Leaders Innovation Forum for Technology

LIFT: Converting Biosolids into Biocrude

WEFTEC 2016
Innovation Pavilion
September 27, 2016

Water Environment Federation
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Agenda

Introduction
Raj Bhattarai, City of Austin (Moderator)

Genifuel Hydrothermal Processing Bench Scale Technology Evaluation
Philip Marrone, Leidos, Inc.

Hydrothermal Processing in Wastewater Treatment:
Planning for a Demonstration Project
Jim Oyler, Genifuel

Project Participant Perspectives
Paul Kadota, Metro Vancouver

Q&A / Discussion

Project Background

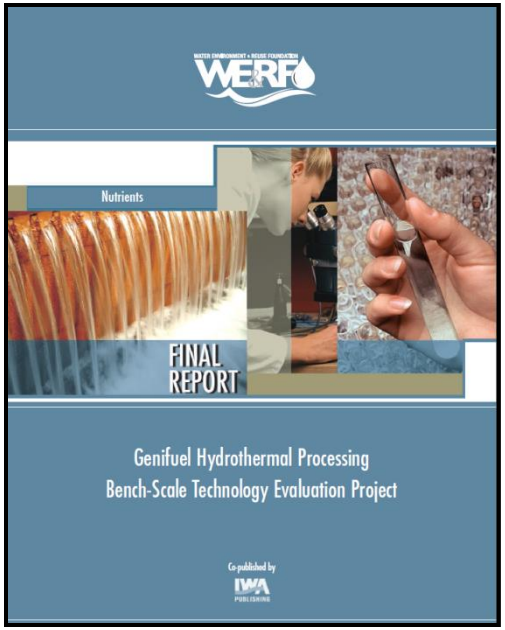
- Spring 2014: LIFT B2E Focus Group Presentation by Genifuel
- Summer 2014: Project Concept Developed
- Fall 2014: Project Funding Assembled
  Independent Evaluator Selected
- Feb 2015: Project Kickoff
- April 2016: Project Completed

Funding Partners:

- City of Calgary
- City of Orlando
- City of Santa Rosa
- Delta Diablo Sanitation District
- Eastman Chemical Company
- Melbourne Water Corporation
- Metro Vancouver
- Silicon Valley Clean Water
- Toho Water Authority
- US EPA
- US DOE (in-kind)

Project Subcommittee:

- Mo Abu-Orf, AECOM
- Bob Forbes, CH2M Hill
- Angela Hintz, ARCADIS
- Bryan Jenkins, Univ. of CA - Davis
- Patricia Scanlan, Black & Veatch
- Jeff Tester, Cornell University



Genifuel Hydrothermal Processing Bench Scale Technology Evaluation

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Philip A. Marrone
Leidos

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Genifuel

Pacific Northwest NATIONAL LABORATORY

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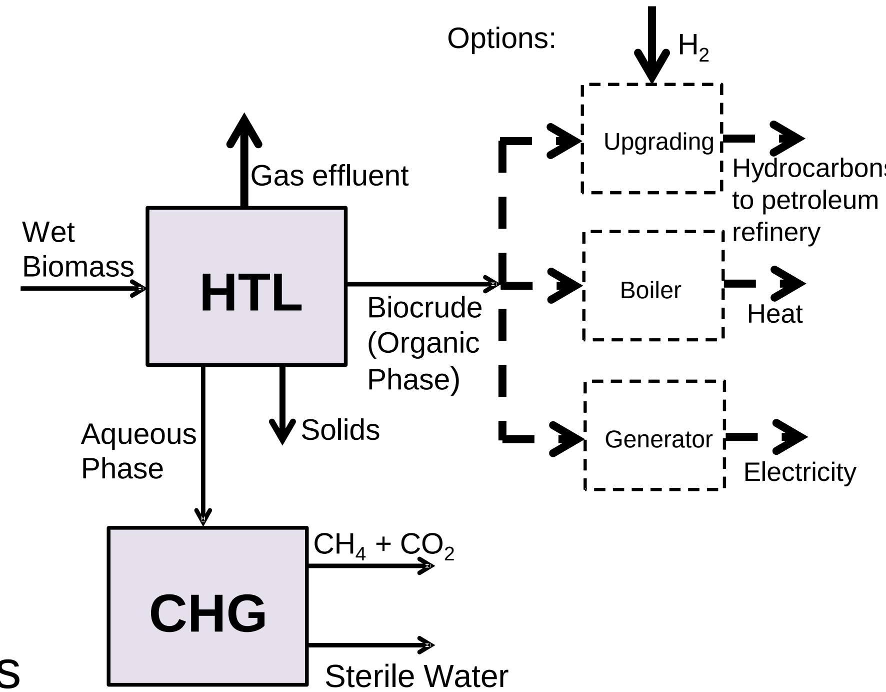
Introduction

