Biofuel Production Technologies: Status and Prospects

Eric D. Larson
Princeton Environmental Institute
Princeton University, Princeton, NJ USA

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Biofuels: Trade and Development Implications of Present and Emerging Technologies

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Purpose of the Report

- Provide context for understanding limitations of 1st generation biofuels.
- Describe leading "second-generation" biofuel technologies.
- Comparative energy/economic/carbon analysis.
- Trade and development implications

2

Biofuel Classifications

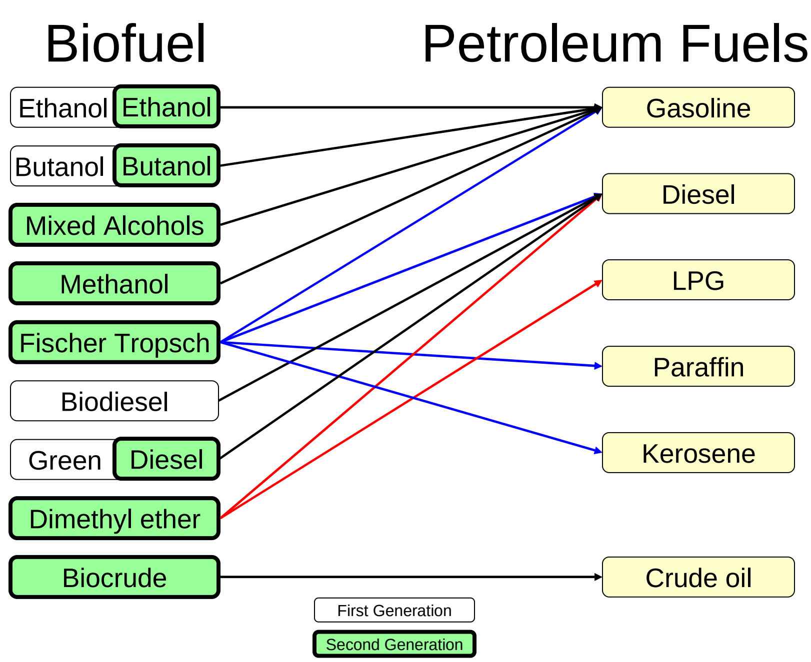
First Generation (from sugars, grains, or seeds)

- Biodiesel (fatty acid methyl ester; fatty acid ethyl ester)
  – rapeseed (RME), soybeans (SME), sunflowers, jatropha, coconut, palm, recycled cooking oil
- Pure plant oils (straight vegetable oil).
- Alcohols (ethanol, butanol)
  – From grains or seeds: corn, wheat, potato
  – From sugar crops: sugar beets, sugarcane

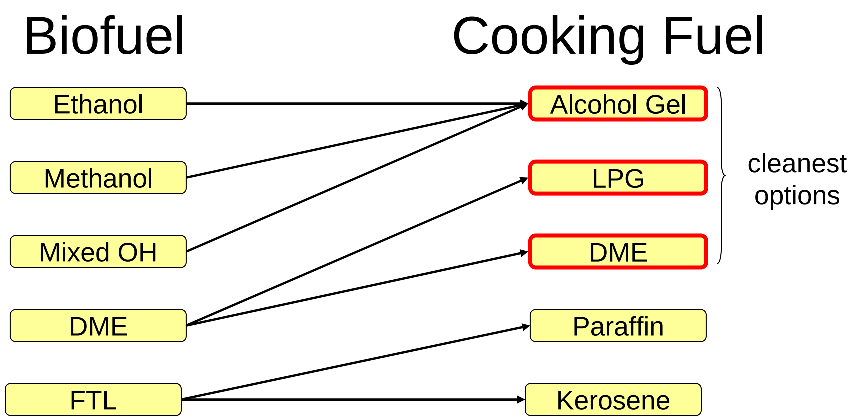
Second Generation (from lignocellulose: crop residues, grasses, woody crops)

- Biological fuels
  – Ethanol (or butanol) via enzymatic hydrolysis
- Thermochemical fuels (most made via “gasification”)
  – Fischer-Tropsch liquids (FTL)
  – Methanol, MTBE, gasoline
  – Dimethyl ether (DME)
  – Mixed alcohols
  – Green diesel

