The Indirect Byproduct Effect of Biofuels

Geoffrey Barrows, Gal Hochman, David Zilberman

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Motivation

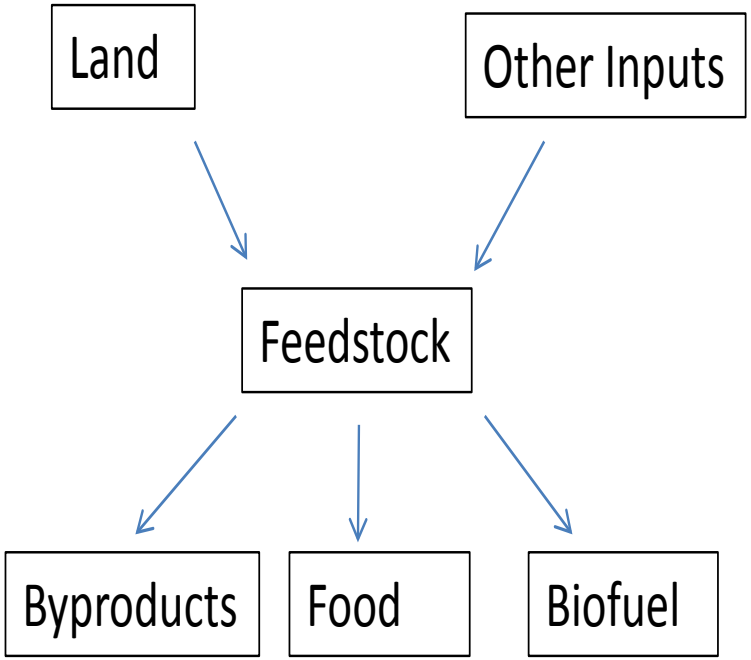
- One of the major objectives of biofuel policy is to contribute to the reduction of greenhouse gas (GHG) emissions
- But in a multi-stage/multi-product production system, there are many GHG emitting activities to account for:

  Conclusions drawn about the benefits and costs of ethanol production will be incomplete or misleading if only part of the total system is assessed

  -David Pimentel 1991 *JAEE*

Indirect Effects

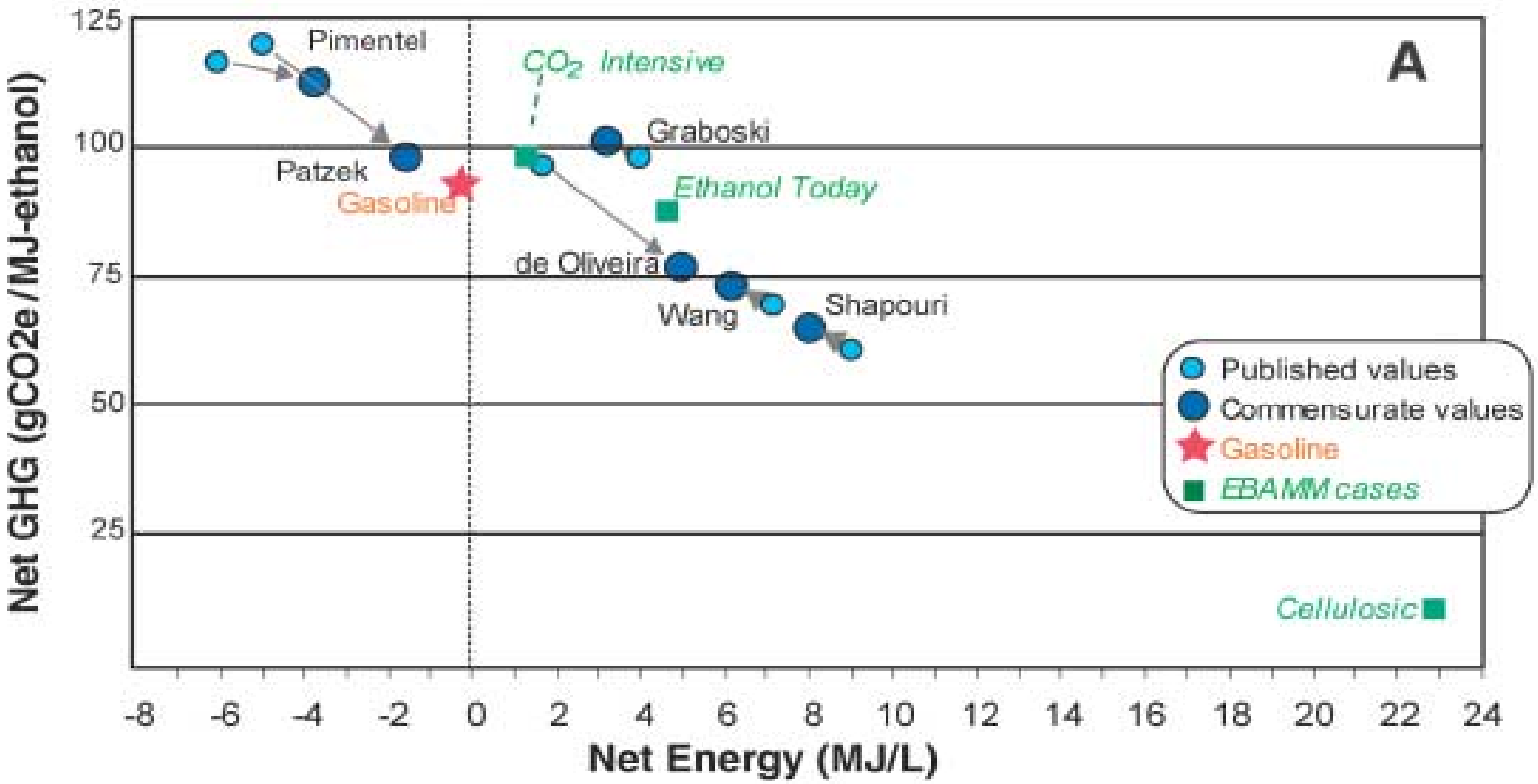
Biofuels results from of a multiproduct and multistage production system with many indirect effects on GHG



