Liquid Biofuel Technologies and Technology Issues

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

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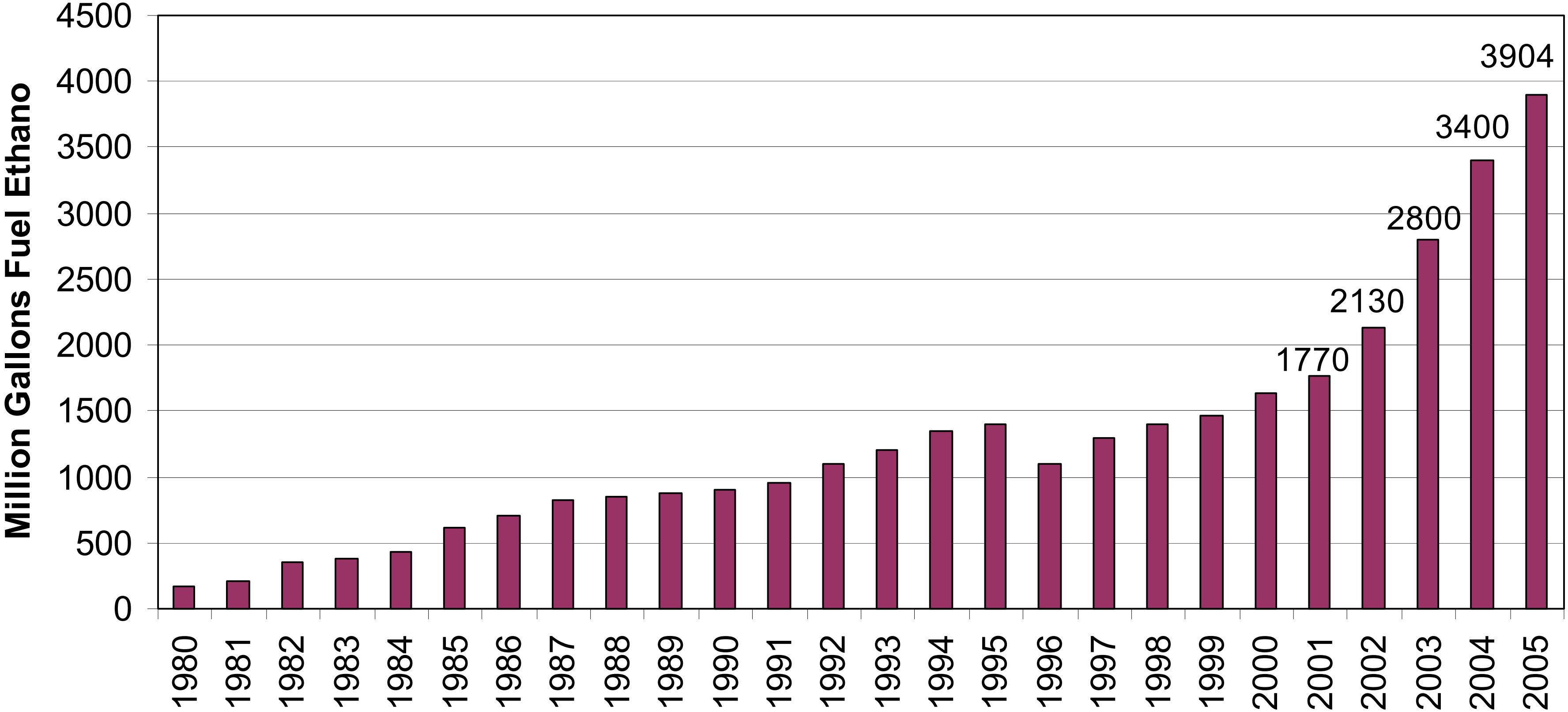
U.S. Fuel Ethanol Production



U.S Ethanol and Biodiesel Capacity

Ethanol (corn)

- 107 existing plants – 5.1 billion gal/yr capacity
  - 1 to 1000 million gal/yr individual plant capacities
- 49 plants being built – 3.9 billion gal/yr capacity
- Approximately 15% of U.S. corn crop in 2005 was used to make ethanol, and the ethanol displaced less than 2% of transportation oil use.

Biodiesel (soy)

- 87 existing plants – 0.6 billion gal/yr capacity
  - 0.5 to 37 million gal/yr individual plant capacities
- 65 plants being built – 1.4 billion gal/yr capacity

Biofuel Technology Issues

Objectives for a biofuel program

- Transportation fuel security vs. broader energy replacement?
- Land reclamation?
- Rural employment and development?
- Export revenue?
- Global warming mitigation?

