THE COST EFFECTIVENESS OF BIOFUELS GIVEN MULTIPLE OBJECTIVES

William Jaeger and Thorsten Egelkraut
Oregon State University

Presented July 1, 2009, WEAI Annual Meetings

Overview

- U.S. biofuels policy motivated mainly by two goals:
  - Energy independence (reduced fossil fuel use)
  - Reductions in greenhouse gas emissions

- The effectiveness and costs of promoting biofuels to achieve those two goals is complicated by:
  - Complex energy accounting
  - Complex GHG accounting, including indirect effects
  - Multiple goals

- Given these complications, current analysis employs:
  - cost-effectiveness analysis
  - Multiple-objective decision framework

Biofuel policy context

Governments policy targets:

USA	15 billion gallons (in 2007 legislation)
EU	5.75 percent target
Brazil	20 – 25 percent blend target

Many other countries also setting targets

Targets set in gallons of biofuel may not indicate progress toward objectives

- Ethanol has less energy/gallon than gasoline
- Production of ethanol requires input energy
- GHG gains lowered due to input energy, indirect effects
- Cost difference per gallon may not reflect cost of progress toward goals

Energy accounting – substituting biofuel for conventional fuel

For comparable outputs (at the pump):

$$\Delta\frac{C}{E}=\left(\frac{\left(C/Q\right)^{bf}}{\left(E/Q\right)^{bf}}\right)-\left(\frac{\left(C/Q\right)^{pf}}{\left(E/Q\right)^{pf}}\right)=\left(C/E\right)^{bf}-\left(C/E\right)^{pf}$$

Energy accounting – substituting biofuel for conventional fuel

For reducing fossil fuel inputs we can write:

$$\Delta \frac{FF}{E} = \left(\frac{FF}{E}\right)^{bf} - \left(\frac{FF}{E}\right)^{pf}$$

Combining the previous two expressions:

$$\frac{\Delta C}{\Delta FF} = \left(\frac{\Delta \frac{C}{E}}{\Delta \frac{FF}{E}} \right)$$

Energy accounting – substituting biofuel for conventional fuel

	Corn ethanol	Gasoline
Energy per gallon (BTUs)	76,300	120,000
FF inputs used per gallon (BTUs)	50,000	148,000
Input FF per unit output energy (BTUs)	0.66	1.23
Gallons needed to achieve same E	1.57	
FF Inputs to replace one gallon of gasoline E with ethanol (BTUs)	78,637	
Reduction in inputs with replacing gas E	69,363	
Gallons ethanol needed to achieve same FF reduction as one gallon of gasoline:	3.36	

Greenhouse gas accounting

Corn Ethanol	g/M BTU
GHG emissions per unit of energy in fuel (GHG/E)	142,400
Carbon uptake from feedstock growth (GHG/E)	65,400
Net GHG per unit of energy in fuel (GHG/E)	77,000
GHG emissions for gasoline (GHG/E)	97,000
Reduction in GHG substituting biofuel for fossil fuel	20,000
Indirect effects on GHG emissions (land use change)*	(29,000)
Total reduction in GHG emissions, direct and indirect	(9,000)

---

* Based on Tyner, Taheripour, Baldos, 2009. Land Use Change Carbon Emissions due to US Ethanol Production. Purdue University.

Cost-effectiveness analytical framework

- Objectives
  - Reduce fossil fuel input use, *F*,
  - Reduce greenhouse gas emissions, *G*.

- With a gas tax, *t*, we can separate

$$CE_t^G = \frac{MC_t}{dG_t} \quad \text{and} \quad CE_t^F = \frac{MC_t}{dF_t}$$

- where MC_t is the marginal social cost associated with the introduction of a gas tax.

Cost-effectiveness measures for multiple objectives

We can generalize the multiple-objective problem in terms of an action involving inputs q_i, and a cost $C_i(q_i)$ resulting in a vector of outcomes $x_i = x_i(v_1, v_2, v_3 \ldots v_m)$.

In a problem involving m objectives, a linear combination of m actions can produce the same vector of outcomes as another outcome vector:

$$CE_i = \frac{C_i}{x_i}$$

where each action or combination has been chosen so that the vector of outcomes, x_i, are the same.

