Conference on

Biofuels: an option for a less carbon-intensive economy

4-5 December 2007

Prospects for Second Generation Biofuels Technologies

by:

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Prepared for
United Nations Conference on Trade and Development (UNCTAD) and the
Energy Planning Agency of the Ministry of Mines and Energy of Brazil (EPE)

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Biofuels: An Option for a Less Carbon-Intensive Economy

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Outline

- Comments on “first generation” biofuels.
- Discussion of leading “second-generation” biofuel technologies.
  - Biological.
  - Thermochemical.
- Summary points.
- Trade and development implications.

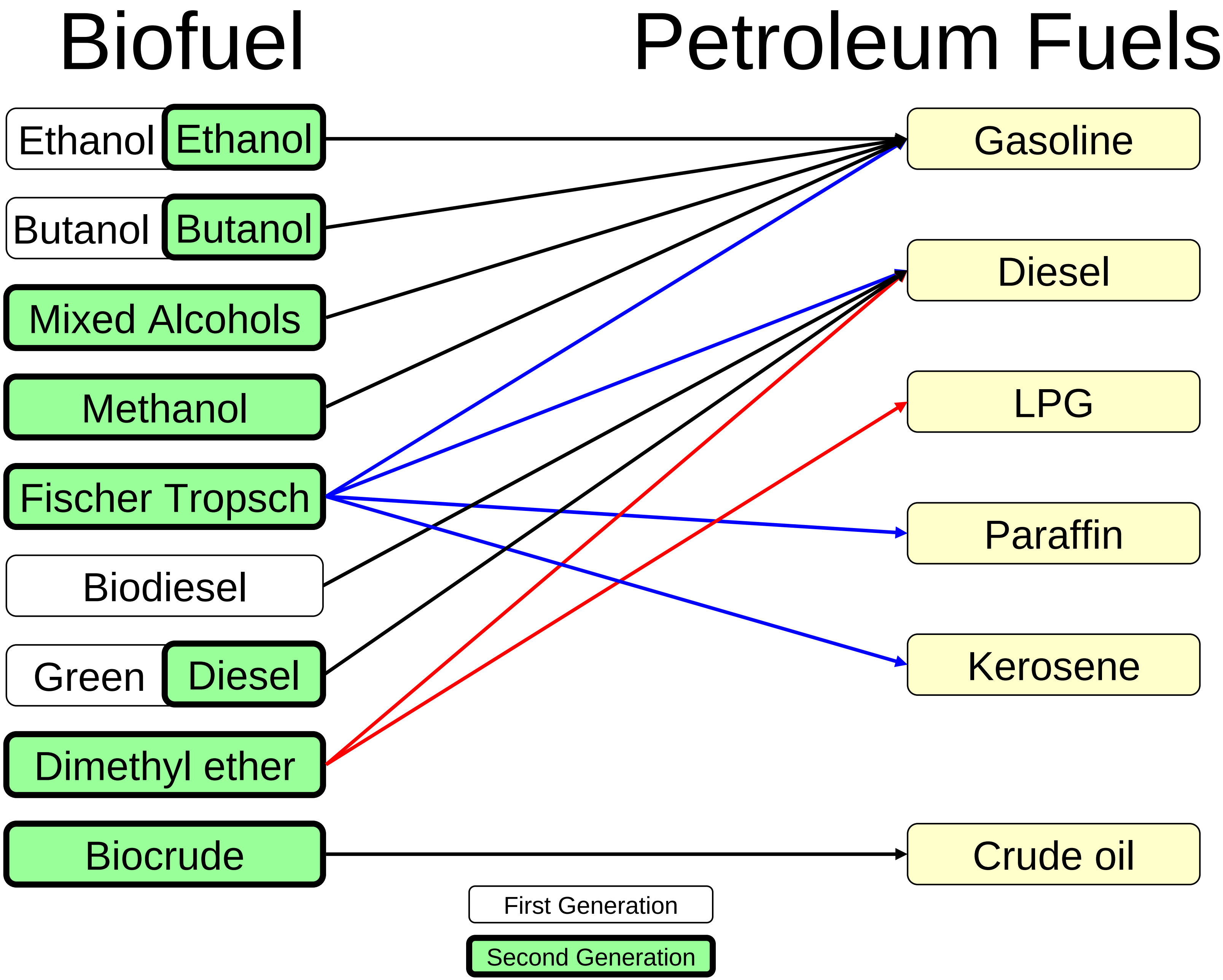
Biofuel Definitions

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

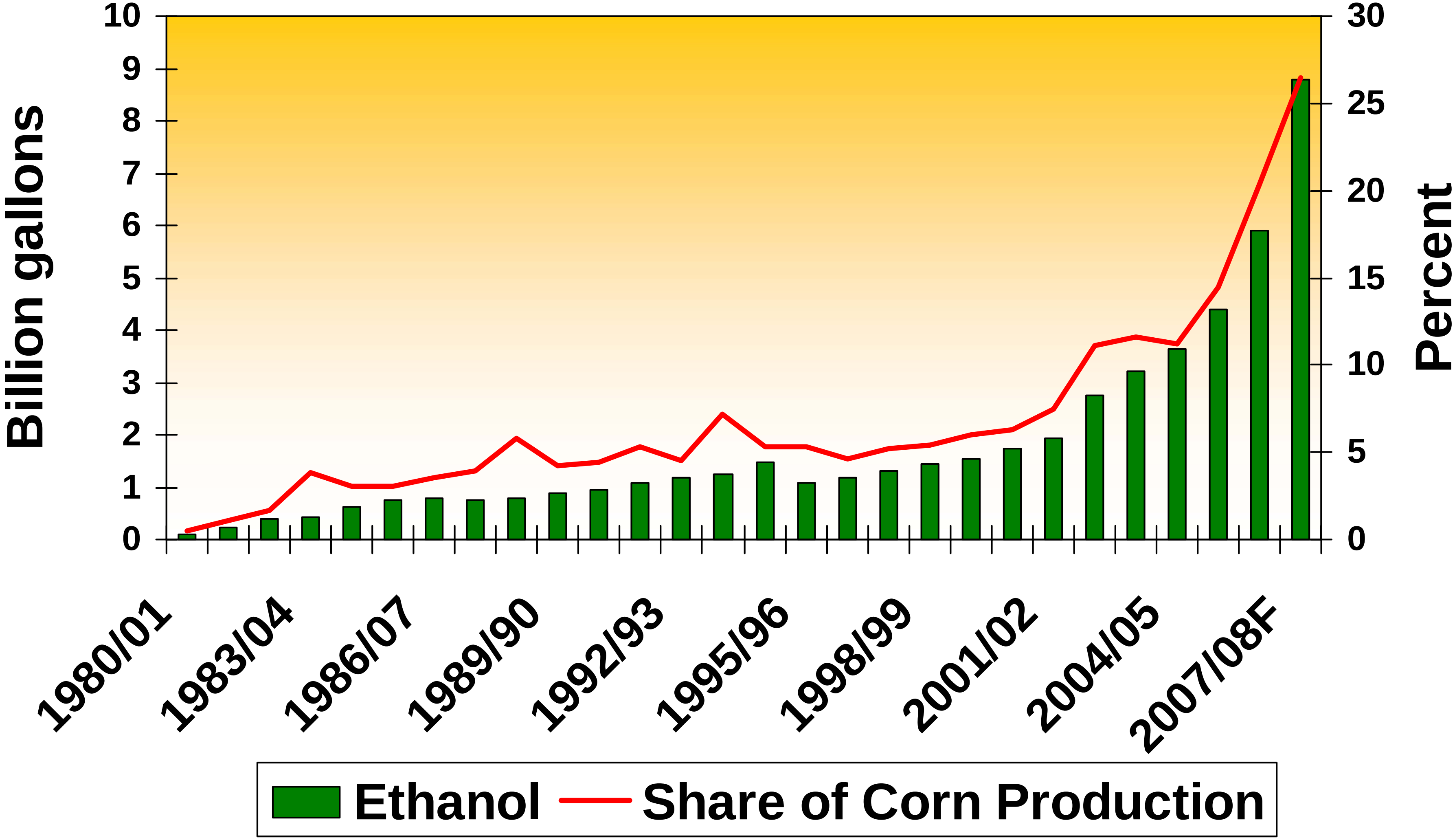
Second Generation (from lignocellulose: crop residues, grasses, woody crops)

