Introduction to Algal Fuel LCA in GREET1_2011

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Plan

- Introduction and motivation
- Architecture and workflow
- Demo #1
  - Examining pre-configured pathway: Basics
    - Details to be covered by Jeongwoo separately
  - Where to find results and highest level configuration
  - Quick tour of APD worksheets
- Key concepts in APD
- Demo #2
  - Nutrients
  - Configure a new model and run it

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

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

Energy Systems Division

Motivation and Architecture

- Can algal biofuels meet GHG reduction goals?
  - Must compare to other transportation pathways
- Challenges for algae LCAs
  - Many algae scenarios & process options
  - Facilitate community LCAs
- Algae Process Description (APD)
  - Assists GREET
  - Allows rapid definition of pathway
  - New processes easy to add
  - Assembles model and passes back to GREET for LCA

APD
- System definition
- Technology selection
- Direct energy for op’s
- Performance parameters
- Nutrient tools

Summarize
&
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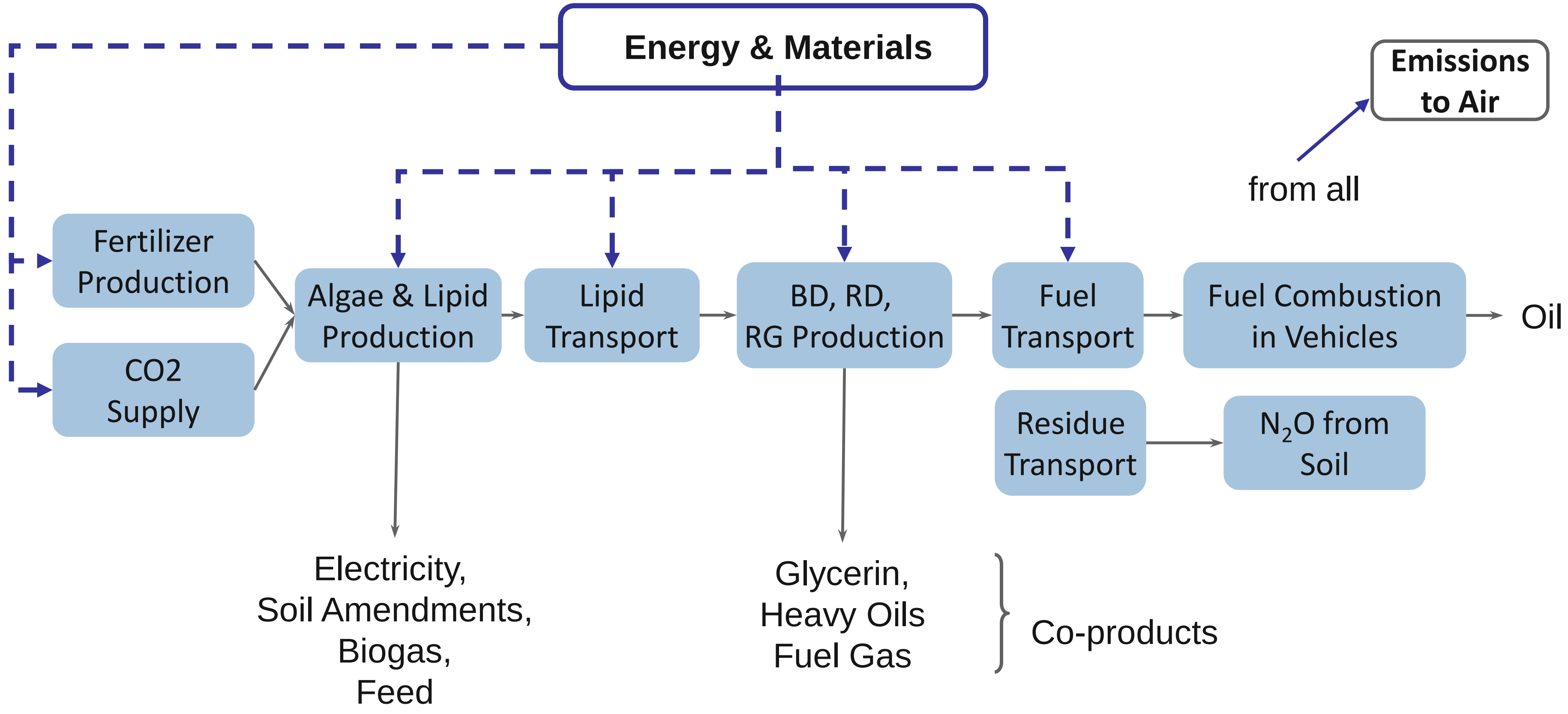
GREET
- Co-product treatment
- Transport & distribution
- Upstream treatment
- Fuel and vehicle
- Results