- Fuel and Feedstock Transport
- Food Vs. Fuel
- Carbon Sequestration
- Biofuel Byproducts

Earlier Work

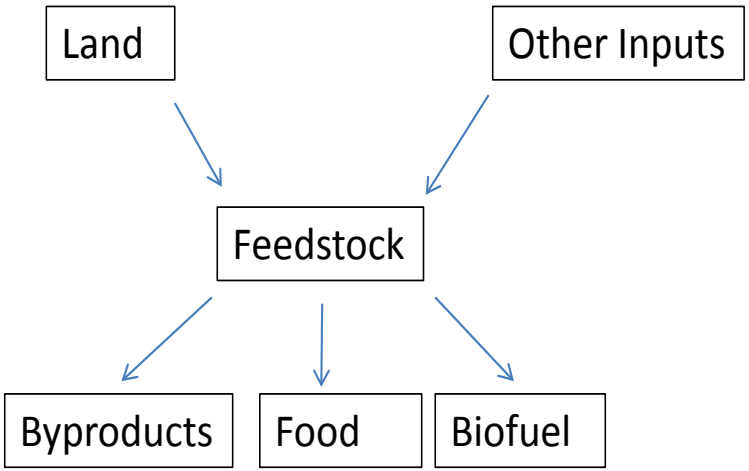
Figure: GHG emissions for corn-based ethanol compared to gasoline