- 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

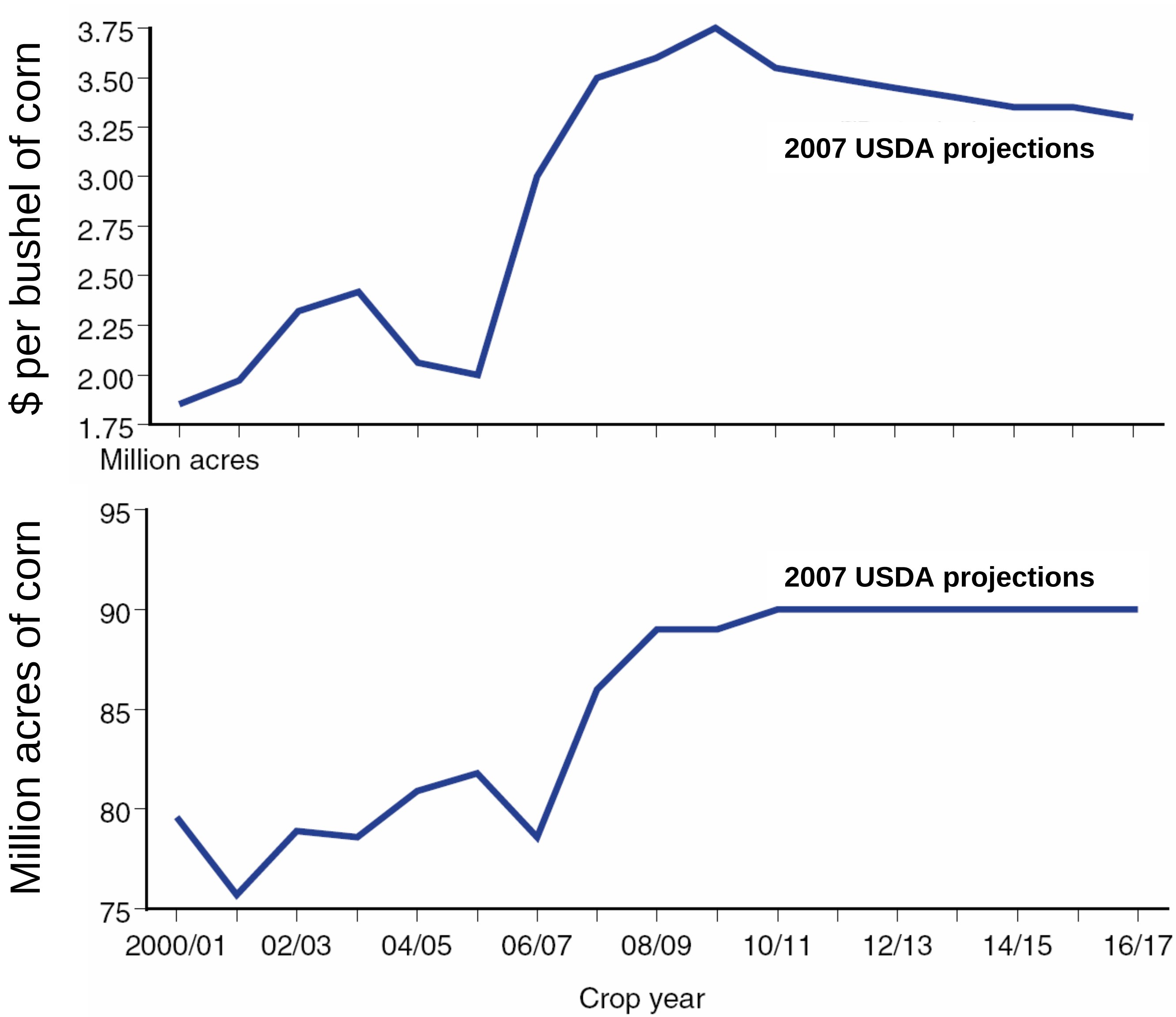

Biofuel
Petroleum Fuels
Ethanol
Ethanol
Butanol
Butanol
Mixed Alcohols
Methanol
Fischer Tropsch
Biodiesel
Green
Diesel
Dimethyl ether
Biocrude
Gasoline
Diesel
LPG
Paraffin
Kerosene
Crude oil
First Generation
Second Generation