- Assess the potential of the Genifuel **hydrothermal process technology (HTP)** for handling municipal wastewater sludge
- **HTP** is a thermochemical process where water is used as the medium for the breakdown and reconstituting of organic matter into relatively simpler chemical compounds at elevated temperatures and pressures
  - No drying of feed needed
  - Utilizes all components of feed
- Proof-of-concept bench-scale tests were performed at Pacific Northwest National Laboratory (PNNL)



T = 350˚C (662˚F)
P = 3000 psi

HTL = Hydrothermal Liquefaction
CHG = Catalytic Hydrothermal Gasification

Sludge Feed Procurement/Preparation

- **Sludge Types Tested** (one HTL + CHG test each):
  - Primary
  - Secondary
  - Post-digester (Digested Solids)

Annacis Island WWTP, Delta, BC, Canada

- **Sludge Provider:**

  Metro Vancouver – Annacis Island WWTP

- **Sludge Preparation:**

Sludge	Initial Solids Conc.	Dewatering Method	Autoclave Conditions	Solids Conc. At Shipment	Dilution at PNNL	Final Solids Conc.
Primary	4.5 wt%	Filter press (40 psi for 20 min; 300 μm filter), followed by hand press	Yes (121°C for 5 hrs)	26.0 wt%	Yes	11.9 wt%
Secondary	3.9 wt%	55 L Dewatering bags for 48 hrs	Yes (121°C for 5 hrs)	10.9 wt%	No	10.0 wt%
Digested Solids	28 wt%	None	None	28 wt%	Yes	16.4 wt%

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Sludge Feed Procurement/Preparation

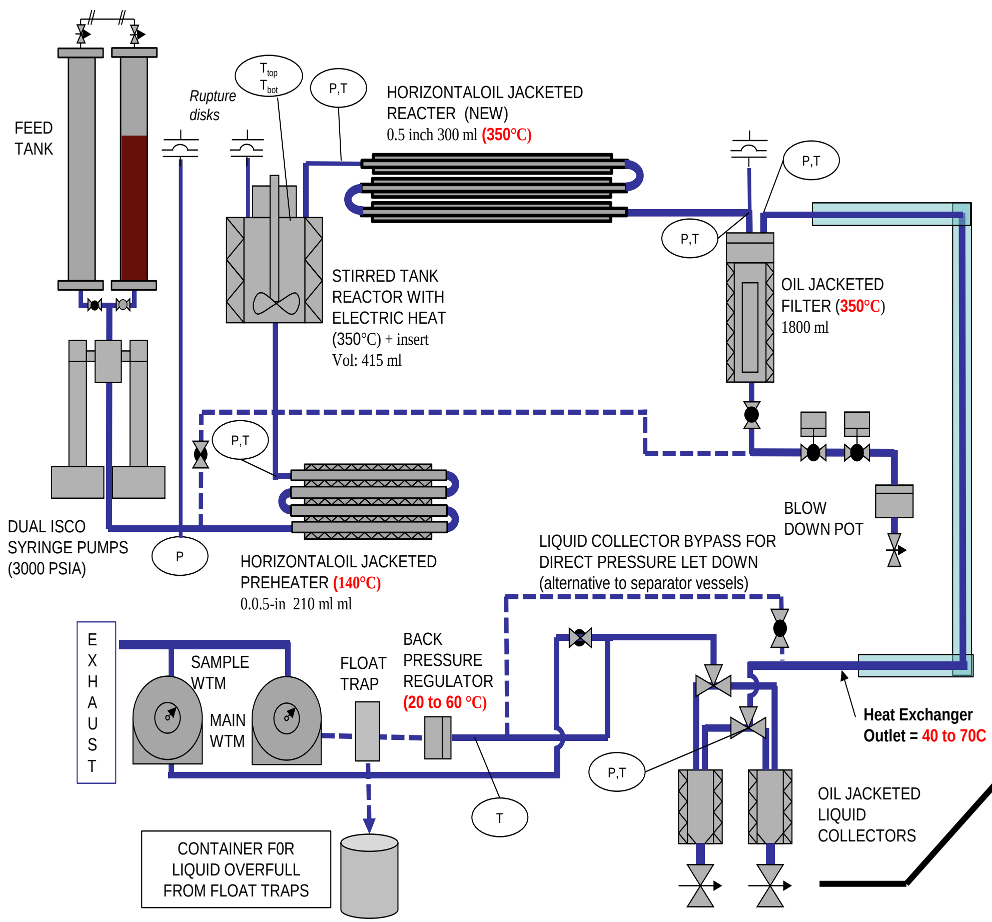
Primary (11.9 wt % solids)

