Life Cycle Analysis

With examples from biofuel analysis

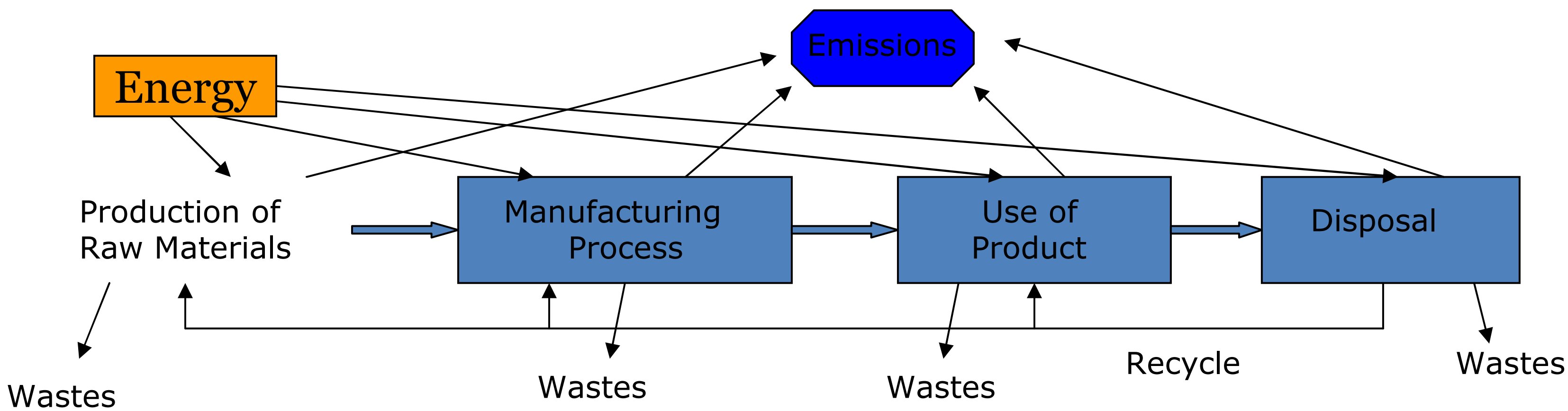
Sustainable Energy
18th November 2010

Outline of Presentation

- Introduction to Life Cycle Analysis (LCA)
- LCA Basics
- Examples and challenges to implementation
  - Corn Ethanol
  - Cellulosic Ethanol
  - Cellulosic Biofuels
- Illuminating Biofuel Trade-offs
- Consideration of Biofuel Policy

Introduction to LCA

- What is LCA?
  - A system analysis methodology (remember toolbox 4?)
  - “cradle-to-grave analysis”



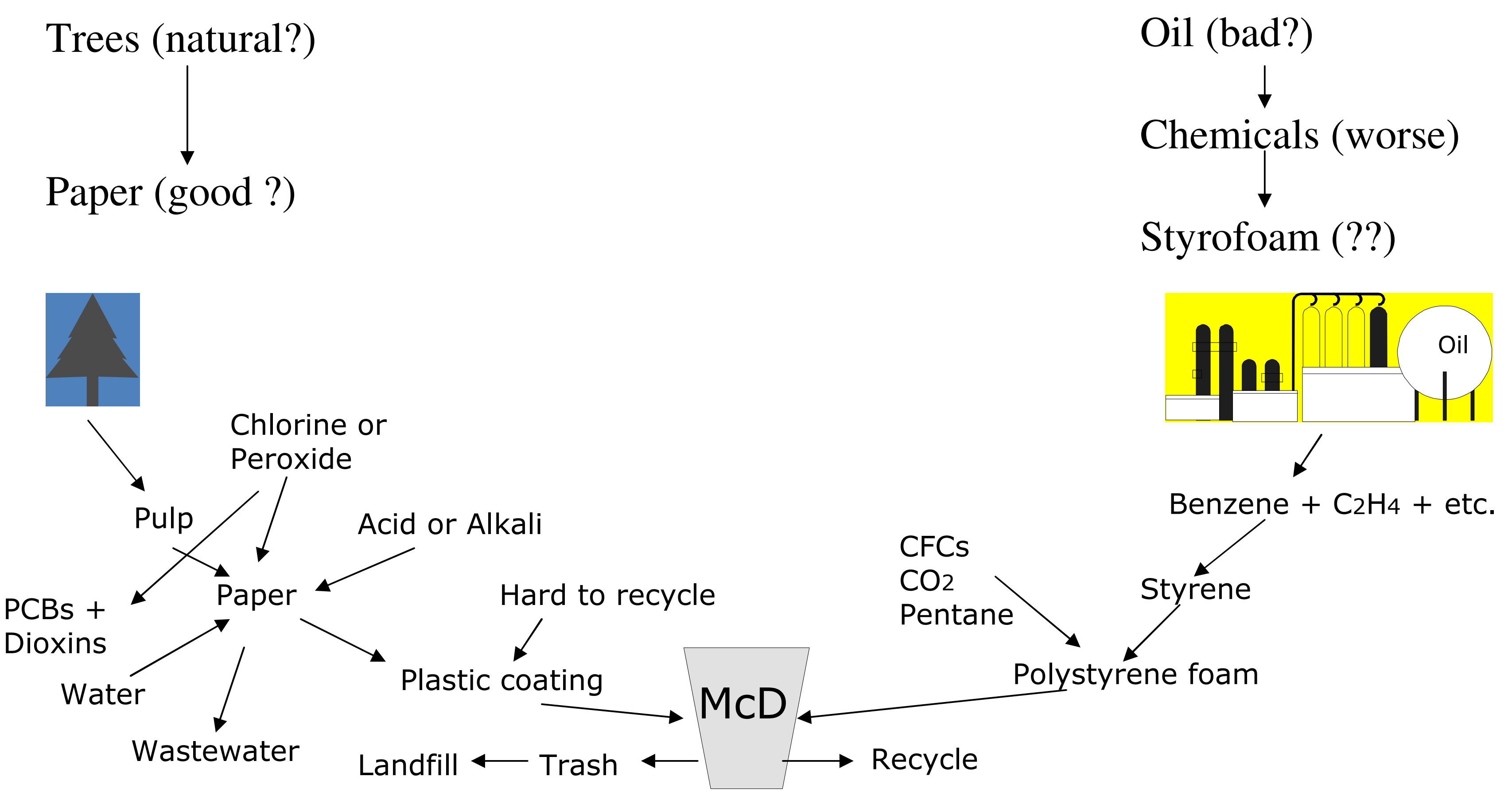
Components of LCA

- Inventory
  - Quantification of energy and raw material requirements, emissions, effluents, and wastes
  - i.e. mass and energy balances are integrated over each process in system
- Impact Assessment
  - Values can be assigned to effects for quantification
- Improvement
  - Systems can then be optimized with respect to parameters from impact assessment

Why is LCA methodology Useful?

- Many parameters we are interested in don't occur in just one step of a product's lifecycle
  - Carbon dioxide emissions from Coal-to-Liquid fuels.
- Optimizing one production step doesn't mean system is optimal.
  - Hydrogen as a transportation fuel
- Lifecycle analysis is intended to be used to optimize the aggregate outcomes

Allow for comparison of potential products: MacDonald's - Styrofoam or paper?