3

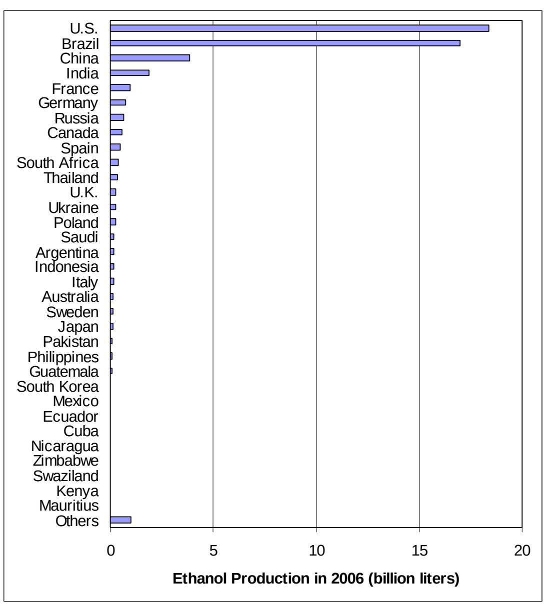


4



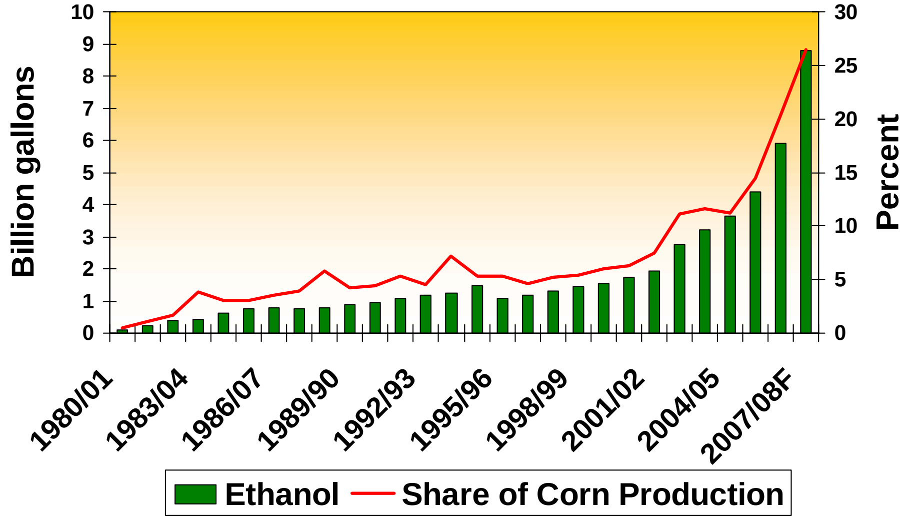
- Three billion people cook with solid fuels today.
- World Health Organization identifies indoor air pollution from cooking as 2nd highest environmental risk factor (after unsanitary water) contributing to global burden of disease – conservative estimate is 1.6 million premature deaths/yr.
- 4 to 5 EJ/yr of biofuel [~*35 kg/cap/yr LPG$_{eqiv}$*] is sufficient to "solve" this problem. *(This is ~1% of global commercial energy use today).*

1st Generation Ethanol Production



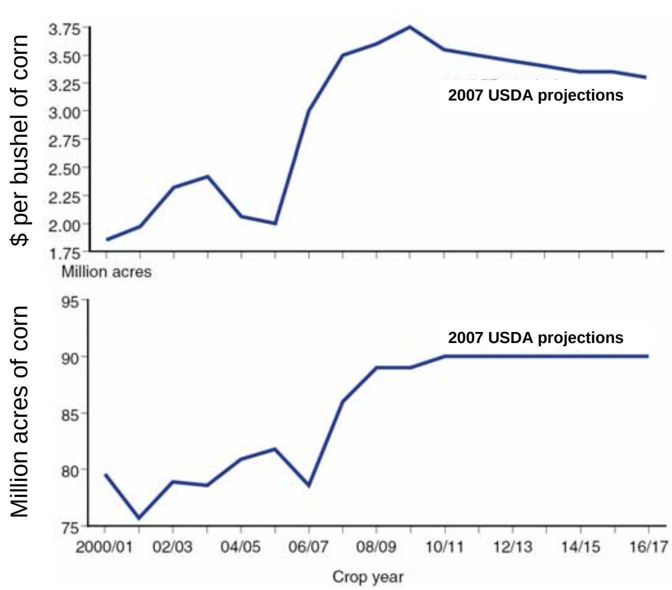
U.S. Corn Ethanol Production

27% of 2007 corn ➔ 34 billion liters (<4% of gasoline demand)