Issues for different biofuels

- Land requirements.
- Conversion technology scale and sophistication.
- Economics (feedstock, conversion, delivery, and use).
- Environmental impacts (lifecycle)
- Compatibility with existing fuel delivery/use infrastructures
- Competing uses for biomass (for energy or for other).

Biofuels

First Generation (from sugars, grains, or seeds)

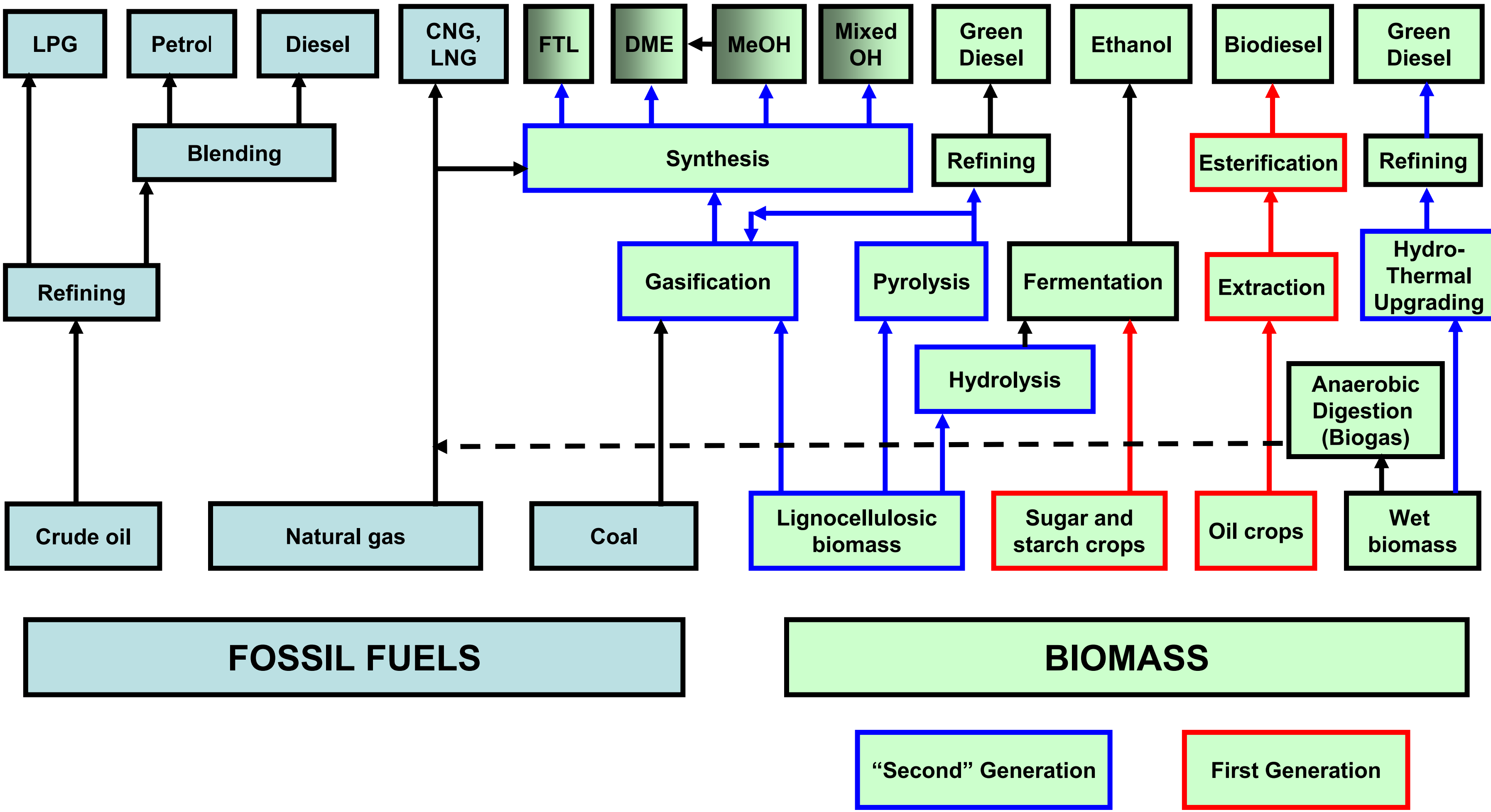
- Biodiesel (fatty acid methyl ester; fatty acid ethyl ester)
  - rapeseed (RME), soybeans (SME), sunflowers, jatropha, coconut, palm, recycled cooking oil
- Pure plant oils (straight vegetable oil).
- Bioethanol
  - From grains or seeds: corn, wheat, potato
  - From sugar crops: sugar beets, sugarcane