What You Can Do with GREET and APD

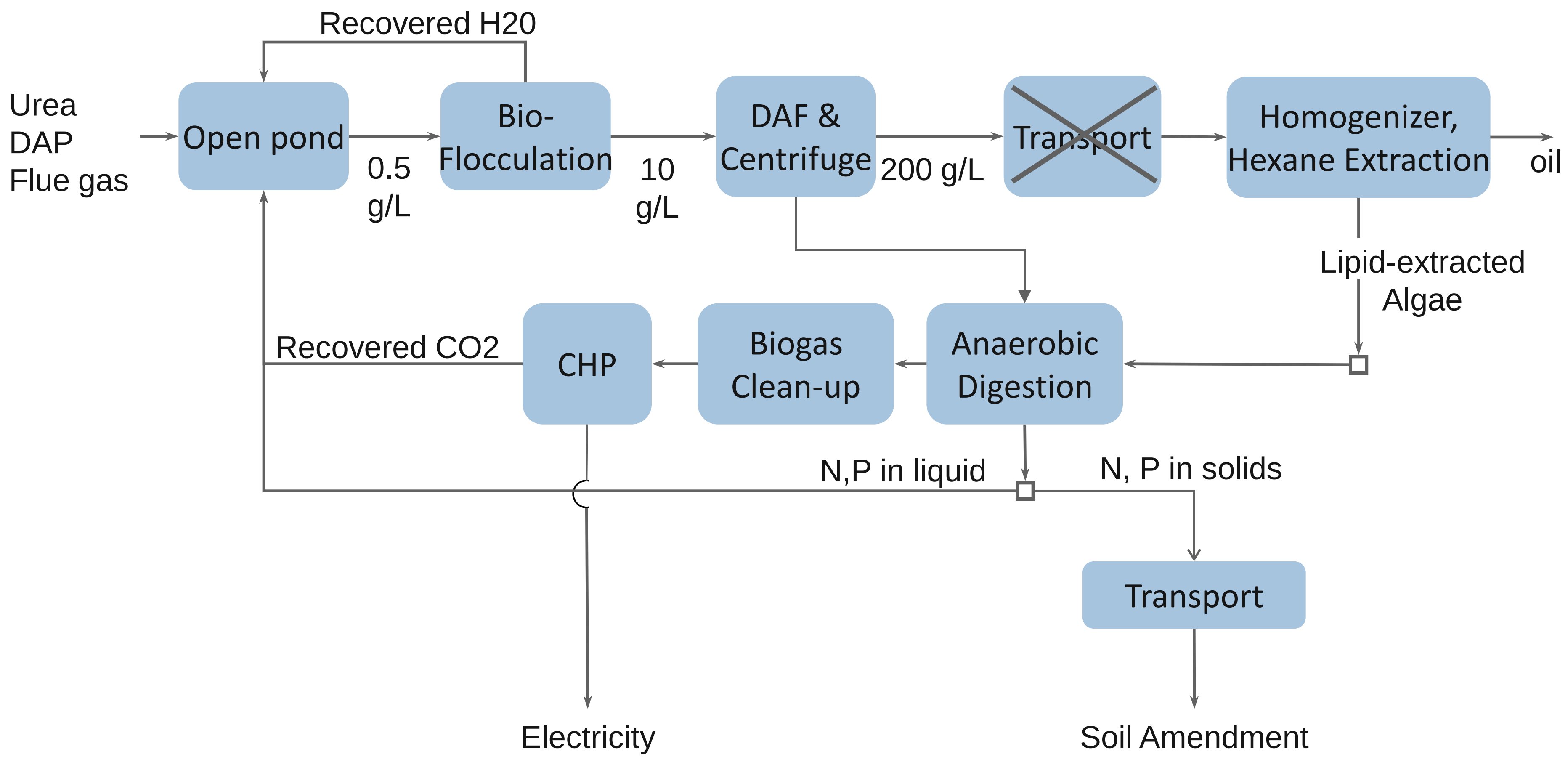
- Assemble algae production model from process inventory
- Compute total energy use
  - Fossil: petroleum, natural gas, and coal
  - Renewable energy: biomass, nuclear, hydro, wind, and solar
- Compute total greenhouse gases (GHGs)
  - CO_2, CH_4, and N_2O individually
  - CO_2e of the three including C in CO and VOC
- Compute total criteria pollutants
  - VOC, CO, NO_x, PM_{10}, $PM_{2.5}$, and SO_x
- Study many vehicle/fuel systems
- Compare algae results with many other feedstocks, fuels, and vehicles

