GREET Model and Applications to Bioenergy

Joint Forum on Bioenergy Sustainability and Lifecycle Analysis

Sacramento, CA
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Session 6: Life Cycle Analysis Methods

Discuss the GREET model,

Its Scope and Limitations

Sustainability and Land Use Change

Data Needs and how they are addressed

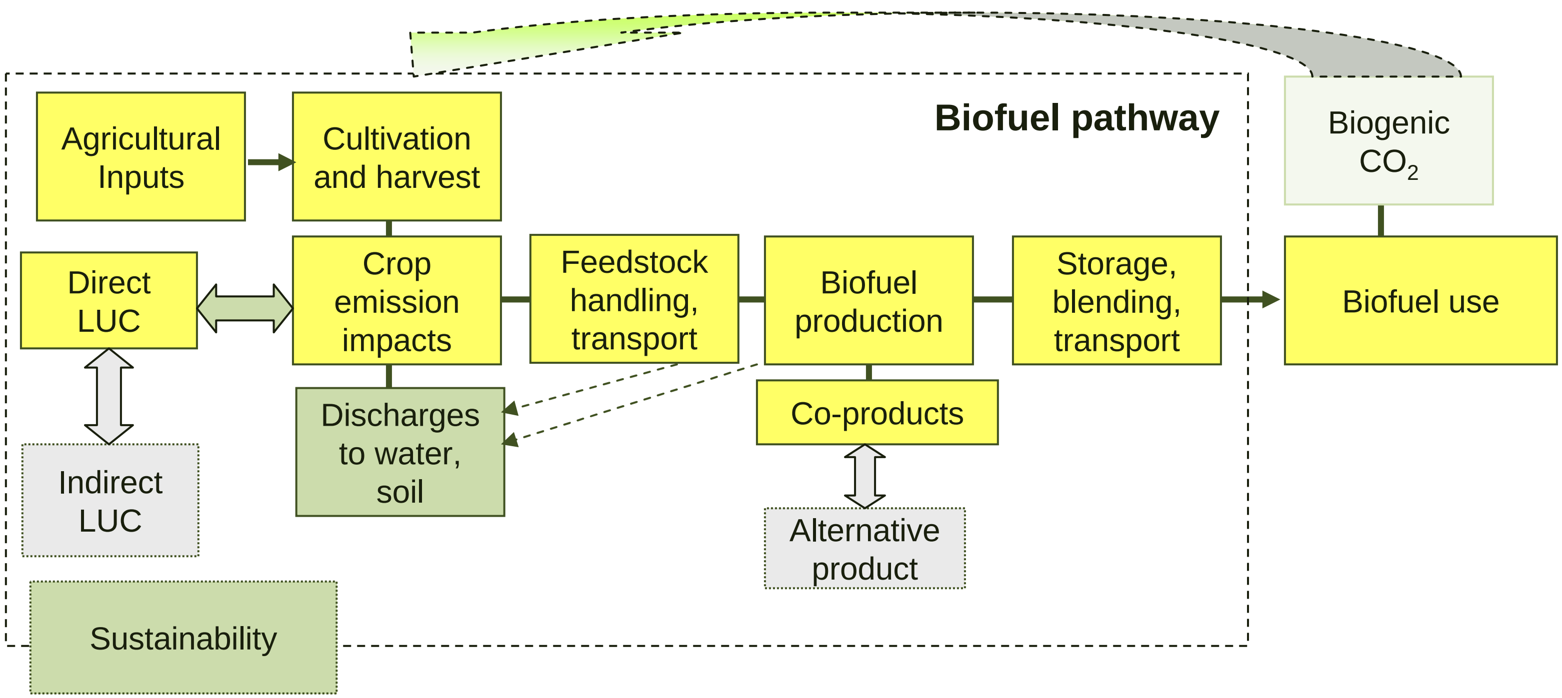
Its use in the Policy Context

And Plans for Future Work

Outline

- Life Cycle Assessment of Fuels
- Fuels Policy Initiatives
- GREET Model
- Scope and Limitations
- Future Work

Life Cycle Analysis of Biofuels



- Follow ISO 14040 methods
- Compare with baseline system with consistent boundary assumptions

Fuel Cycle and Life Cycle Models

- GREET
- LEM
- GHGenius
- Acurex 1996
- LBST E3 Database
- PWC Ecobalance
- SimaPro
- Eco-Invent

Fuel Pathways

Resource

- Crude oil
- Coal
- Natural Gas
- Biomass
  - Cellulose
  - Sugar
  - Algae
- Wind
- Solar
- Nuclear

Fuels

- Conventional Gasoline/Diesel/LPG
- Synthetic Diesel
- CNG, LNG (inc. biogas)
- MTBE/ETBE
- Hydrogen (compressed / liquid)
- Methanol, DME
- Ethanol
- Butanol
- Renewable diesel (FAME, NERD, SVO)
- Electric Power