Source: Farrell et al 2006

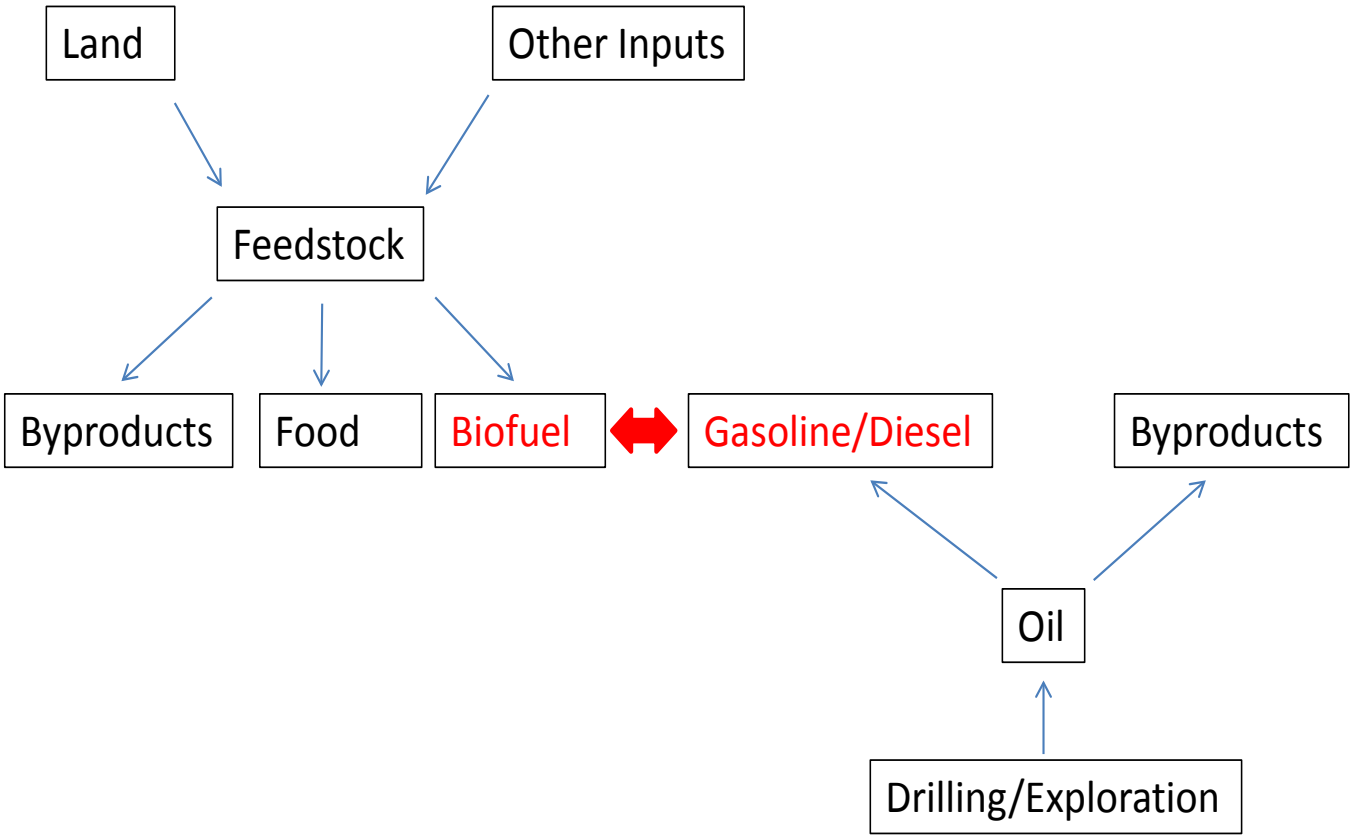
Motivation

The debate has focused on indirect effects of increased biofuel production



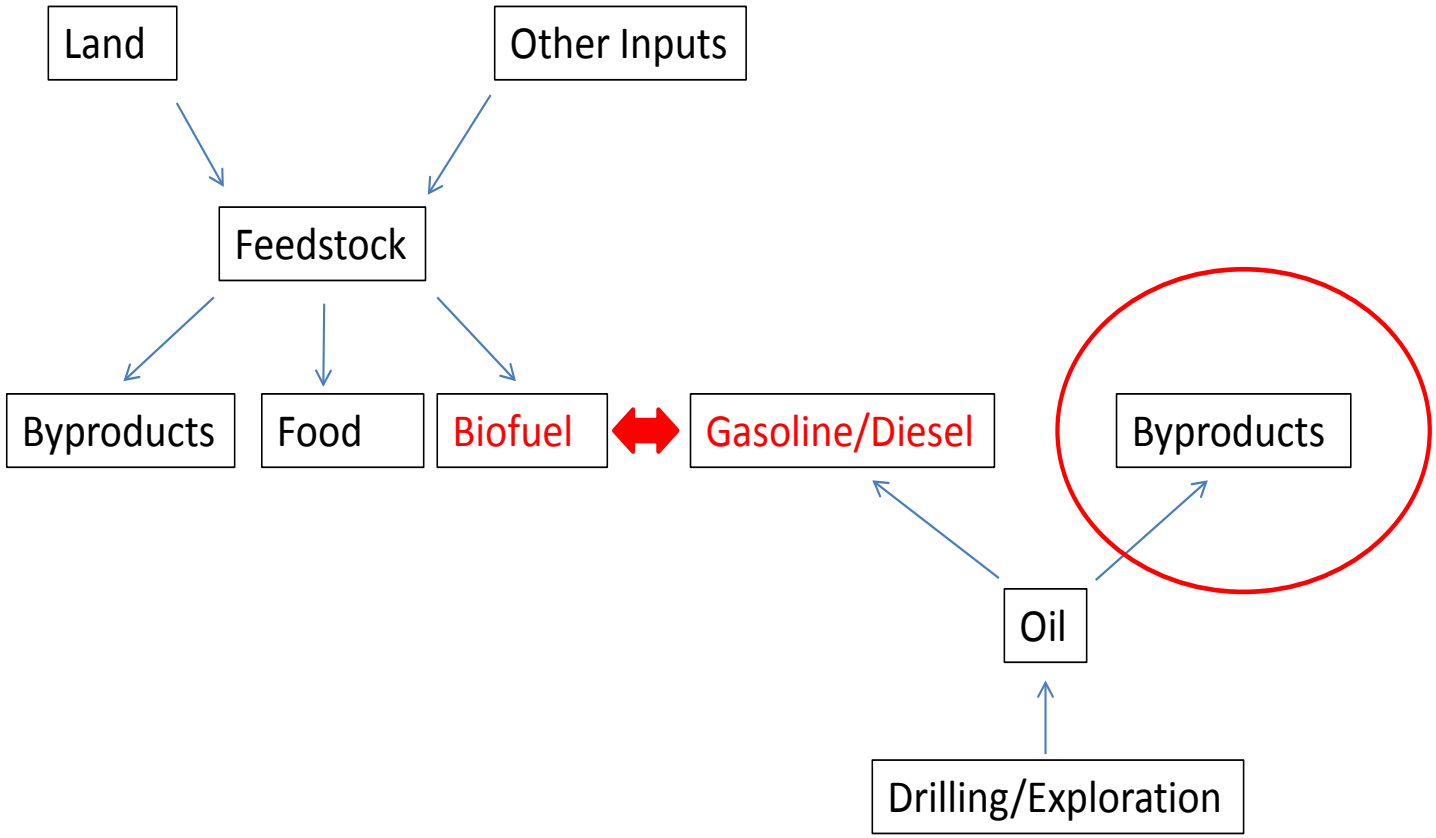
Motivation

But Gasoline/Diesel also result from of a multiproduct and multistage production system