Life-Cycle Analysis - approach

- Define "cradle-to-grave" alternative systems
- Set system boundary conditions
- Set time basis (snapshot of industry in time vs. one life cycle of representative product)
- Identify impacts of interest to decision-makers
  - Costs, air pollution, GHG emissions, wastes, resource depletion, etc.
- For each portion of the life-cycle, estimate the impacts of interest
- Assess overall tradeoffs, considering uncertainties
- Identify major sources of adverse impact and assess improvements

Life Cycle Analysis Software

- Dedicated Packages
  - GaBi
  - Umberto
- DIY (for simple cases)
  - Excel
  - Matlab

Life Cycle Analysis for Energy Systems

- Major process steps
  - Resource extraction/ production
  - transport
  - Fuel/electricity production
  - Distribution
  - end-use
- Important Parameters
  - Emissions
  - <u>Useful</u> work
  - Costs
- Useful simplification
  - *Most energy conversion facilities non-fuel resource use negligible.*

LCA studies for biofuels are <u>mandated</u>

- Text of the Energy Independence and Security Act of 2007:
  - "GENERAL.—The term **'advanced biofuel'** means renewable fuel, other than ethanol derived from corn starch, that has **lifecycle greenhouse gas emissions**, as determined by the Administrator, after notice and opportunity for comment, that are at least **50 percent** less than baseline lifecycle greenhouse gas emissions."
  - "CELLULOSIC BIOFUEL.—The term **'cellulosic biofuel'** means renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emissions, as determined by the Administrator, that are at least **60 percent** less than the baseline lifecycle greenhouse gas emissions."
  - Baseline: average LCA GHG emissions from gasoline or diesel, whichever a particular biofuel replaces
- The act calls for 36 billion gallons of renewable fuel by 2022, with at least 21 billion gallons of this being "advanced biofuels".

Life-Cycle Analysis – biofuels approach

- **Define "cradle-to-grave" alternative systems**
  - **Choose alternate fuel options**
- **Set system boundary conditions**
  - **This is where the big fights have been/are going to be**
- **Identify impacts of interest to decision-makers**
  - **Costs, air pollution, GHG emissions, land-use change, Food Versus Fuel?**
- **Assess overall tradeoffs, considering uncertainties**
- **Identify major sources of adverse impact and assess improvements**

System Boundaries for Biofuels

- Where do we draw the boundaries for our analysis? Why?
- This turns out to be a MAJOR point of contention.
  – The California Low Carbon Fuel Standard
- If there is a comprehensive carbon tax – won't double counting then occur?

The California Low Carbon Fuel Standard (LCFS)

- The Governor's Executive Order directs the Secretary for Environmental Protection to coordinate the actions of the California Energy Commission, the California Air Resources Board (ARB), the University of California and other agencies to develop the protocols for measuring the "**life-cycle carbon intensity**" of transportation fuels…

California LCFS (Continued)

- In the California rule-making a large fight revolved around the quantification *secondary* land-use changes.
  - Argument for inclusion:
    - Will include deforestation caused by land use change to meet demand for food
  - Argument for exclusion:
    - Double counting
    - Measuring a counterfactual
    - Not applied to petroleum baseline

System Boundaries for Biofuels (Revisited)

- Policy is likely to play a major role in defining system boundaries
  - The term 'advanced biofuel' means renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions, **as determined by the Administrator**, after notice and opportunity for comment, that are at least 50 percent less than baseline lifecycle greenhouse gas emissions."
- Assuming that system boundaries are "non-overlapping" could there still be double counting?

Identifying the Process Steps

- System contains a connected web of individual processing steps each with their own:
  - Energy balances
  - Mass balances
  - Cash flows
  - Emissions
  - Regulations
  - …
- How do we determine the necessary amount of granularity?
  - Only major steps?
  - Every subprocess?
  - Down to the last valve?
- This is a matter of identifying goals of analysis (think back to SD lecture)

Key Issues

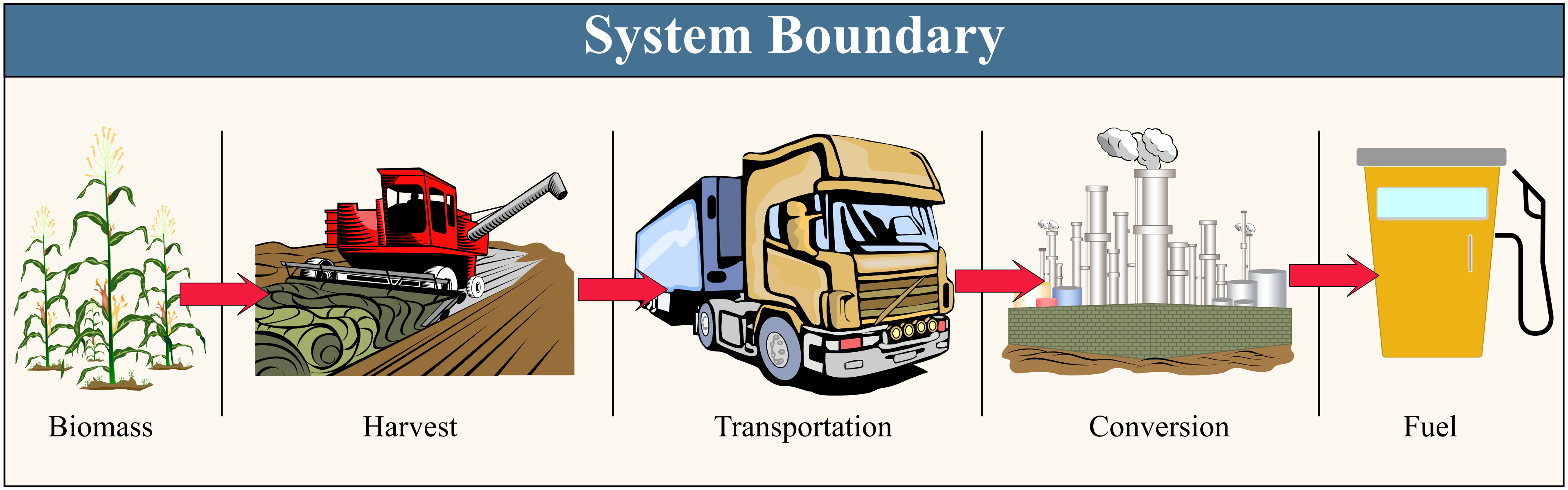
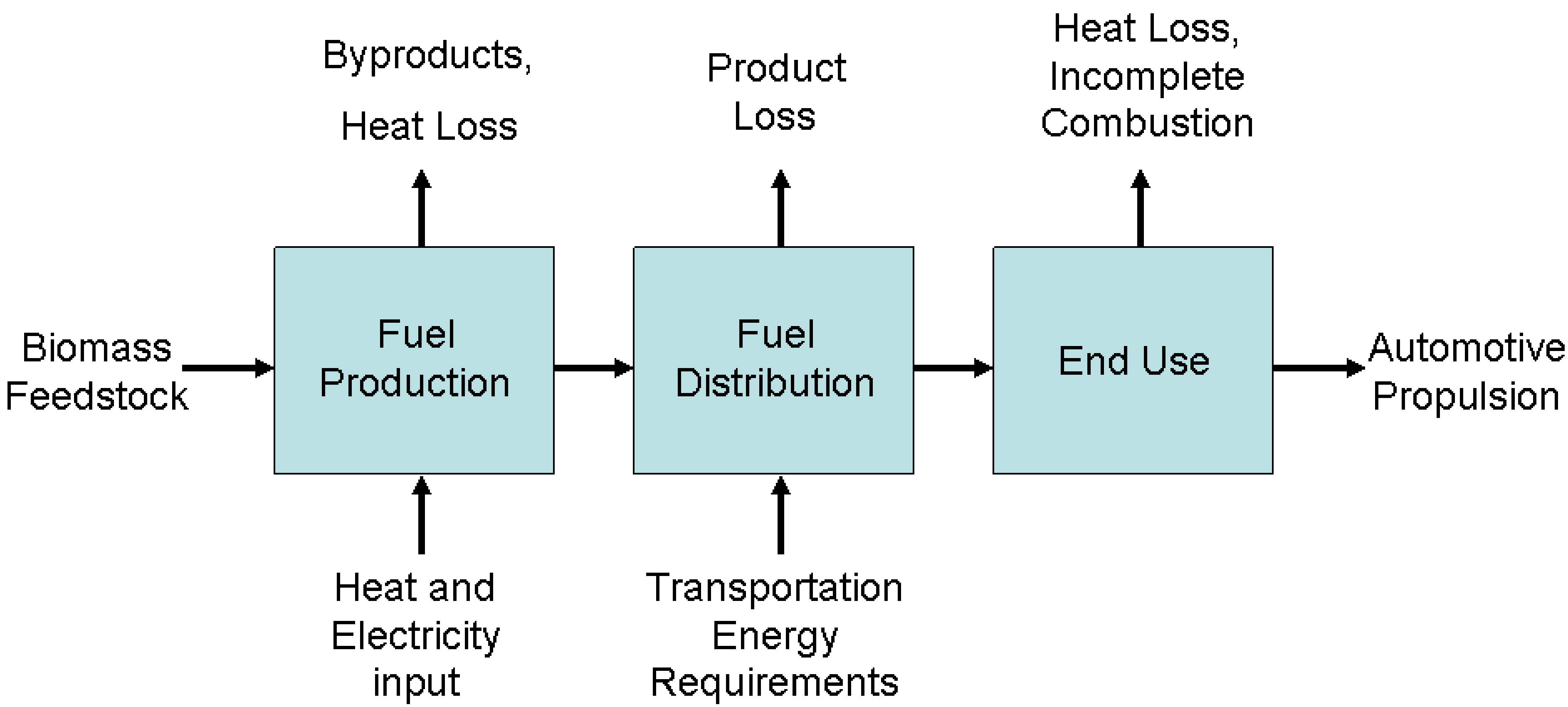


