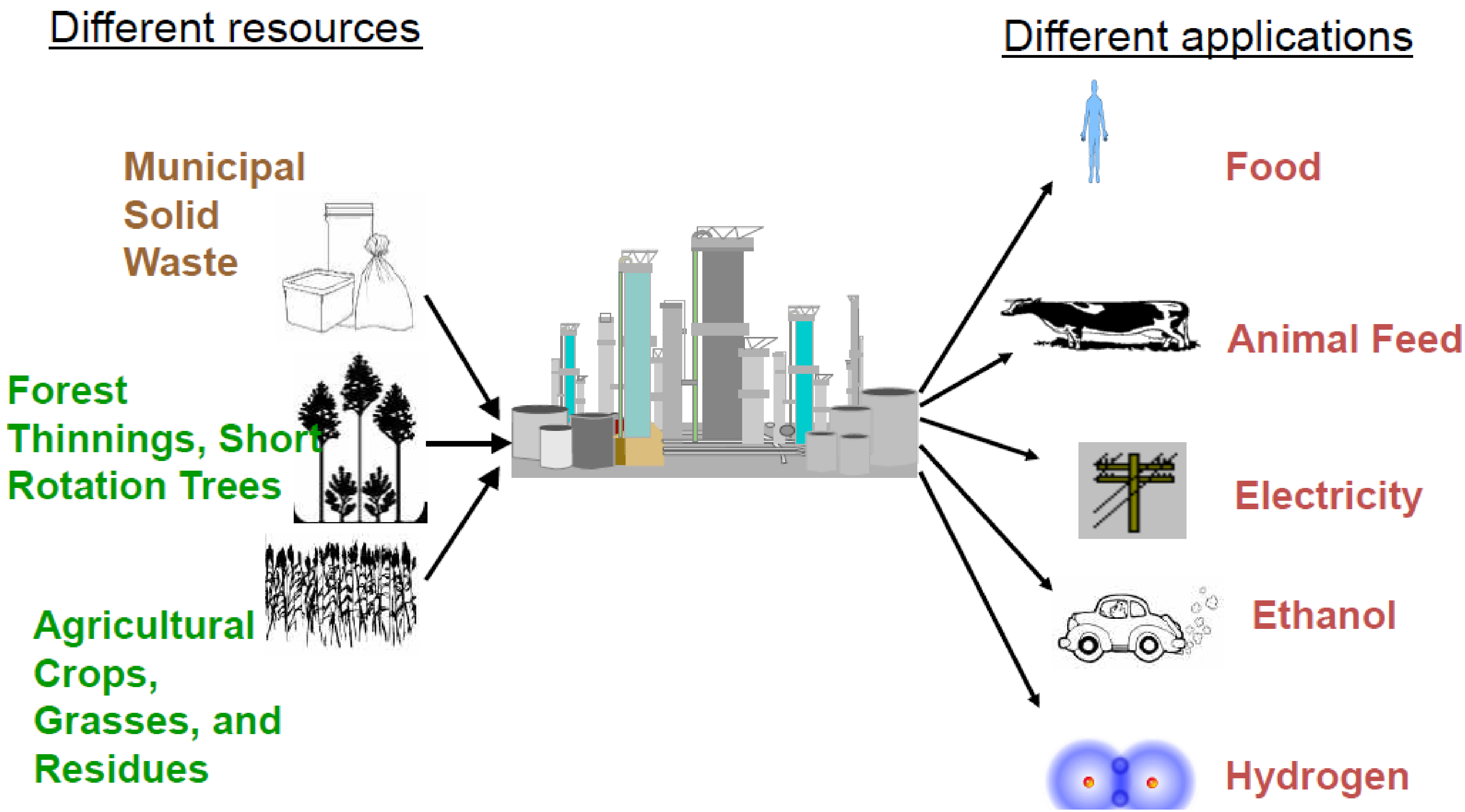
Lignin



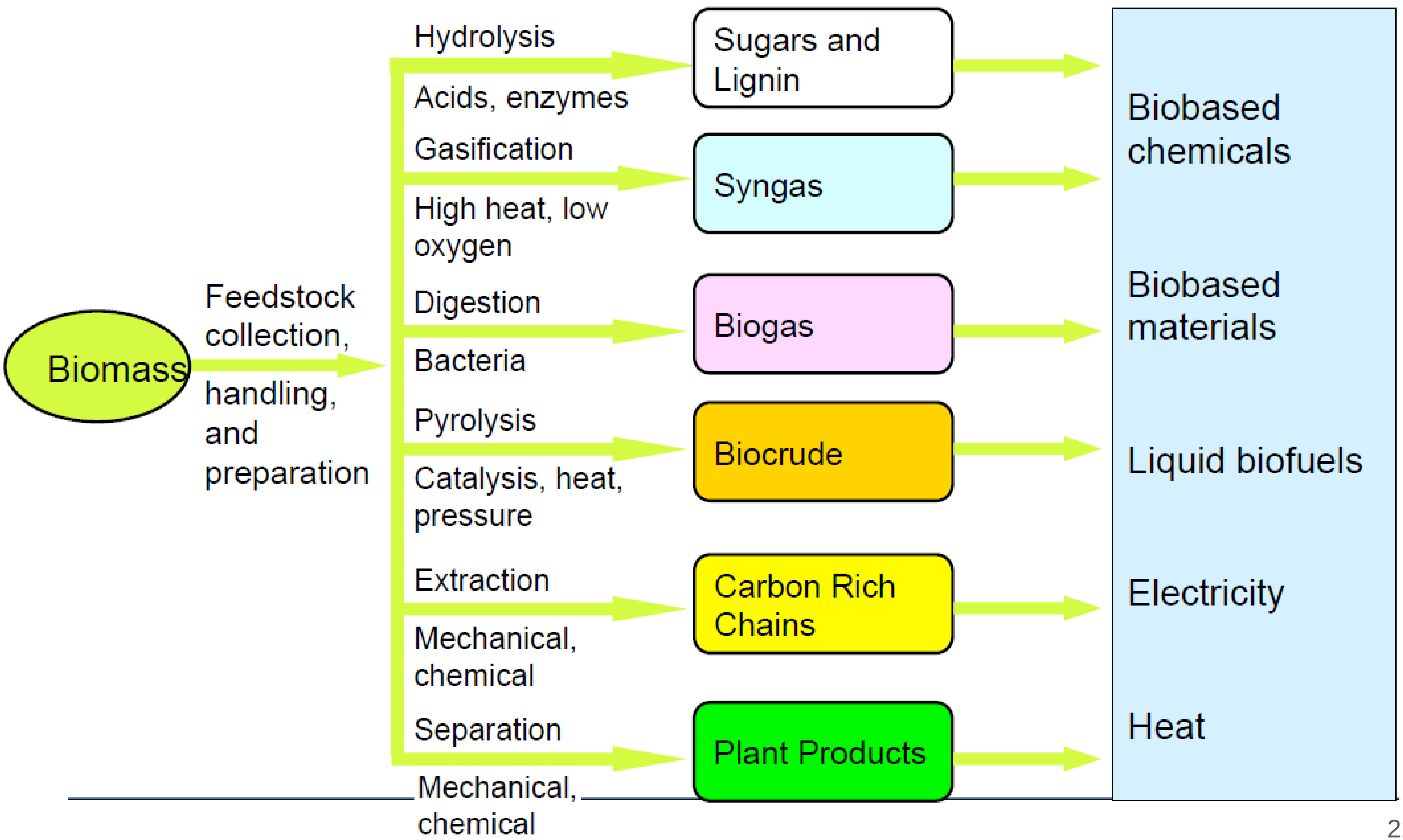
- Phenylpropane units [not fermentable]
- Structure:
  - highly polymerized
  - cement-like role in cells

  [difficult to break down]
- ~21 MJ/kg

Transitioning to Biorefineries



Tomorrow's Biorefinery "Platforms"



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Advanced Techniques – Better Fuels

- Better fuels
  - butanol, propanol, etc.
  - high lipids
  - hydrocarbon excretion

- Better feedstock utilization
  - Cheaper enzymes
  - Lynd's single-pot technique
  - Syngas: H_2, CO

LS9, INC.