Motivation

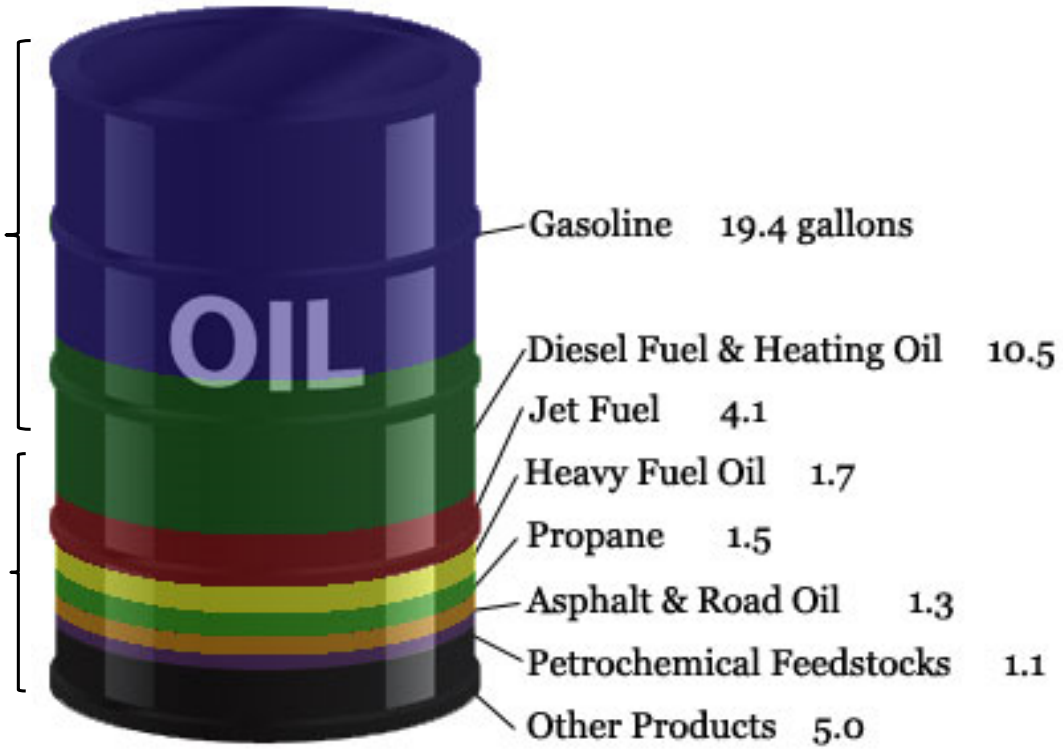
Question: What happens to LCA if we consider the effect on petroleum byproducts?



Co-production

Gas and Diesel

Byproducts



Source: EIA

Example

What happens to the level of petroleum byproduct consumption when you replace gas/diesel with biofuel?

- Let $\alpha \in (0, 1)$ denote the share of gas/diesel displaced by biofuels
- Let $\beta \in (0, 1)$ denote the percentage reduction in petroleum byproducts

Assuming fixed proportion technology:

- $\alpha = \beta$, so petorleum byproducts are displaced 1-1 with gas/diesel.