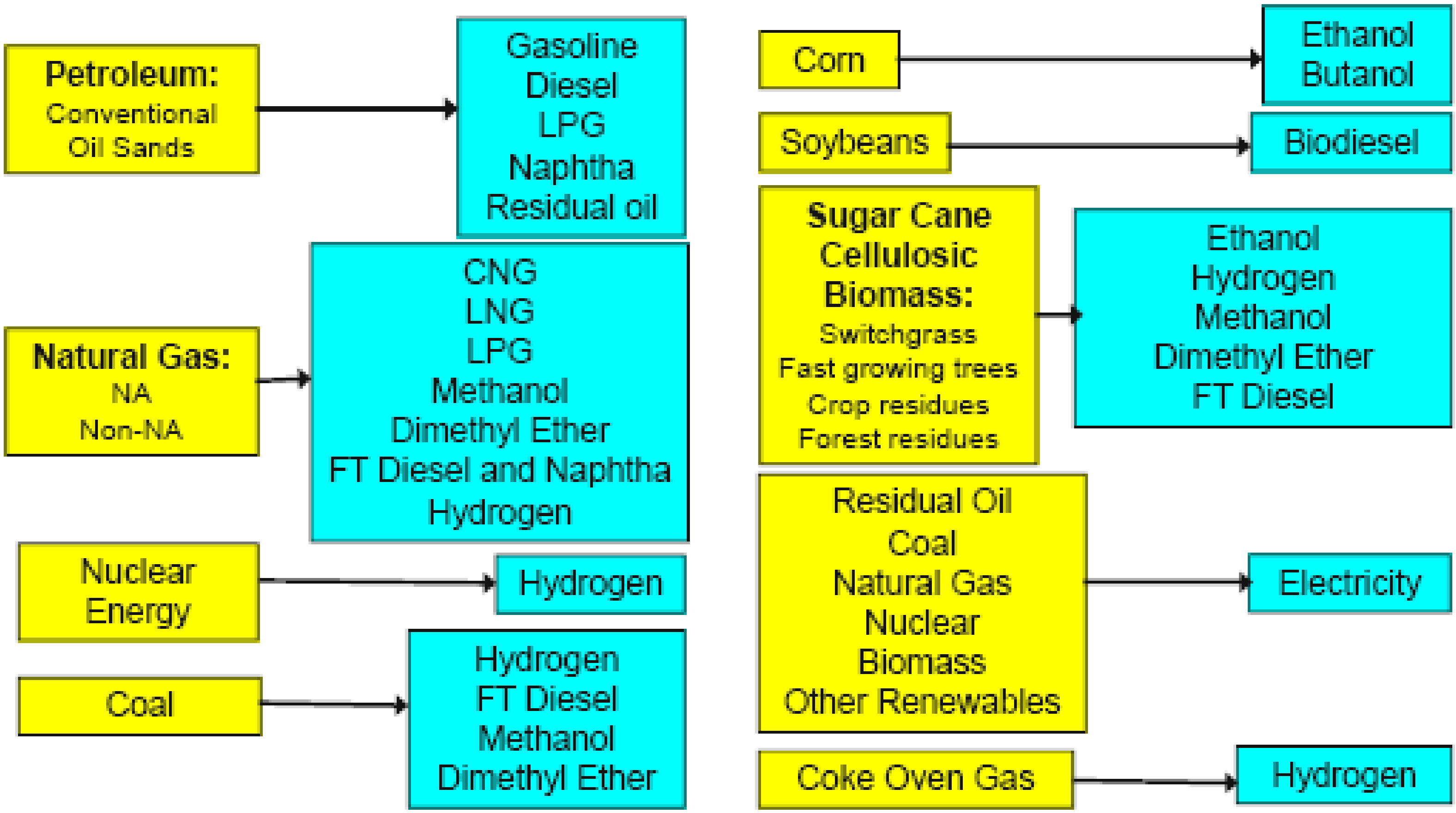
Powertrains

- Spark Ignition: *Gasoline, LPG, CNG, Ethanol, H_2*
- Compression Ignition: *Diesel, DME, Bio-diesel*
- Fuel Cell
- Hybrids: *SI, CI*, FC
- Hybrid Fuel Cell + Reformer