LS9 plans to make petroleum from sugar

MASCOMA

Mascoma has microbes that make cellulase and ethanol

bp

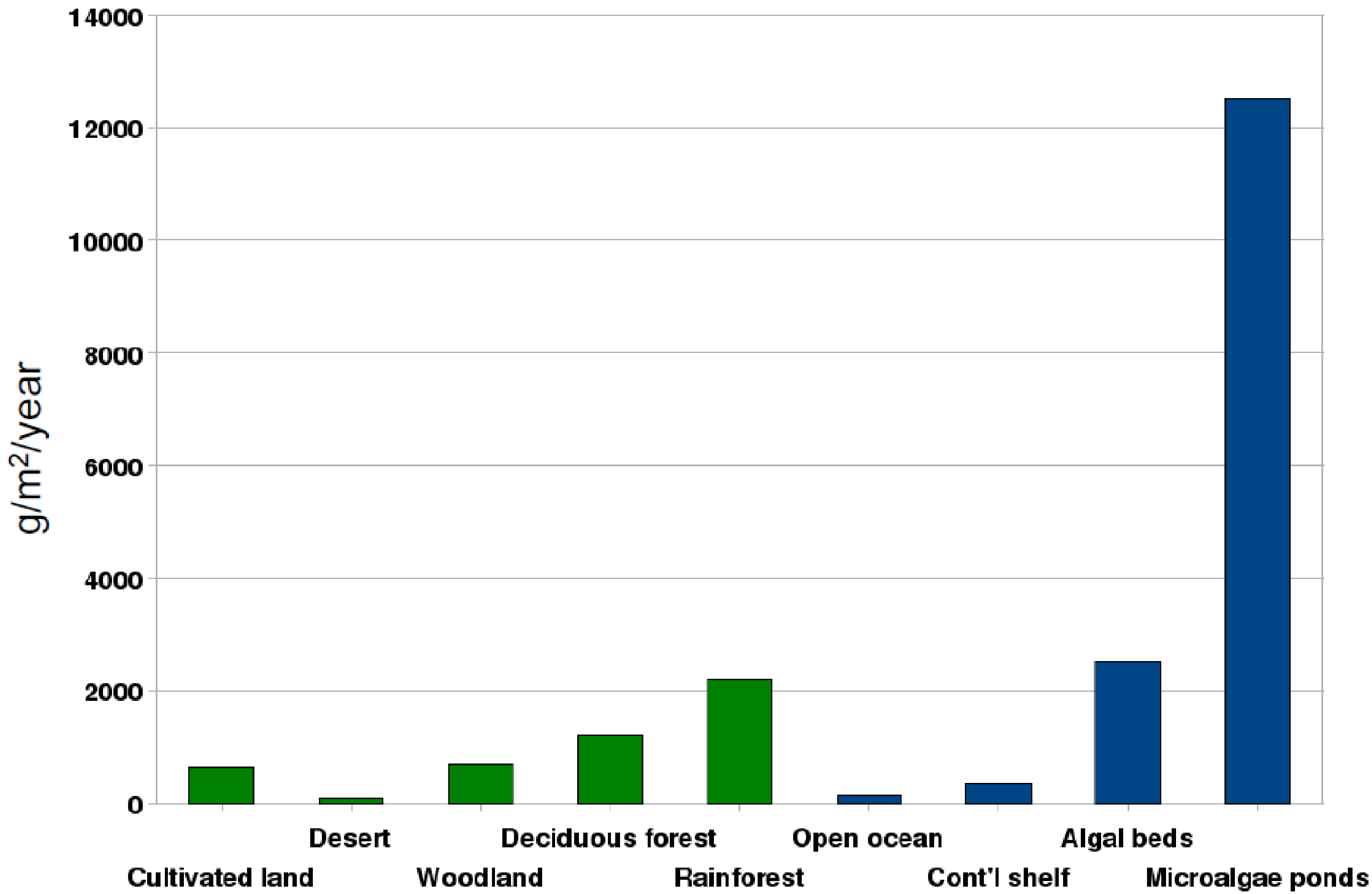
DUPONT The miracles of science

BP and DuPont aim to commercialize butanol

coskata

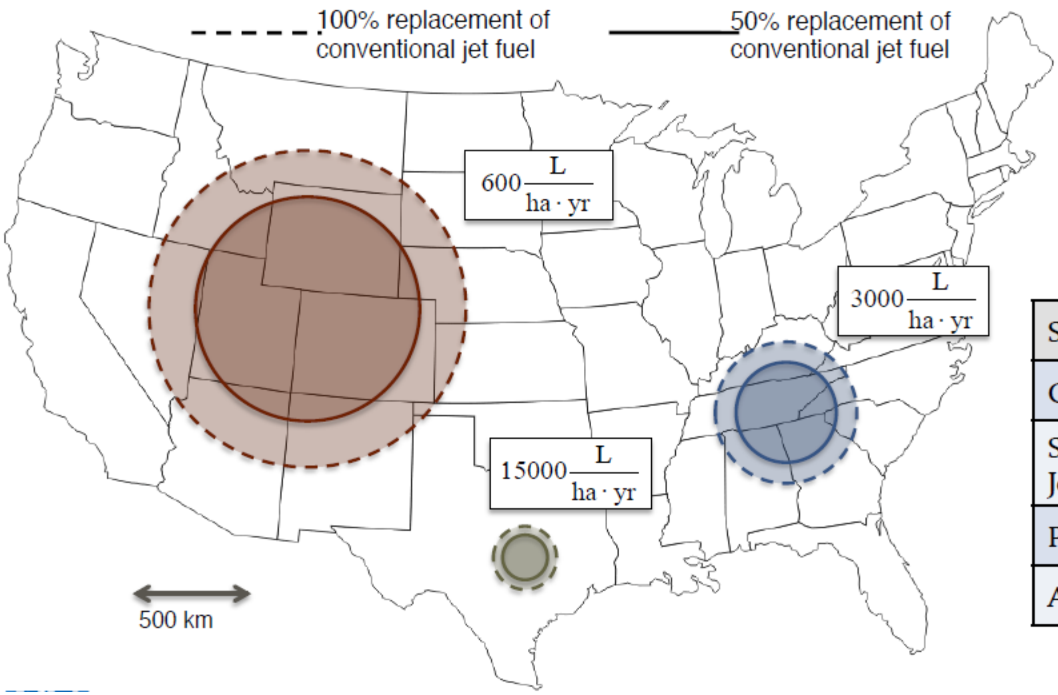
Coskata can make ethanol from syngas for $1/gal

