Case Simulation and Users Q&A: Ground Transportation Fuels

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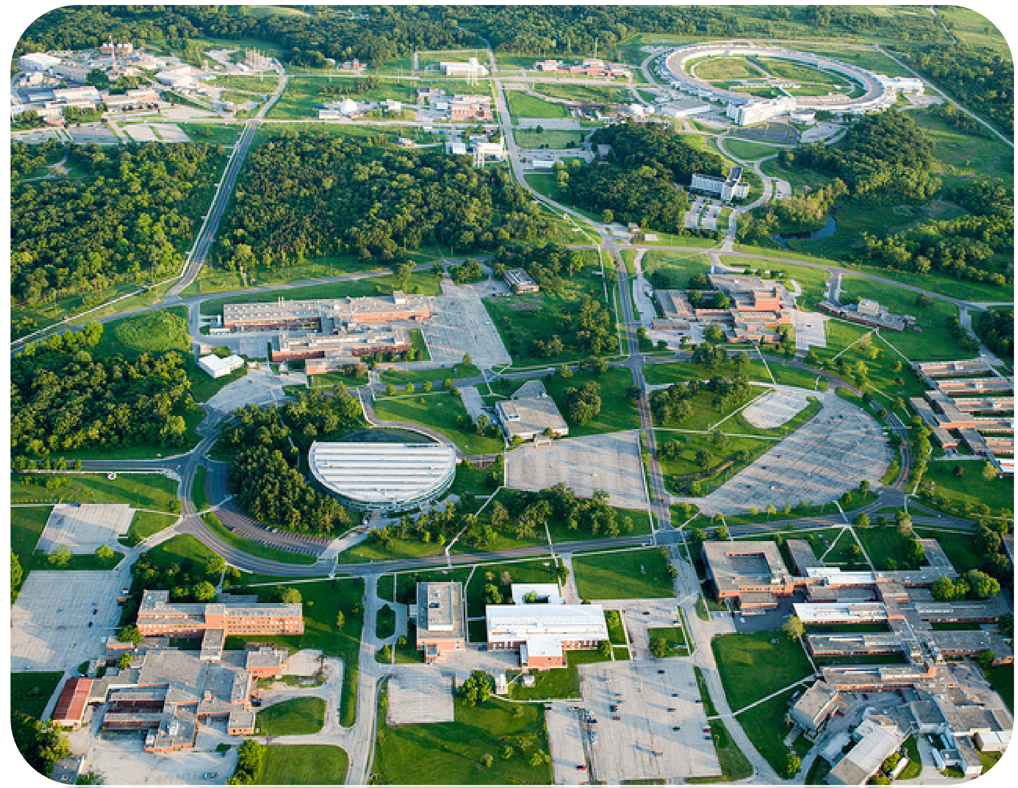
Systems Assessment Group

Center for Transportation Research

Argonne National Laboratory



The GREET Training Workshop

Washington, DC, Jan. 31, 2012

Case Simulation and Users Q&A:
Petroleum and Natural Gas Pathways

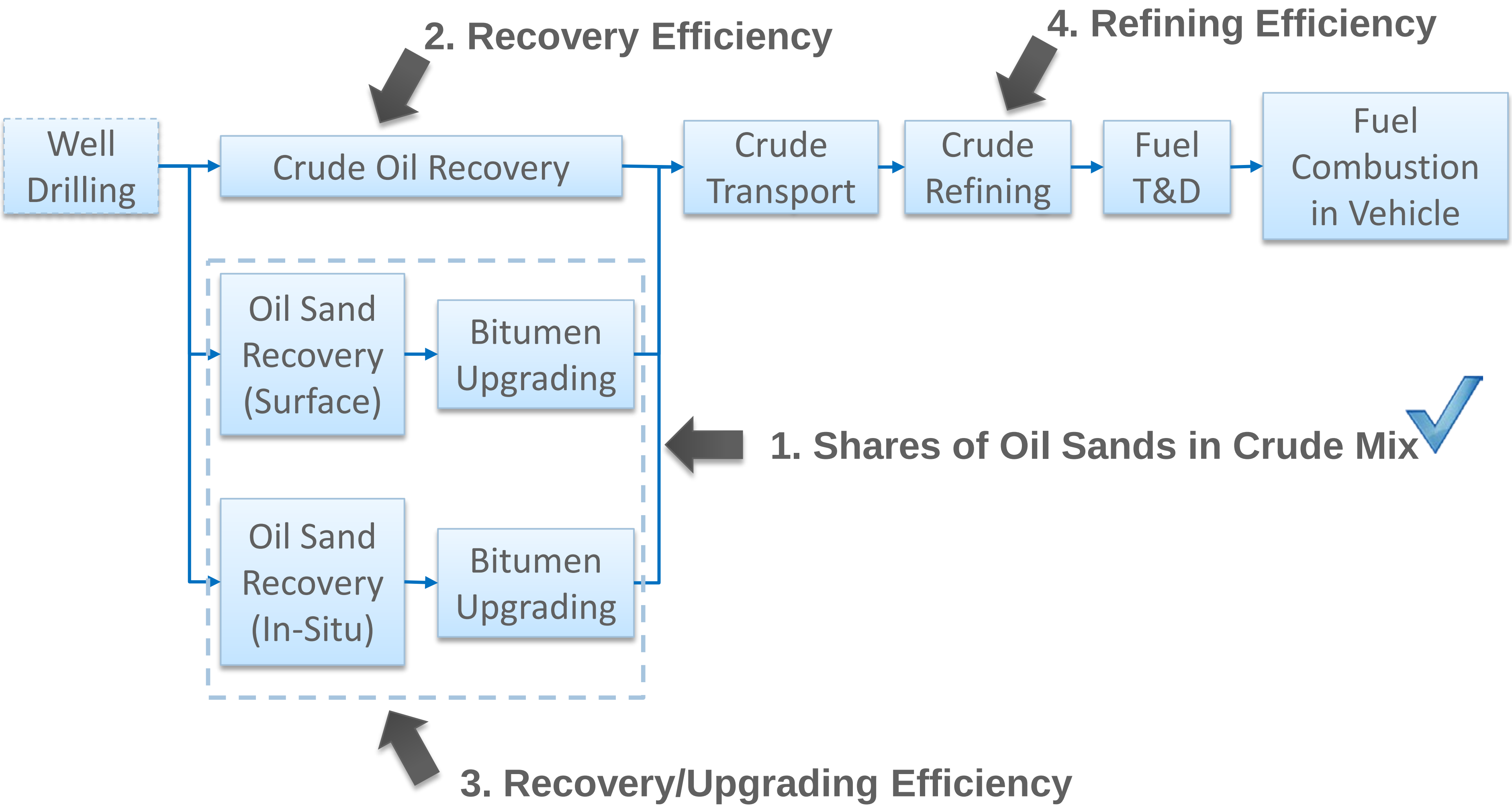
Supporting Documents for Petroleum and Natural Gas Pathways : Journal Article, Technical Report and Technical Memo

1. Burnham, A., J. Han, C. E. Clark, M. Wang, J. B. Dunn, and I. Palou-Rivera. "Life-Cycle Greenhouse Gas Emissions of Shale Gas, Natural Gas, Coal, and Petroleum." *Environmental Science Technology* 46, no. 2 (2011): 619-627. http://pubs.acs.org/doi/abs/10.1021/es201942m

2. Han, J., M. Mintz, M. Wang. *Waste-to-Wheel Analysis of Anaerobic-Digestion-Based Renewable Natural Gas Pathways with the GREET Model*. Argonne, IL: Argonne National Laboratory, 2011 http://greet.es.anl.gov/publication-waste-to-wheel-analysis

3. Palou-Rivera, I., J. Han and M. Wang. *Updated Estimation of Energy Efficiencies of U.S. Petroleum Refineries*. Argonne, IL: Argonne National Laboratory, 2011. http://greet.es.anl.gov/publication-petroleum

System Boundary and Key Parameters of Petroleum Pathways



System Boundary and Key Parameters of Natural Gas Pathways

- ✓ Share of conventional and shale gas in the U.S. NG mix
- Methane emissions from
  - Well completion and workover
  - Liquid unloading
  - Well equipment
  - NG transmission and distribution
- NG recovery efficiency
- NG processing efficiency

Significant Uncertainty in Methane Emissions

Key Parameters on per-well-basis
Uncontrolled methane emissions from well completion, workover and liquid unloading

÷

Estimated ultimate recovery (EUR)

×

Occurrence during well lifetime

×

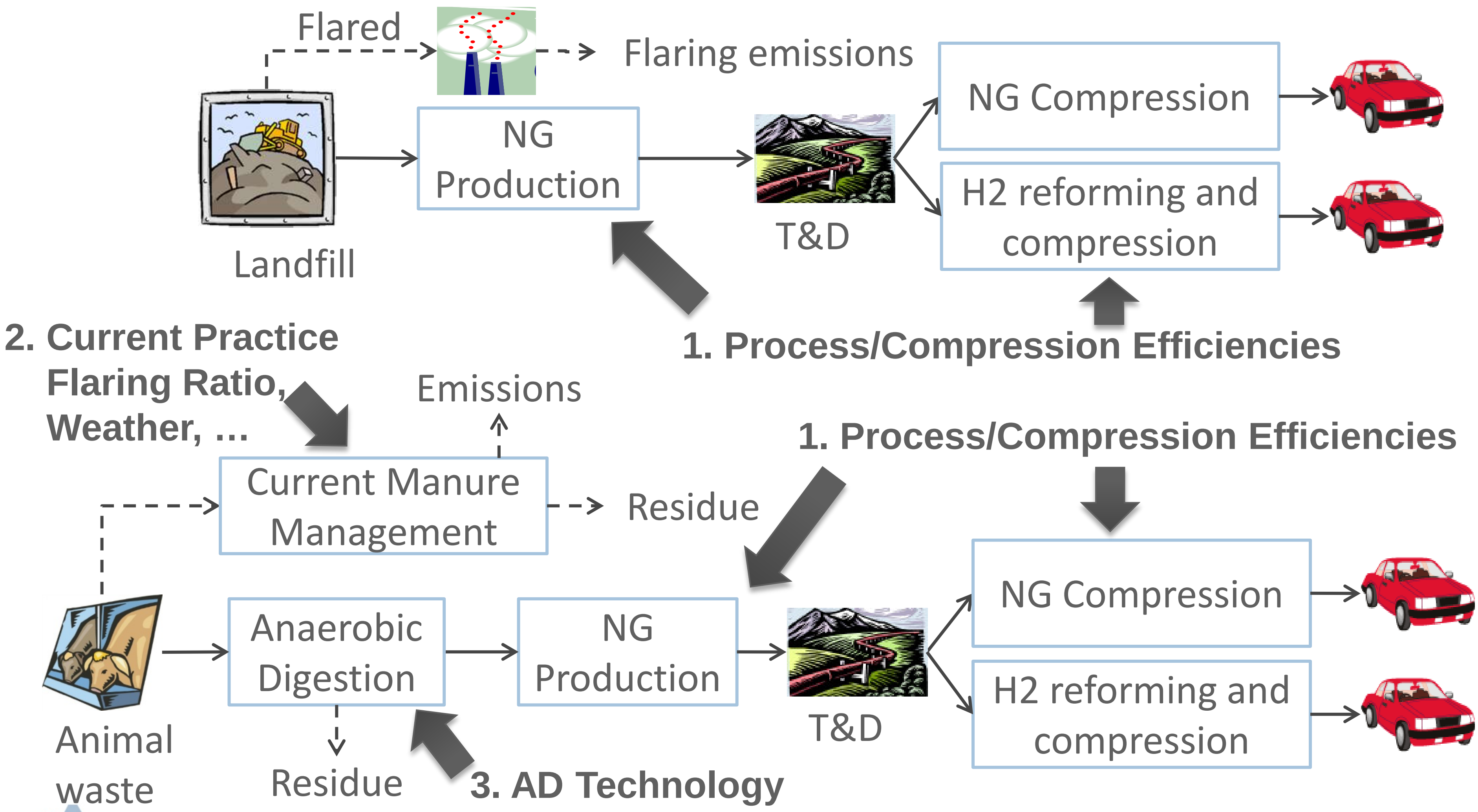
% of vented CH_4 after recovery and flaring

=

Key Parameters on per-mmBtu-basis
Controlled methane emissions from well completion, workover and liquid unloading

Argonne has Examined Renewable Natural Gas From Landfills and Anaerobic Digesters

(RNG-based CNG and gaseous H_2 shown as example)

