DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Waste-To-Energy Techno-Economic Analysis and Life-Cycle Analysis

March 24, 2015

Conversion

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Goal Statement

- Conduct the techno-economic analysis (TEA) and life-cycle analysis (LCA) of Waste-To-Energy (WTE) pathways to evaluate their economic viability and environmental sustainability
  - Strategic selection of pathway technologies and process alternatives (MSW, biosolids from WWTPs)
  - Transparent TEA and LCA addressing uncertainties and variations in other studies

- Interactions with and outreach to WTE stakeholders
  - Generate TEA and LCA results to agencies, technology developers, and other stakeholders to help identify research, development, and deployment opportunities
  - Interact with researchers and industries to examine critical issues affecting WTE TEA and LCA results
  - Provide TEA and LCA tools to the WTE community

Quad Chart Overview

Timeline

- Started: January 2014
- End: Determined by BETO
- 60% complete

Barriers

- Barriers addressed
  - At-A: Comparable, Transparent, and Reproducible Analyses
  - At-C: Data Availability across the Supply Chain
  - Bt-K: Biological process integration
  - Bt-B: Biomass variation

Budget

	Total Costs FY 10 – FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date)
DOE Funded (NREL)	-	-	$250k	$200k
DOE Funded (ANL)	-	-	$250k	$150k

Partners

- Partners
  - PNNL
- Outreach
  - Industry stakeholders (e.g., local wastewater treatment plants operators)
  - Research institutions and NGOs

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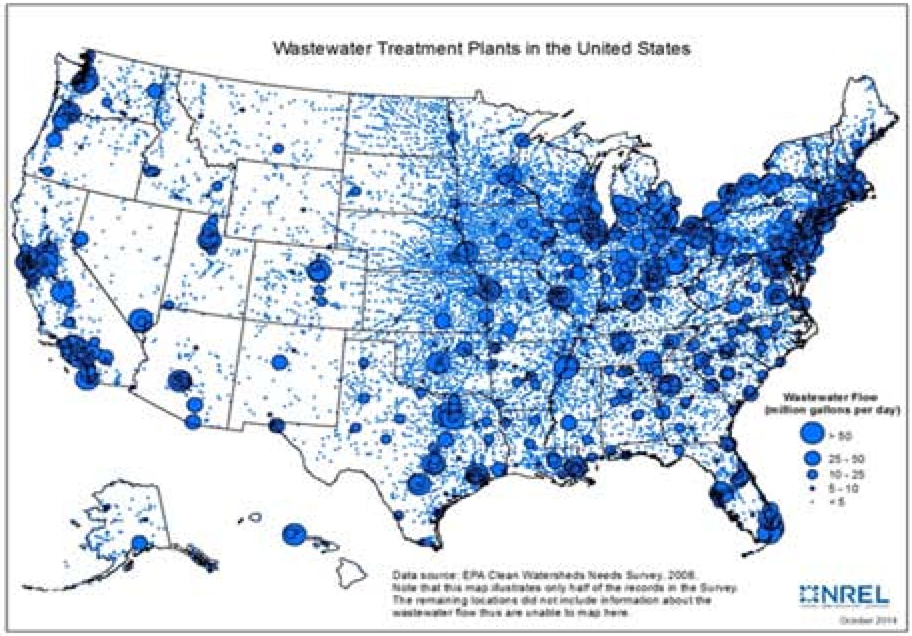
1. Project Overview

- Waste is an emerging biomass resource
  - WTE mitigates methane emissions from current waste treatment processes while recovering energy and producing fuels
  - WTE can utilize existing collection/treatment infrastructure
  - Most of D3 RINs have been from biogas since EPA allowed it
- For high-impact, widespread deployment of WTE pathways, the development of alternative fuels with higher values than biogas, compatible with the current infrastructure, is essential
  - Economic and environmental benefits have yet to be addressed
- Transparent TEA and LCA will evaluate economic viability and environmental sustainability of alternative WTE pathways.
  - Strategically structure sensitivity and uncertainty analysis for data gaps
- Interact with stakeholders (researchers, agencies, industries)
  - Investigate potentials for improving both cost and sustainability by exploring process alternatives, integration, and optimizations

2. WTE TEA and LCA Approach – Resource Assessment

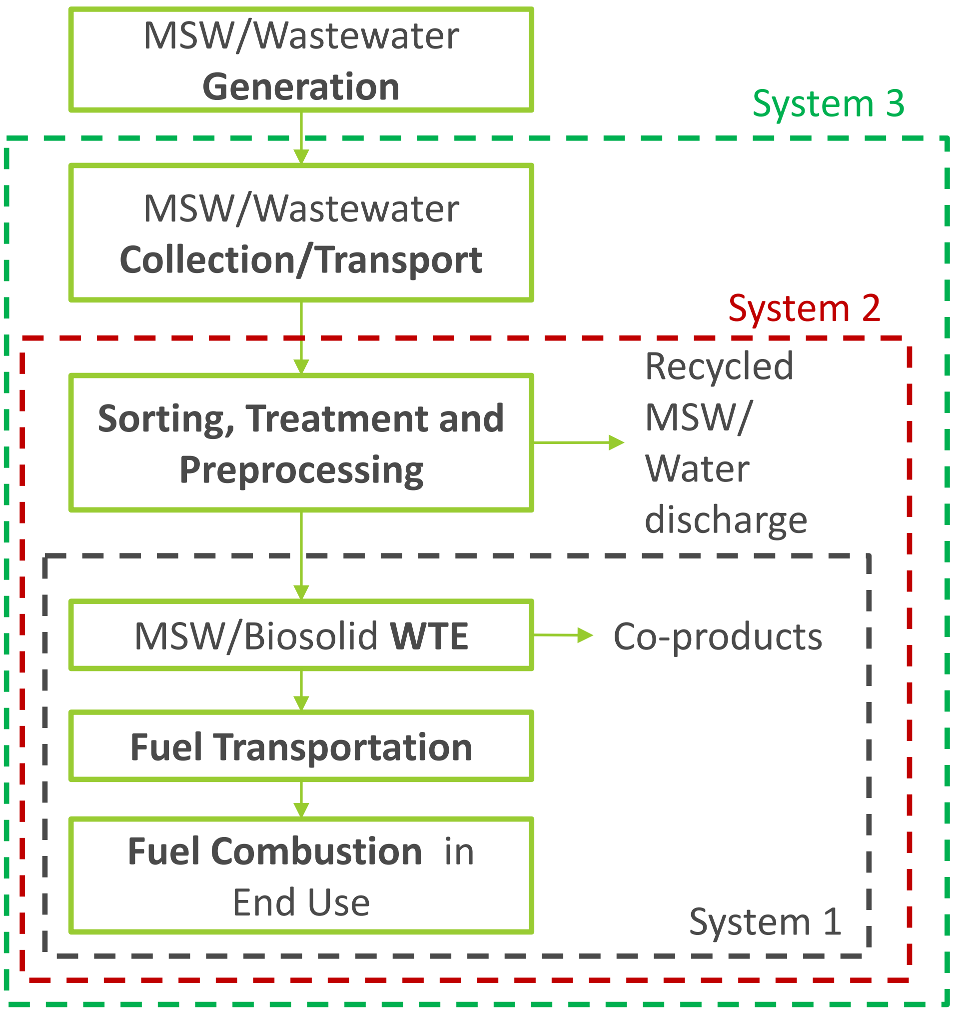


- MSW and biosolids have potential to produce about 590 TBtu (equivalent to 5 billion gallons of gasoline) per year
  - 1/3 of current biofuel production or 1/7 of 2022 biofuel mandates by EISA

- Plant size assumptions
  - ➢ MSW: 2,000 dry tonnes/day estimated on the basis of EPA and BioCycle
  - ➢ Biosolids: 500 dry tonnes/day estimated on the basis of EPA
    - – Key assumptions from literature: Sludge generation, and total and volatile