The Allure of Algae



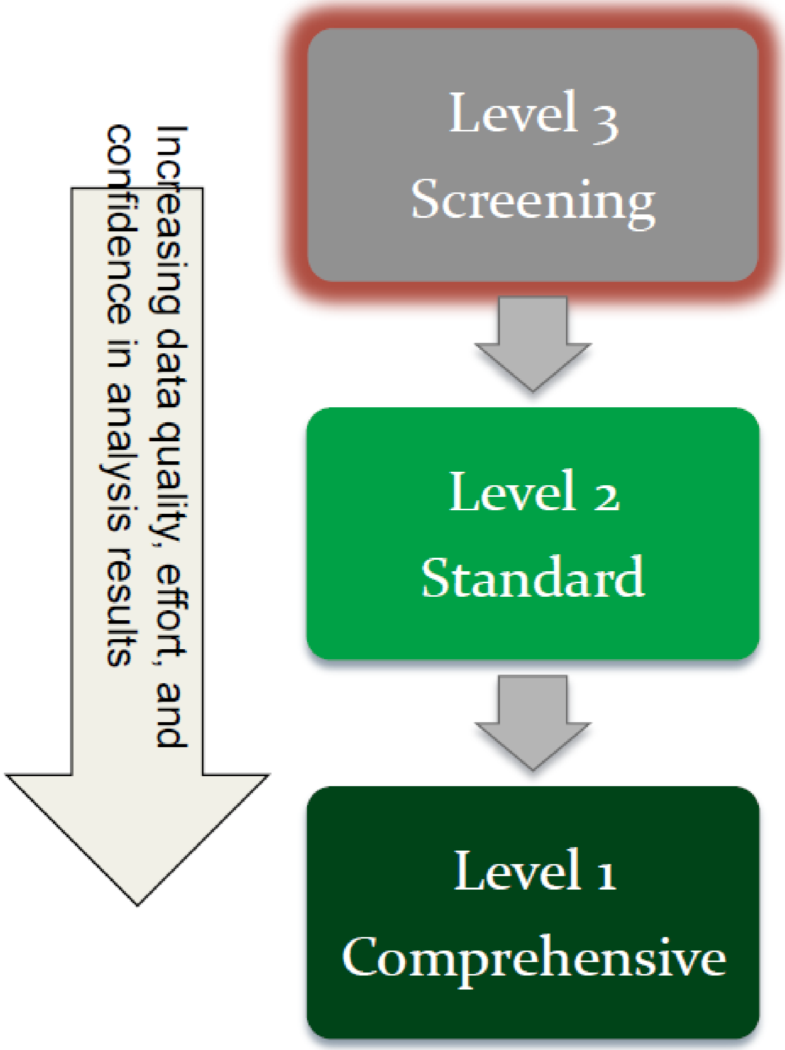
Biofuel Land Requirements

- Considered current jet fuel usage of 1.4 million bpd (EIA, 2009).
- Assessed land requirements to replace conventional jet fuel with 50/50 biofuel blend and 100% biofuel.



Synthetic Fuel	L / ha / yr
Camelina Jet	751
Salicornia Jet / Diesel	1,200 / 1,721
Palm Jet	3,311
Algae Jet	16,969

Life-cycle Analysis Resolution Levels



Conducted in support of a preliminary assessment of a technology alternative, to inform policy makers about research funding.

All major operations examined, but with a lower degree of completeness and data quality than comprehensive LCA.

Conducted to meet regulation, such as Section 526 of EISA 2007.

RSB Principles

Principle 1: Legality
Biofuel operations shall follow all applicable laws and regulations.

Principle 2: Planning, Monitoring and Continuous Improvement
Sustainable biofuel operations shall be planned, implemented, and continuously improved through an open, transparent, and consultative impact assessment and management process and an economic viability analysis.

Principle 3: Greenhouse Gas Emissions
Biofuels shall contribute to climate change mitigation by significantly reducing lifecycle GHG emissions as compared to fossil fuels.

Principle 4: Human and Labor Rights
Biofuel operations shall not violate human rights or labor rights, and shall promote decent work and the well-being of workers.

Principle 5: Rural and Social Development
In regions of poverty, biofuel operations shall contribute to the social and economic development of local, rural and indigenous people and communities.

Principle 6: Local Food Security
Biofuel operations shall ensure the human right to adequate food and improve food security in food insecure regions.

Principle 7: Conservation
Biofuel operations shall avoid negative impacts on biodiversity, ecosystems, and conservation values.

Principle 8: Soil
Biofuel operations shall implement practices that seek to reverse soil degradation and/or maintain soil health.

Principle 9: Water
Biofuel operations shall maintain or enhance the quality and quantity of surface and ground water resources, and respect prior formal or customary water rights.

Principle 10: Air
Air pollution from biofuel operations shall be minimized along the supply chain.

Principle 11: Use of Technology, Inputs, and Management of Waste
The use of technologies in biofuel operations shall seek to maximize production efficiency and social and environmental performance, and minimize the risk of damages to the environment and people.

Principle 12: Land Rights
Biofuel operations shall respect land rights and land use rights.

Research at Masdar Institute

Why Aviation?

◇ Tens of thousands fueling stations

● Hundreds of millions of vehicles

◇ Several hundred fueling stations (airports)