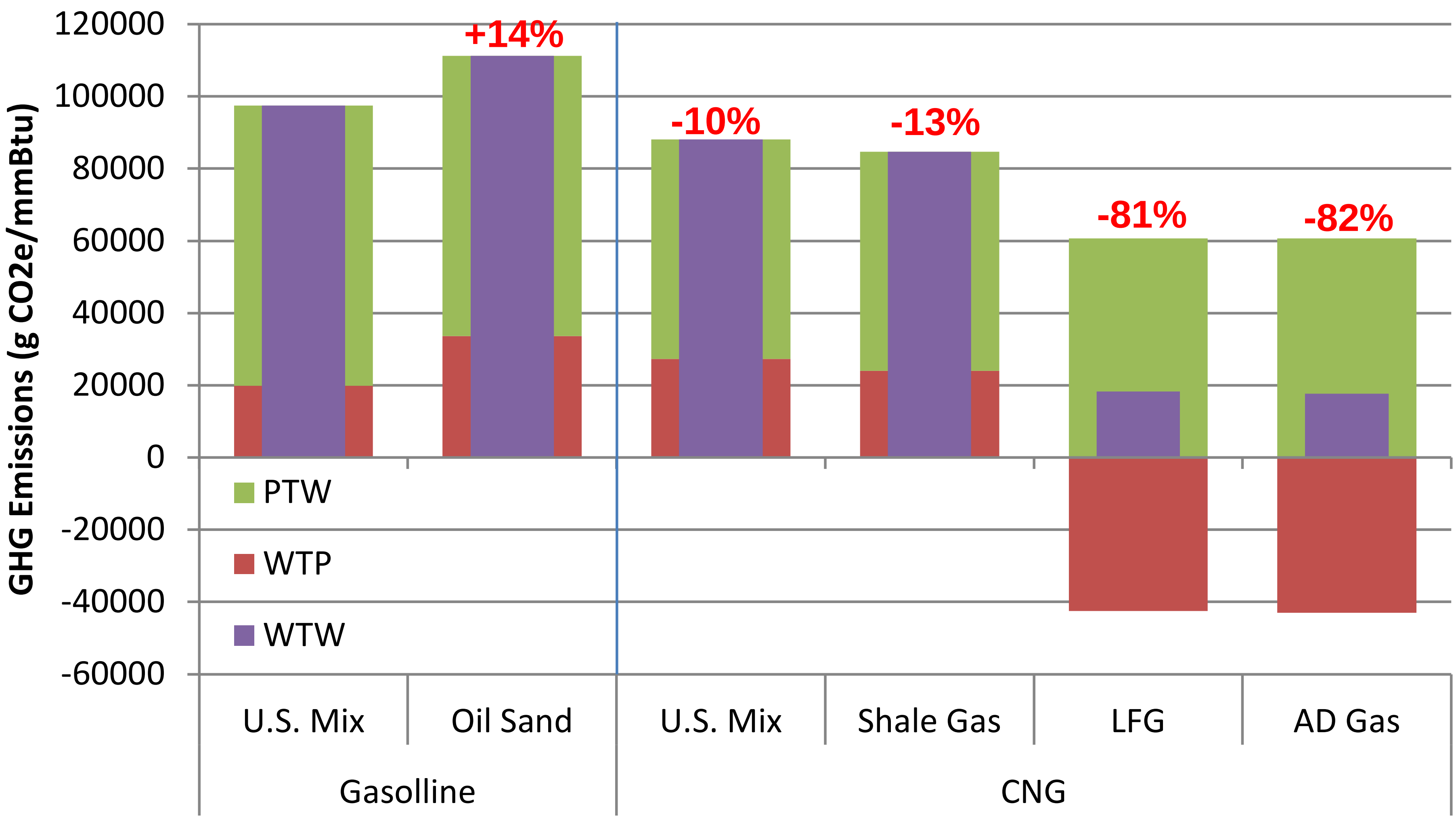


Demo

Case No.	Fuel	Share of Oil Sands Products in Crude Oil Blend	NG Feedstock[a]	Share of Shale Gas in Natural Gas Supply	Share of LFG for RNG	
1	U.S. average gasoline and NG	9.4%	1	22.6%	100%	**Default**
2	Gasoline from oil sands	**100.0%**	1	22.6%	100%	
3	Shale gas	9.4%	1	**100%**	100%	
4	Landfill Gas	9.4%	**4**	22.6%	100%	
5	AD Gas	9.4%	**4**	22.6%	**0%**	

[a] 1:North America Natural Gas; 4: Renewable Natural Gas

Demo Results



Reduction in GHG emissions relative to gasoline

Case Simulation and Users Q&A:
Electricity Generation

Outline

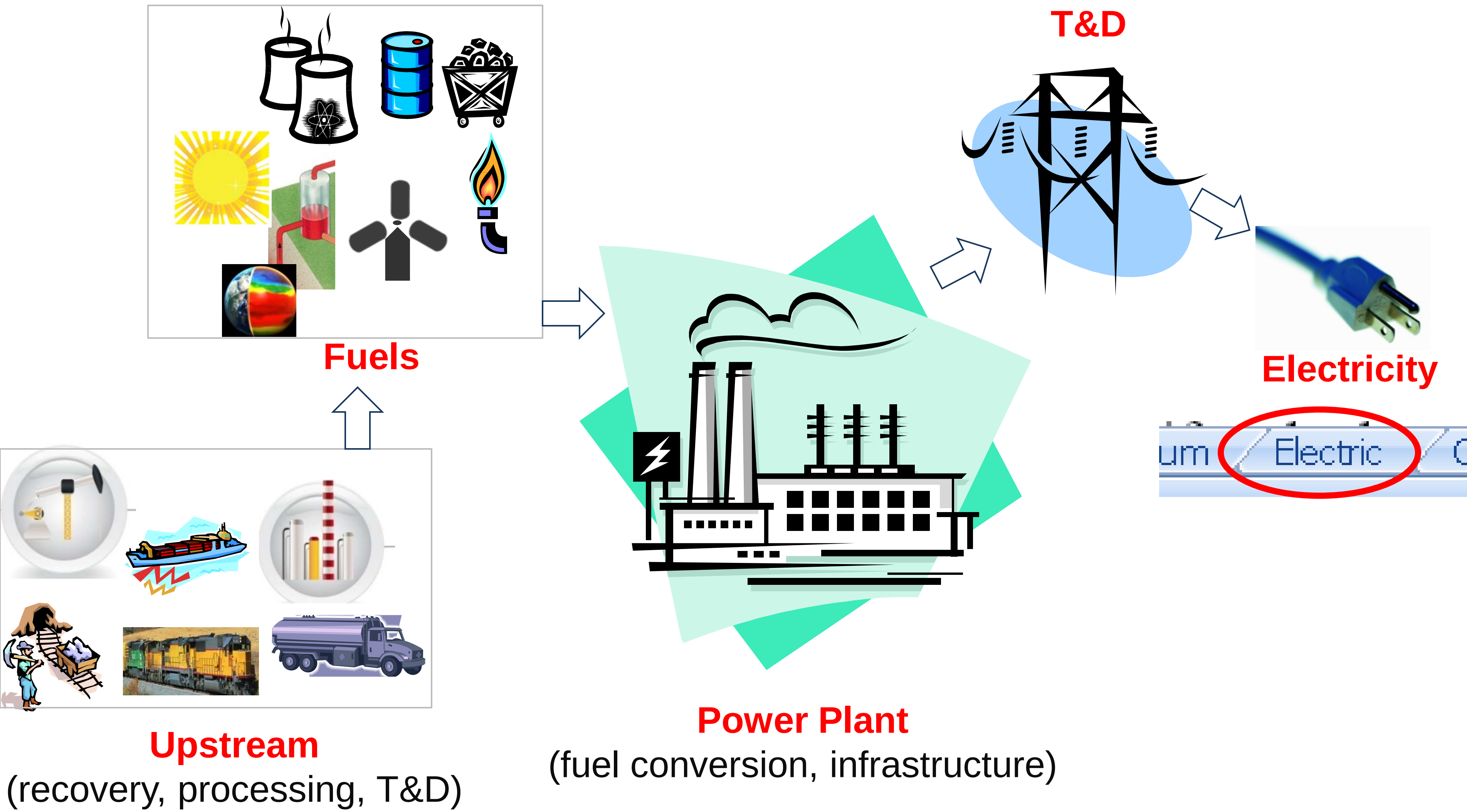
- Electricity generation (fuel cycle)
- Electricity generation (infrastructure)

Supporting Document: Journal Article and Technical Reports

A. Elgowainy, J. Han, L. Poch, M. Wang, A. Vyas, M. Mahalik, A. Rousseau, 2010, "Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Plug-In Hybrid Electric Vehicles," http://greet.es.anl.gov/publication-xkdaqgyk

J. Sullivan, C. Clark, J. Han, M. Wang, 2010, "Life-Cycle Analysis Results of Geothermal Systems in Comparison to Other Power Systems," http://greet.es.anl.gov/publication-geothermal_and_other_power

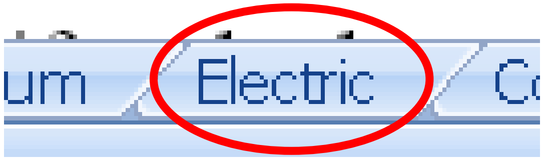
Electricity Generation LCA Key Stages:



Electricity Generation Technology Mix:

- ❑ By fuel and technology
  - ➢ NG: steam, simple combustion, CC
  - ➢ Coal: steam, IGCC
  - ➢ Nuclear: LWR
  - ➢ Oil: steam cycle
  - ➢ Biomass: steam, IGCC
  - ➢ Renewable: geothermal, wind, solar, hydro
- ❑ By region
  - ➢ U.S. average
  - ➢ California
  - ➢ Northeastern
  - ➢ User defined (specific)
- ❑ By application
  - ➢ Stationary applications (process use)
  - ➢ Transportation (marginal) applications (e.g., EVs)

Electricity



Electric sheet in GREET

9.2) Electricity Generation Mix

9.2.a) Selection of Electricity Generation Mix for Transportation Use

Mix for transportation use	1	1 -- U.S. Mix	4 -- User Defined Mix	7 -- Nuclear Power Plants (transportation only)
Mix for stationary use	1	2 -- NE U.S. Mix	5 -- NG Power Plants (transportation only)	8 -- Hydro Power Plants (transportation only)
		3 -- CA Mix	6 -- Coal Power Plants (transportation only)	9 -- NGCC Turbine (transportation only)

Conventional Electricity Generation Systems

1. Coal: Steam Boiler and IGCC
Coal mining & cleaning
Coal transportation
Power generation

2. Natural Gas: Steam boiler, Gas Turbine, and NGCC
NG recovery & processing
NG transportation
Power generation

3. Nuclear: light water reactor
Uranium mining
Yellowcake conversion
Enrichment
Fuel rod fabrication
Power generation

4. Petroleum: Steam Boiler
Oil recovery & transportation
Refining
Residual fuel oil transportation
Power generation

5. Biomass: Steam Boiler
Biomass farming & harvesting
Biomass transportation
Power generation

6. Hydro-Power

7. Wind Turbine

8. Solar PV and CSP

9. Geothermal

Electricity Generation Technology Mix:

GREET uses EIA projections for future generation mixes in different regions (AEO 2011)

U.S. Mix: Stationary Use

5-year period	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Others
	1.0%	22.9%	46.4%	20.3%	0.2%	9.2%
1990	4.2%	12.3%	52.5%	19.0%	1.1%	10.9%
1995	2.2%	14.8%	51.0%	20.1%	1.2%	10.7%
2000	2.9%	15.8%	51.7%	19.8%	1.1%	8.7%
2005	2.9%	15.7%	51.7%	20.3%	1.2%	8.2%
2010	**1.0%**	**22.9%**	**46.4%**	**20.3%**	**0.2%**	**9.2%**
2015	0.9%	21.5%	44.2%	21.0%	0.5%	11.8%
2020	0.9%	20.2%	45.1%	21.1%	0.9%	11.7%

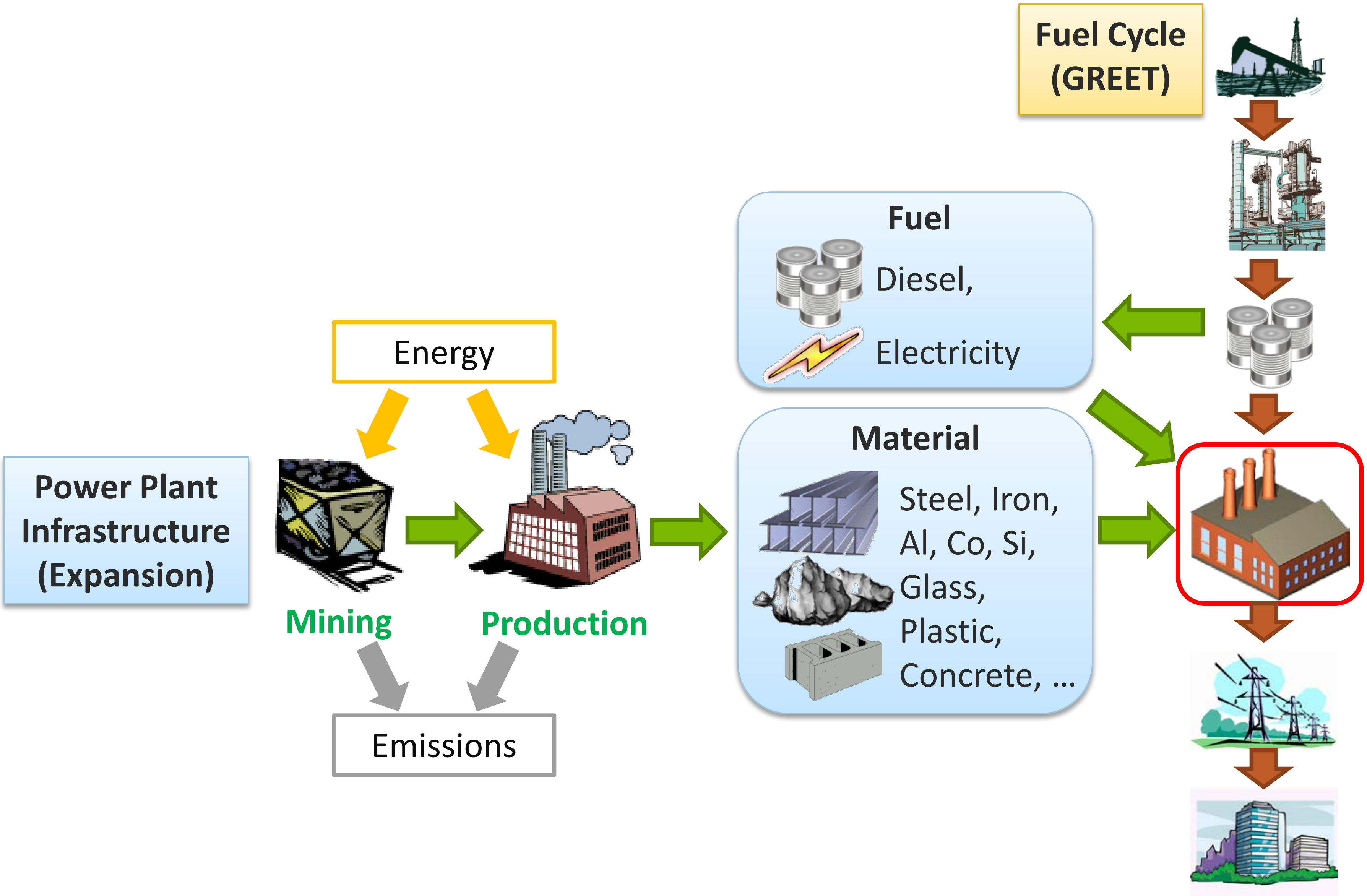
CA Mix: Stationary Use

5-year period	Residual Oil	Natural Gas	Coal	Nuclear	Biomass	Others
	0.0%	41.0%	8.1%	23.1%	0.9%	26.8%
1990	2.3%	40.0%	11.2%	19.2%	1.6%	25.7%
1995	0.2%	37.5%	8.6%	17.3%	1.6%	34.8%
2000	0.2%	42.1%	14.5%	17.1%	1.6%	24.5%
2005	0.8%	35.2%	15.9%	21.5%	1.6%	25.0%
2010	**0.0%**	**41.0%**	**8.1%**	**23.1%**	**0.9%**	**26.8%**
2015	0.0%	37.4%	7.5%	22.5%	0.5%	32.2%
2020	0.0%	36.2%	7.6%	21.4%	1.4%	33.3%

