Catalytic Pyrolysis of Human Feces for Biofuel Production

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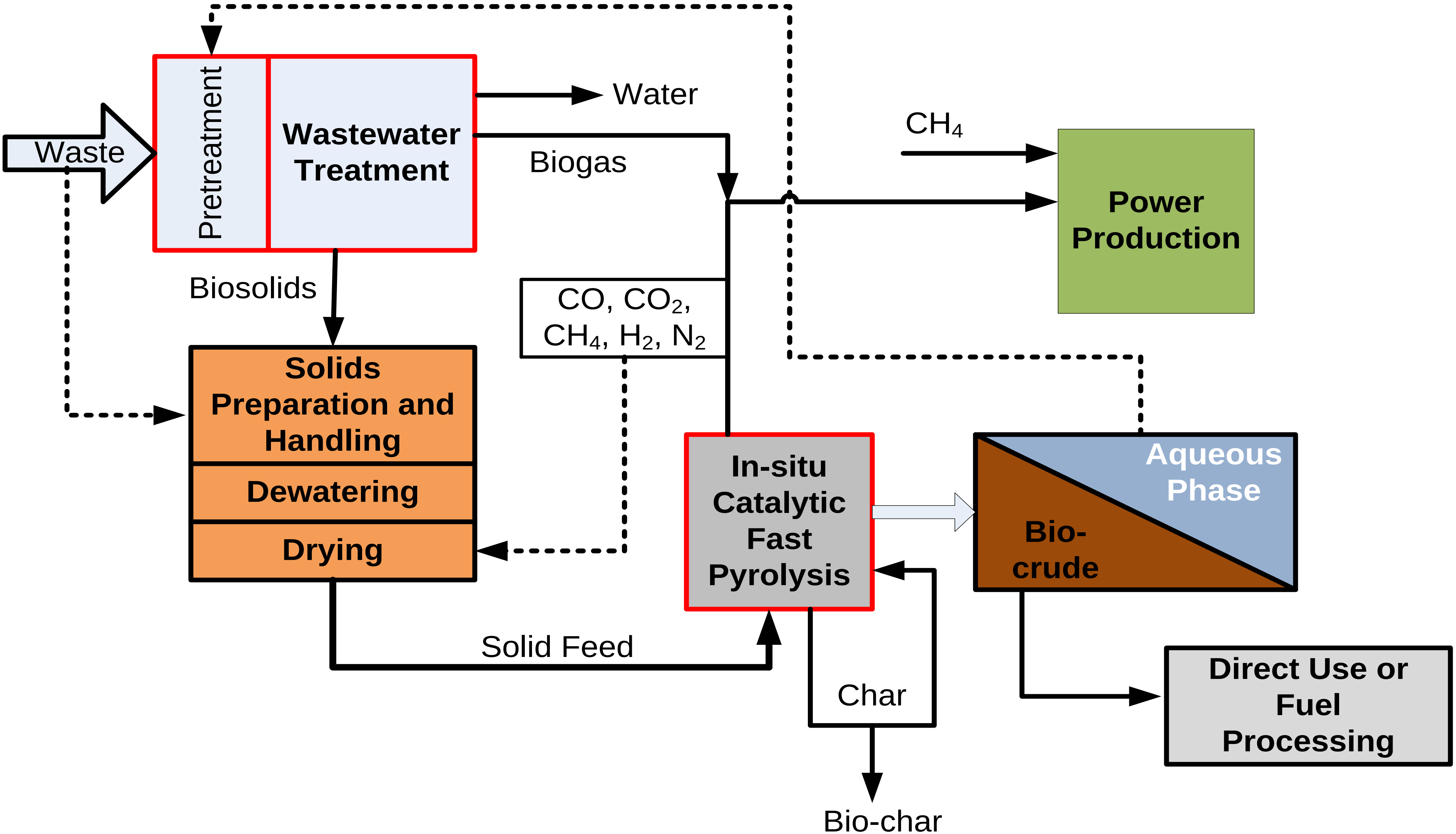
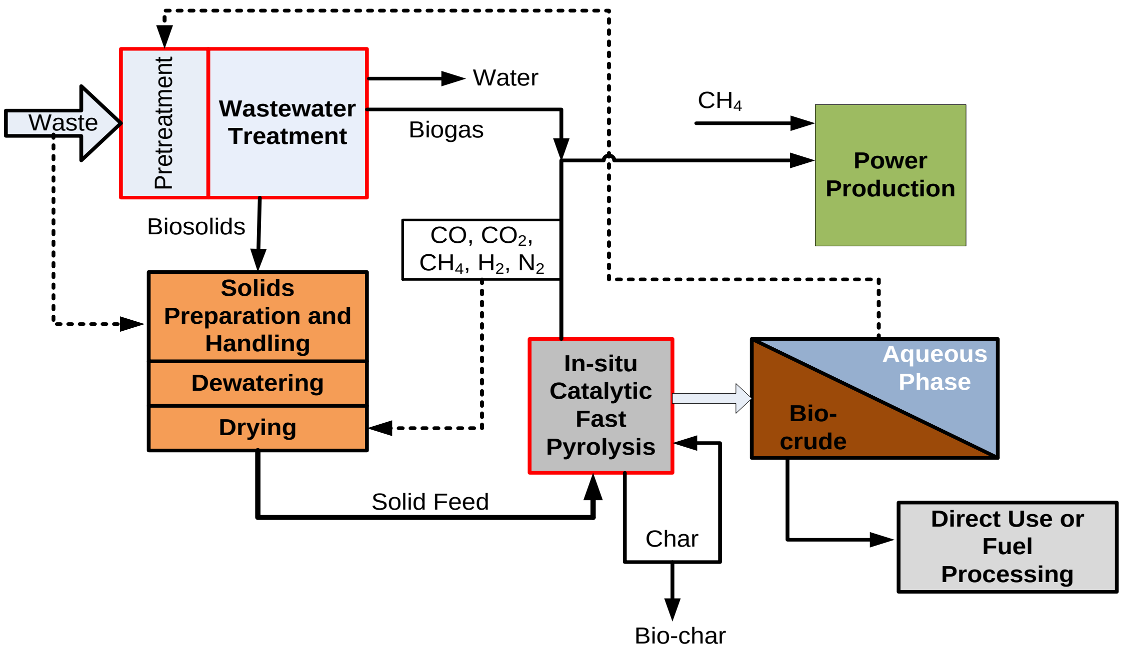
Integrated Concept