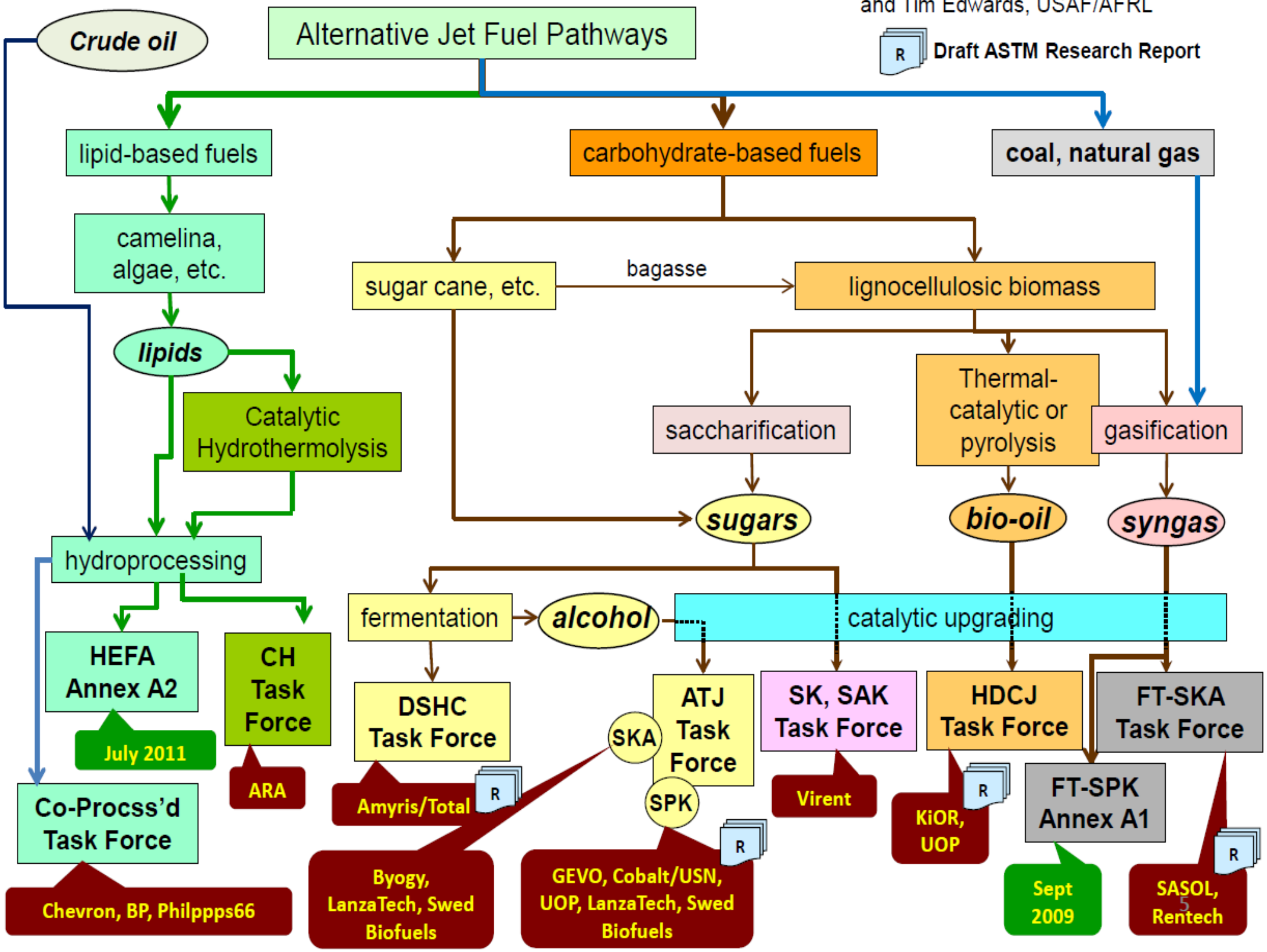
● 20,000 vehicles

Alternative Aviation Fuels

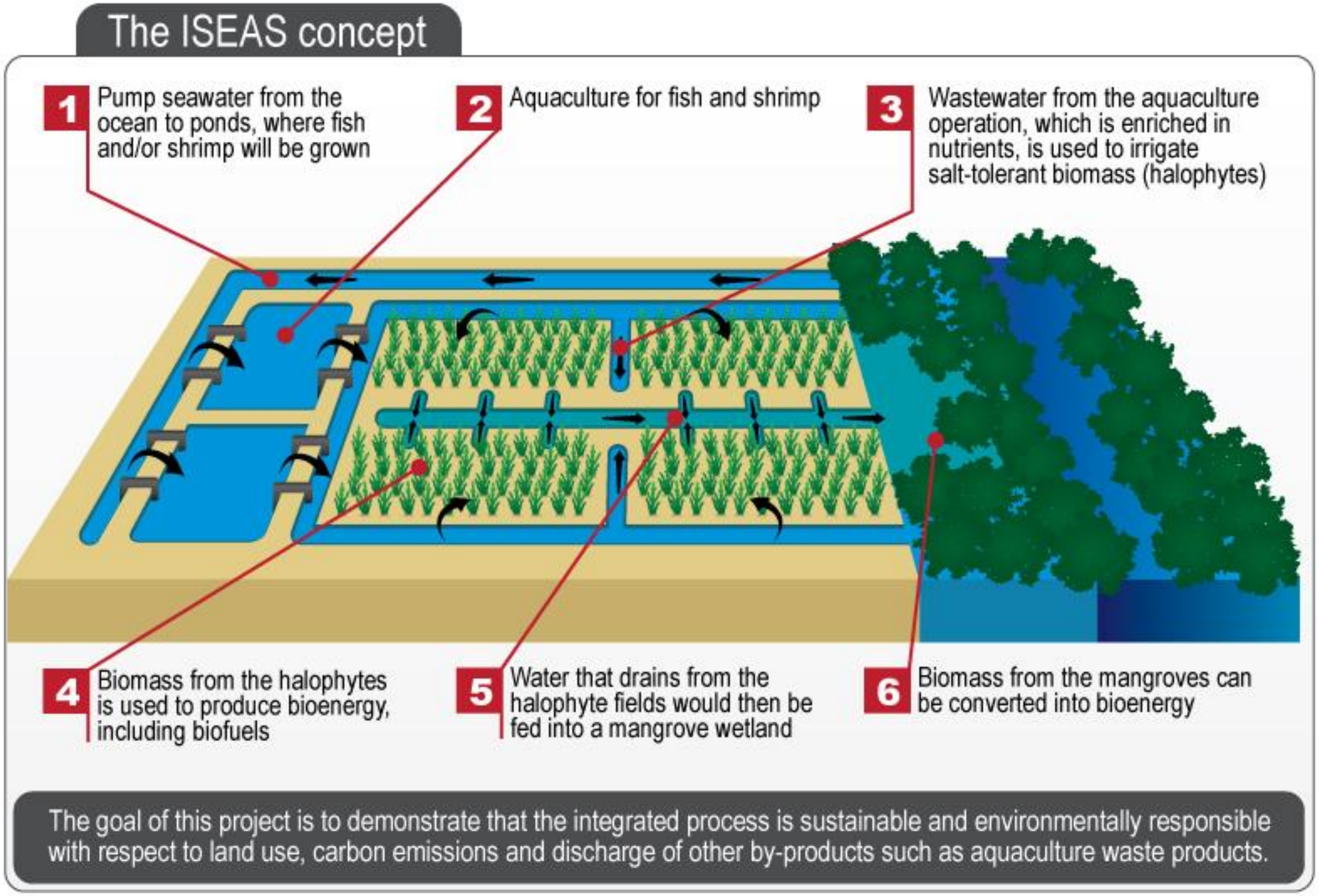
- Why BioJet?
  - Aviation last sector to become fossil fuel independent (probably)
  - High-energy requirement
- **Drop-in replacement**
  - Energy density: > 44MJ/kg
  - Freezing Temperature range: < -40C
- **Zero (or negative) net GWP**
  - Independent from fossil fuel inputs
  - System Atmospheric Carbon Benefit SACB>1
- **Low production costs**
  - Limited resource inputs
- **Scalable**
- **Sustainable – RSB Compliant**:
  - Non-competitive with food supply (land and water)
  - Development Potential
- Existing alternatives fail to meet one or more: **feedstock is *key***