LCA of Power Plants

John Sullivan
ANL

GREET Expansion for Power Plant Infrastructure



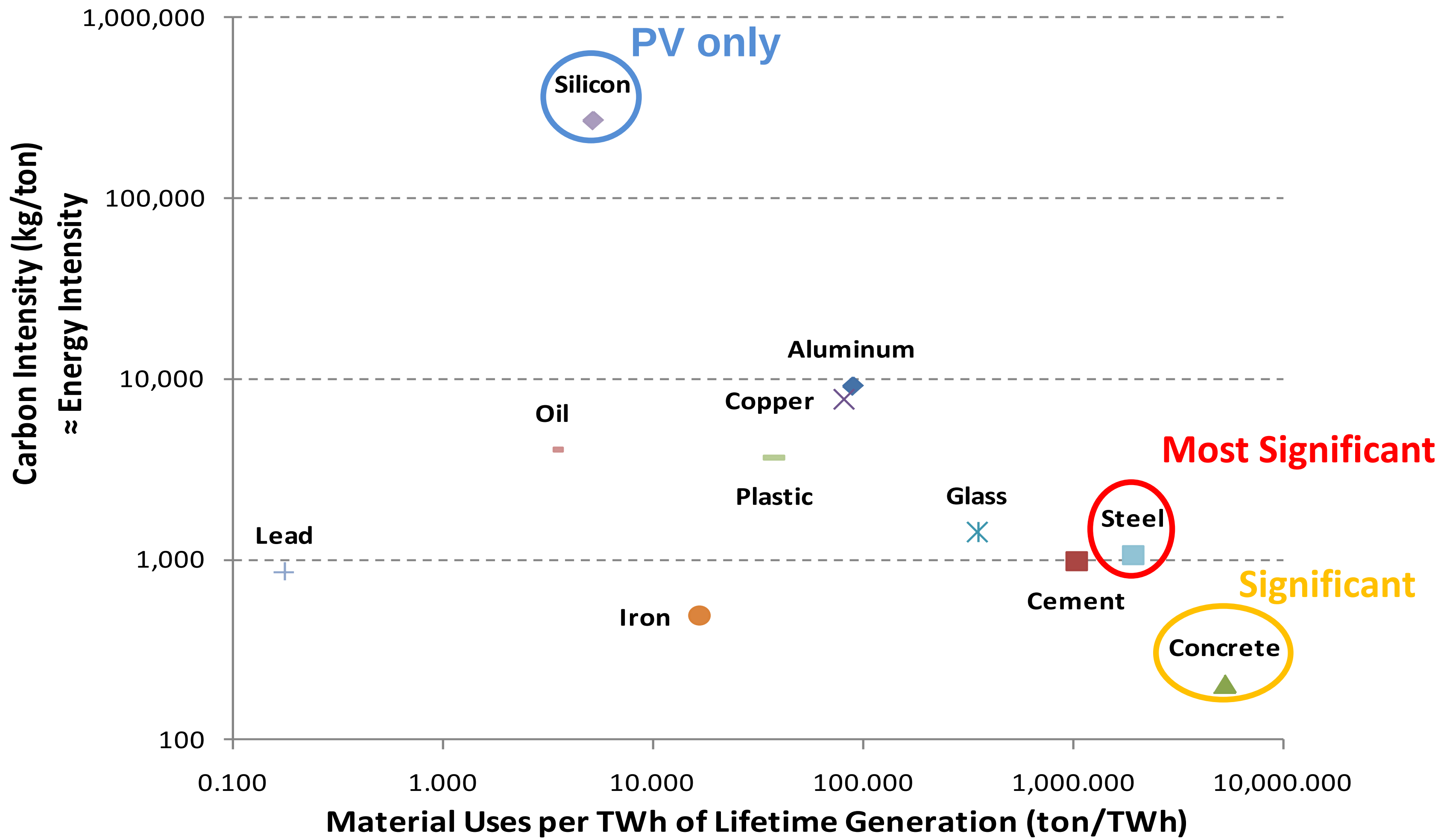
Three Steps

1. Power plant activities:
   - Gather power plant infrastructure data for all power plant types (geothermal, coal, solar, etc.) including:
     - Plant and equipment material composition
       - ✓ For geothermal power, this includes the well
     - Develop material to power ratios (MPRs)
     - Construction energy (diesel for excavators, cranes) added where data available
   - Fuel conversion to electricity – data based on GREET

2. Fuel Production (e.g. drilling and delivering geothermal fluid, oil, gas, etc.):
   - For most fuels, it is well characterized in GREET
   - For geothermal well infrastructure, gather data on material composition, drilling energy and water requirements.
     - Conduct for binary, flash technologies, and co-produced geopressured gas/electricity

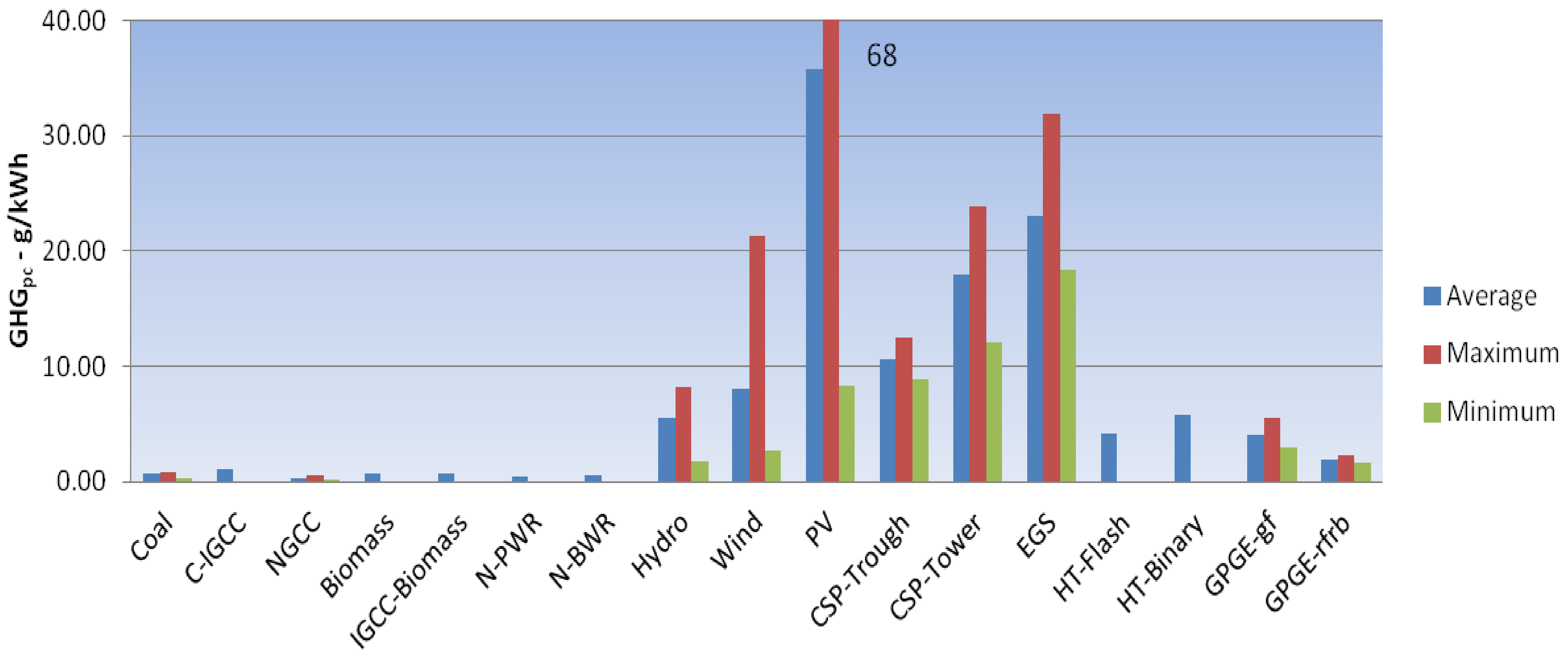
3. Integrate infrastructure and fuel information into GREET for plant modeling

Impact of Materials on Life Cycle Analysis Results

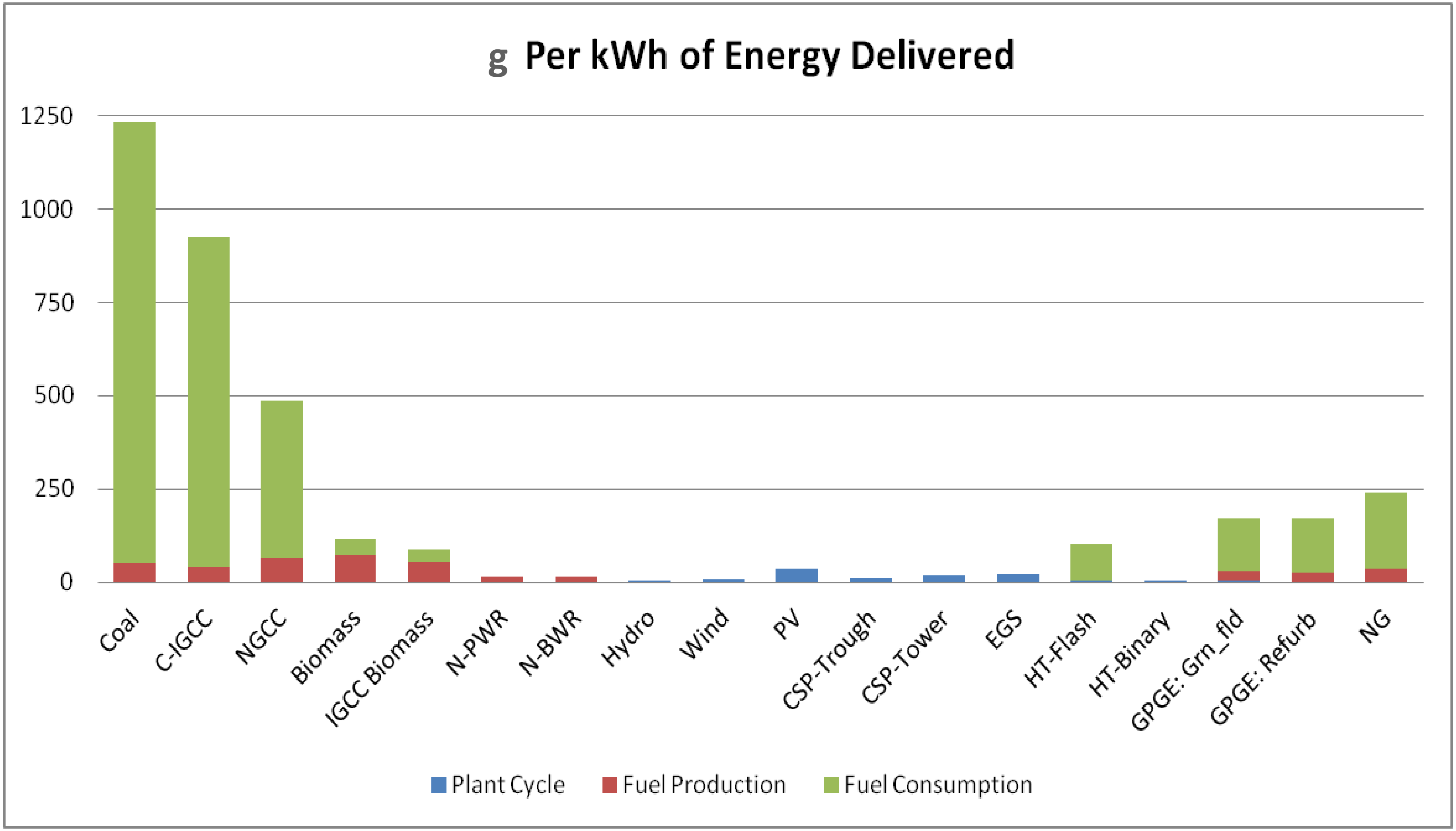


- PV requires significantly larger amount of energy/carbon intense materials (Si, Al, and glass) than other power plants
- Steel and concrete are widely used for various power plants
- 30 years lifetime

CO2 Emissions Attendant the Construction and Production of Constituent Materials for a Power Plant