Algae LCA System Boundary



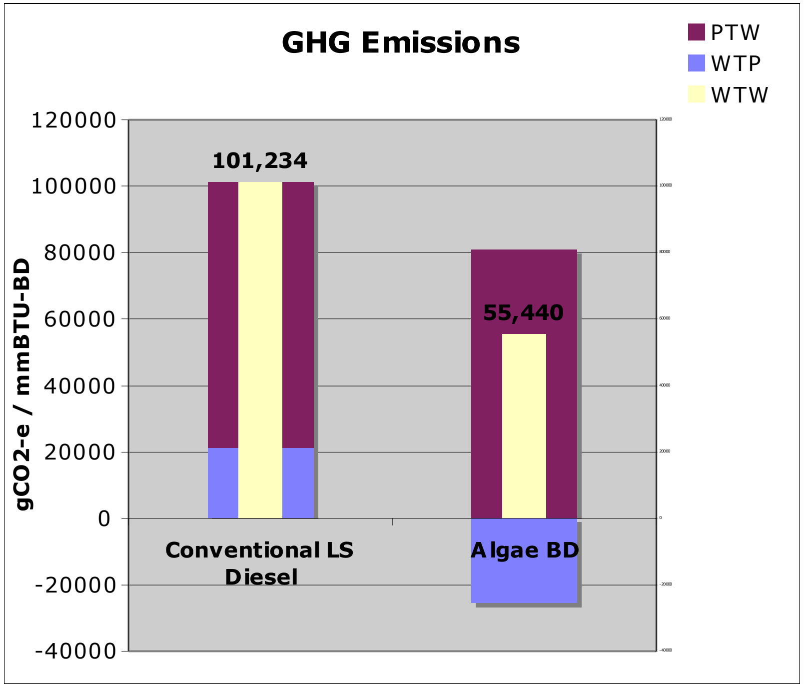
- System boundary currently excludes infrastructure materials and land-use change

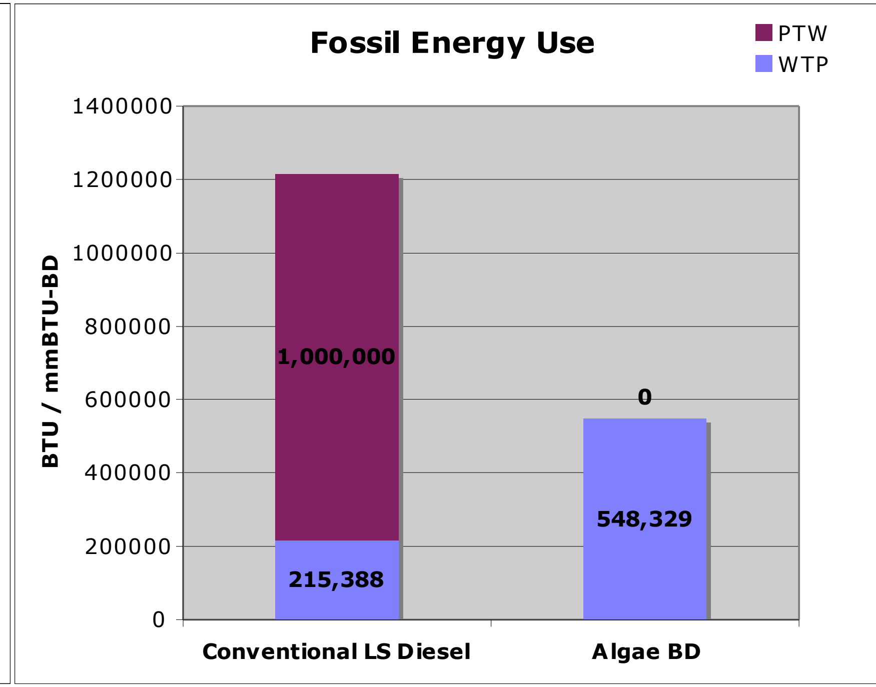
Pre-configured Pathway- See Reports for Details



- Baseline: As shown
- Low-A: Catalytic hydrothermal gasification rather than AD
- Low-B: Different performance parameters

