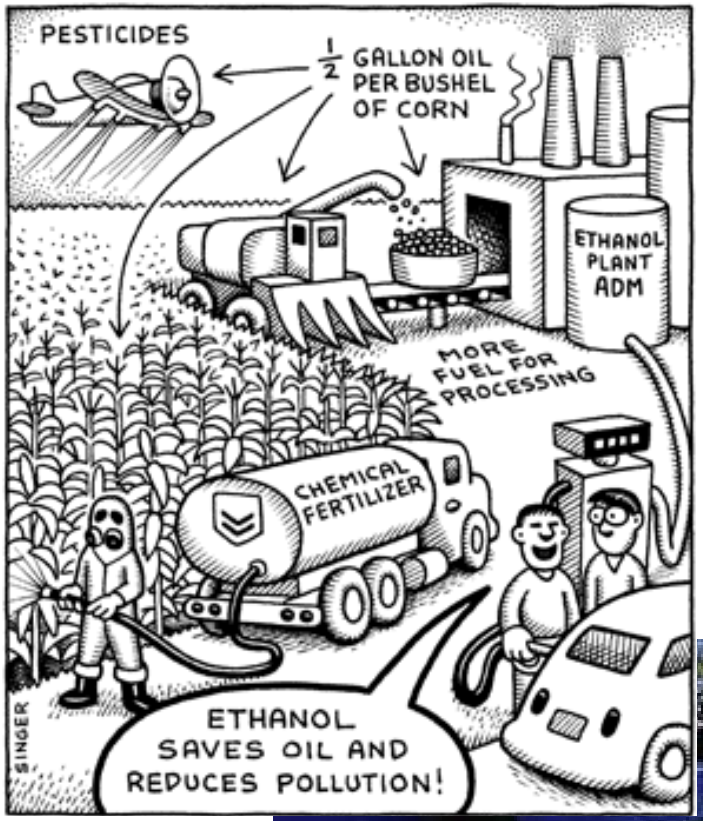
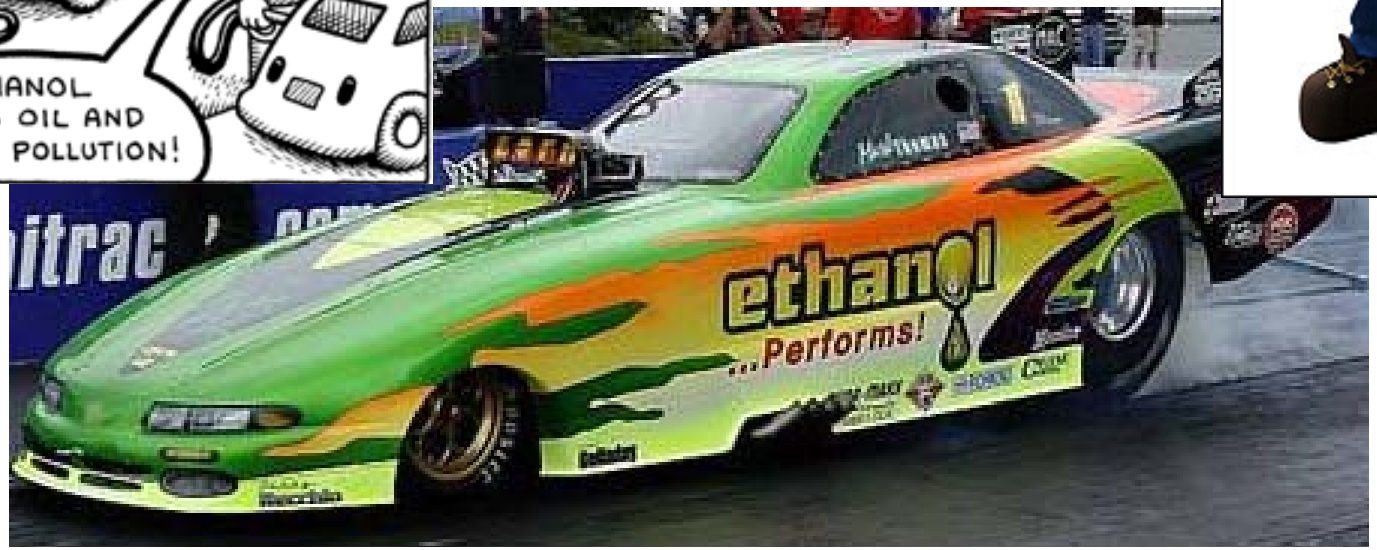
Emissions from Fuel Ethanol:

Separating the Confusion From the Uncertainties



California Air Resources Board
May 16, 2006

Alex Farrell
Energy & Resources Group
UC Berkeley



REPORTS

Ethanol Can Contribute to Energy and Environmental Goals

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http://rael.berkeley.edu/ebamm