ASTM D7566 TASK FORCES

Adapted from Brown, Iowa State, 2012
and Tim Edwards, USAF/AFRL



The ISEAS



The ISEAS concept
1 Pump seawater from the ocean to ponds, where fish and/or shrimp will be grown
2 Aquaculture for fish and shrimp
3 Wastewater from the aquaculture operation, which is enriched in nutrients, is used to irrigate salt-tolerant biomass (halophytes)
4 Biomass from the halophytes is used to produce bioenergy, including biofuels
5 Water that drains from the halophyte fields would then be fed into a mangrove wetland
6 Biomass from the mangroves can be converted into bioenergy
The goal of this project is to demonstrate that the integrated process is sustainable and environmentally responsible with respect to land use, carbon emissions and discharge of other by-products such as aquaculture waste products.

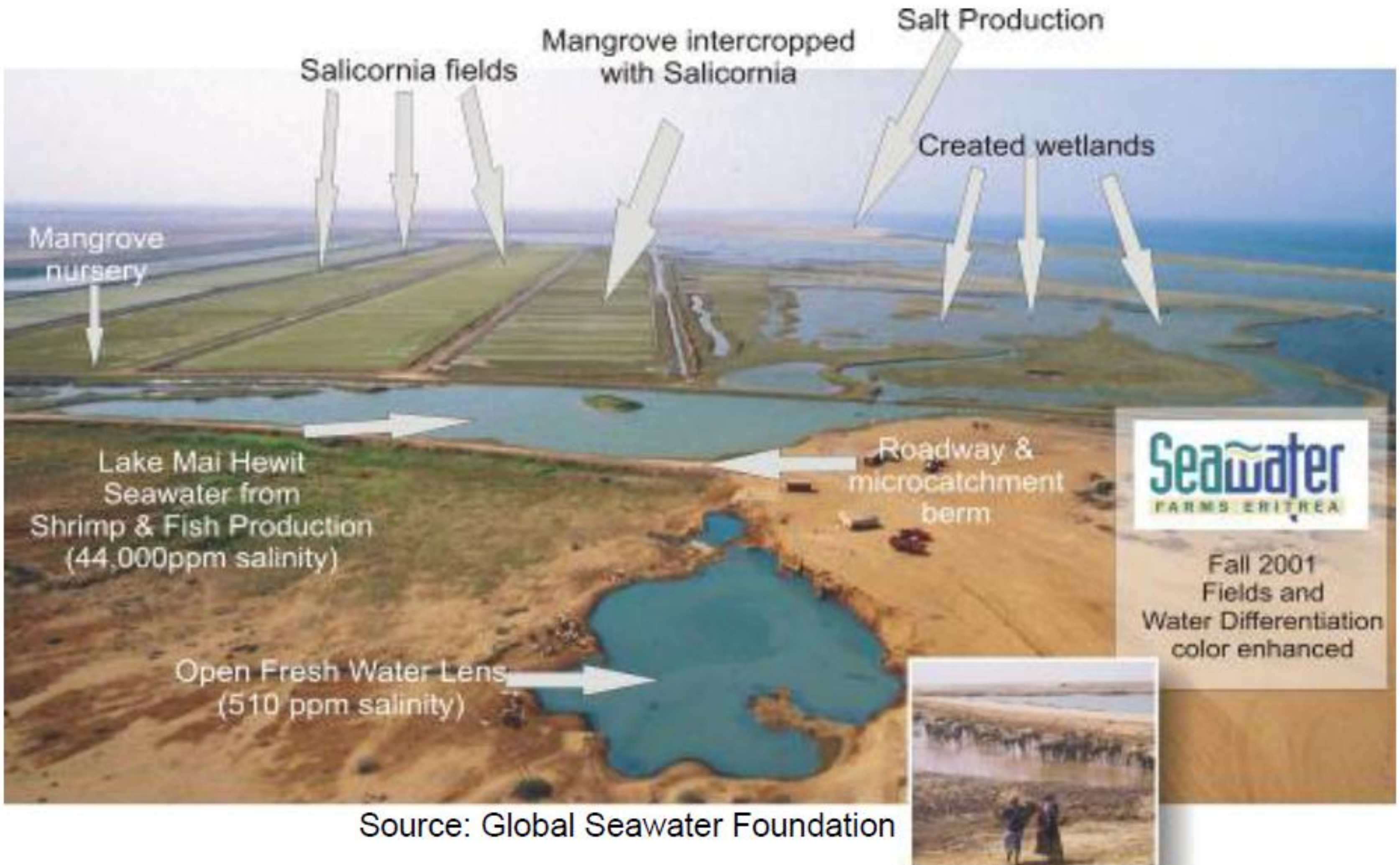
ISEAS

- Land will be used to grow salicornia, mangroves and aquaculture
- **Aquaculture**(~10% of allocated land)
  - Shrimp & fish production providing nutrients and downstream fertilizer to boost production of Salicornia, Mangroves
- **Salicornia**(~70% of allocated land)
  - Potentially two annual harvests for Oil Processing yields Diesel and Kerosene in addition to Solid biomass
- **Mangroves**(~20% of allocated land)
  - Carbon sequestration, solid Biomass for electricity, ecosystem improvement, biodiversity increase

- Aquaculture and mangroves enhance the sustainability and economics of the fuel.