U.S. Corn Ethanol Production

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

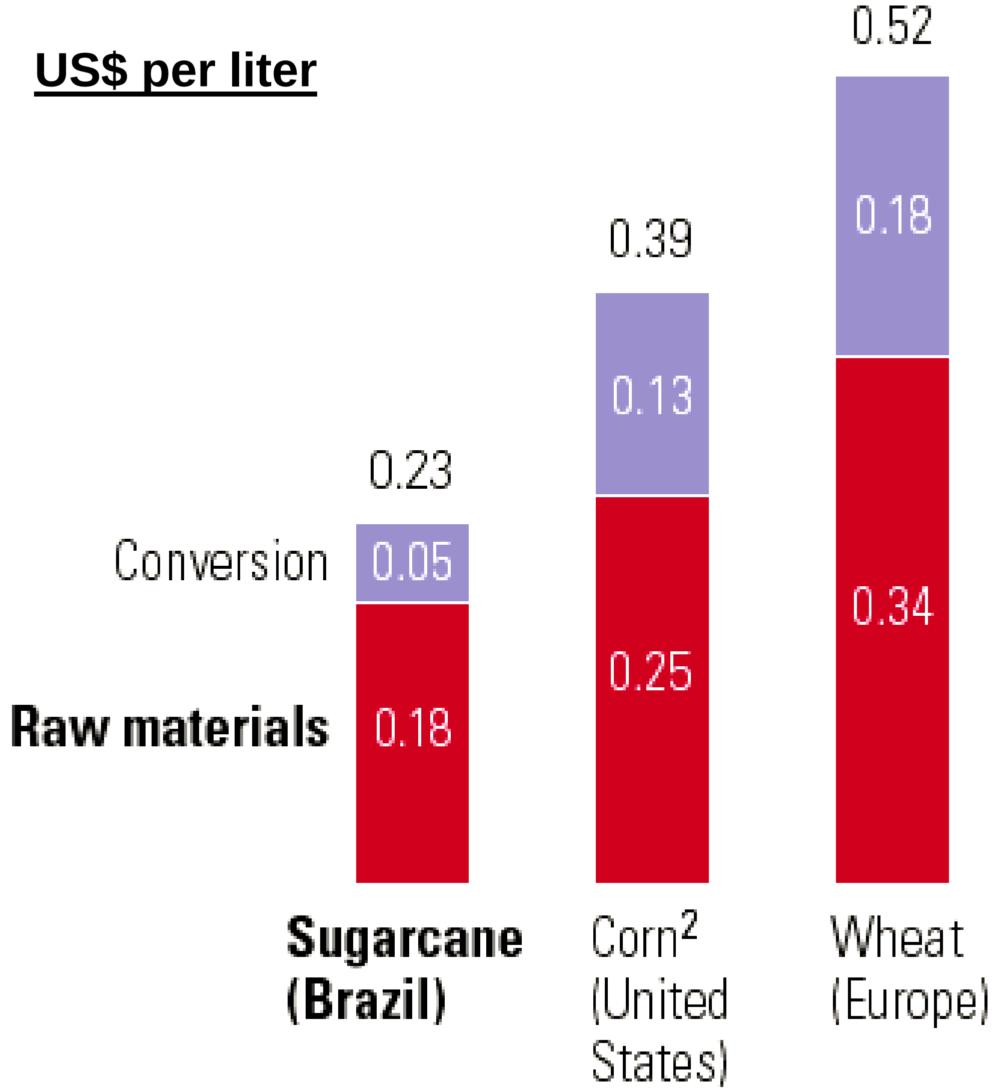


U.S. Corn Prices and Planted Areas



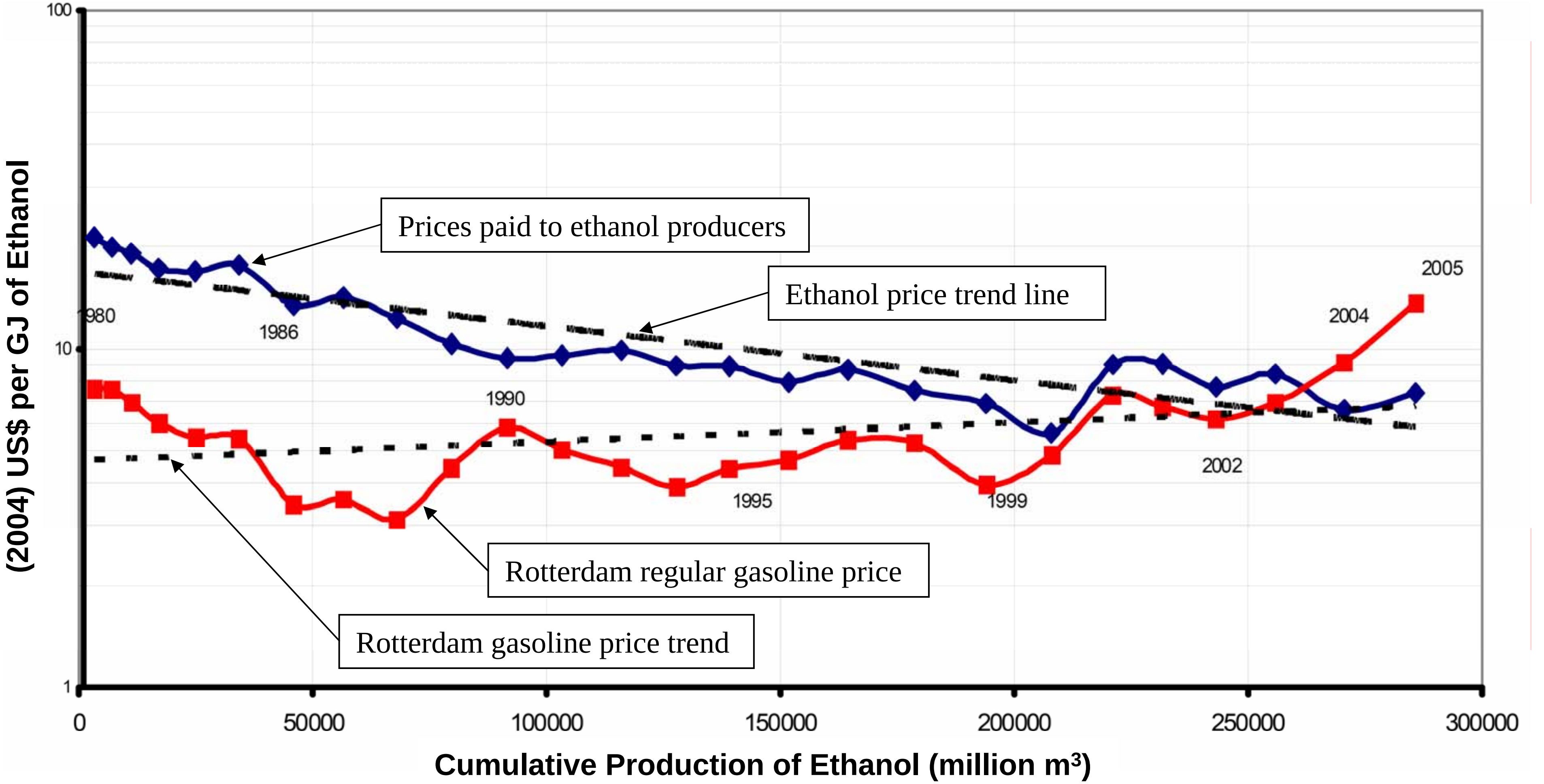
1st Generation Ethanol Costs

(feedstock is largest component)