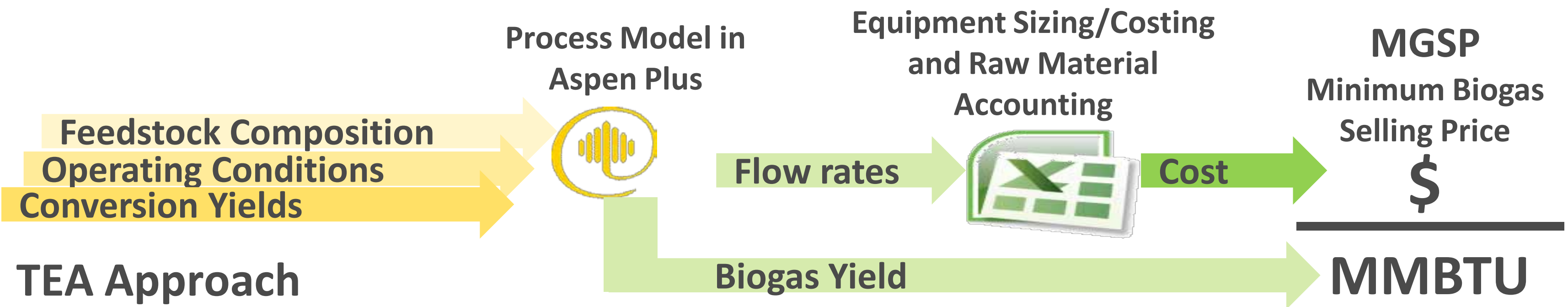
- Analyze application potentials of WTE technologies to existing facilities

WTE LCA Technical Approach: System Boundary and Critical Issues



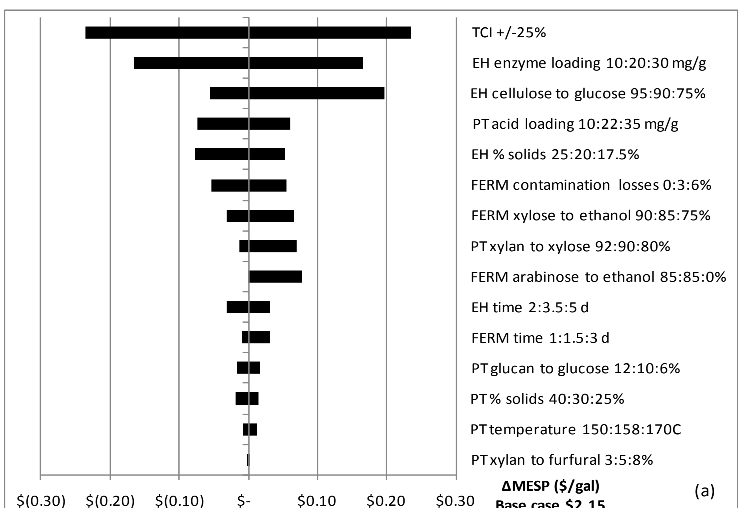
- System boundary: 3 cases
- Tracking carbon's fate
    1. Emissions from **all carbon in waste** are treated as net zero CO_2 emissions
    2. Emissions from **only carbon in biodegradable** material are treated as net zero CO_2 emissions
- Co-product methods in LCA
    - Allocation: mass, volume, market-value
    - Displacement
- Data quality
    - Based on TEA results and a literature review
    - Regional variations in collection energy consumption, feedstock quality, etc.

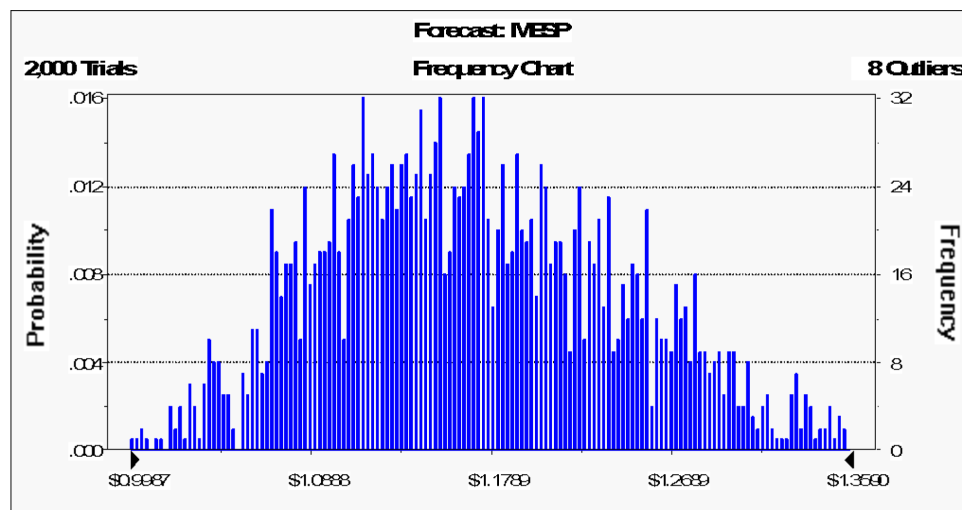
WTE TEA Technical Approach



TEA Approach

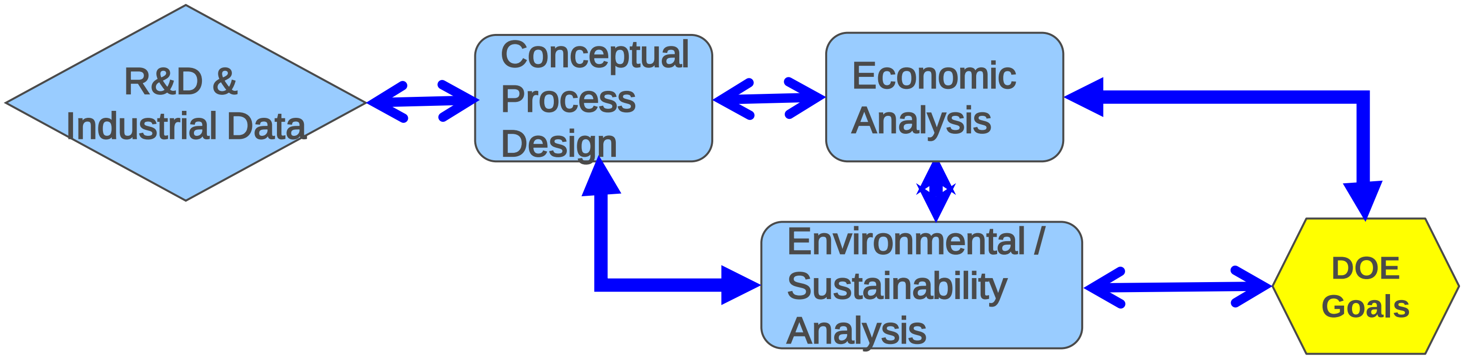
- Modeling is rigorous and detailed with transparent assumptions
- Discounted cash-flow rate of return on investment, equity payback, and taxes
- Provide strategic, comparative cost analysis for various conversion technologies
- Iterative analysis process among R&D, DOE goals, industry, LCA on key technology targets





WTE TEA and LCA Management Approach

- **Project Management**
  - Routine updates to BETO sponsors
    - Quarterly progress reports and conference calls on an as-needed basis
  - Biweekly conference calls between the TEA and LCA teams
  - Communication with stakeholders for data availability, representativeness, and reliability
- **Challenges**
  - Large data sets in literatures and various WTE conversion pathways
  - Provide credible and reliable TEA and LCA information to support decision-making at different level
- **Critical Success Factors**
  - Collaboration and communications with industries to enhance credibility and quality
  - Collaborative and iterative approach among R&D, DOE goals and existing industries using TEA and LCA to evaluate the technologies strategic and to compare various pathways
  - Provide strategic and comparative cost analysis for various conversion technologies