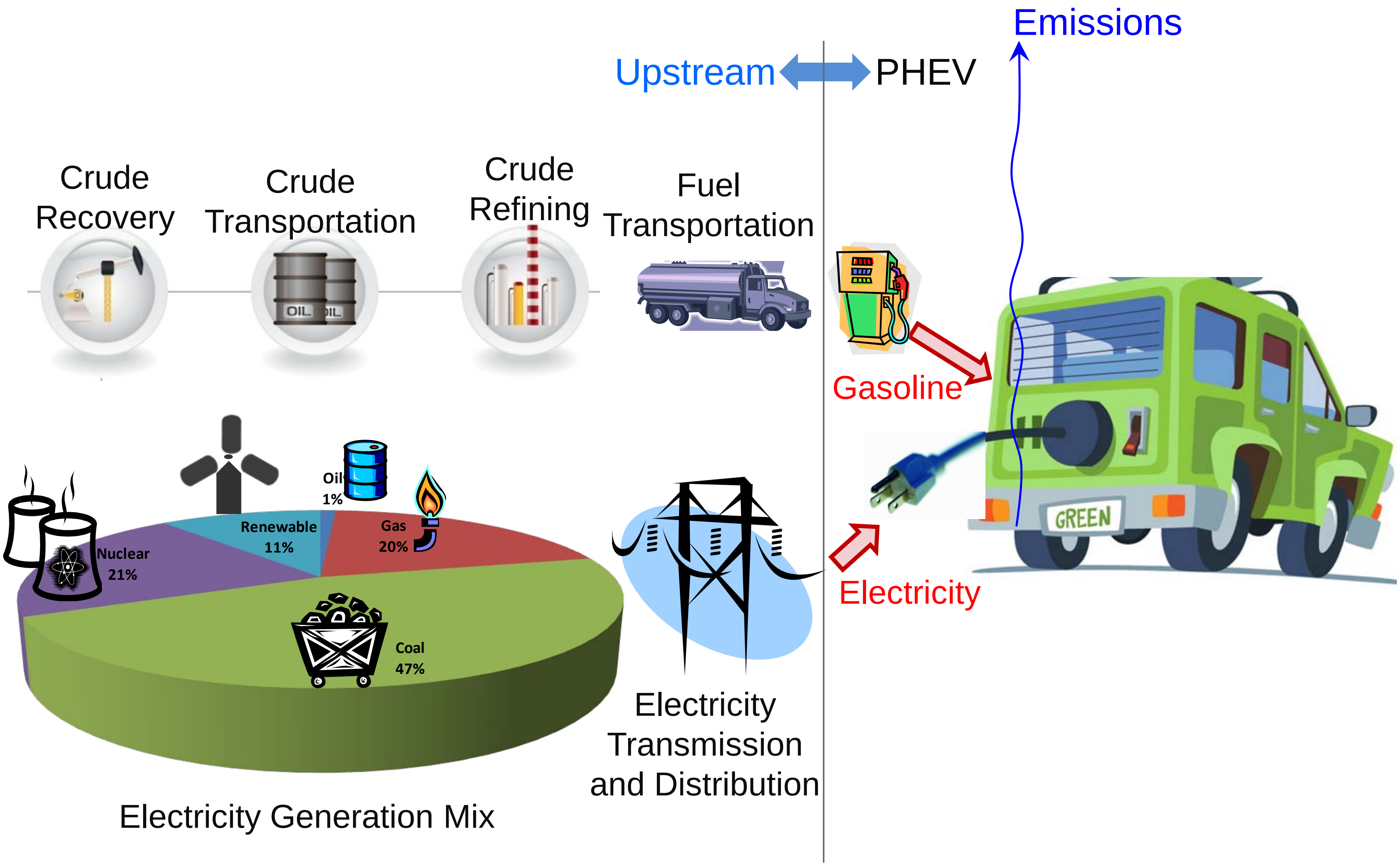


GHGs for Various Power Plant Technologies

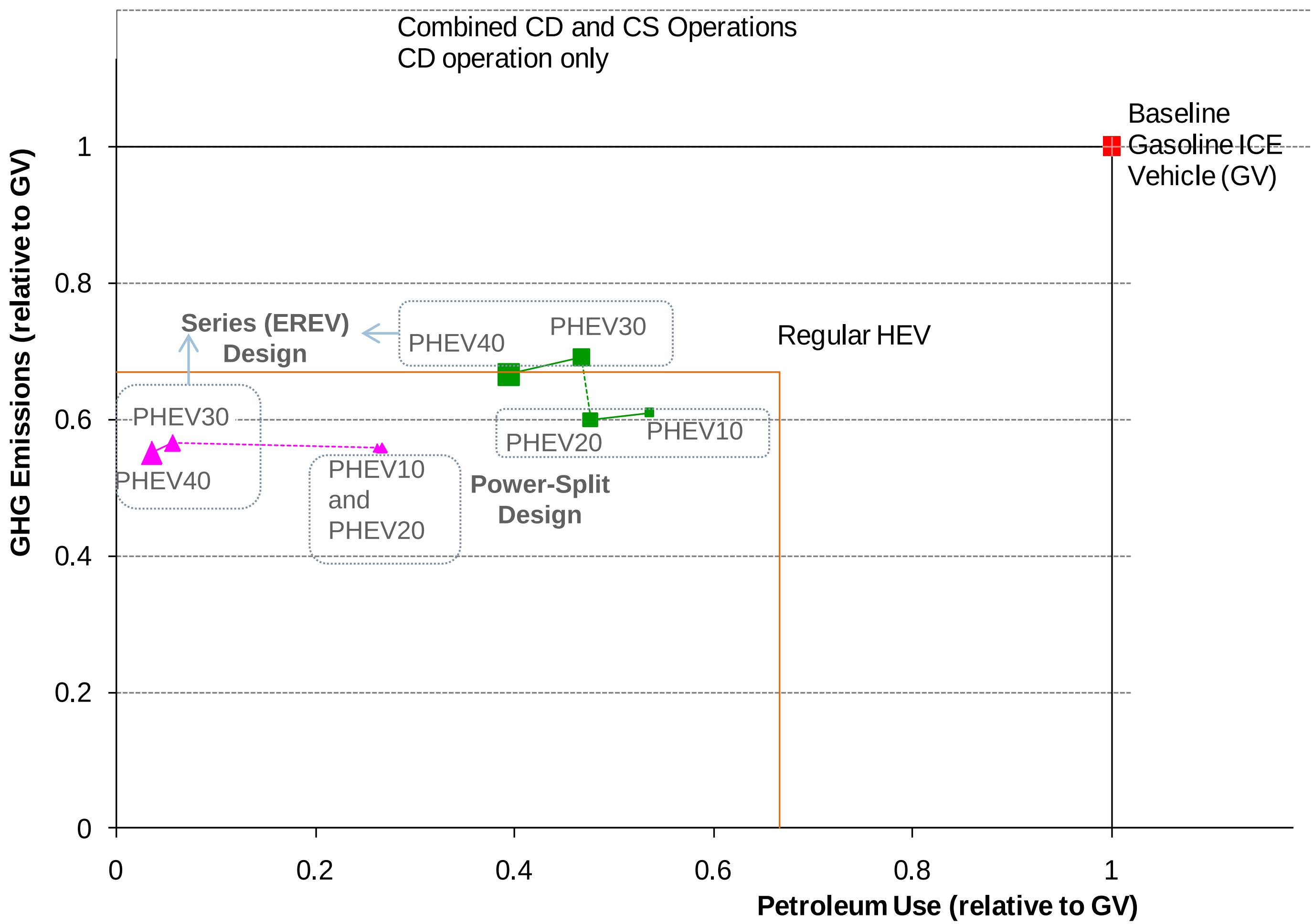


WTW Analysis of PHEVs

PHEVs WTW Pathway



Significant WTW Petroleum Savings for PHEVs Relative to ICEV and HEVs But WTW GHG Emissions Comparable to HEVs
(Figure Shown for Unconstrained Charging in WECC)



Case Simulation and Users Q&A:
Corn and Cellulosic Ethanol

Ethanol Life Cycle Supporting Documentation

Available at: www.greet.es.anl.gov/publications and journal websites

REVIEW

Estimated displaced products and ratios of distillers' co-products from corn ethanol plants and the implications of life-cycle analysis

Biofuels (2010) 1(6), xxx–xxx

Salil Arora[1], May Wu[†1] & Michael Wang[1]
Displacement of conventional animal feed component

BIOMASS AND BIOENERGY 35 (2011) 1885–1896

Available at www.sciencedirect.com

ScienceDirect

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http://www.elsevier.com/locate/biombioe

BIOMASS & BIOENERGY

Energy and greenhouse gas emission effects of corn and cellulosic ethanol with technology improvements and land use changes

Michael Q. Wang[a,*], Jeongwoo Han[a], Zia Haq[b], Wallace E. Tyner[c], May Wu[a], Amgad Elgowainy[a]