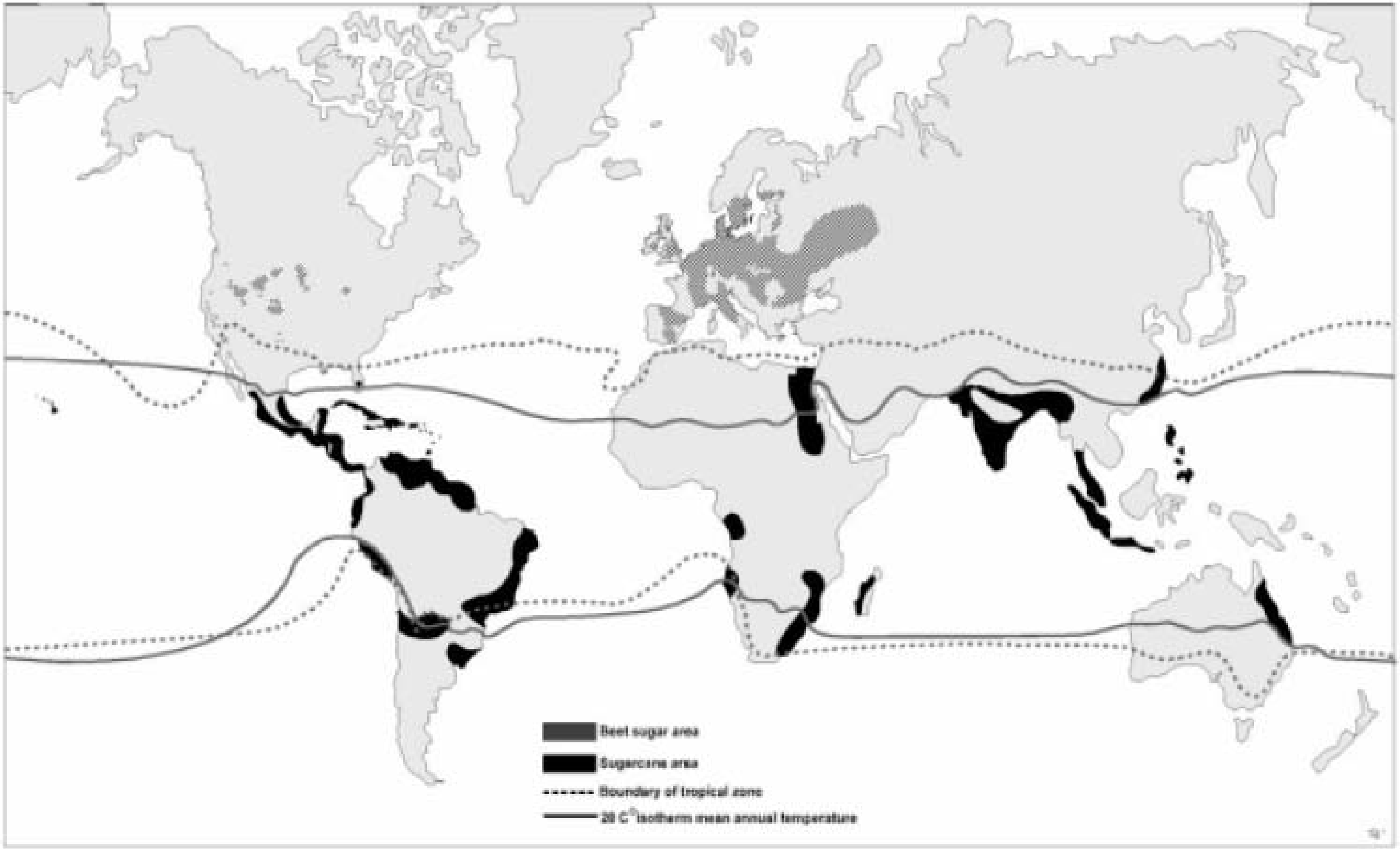
Source: Assis, V., Elstrodt, H-P., and Silva, C.F.C., "Positioning Brazil for Biofuels Success," *The McKinsey Quarterly*, special edition on Shaping a New Agenda for Latin America, 2007.

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.

Brazil Experience is Widely Relevant



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

First Generation Biofuels

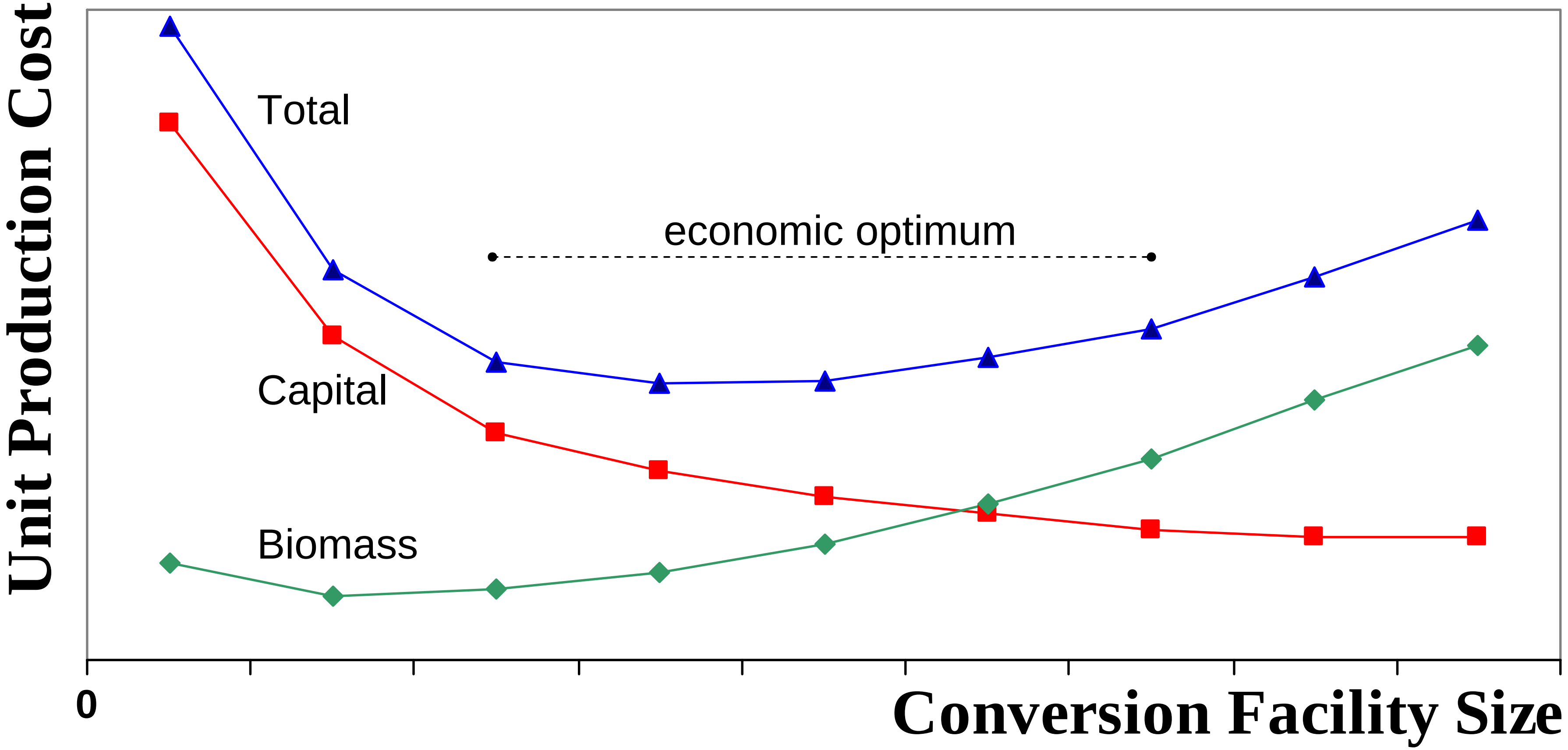
- Use of sugar or starch crops creates limitations:
  - Plants are optimized for food production, not energy.
  - Only part of the plant is converted to biofuel.
  - Competition with food leads to high-cost energy feedstocks and high cost food.
  - Co-product sales often important for acceptable economics.
  - Only modest energy and GHG benefits (EXCEPT with sugarcane ethanol due to use of cane fiber for energy).
  - High production costs (except Brazilian ethanol) requires subsidies, even when oil price is high.
- Positive attributes
  - Can blend with existing petroleum-derived motor fuels.
  - Large-scale experience in Brazil and USA.
  - Production possible at small or large scales.

Second Generation Biofuels

- Made from lignocellulosic biomass
  - 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 1^{st} generation biofuels due primarily to larger amount of biomass converted per unit land area.
- Greater capital-intensity than 1^{st} generation biofuels, but lower feedstock costs → higher cost-scale sensitivity.