Example

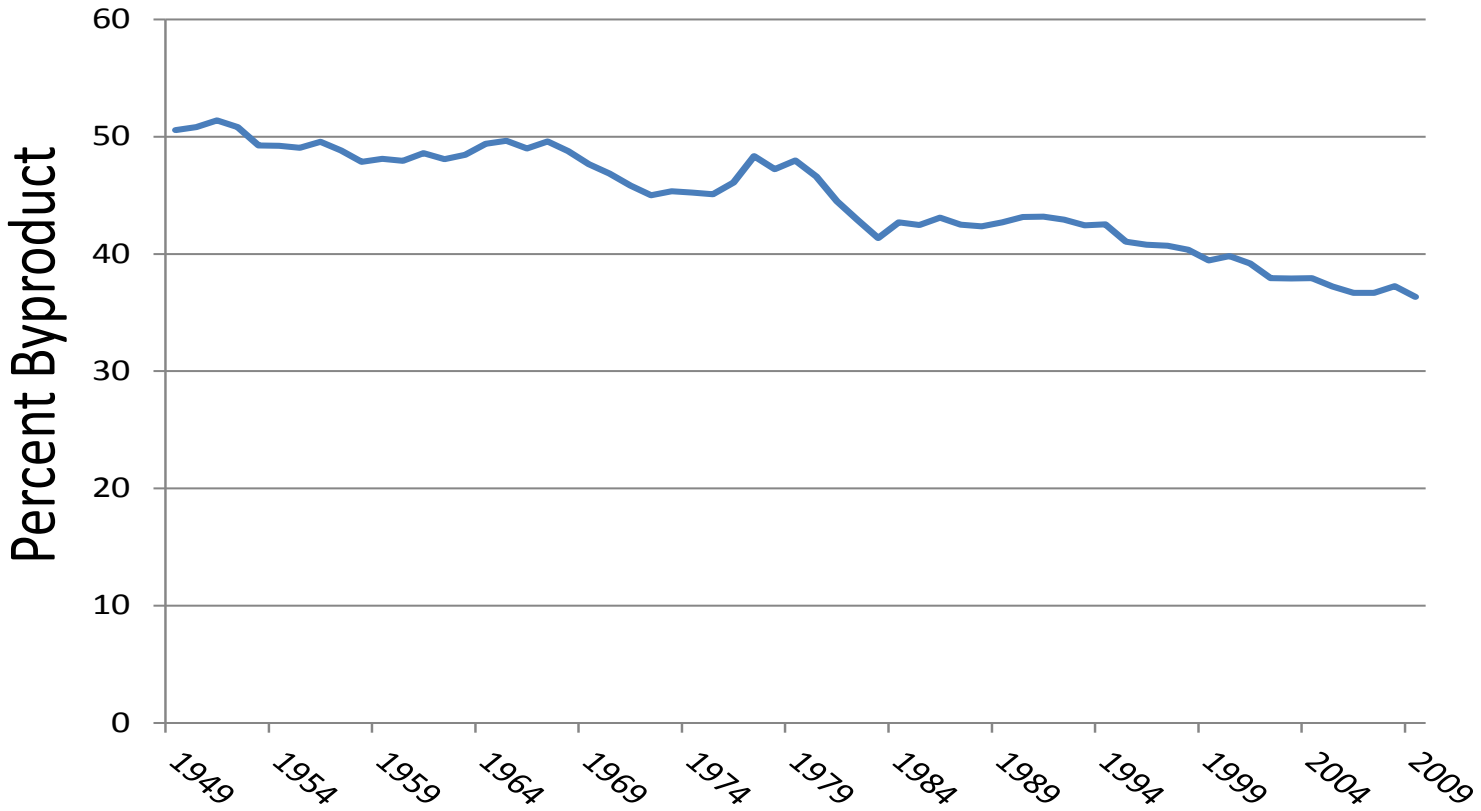
But what if the refineries adjusted output shares?

- Let $\rho \in (0, 1)$ denote the maximum percentage by which a refinery can adjust the share of byproducts produced from a barrel of oil
- $0 < \beta = F(\alpha, \rho) < \alpha$

The total reduction of petroleum byproducts resulting from increased biofuel use will depend crucially on ρ, refinery adjustment.

Adjustment

Figure: Byproduct Share by Volume in a Barrel of Oil Produced in US



Source: EIA

Adjustment

Fixed Proportion: Assume $\rho = 0$, then we have $\beta = \alpha$.

Flexible Response: Assume adjustment phases in over time such that in 30 years, the share of byproduct increases enough to return byproduct levels to no biofuel scenario levels.

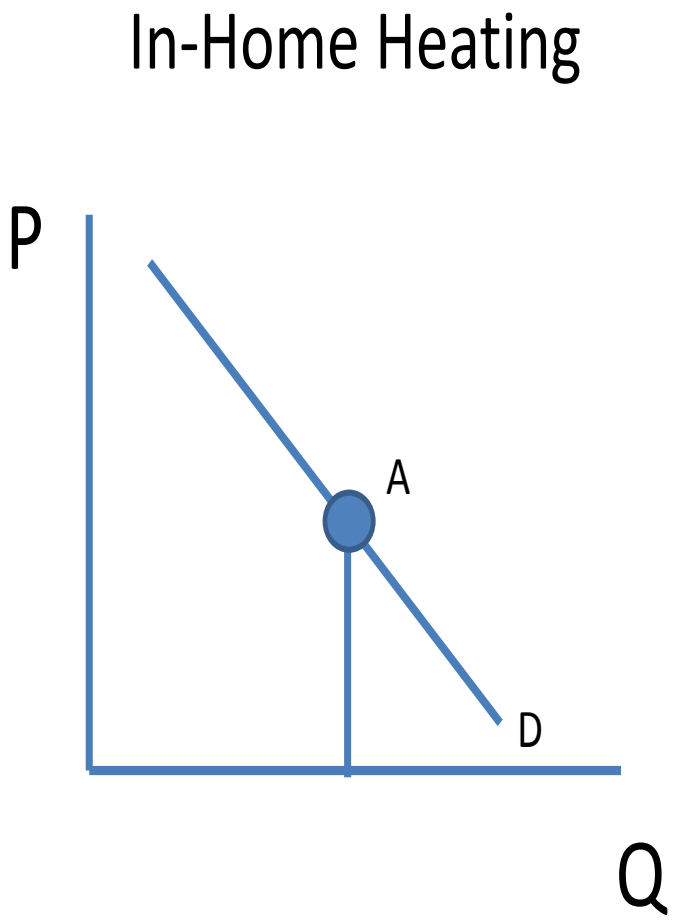
$\Longrightarrow$ Implies $\rho = .1$ or refineries have 8% flexibility in the medium run (30 years) to adjust product shares. This translates into 3 percentage points of flexibility. For example, refineries would increase byproduct share from 36% to 39%.