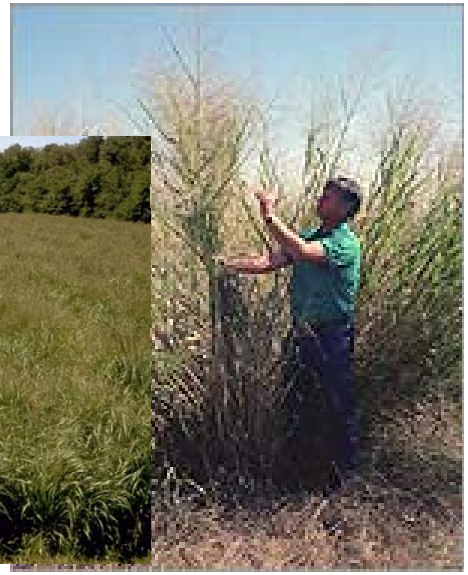
Outline

- Introduction
- Methods
- Results
- Discussion

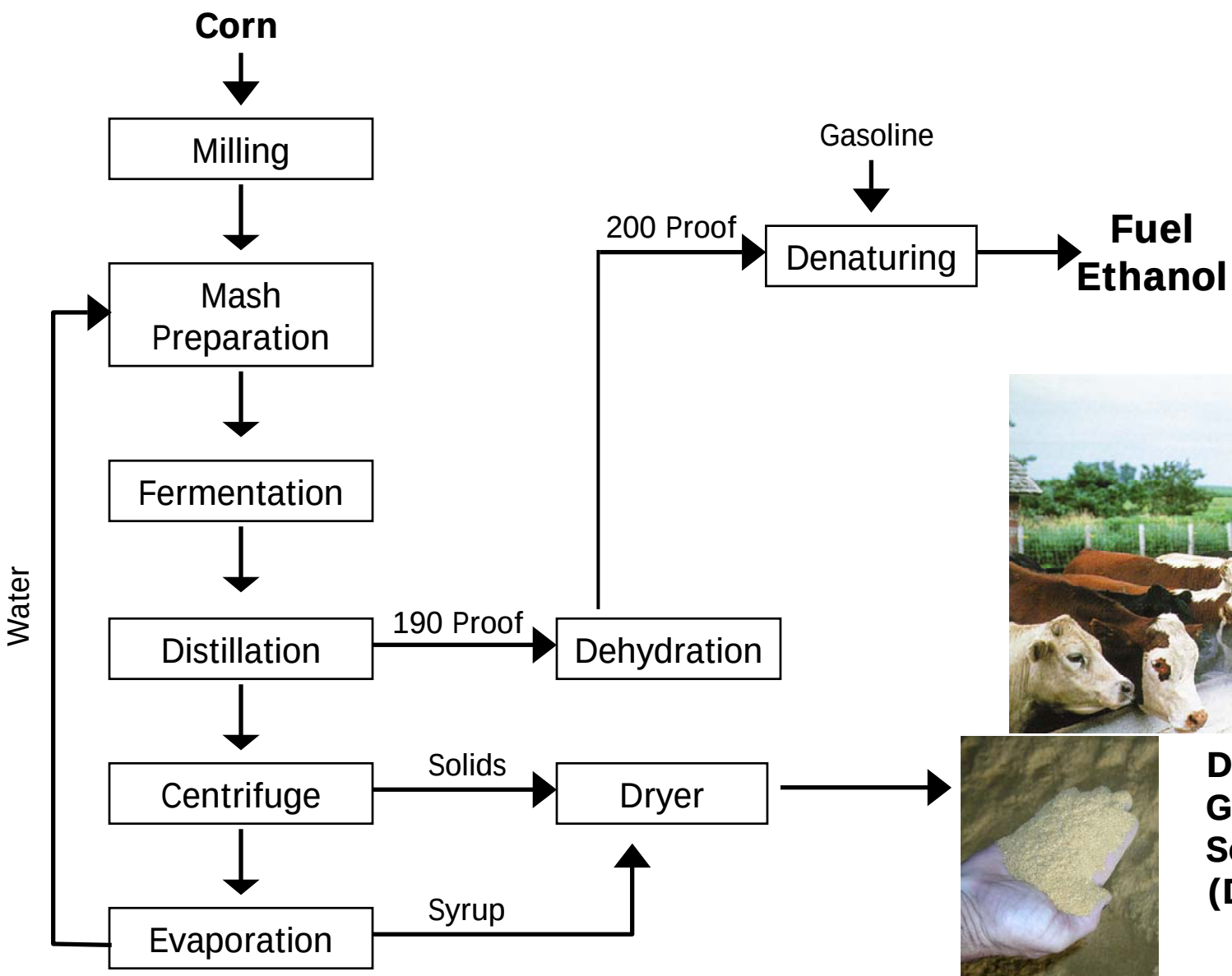
Introduction

Possible crop inputs

- Corn
- Stover & other residues
- Poplar
- Sugar cane/Bagasse
- Switchgrass

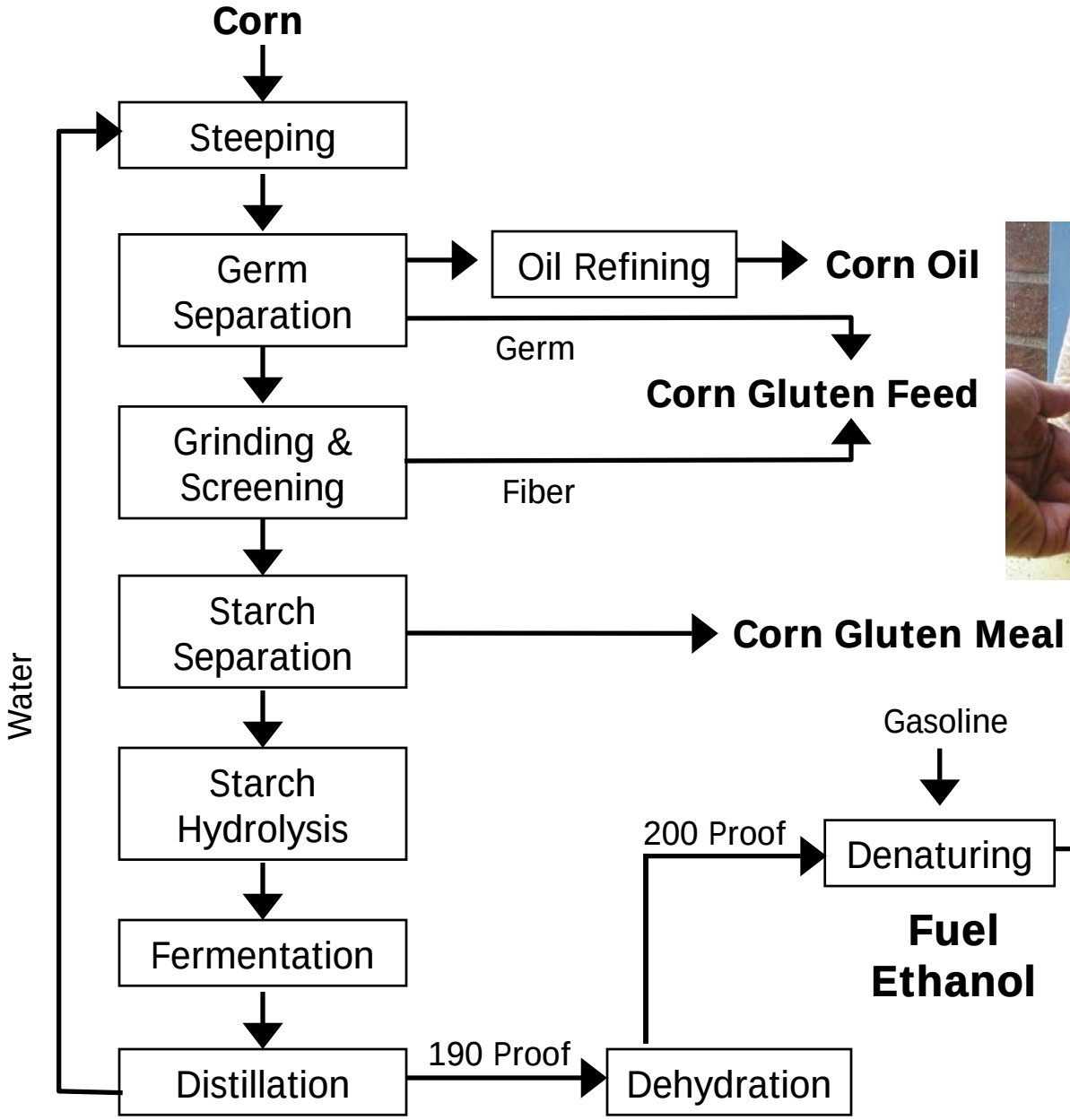


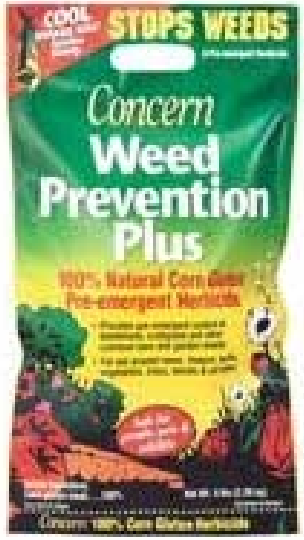
Starch to ethanol – Dry milling



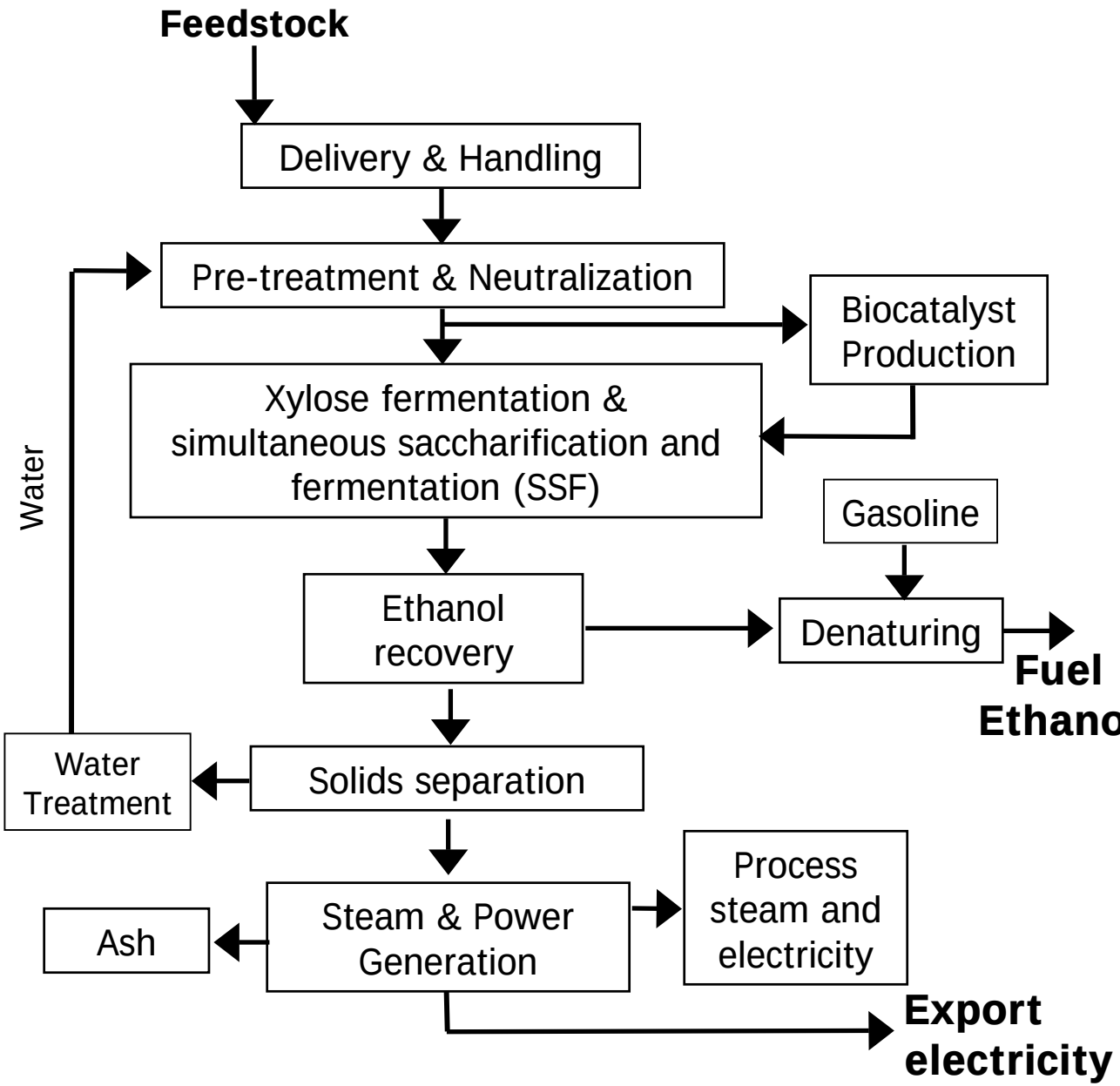
Dried Distiller's Grains and Solubles (DDGS)

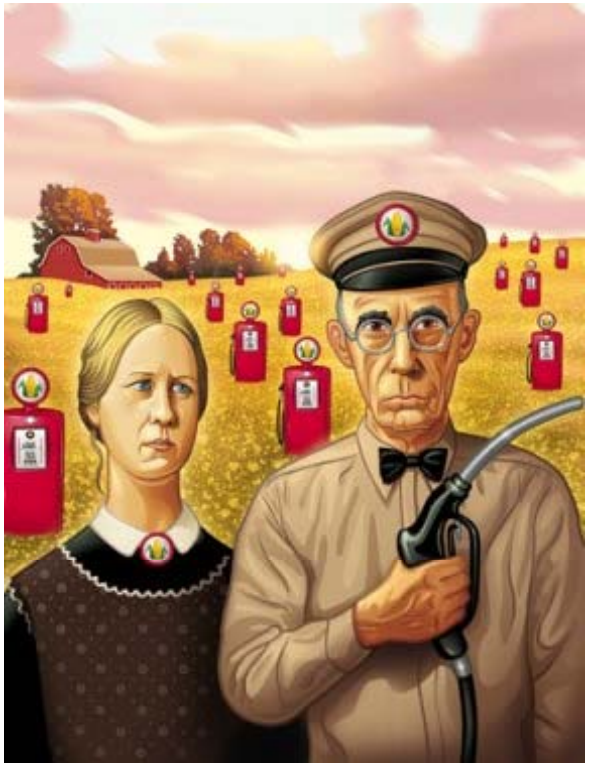
Starch to ethanol – Wet milling





Cellulose to ethanol





Methods

Methods

- Literature review
- ERG Biomass Analysis Meta-Model
  - Simplified energy and GHG accounting model
  - Transparent
  - Open source
  - Comparable units
    - Net energy value (NEV)
    - Primary energy
    - Greenhouse gas emissions
- Compare assumptions and data across prior studies
- Sensitivity and uncertainty analyses

Open source energy analysis

ERG Biofuel Analysis Meta-Model (EBAMM) - Mozilla Firefox

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http://rael.berkeley.edu/EBAMM/ Go

EBAMM

ERG Biofuel Analysis Meta-Model

The ERG Biofuel Analysis Meta-Model (EBAMM) was developed by students and faculty of the **Energy and Resources Group** and **Richard & Rhoda Goldman School of Public Policy** at UC Berkeley to review the current state of biofuel energy analyses.

The paper was published in ***Science*** on January 27, 2006 and is available here. Use the links below to download the paper, the spreadsheet model, and the supplemental materials.

- **Download the paper** (175 KB)
- **Download the model** (895 KB)
  Contains energy and greenhouse gas (GHG) analyses of all papers reviewed, plus summary sheets facilitating comparison between studies.
  Requires Microsoft Excel or work-alike.
- **Download the Supplemental Online Materials** (961 KB)
  Contains detailed model descriptions and a summary of errors and omissions found in the studies reviewed.
  Requires PDF file viewer.
- **Download a zipped archive** (1.1 MB)
  Contains both the model and the supplemental materials.

Studies compared in the meta-analysis

- Patzek, T. (2004). "Thermodynamics of the Corn-Ethanol Biofuel Cycle." *Critical Reviews in Plant Sciences* 23(6): 519-567.

- Pimentel, D. and T. Patzek (2005). "Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower." *Natural Resources Research* 14(1): 65-76.

- Shapouri, H., J. A. Duffield, et al. (2004). *The 2001 Net Energy Balance of Corn-Ethanol*. Corn Utilization and Technology Conference, Indianapolis.

- Graboski, M. (2002). *Fossil Energy Use in the Manufacture of Corn Ethanol*. St. Louis, National Corn Growers Association: 108.

- de Oliveira, M. E. D., B. E. Vaughan, et al. (2005). "Ethanol as fuels: Energy, carbon dioxide balances, and ecological footprint." *Bioscience* 55(7): 593-602.

- Wang, M. (2001). *Development and Use of GREET 1.6 Fuel-Cycle Model for Transportation Fuels and Vehicle Technologies*. Argonne, IL, Argonne National Laboratory, Center for Transportation Research: 218.

EBAMM – Net Energy Value (NEV)

$$NEV(MJ / L_{Fuel})$$
$$= Output\ \ Energy(MJ_{Fuel} / L_{Fuel}) - Input\ \ Energy(MJ_{Input} / L_{Fuel})$$

$$Outut\ Energy\ (MJ / L_{fuel})$$
$$= Fuel\ Energy\ (MJ / L_{fuel})$$
$$+ Coproduct\ Energy\ (MJ / L_{fuel})$$

$$Input\ Energy\ (MJ_{input} / L_{fuel})$$
$$= \frac{Agricultural\ Energy\ (MJ_{input} / ha)}{Net\ Yield(L_{fuel} / ha)}$$
$$+ Biorefinery\ Energy\ (MJ_{input} / L_{fuel})$$

EBAMM – Farm phase

$$
\begin{aligned}
&Agricultural\ Energy(MJ/ha) \\
&\quad = \sum_{i \in FarmInputs} \left(Embodied\ Energy_i\ (MJ/kg) \times Application\ Rate_i\ (kg/ha) \right) \\
&\quad + \sum_{i \in FarmInputs} \left(Transport\ Energy\ (MJ/kg) \times Application\ Rate_i\ (kg/ha) \right) \\
&\quad + Farm\ Direct\ Energy\ (MJ/ha) \\
&\quad + Farm\ Machinery\ Energy\ (MJ/ha) \\
&\quad + Inputs\ Packaging\ Energy\ (MJ/ha)
\end{aligned}
$$

$$
\begin{aligned}
&Farm\ Inputs \\
&\quad = N\ fertilizer, P\ fertilizer, K\ Fertilizer, Lime, Herbicides, Insecticides, Seed
\end{aligned}
$$

$$
\begin{aligned}
&Net\ Yield\ (L/ha) \\
&\quad = Crop\ Yield\ (kg/ha) \times Ethanol\ Production\ Yield\ (L/kg)
\end{aligned}
$$

EBAMM – Biorefinery phase

$$
\begin{aligned}
&Biorefinery\ Energy(MJ_{input} / L_{fuel}) \\
&\quad = Feedstock\ Transport\ Energy(MJ / L) \\
&\quad + Electricity\ Inputs(MJ / L) \\
&\quad + Coal\ Inputs(MJ / L) \\
&\quad + Natural\ Gas\ Inputs(MJ / L) \\
&\quad + Diesel\ Inputs(MJ / L) \\
&\quad + Biomass\ Energy\ Inputs(MJ / L) \\
&\quad + Process\ Water\ Inputs(MJ / L) \\
&\quad + EffluentWater\ Energy(MJ / L) \\
&\quad + Embodied\ Energy(MJ / L)
\end{aligned}
$$