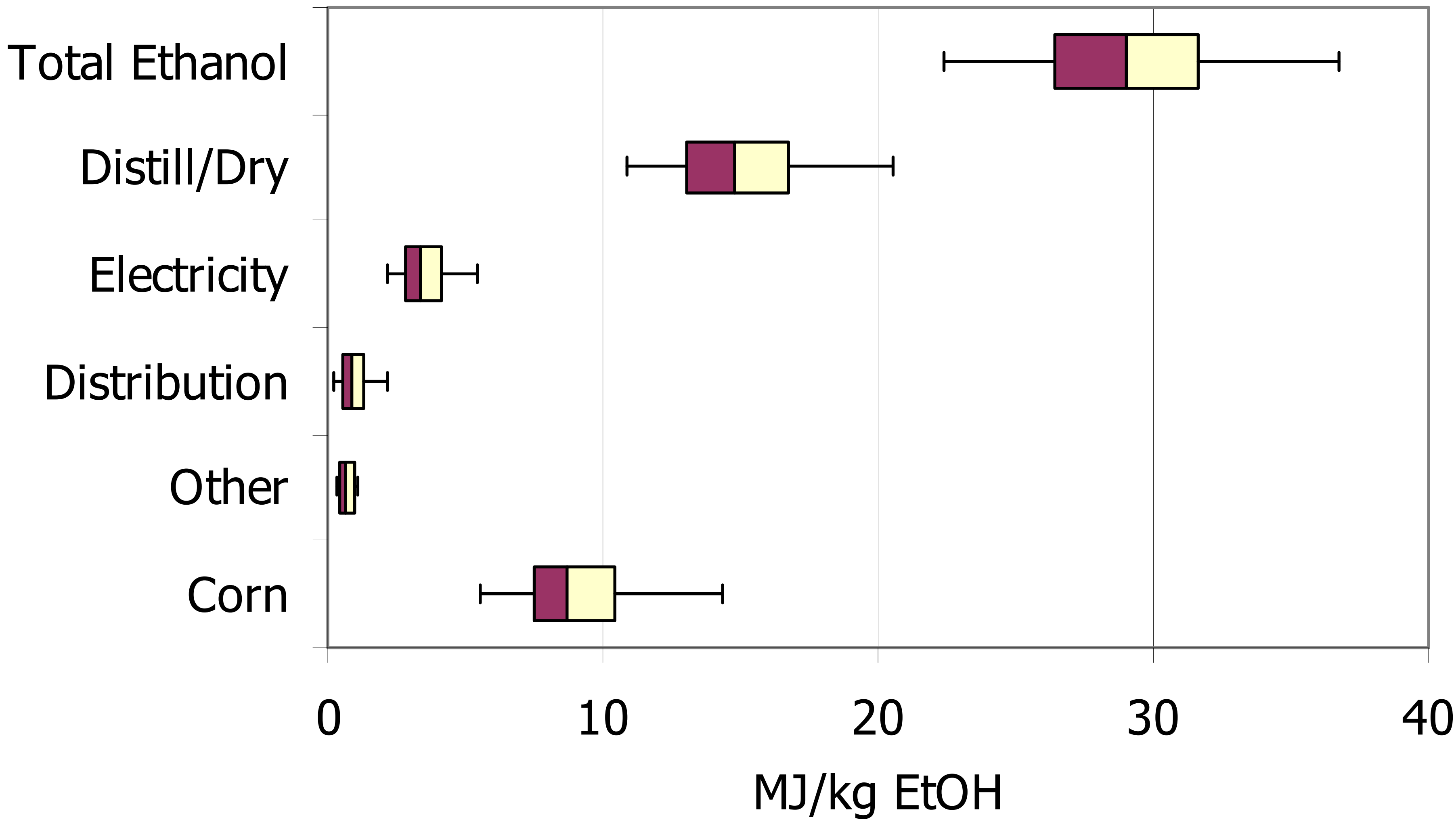
Image by MIT OpenCourseWare.