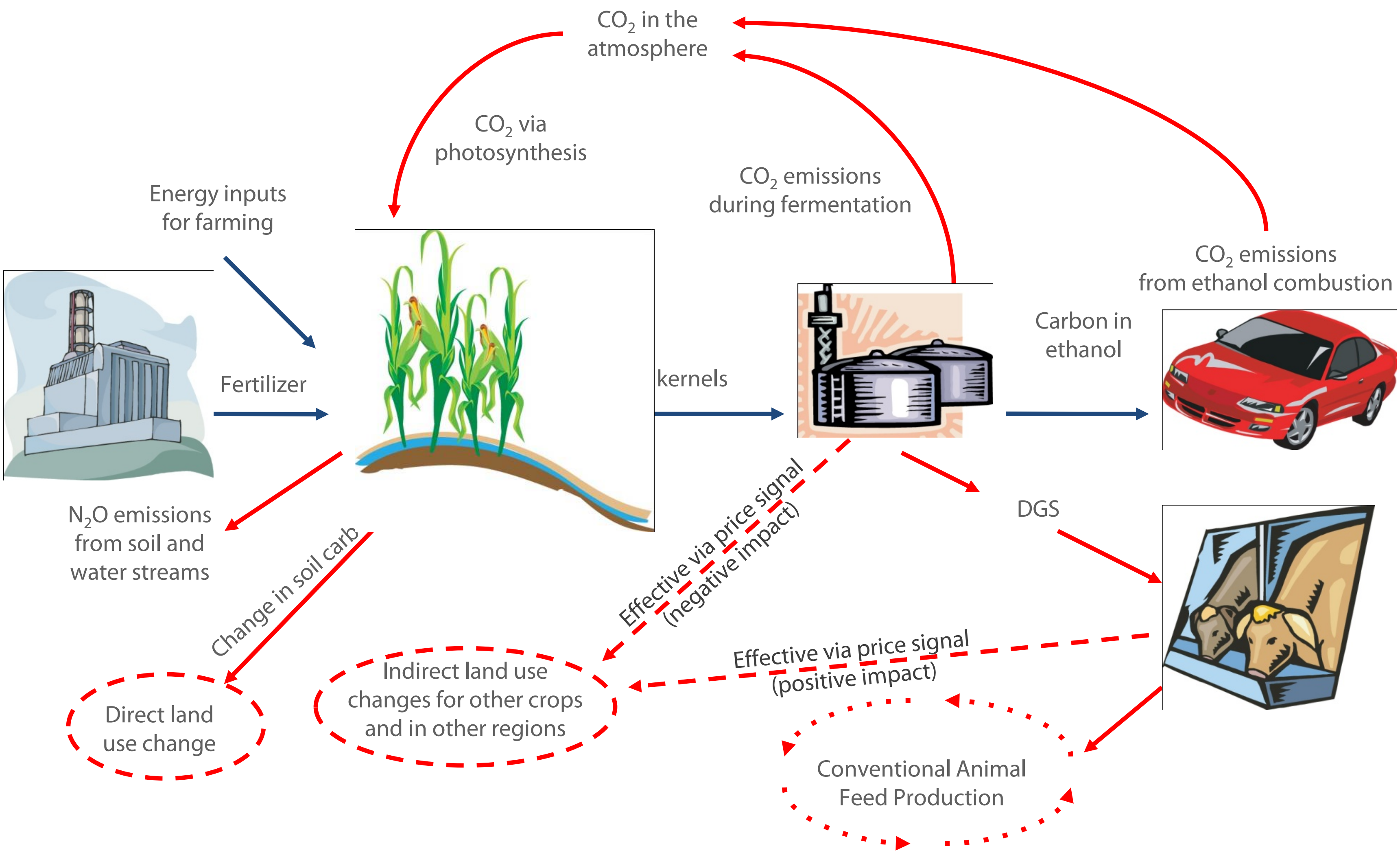
ENVIRONMENTAL RESEARCH LETTERS

Environ. Res. Lett. 2 (2007) 024001 (13pp) doi:10.1088/1748-9326/2/2/024001

Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types

Michael Wang, May Wu and Hong Huo

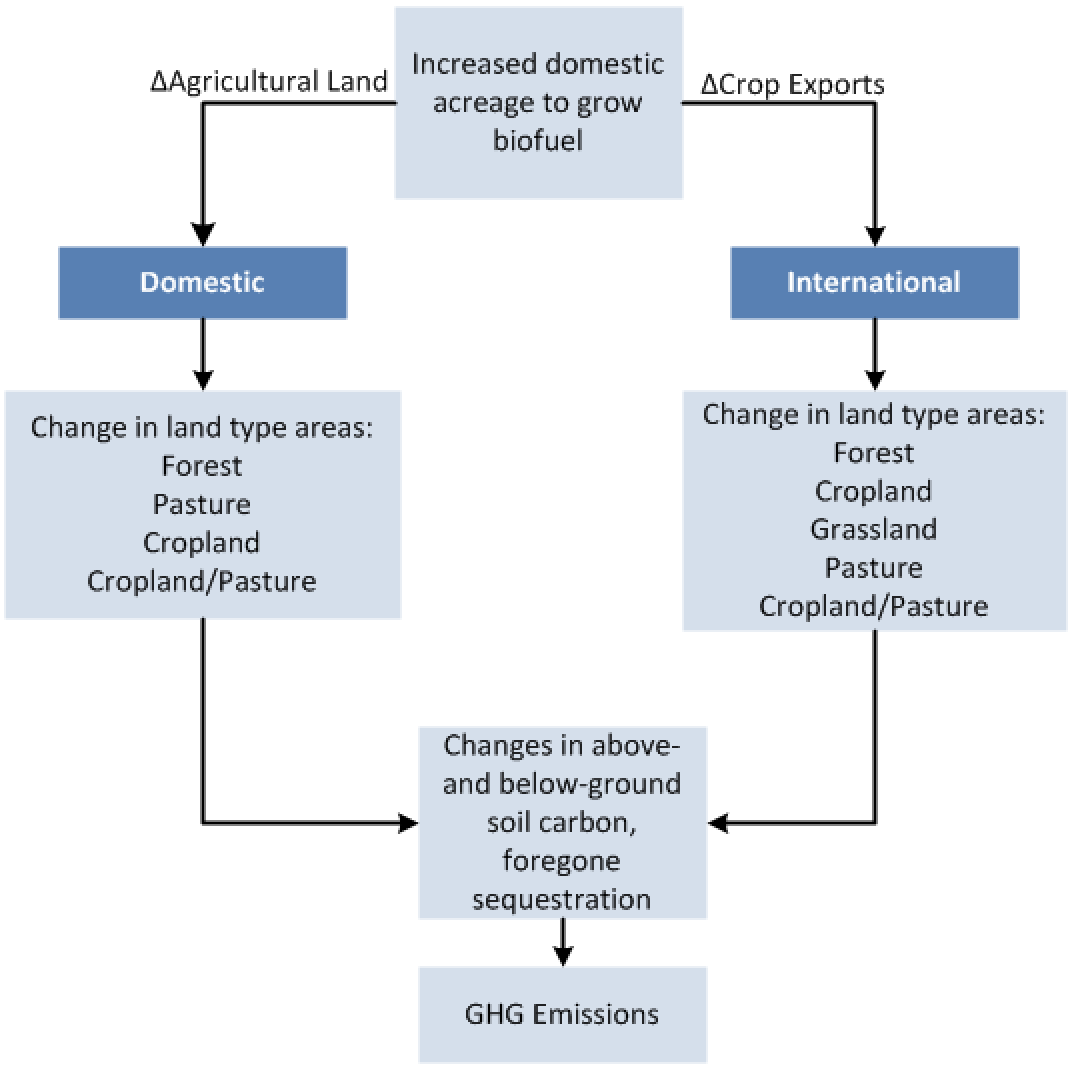
Corn Ethanol Life Cycle



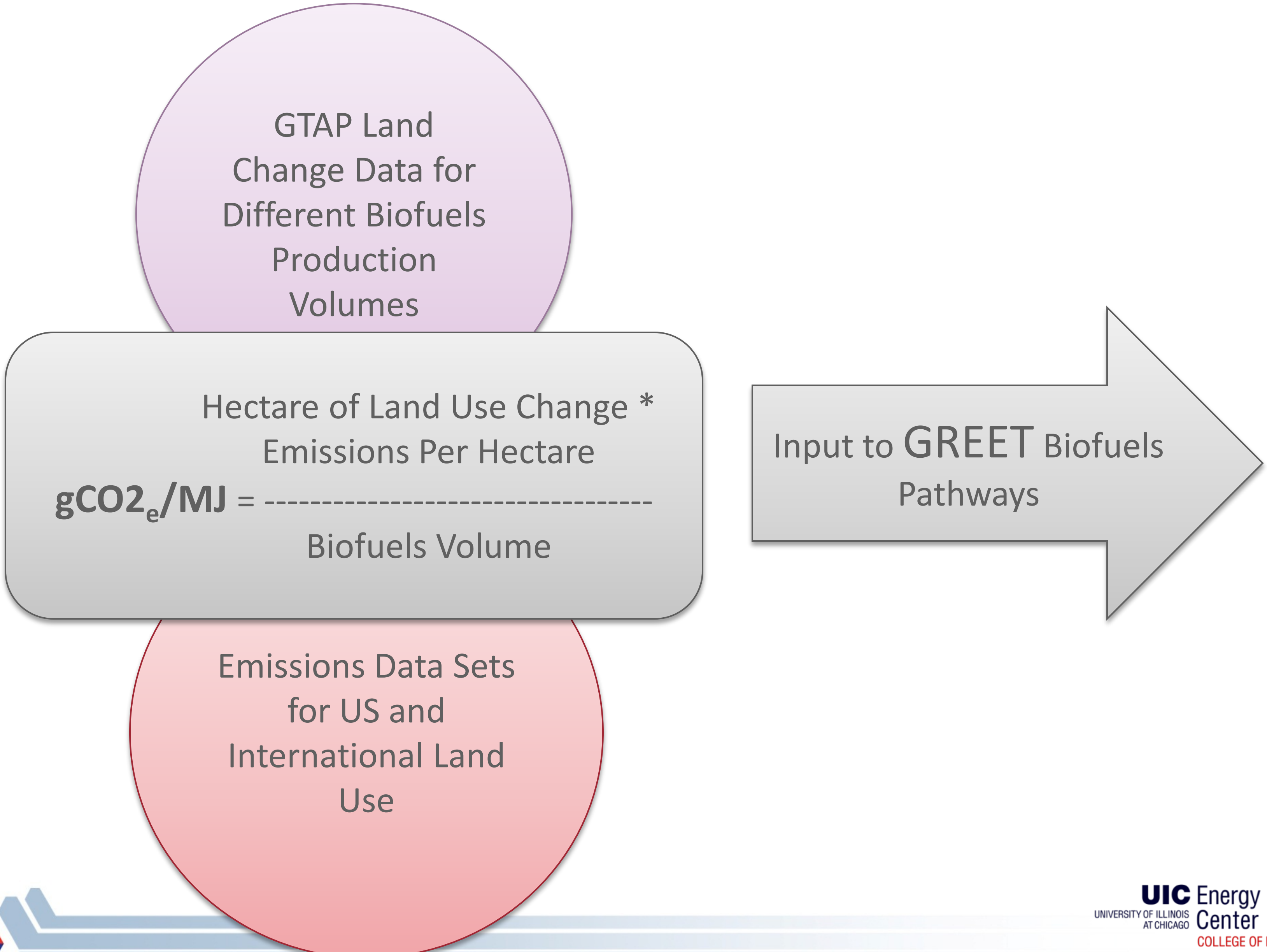
Key Parameters of the Corn Ethanol Pathway

- Land-Use Change
- Co-Product Allocation Methodology
- Plant Type – process fuel and co-products

Land-Use Change Review



Carbon Calculator for Land Use Change from Biofuels Production (CCLUB) Overview



Current CCLUB Version

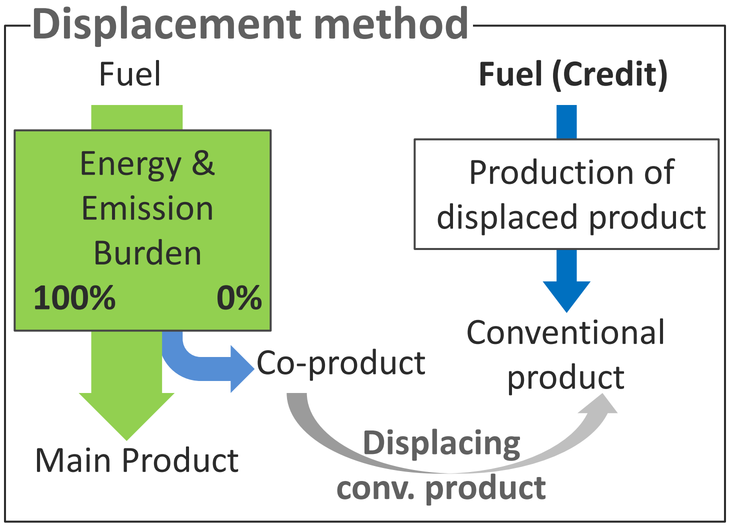
3 Corn Ethanol Scenarios (C1, C2, C3):
- Different GTAP Databases
- C3 Scenario Assumes Yield and Population Growth

6 Different Cases:
Ramping corn ethanol production up to 15 billion gallon in 2 billion gallon incremental volume changes

3 Land Transitions:
GTAP Reports conversions of forest, pasture, and cropland-pasture to feedstock lands

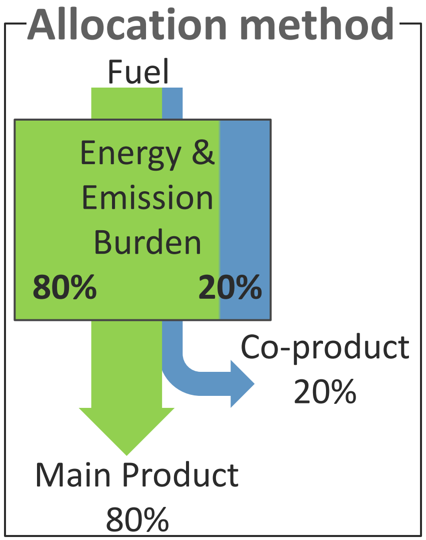
GTAP Land Change Data for Different Biofuels Production Volumes

Allocation Method Options for Corn Ethanol



Allocate by

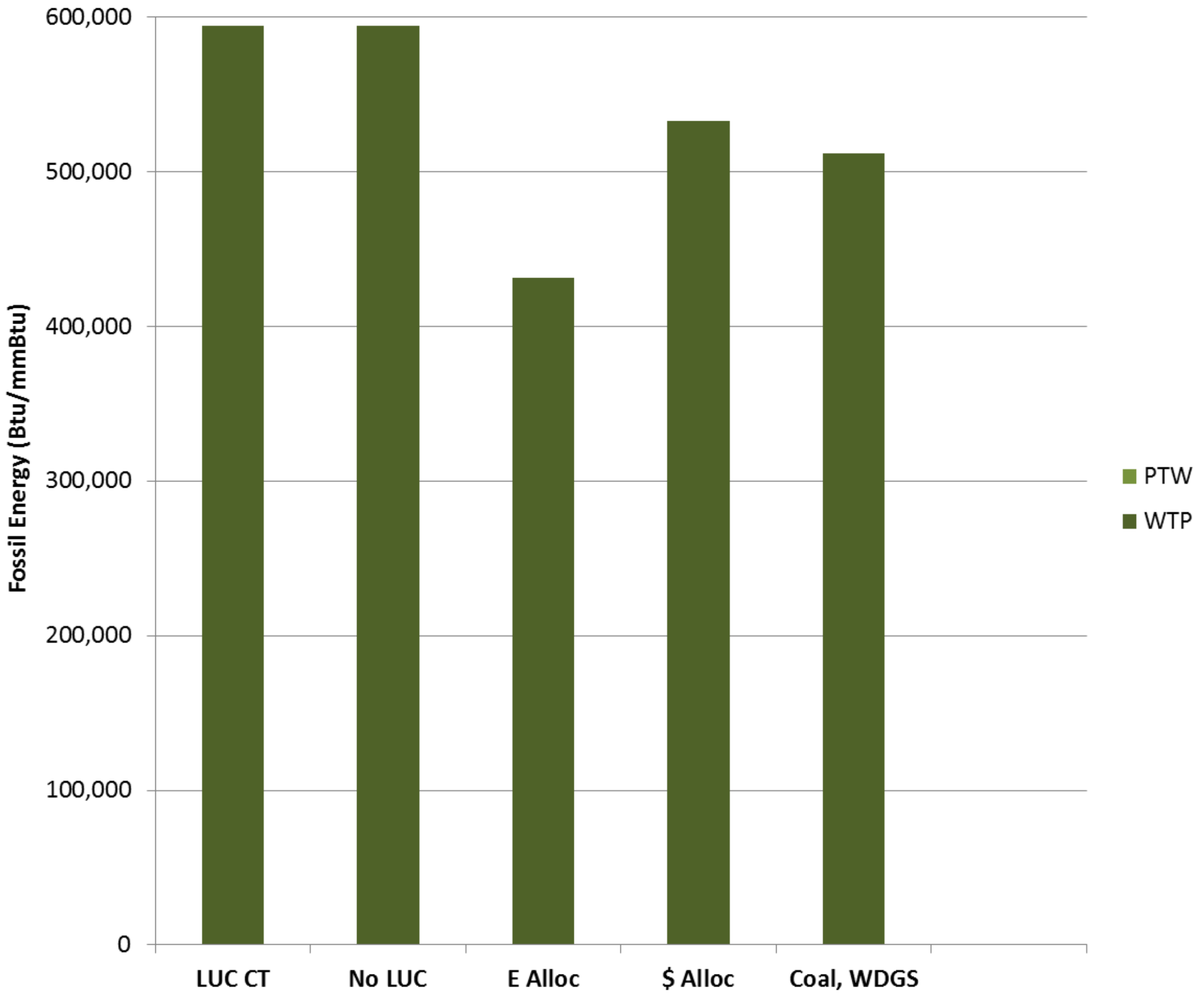
- **Energy**
- **Market Value**



Selection of corn ethanol plant type affects LCA results

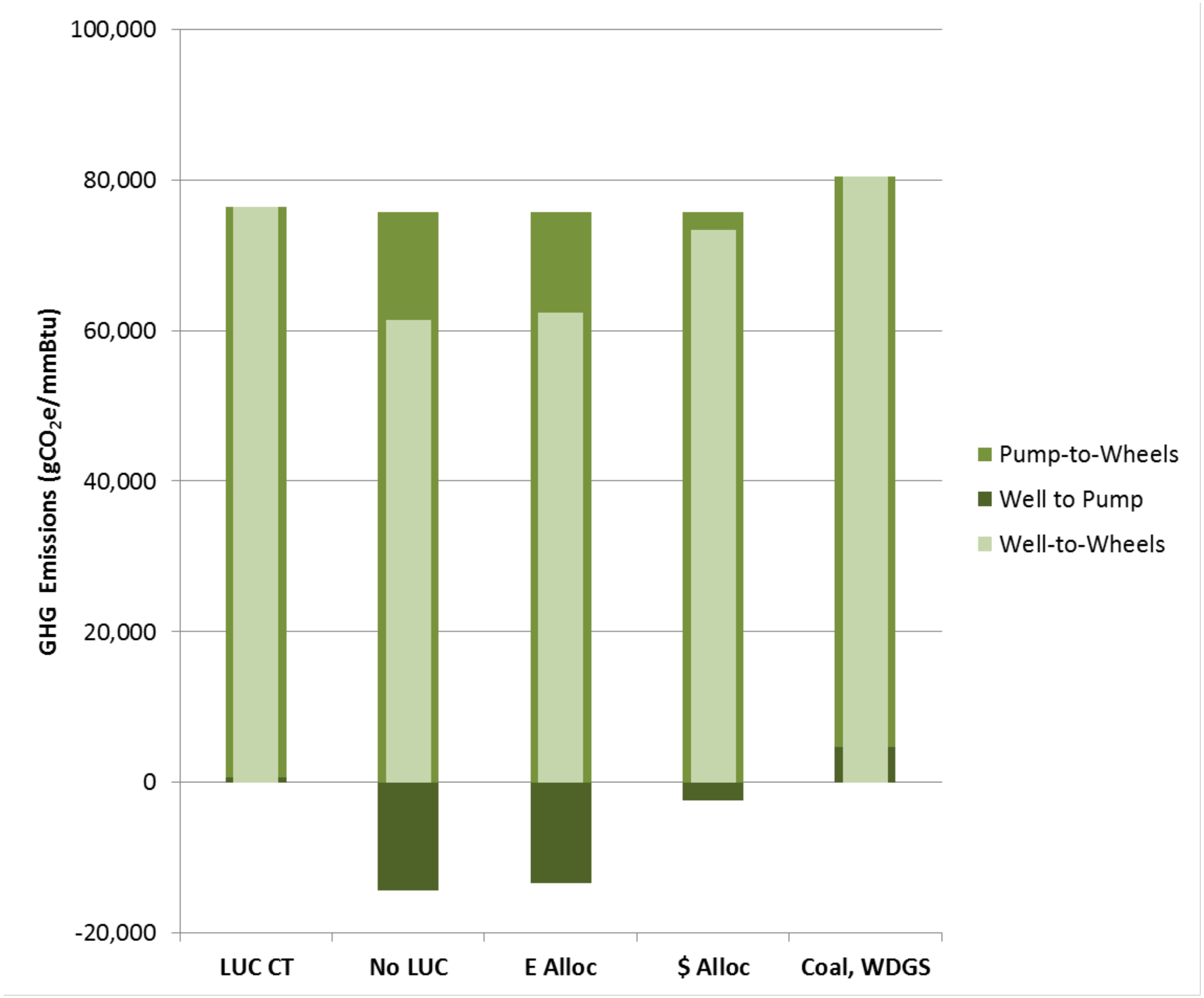
- Dry Mill (nearly 90% of fleet)
- Wet Mill
- Process fuel
  - Natural gas
  - Coal
  - Biomass