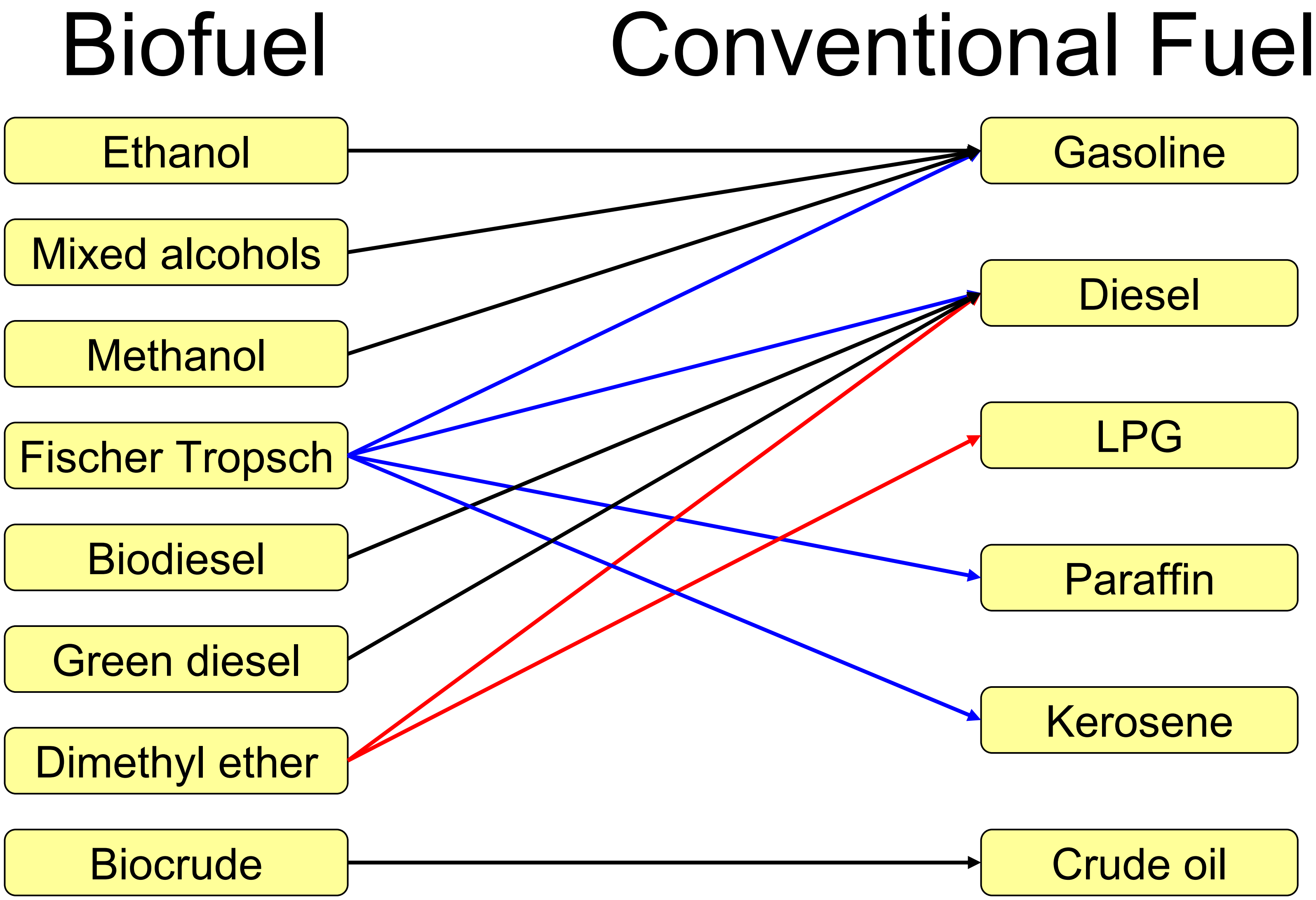
“Second” Generation (from lignocellulose: crop residues, grasses, woody crops)