EBAMM Implementation

Microsoft Excel - EBAMM_1_0

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	A	B	C	D
1	**EBAMM Release 1.0**			
2	December 26, 2005			
3				
4	This workbook consists of the following:			
5				
6	Summary worksheets			
7		**Scatterplot**	Chart of Net Energy Ratio versus Petroleum energy usage and GHGs emissions	
8		**Petroleum**	Summary of petroleum energy used in each stage of ethanol production, for each paper.	
9		**GHGs**	Summary of greenhouse gases (GHGs) emitted in each stage of ethanol production, for each paper.	
10		**NetEnergy**	Summary of energy consumed in each stage of ethanol production, for each paper.	
11				
12	Study worksheets:			
13		**Patzek**	Values as reported in Patzek 2004.	
14		**Patzek (adjusted)**	Patzek 2004 adjusted for consistent system boundaries. Modified values are highligted.	
15		**Pimentel**	Values as reported in Pimentel and Patzek 2005.	
16		**Pimentel (adjusted)**	Pimentel and Patzek 2005 adjusted for consistent system boundaries. Modified values are highligted.	
17		**Shapouri**	Values as reported in Shapouri, et al. 2004.	
18		**Shapouri (adjusted)**	Shapouri, et al. 2004 adjusted for consistent system boundaries. Modified values are highligted.	
19		**Graboski**	Values as reported in Graboski 2002.	
20		**Graboski (adjusted)**	Graboski 2002 adjusted for consistent system boundaries. Modified values are highligted.	
21		**de Oliveira**	Values as reported in de Oliveira 2005.	
22		**de Oliveira (adjusted)**	de Oliviera 2005 adjusted for consistent system boundaries. Modified values are highligted.	
23		**Wang**	Values as per Wang, based on GREET 1.6 and from other documentation published by Michael Wang.	
24		**Wang (adjusted)**	Wang / GREET adjusted for consistent system boundaries. Modified values are highligted.	
25		**Ethanol Today**	Values chosen to represent current state of ethanol production in the US.	
26		**CO2 Intensive**	Values chosen to represent a realistic scenario under which a larger amount of CO2 would be emitted.	
27		**Cellulosic**	Values chosen to represent a realistic scenario under which CO2 emissions are minimized.	
28		**Pimentel Switchgrass**	Values as reported in Pimentel and Patzek 2005 for cellulosic ethanol production using switchgrass.	
29		**Wang Switchgrass**	Values based on GREET 1.6 for cellulosic ethanol production using switchgrass.	
30				
31	Supporting data			
32		**Conversions**	Various energy conversion factors	
33		**GHG factors**	Various constants used for computing GHG emissions.	
34		**Energy Sources**	Information about energy use in agricultural inputs, electricity, etcetera.	
35		**Farm Machinery**	EIOLCA analysis of farm machinery energy based on eiolca.net	
36				

EBAMM implementation

Author, year	Pimentel and Patzek* (2005)		As Reported	Units
Article title	Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower			
Journal	Natural Resources Review			
Heating Value basis	LHV	Not explicitly specified.		
Agricultural Phase				
Nitrogen (MJ/kg)	66.9	Cited as Patzek 2004, but the value there (Table 3, p. 525.) is 54.43 MJ/kg. No explanation for the discrepancy	2,448,000	kcal/ha
N Application rate (kg/ha)	153.0	Cited as USDA 2002 (matches NASS 2003 (2002 data))		
Phosphorus (MJ/kg)	17.4	Source not cited.	4,154	kcal/kg
P2O5 application (kg/ha)	65.0	Cited as USDA 2002 (matches NASS 2003 (2002 data))		
Potassium (MJ/kg)	13.6	Source not cited.	3,260	kcal/kg
K2O application (kg/ha)	77.0	Cited as USDA 2002 (matches NASS 2003 (2002 data))		
Lime (MJ/kg)	1.2	Source not cited.	281	kcal/kg
Lime CaO application (kg/ha)	1120.0	Cited as Brees 2004. The reference is for corn production in Missouri, and reports an average 0.5 tons of lime are used per acre per year (which is equal to 1120 kg/ha).		

EBAMM – Primary Energy

- Gasoline/Diesel
- Natural Gas
- Coal
- Electricity
  - Nuclear/Hydro
  - Coal
  - Natural Gas
  - Petroleum

Note: **Denaturant <u>is</u> accounted for.**

Pimentel

Coal Calculator	
Agricultural phase	
Nitrogen fertilizer production (MJ/ha)	1,341
Phosphorus fertilizer production (MJ/ha)	420
Potassium fertilizer production (MJ/ha)	368
Lime production (MJ/ha)	296
Herbicide production (MJ/ha)	514
Insecticide production (MJ/ha)	232
Seed production (MJ/ha)	488
Electricity (MJ/ha)	72
Energy used in irrigation (MJ/ha)	574
Farm machinery (MJ/ha)	956
Inputs packaging (MJ/ha)	-
Agricultural phase total (MJ coal energy / ha)	**5,260**
Biorefinery Phase	
Primary energy (MJ/L)	6.4
Coal (MJ/L)	-
Electricity (MJ/L)	2
Capital (plant and equipment) (MJ/L)	0
Process water (MJ/L)	0
Effluent restoration (BOD energy cost to PWTPs) (MJ/L)	0
Total Biorefinery Phase (MJ coal energy / L)	**8.8**
Totals	
Agricultural phase total (MJ coal energy / L)	1.6
Gross Coal Inputs (MJ/L)	10
Co-products Credits (MJ/L)	-
Net Coal Inputs (MJ/L)	10
Percentage of input energy from coal	**38%**

EBAMM – GHG emissions

- All fossil carbon: fuel feedstock (petroleum), plus process energy
- Nitrogen fertilizer: production (CO_2) and soil (N_2O) emissions
- Lime: decomposition and N-cycle effects

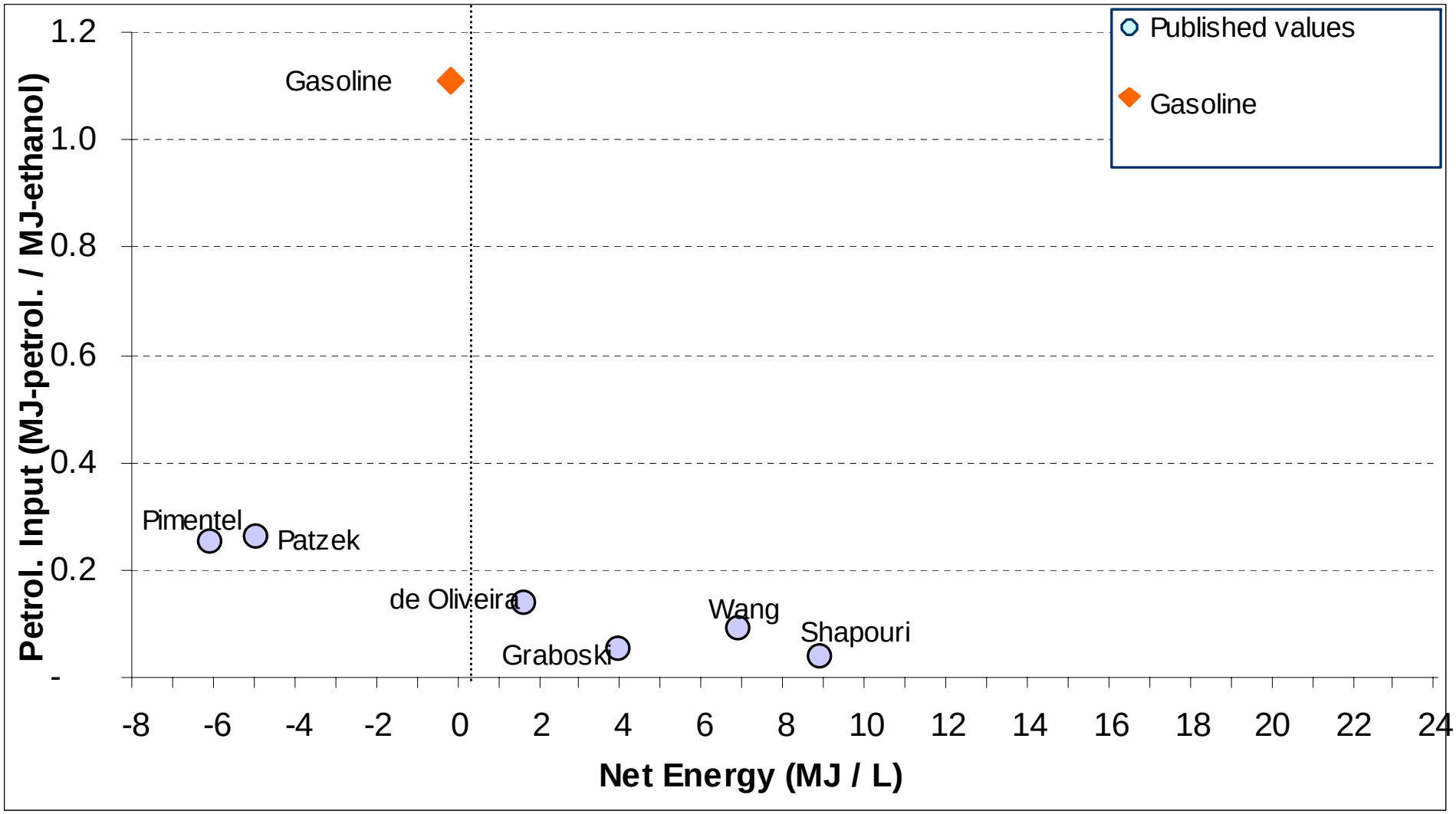
	A	B	C	D	E
1	**GHG Factors**			CO2	CH4
2				kg per kg of material, or g per mmbtu energy	
3	Nitrogen production (kg CO2e/kg N)	4.0	Reported in GREET 1.6, Ag_Inputs!B55:B57	3.72	0.01
4	N2O emissions from N fertilizer (kg CO2e/kkg N)	7.0	Derived from GREET 1.6, 1.5% of N in N fertilizer converted to N in N2O through nitrification and denitrification, multiplied by molecular ratio (44/28) of N to O in N2O	0.00	0.00
5	Phosphorus (kg CO2e/kg)	1.6	Reported in GREET 1.6, Ag_Inputs!C55:C57 as 1.5553 g CO2, 0.0023 g CH4, and 0.0000 g N20 per g P2O5	1.56	0.00
6	Potassium (kg CO2e/kg)	0.71	Reported in GREET 1.6, Ag_Inputs!D55:D57 as 0.6888 g CO2, 0.0010 g CH4, and 0.0000 g N20 per g K2O	0.69	0.00
7	Lime (kg CO2e/kg CaO)	0.44	Calculated from emissions factors for use of limestone or dolomite for agricultural liming from Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories	0.44	0.00

Model validation

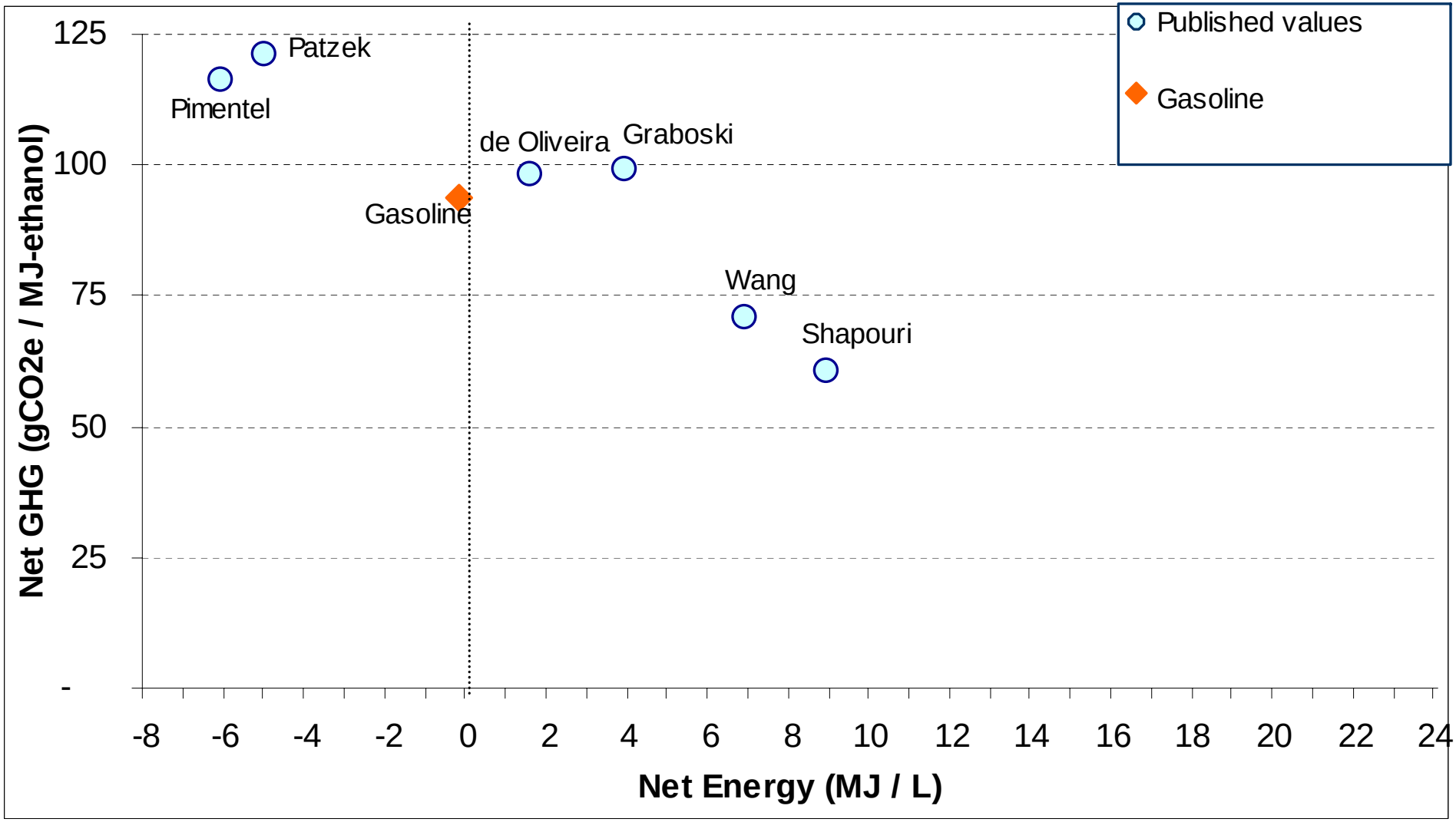
	A	B	D	F	H	J	L
1	**Net Energy Summary**	**Patzek**	**Pimentel**	**Shapouri**	**Graboski**	**de Oliviera**	**Wang**
2	Article title	Thermodynamics of the Corn-Ethanol Biofuel Cycle	Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower	The 2001 Net Energy Balance of Corn-Ethanol	Fossil Energy Use in the Manufacture of Corn Ethanol	Ethanol as Fuel: Energy, Carbon Dioxide Balances, and Ecological Footprint	Actual spreadsheet, also consulting documentation in Wang 1999, Wang 2001, and GM, Wang et al 2005
58	**Net energy value, NEV**	**-5.0**	**-6.1**	**8.9**	**3.9**	**1.6**	**6.9**
60	**Validation**						
61	Ethanol Distribution (MJ/L)	0	0	0.4	0	0.4	0
62	Reported Output:Input Ratio	0.81	0.78	1.67	3.71	1.1	NR
63	Reported Total Energy Input (MJ/L)	26.2	27.6	20.1	21.6	n/a	18.7
64	Our result as a fraction of reported values	100.0%	99.9%	100.0%	100.5%	100.0%	100.2%

Results

Petroleum use



Greenhouse gases



What explains the range in results?