Secondary (10.0 wt% solids)

Sludge Feeds

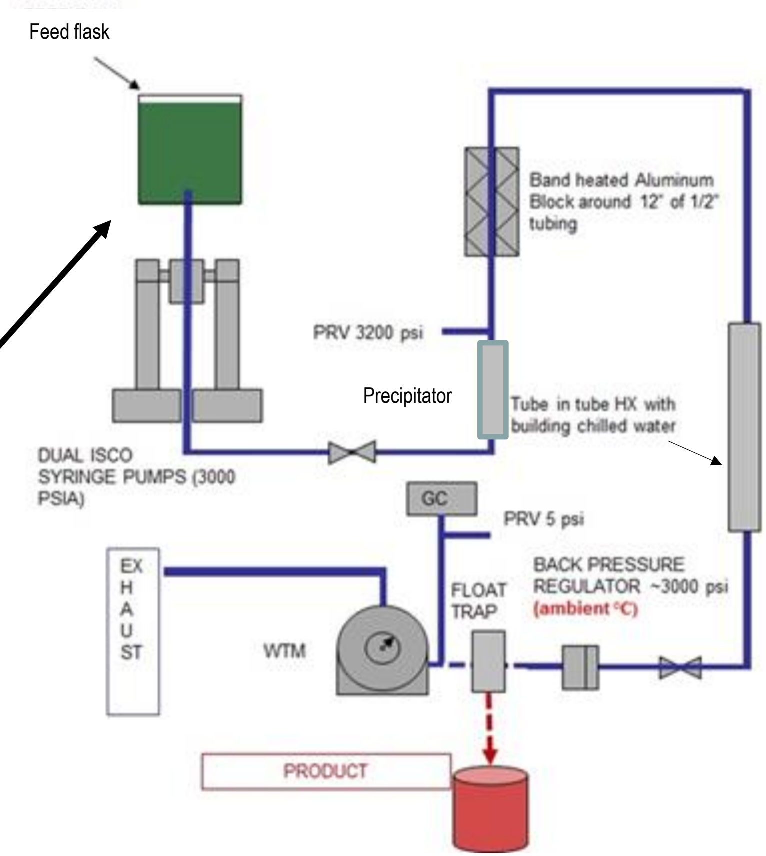
Post-digester (16.4 wt % solids)

Hydrothermal Processing Tests - Equipment



PNNL Bench-scale HTL System

PNNL Bench-scale CHG System



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Hydrothermal Processing Tests – Observations