Integrated Concept



- Leverage Cataytic Fast Pryolysis (CFP) to add value in the sanitation value chain.
- High temperatures effectively sterilize bio-solids
- Yield gas, liquid (biofuel), and solid streams can be used for alternative energy applications

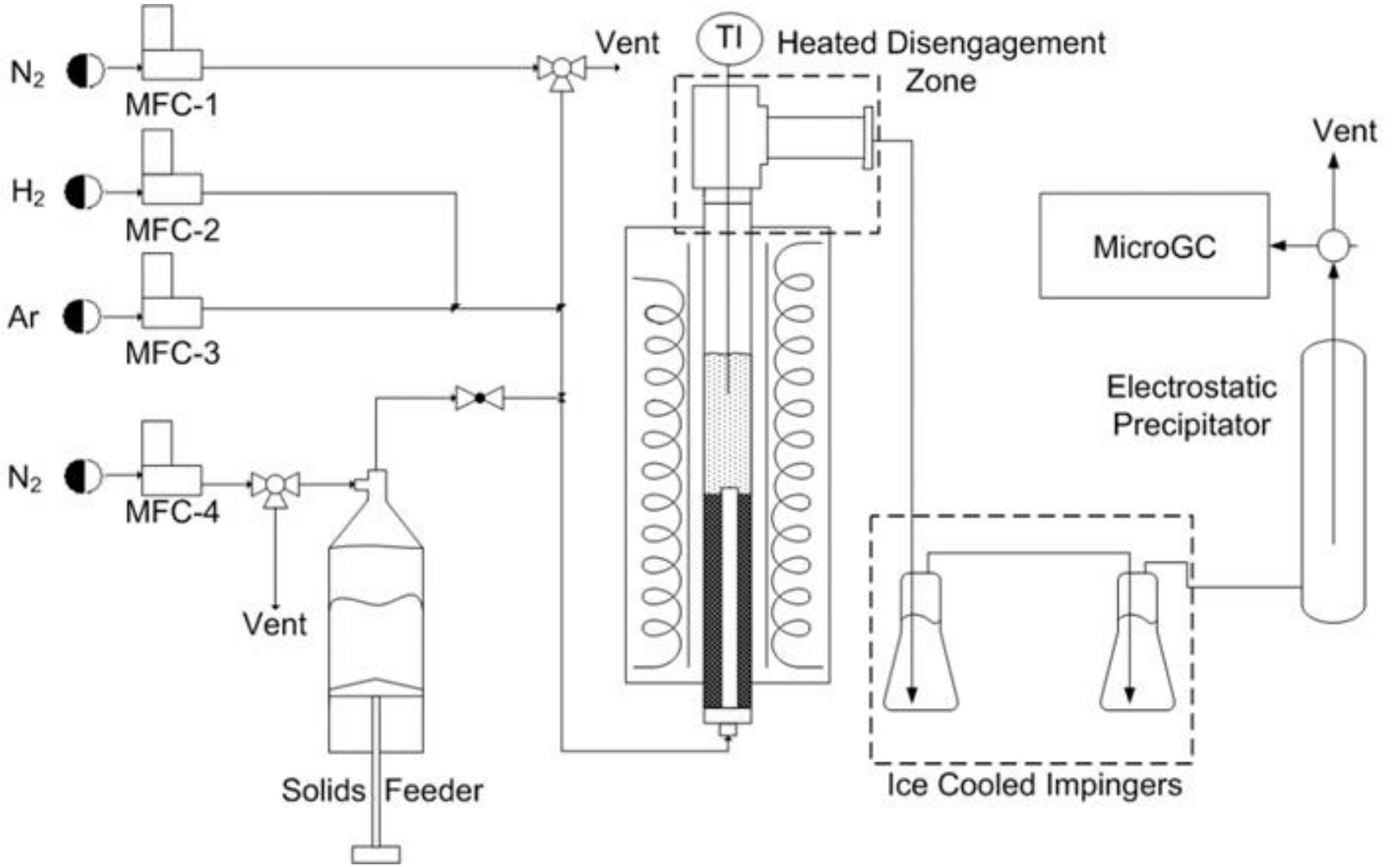
Feedstock Characterization

Sample	Elemental Analysis*					Proximate Analysis*			
	C	H	N	O (diff)	Ash	Moisture	Volatiles	Fixed C	Ash
Dried Sewage Sludge**	36.9	5.7	5.3	26.2	25.5	4.0	56.9	13.6	25.5
Fecal sludge	47.5	6.8	4.8	25.9	14.9	1.7	69.6	13.8	14.9
Loblolly Pine	45.4	6.3	0.15	48.1	0.7	7.8	78.1	14.1	0
Corn Stover	44.0	5.9	0.5	47.1	2.5	4.4	77.8	17.8	2.5