Fossil Energy and GHG Results





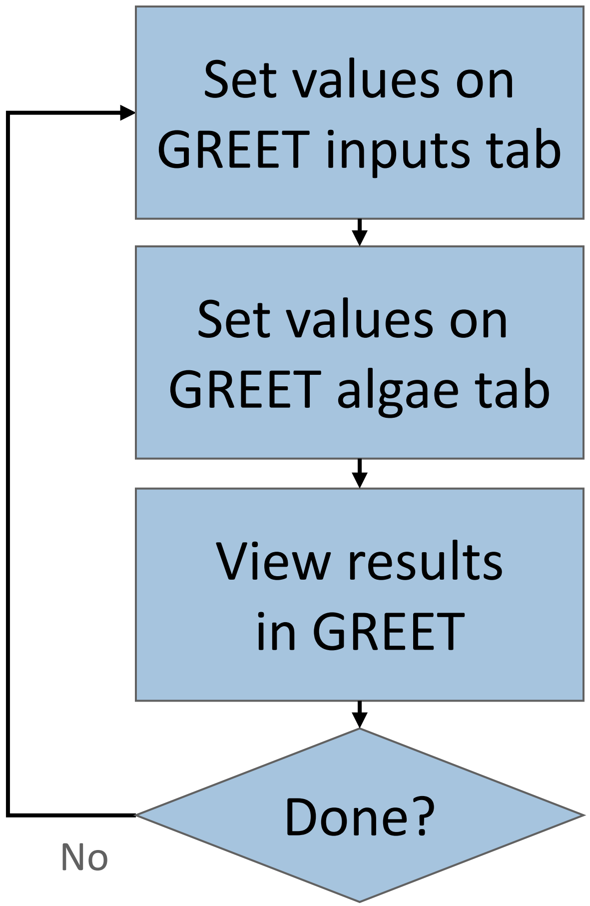
- Baseline scenario has significant GHG reduction
- Accurate treatment of recovery (AD, CHP) is essential
  - 128,000 BTU-electricity imported (fossil) per mmBTU of biofuel
  - Would be 514,000 BTU-electricity without AD recovery
  - 76% of N and 100% of P recovered

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

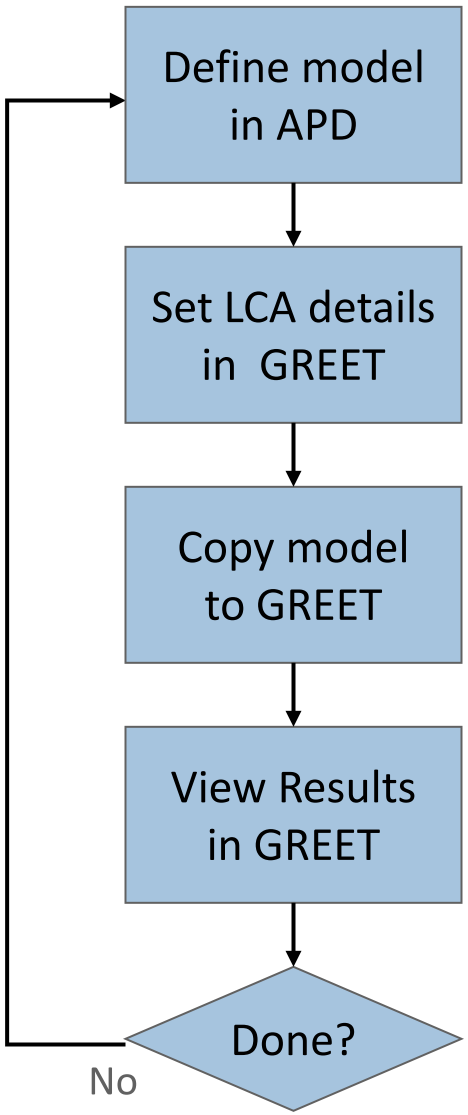
Workflow for Pre-configured Pathway

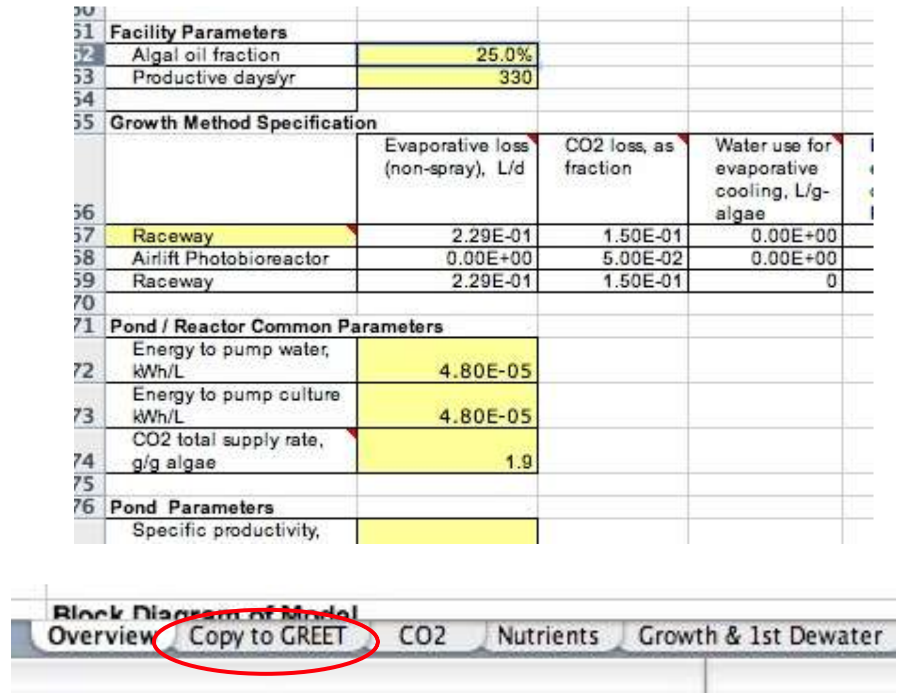


- Set feedstock in Sec. 8.1 to, “algae.”
- Consider share in BD, Sec. 11.1
- Co-product treatment, transportation
- Vehicle and fuel