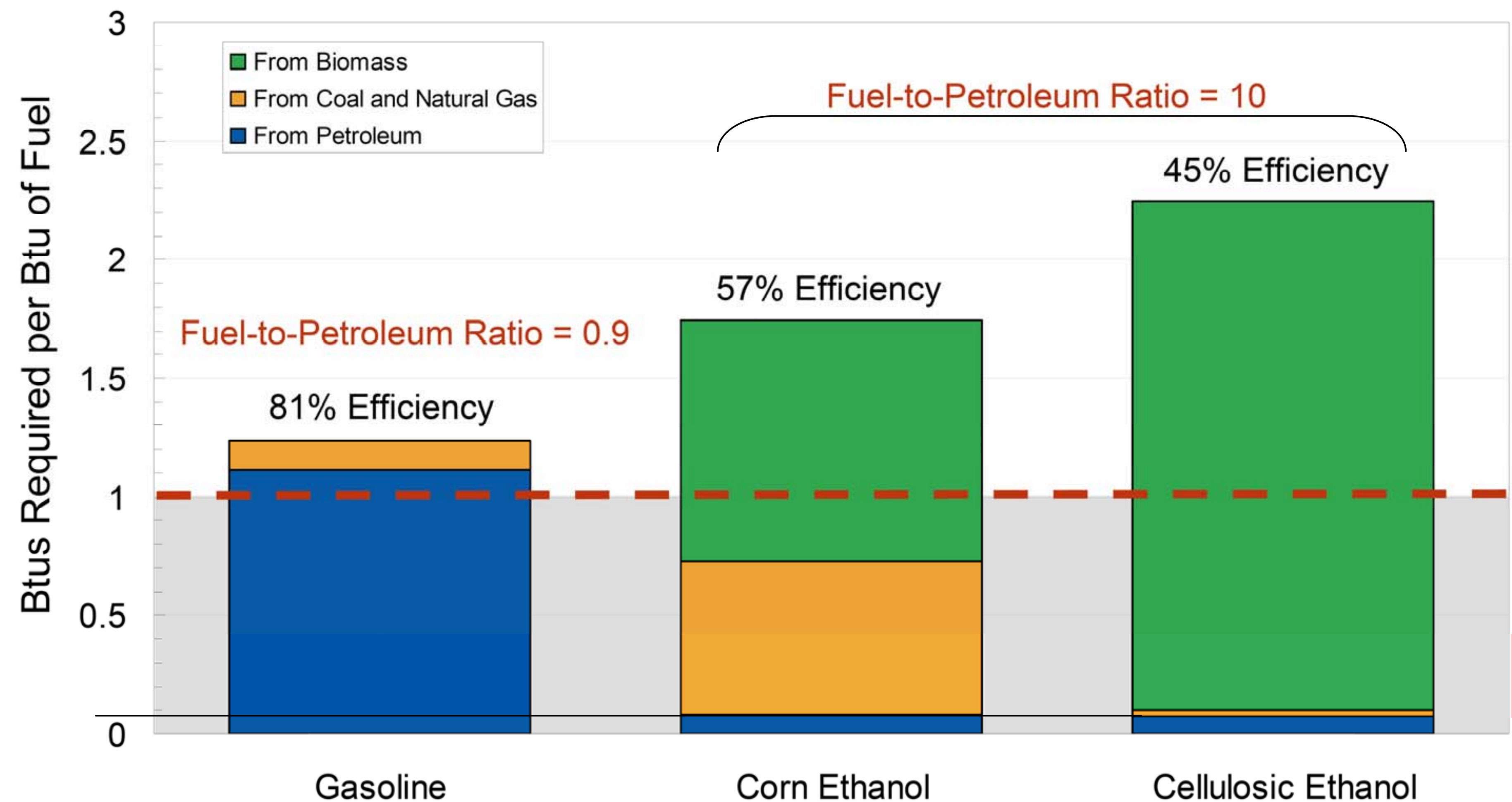
→ Larger scale facilities needed for optimum economics.

2nd Generation: Cost vs. Scale

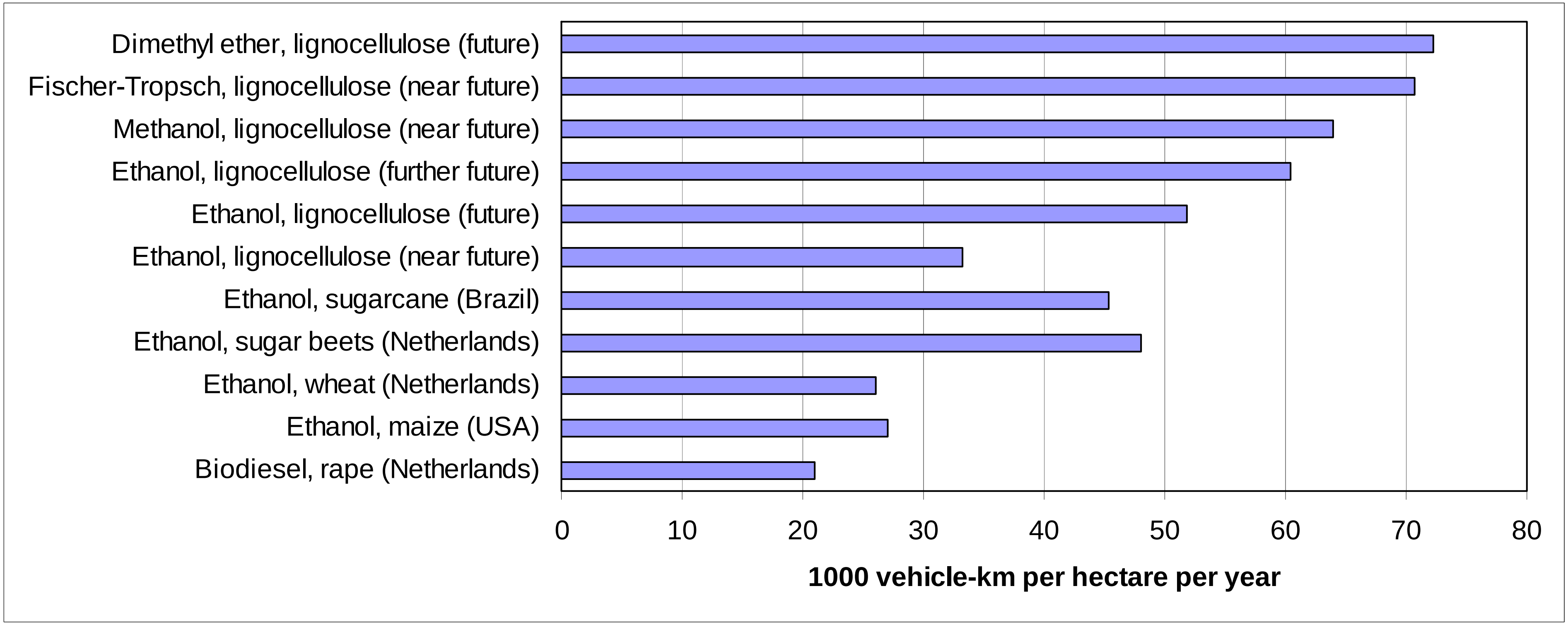


Comparing Energy Balances

(related to GHG emission profiles)