Replacement

Given α and ρ, we have a reduction β of petroleum byproducts. What will be the Economic effects and the resulting effects on GHG Emissions?

- Answer depends on the availability of substitutes.

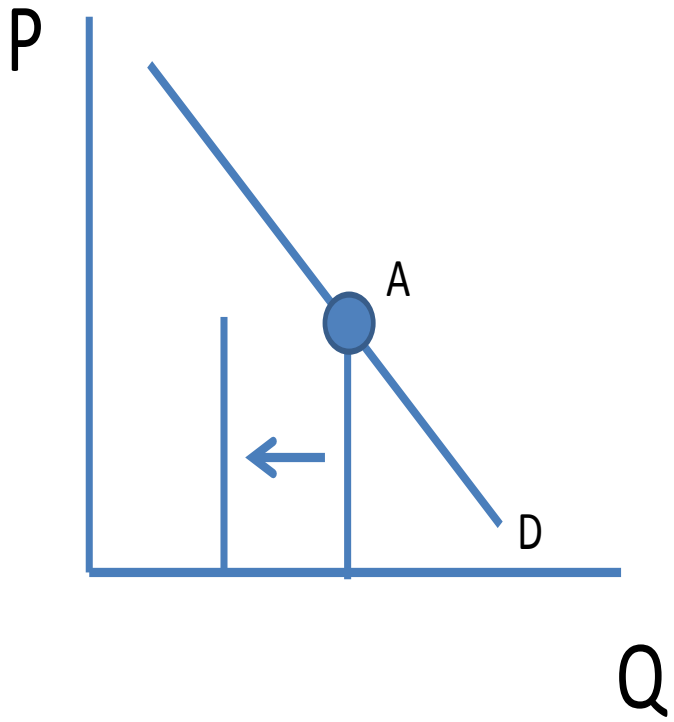
Replacement



- Initial Equilibrium at A

Replacement

In-Home Heating



- Initial Equilibrium at A

Replacement

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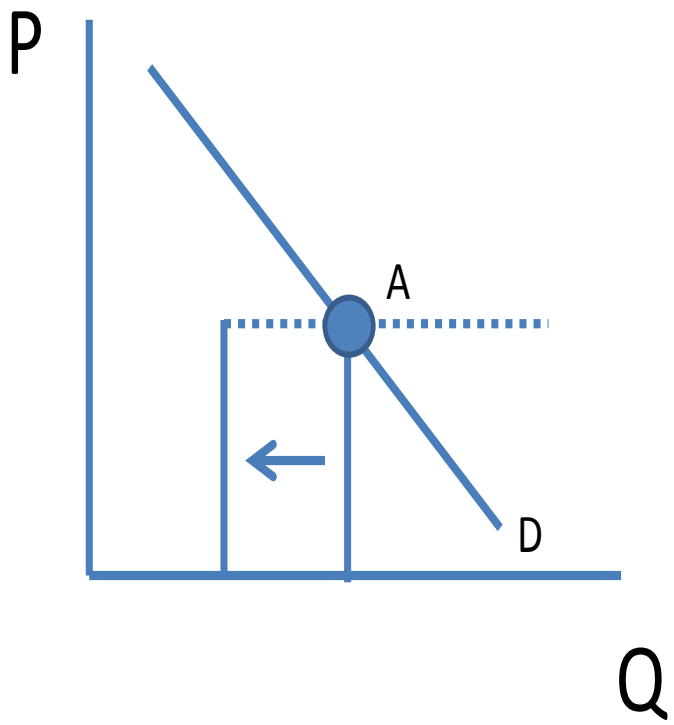
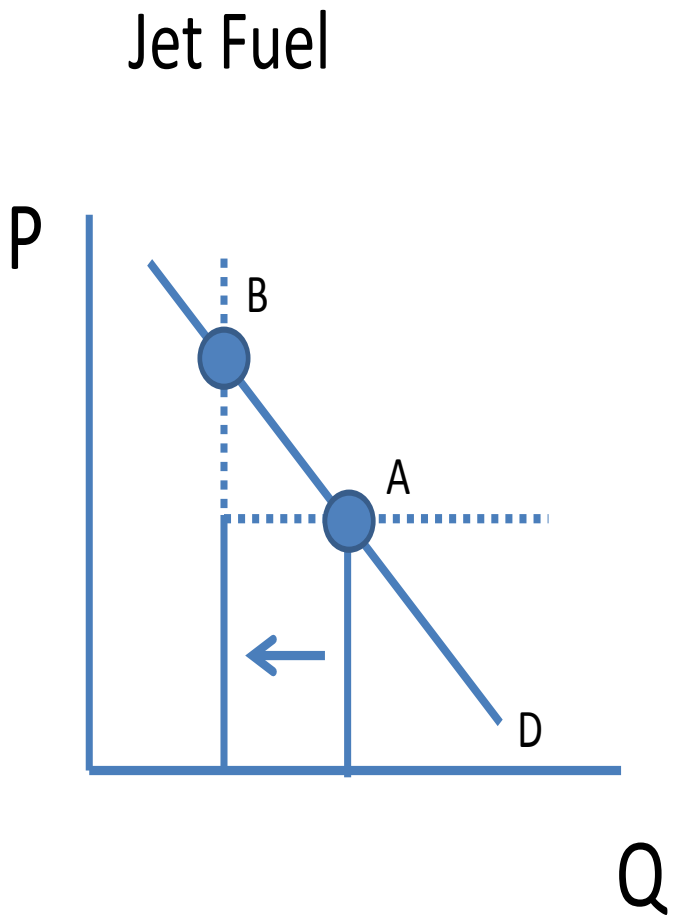