* as received basis; ** secondary sludge after anaerobic digester

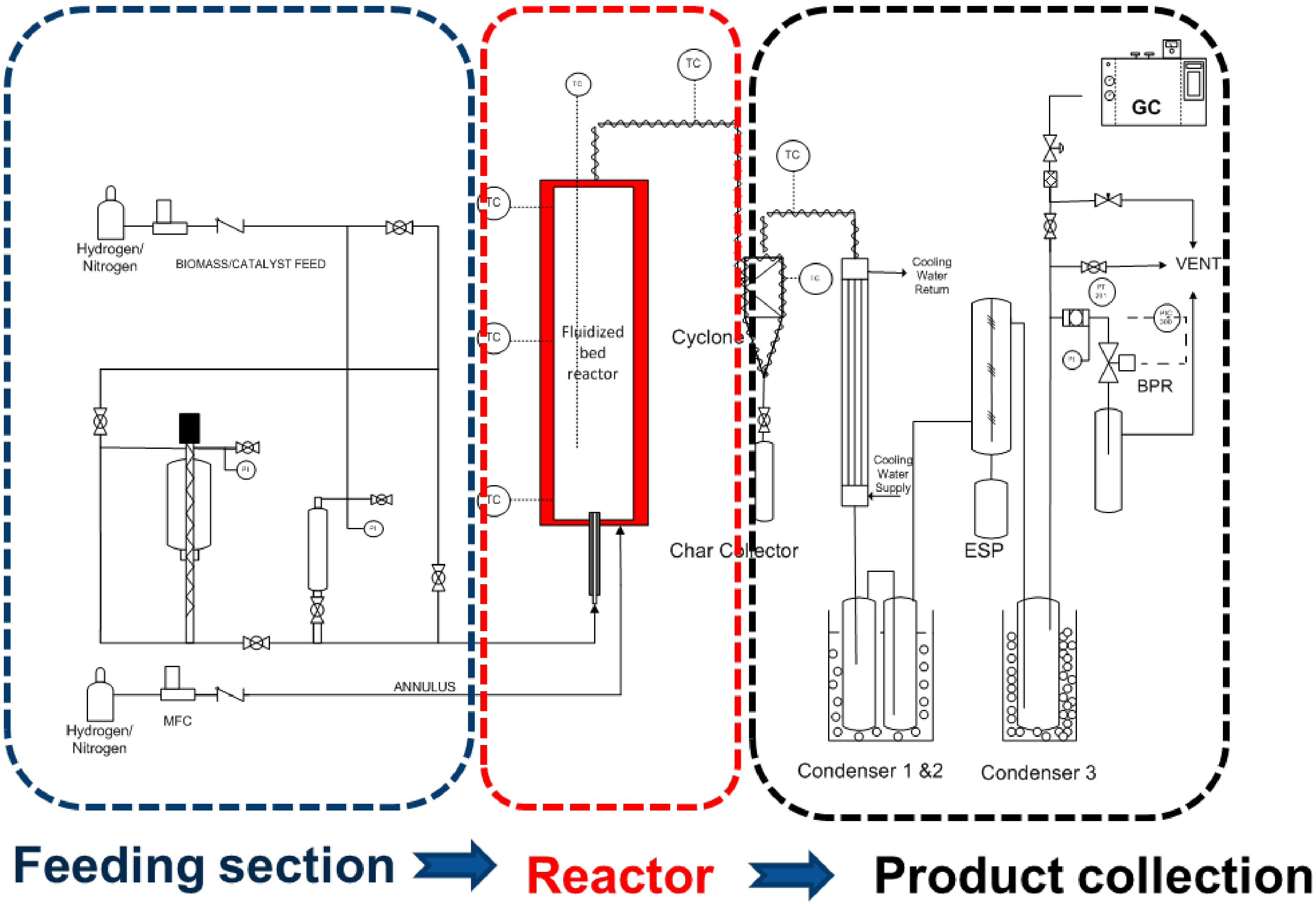
- Sewage sludge contains high nitrogen content (5.3wt%)
- Higher ash content (25.5wt%) than fecal sludge – anaerobic digestion may have removed part of the organic matter

Laboratory Proof of Concept – 1” CFP



RTI process flow diagram – bench-top 1” diameter fluidized bed system

Laboratory Proof of Concept – 2.5” CFP



Product Distribution

Feedstock	Loblolly Pine	Sewage Sludge
Product yield (wt%)		
Bio-crude (Organic)	9.3	**13.7**
Aqueous	42.3	26.0
Gas	25.2	17.7
Solid	25.4	**35.8**
Gas breakdown (wt%)		
CO	10.4	**1.5**
CO_2	8.1	8.5
CH_4	1.4	0.6
C_2	0.6	0.5
C_3	1.5	1.5
C_4+	3.0	5.1

Biochar Aqueous ESP organics Light organics

- Higher yield of organic liquid indicates the greater potential for liquid transportation fuel production from sewage sludge
- Higher yield of biochar due high ash content of the sewage sludge feedstock
- Higher yield of gaseous hydrocarbons: potential for combined heat and power generation or tail gas recycling to improve carbon efficiency
- Lower CO/CO_2 ratio suggest more efficient deoxygenation or different mechanism