- Scale -- Biomass availability
- Performance -- Energy balance
- Economics today and tomorrow
- transitioning from corn–based to cellulosic fuel

Simplified Lifecycle of Biofuel Production



Energy Inputs to Corn Ethanol



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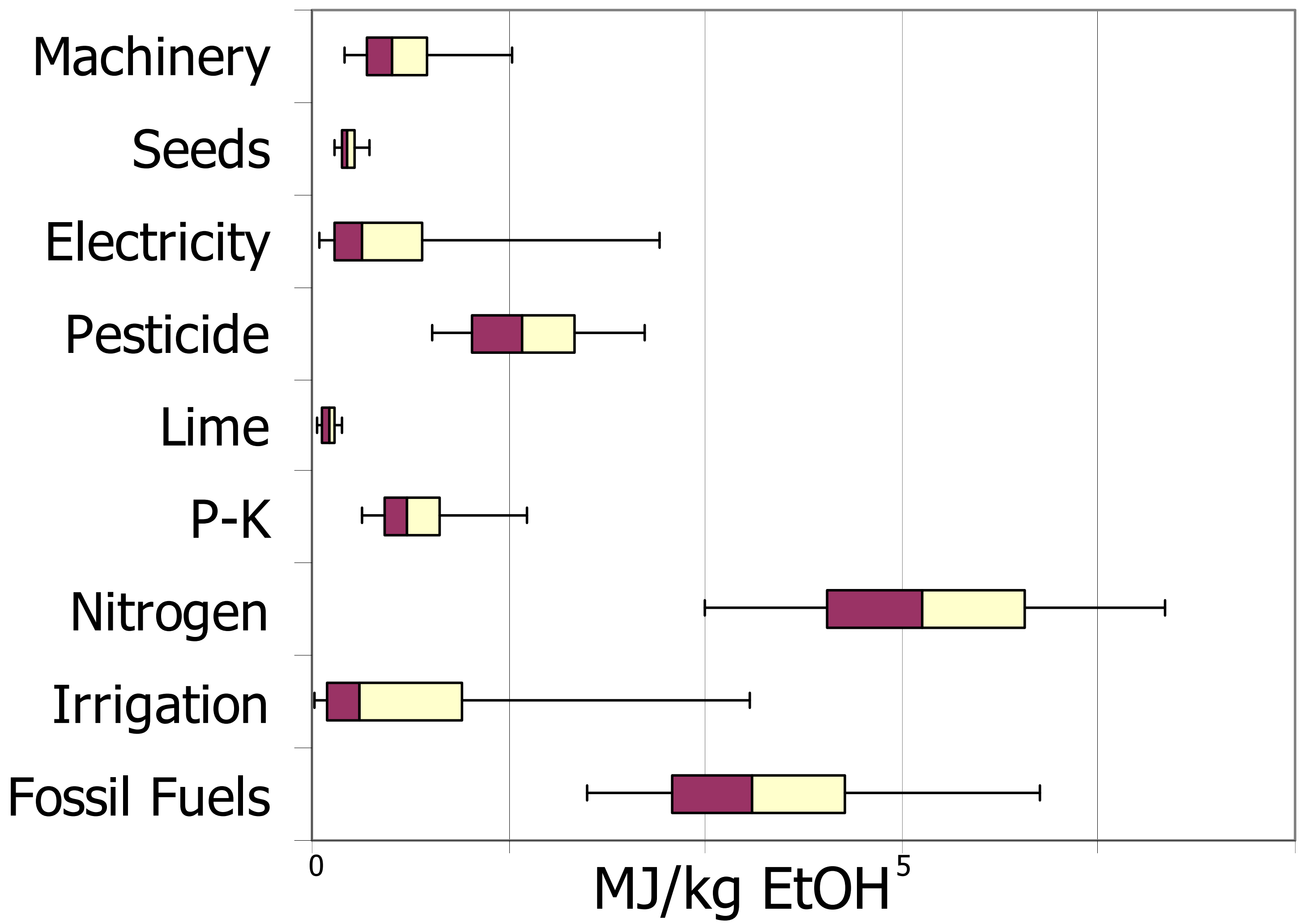
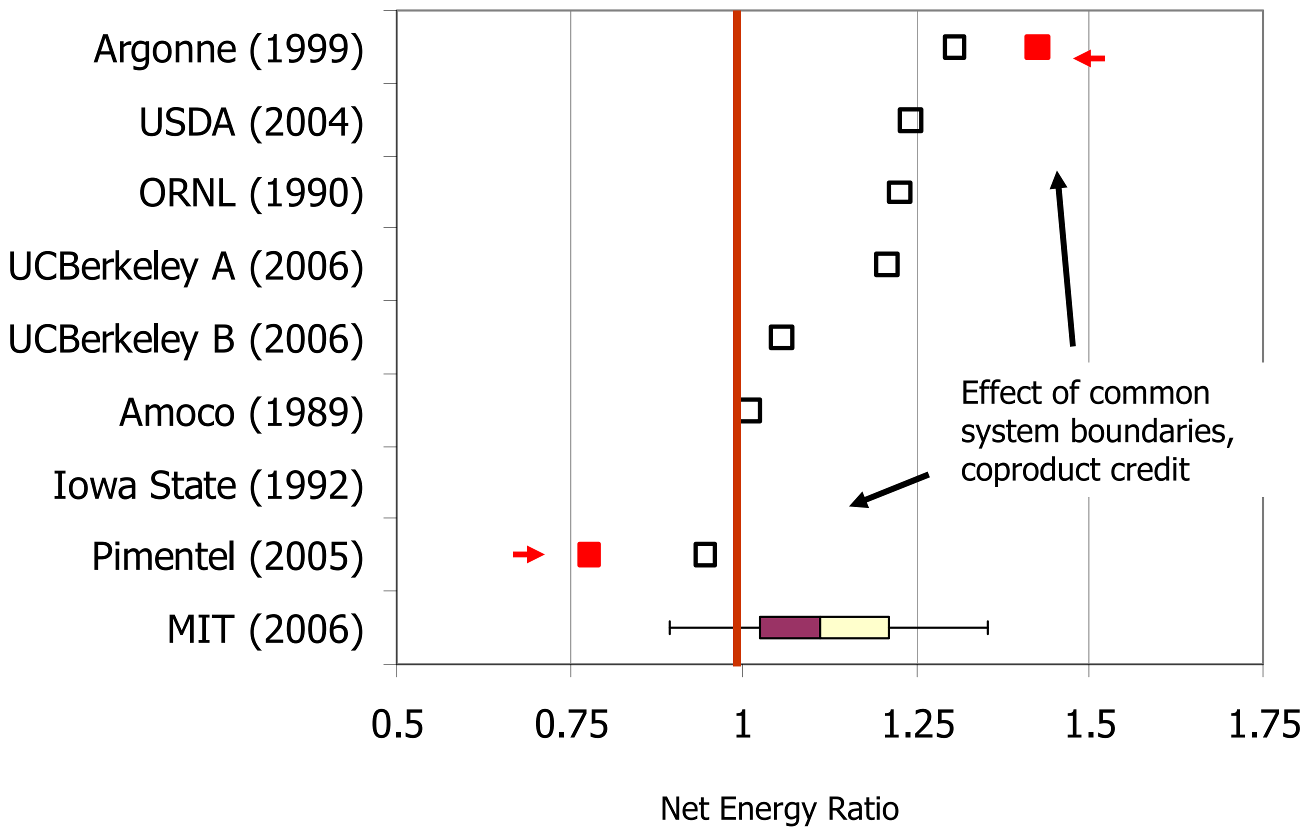
Energy Inputs to Corn



Corn Ethanol – comparison of estimated net energy ratio.