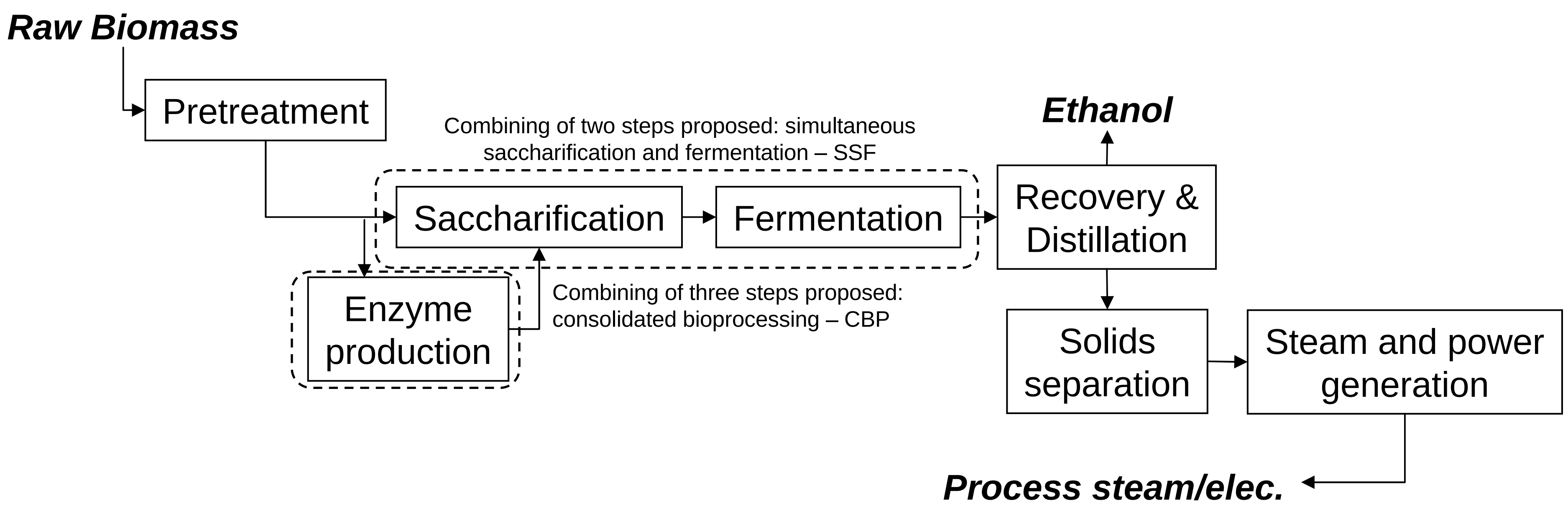
Transportation Services Per Hectare



- Similarly, GHG emissions avoided with biofuels depends on prior use of the land, biofuel feedstock and cultivation method, conversion process, and the biofuel produced.
- The range of GHG savings can vary from negative (for some 1st generation biofuels) to very positive (for some 2nd generation biofuels.

2nd Generation Ethanol Processes "Cellulosic Ethanol"

(similar routes for butanol)

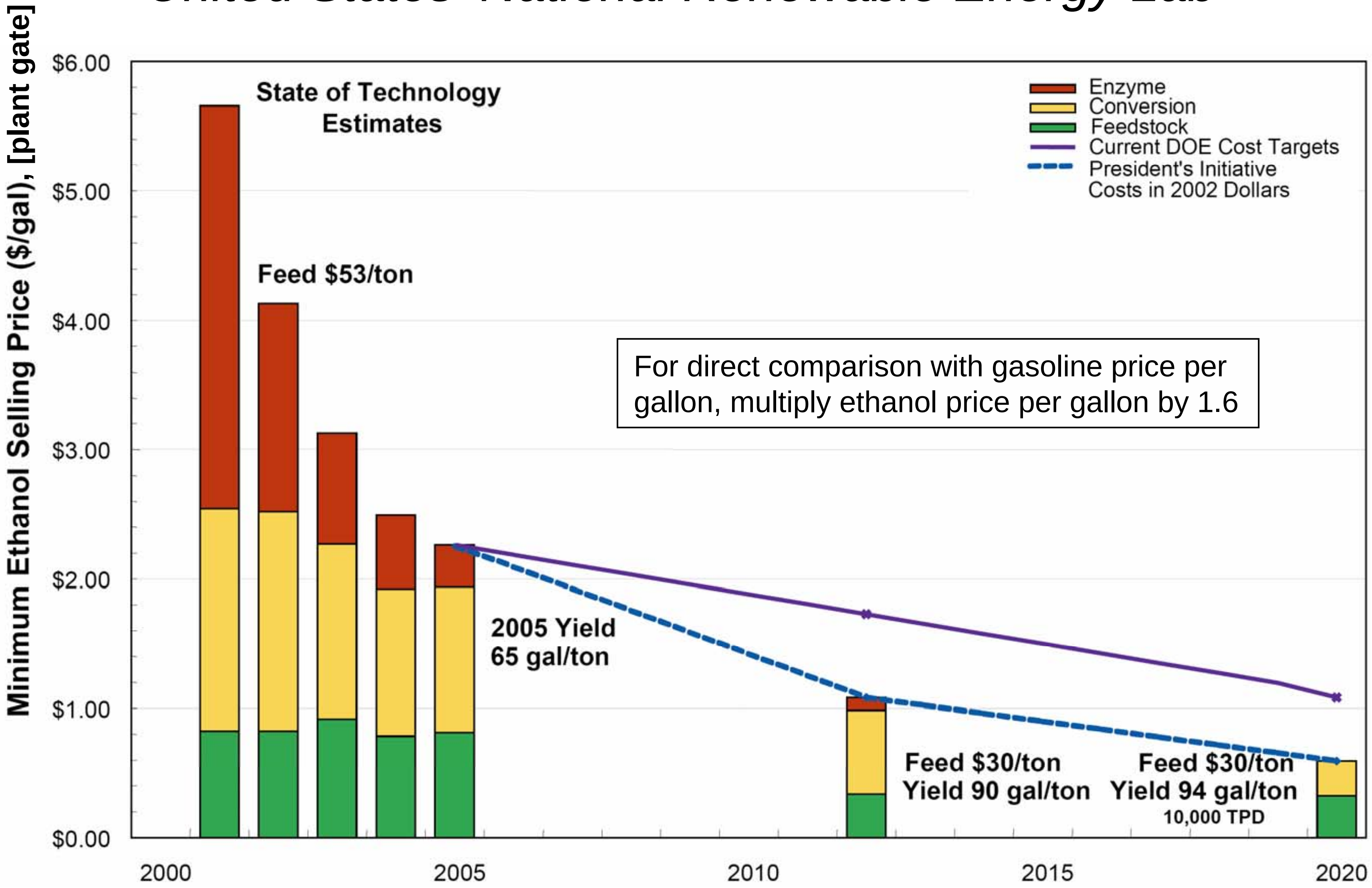


2nd Generation Biological Conversion

- "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.
- First commercial demonstration projects are in planning (in U.S.) – will be heavily subsidized.