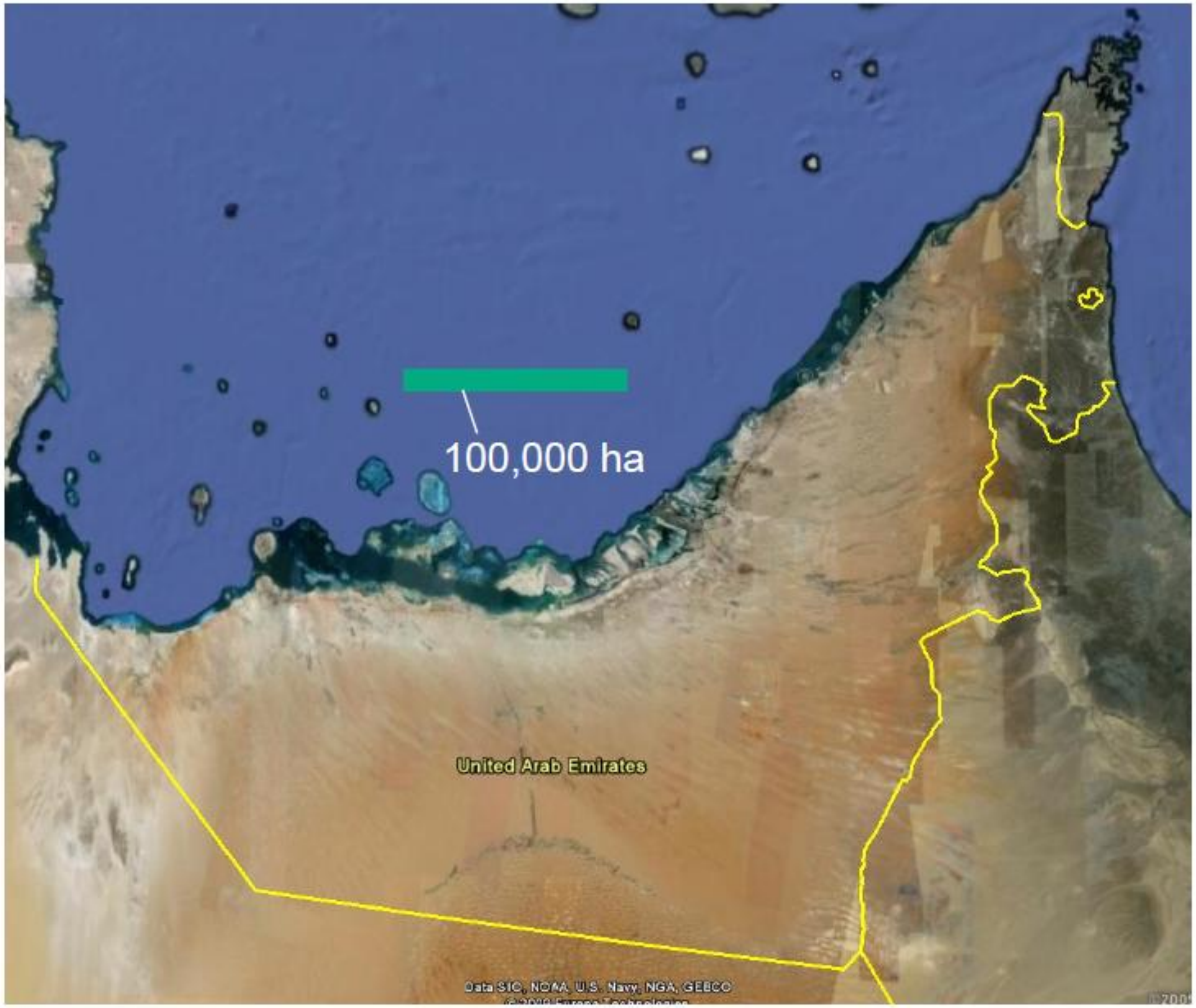
- Oil is processed to jet fuel for using fuel processing technology from Honeywell/UOP.