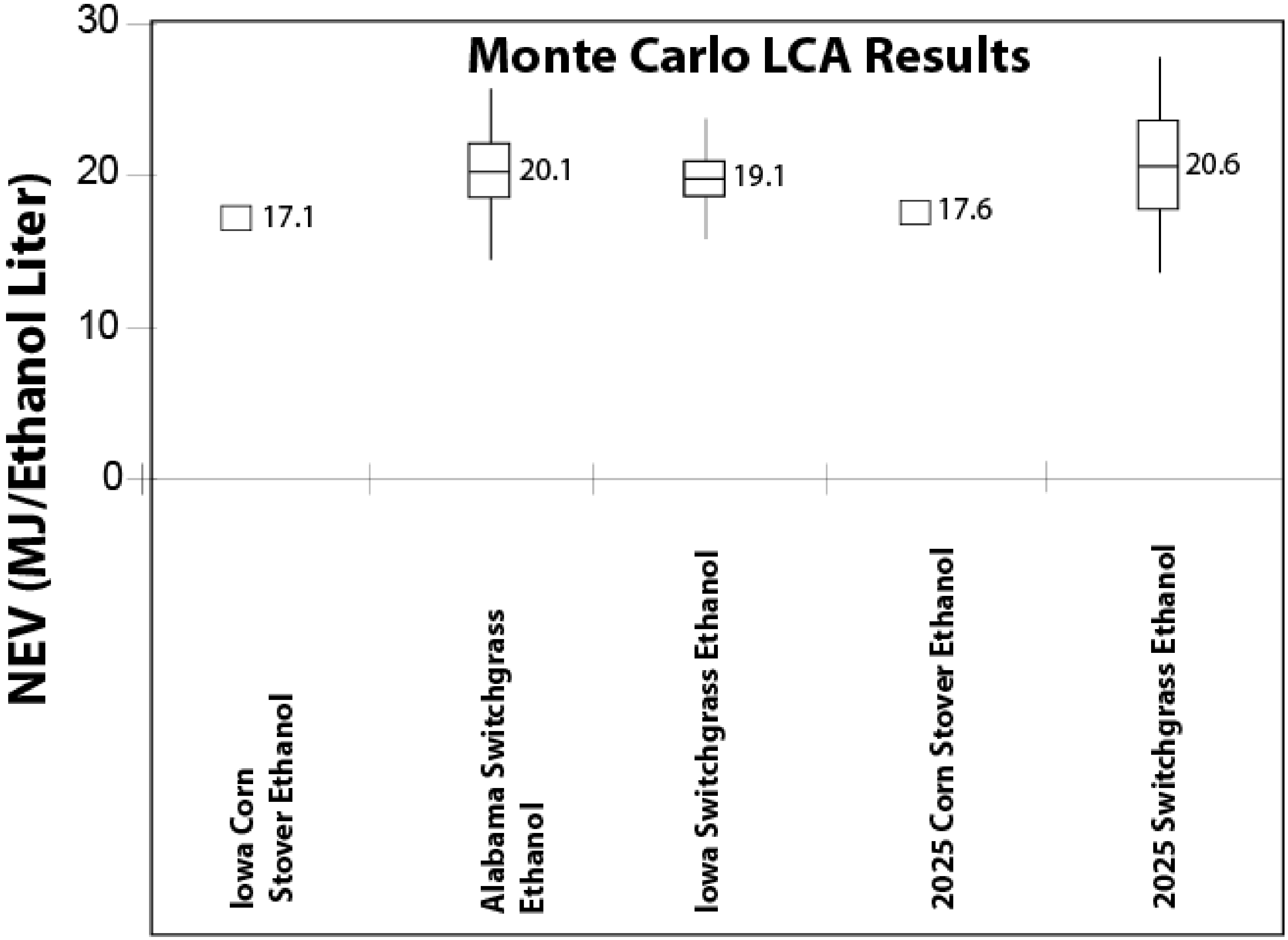


Corn Ethanol

Key conclusions

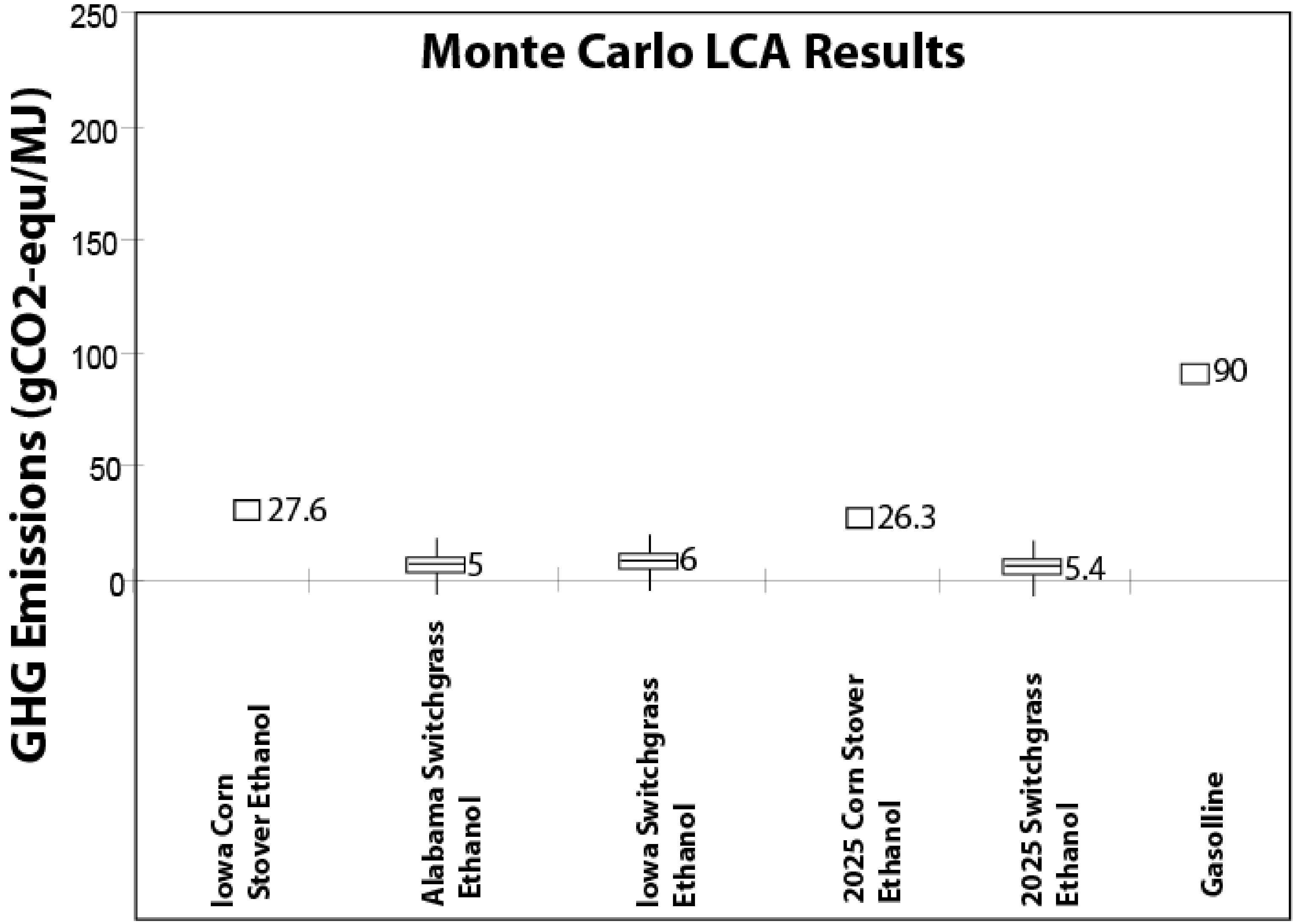
- Corn grain ethanol has a slightly positive net energy on average, but is very dependent on
  - Ethanol production efficiency
  - Location and practices in corn production
  - Transportation distances
- Improved corn yield, conversion and purification technology can help, but most gains are incremental
- Expansion of corn production will probably lead to more energy intensity