Characterization of Biocrude

Feedstock	Loblolly Pine	Sewage Sludge*
Elemental analysis (wt%)		
C	74.4	73.0
H	7.6	8.8
N	0.1	11.1
O	17.2	7.0
GC/MS analysis (peak area %)		
aliphatics	1.7	**15.3**
aldehydes/ketones	19.4	3.9
acids	1.6	0.1
Monoaromatics	5.3	**18.1**
PAHs	32.5	8.8
phenols	34.5	3.5
Nitrogen compounds	4.7	**48.4**

- Higher hydrogen content of the sewage sludge biocrude may decrease the hydrogen demand for final fuel production
  - Additionlly, large amount of aliphatics and monoaromatics benefits hydroprocessing
- High nitrogen content will be problematic in fuel production (NOx emissions) - lends to potential for chemicals recovery.

Nitrogen Distribution

	Liquid products			Solid products	
Product	Aqueous	ESP organics	Dry ice organics	Char	Coke
Nitrogen Yield */%	13.49	11.94	16.65	6.94	n.d.

* Nitrogen yield is defined as the ratio of nitrogen in a certain product to the feedstock nitrogen

- Approximately 40% nitrogen in feedstock was fixed in liquid products
- Nitrogen compounds in liquid products are primarily nitriles
- Ammonia (not analyzed in this study) produced from CFP of sewage sludge have potential to be recovered as fertilizer

Fecal vs Sewage Sludge

Feedstock	Fecal Sludge	Sewage Sludge
Reactor Type	1” FB	2.5” FB
Carbon Balance (mole C%)		
Bio-crude- Organic	46.0	23.4
Aqueous	5.6	0.7
Gas	14.2	48.8
Solid	12.3	25.1
Gas breakdown (mole%)		
CO	2.2	1.8
CO2	5.3	6.3
CH4	1.5	1.4
C2	1.0	1.2
C3	2.2	3.2
C4+	2.2	11.8

- Fecal sludge CFP had higher biocrude yield
- Heating value of gases calculated to be 14.3 MJ/kg

Fecal vs Sewage Sludge

Liquid organic compositions		
Elemental composition/wt%	**Fecal Sludge**	**Sewage Sludge**
C	75.6	73.0
H	9.6	8.8
N	5.7	11.1
O	9.4	7.0
GC-MS/ peak area%		
Aliphatics	28.9	15.3
Furans/ketones	5.2	3.9
Acids	3.5	0.1
Monoaromatics	5.2	18.1
PAHs	10.4	8.8
phenols	6.6	3.5
Nitrogen Compounds	37.9	48.4