7

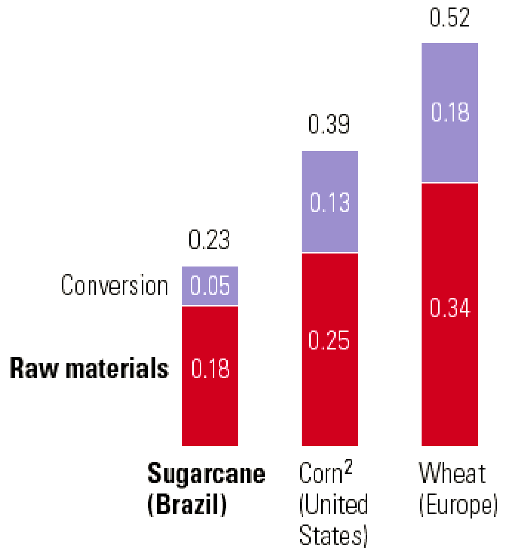
U.S. Corn Prices and Planted Areas



8

1st Generation Ethanol Costs

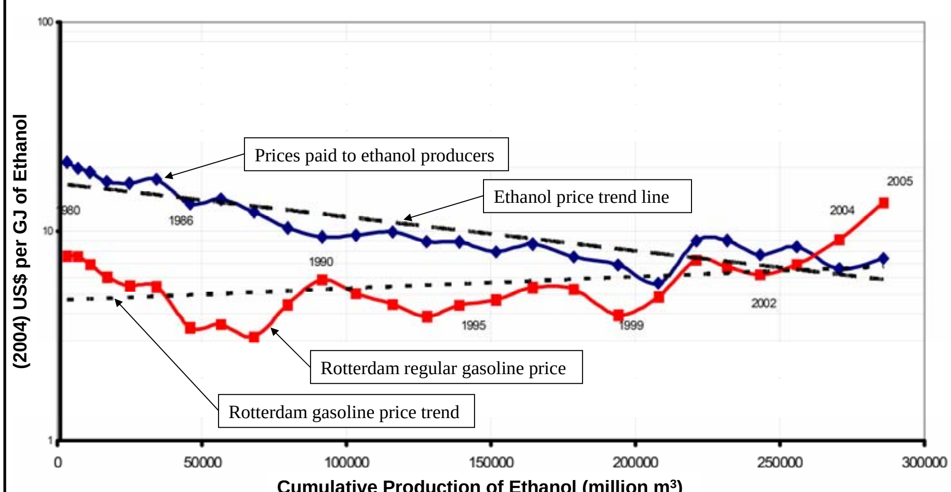
(feedstock is largest component)



Source: Assis, V., Elstrodt, H-P., and Silva, C.F.C., "Positioning Brazil for Biofuels Success," *The McKinsey Quarterly*, special edition on Shaping a New Agenda for Latin America, 2007.

9

Evolution of Ethanol Price in Brazil



Source:
Nastari, P.M. "Competitividade da Produção de Etanol de Cana-de-açúcar no Brasil: as três ondas de desenvolvimento", V Conferência Internacional da Datagro sobre Açúcar e Álcool, Grand Hyatt São Paulo, 20 de setembro de 2005, São Paulo, SP.

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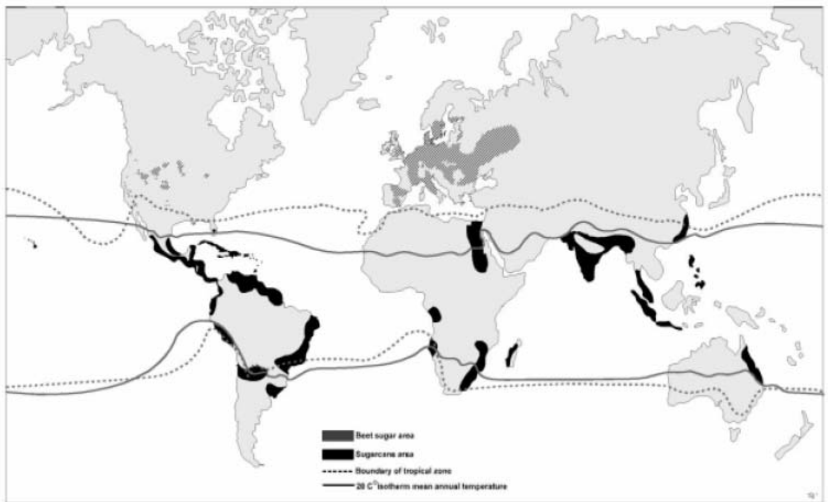
Brazil Experience is Widely Relevant



Source:
As cited in Coehlo, S.,"Brazilian Sugarcane Ethanol: Lessons Learned," *Energy for Sustainable Development*, **X**(2): 26-39, 2006.