3. WTE TEA and LCA: *Accomplishment*

- Performed resource assessment on municipal solid waste (MSW) and biosolids from WWTPs

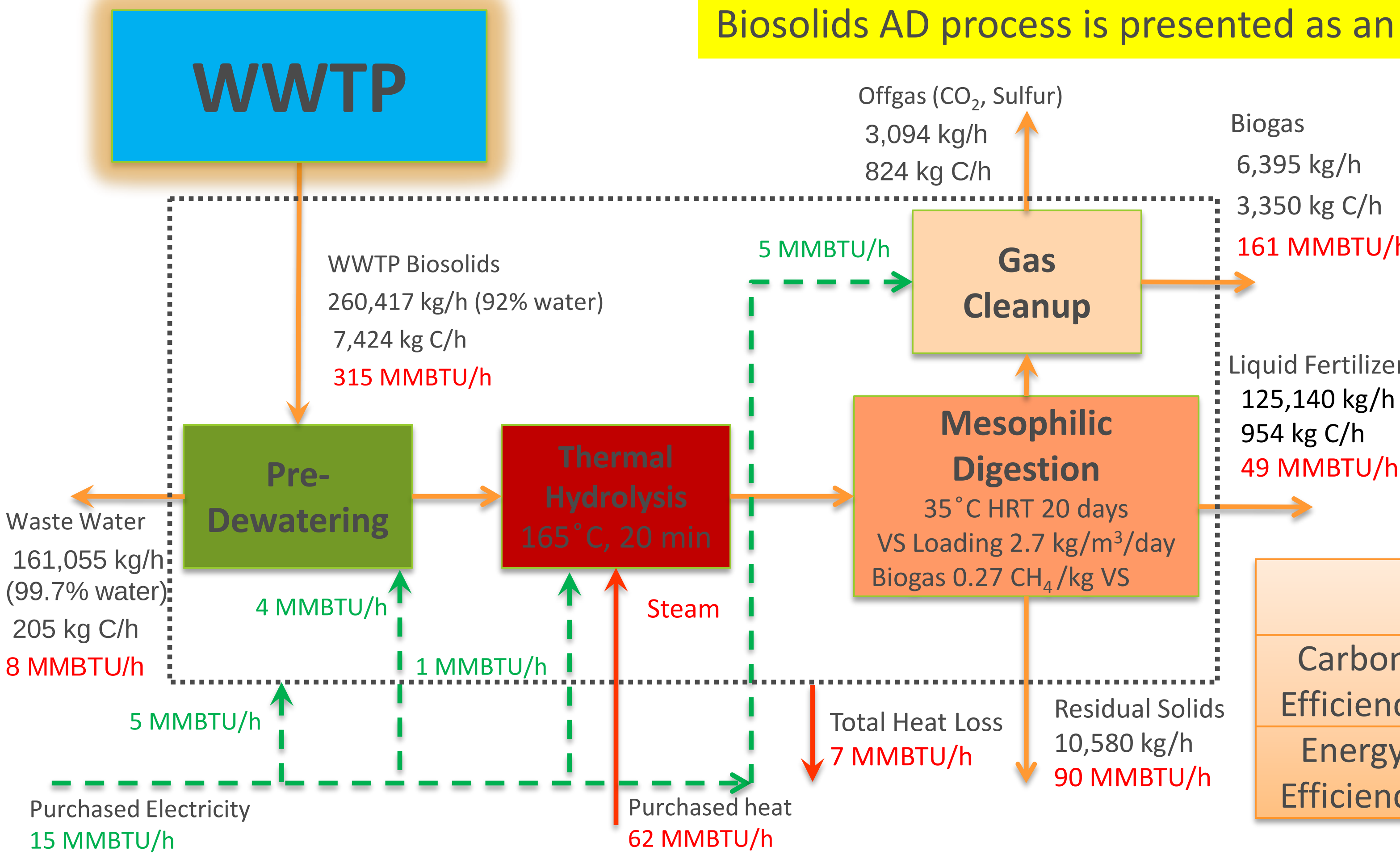
- Established four TEA baseline models (2 feedstocks x 2 processes)
  - Hydrothermal liquefaction (HTL)
  - Anaerobic digestion (AD)

- Conducted LCA for the four WTE pathways

- Performed sensitivity and uncertainty analysis that has identified:
  - Plant scale impacts cost significantly so additional resource analysis is necessary for WTE
  - Biogas yield for anaerobic digestion is key cost driver for improving biogas selling prices
  - Case scenarios analysis implies various potentials of expanding existing WWTP with AD with combination of pretreatment technologies to enhance yield and cost

WTE TEA: *Biosolids Anaerobic Digestion (AD) Co-Located with WWTP*

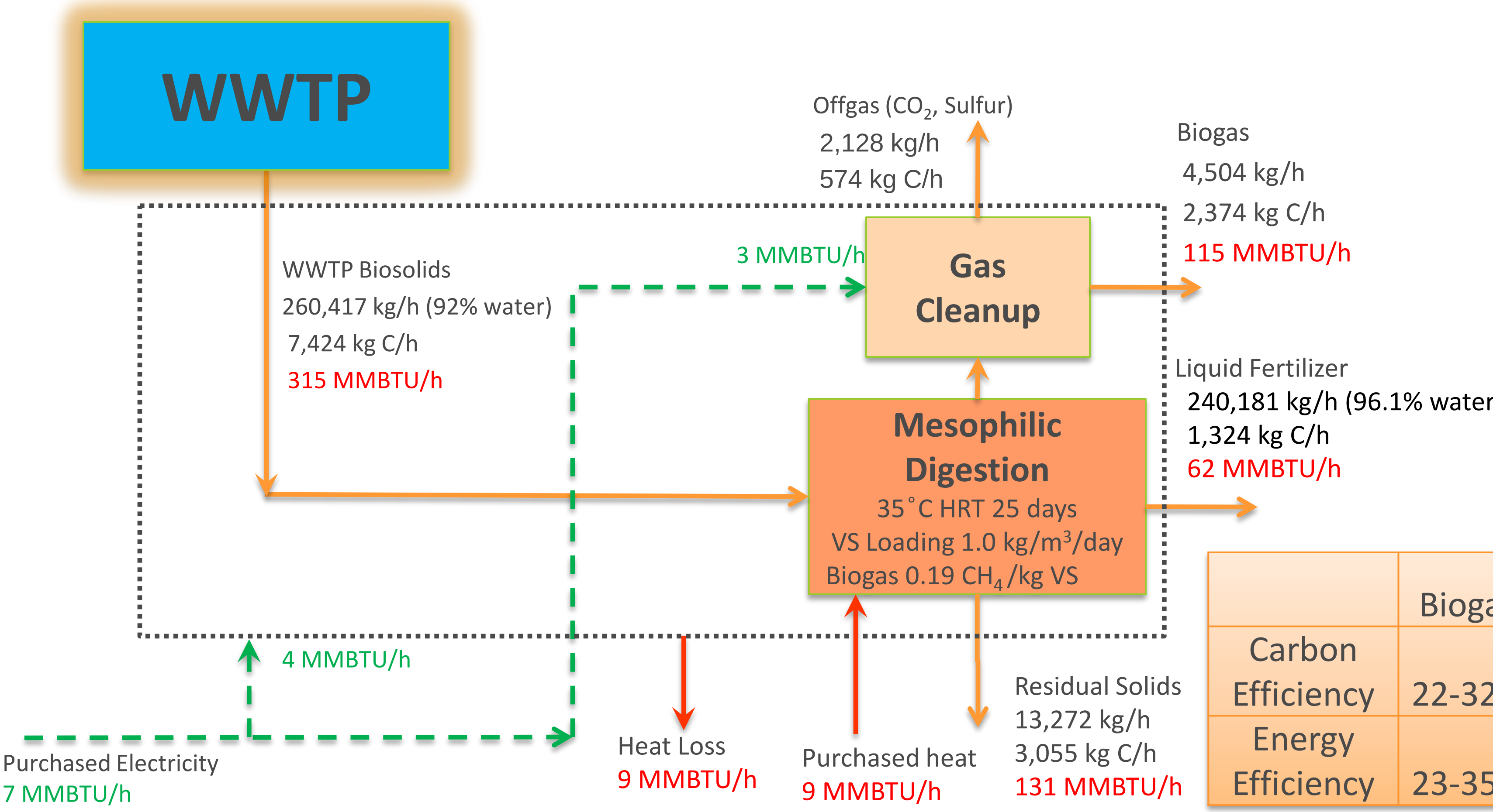
Biosolids AD process is presented as an example