- Incommensurate assumptions
  - Coproduct energy
  - Farm machinery
  - Inputs packaging
  - Biorefinery capital energy
  - Process water
  - Effluent restoration
  - Labor transportation
- Inconsistent data
  - Lime application rates
  - Farm machinery
  - Biorefinery yield
  - others

Coproduct energy allocation

Study	**Value (MJ/L)**	**Allocation method**
Patzek	0	None
Pimentel	0	None (-1.9 calculated)
Shapouri	-7.3	Corn production and transport: mass Ethanol production: process simulation
Graboski	-4.1	Displacement
de Oliviera	0	None
Wang	-4.0	Displacement

Coproduct markets

- Dry milling of corn ethanol:
  - 0.77kg DDGS/L ethanol
  - $0.08/L (@ $0.10/kg)
  - Compare to:
    - Ethanol: $0.40/L (at $=1.50/g)
    - Tax credit: $0.14/L
- U.S. market size
  - ~8 million metric tons (2005)
  - Almost all from ethanol plants
  - Domestic and export growth potential
- Possible alternative uses
  - Cogeneration fuel
  - WDGS
  - Value-added products

Market effects of increased ethanol coproducts

- U. of Missouri Food and Agricultural Policy Research Institute
  - Study of the renewable fuels provisions of EPACT 2005
  - 7 billion gallons of corn ethanol in 2012
  - Added corn production:
    632 million bushels

Google: FAPRI ethanol

82% shift in use corn use (less animal feed and exports)
18% new corn production

9% reduced soy and wheat acreage
9% currently fallow land

Unaddressed:
- Larger scale biofuels production
- International effects
- Technological and product change

Adjustments for commensurability

- Added
  - Coproduct energy
  - Farm machinery
  - Inputs packaging
  - Biorefinery capital energy
  - Process water
  - Effluent restoration
- Removed
  - Labor transportation
- Data adjustments
  - N fertilizer (transcription error)

Microsoft Excel - EBAMM v33a

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A59 = Net energy ratio (see Suppl. Online Material)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Net Energy Summary** *** - adjusted for comparability**	**Patzek**	**Patzek'**	**Pimentel**	**Pimentel'**	**Shapouri**	**Shapouri'**	**Graboski**	**Graboski'**	**de Oliviera**	**de Oliviera'**	**Wang**	**Wang'**
33	**Biorefinery Phase**				-				-		-		
34	Transportation of feedstock to biorefinery	-	-	1.35	1.35	0.59	0.59	0.49	0.49	0.60	0.60	0.64	**0.64**
35	Primary energy (MJ/L)	14	14	11	11	14	14	15	15	13	13	-	-
36	Electricity (MJ/L)	-	-	4	4	-	-	-	-	-	-	-	-
37	Coal (MJ/L)	-	-	-	-	-	-	-	-	-	-	7	**7**
38	Natural gas (MJ/L)	-	-	-	-	-	-	-	-	-	-	4.6	**4.6**
39	Diesel (MJ/L)	-	-	-	-	-	-	-	-	-	-	-	-
40	Biomass (MJ/L)	-	-	-	-	-	-	-	-	-	-	-	-
41	Capital (plant and equipment) (MJ/L)	-	0.13	0.13	0.13	-	0.13	-	0.13	-	0.13	-	0.13
42	Process water (MJ/L)	-	0.38	0.38	0.38	-	0.38	-	0.38	-	0.38	-	0.38
43	Effluent restoration (BOD energy cost in MJ/L)	-	0.29	0.29	0.29	-	0.29	-	0.29	-	0.29	-	0.29
44	Transportation of chemicals to plant	1.7	1.7	-	-	-		-	-	-	-	-	-
45	**Totals**												
46	Crop yield (kg/ha)	7,310	7,310	8,655	8,655	8,746	8,746	8,799	8,799	7,850	7,850	7,846	7,846
47	Biorefinery yield (L/kg corn)	0.37	0.37	0.37	0.37	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.39
48	Net ethanol yield per land area (L/ha)	2,719	2,719	3,217	3,217	3,463	3,463	3,474	3,474	3,038	3,038	3,060	3,060
49	Net ethanol yield per land area (MJ/ha)	57,650	57,650	69,060	69,060	73,424	73,424	73,553	73,553	64,101	64,101	64,870	64,870
50	Agricultural energy (MJ/L)	10	10	11	10	5.2	5.3	5.5	5.5	6.2	6.3	6.6	6.6
51	Biorefinery energy (MJ/L)	16	17	17	17	14	15	16	17	13	14	12	13
52	Recycled biomass energy (MJ/L)	-	-	-	-	-	-	-	-	-	-	-	-
53	**Input energy (MJ/L)**	**26**	**27**	**28**	**27**	**20**	**21**	**21**	**22**	**20**	**20**	**18**	**19**
54	Reported HV of ethanol (MJ/L)	21	21	21	21	21	**21**	21	21	21	21	21	21.2
55	Coproduct credits (MJ/L)	0.0	4.1	0.0	1.9	7.3	7.3	4.1	4.1	0.0	4.1	4.0	4.0
56	Coproducts as % of total energy	0%	15%	0%	7%	37%	36%	19%	19%	0%	20%	22%	21%
57	**Output Energy (MJ/L)**	**21**	**25**	**21**	**23**	**29**	**29**	**25**	**25**	**21**	**25**	**25**	25.2
58	**Net energy value, NEV (MJ/L)**	**-5.0**	**-1.6**	**-6.1**	**-3.7**	**8.9**	**8.0**	**3.9**	**3.1**	**1.6**	**4.8**	**6.9**	**6.1**
65													
66	*Values highlighted in pink have been added to normalize all studies to the same system boundary.*												
67													
68													
69													

Intro / Scatterplot / Petroleum / GHGs / **NetEnergy** / Patzek / Patzek (adjusted) / Pimentel / Pimentel (a