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

Demonstration 1

- Examining pre-configured pathway: Basics
  - Details to be covered by Jeongwoo separately
  - Crucial configuration
  - Where to find results

- Quick tour of APD
  - Organization: Worksheets
  - Process selection, process parameters, process description
  - “Copy to GREET” operation including GREET1_2011 location

Key Concepts in APD

WTP, PTW, WTW Definitions for Algae

Nutrients:

CO_2 transport & transfer
N, P fertilizer production & transport
Water

Algal Lipids:

Production, transport, and storage
Energy & nutrient recovery
Co-product transport & use

Fuel:

Production, transport, and storage

Vehicle:

Vehicle use

Well-to-Pump (WTP) | **Pump-to-Wheels**

Well-to-Wheels (WTW)

Process Description

- Each process is described by three blocks:

1) Linkage block
   - Describes key outputs
2) Materials block
   - Direct material consumption
3) Process fuels
   - Direct energy consumption

"Per gram output"

Dry-gram algae <u>out</u> of operation

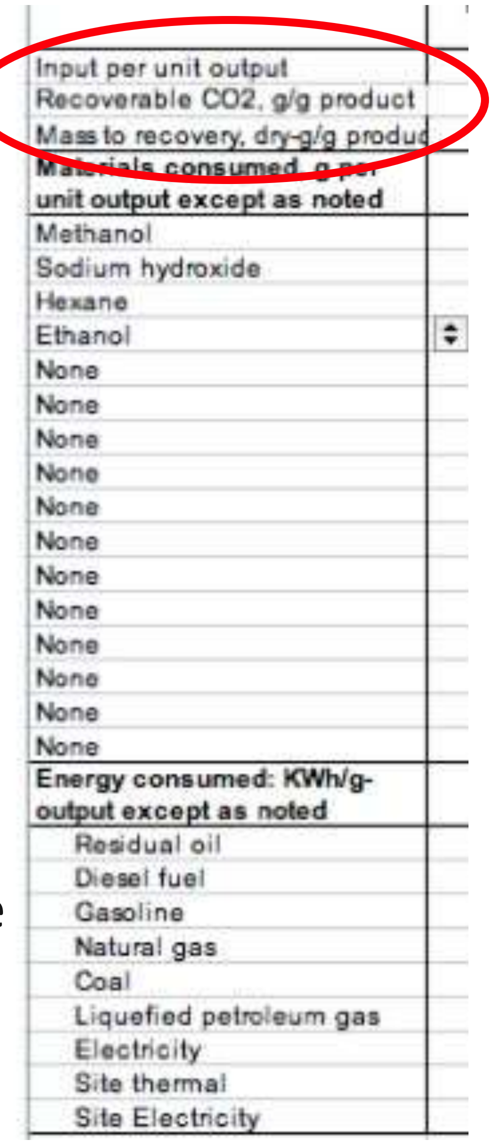
Input per unit output		
Recoverable CO2, g/g product		
Mass to recovery, dry-g/g produ		Block 1: Linkage block
Materials consumed, g per unit output except as noted		
Methanol		
Sodium hydroxide		
Hexane		
Ethanol		
None		
None		
None		
None		
None		Block 2: Material inputs
None		
None		
None		
None		
None		
None		
None		
Energy consumed: KWh/g-output except as noted		
Residual oil		
Diesel fuel		
Gasoline		
Natural gas		
Coal		Block 3: Process fuel inputs
Liquefied petroleum gas		
Electricity		
Site thermal		
Site Electricity		