11

First Generation Biofuels

- Use of sugar or starch crops creates limitations:
  - Competition for food uses.
  - Plants optimized for food, not energy.
  - Only part of the plant is converted to biofuel.
  - Co-product sales often important for acceptable economics.
- Only modest energy and GHG benefits, except with sugarcane ethanol (due to greater utilization of the above-ground biomass).
- Can blend with existing petroleum-derived motor fuels – minimal infrastructure change.
- Large-scale experience in Brazil and USA.
- Relatively high costs (except sugarcane ethanol in Brazil) due to high feedstock cost.
- Cost penalties less severe at smaller scales.

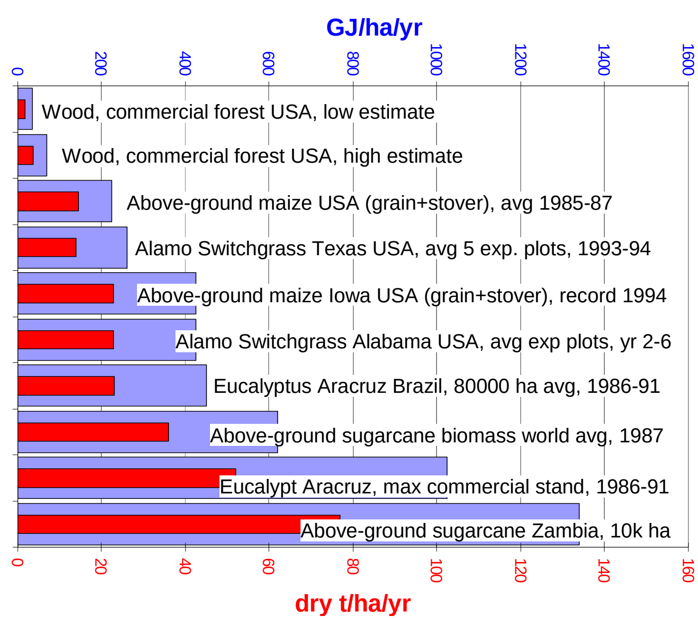
12

Second Generation Biofuels

- Made from lignocellulosic materials
  - Biomass that is generally not edible.
  - Larger fraction of the plant is converted to fuel.
  - Plants can be bred for energy characteristics (high yield, low inputs).
- Two generic processing routes: biological or thermochemical (also hybrids have been proposed).
- Can blend with petroleum fuels in most cases.
- Substantial energy/environment benefits compared with most 1st generation biofuels due primarily to greater biomass useability per unit land area.
- Greater capital-intensity than 1st generation biofuels, but lower feedstock costs → higher cost-scale sensitivity.
  - → larger scale facilities needed for optimum economics