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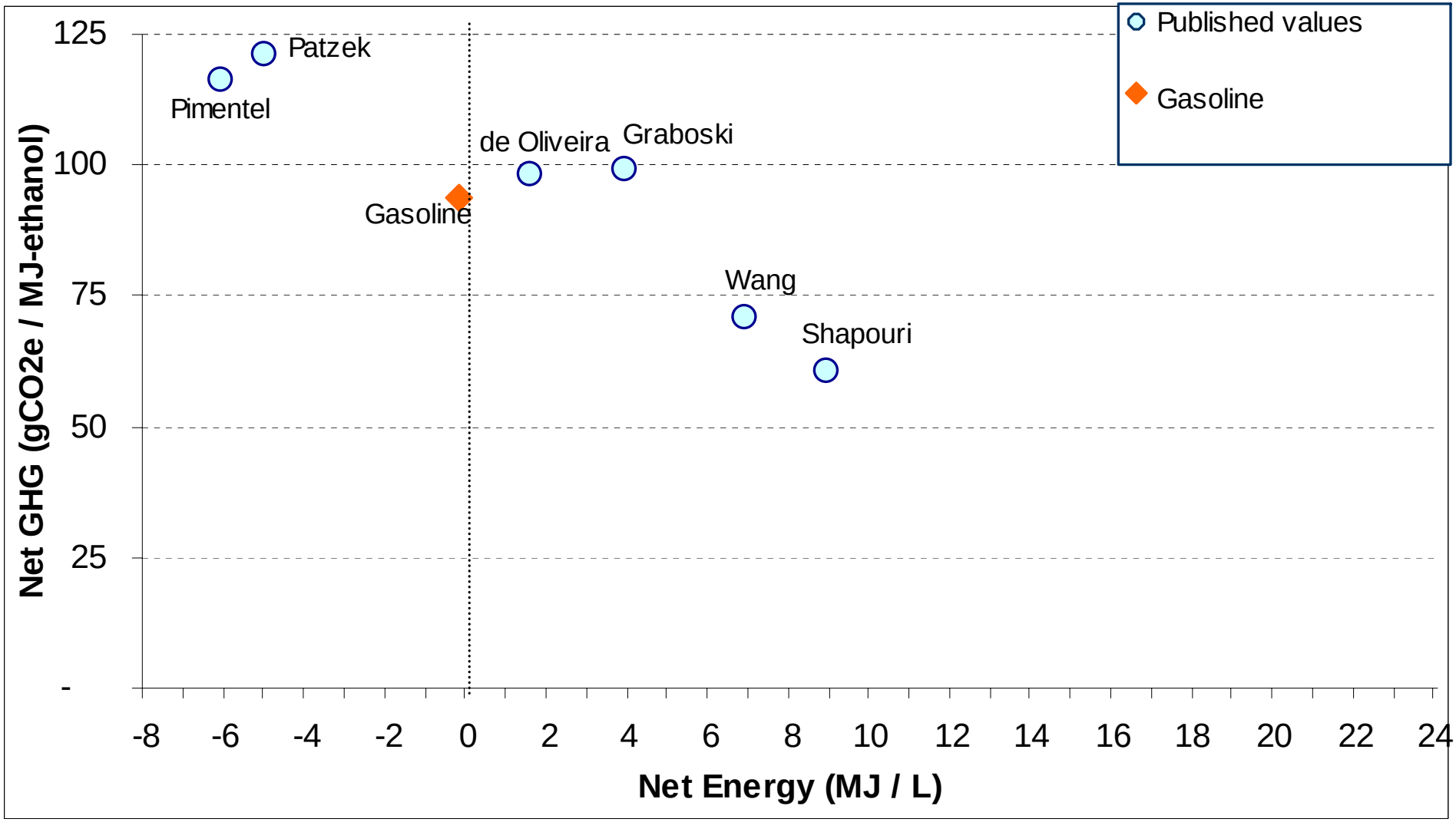
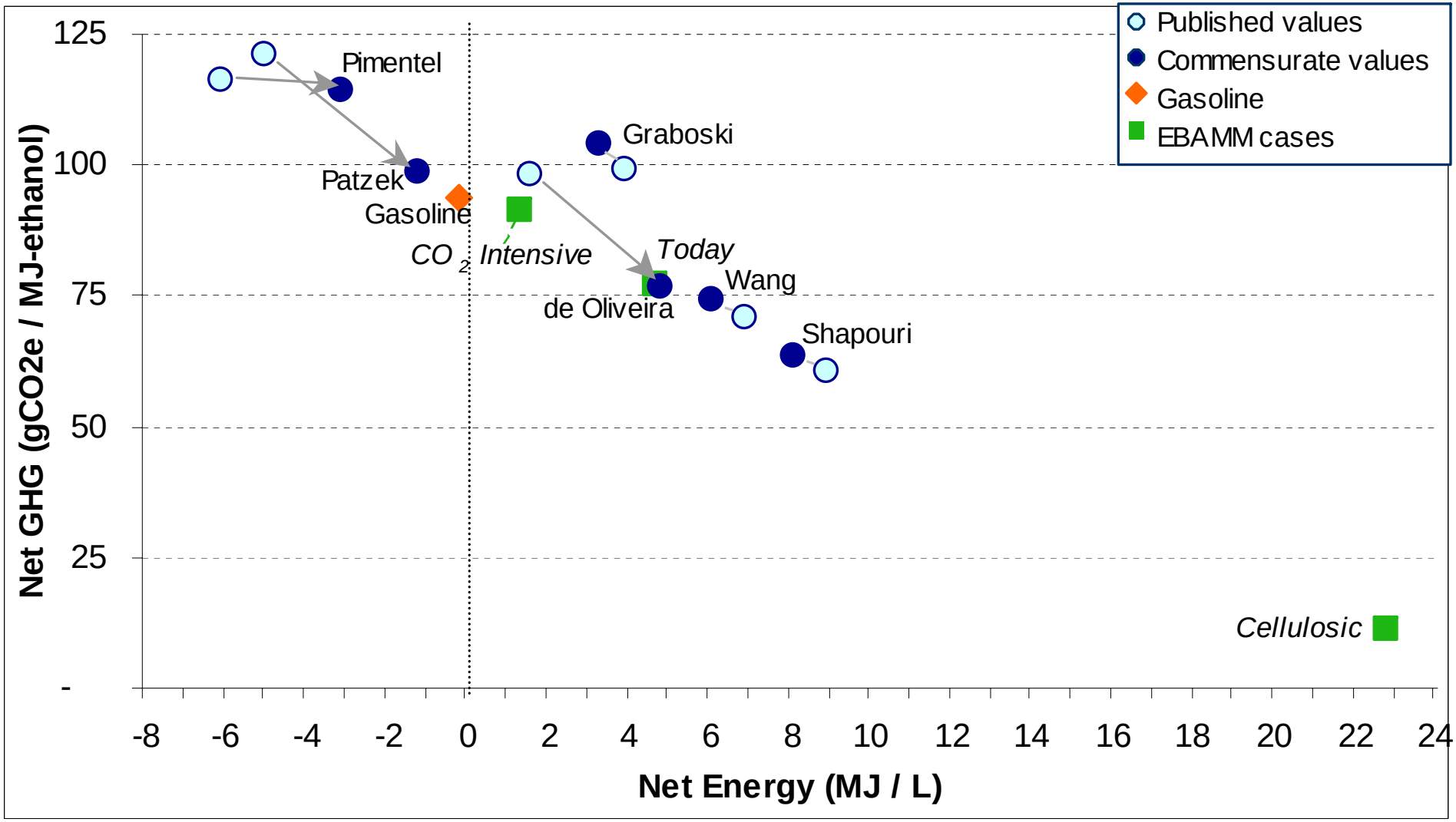
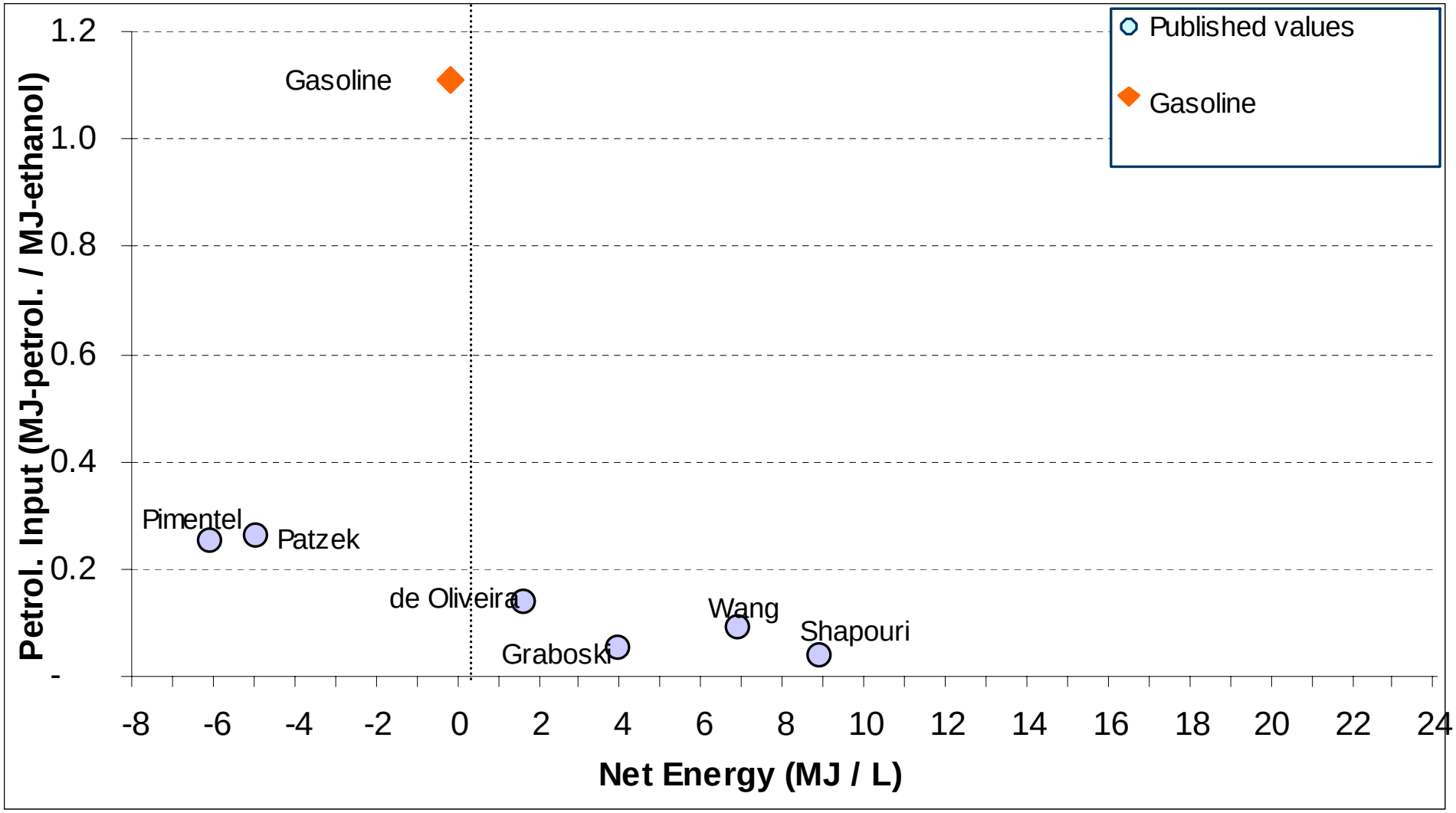
Greenhouse gases