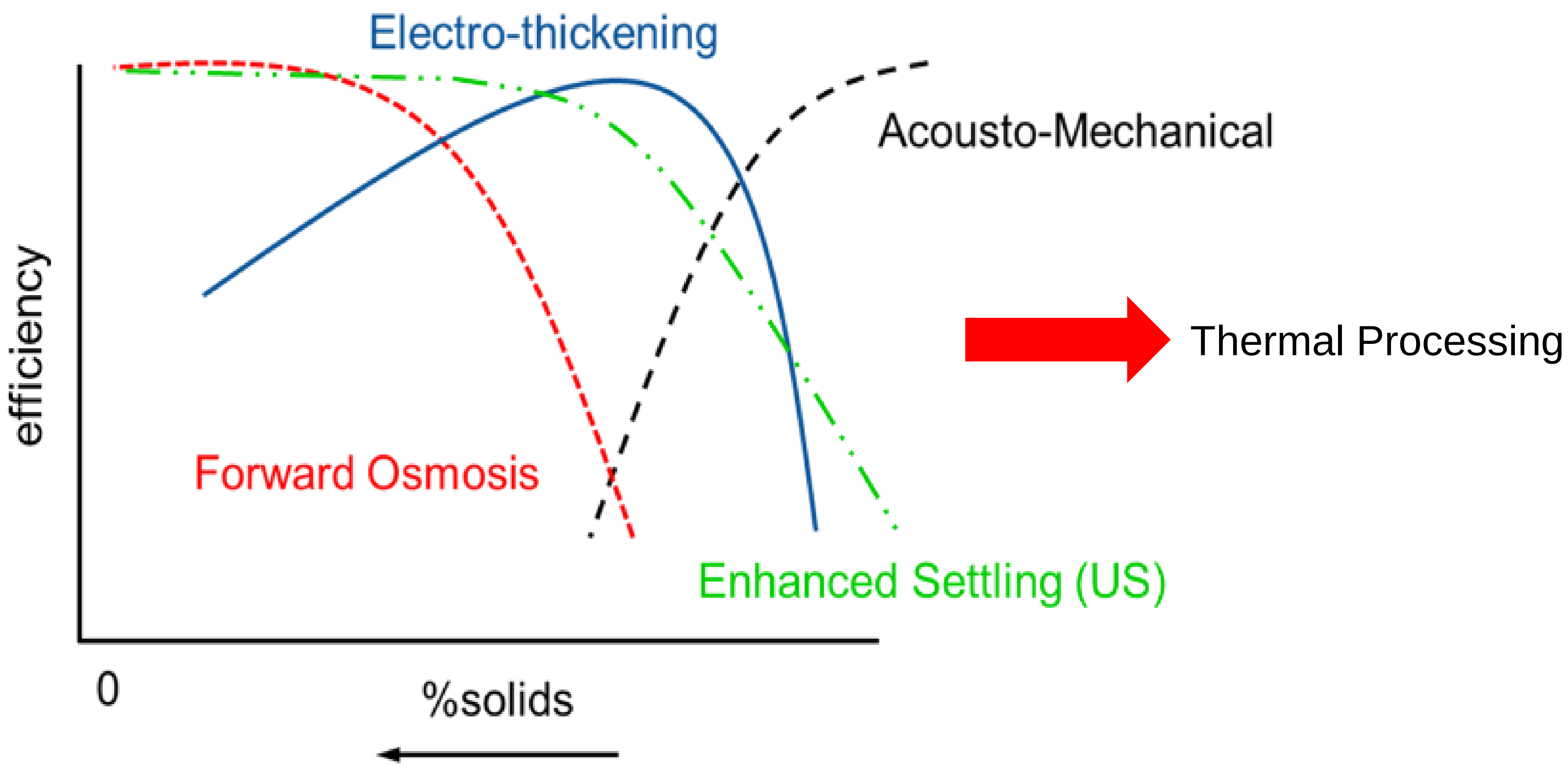
- Composition of the biocrude from sewage sludge and feces are comparable in terms of elemental and GC-MS analyses

Next Steps

Goals:

- Produce gallon quantities of bio-crude for future characterization, upgrading, and utilization
- Material balance and process conditions for prototype design basis
- Determine best options for integrating FS drier in prototype
- Develop pilot-scale data for updated techno-economics

Efficient Up-front De-watering



Technologies can be evaluated/mapped based on “de-watering efficiency” as a function of moisture content, creating a modular-hybrid solution that can effectively de-water low % solid streams all the way through to low-moisture-content feedstocks

Summary

- CFP is a promising technology for management of fecal / sewage sludge assuming cost-effective dewatering and drying can be achieved for feedstock preparation
- Transportation fuels and nutrient-rich biochar can be produced from sewage sludge
- Composition of the sewage sludge biocrude has benefits and challenges for further upgrading to biofuels:
  - Low oxygen content improves thermal stability and reduces hydrogen demand in hydroprocessing
  - High nitrogen content means hydro-denitrification needed for biofuel production (increased hydrogen demand)
  - Recovery of value-added nitrogen containing chemicals could be a benefit

Thank you

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Duke UNIVERSITY

RTI INTERNATIONAL

POWERHOUSE ENERGY INSTITUTE Colorado State University

NASA Ames Research Center

BIOMASS CONTROLS

Will this work…. CapEX?

- Largest fixed cost in economic model, highly variable based on assumptions about growth relative to plant capacity (e.g. linear, exponential growth)
- Comparative analysis: Biomass breaks even at lower plant capacity
- Break-even at ~530 tons/day (FS); 415 (biomass)