Linkage Block

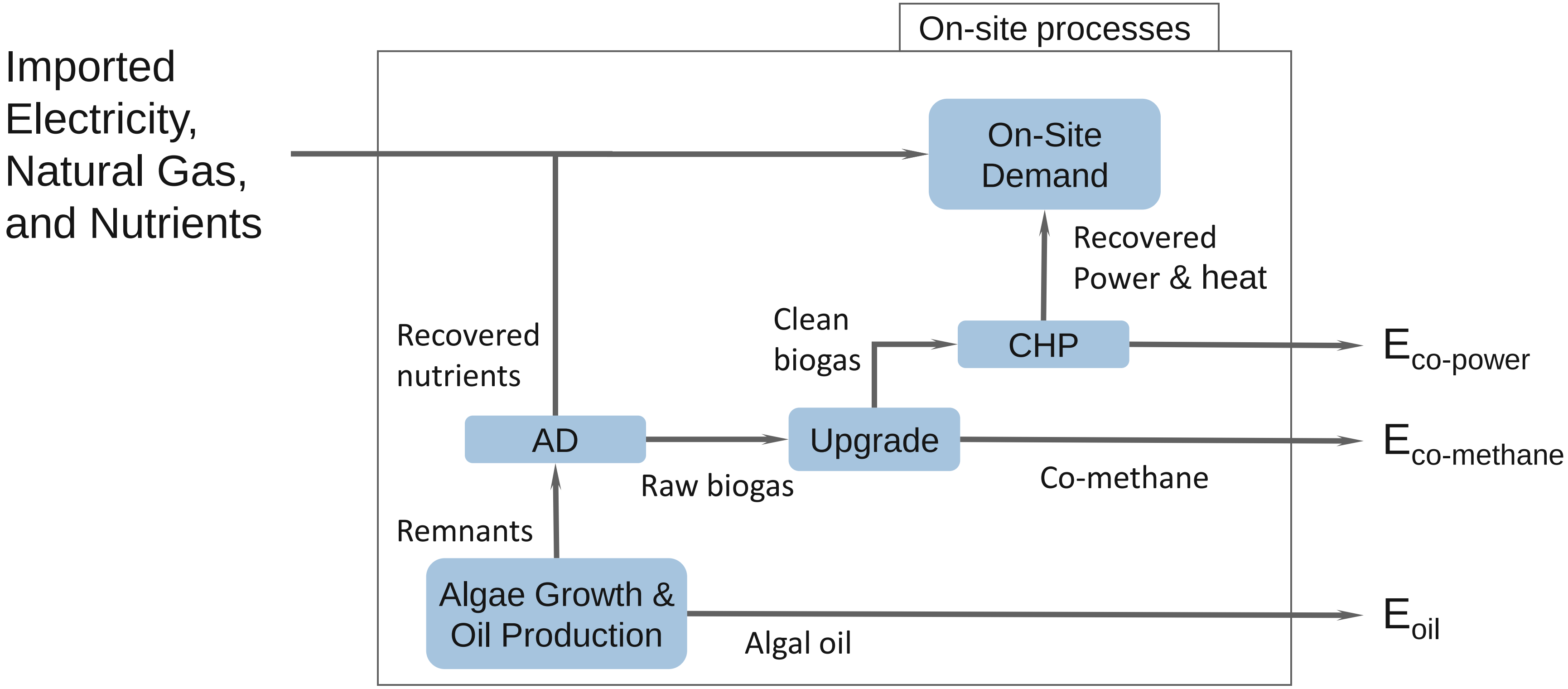
- Input per unit output
  - Enables chaining unit-operations into a pathway

Worksheet Name	Meaning of Input per Output Value
CO_2	Not used
Growth and 1st Dewater	Grams of CO_2 per gross dry-gram of algae grown
Remaining Dewatering	Dry-gram of algae required to produce one dry-gram of dewatered algae
Extraction	Dry-gram of dewatered algae required to produce one gram of extracted lipids
Recovery	Not used; material and fuel consumption are per dry-gram of material sent to Recovery

- Recoverable CO_2
  - Accounts for CO_2 that can be returned to culture
  - Example: CO_2 in CHP flue gas
- Mass to recovery
  - Describes flows to biogas production on dry-gram basis
  - Example: Residues after lipid extraction



Site-Electricity and Site-Thermal



On-site combined heat and power (CHP) allows energy recovery

- Model must flag inputs as "site" if they can be satisfied from CHP
- On-site pump electricity consumption
  - Example of Site-electricity
- Regional extraction center electricity consumption
  - Example of "Electricity"

Energy Units

- <u>All</u> energy consumptions are in KWh
  - Electrical
  - Fuels (NG, coal, etc.)
    - Specify <u>gross</u> energy consumed
    - Example: 3412 BTU of NG <u>*input*</u> to a boiler would be 1 KWh NG
  - Site-thermal
    - Odd-ball: Specify <u>net</u> heat
    - Example: 3412 BTU <u>*output*</u> from a boiler would be 1 KWh site-thermal

Example: Centrifuge

- A centrifuge requires 3.29e-3 KWh per liter influent containing 10 wt% algae. 95% of the algae are recovered, the balance going to anaerobic digestion.