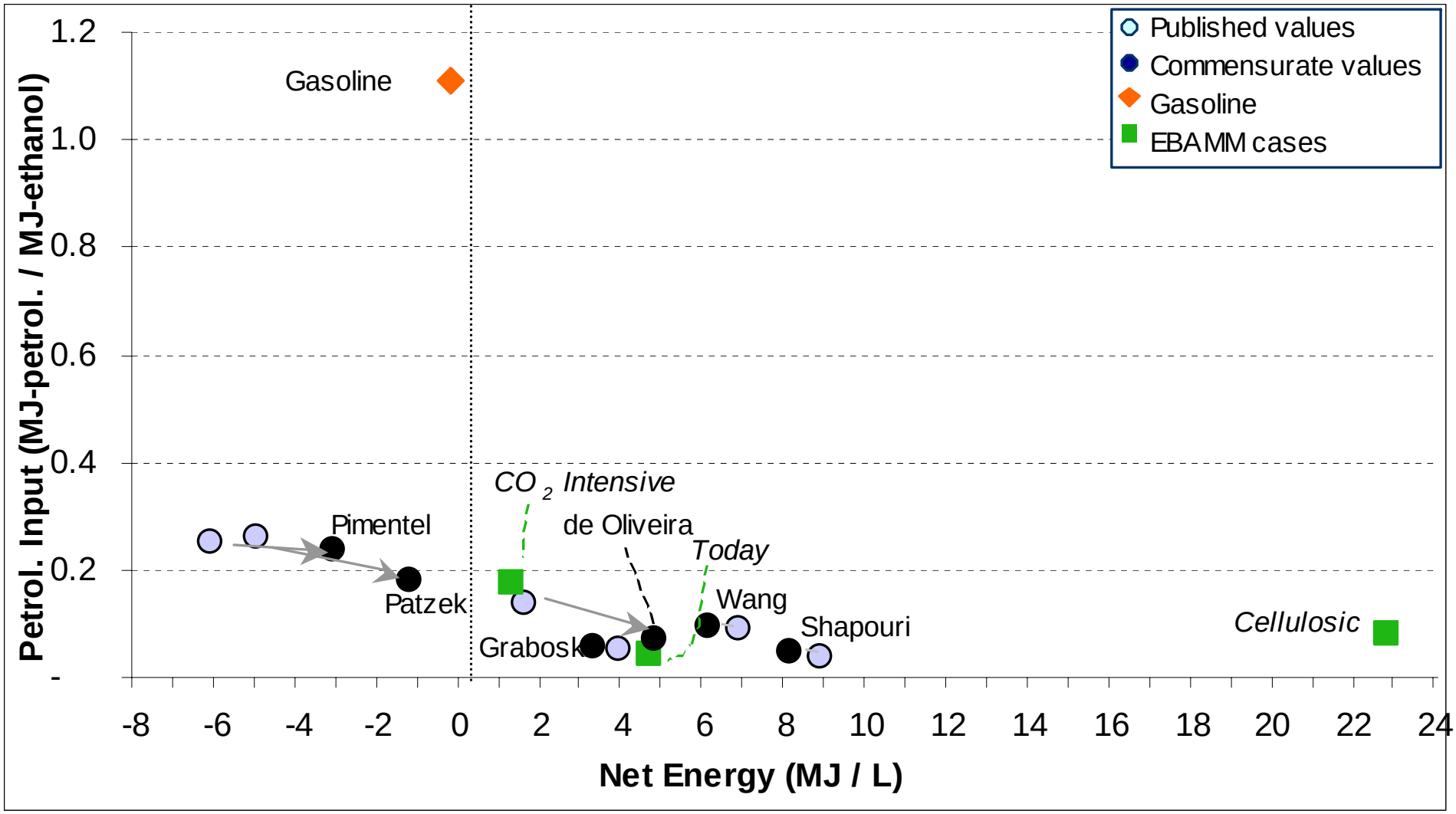
Greenhouse gases



Petroleum use

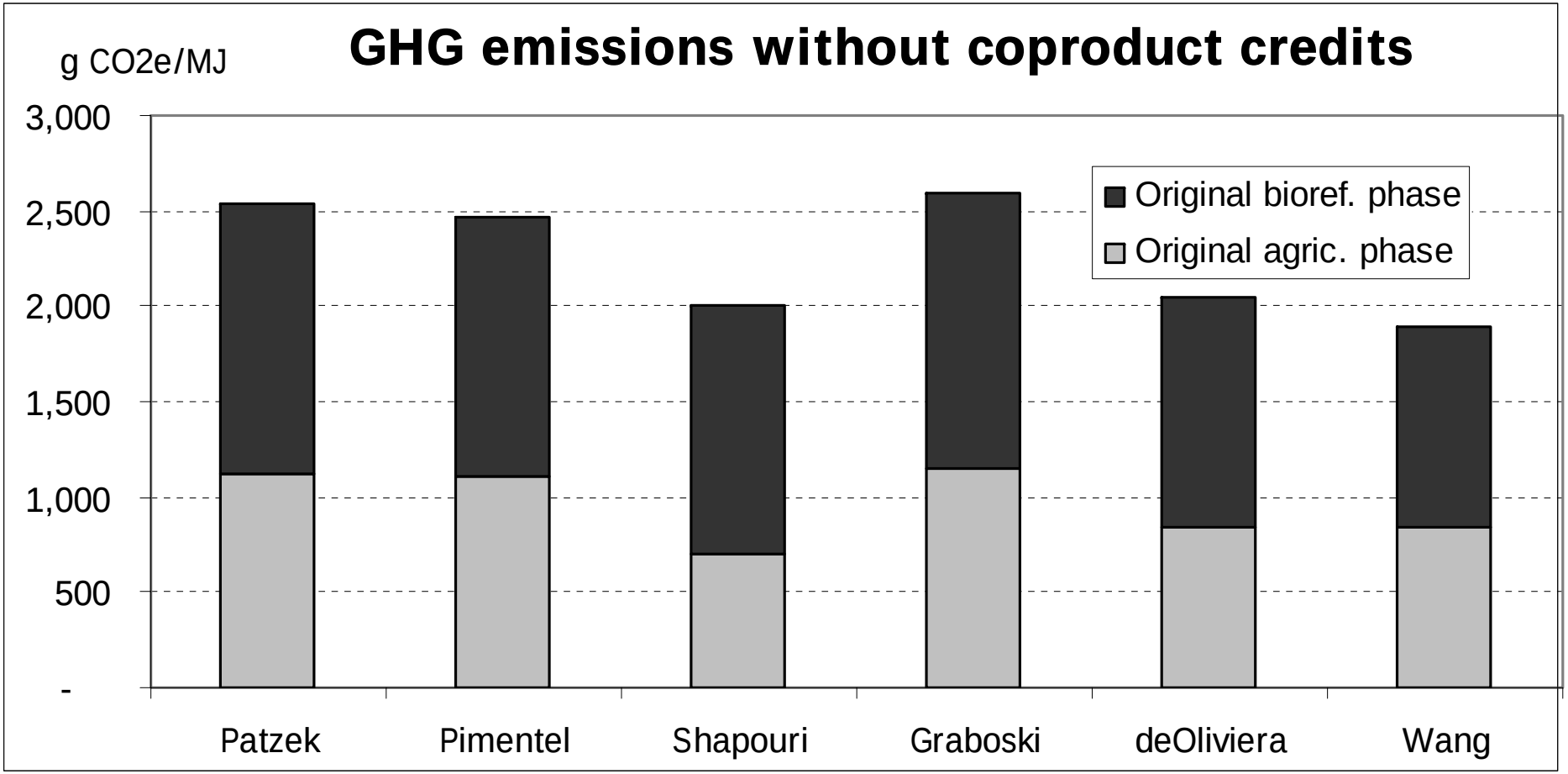


Petroleum use



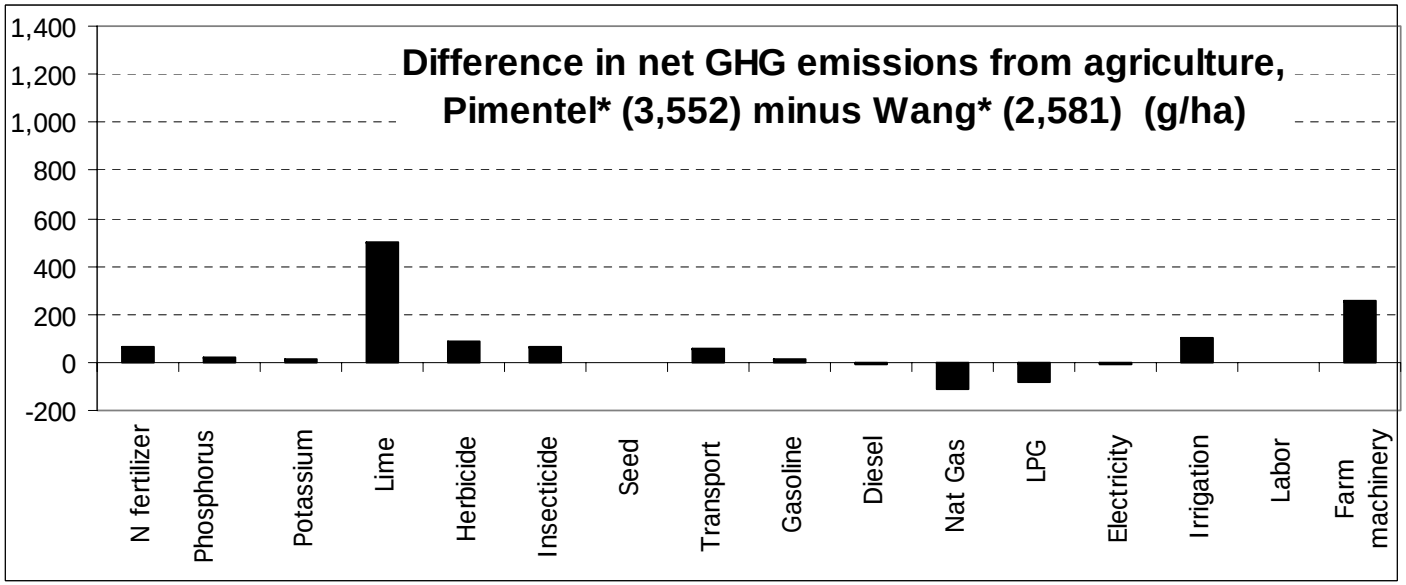
What explains the remaining differences?

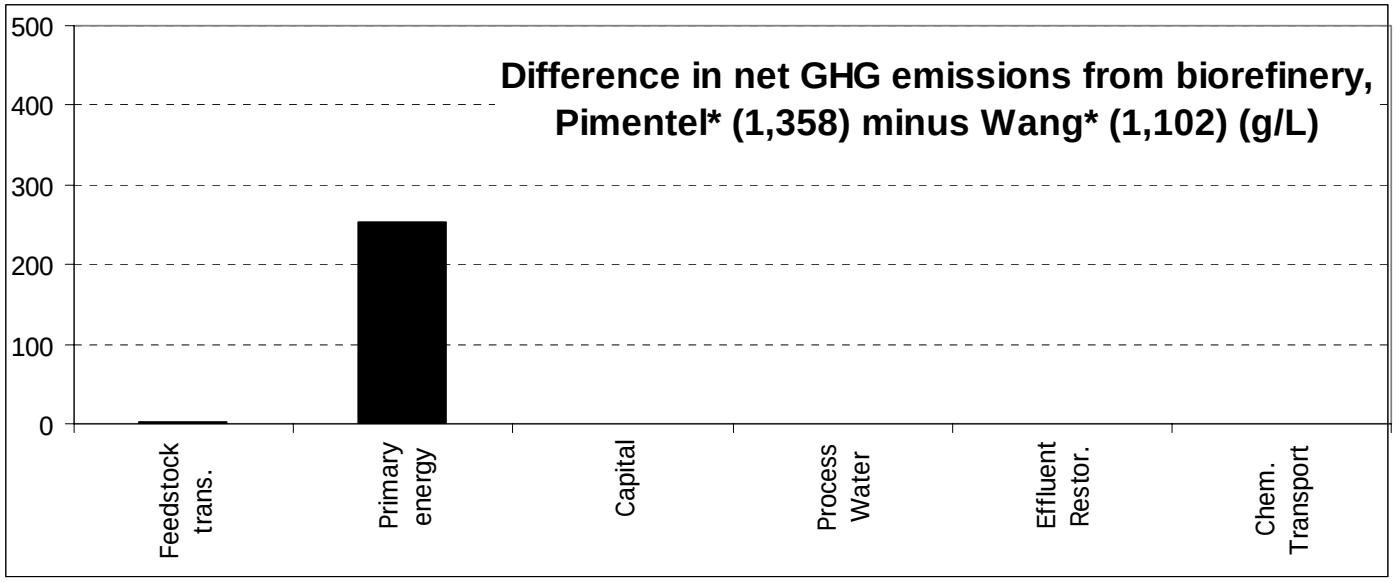
- Agricultural and biorefinery GHG emissions are similar in magnitude



What explains the remaining differences?

- Obsolete, non-representative, and unverifiable data





Results

1. Studies with negative net energy results contain two errors
   - Co-products are ignored to convert soil erosion into energy units
   - Obsolete, non-representative, and unverifiable data
2. Ethanol requires far less petroleum than gasoline
3. Unclear if corn ethanol is better than gasoline for GHGs, and has other environmental problem, e.g. soil erosion, nutrient runoff.
4. NEV is poor metric
   - Inappropriately aggregates energy types
   - Doesn't tell us anything we would not get from metrics we *do* care about, such as petroleum or GHG
   - Calculation is arbitrary (NER is even worse)
   - Either includes arbitrary conversions of environmental damage (e.g. soil erosion) to energy or ignores these effects

Recent developments – Uncertainty analysis

- Letter from Michael Wang (Argonne National Laboratory) on <u>limestone application rates</u>
  - Shaporui and Wang – 18kg/ha citing USDA
  - De Oliveira – 275 kg/ha citing USDA
  - Graboski – 3000 kg/ha citing USDA
  - Brees – 1121 kg/ha quoting a thumbrule

Lime input to corn production (lb/ac), USDA

	IL	IN	IA	MN	NE	OH	MI	SD	WI	Wtd. Avg.
1990-92	480	340	280	40	0	140	680	0	120	242
1995-97	20	20	20	0	0	20	20	0	60	15
2000-02	20	20	20	0	0	20	20	0	60	15

- Discussions with USDA –
  - Custom report (February 2006) – now gives ~400lb/ac

Further uncertainties

- Lime emission factor
  - Strongly acidic soils (pH<5) net CO_2 **source**

    $$CaMg(CO_3)_2 + 4HNO_3 \leftrightarrow Ca^{2+} + Mg^{2+} + 4NO_3^- + 2CO_2 + 2H_2O$$

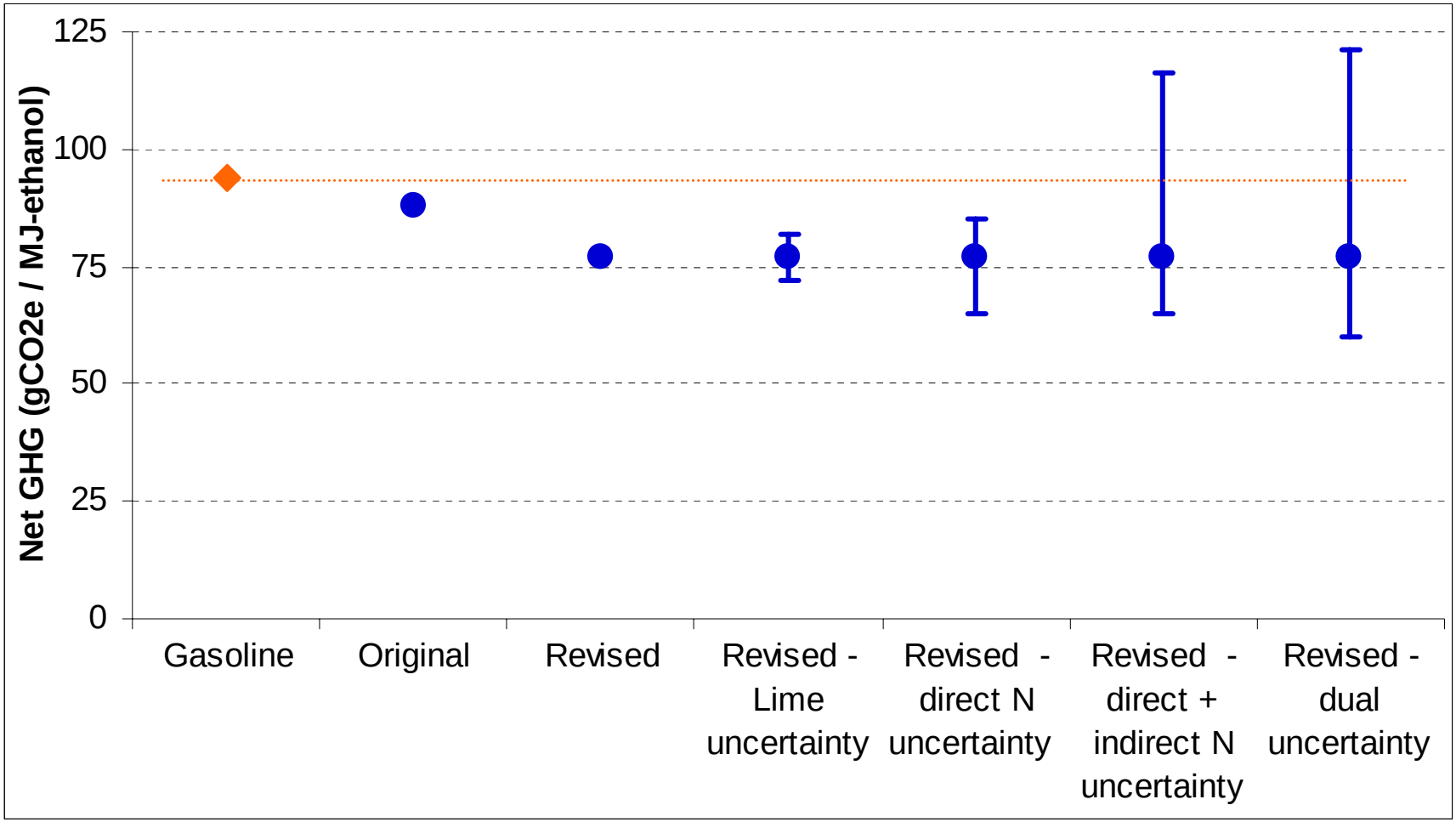
  - Mildly acidic soils (pH 6.5-5) net CO_2 **sink**

    $$CaMg(CO_3)_2 + 2H_2CO_3 \leftrightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^-$$

- Allocation to corn in a multi-crop rotation

- Nitrogen fertilizer to N_2O
  - Application rates vary significantly
  - Direct emissions: 0.25% to 2.25% (IPCC)
  - Indirect emissions: up to 3% more (IPCC)