Initiatives Based on WTW Analysis

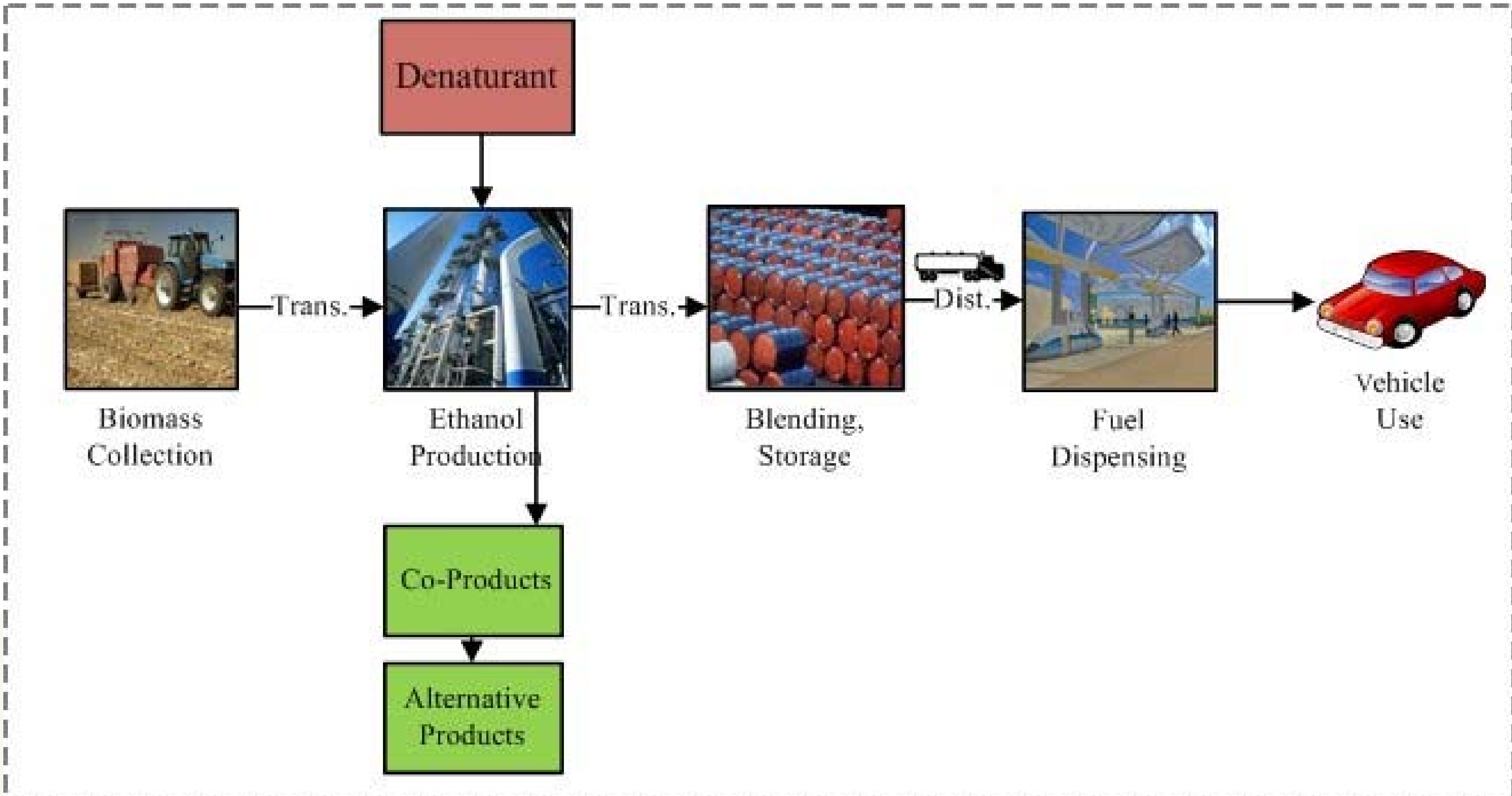
Initiative	**Application**
Low reactivity fuels	Methanol, Alt Fuels
ZEV Program	Battery EVs, Alt Fuels
AB2076	Petroleum Dependency
AB1493	Vehicle CO_2
SB1505	H2 Vehicle Emissions
AB1007	Alt Fuels FFCA
Federal EISA	EtOH, Biofuels GHG Impact
LCFS	Fuels GWI