Corn Ethanol Demonstration Results: Fossil Energy



LUC: Land-use change; CT: Conventional till; E: Energy; WDGS: Wet Distillers Grains Solubles

Corn Ethanol Demonstration Results: GHG Emissions



LUC: Land-use change; CT: Conventional till; E: Energy; WDGS: Wet Distillers Grains Solubles

Cellulosic Ethanol Feedstock Supporting Documents

Available at:
www.greet.es.anl.gov/publications

Updated Sugarcane and Switchgrass Parameters in the GREET Model

Jennifer B. Dunn, John Eason, and Michael Q. Wang
Center for Transportation Research
Argonne National Laboratory

October 2011

Background

The feedstock from which a biofuel derives
consumption and emissions of greenhouse g
our approach to developing GREET para
feedstocks that affect their life-cycle air
(including the upstream energy to manuf

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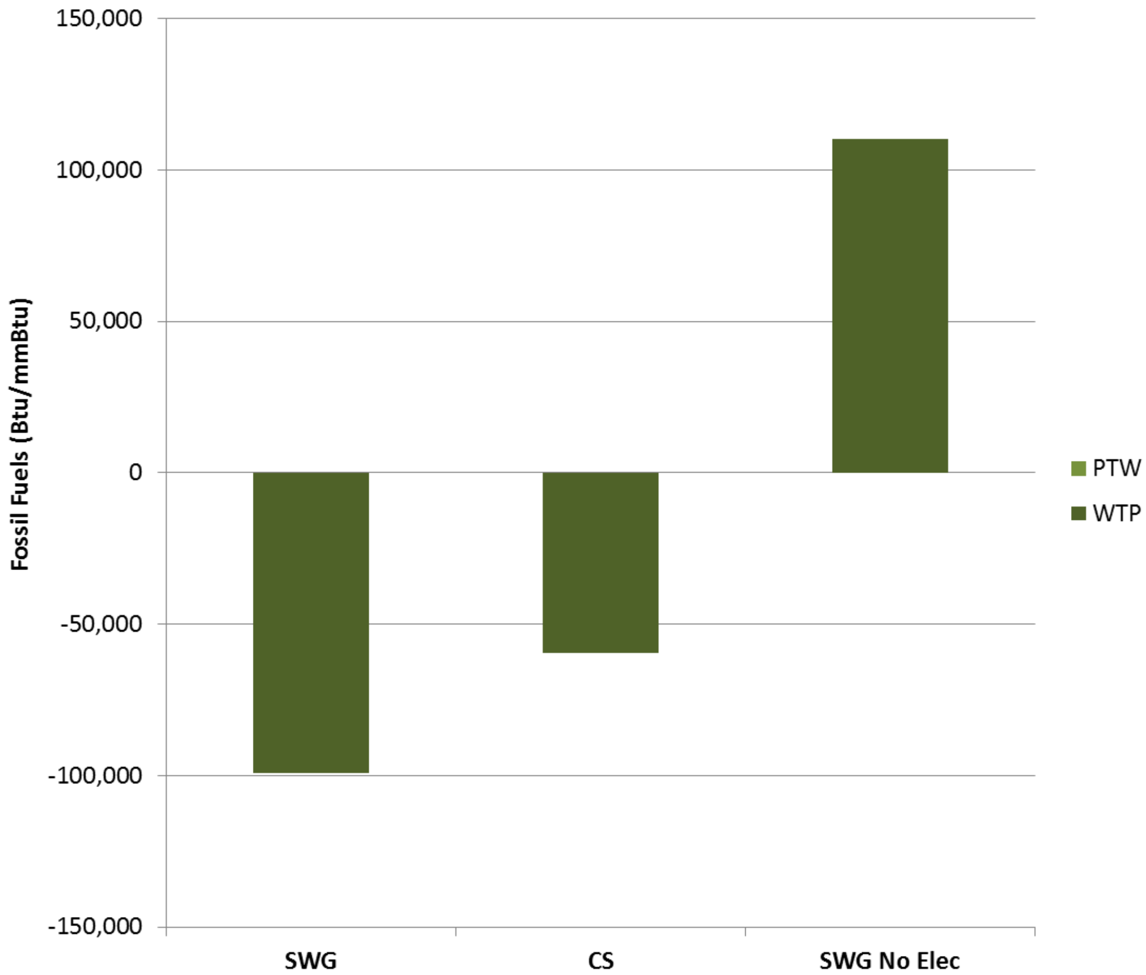
ANL/ESD/11-8

Well-to-Wheels Analysis of Fast Pyrolysis Pathways with GREET

Key Parameters of Cellulosic Ethanol Pathways

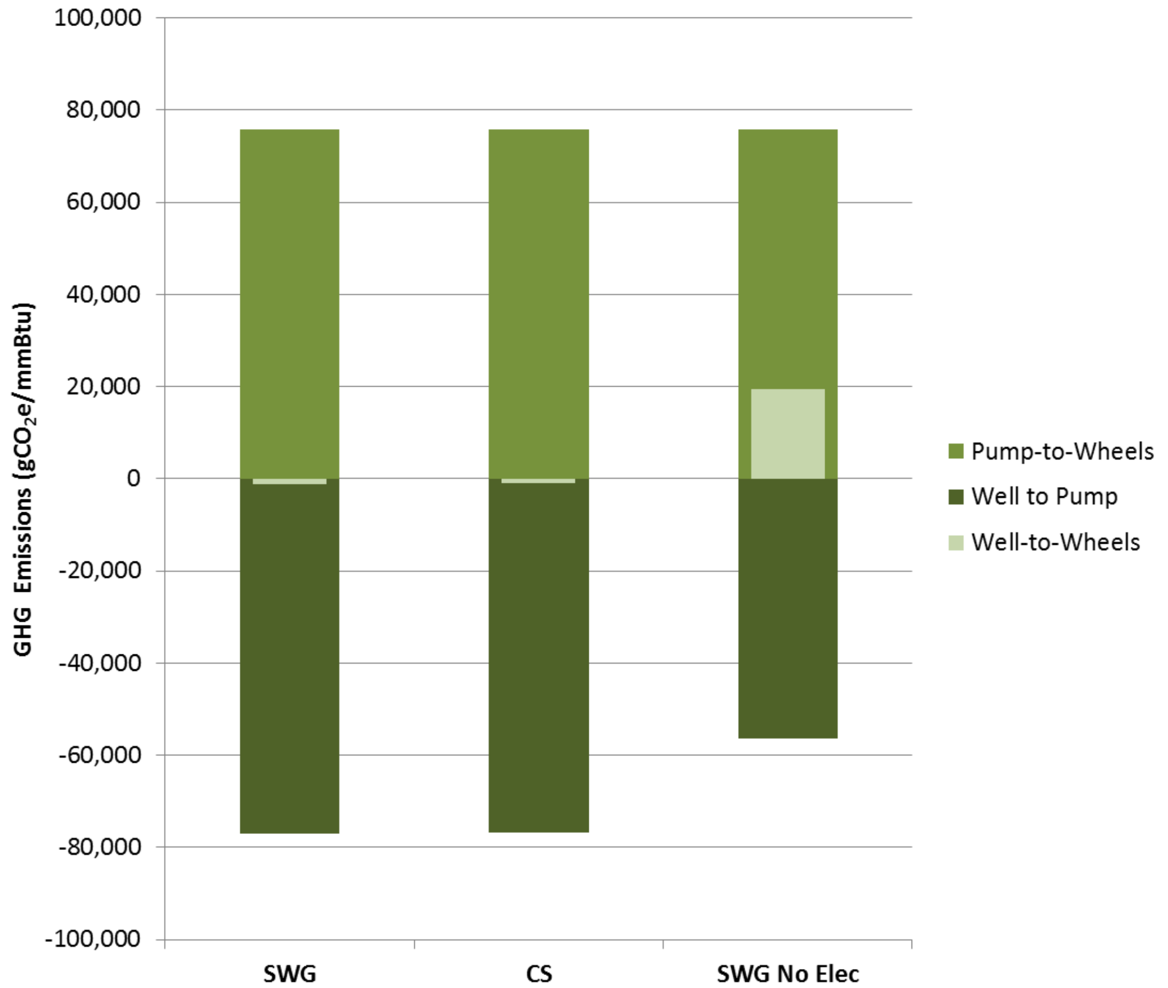
- Two recently-updated feedstocks:
  - Switchgrass
  - Corn Stover
- Effect of co-produced electricity

Cellulosic Ethanol Demonstration Results: Fossil Energy



SWG: Switchgrass; CS: Corn stover

Cellulosic Ethanol Demonstration Results: GHG Emissions



SWG: Switchgrass; CS: Corn stover

Case Simulation and Users Q&A:
Algae Biofuel Pathways

Supporting Documents: LCA Report and User Manual

- Available at http://greet.es.anl.gov/publications

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Life-Cycle Analysis of Algal Lipid Fuels with the GREET Model