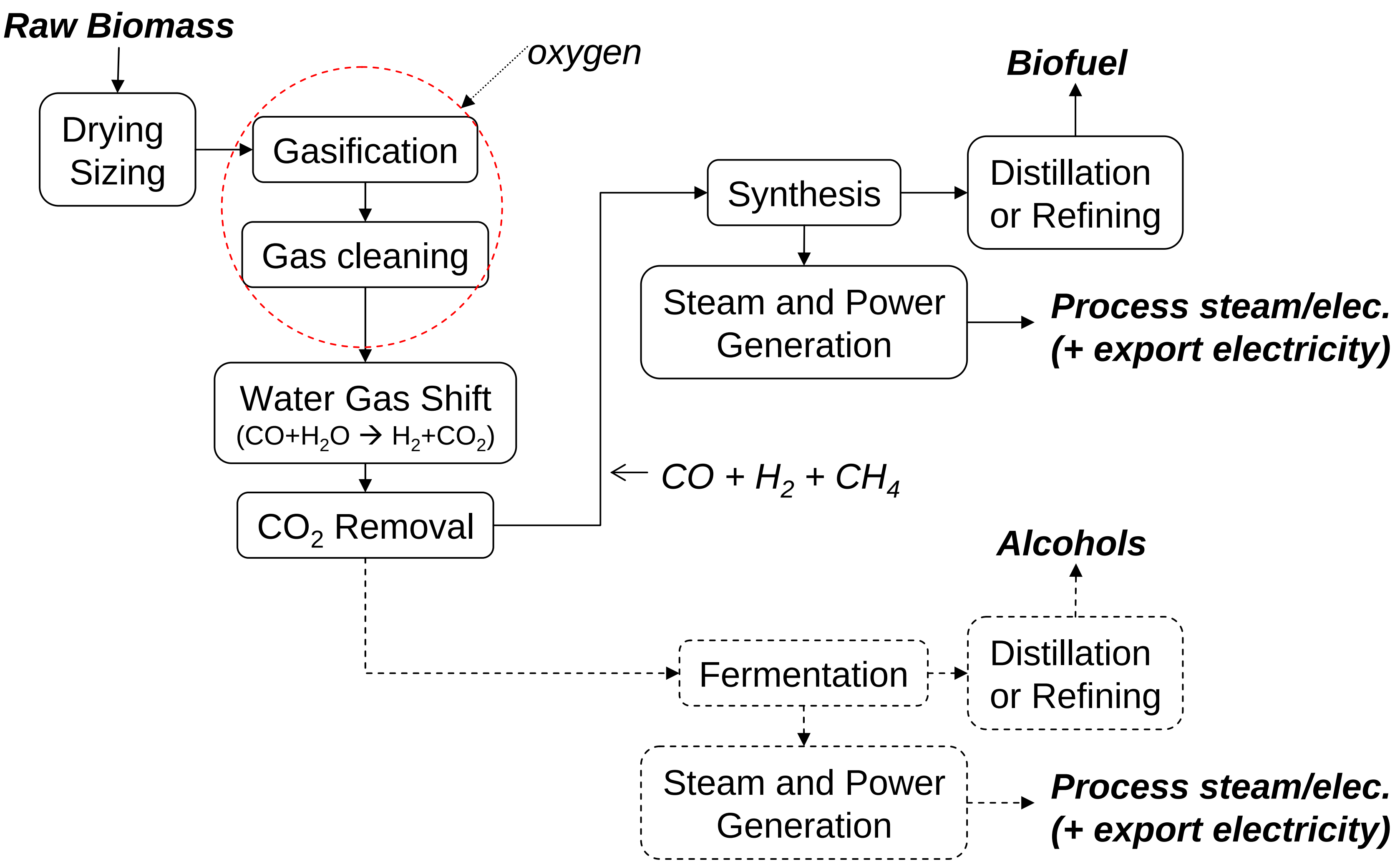
Cost Targets For Cellulosic Ethanol

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.

2^{nd} Generation Thermochemical

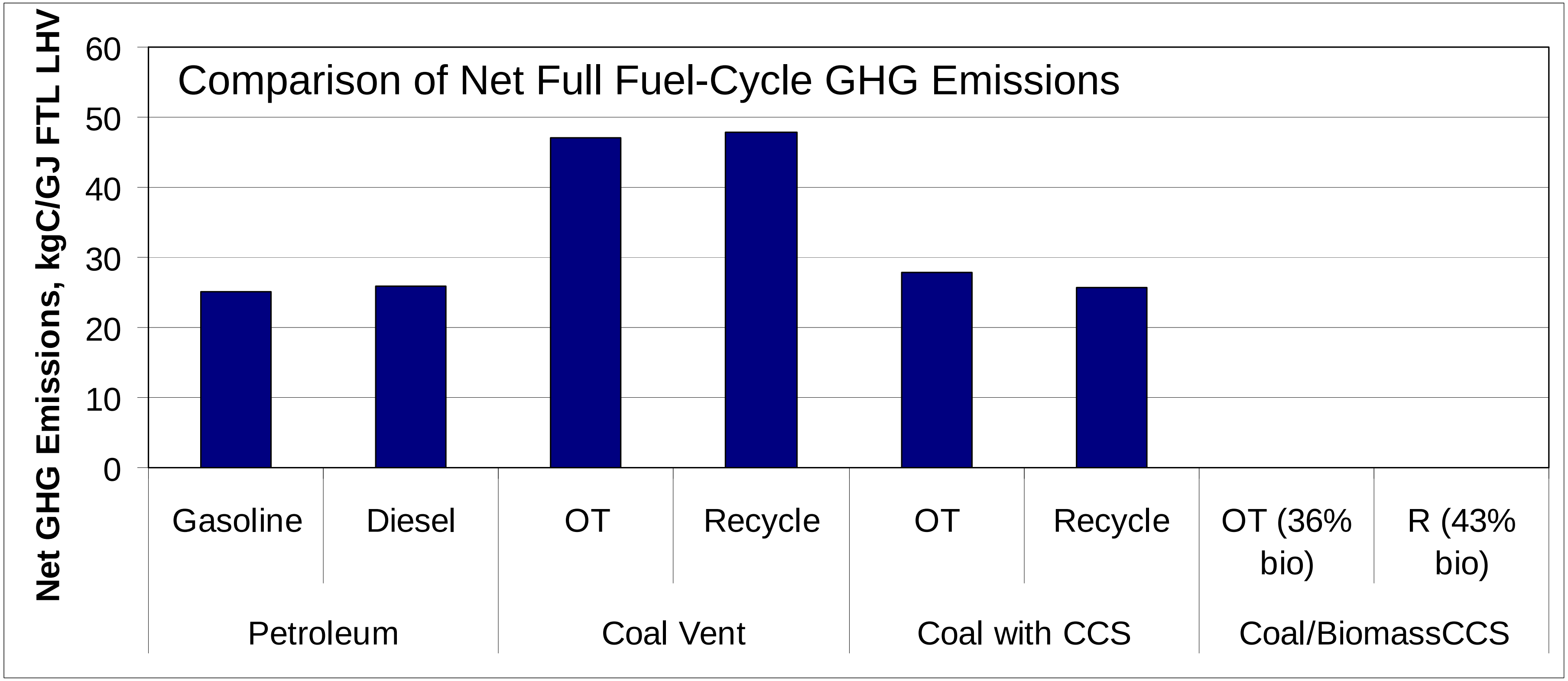


2nd Generation Thermochemical Conv.

- Complete utilization of the biomass; diverse feedstocks can be used (including lignin-rich feedstocks).
- Conversion technologies available –R&D breakthroughs not essential to get started.
  - Commercial-scale demonstration plants for gasification+catalytic synthesis being built in U.S.A. and Germany (subsidized).
  - Commercial-scale demo for gasification+fermentation of syngas in planning in USA (subsidized).
- With biomass price of $3-5/GJ ($54-90/dry t -- reasonable expectation for USA or OECD), FTL would be competitive when oil is $70 to $90 per barrel with known technology.
  - Lower biomass costs in developing countries and "learning-by-doing" (as has occurred with the Brazilian ethanol program), will make thermochemical fuels competitive at lower oil prices.
- Large overlap with coal gasification technologies and practical experience, including CO_2 capture.
  - Co-gasification of biomass with coal + utilizing CO_2 capture and storage (CCS) gaining strong interest in USA and Europe.