GREET Pathways

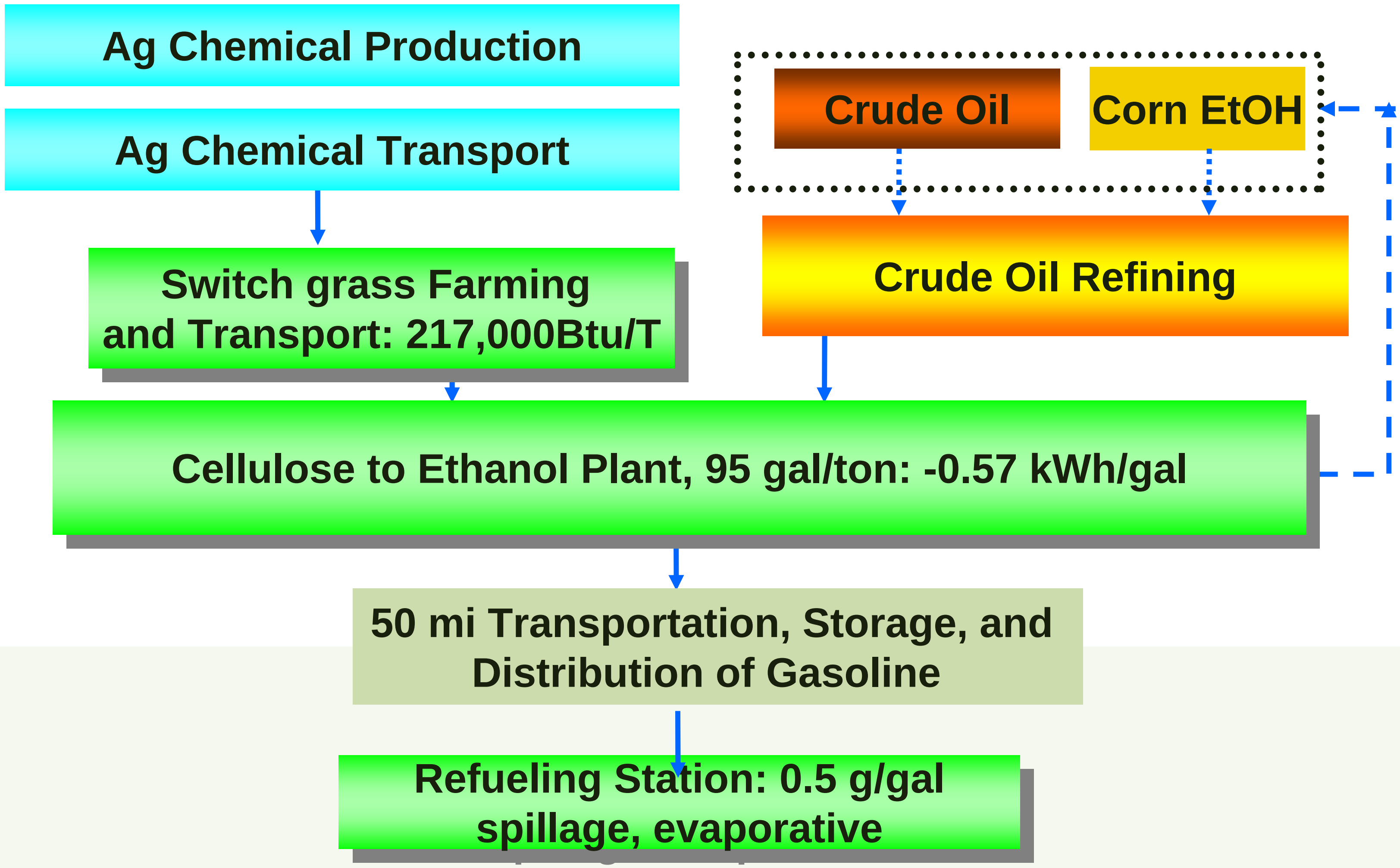


Source: Argonne National Laboratory

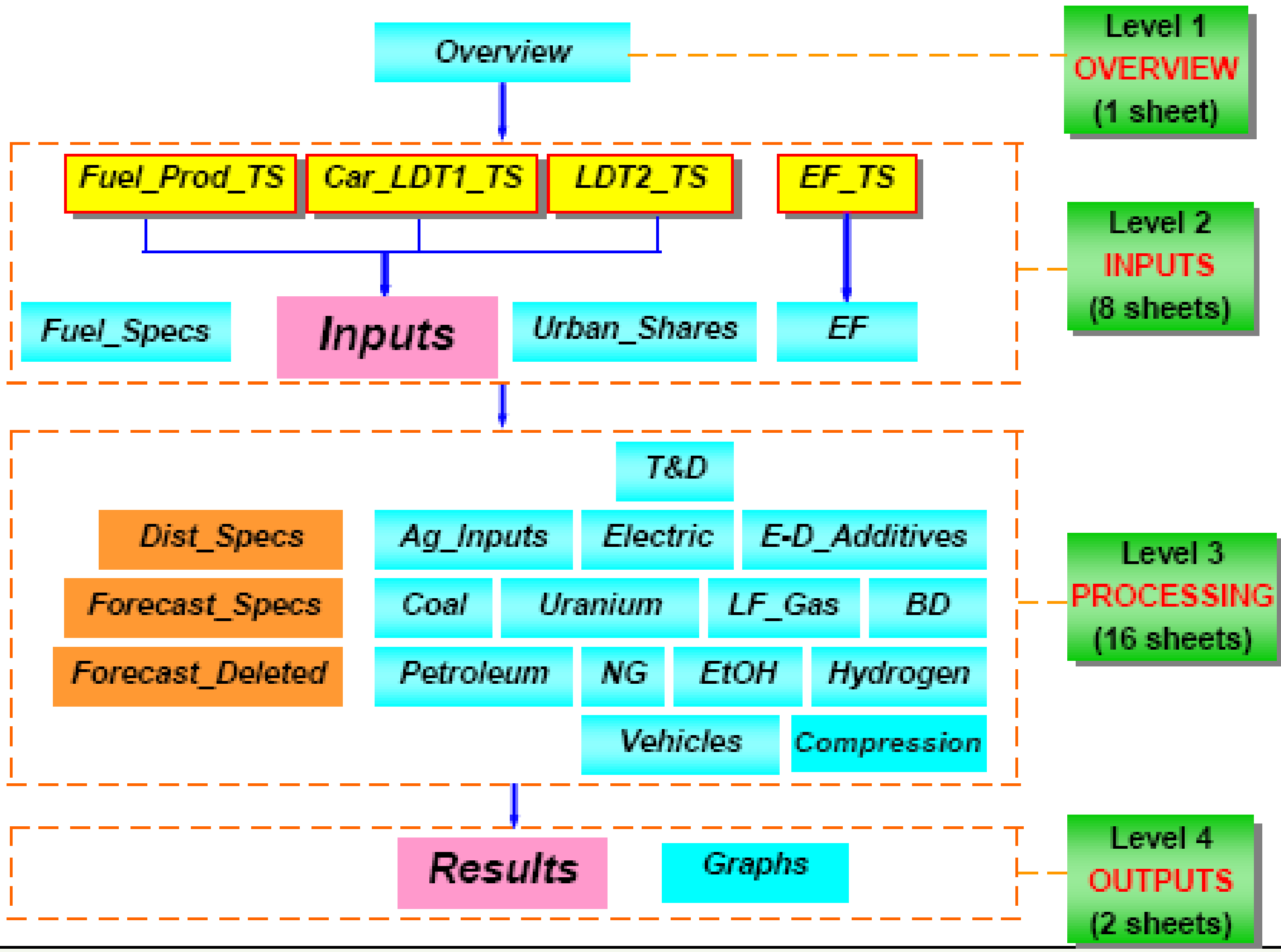
Switch Grass to Ethanol Inputs



Switch Grass to Ethanol Inputs



GREET Model Structure



Source: Argonne National Laboratory

GREET Model Inputs

- EtOH Process Data
  - Inputs
  - Fuel_Prod_TS
  - EtOH
- T&D
- Fuel properties
- Emission factors
- Other fuels

	A	B	C	D	E	F	G	H
196	7.2) Farming Energy Use and Fertilizer use							
197			Corn (per bushel)	Trees (per d.ton)	H. Biomass (per d.ton)	Corn Stover (per d.ton)	Residue (per d.ton)	Cane (per tonne)
198		Farming Energy Use: Btu	22,500	234,770	217,230	235,244	612,700	41,592
199		Fertilizer Use						
200		Grams of Nitrogen	420.0	709.0	10,635	3,175		1091.7
201		Grams of P2O5	149.0	189.0	142.0	1,633		120.8
202		Grams of K2O	174.0	331.0	226.0	8,346		193.6
203		Grams of $CaCO_3$	1202.0	0.0	0.0			5337.7
204		Pesticide Use						
205		Grams of Herbicide	8.10	24.00	28.00	0.00		26.90
206		Grams of Insecticide	0.68	2.00	0.00	0.00		2.21