  - Input per output = (1 dry g algae in)/(0.95 g algae out) = 1.05
  - Mass to recovery = 1.05 grams in - 1.0 grams out = 0.05 g
  - Recovered CO_2 = 0
  - Site electricity = (3.29e-3 KWh/L) / (95 dry-g Algae out per L)
    = 3.45e-5 KWh/dry-g algae

Demonstration 2

- Nutrient tools
  - What they do
  - How they connect to GREET

- Configure a new process and run it
  - Modify extraction: regional center
  - Data from Xu et al.

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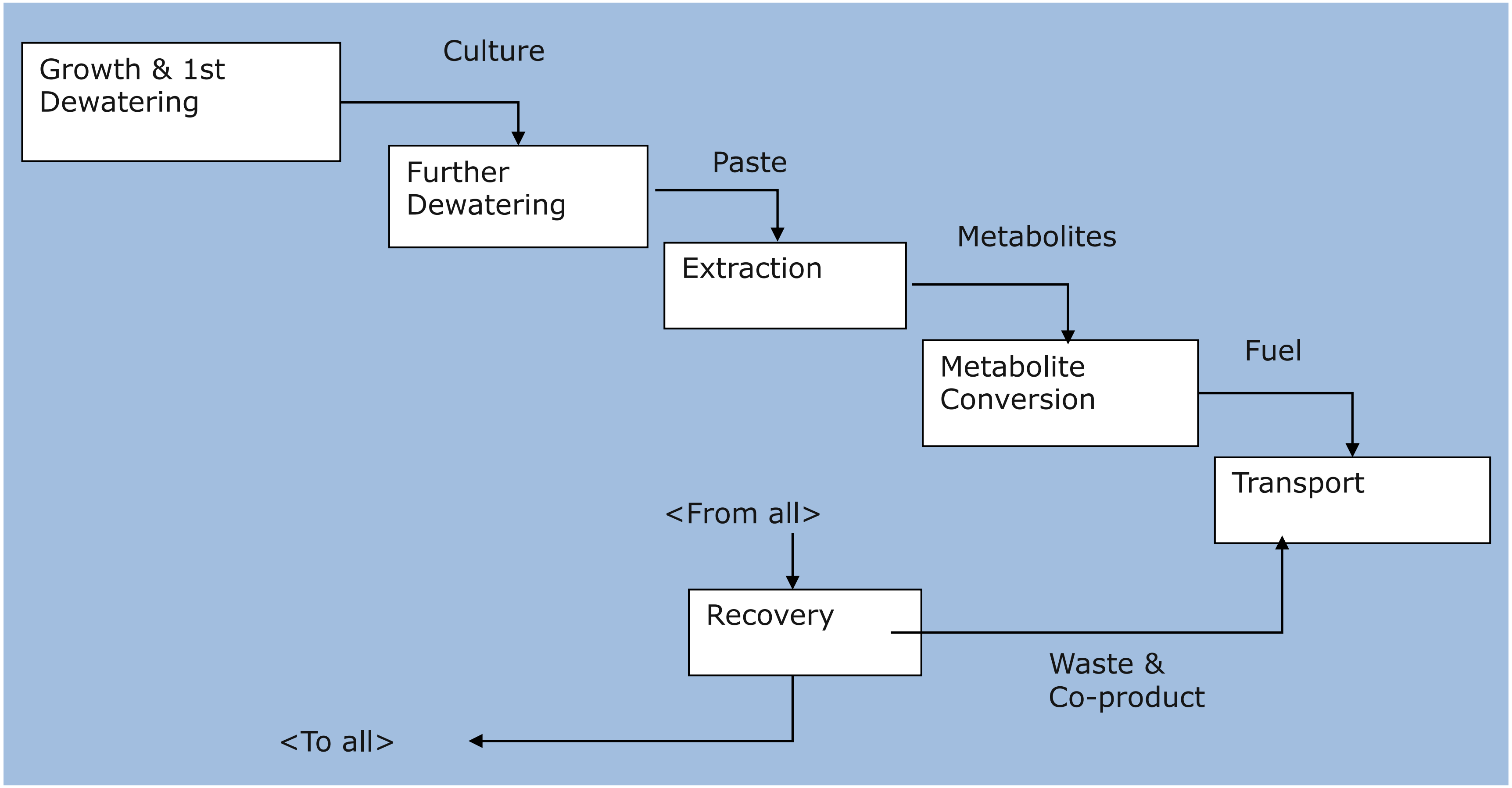
Additional Slides

Pathway Abstraction in APD

- Organizes process inventory, accounting, and reporting
- Helps user know where to plug-in and set parameters



APD Example: Process Selection for Dewatering

Net-Process Summary		Step 1	Step 2	Step 3	Step 4
	Summary of remain-ing 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
None	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
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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