	Biogas
Carbon Efficiency	31-45%
Energy Efficiency	28-41%

- Co-location with 300 MGD WWTP with 500 dry ton per day biosolids
- Biosolids is reduced 55% (dry basis) by AD coupled with thermal hydrolysis, and cost can be further reduced if credit residual solids as EPA class A biosolids.

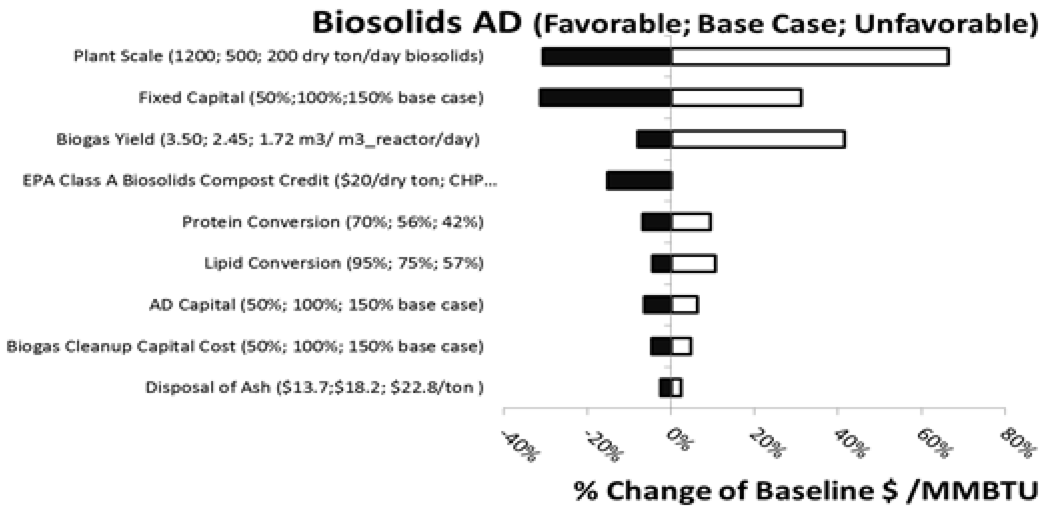
WTE TEA: *Biosolids AD Co-Located with WWTP without Thermal Hydrolysis*

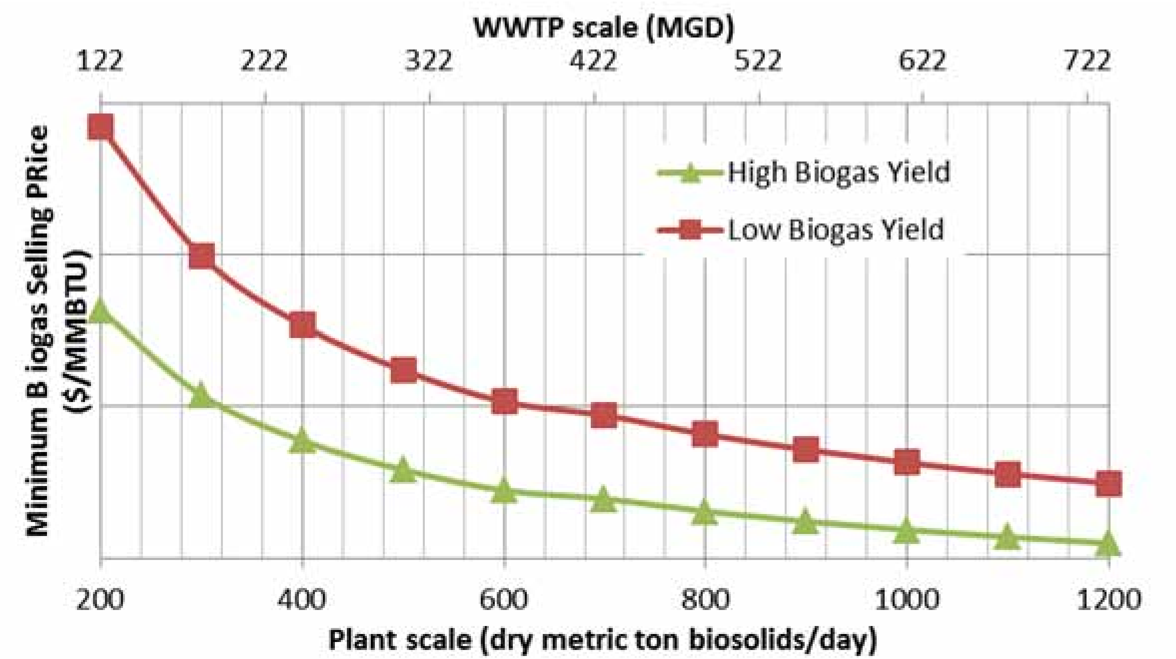


	Biogas
Carbon Efficiency	22-32%
Energy Efficiency	23-35%

- Biosolids is reduced 48% by AD.
- Residual solids cannot be classified as EPA class A biosolids, so still need to be landfilled with additional cost.