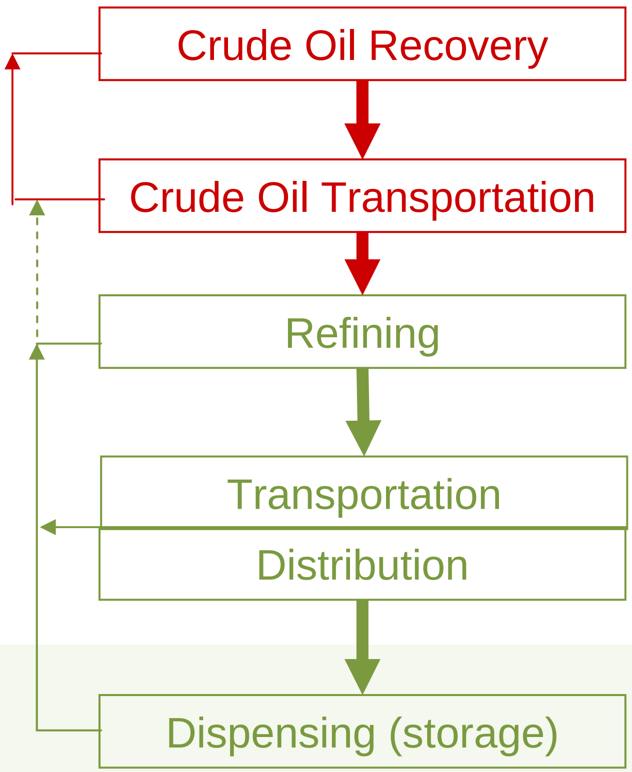
	B	C	D
299	**7.11.b) Ethanol Yield: Gallons per Dry Ton of Biomass**		
300		Fermentation	Gasification
301	Farmed Trees Plant	90.0	87.0
302	Herbaceous Biomass Plant	95.0	91.5
303	Corn Stover Plant	95.0	91.5
304	Forest Residue Plant	92.8	90.4
305	**7.11.c) Amount of Electricity Co-Produced**		
306		Fermentation	Gasification
307	Farmed Trees Plant	-1.145	-1.145
308	Herbaceous Biomass Plant	-0.572	-0.572
309	Corn Stover Plant	-0.572	0.000
310	Forest Residue Plant	-1.145	0.000

87.0

90.0

5-year period	EtOH Yield of Farmed Trees Fermentation EtOH Plant: gal/dry ton	Relative Efficiency (to yr 2010)
1990	82.0	91.1%
1995	83.0	92.2%
2000	84.0	93.3%
2005	85.0	94.4%
2010	90.0	100.0%
2015	95.0	105.6%
2020	100.0	111.1%

GREET Calculations RFG



RFG WTT, $E_{RFG} =$

$$E_C \times LF_D + E_{RFGD}$$

- Crude Oil WTT, EC = $EC_R \times LF_{T\&D} + EC_{T\&D} + EC_S$
- E_{RFGD} = Downstream RFG Blending Component
- LF_D = Downstream Loss Factor
- $E_{RFGD} = E_{RFGRef} \times (LF_{T\&DD} \times LF_{SD}) + E_{T\&DD} + E_{SD}$
- LF = Loss Factor (Delivery Truck, Fuel Station)
- RFG WTT, $E_{RFG} = EC \times LF_D + E_{RFGD}$

GREET Model Calculations

- EtOH Worksheet
  - Switch grass LCI
  - Ethanol plant
  - Electricity co-products
  - T&D, Loss factors
  - EtOH WTT
- Results
  - Average WTT for EtOH and denaturant
  - Calculate vehicle emissions in WTW