- Initial Equilibrium at A
- Assume full replacement:

  $A \longrightarrow A$

Replacement



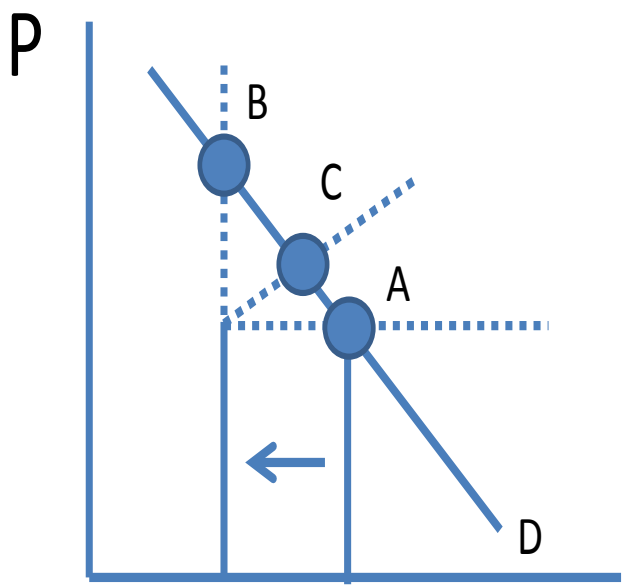
- Initial Equilibrium at A
- Assume full replacement:

  $A \longrightarrow A$
- Assume no replacement:

  $A \longrightarrow B$

Replacement

End Use Market



- Initial Equilibrium at A
- Assume full replacement:

  A $\longrightarrow$ A
- Assume no replacement:

  A $\longrightarrow$ B
- In General:

  A $\longrightarrow$ C

IBE Definition

The Indirect Byproduct Effect (IBE) is defined as the per energy unit change in GHG emissions resulting from decreased petroleum byproduct use:

$$\begin{aligned} \Delta Z &= \Delta X z_x - \Delta B z_b \\ &= \underbrace{\delta B_0 z_x}_{\text{more alternative}} - \underbrace{\beta(\alpha, \rho) B_0 z_b}_{\text{less byproduct}} \end{aligned}$$

End Use Markets

Consider the markets for 8 petroleum byproducts

Petroleum Byproduct	Alternative Input	Emissions Differential
Heating Oil	Natural Gas	-20
Residual Fuel	Natural Gas	-15
LPG	Natural Gas	-10
Still Gasses	Natural Gas	5
Petroleum coke	Coal	0
Asphalt	Concrete	-32
Jet Fuel	Biofuel	-20
Other Products	Biofuel	-15

Application

Example: RFSII adopted by the EPA in March 2010

- 36 billion gallons of renewable fuel by 2022
- EISA stipulates a "renewable fuel" must have LCA GHG emissions at least 20% lower than traditional gasoline
- We adopt EPA LCA assumptions (30 year amortization, 0% discount rate) and compare LCA GHG calculations for corn-based ethanol with and without IBE

We calculate IBE for corn-based ethanol because the LCA debate has focused on that fuel-type, but the IBE can be associated with any gas/diesel substitute.