WTE TEA: *Sensitivity analysis*





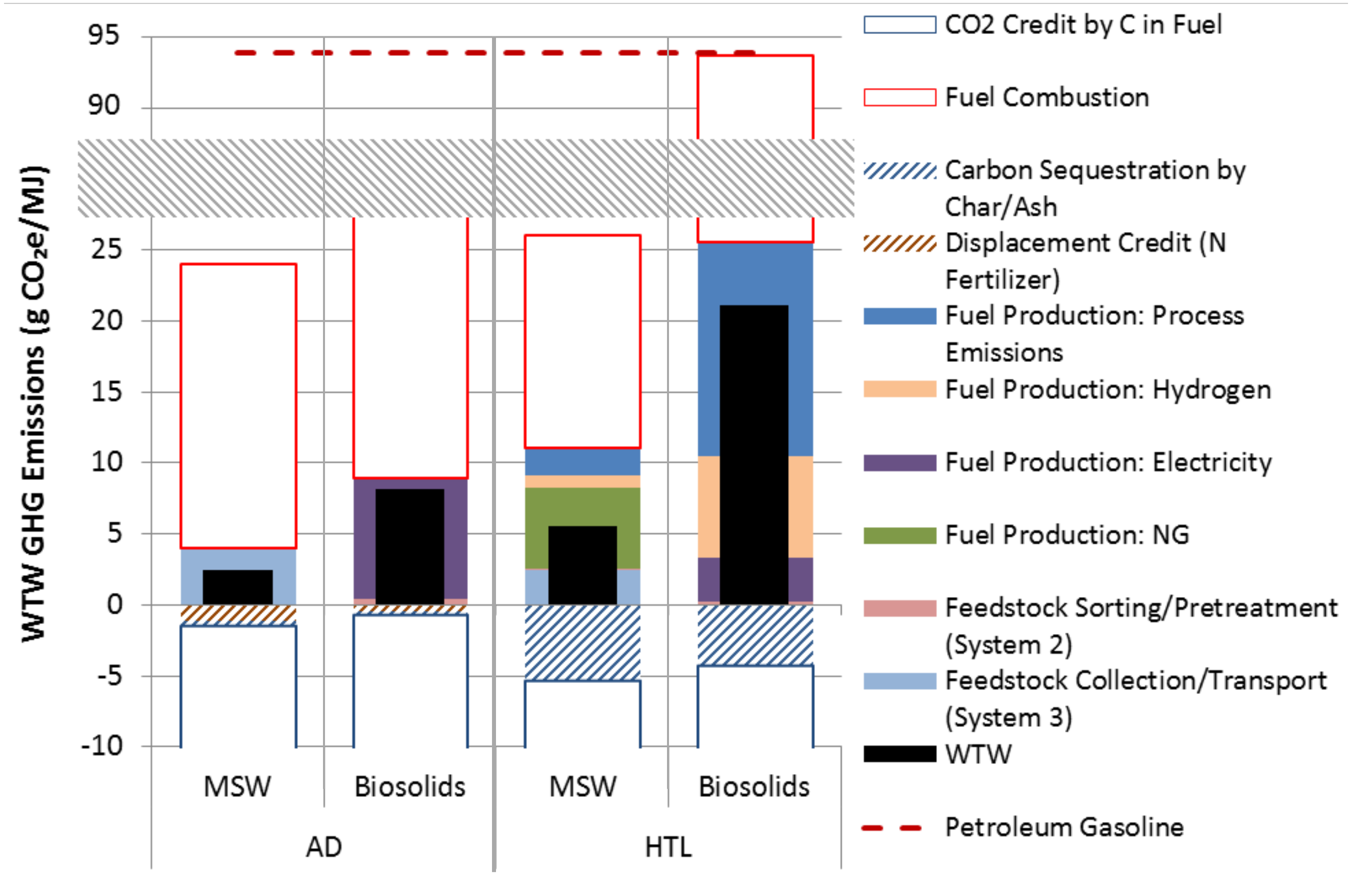
Single point sensitivity analysis

- Identify key cost drivers
- Plant scale, capital expense and biogas yield have the most impacts on minimum biogas selling price

Economies of scale

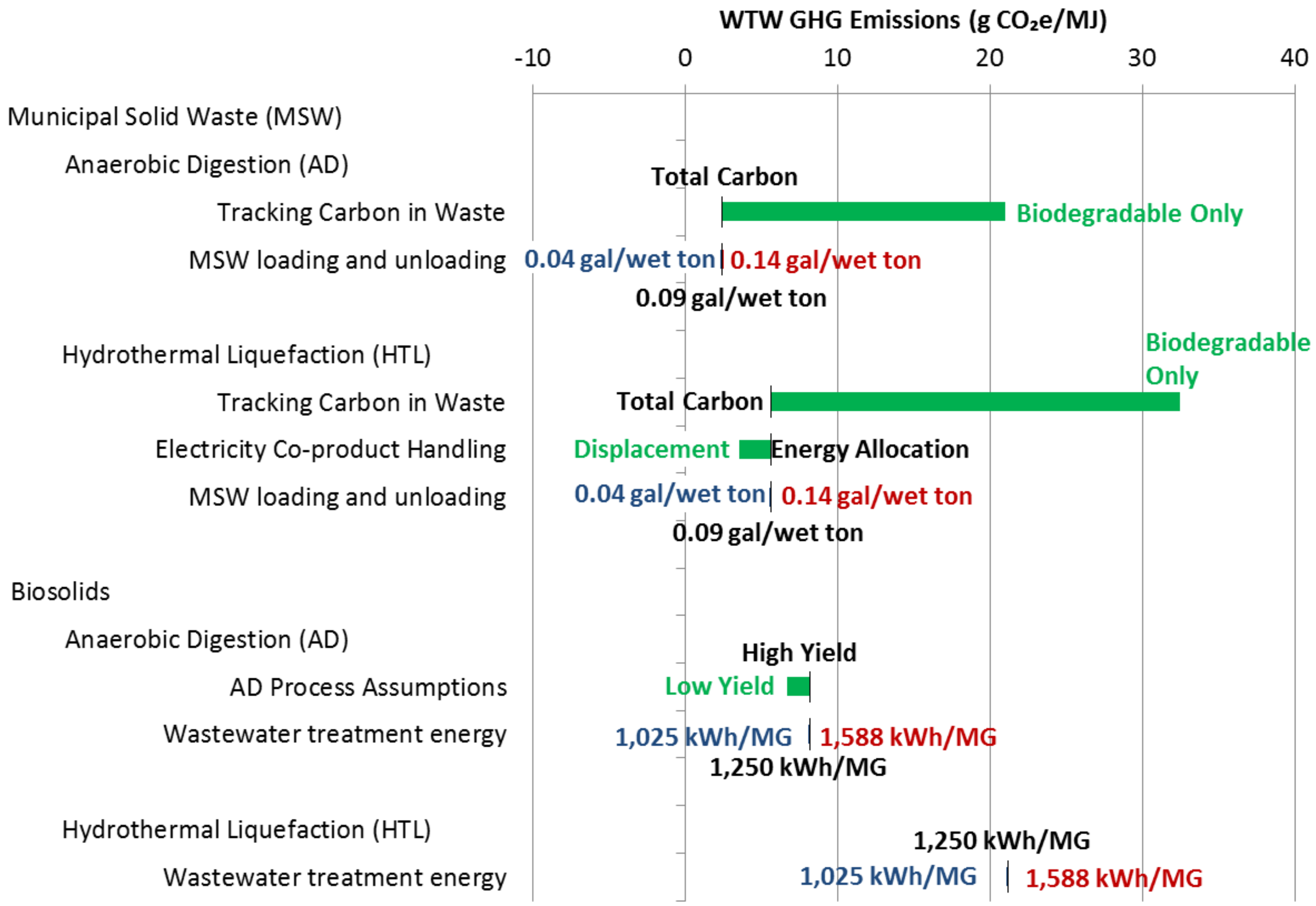
- Clear impact of economies of scale until 700 – 800 dry metric tonnes per day where the cost begins to level off

WTE LCA: WTW GHG emissions are reduced by 77 – 97% relative to petroleum gasoline



- Major GHG emissions sources
  - Biosolid AD: Electricity consumptions; Biosolid HTL: Process CH_4 emissions
- HTL pathways have large GHG emissions credits from carbon in char
- The remaining three pathways are also presented in addition to the example TEA pathway (biosolids-AD) for comparison

WTE LCA: WTW GHG emissions are sensitive to LCA methodology rather than parametric assumptions



4. Relevance of WTE TEA and LCA

- WTE is an emerging technology area of national and BETO's interest
  - Mitigate CH_4 emissions from current waste treatment while recovering energy
  - Utilize existing collection/treatment infrastructure
  - "Urban resource": Short transportation and distribution if any
  - Potential 5 billion gasoline equivalent gallons can fill a gap of the current BETO portfolio (1/3 of current biofuel production or 1/7 of 2022 biofuel mandates by EISA)
  - WTE (especially biogas) has a significant near-term market entry opportunity in the U.S. as EPA allows RINs for WTE biogas
- Transparent WTE TEA and LCA can provide economic viability and environmental sustainability criteria, supporting decision-making at different levels (e.g., BETO, federal and state governments, industry, etc.)
  - Investigate benefits from alternative pathways for high-impact transportation fuels
  - Examine possibility to integrate waste feedstock with biomass
  - Identify key drivers for TEA and LCA results
- Open, transparent TEA/LCA models from this task support BETO's mission
  - Provide consistent, reliable data across WTE pathways
  - Help BETO communicate the benefits of WTE pathways with various stakeholders