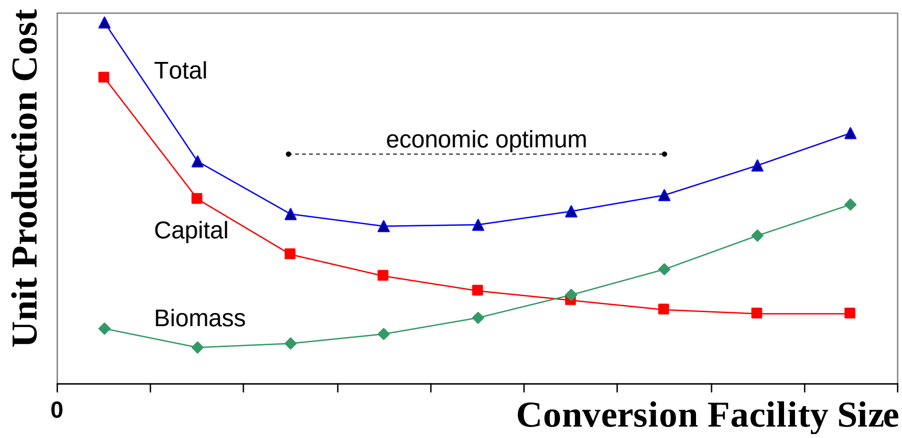
13

Yields for Different Biomass Types



14

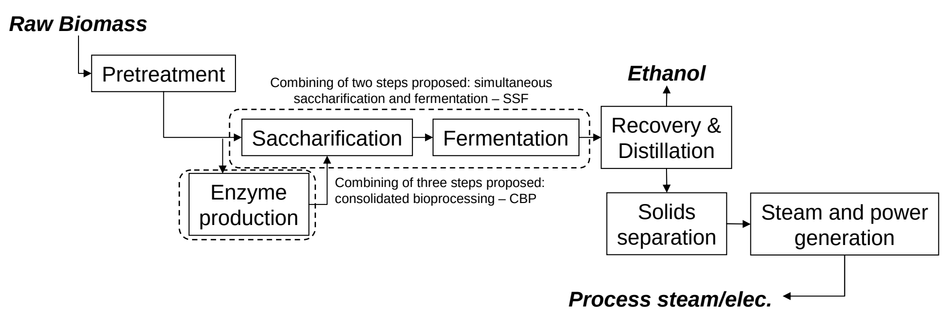
2nd Generation: Cost vs. Scale



15

2nd Generation Ethanol Processes

(similar routes for butanol)



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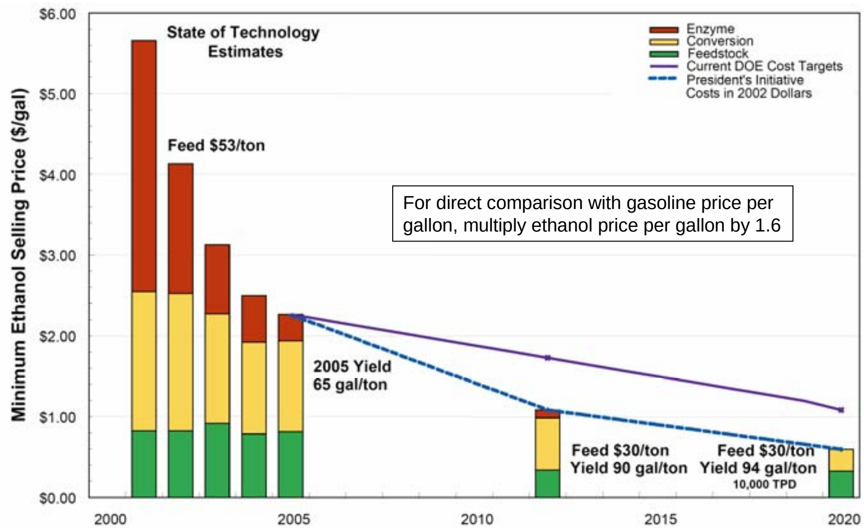
Cost Targets For Cellulosic Ethanol

United States' National Renewable Energy Lab



$30/t biomass cost in long term is probably unrealistically low for large-scale, sustainable biomass supply in the USA, but not in many developing countries.