Learning from the Experience in Eritrea

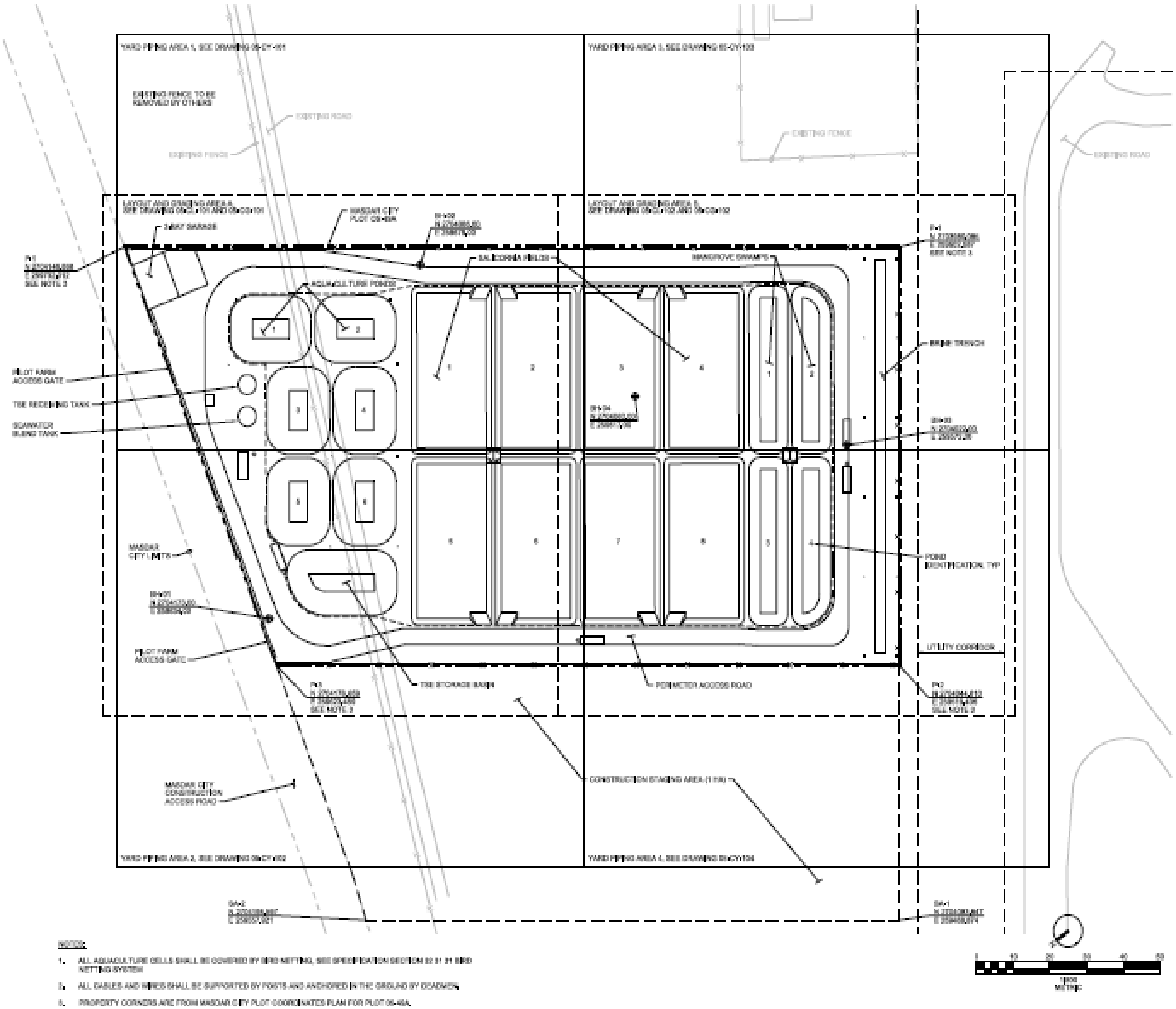


Source: Global Seawater Foundation

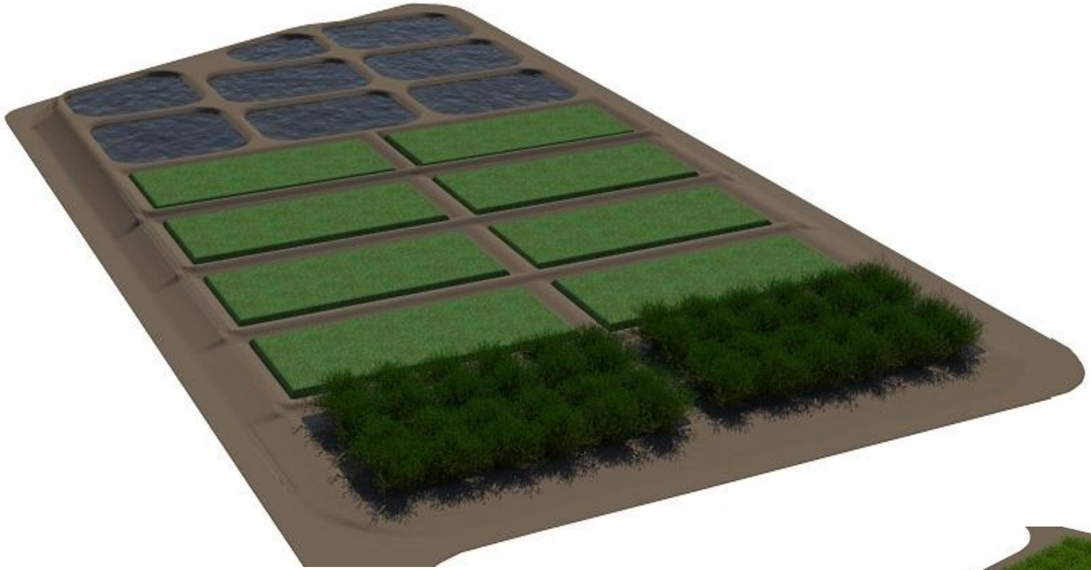
Halophytes in the UAE?



Pilot Basic Layout



Pilot Visualization



Sustainable bioenergy?

- Water use
- Land use
- Food vs. fuel

– Aquaculture effluent

Take-away points

- Biomass has significant potential but low solar conversion efficiency.
- Sustainable feedstock production is the main bottleneck.
- Many “breakthrough” possibilities not yet large-scale viable.
- Don't invent new fuels, find ways to make existing fuels from biomass.
- Chemically, the name of the game is oxygen removal.
- For efficiency, the most important thing you can do is handle water intelligently.
- Integrating processes and utilizing of co-products is necessary.
- Be careful about sustainability issues across the full life cycle of biomass. Assessing sustainability requires careful LCA and allocation of impacts among co-products.

Questions/Comments?

EISA

Section 526 of the Energy Independence and Security Act of 2007 (EISA) limits federal agencies with respect to the purchase of petroleum products derived from unconventional or alternative fuel sources whose life-cycle greenhouse gas emissions exceed those from conventional crude oil. Petroleum products derived from oil sands crude are estimated to have life-cycle emissions exceeding those from conventional oil and under some interpretations of section 526, might be significantly restricted from government purchase.