5. Future Work

- Investigate key TEA parameters
  - Calibrate TEA baselines with real-world examples
  - Establish reasonable cost ranges due to uncertainties in the data available for WTE, making it difficult to support a single economic target/potential
  - Expand and enhance applications of studied process technologies to existing facilities
- Investigate key LCA assumptions/methodologies
  - Fate of carbon in waste material
  - Analysis on benefits/burdens of diverting waste from additional treatment, otherwise necessary (e.g., landfill, incineration, etc.)
  - CH_4 emissions in AD
- Examine additional process alternatives to increase value proposition
  - Upgrading process to transportation fuels, electricity or bio-products
  - Process intensification or process optimization
- Produce updated TEA and LCA tools/results and peer review publications and communicate them with stakeholders
  - Set as basis for R&D efforts with areas of great potentials
  - Help DOE and industry in identifying near-term R&D opportunities, medium-term economic and sustainability targets, and long-term market penetration goals

Summary

- WTE technologies such as AD have significant near-term market entry opportunity to deploy in the U.S. (e.g., biogas with D3 RIN)
- Established four TEA models (2 feedstocks x 2 processes)
  - In addition to setup baseline models, performed sensitivity and uncertainty analysis
  - Established AD biosolids process alternatives under collaborative efforts with LCA, DOE and inputs from industrial partners
- LCA showed that WTE pathways reduce WTW GHG emissions by 77 – 97% relative to petroleum gasoline
  - WTW GHG emissions are sensitive to LCA methods
  - Calibrated TEA results would provide more reliable, precise LCA results
- Outstanding TEA and LCA issues and additional process alternatives have yet to be fully investigated

Additional Slides

Acronym List

AD	Anaerobic Digestion
D3 RIN	Cellulosic Biofuel
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
HTL	Hydrothermal Liquefaction
LCA	Life-Cycle Analysis
MESP	Minimum Energy Selling Price
MGD	Million Gallons per Day
MGSP	Minimum Biogas Selling Price
MSW	Municipal Solid Waste
RIN	Renewable Identification Number
TEA	Techno-Economic Analysis
VS	Volatile solid
WTE	Waste-To-Energy
WTP	Well-to-Pump
WTW	Well-to-Wheels
WWTP	Wastewater Treatment Plant

Quad Chart Overview (NREL)

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  - At-C: Inaccessibility and unavailability of data
  - Bt-K: Biological Process Integration

Partners

- Partners
  - NREL (50%); ANL (50%)
- In-kind
  - Industry stakeholders (e.g., local wastewater treatment plants operators)
  - Research institutions and NGOs

Quad Chart Overview (ANL)

Timeline

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  - NREL (50%); ANL (50%)
- In-kind
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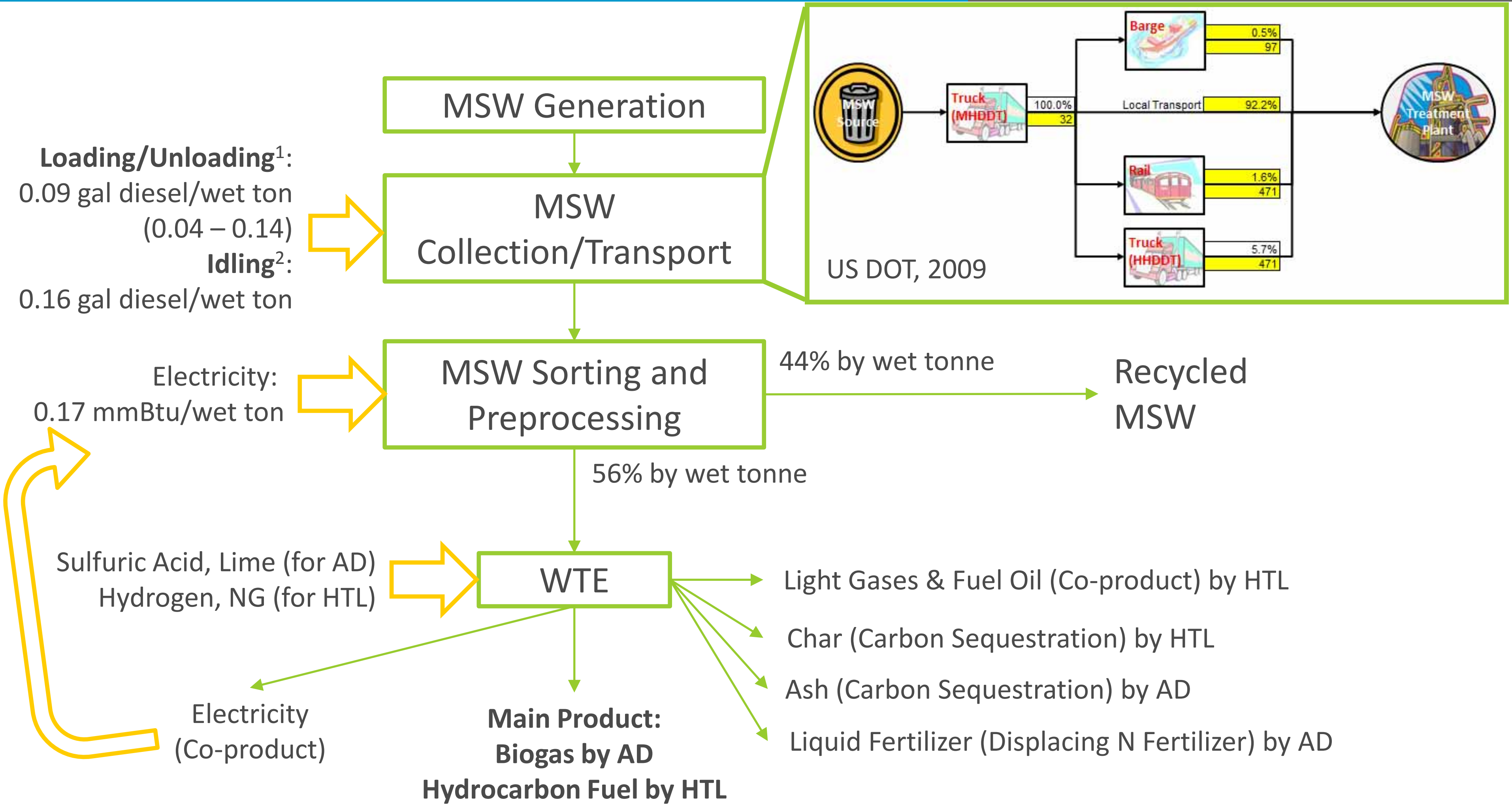
Tracking Carbon's Fate

- Low Bookend: All carbon emissions derived from waste feedstock are treated as net zero CO_2 emissions