How to compare specific alternatives?

- A gas tax (that lowers consumption by 100 gal.)
  - reduces fossil fuel inputs by 14.8 million BTUs
  - reduces GHGs by 1.17 tons (CO_2e).
- Corn ethanol (that reduces fossil fuel inputs by 14.8 million BTUs (175 gallons of biofuels)
  - Increases GHGs of 0.38 tons (CO_2e)

Combining biofuel with carbon sequestration

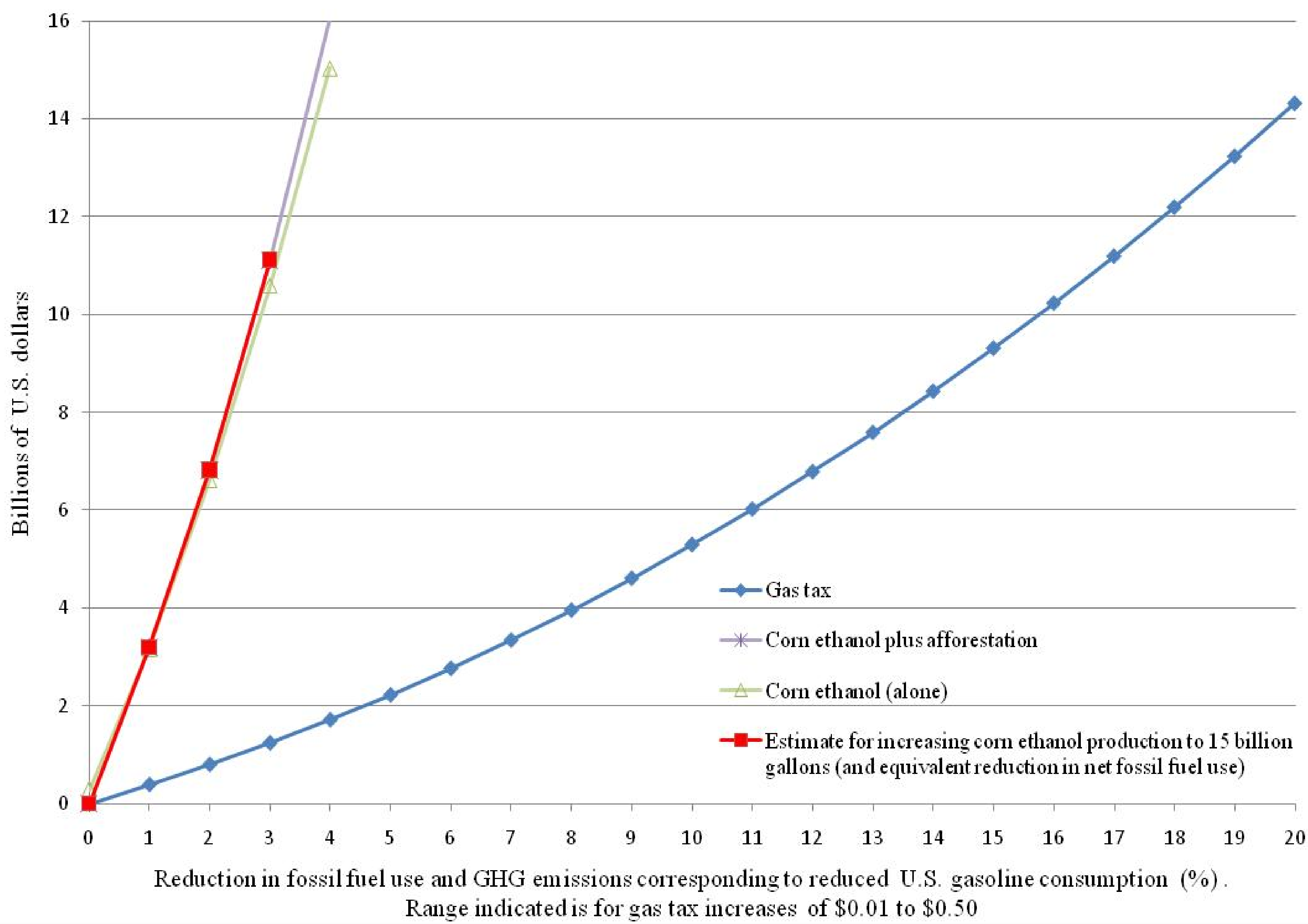
Afforestation:

- Consider a combined intervention:
  - a) 175 gallons of biofuels plus
  - b) afforestation to sequester 1.54 tons of CO2e
  - This equals the outcomes for the gas tax option

- Thus we can compare costs directly, for identical increments toward both goals

Table 1. Biofuel marginal cost, energy and greenhouse gas accounting - and alternatives						
	Corn ethanol	Soy biodiesel	Canola (EU) biodiesel	*Brazilian ethanol (CIF US)*	Gasoline	Diesel (petroleum)
Cost of production ($/gallon)	$ 1.75	$ 2.75	$ 3.22	*$ 1.30*	$ 2.00	$ 2.25
Energy per gallon (BTU/gallon)	76,300	118,000	118000	*76,300*	120,000	132,000
Cost of production ($/M BTU)	22.94	23.31	27.29	*17.04*	16.67	17.05
Fossil fuel inputs per unit of energy in fuel (BTU/BTU)	0.66	0.38	0.36	*0.12*	1.23	1.15
Fossil fuel input use (BTU/gallon)	50,358	44,840	42,480	*9,156*	148,000	152,000
Cost per reduction in fossil fuel use when substituted for conventional fuel ($/M BTU)	$ 13.00	$ 11.00	$ 18.70	*-0.40*		
Cost to reduce fossil fuel use with gas tax ($/M BTU)					1.75	1.75
Change in greenhouse gas emissions when substituted for conventional fuel (g/M BTU)	8,950	148,000	148000	*-5500*		
Cost per reduction in GHG emissions when substituted for conventional fuel ($/M BTU)	∞	∞	∞	*< 0*		
Cost per reduction in GHG emissions with a gas tax ($/ton CO2-e)					22.34	22.34
Cost per reduction in GHG emission with carbon sequestration (afforestation) ($/ton CO2-e)	2.72	2.72	2.72	*2.72*		
Incremental cost-effectiveness of biofuels-plus-afforestation relative to gas tax (%)	833%	810%		*< 0*		

Figure 1. Costs for reducing fossil fuel use and GHG emissions with alternative interventions



The way policy objectives are framed can lead to very different debates about policy goals,

and this in turn can lead to very different outcomes resulting from those debates.

(e.g., N. Keohane, 2009. Cap and Trade, Rehabilitated: Using Tradable Permits to Control U.S. Greenhouse Gases, REEP 2009)

Table 2. Different Ways of Framing the Policy Objective for Biofuels		
Framed as an alternative source of liquid fuel		
	Cost per gallon (corn ethanol)	$1.75
	Cost per gallon (gasoline)	$2.00
	National ethanol production target (15 B gal.) as % of 2007 U.S. gasoline consumption:	11%

Table 2. Different Ways of Framing the Policy Objective for Biofuels	
<u>Framed as an alternative source of liquid fuel</u>	
Cost per gallon (corn ethanol)	$1.75
Cost per gallon (gasoline)	$2.00
National ethanol production target (15 B gal.) as % of 2007 U.S. gasoline consumption:	11%
<u>Framed as a means to reduce fossil fuel use and CO2 emissions</u>	
Cost per million BTUs (corn ethanol)	$23.00
Cost per million BTUs (gasoline)	$16.67
Gallons of ethanol required to eliminate one gallon's worth (of gasoline's) fossil fuel inputs	3.36
Gallons required to eliminate one gallon's worth (of gasoline's) CO2 emissions	Not possible
Cost to reduce fossil fuel use (& related CO2 emissions) compared to cost of a gas tax (%)	833%
Cost per reduction in CO2 emissions (compared to a gas tax (ratio)	Infinite
Net energy contribution represented by U.S. ethanol production target (15 billion gallons):	
As a % of U.S. petroleum consumption	1.90%
As a % of U.S. fossil fuel consumption	0.88%