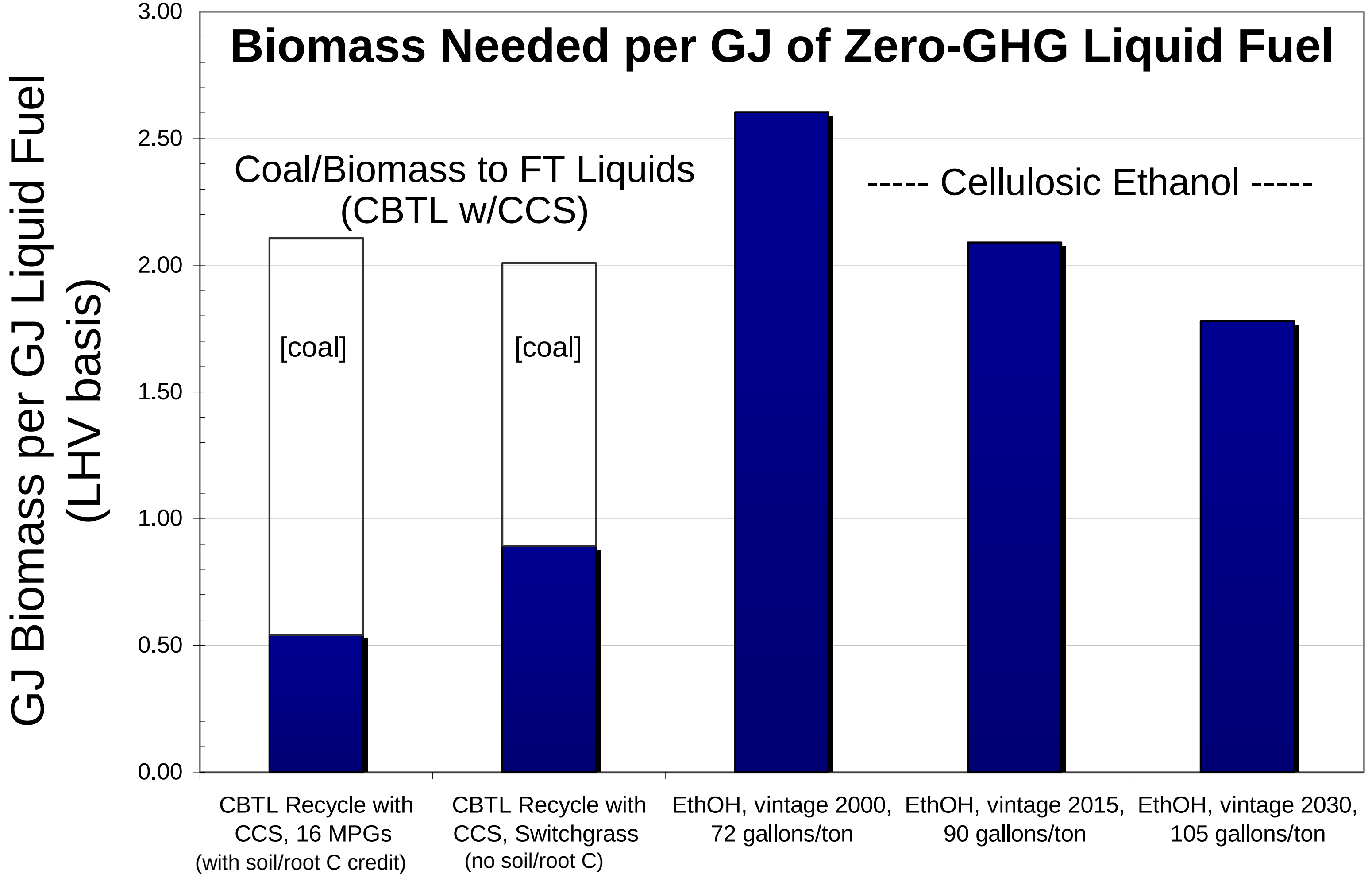
Coal/Biomass-to-FTL w/CCS

- CCS for fossil fuels is focus of major commercial-scale demonstration projects worldwide; IPCC has given favorable assessment.
- If CCS works for fossil fuels, it works for biomass ➔ negative GHG emissions.
- CBTL w/CCS → zero-GHG FTL with ~40/60 biomass/coal input mix.*



* *See:* Larson, Jin, Liu, Williams, "Zero-Carbon FT Liquids via Gasification of Coal and Biomass with CCS" and Williams, Consonni, Fiorese, Larson, "Synthetic Gasoline and Diesel from Coal and Mixed Prairie Grasses for a Carbon-Constrained World," both papers presented at *6th Annual Carbon Capture and Sequestration Conference*, NETL, Pittsburgh, PA, 7-10 May 2007.

CBTL w/CCS Reduces Biomass Use



- 50-70% less biomass per unit of fuel compared to future cellulosic ethanol.
- Biofuel economics improve via capital cost scale economies of coal conversion and low costs of coal.
- Lower biomass input/gallon of fuel ➔ more market power for grower.

Summary (1)

- Biofuels have the potential to
  - Play a significant role in the transport sector of many developing countries (due to low per-capita transport-sector fuel use today).
  - Provide biofuels for clean cooking to <u>all</u> households currently using polluting solid fuels (equivalent of 1% of global commercial energy use).
- Sugarcane ethanol, plus most 2nd generation biofuels, will significantly reduce GHG emissions per unit of transportation service provided. First generation biofuels have only modest (if any) 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.

Summary (2)

Second generation biofuels

- Under development primarily in the North. Further R,D&D needed to achieve 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 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.

Trade/Development Implications (1)

- Potential land use conflicts for food vs. biofuel may be mitigated to some extent by
  a) Utilizing "waste" biomass (crop residues, forest residues, etc.) requiring no new land use.
  b) Increasing productivity of food agriculture (yields per hectare) – large gains are possible;
  c) Targeting biofuel feedstock production on lands less-suited to food crop production;
  d) Targeting the production of 2nd generation biofuels to maximize land-use efficiency.
  e) Co-utilizing biomass and coal with CCS.
- Economics of 2nd generation biofuels in the South have the potential to be much better than in the North since many countries of the South have comparative cost advantages in producing feedstocks due to better growing climates, lower labor costs, and lower land costs.
- More capital investment needed per unit production.

Trade/Development Implications (2)

- Significant global markets for biofuels exist and will grow in most industrialized countries due to regulatory mandates and expected oil prices > $50-$60/bbl.
- Significant export potential for biofuels or biofuel feedstocks from South to North could offer CDM credit possibilities to improve biofuel production economics.
  - GHG emissions from land conversions forced by biofuels?
- For larger developing countries, becoming competitive exporters will be helped by encouragements of domestic biofuel programs to pursue world-class scales and efficiencies, and seek low capital investment intensities.
  - Establishing sustained domestic demand (e.g., through regulatory mandates) could be an important first step (Brazilian model) in supporting such industries.