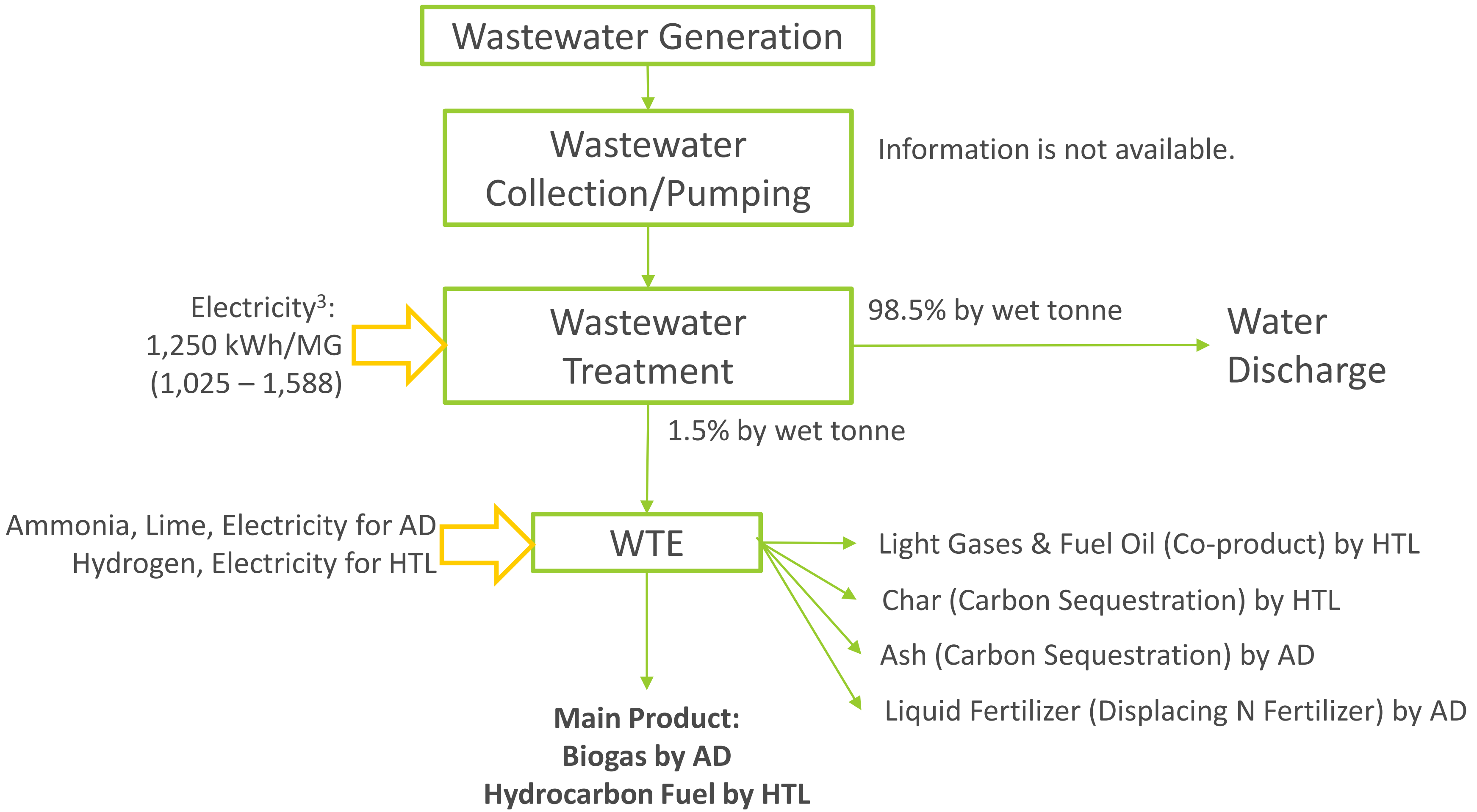
- High Bookend: Carbon emissions derived from only biodegradable materials are treated as net zero CO_2 emissions
  - Carbon in non-biodegradable materials would stay in the form for a long period of time if have not processed/combusted, which would release carbon much earlier.
  - Thus, carbon emissions derived from only biodegradable materials are treated as net zero CO_2 emissions
  - Waste components in MSW
    - Biodegradable: Paper, textile, wood and other organics
    - Non-biodegradable: Glass, metal, plastics, leather/rubber and other materials
  - All biosolids is assumed biodegradable.

MSW LCA System Boundary



- 1. Kosmicki, B., 1997. Transfer station process model. RTI International, Research Triangle Park, NC.
- 2. RTI International, 2012. Municipal Solid Waste - Decision Support Tool [WWW Document]. URL https://mswdst.rti.org/ (accessed 6.30.14)

WWTP Biosolids LCA System Boundary



- 3. WEF, 2009. Energy Conservation in Water and Wastewater Facilities - MOP 32, 1 edition. ed. McGraw-Hill Professional, Alexandria, VA : New York

Anaerobic Digestion (AD)

	Unit (Per mmBtu of Biogas)	MSW	Biosolids (High yield)	Biosolids (Low yield)
Inputs				
Feedstock	dry tonne	0.21	0.15	0.22
Sulfuric Acid	kg	5.6		
Lime	kg	0.2	0.05	0.104
Electricity	mmBtu		0.125	0.049
Outputs				
Biogas	mmBtu	1	1	1
Electricity (Excess)	mmBtu	0.666‡		
Liquid Fertilzer†	wet tonne	0.26	0.05	0.07
Ash	kg	2.6	41	61
Process Emissions				
CO	g	20	7	10
NOx	g	20	7	10
SOx	g	12	3	6

† 0.1 – 0.2% of N contents

‡ Including the electricity used in the MSW sorting and preprocessing step

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Hydrothermal Liquefaction (HTL)

	Unit (Per mmBtu of hydrocarbon fuel, light gases and fuel oil)	MSW	Biosolids
Inputs			
Feedstock	dry tonne	0.08	0.10
Hydrogen	mmBtu	0.14	0.16
NG	mmBtu	0.033	
Electricity	mmBtu		0.018
Outputs			
Hydrocarbon fuel	mmBtu	0.747	0.810
Light Gases	mmBtu	0.190	0.180
Fuel oil	mmBtu	0.063	0.010
Electricity (Excess)	mmBtu	0.055‡	
Char†	kg	3.0	2.3
Process Emissions			
VOC	g		116
CO	g	81	0.56
NOx	g	14	912
SOx	g	5	236
CH_4	g	79	586

† With 67 – 68% of carbon contents, 80% of which is sequestrated

‡ Including the electricity used in the MSW sorting and preprocessing step

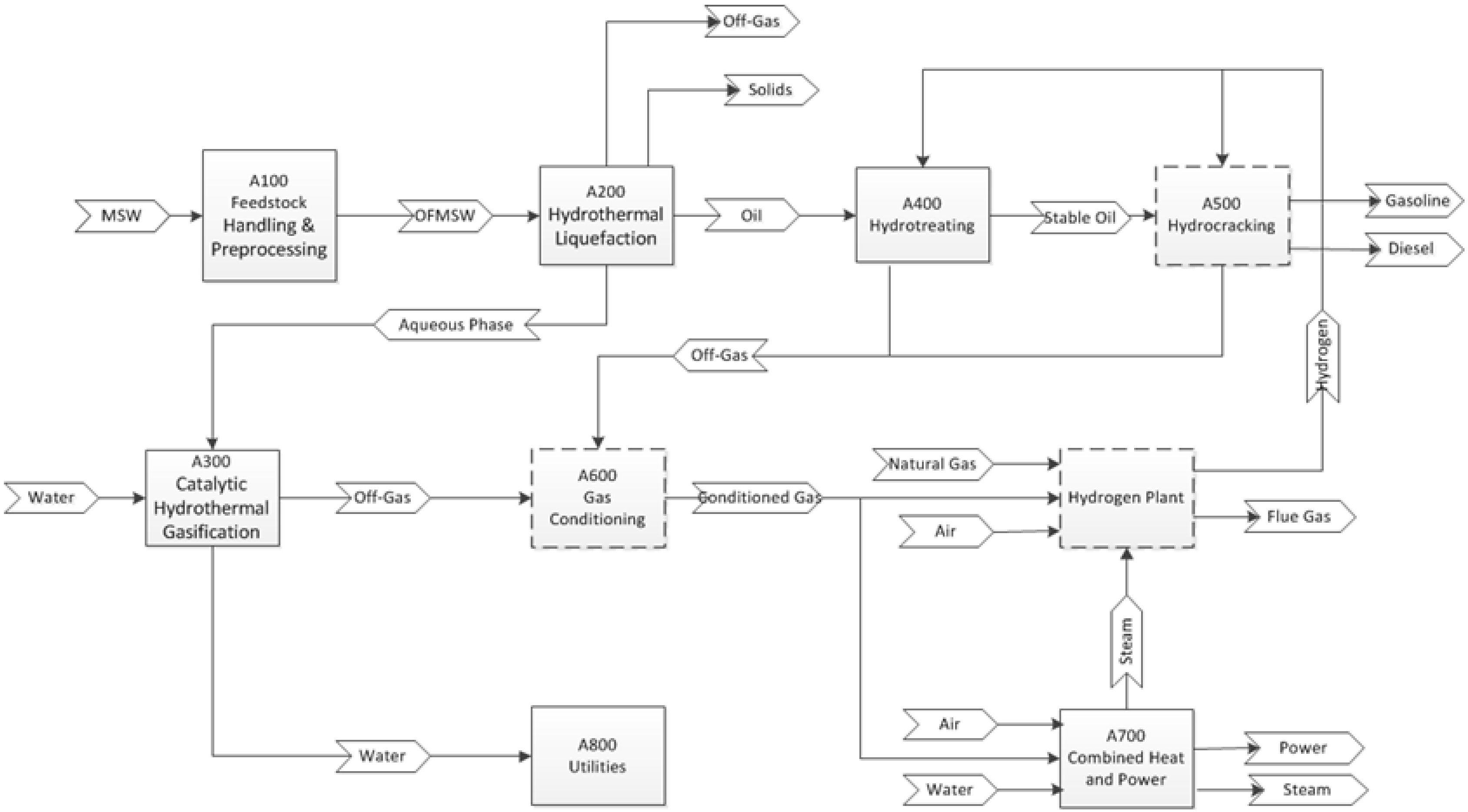
Biosolids Feedstock Composition and Characteristics