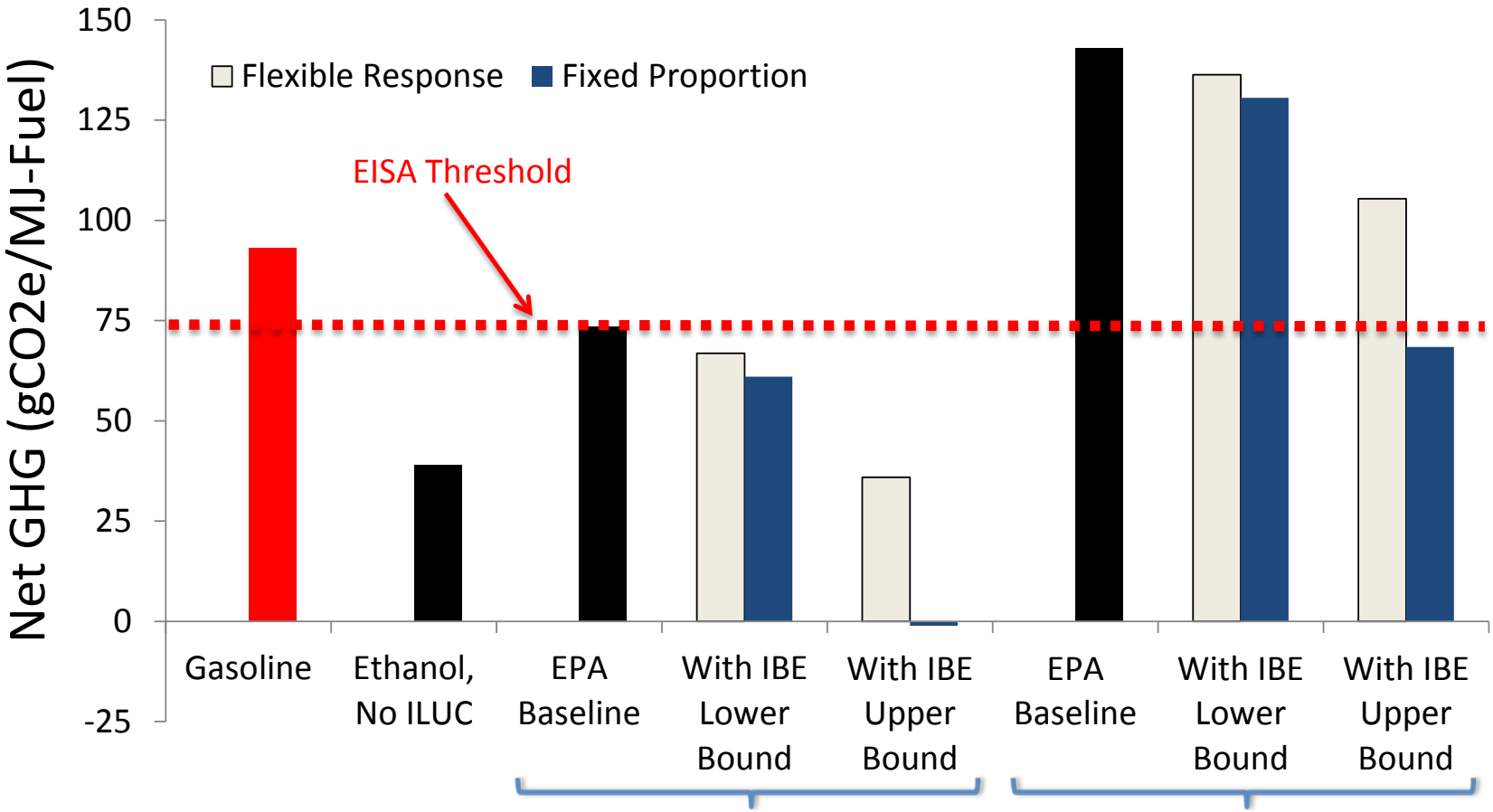
Simulation

$$IBE = \Delta Z = \delta B_0 z_x - \beta(\alpha, \rho) B_0 z_b$$

Scenario	Adjustment	Replacement
1	Fixed ($\rho = 0$)	None ($\delta = 0$)
2	Fixed ($\rho = 0$)	Full ($\delta = \beta$)
3	Flexible ($\rho = .08$)	None ($\delta = 0$)
4	Flexible ($\rho = .08$)	Full ($\delta = \beta$)

Results

Figure 1: Annualized Emissions for Corn-Based Ethanol



Conclusion

- There are significant GHG savings from gasoline/diesel substitutes associated with decreased supply of petroleum byproducts
- When IBE is accounted for, LCA of biofuels is lower: in lower bound case, LCA of corn-based ethanol moves from 21% to 28% cleaner than gasoline
- While indirect land use changes from later-generation biofuels will be lower, the IBE will be the same, so these fuels may carry even larger environmental benefits than are currently believed