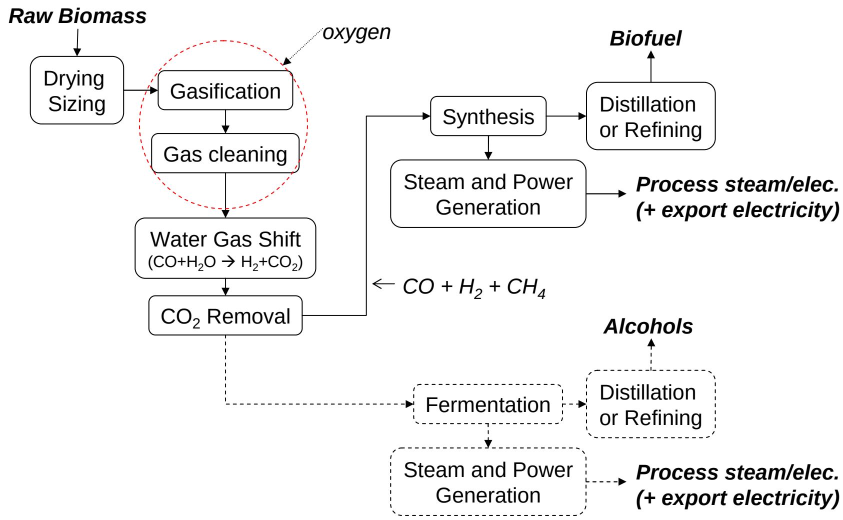
17

2nd Generation: Biological

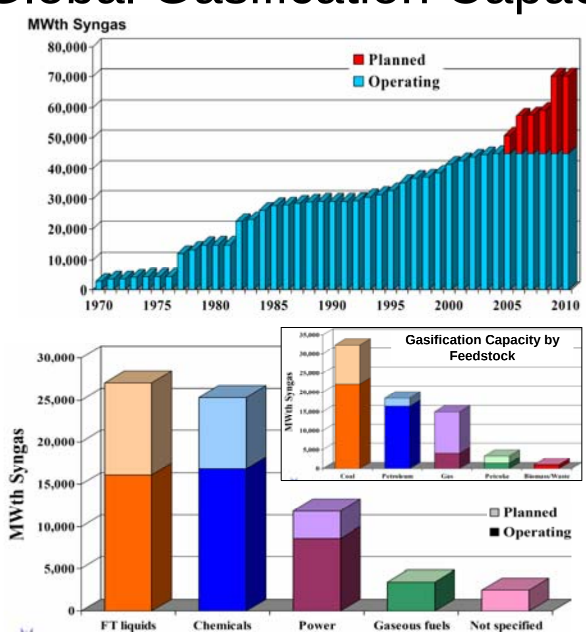
- "Cellulosic ethanol" (cellulosic biobutanol)
- Limited fraction of the biomass can be converted with known enzymatic technology today.
  - Lignin not convertible in any case, but can use for heat or co-product.
- Limited feedstock flexibility – micro-organisms must be tailored to the feedstock.
- R&D breakthroughs needed to improve conversion and reduce costs.
- Production costs may be somewhat less scale sensitive than for thermochemical fuels.

18

2nd Generation Thermochemical



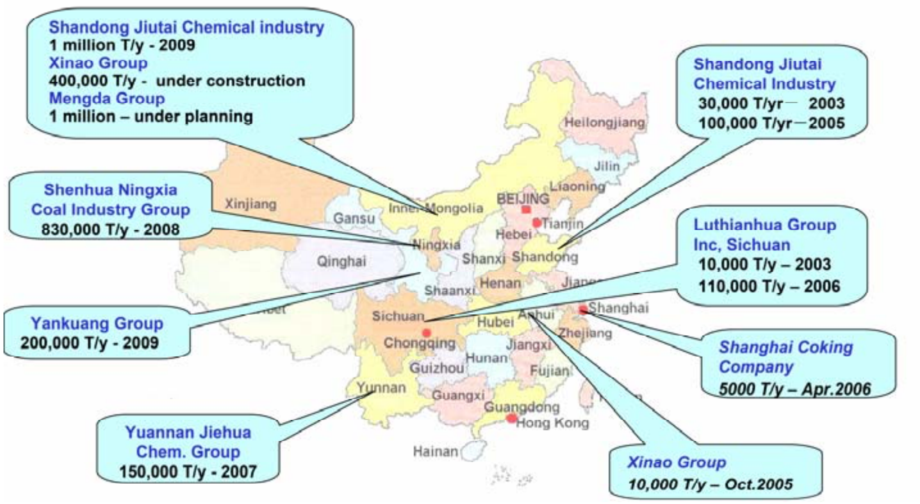
Global Gasification Capacity



20

China DME Production

(for LPG and diesel bus markets)