	Average	Min	Max	ASPEN MODEL
Basic Characteristics				
Total Dry Solids (TS)	7.6%	0.8%	23.4%	8.0%
Volatile Solids (% of TS)	61.0%	60.0%	62.0%	61.0%
Energy Content (BTU/dry lb)	9,273	6,540	12,500	6851
Component Composition				
Grease and Fats (% of TS)	17.7%	5.0%	65.0%	17.7%
Protein (% of TS)	29.2%	20.0%	41.0%	29.2%
Carbohydrate (% of TS)	9.8%	2.5%	15.0%	11.4%
Ash (% of TS)	39.0%	38.0%	40.0%	39.0%
Elemental Composition				
Carbon (% of TS)	38.4%	36.0%	42.0%	35.6%
Hydrogen (% of TS)	5.4%	4.9%	6.2%	5.0%
Oxygen (% of TS)	11.4%	8.3%	14.5%	14.8%
Sulfur (% of TS)	0.4%	0.3%	0.5%	0.4%
Nitrogen (% of TS)	4.2%	3.6%	5.2%	5.2%
Ash (% of TS)	39.0%	38.0%	40.0%	39.0%

MSW Feedstock Composition and Characteristics

	Generated	Recycled	Non-Recycled	Landfilled	EISA MSW	All Convertible MSW
Metal	20	6	14	11	3	3
Glass	12	3	8	7	2	2
Plastics	32	3	29	24	7	24
Paper	69	44	24	20	6	20
Leather	5	0	5	4	4	4
Rubber	3	1	2	1	0	1
Textiles	14	2	12	10	10	10
Wood	16	2	13	11	11	11
Food	36	2	35	28	28	28
Yard Trimmings	34	20	14	12	12	12
Other	11	3	8	7	7	7
Total	325	108	218	179	121	163
Total Organics	98	49	50	41	27	41
Organic% (Paper, Textiles, Wood)	30%	46%	23%	23%	22%	25%
Moisture %	23%	19%	25%	25%	25%	25%
Others %	47%	46%	23%	23%	22%	25%

Thermochemical HTL Pathway for MSW



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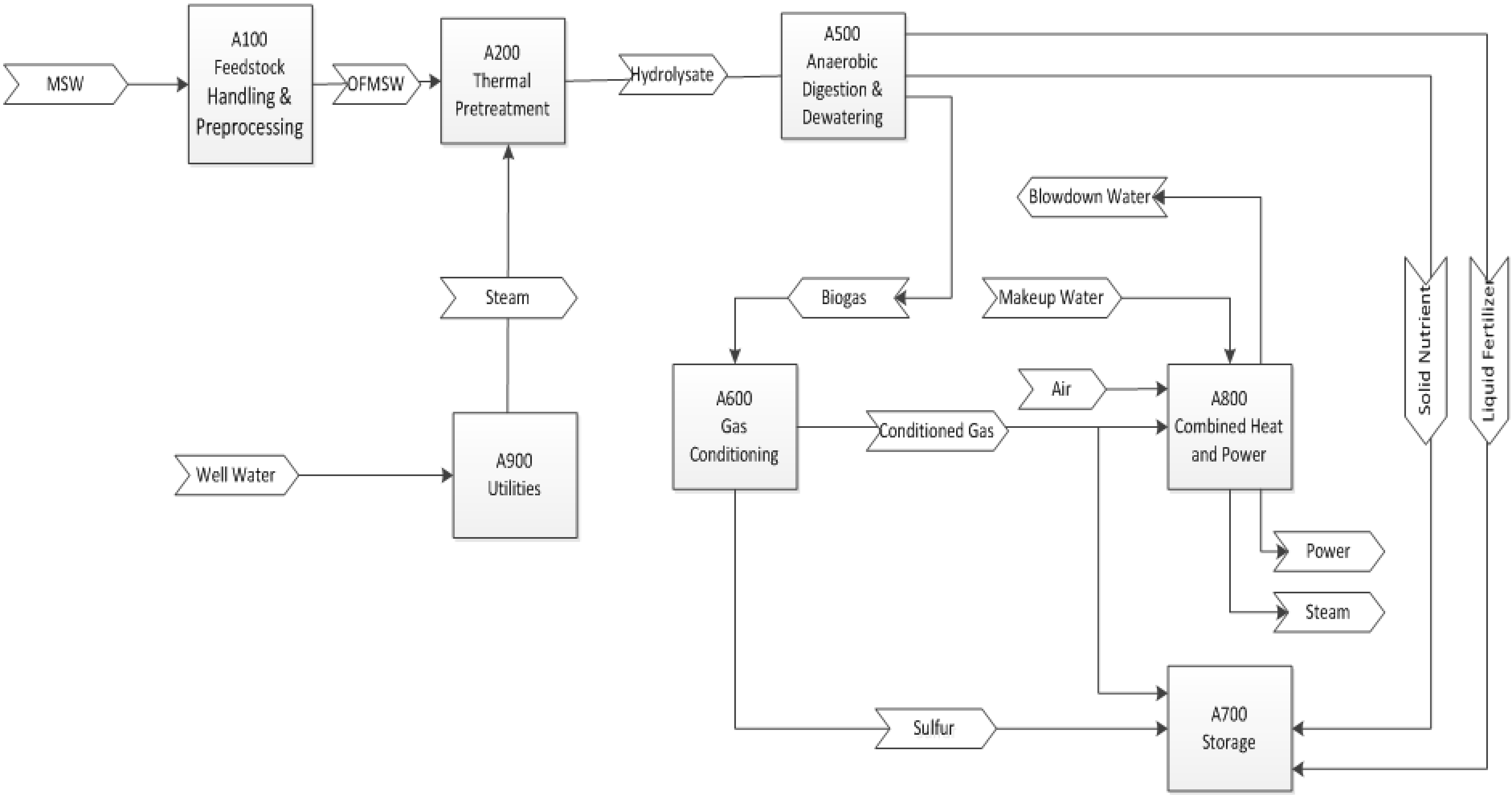
Biological Anaerobic Digestion Pathway for MSW



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