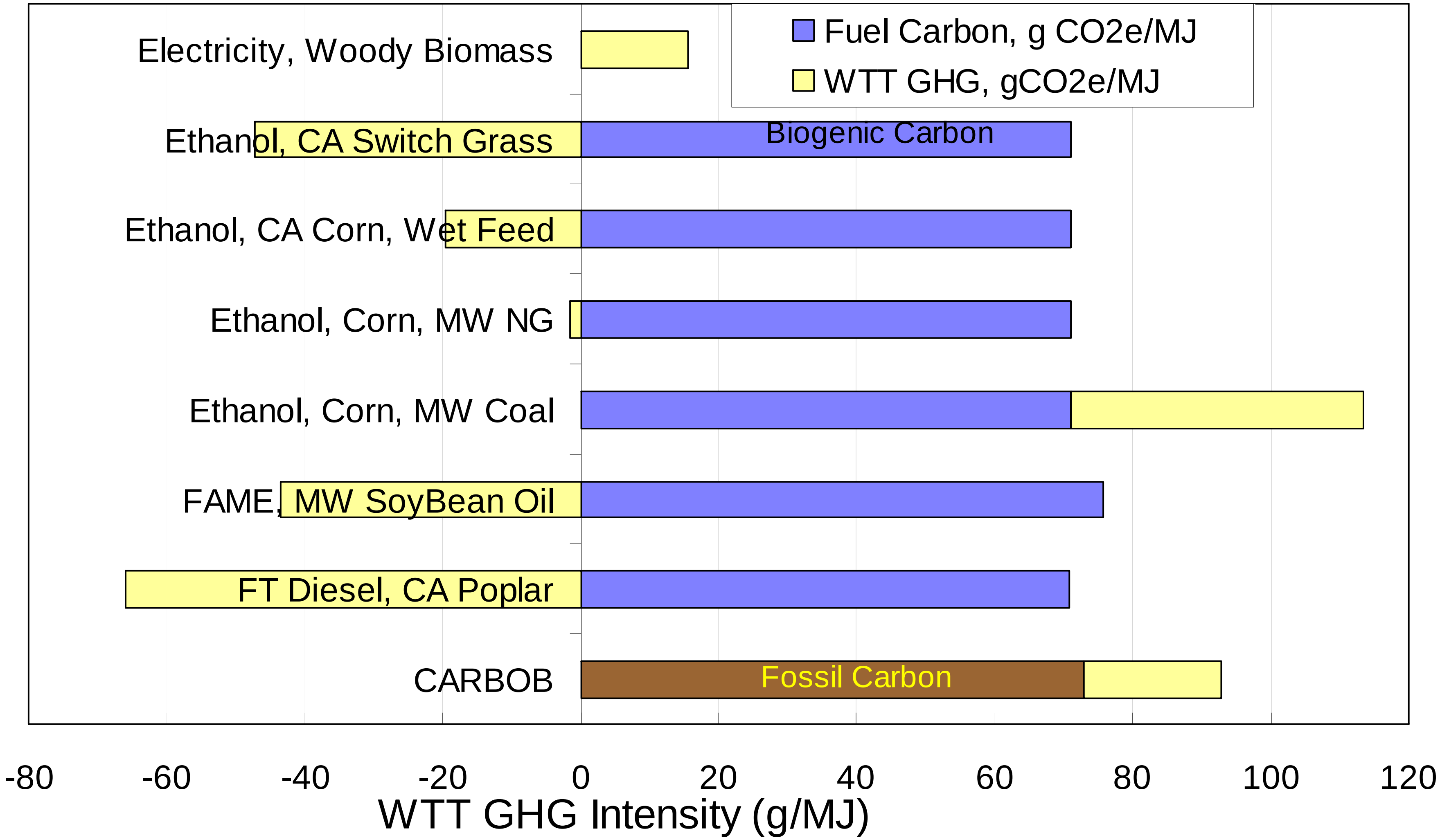
	B	C	AN	AU
142		Corn Farming	H. Biomass Farming	H. Biomass Transportation
143		Btu/bushel	Btu/dry ton	Per dry ton
144	**Production inputs**	22,500	217,230	
145	**Urban emission share**	0.0%	0.0%	
146	**Loss factor**			
147	**Shares of process fuels**			
148	Residual oil	0.0%		
149	Diesel fuel	38.3%	92.8%	
150	Gasoline	12.3%		
151	Natural gas	21.5%	0.0%	
152	Coal	0.0%		
153	Liquefied petroleum gas	18.8%	0.0%	
154	Biomass			
155	Electricity	9.0%	7.2%	
156	Feed loss	0.0%	0.0%	
157	**Energy Use: Btu/mmBtu of fuel throughput, except as noted**	**Per bushel**	**Per dry ton**	
158	Residual oil	0	0	
159	Diesel fuel	8,618	201,589	
160	Gasoline	2,768	0	
161	Natural gas	4,838	0	
162	Coal	0	0	
163	Liquefied petroleum gas	4,230	0	
164	Biomass			
165	Electricity	2,025	15,641	
166	Total energy	30,646	399,606	116,891
167	Fossil fuels	29,419	385,170	116,423
168	Coal	2,236	57,611	1,857
169	Natural gas	12,727	99,009	6,261
170	Petroleum	14,457	228,550	108,305
171	**Total Emissions: grams/mmBtu of fuel throughput, except as noted**	**Per bushel**	**Per dry ton**	
178	CH4	5.348	43.617	10.363
179	N2O	0.053	0.440	0.224
180	CO2	2,154	31,117	9,104
181	CO2 from Land use change	195	-48,500	
182	VOC from bulk terminal			
183	VOC from refueling station			