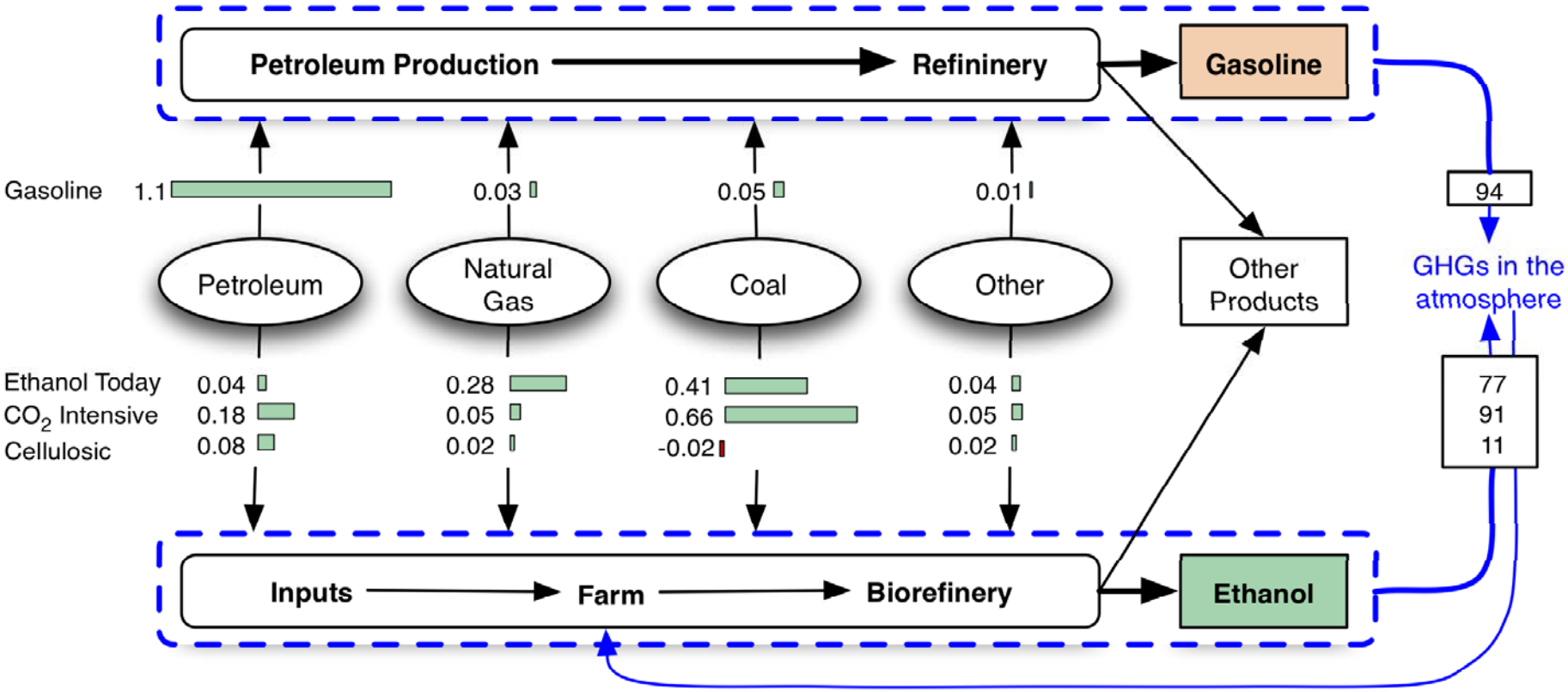
Uncertainty in GHG emissions



	Original	Revised	Revised - Lime uncertainty	Revised - direct N uncertainty	Revised - direct + indirect N uncertainty	Revised - dual uncertainty
	-12%	-18%	-12%	-9%	+24%	+29%
			-23%	-31%	-31%	-36%

Discussion

EBAMM cases



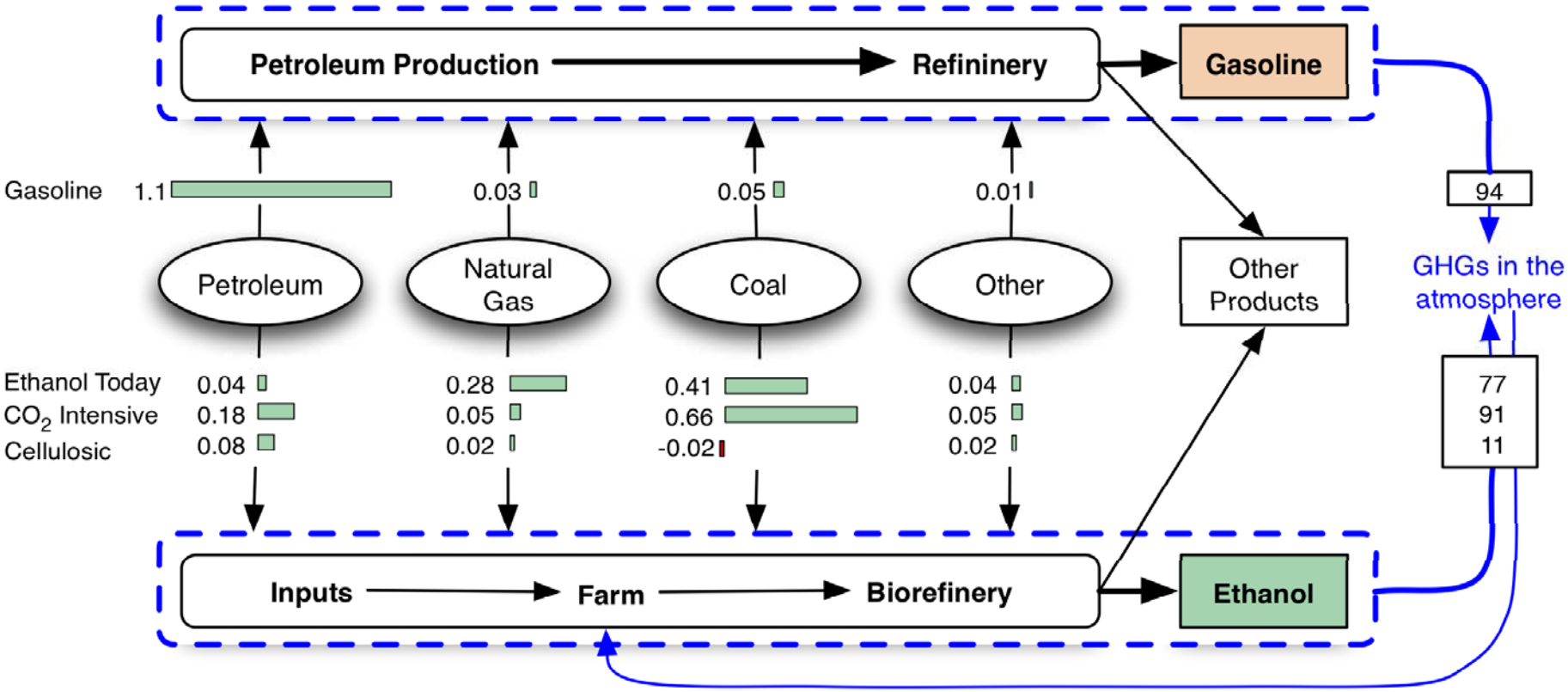
MJ of input energy required for 1MJ of fuel and gCO_2e / MJ of fuel

Ethanol Today – Average corn ethanol (Wang with adjustments)

CO_2 Intensive – Lignite-fueled plant using rail-shipped corn

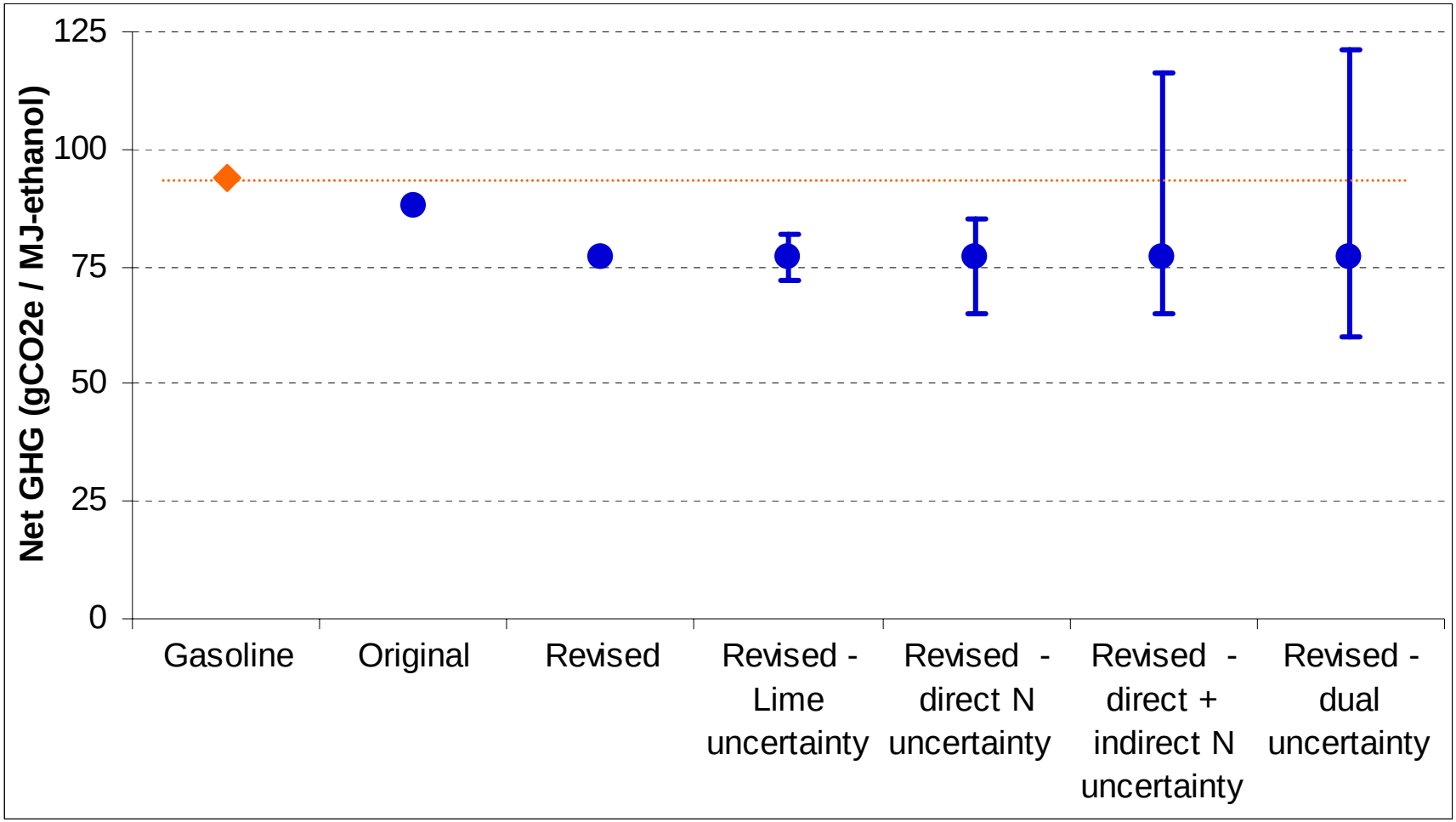
Cellulosic – Switchgrass (Wang with adjustments)

EBAMM cases



	Net Energy	Petroleum	GHGs
Gasoline	1.19	1.10	94
EtOH Today	0.77 (-35%)	0.04 (-96%)	77 (-18%)
CO_2 Intensive	0.94 (-21%)	0.18 (-84%)	91 (-3%)
Cellulosic EtOH	0.10 (-92%)	0.08 (-88%)	11 (-88%)
2000mi rail/200mi truck	0.05	0.05	5