21

2nd Generation: Thermochemical

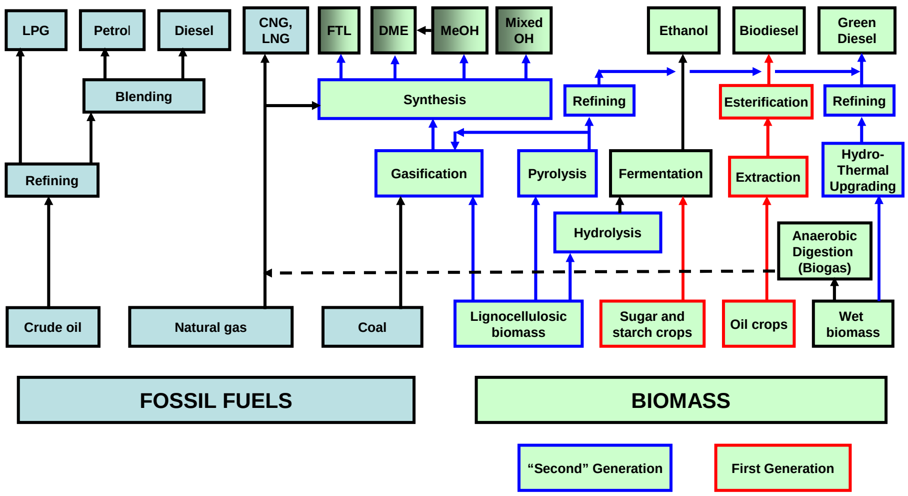
- Allows complete utilization of the biomass and can accommodate wide range of feedstocks with little difficulty.
- Conversion technologies available today for FTL, DME, MeOH – no R&D breakthroughs needed.
- For ethanol or butanol (by fermentation of syngas), further research is needed to identify and apply appropriate micro-organisms.
- With biomass costing $3-5/GJ ($54-90/dry t) – reasonable expectation for large-scale sustainable biomass supply in OECD – FTL would be competitive when oil is $70*-90**/barrel with known technology.
  - Lower biomass costs in developing countries and "learning-by-doing" (like Brazilian ethanol program), should make thermochemical fuels competitive at much lower oil prices.
- Commercial-scale implementation of large-scale biomass gasification systems are lacking today, but large overlap (and synergies) with commercially established fossil fuel conversion technologies, so practical experience base already exists.

* Larson, Williams, Jin, paper at 8th International Conference on Greenhouse Gas Control Technologies, June 2006.

** van Ree, van der Drift, Zwart, Boerigter, presented at the First International Biorefinery Workshop, Washington DC, July 2005.

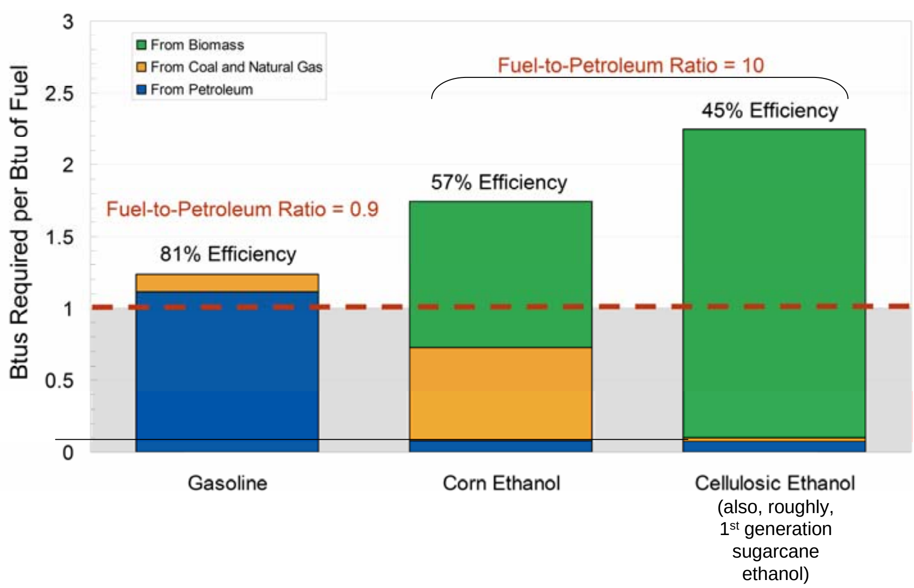
22

Biofuel Production Pathways

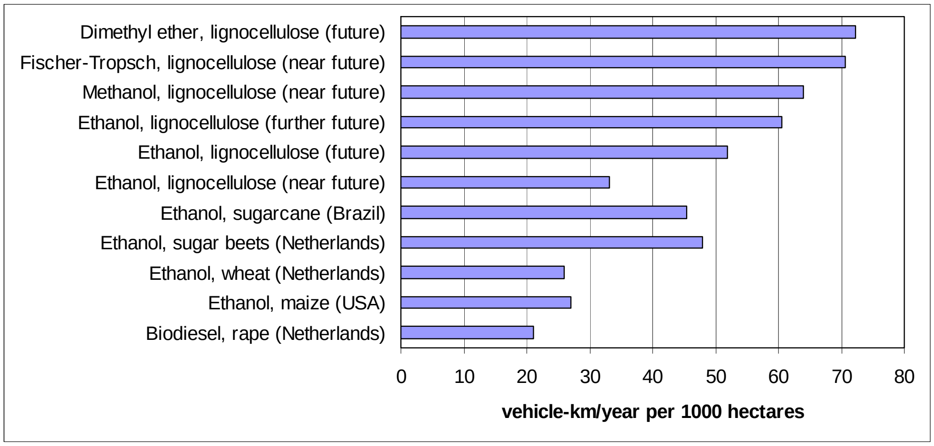


(Biomass can be co-gasified with coal for thermochemical fuels production)