LUC and Sustainability

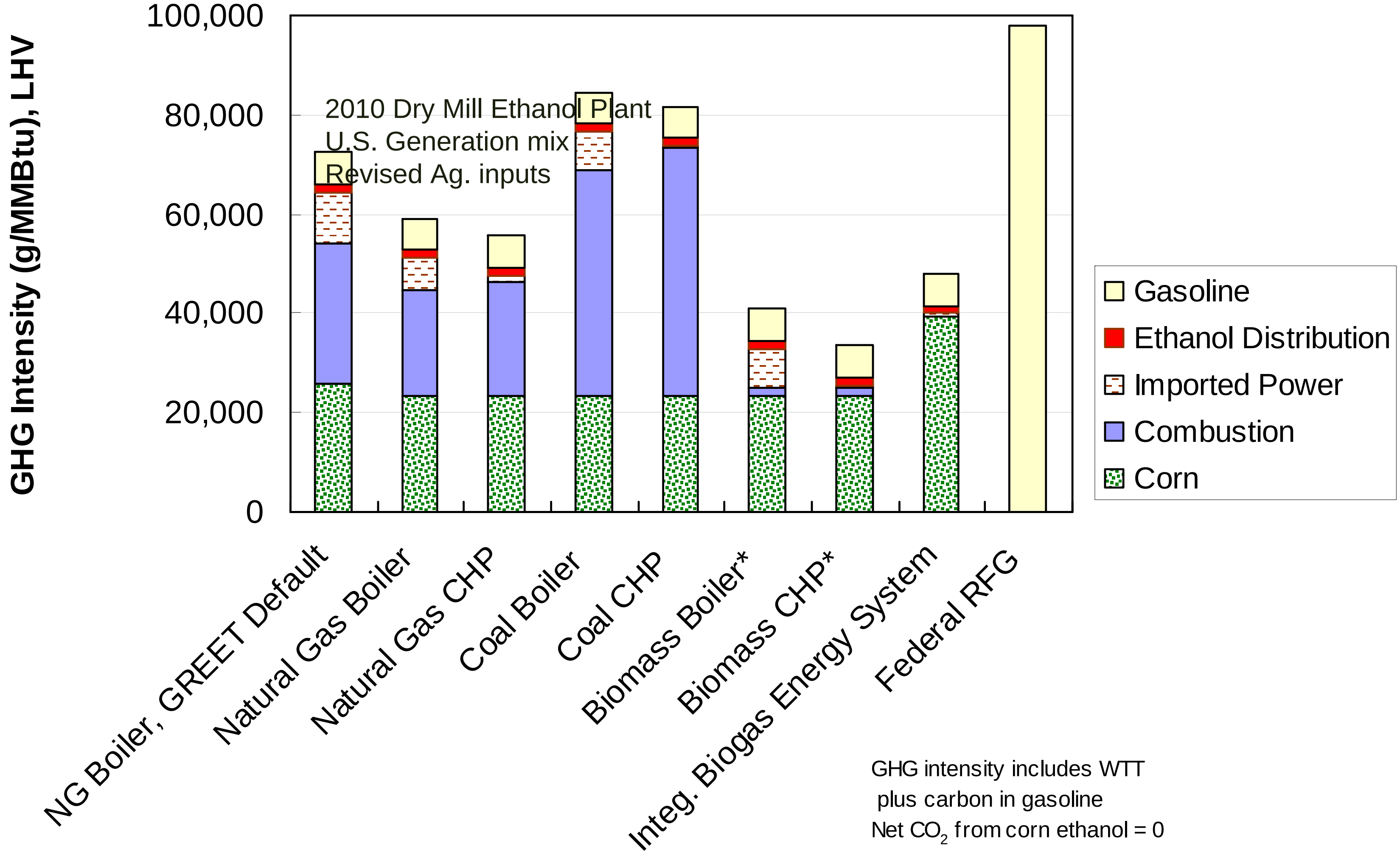
	B	C	D	E	F	G	H
208	**7.3) CO2 Emissions from Potential Land Use Changes of Farming:**						
209		**Corn**	**Farmed Trees**	**Herbaceous Biomass**	**Corn Stover**	**Forest Residue**	**Sugar Cane**
210		**g/bu**	**g/ton**	**g/ton**	**g/ton**	**g/ton**	**g/tonne**
211	Data cells	195	-112,500	-48,500	0	0	0
212	Calculation cells	195	-112,500	-48,500	0	0	0

- LUC in GREET
  - Exogenous value
  - Existing inputs based on old studies
  - System boundaries?
  - Global market mitigated effects?
- Sustainability?
  - Multi attributes

WTT GHG Emissions + Fuel



Various Results for Corn Ethanol



Source: Mueller, S and Unnasch, S. (2007). "An Analysis of the Projected Global Warming Impact of Corn Ethanol Production (Years 2010-2030)"; Report prepared for the Illinois Corn Marketing Board. Results based on GREET 1.7 with Life Cycle Associates building block WTT model

Limitations of GREET Model

- Documentation
- Model Availability
- U.S. Average Inputs
  - Average electricity mix, crude oil, other resource mix
  - Average pathway
- Regional Issues
  - Air quality regulations
  - Urban grouping vs. U.S., Non Attainment Area, etc
- Toxics
- Land Use Change

Limitations and Data Needs

- Documentation $
- Model Availability ✓
- ~~U.S. Average Inputs~~
    - ~~Average electricity mix, crude oil, other resource mix~~
    - ~~Average pathway~~
- ~~Regional Issues~~
    - ~~Air quality regulations~~
    - ~~Urban grouping vs. U.S., Non Attainment Area, etc~~
- Toxics
- Land Use Change

Biofuel Feedstocks

- Sugar Cane
- Corn
- Sugar Beets
- Sorghum, Milo
- Soybean oil
- Canola, Mustard

Non Food Feedstocks

- Hybrid Trees
- Switch grass, Prairie, Cane
- Forest thinnings
- Ag residue
- Sewage Sludge
- MSW
- Algae
- Land Fill Gas
- Digester Gas


Data Needs

- New pathways
  - Today's biomass
    - Urban wood waste, MSW
    - Ag Residue, Rice straw
  - Mixed crop systems
    - Corn/grasses
    - Oilseed cover crop
    - Bermuda grass
  - Advanced biofuels
  - Co-product scenarios
- Data improvements
  - Process specific energy use
  - Process specific emission factors

Process Specific Analysis

- User interface
- Regional specific
- Process inputs
- Composite model runs

Corn Ethanol

Corn Production

General			
Target year	2,010		
Corn farming energy (Btu/bu)	18,700		
Chemical Inputs (Fertilizer, Herbicide, Insecticide)		International Production Share	Ocean Tanker (mi)
N input (g/bu)	420.0		
Ammonia	70.7%	60.0%	3,000
Urea	21.1%	60.0%	5,200
Ammonium nitrate	8.2%	60.0%	3,700

Corn Transport

Corn Stack to Ethanol Plant		
Barge (mi)	200	0.0%
Rail (mi)	200	0.0%
Heavy duty truck (mi)	40	100.0%