Cellulosic Ethanol – Fossil fuel energy requirements



Tiffany Groode, PhD MIT 2008

GHG Emissions – Cellulosic Ethanol



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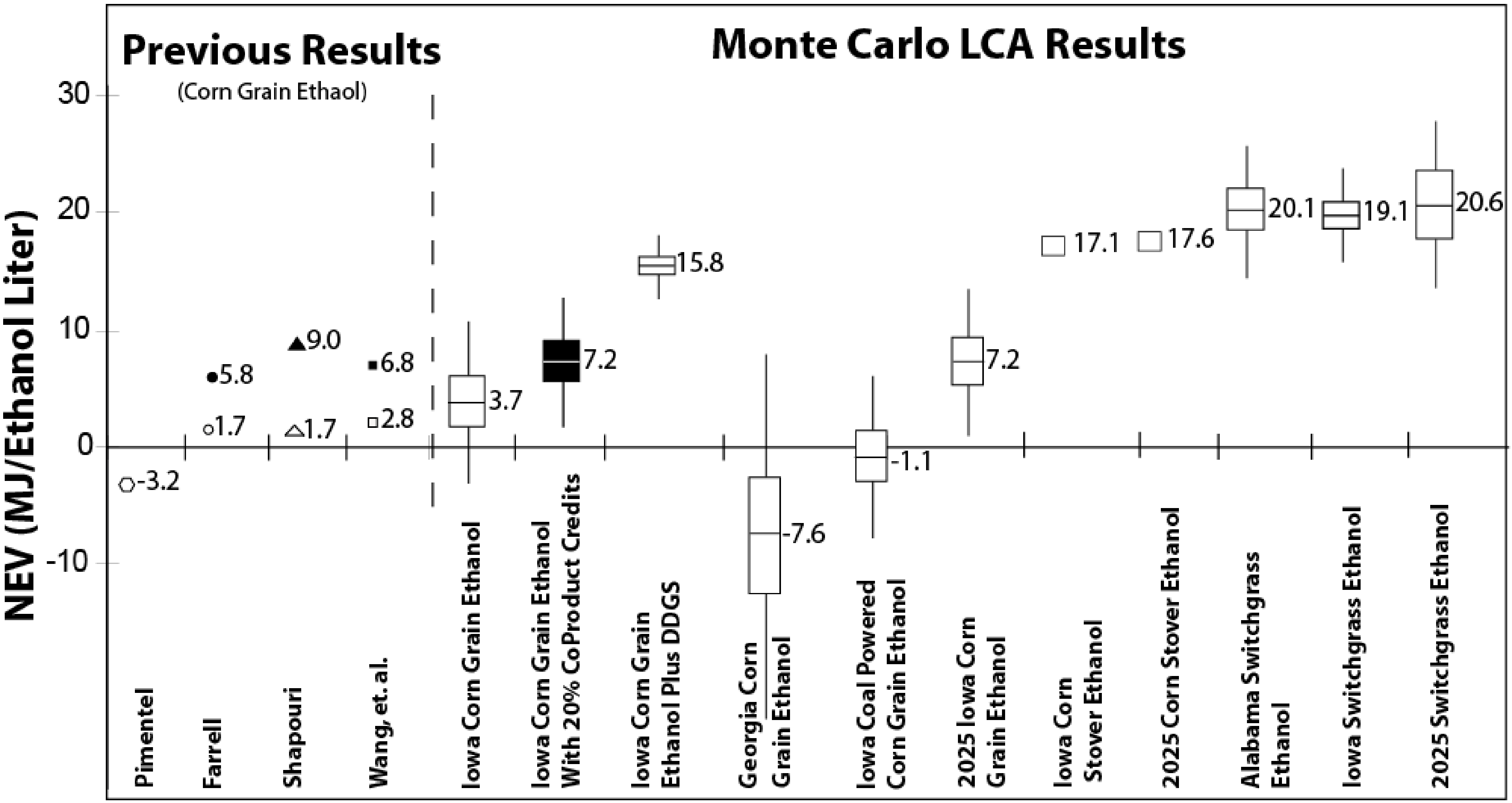
Net Energy Value - Cellulosic Ethanol



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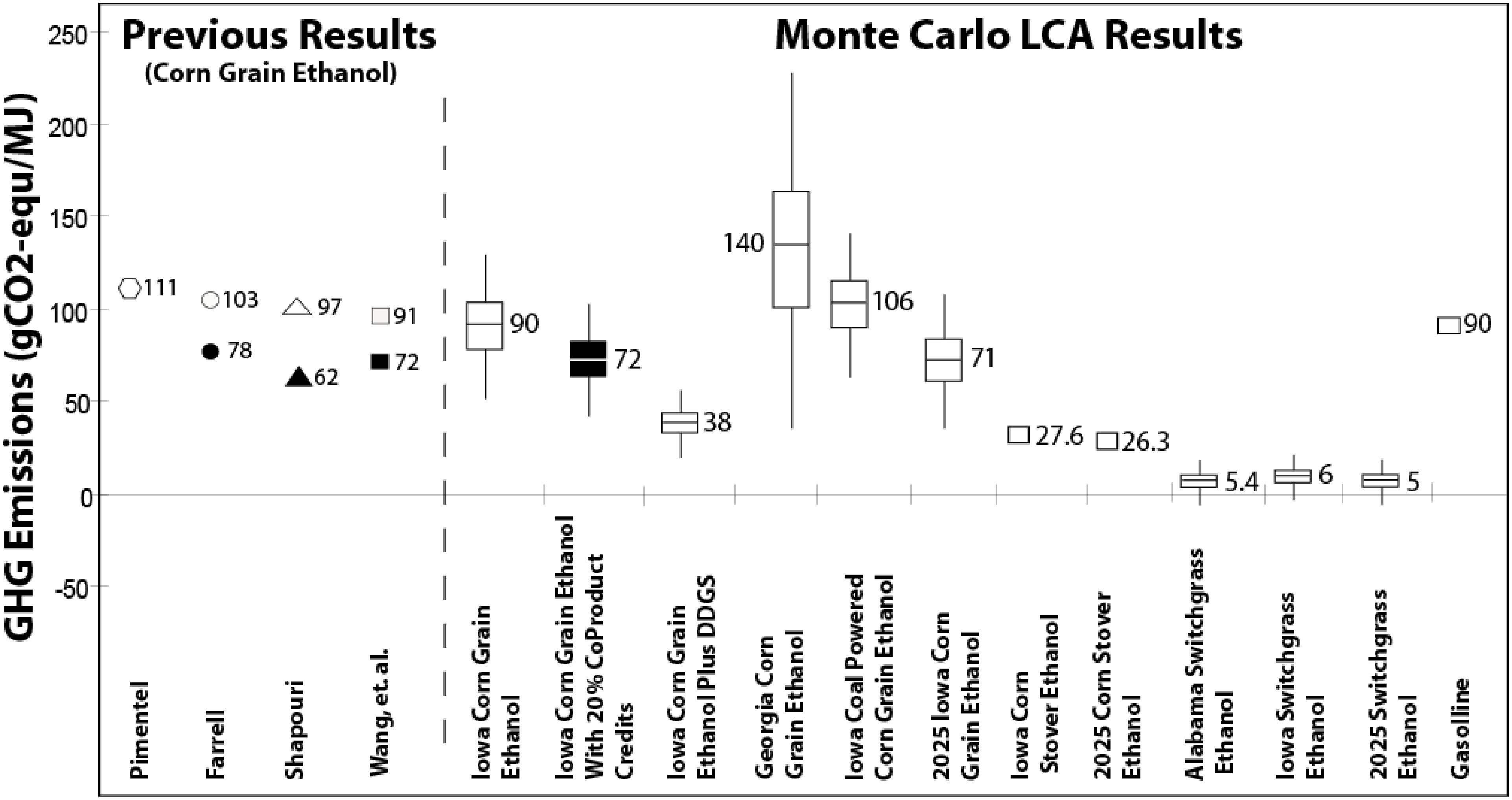
GHG Cellulosic Ethanol