- Ethanol via enzymatic hydrolysis
- Thermochemical fuels
  - Fischer-Tropsch liquids (FTL)
  - Methanol, MTBE, gasoline
  - Dimethyl ether (DME)
  - Mixed alcohols
  - Hydrogen
  - Hydrothermal upgrading oils (HTU)
  - Pyrolysis oils

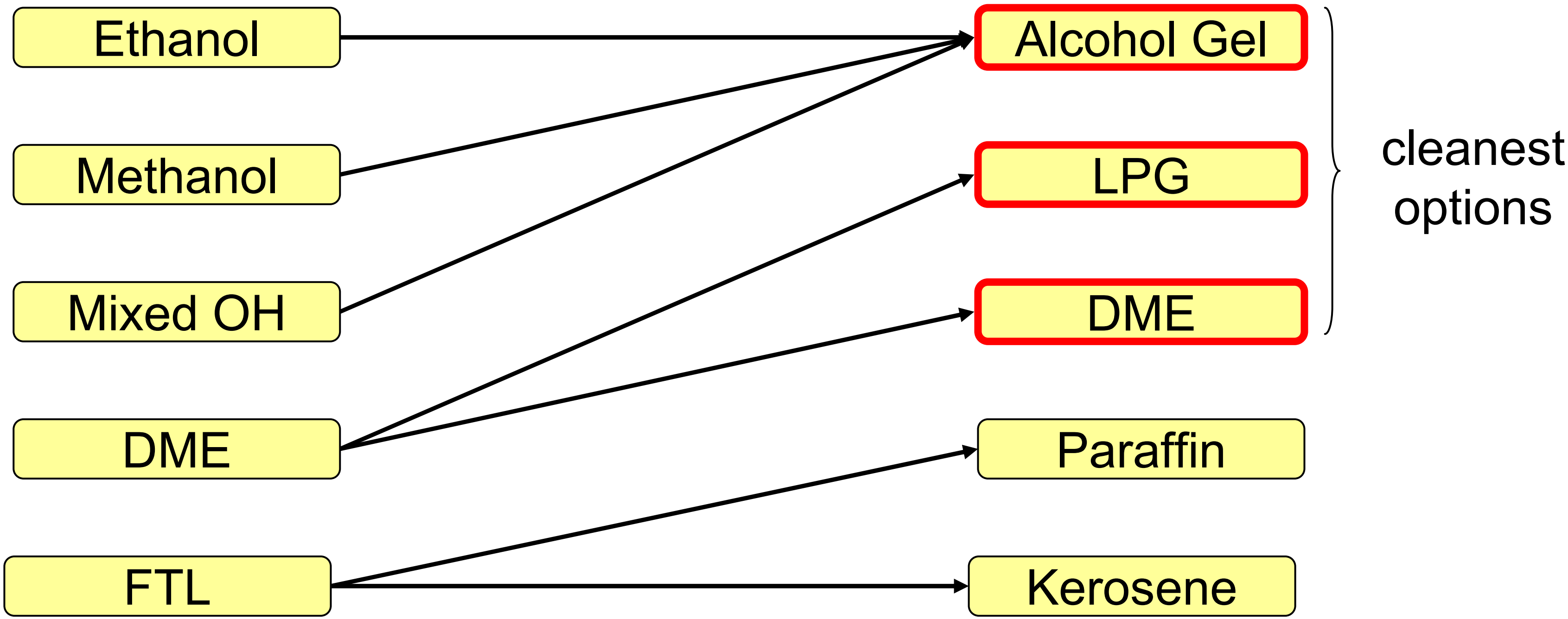
via gasification

Biofuel Production Pathways



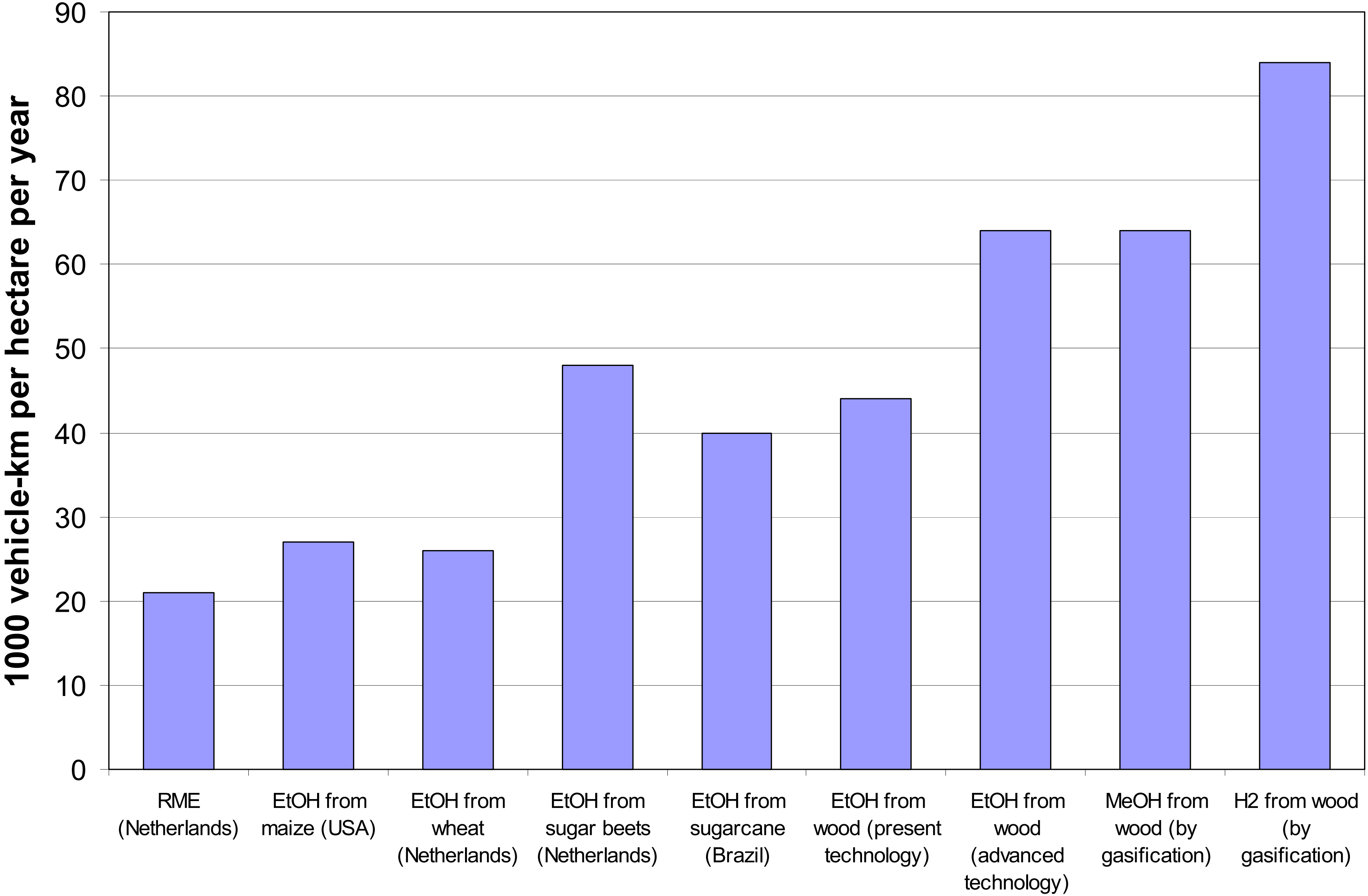

Biofuel
Conventional Fuel
Ethanol
Mixed alcohols
Methanol
Fischer Tropsch
Biodiesel
Green diesel
Dimethyl ether
Biocrude
Gasoline
Diesel
LPG
Paraffin
Kerosene
Crude oil

Biofuel Cooking Fuel



- 4 to 5 EJ/year needed globally if all 3 billion people still cooking with solid fuels were using clean fuels instead [*35 kg/cap/yr of LPG equivalent*].
- U.S. transportation oil use in 2005 was 29 EJ.
- Global commercial energy use in 2005 was ~ 450 EJ.