Revised results and uncertainty analysis



	Original	Revised	Revised - Lime uncertainty	Revised - direct N uncertainty	Revised - direct + indirect N uncertainty	Revised - dual uncertainty
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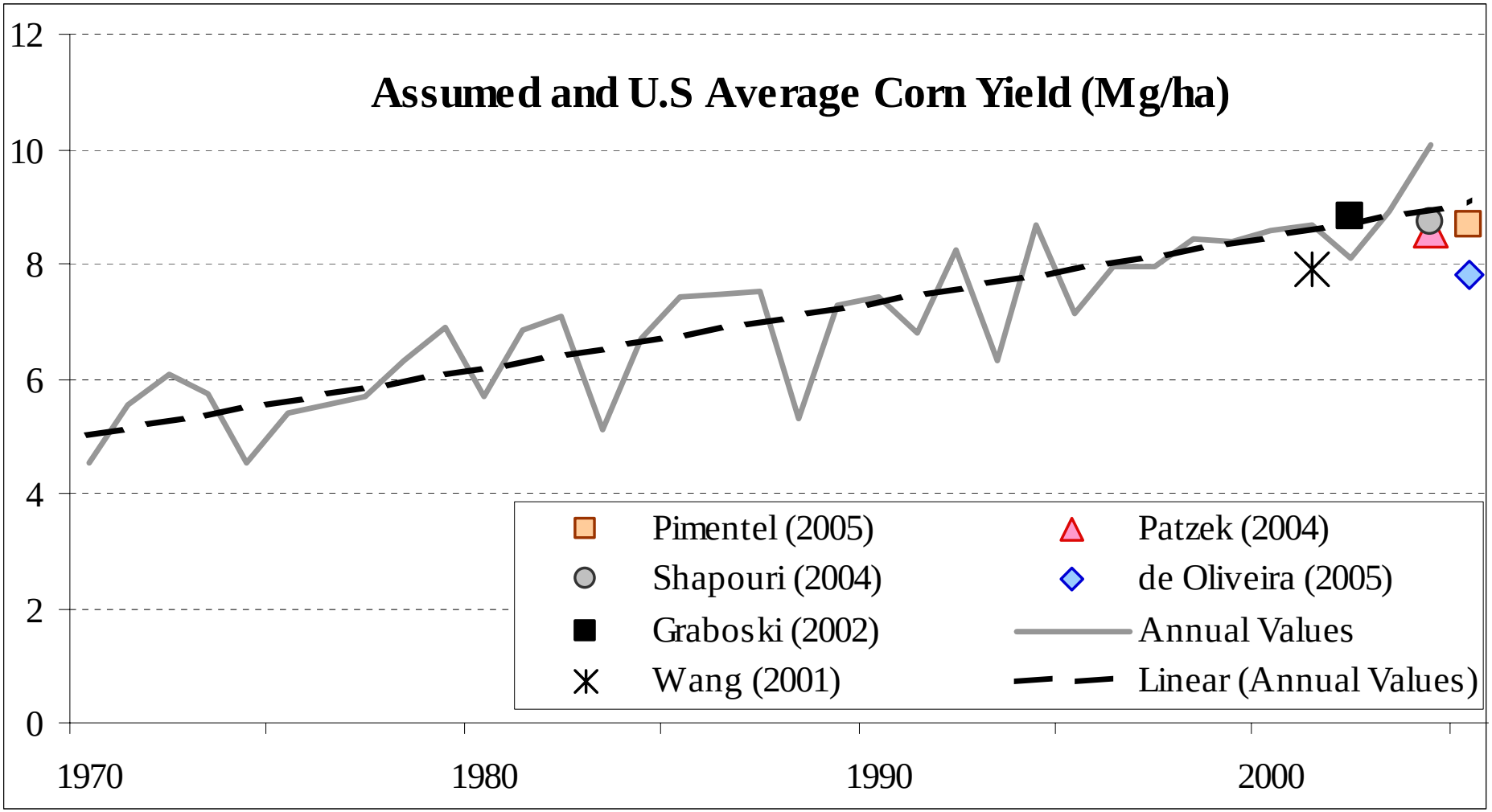
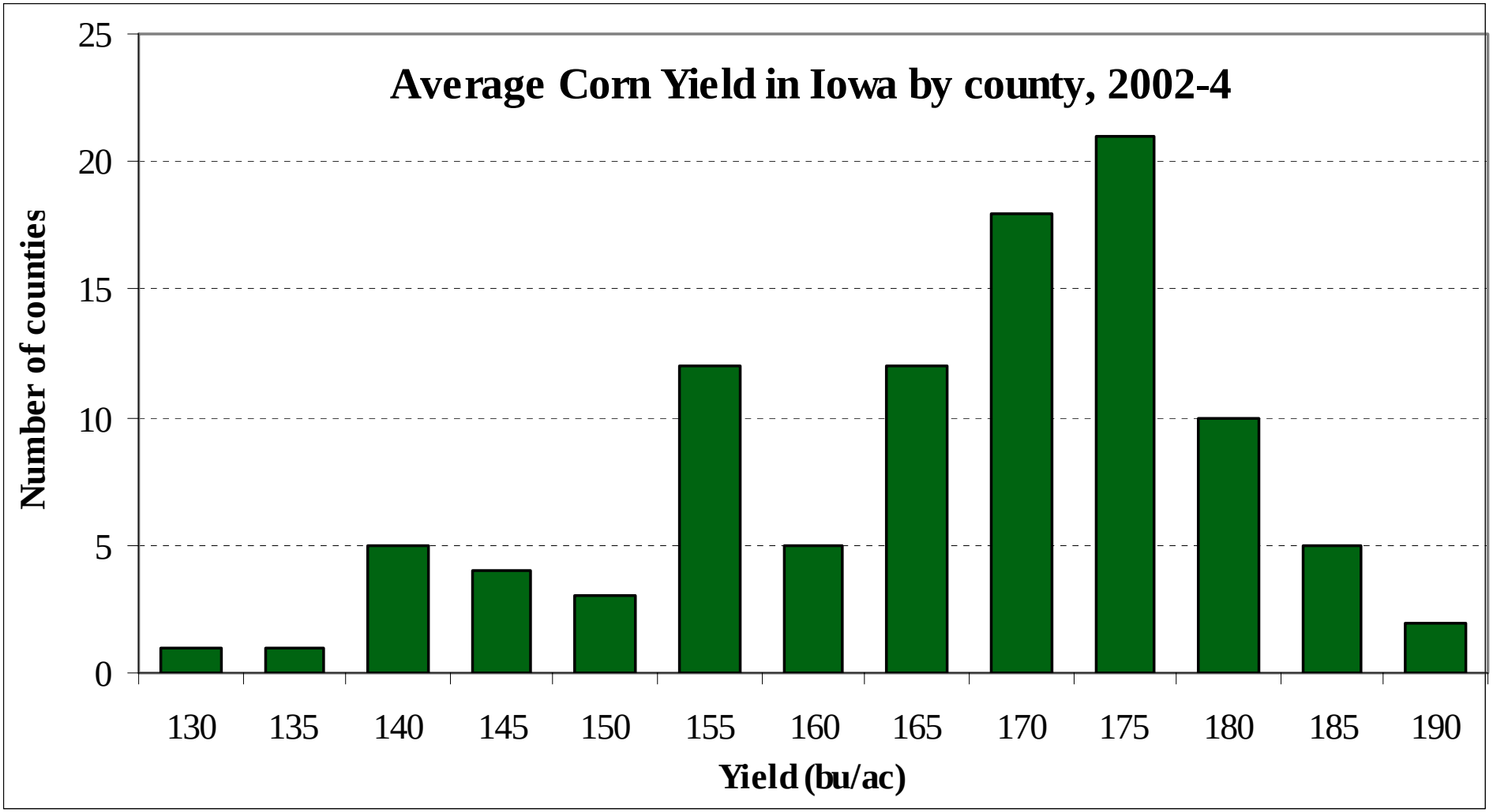
Technological change



Heterogeneity



Air pollution issues

- Existing studies are few and old
- NO_X emissions may increase but somewhat unclear
- VOC emissions may increase, but a declining problem
  - Working and breathing emissions minor
  - Permeation decreasing as older (pre MY1999) cars are replaced
- Higher-ethanol blends may reduce evaporative emission
- Not clear what an optimized E85 vehicle (including emission controls) would be like
- Conflicting evidence on emissions of toxics
  - Risk-weighted emissions may decline

Implications for California

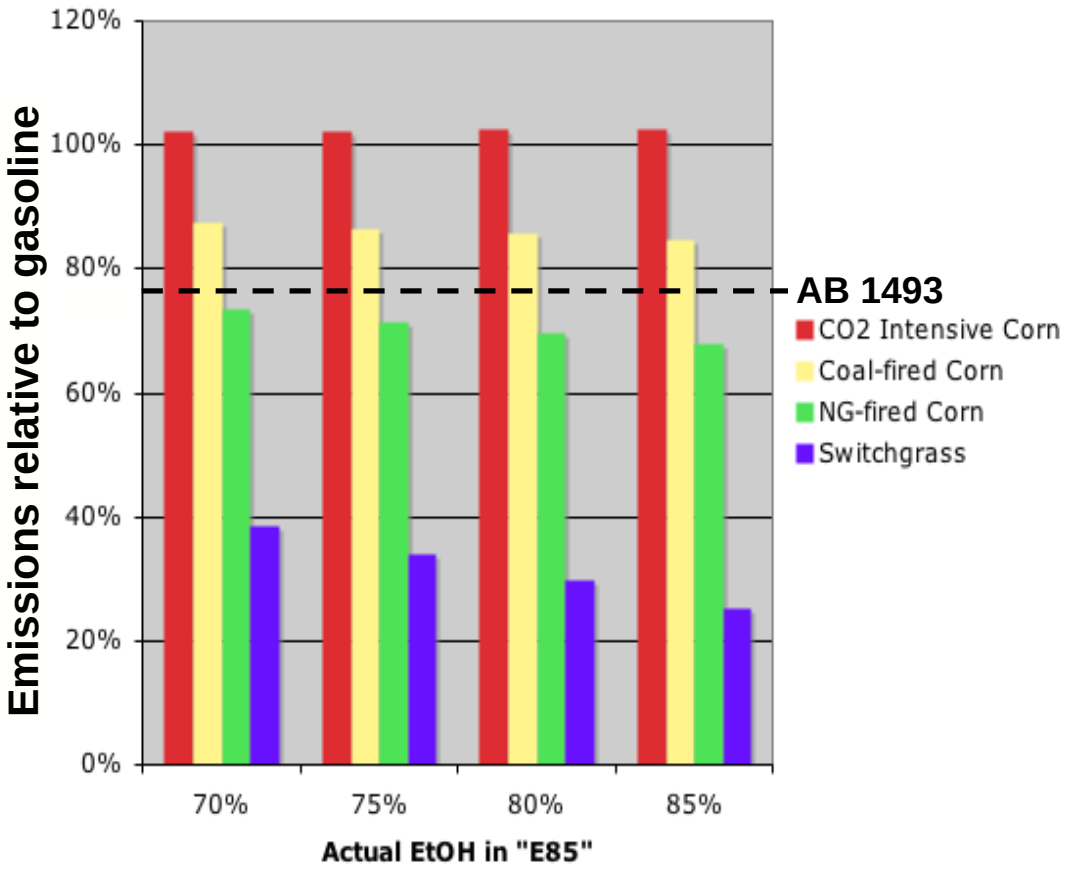
- CA uses ~1 billion gal/year of ethanol
  - 25% of US production
  - Almost all imported from midwest
- Ethanol may be an effective means of reducing petroleum use
- Ethanol may or may not contribute to meeting the Governor's targets for GHG emissions
  - Agronomic practices are key
    - Low-GHG farming
    - Sustainable biofuel agroecology
  - Certification or performance standards may be needed
- Considerable potential for cellulosic ethanol to make a contribution
  - Municipal solid waste
  - Crop and forestry residues

Some relevant California policy

- AB 1493 (Pavley)
  - 30% reduction in automobile GHG emissions (MY2016)
  - “Fuel Adjustment Factor” (-23% for ethanol)
- Executive Order S-3-05
  - Statewide GHG emission reduction targets (~25% in 2020)
- AB 1007 (Pavley 2)
  - “develop a comprehensive strategy...alternative fuels”
- Climate Action Team Report
- Executive Order 06-06
  - Statewide biofuels production targets (40% in 2020)

Features of a uniform fuel adjustment factor

- Simple and relatively easy to apply
- Incorrect
  - Value is too high for ethanol in California today
  - Value is too low for cellulosic ethanol in the future
- Provides no incentives for improved performance



Note: does not include transport of EtOH to market

Ensuring Climate Benefits

- Certified ethanol blends
- Define GHG targets for blend levels
- Track GHGs across production stages
  - Maintain product identity
- Assume high-GHG if uncertified
- Optional certification
  - Mandatory for blenders
  - Opt-in for feedstock and ethanol producers
  - Allow trading of credits and hi- and low-GHG ethanol

E85™
85% Ethanol
CERTIFIED LOW-GHG

Low-GHG certified ethanol

- Feedstock producers standardize GHG accounting for:
  - System boundaries and emission assumptions
  - Embodied CO_2 for inputs and machinery
  - Attributing impacts in rotation systems
- Biorefineries standardize GHG accounting for:
  - feedstock transport, electricity use, denaturant, coproducts
- Fuel Adjustment Factor becomes representative of market average
- Creates market for greener biofuels
- Prevents backsliding on climate benefits
- Encourage technological innovation:
  - Demand for low-GHG EtOH creates demand for low-GHG feedstock and production processes

Conclusions

- There is no unique, unqualified answer to the net energy question.
  - The *production process* matters critically.
  - This is not a very useful metric in any case
- Compared to gasoline, corn ethanol today:
  - requires far less petroleum, but
  - has an uncertain and probably a small net GHG effect, and
  - introduces several added environmental problems (e.g. soil erosion).
- Alternative feedstocks/cropping/processing techniques may greatly improve biofuels performance in metrics we care about.
- GHG emissions certification program may be needed
- Air pollution issues need attention
- We're still early in the race for the next transportation fuel(s)
  - Biofuels, hydrogen, and electricity may all play a role

Future research

- Sugar cane, municipal solid waste, and other feedstocks
- Biofuels in plug-in electric hybrids
- Advanced agricultural practices (low-GHG corn)
- Indicators of sustainable biofuels
- Other bioproducts
- Low-GHG ethanol certification
- Effect on petroleum and product markets
- Etc.

Thank you

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