HTL steady state liquid effluent

Separated biocrude

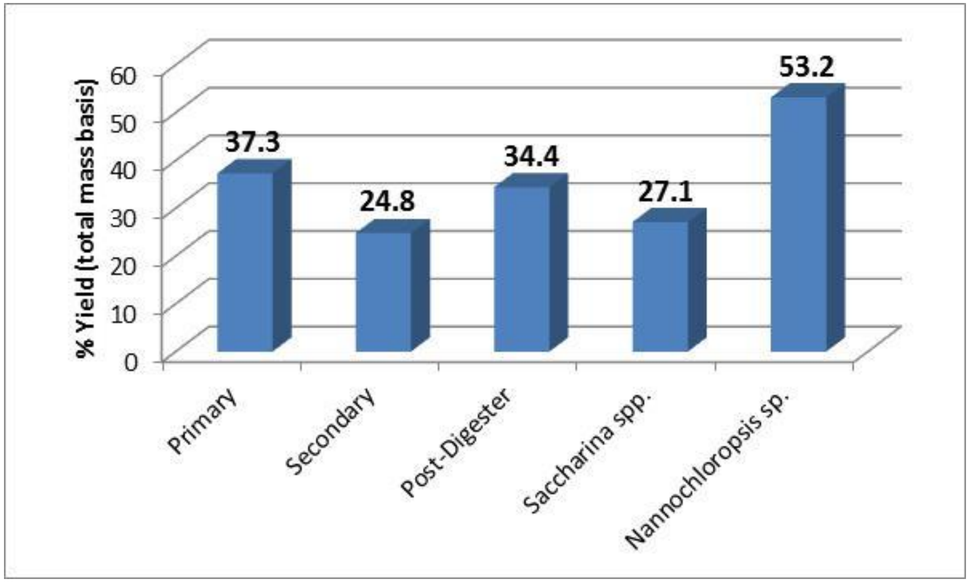
Solids from filter vessel

CHG (far left) and liquid effluent samples

CHG aqueous effluent

Test Results - Biocrude

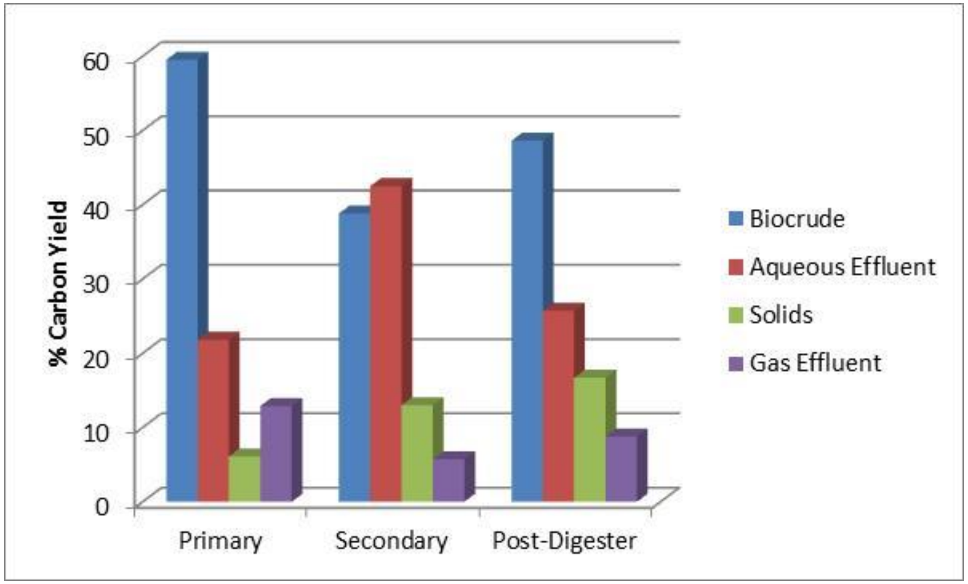
HTL Biocrude Yield (total mass basis)



Algae data for comparison from other PNNL studies (Elliott et al., 2013 and Elliott et al., 2014)