Details for the Baseline Scenario Model

Growth, Harvest, and Extraction

Raceway (pond) → 0.5 g/L → Flocc. & Settle → 10 g/L → DAF → 100 g/L → Centrifuge → 200 g/L → Homogenizer → Wet Hexane Extraction

Raceway (pond):
25 cm/s
48 kWh/ha/d
2.2 g-CO_2/g-algae
(15% CO_2 loss)
1.5m sump
0.6 cm/day
25 g/m^2/d
25 wt% lipid
25 wt% protein
50 wt% carbohydrate
C:N:P = 103 : 9.8 : 1
50 wt% carbon

DAF:
90% effic.
CAPDET
1.5e-4
KWh/dry-g

Centrifuge:
95% effic.
1 HP/gpm

Homogenizer:
90% effic.
25 kWh/dry-ton
EPA/Davis/GEA
Niro Soavi

Wet Hexane Extraction:
95% effic.

Recovery

Anaerobic Digestion → biogas → CHP

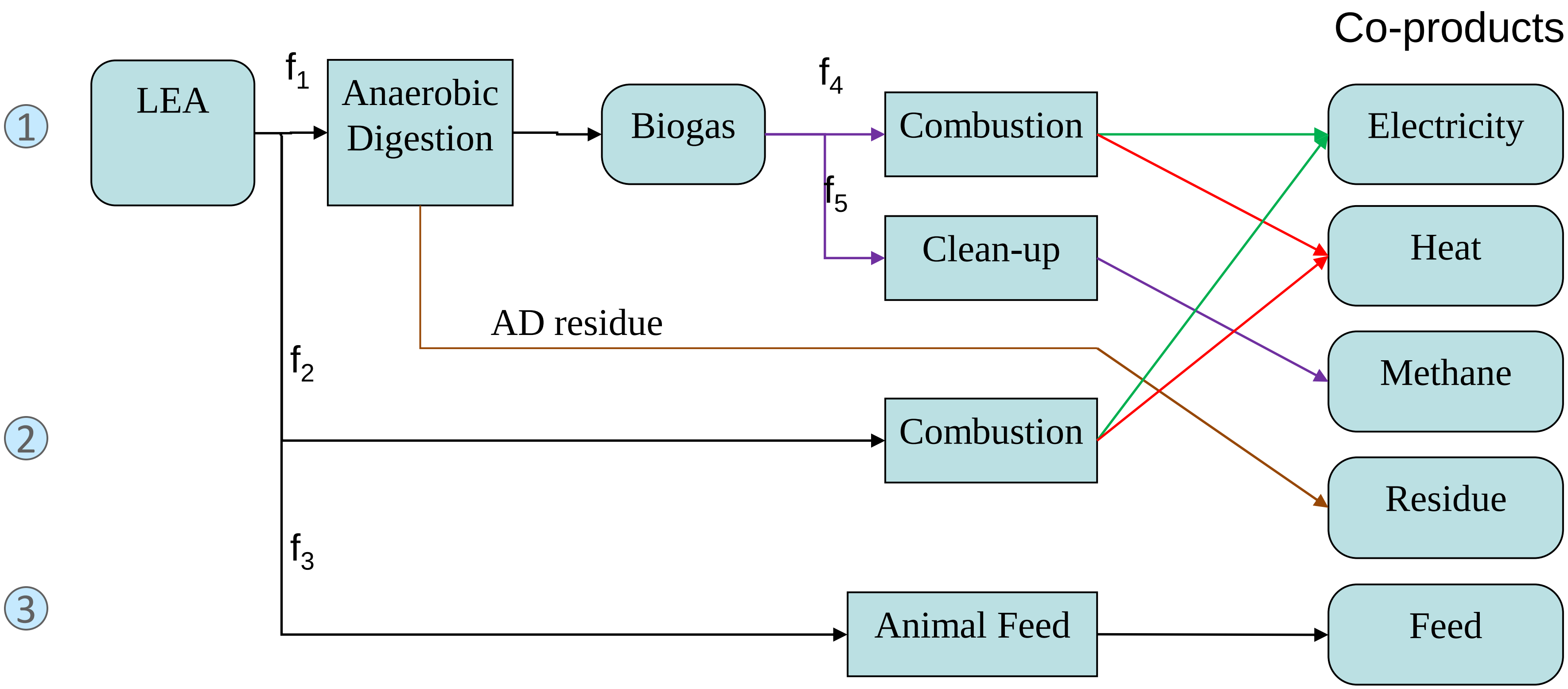
Anaerobic Digestion:
0.3 L/g-TS
67% CH_4

CHP:
33% Elect.
76% Total

g/g-algae

	N	P
New	0.014	0.0063
Recovered	0.042	0.0063

GREET: Co-Product Handling is a Key Issue



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

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Nutrient Flow Accounting