Energy Systems Division

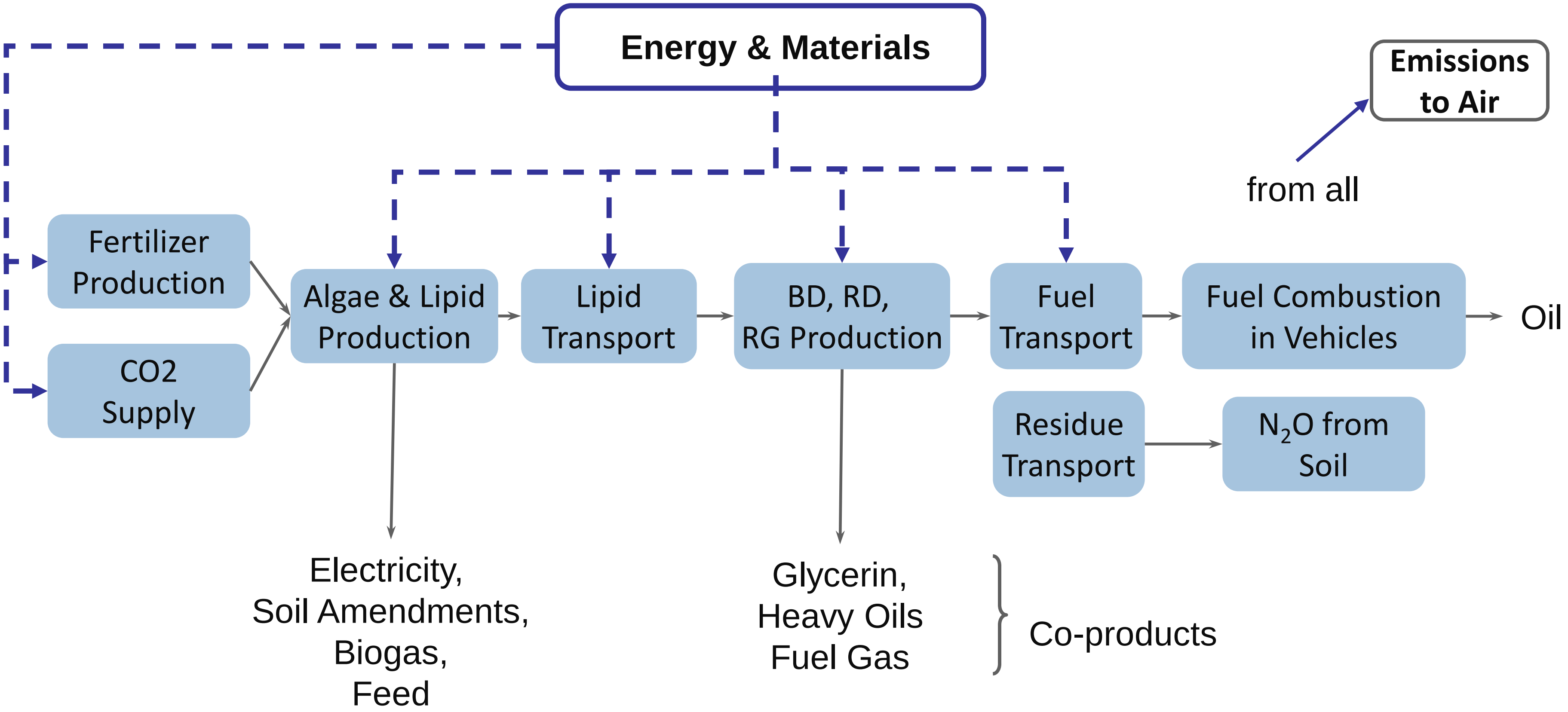
Argonne NATIONAL LABORATORY

ANL/ESD/11-7

User Manual for Algae Life-Cycle Analysis with GREET: Version 0.0

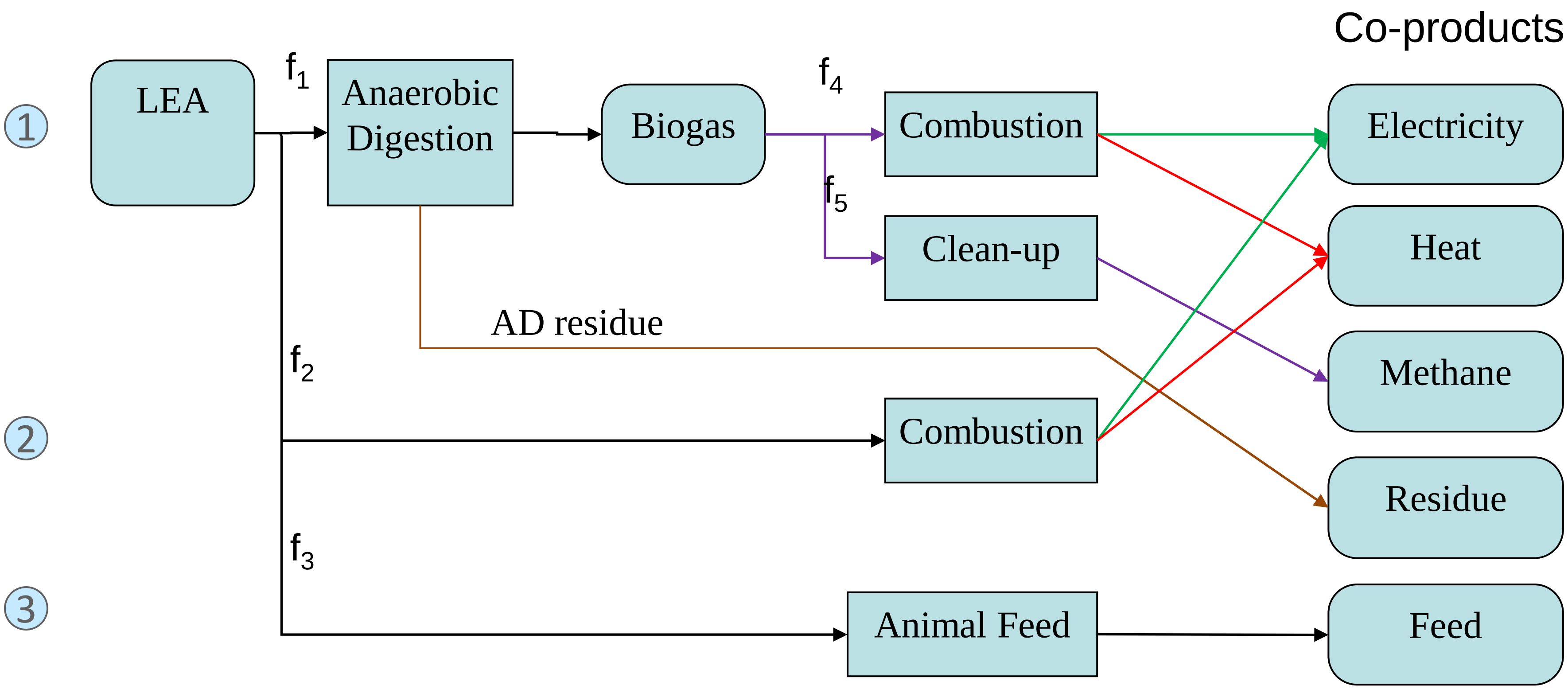
Energy Systems Division

Algae LCA System Boundary



- System boundary currently excludes infrastructure materials and land-use change

GREET: Co-Product Handling is a Key Issue



- ❑ Three Pathways Possible
- ❑ Five processes with co-products
- ❑ Five co-products from algae

Key issues in algae biofuel pathways

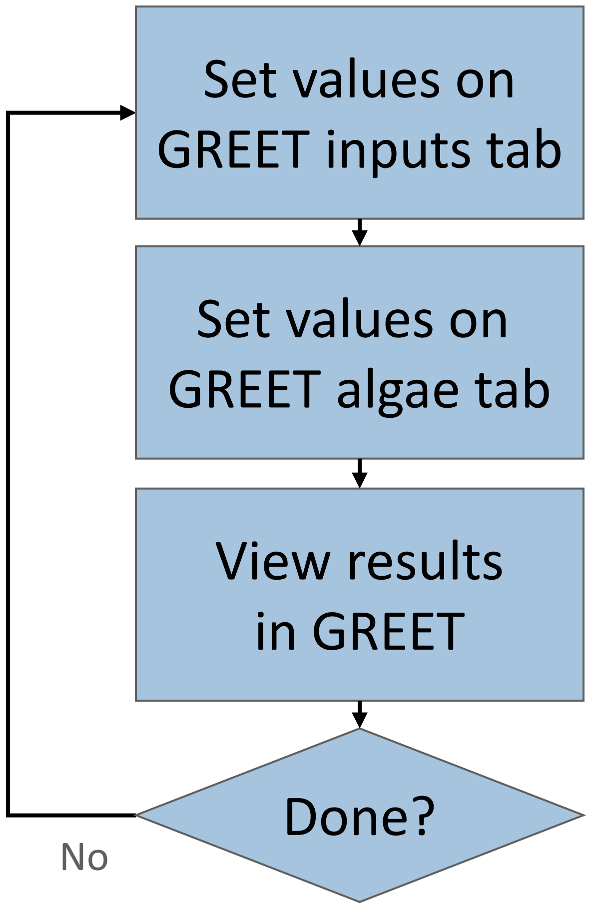
- CH_4 yield from anaerobic digestion
- CHP electrical efficiency
- Fugitive methane emissions
- On-site electricity demand
- Emission factor for N_2O from digestate solids
- Rate of nitrogen recovery to offset NH_3 production
- Fate of unrecovered nitrogen

Two Possible Workflows

1) Study pre-configured algae pathway
   - Three options configured in GREET
     - See Technical Report for detailed description

2) Define Custom Algae Pathways
   - Change unit-operation parameters in default configuration
   - Choose different unit-operations

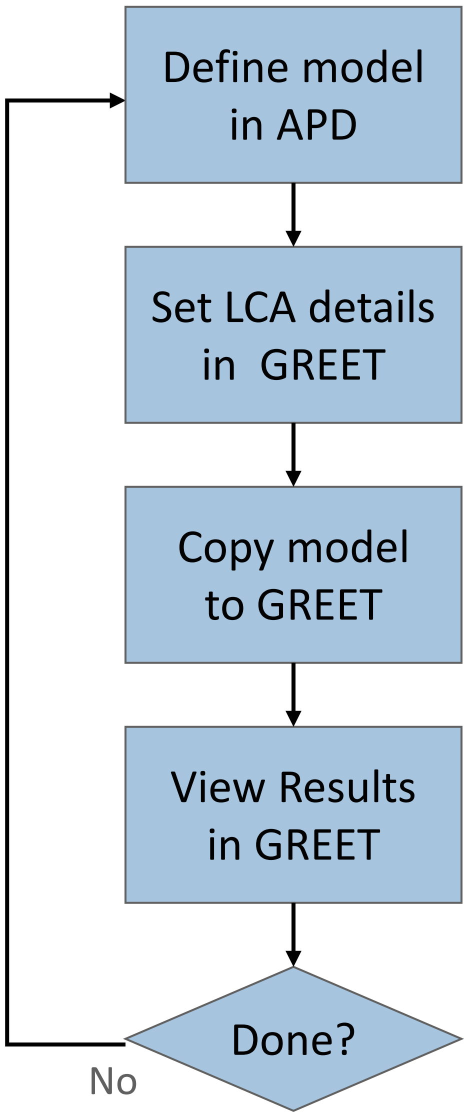
Workflow for Pre-configured Pathway

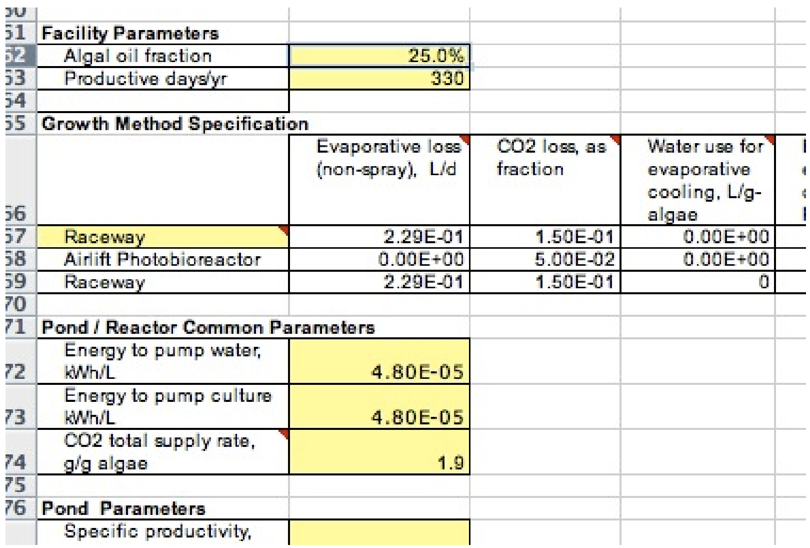


- Set feedstock in Sec. 8.1 to, “algae.”
- Consider share in BD, Sec. 11.1
- Co-product treatment, transportation
- Vehicle and fuel

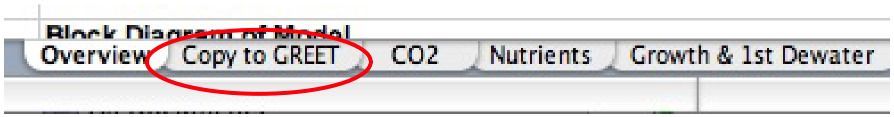
All work is performed in GREET

Workflow for Custom Pathway





51	Facility Parameters				
52	Algal oil fraction	25.0%			
53	Productive days/yr	330			
54					
55	Growth Method Specification				
56		Evaporative loss (non-spray), L/d	CO2 loss, as fraction	Water use for evaporative cooling, L/g-algae	
57	Raceway	2.29E-01	1.50E-01	0.00E+00	
58	Airlift Photobioreactor	0.00E+00	5.00E-02	0.00E+00	
59	Raceway	2.29E-01	1.50E-01	0	
70					
71	Pond / Reactor Common Parameters				
72	Energy to pump water, kWh/L	4.80E-05			
73	Energy to pump culture kWh/L	4.80E-05			
74	CO2 total supply rate, g/g algae	1.9			
75					
76	Pond Parameters				
	Specific productivity,				



Work alternates between APD and GREET

APD Example: Process Selection for Dewatering

Net-Process Summary		Step 1	Step 2	Step 3	Step 4
	Summary of remaining de-watering	Dissolved Air Flotation	Centrifuge	None	None
Input per unit output	1.235E+00	1.11E+00	1.11E+00	1.00E+00	1.00E+00
Recoverable CO2, g/g produ	0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mass to recovery, dry-g/g pro	2.346E-01	1.11E-01	1.11E-01	0.00E+00	0.00E+00
Materials consumed, g per unit output except as noted		0.000E+00	0.000E+00	0.000E+00	0.000E+00
Chitosan	1.111E-02	1.000E-02	0.000E+00	0.000E+00	0.000E+00
None	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
None	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
None	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
None	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
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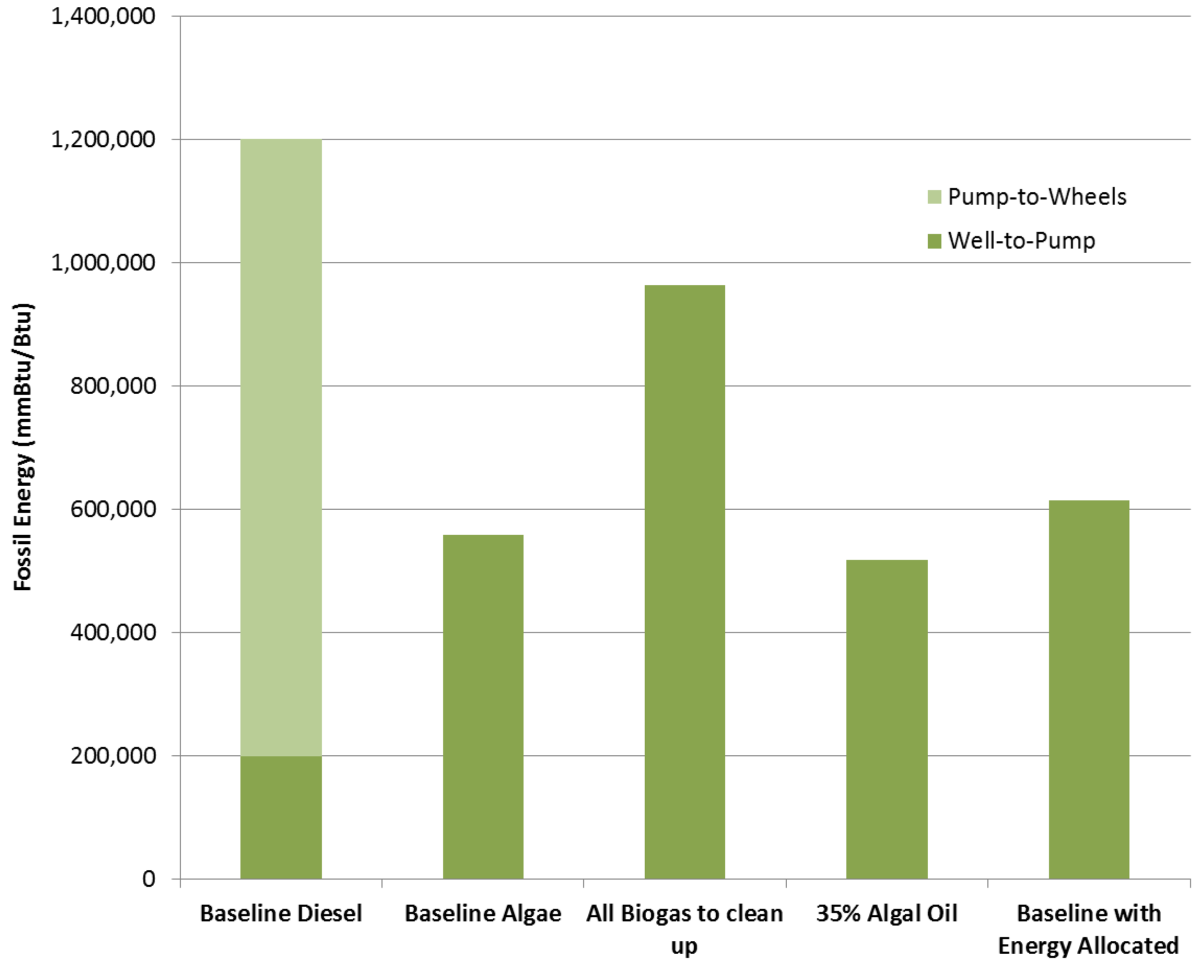
[illegible]	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
[illegible]	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
None		0.000E+00	0.000E+00	0.000E+00	0.000E+00
None	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
None	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Energy consumed: KWh/g-output except as noted		0.000E+00	0.000E+00	0.000E+00	0.000E+00
Residual oil	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Diesel fuel	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Gasoline	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Natural gas	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Coal	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Liquefied petroleum gas	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Electricity	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Site thermal	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Site Electricity	3.454E-03	1.478E-04	3.290E-03	0.000E+00	0.000E+00