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Conclusions - Ethanol

- Corn grain ethanol:
  - Considering economics, energy balance, GHG abatement, not a bad idea, but limited by land constraints
  - Considerable expansion of corn production negates any benefits, so subsidies should be restructured to efficiency
- Lignocellulosic ethanol
  - Significantly better environmental performance plus more availability, but economic cost is a large barrier
  - Multiple technology advancements must be made to achieve commercialization, with feedstock logistics critical
- Overall
  - Potential for non-negligible (~20%) replacement of petroleum, but significant investment is required

Why Ethanol?

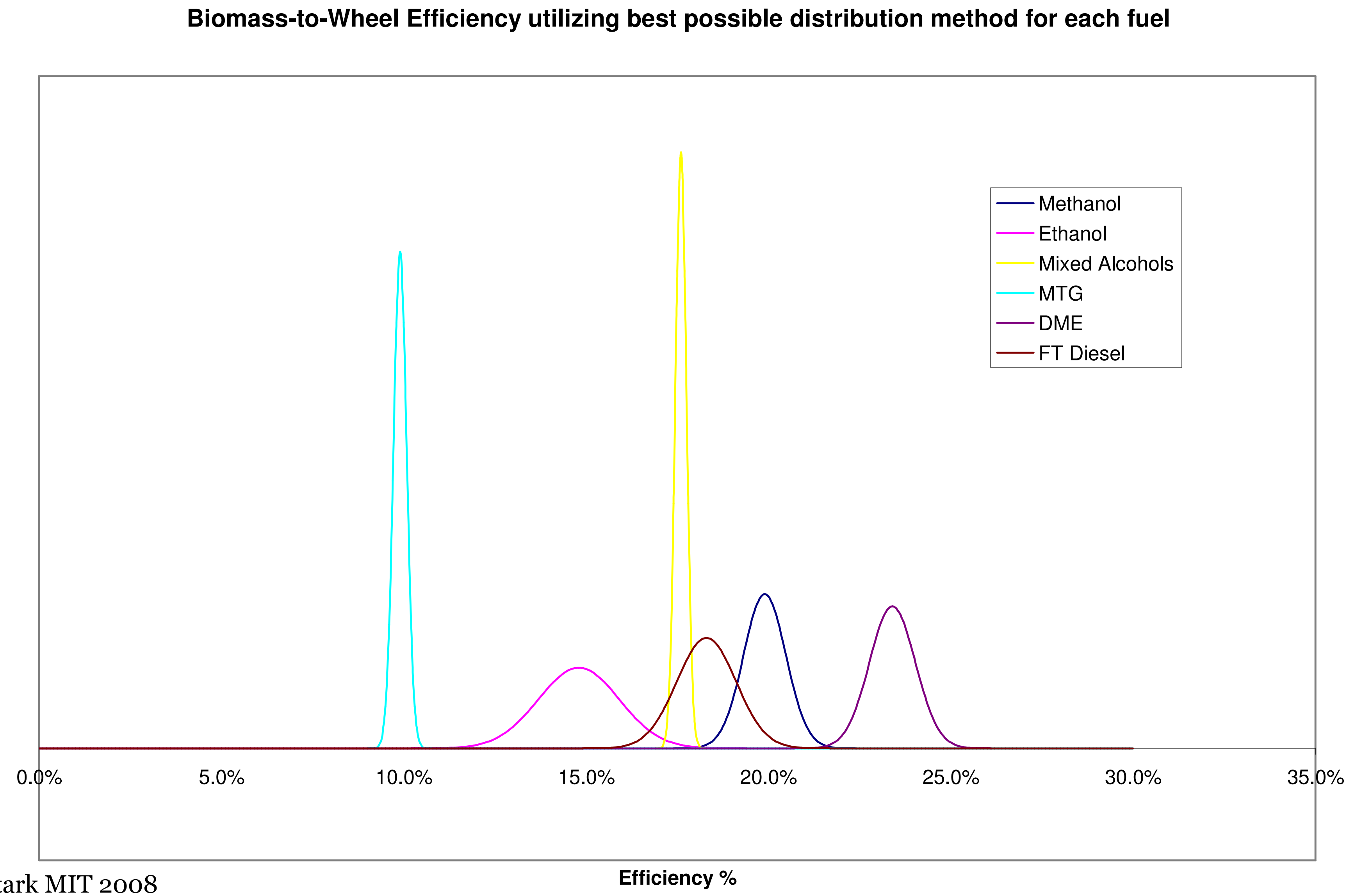
- If one is to use synthetic chemistry, one can make fuels that are not metabolic products:
  - Synthetic Hydrocarbons (Synthetic Natural Gas, Fischer-Tröpsch Diesel, MTG Gasoline)
  - Other Alcohols (methanol, propanol, butanol+)
  - Dimethyl Ether
  - Hydrogen?