Ethanol Plant

Plant type	Dry Mill
Dry Mill Inputs	Dry Mill
Process fuel types:	NG, Coal or Biomass
Thermal energy for NG, coal, biomass (Btu/gal), LHV	32,000
Dry Mill Ethanol Plant Thermal Energy Shares:	
Natural gas	100.0%
Coal	0.0%
Biomass	0.0%
Biomass type shares	
Herbaceous biomass	0.0%
Corn stover	0.0%
Net electricity (kWh/gal)	0.75
EtOH yield (denatured, gal/bu)	2.80
DGS yield (lb/gal denatured EtOH)	6.40
DGS co-product displacement ratios	
DGS displacing feed corn (lb/lb co-prod.)	0.5
DGS displacing soybean meal (lb/lb co-prod.)	0.5
% of co-products used for new cattle production	15.1%

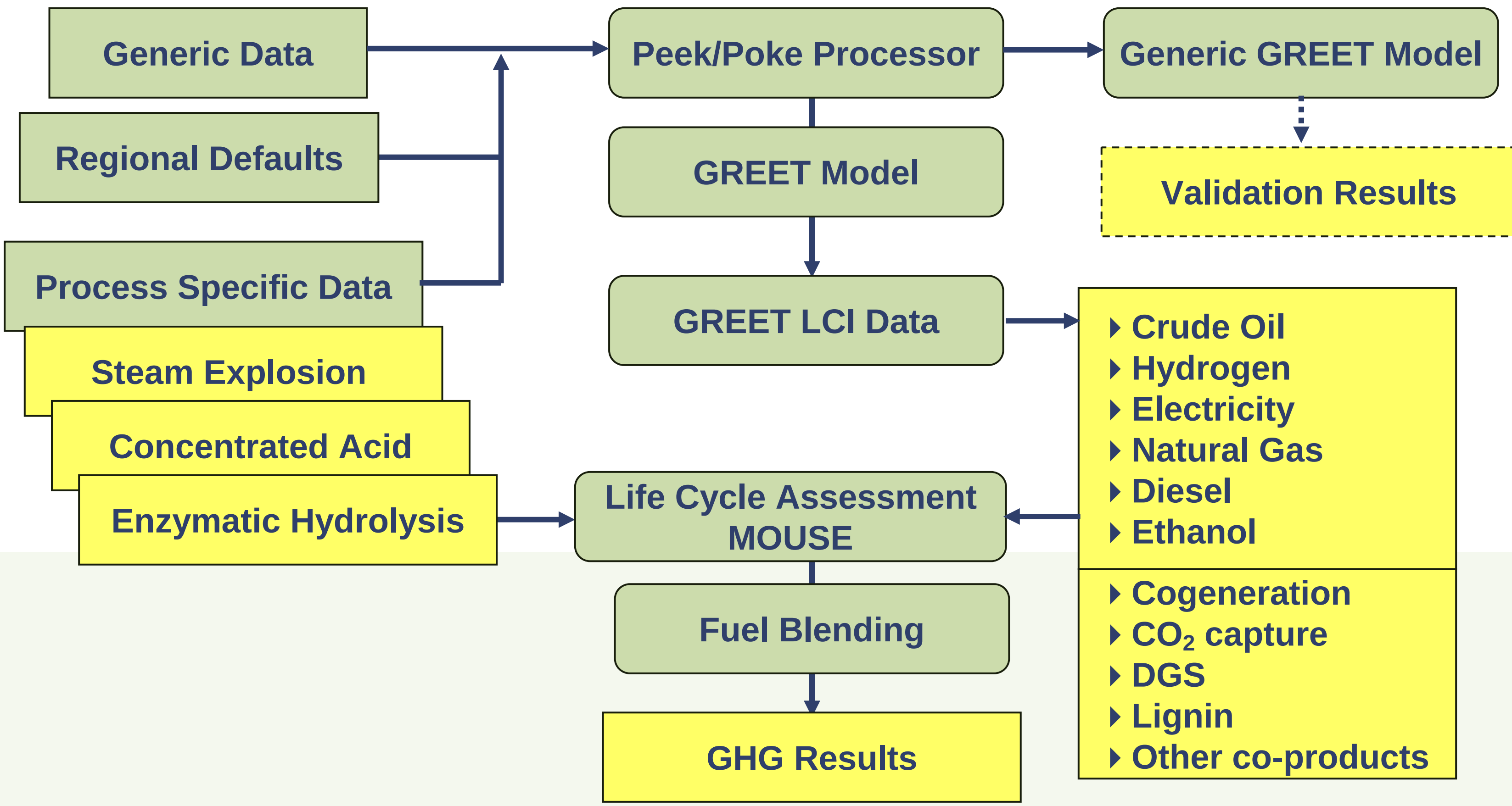
Denaturant

Denaturant type	Conv. Gasoline
Percent denaturant (vol)	4.8%
Denaturant heavy duty truck transport distance (mi)	100

Transport & Distribution

Ethanol Plant to Bulk Terminal		
Barge (mi)	0	0.0%
Pipeline (mi)	0	0.0%
Rail (mi)	1,400	100.0%
Heavy duty truck (mi)	50	0.0%
Bulk Terminal to Refueling Station		
Heavy duty truck to fuel station (mi)	50	100.0%

Modeling Approach



Outlook for GREET

- User base growing to over 5000
- New Features from ANL
  - Water consumption
  - New pathways
- Support CA LCFS
  - RFG, ULSD, Corn EtOH, CNG, Electricity, Soy BD
  - Document fuel pathways
  - More pathways, H2, cellulose EtOH, etc.
- Incorporate LUC
  - ANL and UCB effort with Purdue and GTAP
  - Other approaches