Drop-down for process selection

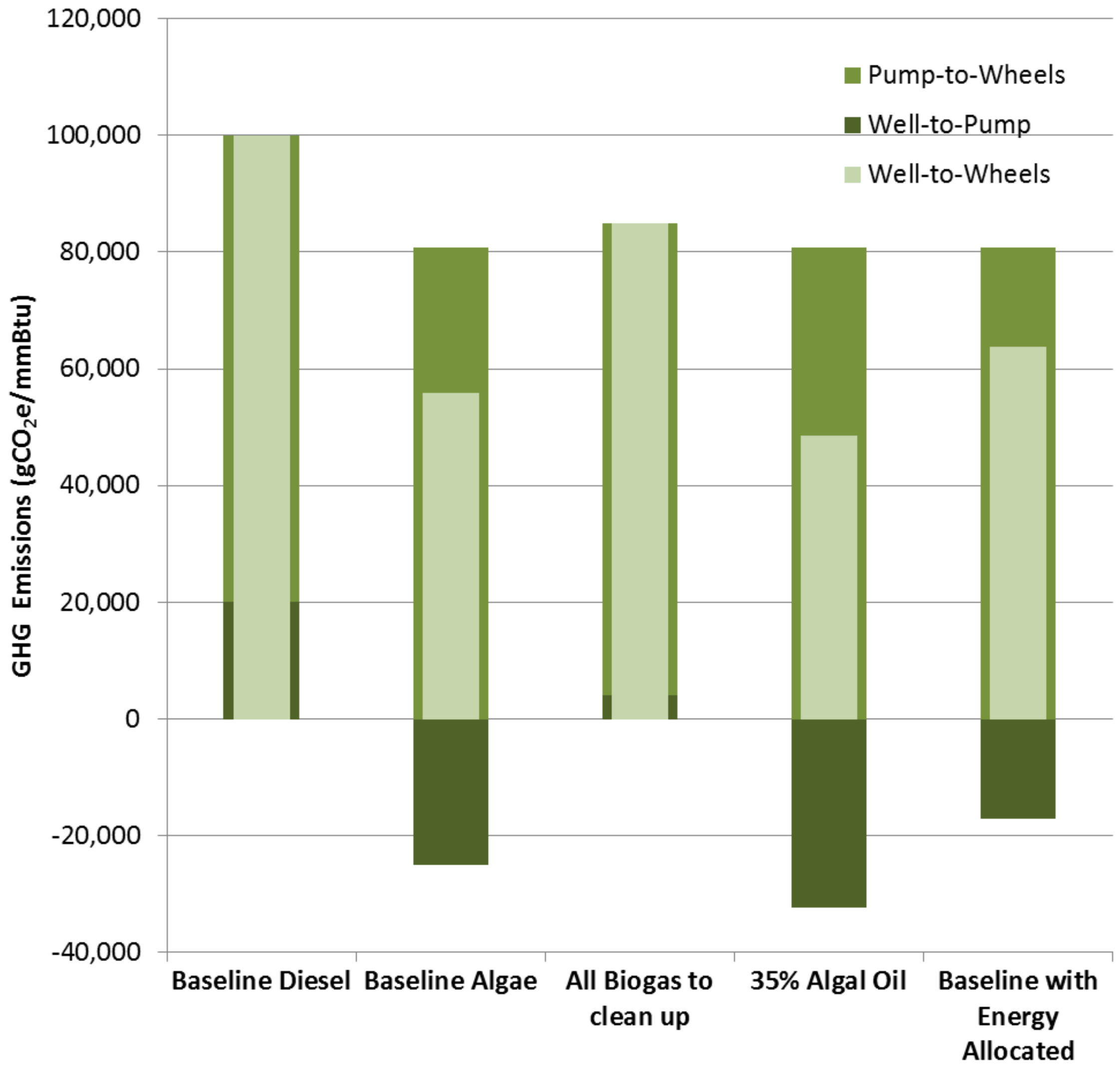
Drop-down for material selection

Tan summary copied back to GREET

Algae Demonstration Results: Fossil Energy



Algae Demonstration Results: GHG Emissions

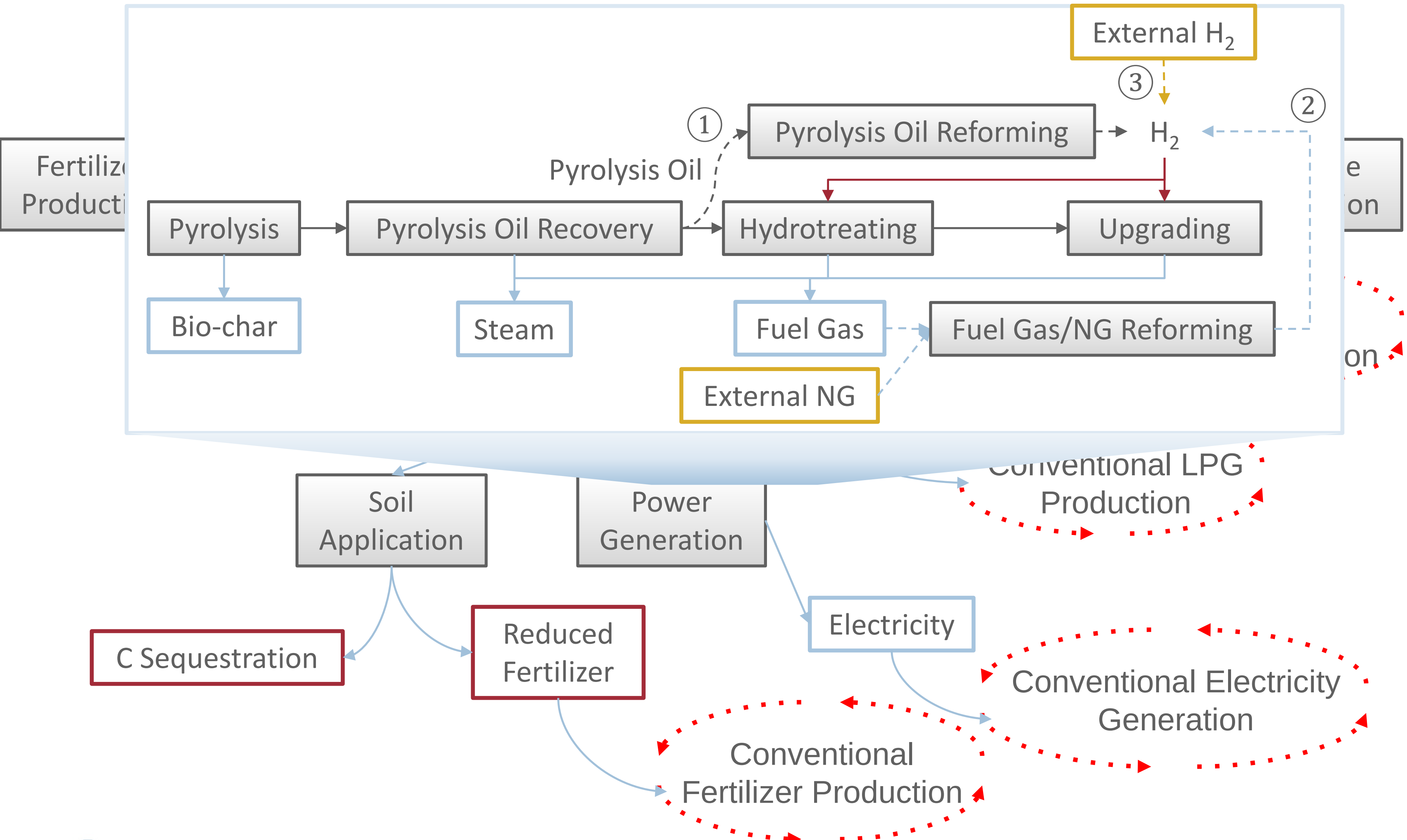


Case Simulation and Users Q&A:
Pyrolysis Biofuel Pathways

Supporting Documents for Pyrolysis Pathway : Technical Report

Han, J., A. Elgowainy, I. Palou-Rivera, J.B. Dunn, M. Wang. *Well-to-Wheels Analysis of Fast Pyrolysis Pathways with GREET*. Argonne, IL: Argonne National Laboratory, 2011. http://greet.es.anl.gov/publication-wtw_fast_pyrolysis

Pyrolysis-Based Pathway System Boundary



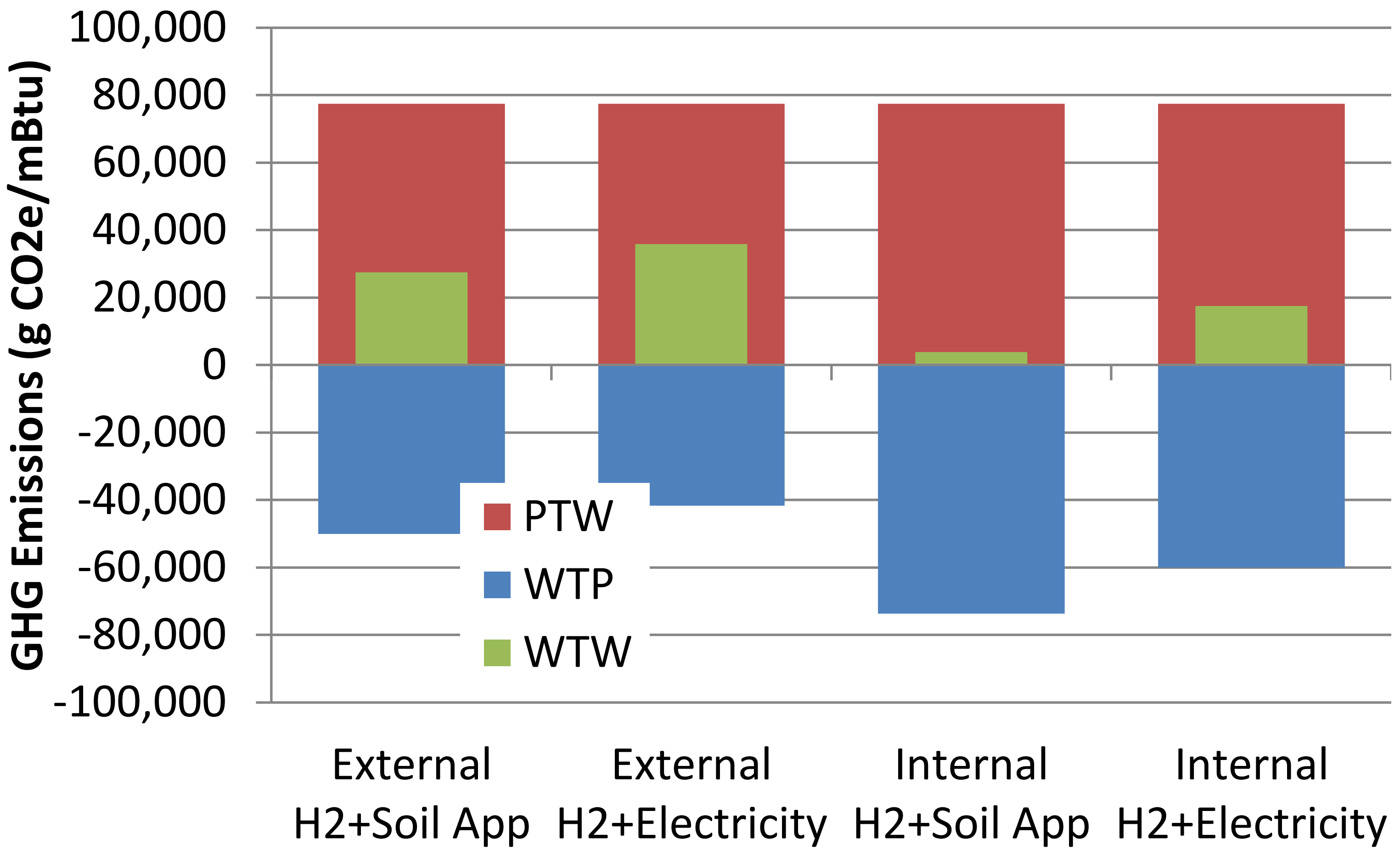
Key Parameters of Pyrolysis-Based Pathways

- Feedstock growth/collection (energy use and agricultural inputs)
- Pyrolysis oil yield (feedstock type, reactor design)
- ✓ Hydrogen source and requirement for bio-oil stabilization
- Upgrading to liquid fuel (product slate and allocation between refined products)
- ✓ Co-products amount and use (biochar for electricity generation or soil amendment)

Demo

Case No.	Description	H2 Source	Bio-char Application
1	External H2 + Soil App.	External H2 Purchase	Soil Application
2	External H2 + Electricity	External H2 Purchase	Electricity Generation
3	Internal H2 + Soil App.	Internal H2 from Pyrolysis Oil Reforming	Soil Application
4	Internal H2 + Electricity	Internal H2 from Pyrolysis Oil Reforming	Electricity Generation

Demo Results



External H2: External H2 purchase
Internal H2: Internal reforming of pyrolysis oil
Soil App: Soil application of biochar for C sequestration
Electricity: Electricity generation with biochar

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