Properties of possible fuels

Fuel	Formula	Molecular Weight	Density (g/cm^3)	Lower Heating Value (MJ/kg)	Heat of Vaporization (KJ/kg)
Methanol	CH_3OH	32.04	0.792	20	1103
Ethanol	CH_3CH_2OH	46.07	0.785	26.9	840
Propanol	$CH_3(CH_2)_2OH$	60.1	0.8	30.5	790
Butanol	$CH_3(CH_2)_3OH$	74.14	0.81	33	580
MTG Gasoline	$CH_{1.85}$	~110	0.75	44	350

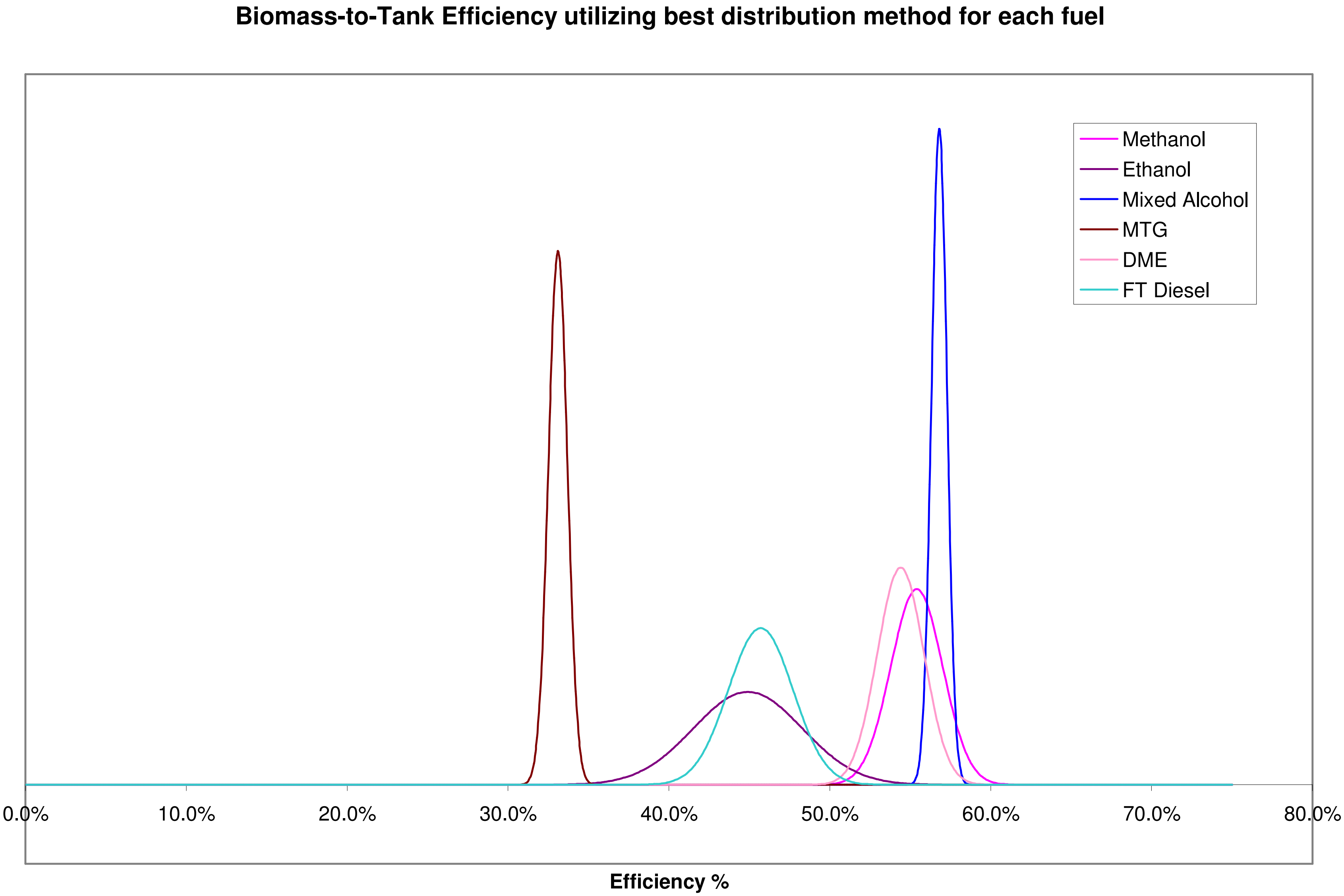
Fuel	Formula	Molecular Weight	Density (g/cm^3)	Lower Heating Value (MJ/kg)	Heat of Vaporization (KJ/kg)
DME	CH_3OCH_3	46.07	0.668	28.7	467
Fischer-Tröpsch Diesel	$CH_{1.8}$	170	0.8	43	270

Life Cycle Energy Efficiency of Thermochemical Biofuels



A. Stark MIT 2008

Biomass-to-Tank Efficiency of Thermochemical Biofuels



Fuel Integrability

Fuel	Truck	Rail	Pipeline
Methanol	Y	Y	N
Ethanol	Y	Y	N
Mixed Alcohol	Y	Y	N
MTG Synthetic Gasoline	Y	Y	Y
FT Diesel	Y	Y	Y
DME	Y	Y	Y/N

	cost of shipping per liter 1000km	cost of shipping per GJ 1000km
methanol	$0.050	$3.141
ethanol	$0.050	$2.185
MTG	$0.003	$0.101
FTD	$0.003	$0.095
DME	$0.060	$3.130

- A fuel's properties will dictate whether it is accepted into the current fuel infrastructure
- This will greatly impact the economics of distribution

End-Use emissions Regulations

- Existing emissions regulations will also play a role in dictating which fuels are used.
  - The Clean Air Act
  - Oxygenate requirements
  - Zero Emission Vehicles
  - California

	CO	NO_x	Particulates
methanol	Slight reduction	Significant reduction	N/A
ethanol	Slight reduction	Significant reduction	N/A
mixed alcohol	Slight reduction	Slight reduction	N/A
MTG synthetic gasoline	No change	Slight increase	N/A
FT Diesel	Moderate reduction	Moderate reduction	Moderate reduction
DME	No change	Moderate reduction	Significant Reduction

•Food Versus Fuel

•Land-use changes

ILLUMINATING THE TRADE-OFFS

Food Versus Fuel

- Increasing demand for biofuels may incentivize farmers to switch land away from food production
  - Decreasing food supplies
  - Increasing food prices
- Some argue that this was the case in 2008.
  - Data for making a conclusion either way is somewhat lacking.
  - Innovation in agriculture is far outpacing demand growth.

Land-use Changes

- Increasing demand for biofuels may incentivize farmers to put more land into production
  - The rainforests for soy/sugar cane
  - Jatroptha in Indonesia
- How do we quantify these secondary effects?
  - Measuring a counterfactual

Photo of soya growing in Brazil removed due to copyright restrictions.

The Biofuel Policy Landscape

- Blender-Tax Credits (Volumetric Ethanol Excise Tax Credit, VEETC)
  - 45 cents per gallon tax credit for ethanol blenders.
  - This year ~9 billion gallons of ethanol were used
  - This subsidy creates a perverse incentive to produce low energy density fuels (ethanol instead of Fischer-Tröpsch Diesel)

Biofuel Policy Landscape (cont.)

- The Energy Independence and Security Act (EISA) requirements
  - In 2022 36 billion gallons of biofuel use is mandated
    - Of this, majority must be advanced/cellulosic
  - We are not meeting this target.
- EPA limits the percentage of ethanol which can be blended in RFG
  - Oxygenate requirements
  - Blending wall

General Conclusions

- No one fuel constitutes a silver-bullet
- Technology specific subsidies have not worked and are likely not to work
- US biofuel policy is very friendly to ethanol and will make it hard for other fuels to enter the market
- System thinking is necessary in analyzing such complex value chains

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