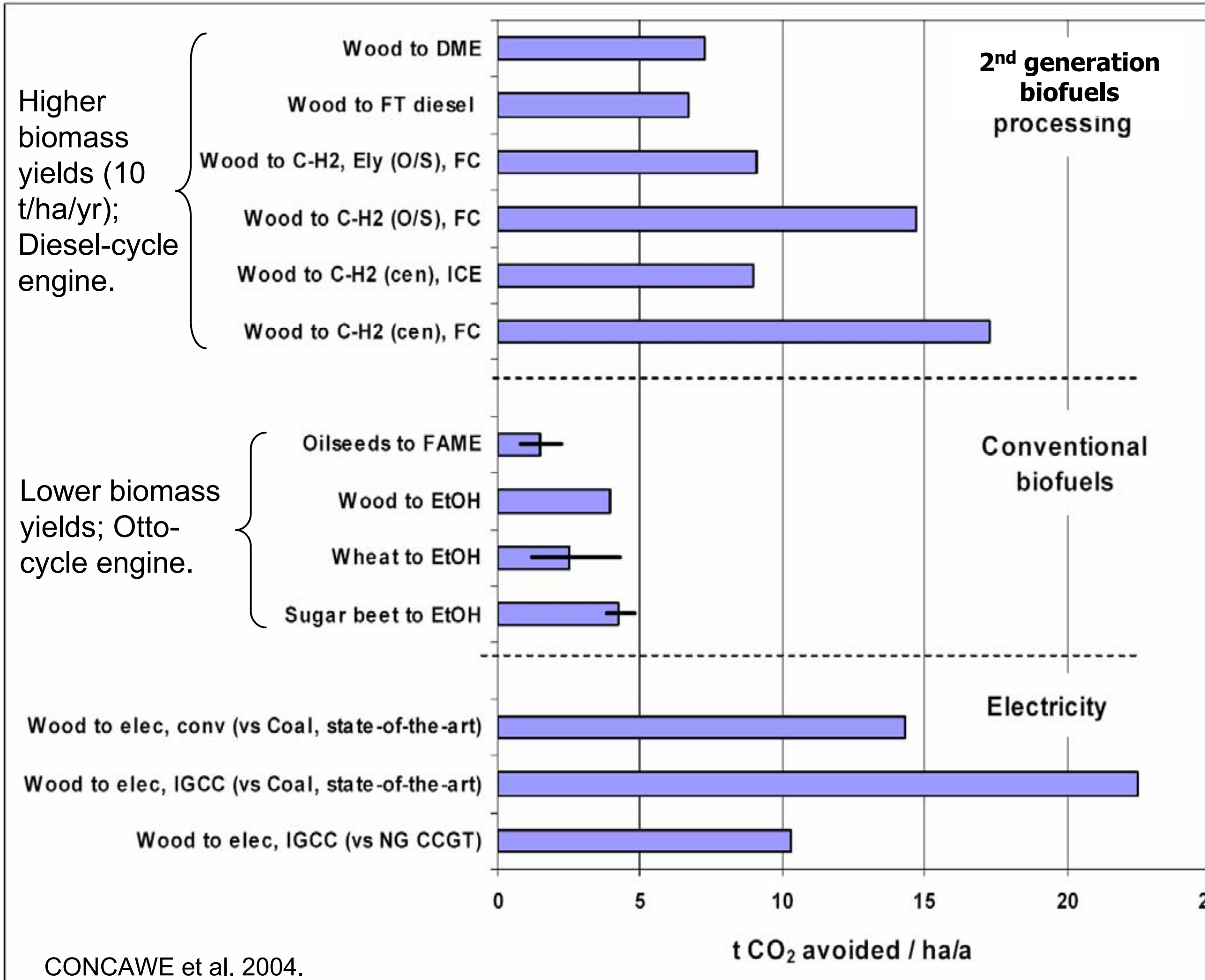
Transportation Services Per Hectare



IPCC, 1996

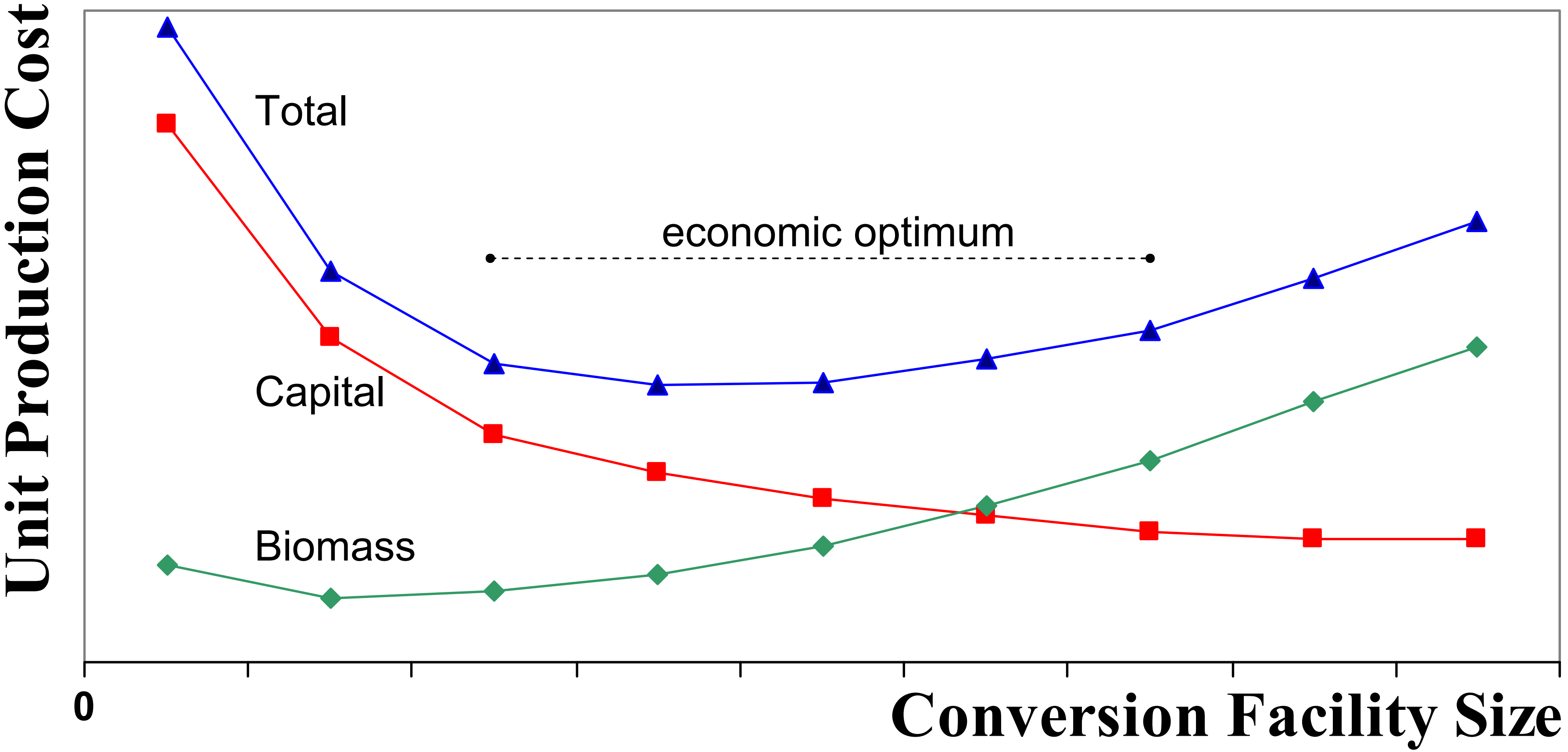
Relative GHG mitigation with biofuels vs. bio-electricity depends on:

- 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.

Cost vs. Scale, 2nd Generation Biofuels



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.
- Limited large-scale experience outside Brazil and USA.
- Relatively high costs (except sugarcane ethanol in Brazil) due to high feedstock cost.
- Cost penalties less severe at smaller scales.

“Second” Generation Biofuels

- Made from lignocellulosic materials
  - These are generally not edible.
  - Plants can be bred for energy characteristics.
  - Larger fraction of the plant is converted to fuel.
  - “Biorefinery” maximizes plant utilization.
- Substantial energy/environment benefits.
- Can blend with petroleum fuels in most cases.
- Greater capital-intensity than 1st generation biofuels, but lower feedstock costs ➔ higher cost-scale sensitivity than with 1st generation means larger scale of conversion facilities needed.
- Thermochemical and biological second-generation biofuels are different.

2^{nd} Generation: Thermochemical

- FT, DME, methanol, mixed-alcohols
- Allows complete utilization of the biomass.
- High degree of feedstock flexibility.
- Conversion technologies available today for FT, DME, MeOH – no R&D breakthroughs.
- Commercial-scale implementation is lacking today, but large overlap (and synergies) with commercially established fossil fuel conversion technologies.
- One commercial facility in planning (Germany).

2nd Generation: Biological

- "Cellulosic ethanol"
- 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 feestock.
- R&D breakthroughs needed to improve conversion and reduce costs.
- Projected costs are somewhat less scale sensitive than for thermochemical fuels.
- One commercial facility in planning (Idaho, USA).