Comparing Energy Balances



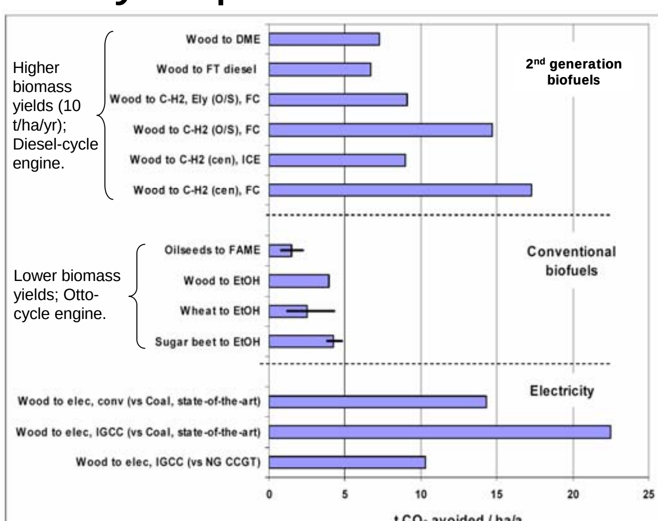
Transportation Services Per Hectare



25

Relative GHG mitigation with biofuels vs. bio-electricity depends on:

- The cultivation process to make the biomass.
- The biofuel being produced.
- The conversion technologies being used.
- The fossil fuel systems being displaced.



CONCAWE et al. 2004.

26

Summary (1)

- 1st or 2nd generation biofuels have the potential to
  - Substitute significant percentage of transport oil use in most developing countries (given low per-capita transport-sector fuel use today).
  - Provide clean cooking fuels for all households currently using polluting solid fuels.
- Sugarcane ethanol, plus most 2nd generation biofuels, will significantly reduce GHG emissions per unit of transportation service provided. Other first generation biofuels have only modest GHG reduction potential.
- Economics of 1st gen. biofuels (other than cane-ethanol):
  - In the Northern countries, subsidies (or oil price at least $50-$60/bbl) needed for competitiveness, even for large-scale facilities, due primarily to the use of (expensive) food crops as the feedstock.
  - In the Southern countries, economics unlikely to be much better than in the North, despite lower labor costs, due to lower agricultural productivities, global markets for commodity crops, and generally smaller scales of biofuel production facilities.

27

Summary (2)

Second generation biofuels

- Under development primarily in the North. Further R,D&D needed for plausibly competitive economics.
  - Time to commercial readiness: 10-20 years for cellulosic ethanol; ½ or less of this for thermochemical fuels.
- Both biological and thermochemical will require larger scales of application (with purpose-grown biomass) than most 1st generation facilities for optimum economics.
- Higher investment costs per unit production than 1st generation fuels, but lower feedstock costs → lower total costs.
- Key intellectual property elements: 1) micro-organisms for biological conversion, 2) synthesis catalysts for thermochemical conversion.

28

Trade/Development Implications

- Potential land use conflicts for food vs. biofuel may be mitigated to some extent by a) increasing productivity of food agriculture (yields per hectare) – large gains are possible; b) targeting biofuel feedstock production on lands less-suited to food crop production; c) targeting the production of 2nd generation biofuels to maximize land-use efficiency.
- Economics of 2nd generation biofuels in the South have the potential to be much better than in the North since many South countries have comparative cost advantages in producing feedstocks due to better growing climates, lower labor costs, and lower land costs.
- Large global markets for biofuels exist and will grow over time in most industrialized countries due to regulatory mandates and expected continuation of oil prices in the $50-$60/bbl range.
  - Significant export opportunities for biofuels or biofuel feedstocks from South to North may materialize (but import tarriffs are constraining right now) and could offer CDM credit possibilities to improve biofuel production economics.
  - To be fully competitive exporters taking advantage of low feedstock costs, biofuel programs in countries of the South will need to encourage production systems with world-class scales and efficiencies, and low capital investment intensity. Establishing sustained domestic demand (e.g., through regulatory mandates) could be an important first step (Brazilian model) in supporting such industries.

29