All yield values are normalized per appropriate mass balance

HTL Carbon Yields



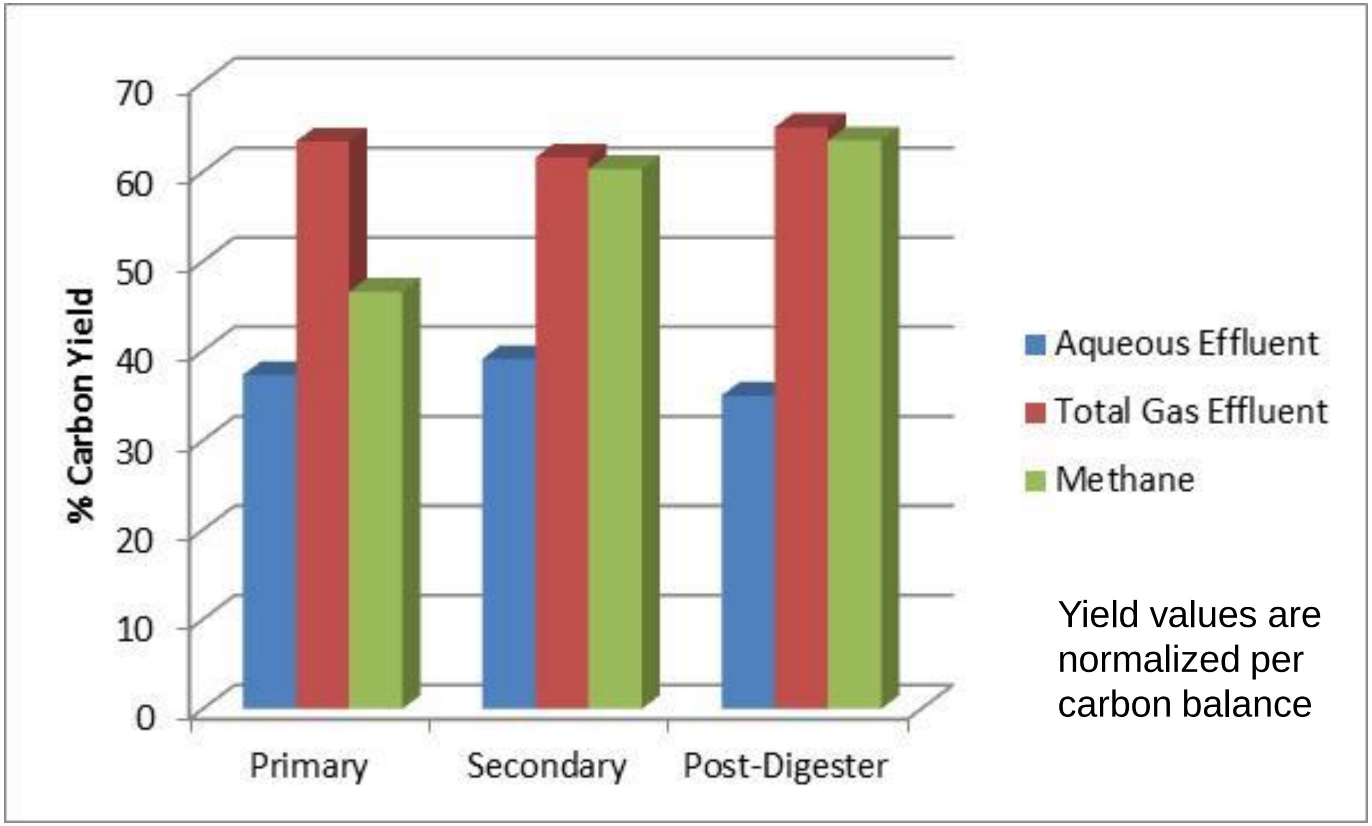
Test Results - Biocrude

HTL Biocrude Quality

Data	Biocrude from Sludge			Biocrude from Algae	
	Primary	Secondary	Post-Digester	*Saccharina spp.*	*Nannochloropsis sp.*
wt% Carbon (dry)	76.5	72.5	78.5	79.4	79.2
wt% Hydrogen (dry)	10.1	8.7	9.51	8.0	10.0
H:C molar ratio	1.6	1.4	1.4	1.2	1.5
wt% Oxygen(dry)	8.1	6.5	6.21	8.3	5.7
wt% Nitrogen(dry)	4.3	5.1	4.46	4.1	4.7
wt% Sulfur (dry)	0.63	0.90	1.16	0.3	0.5
wt% Ash (dry)	0.38	6.3	0.21	Not determined	Not determined
wt% Moisture	13.0	1.0	13.5	9.2	7.8
TAN (mg KOH/g)	65.0	44.8	36.0	36	Not determined
Density (g/ml)	1.000	0.985	1.013	1.03	0.95
Kinematic viscosity (cSt)	571	624	1160	1708	205
Heating Value (MJ/kg)	37.8	34.8	38.0	-	-

Test Results - Methane

CHG Carbon Yields



CHG gas effluent comprised mostly of methane

Test Results - CHG Aqueous Effluent

- **Organic Removal**

COD (units in ppm)

Sludge Feed	HTL Feed	Post-HTL	Pre-IX	Post-IX	Post-CHG
Primary	187,000	41,000	40,800	20,300	54
Secondary	153,000	73,000	72,300	21,700	25
Digested Solids	203,000	48,200	49,900	23,700	19

> 99% reduction in COD over HTL-CHG process

- **Sulfate / Catalyst Performance**

	Total Sulfur (ppm)	
	Raney Ni	Ru/C
Primary	4100	1700
Secondary	16,000	3400
Digested Solids	9900	1410

Ru Catalyst active at end of each CHG test (52-85 hrs exposure), but total sulfur concentrations on catalyst indicate poisoning per PNNL (> 1000 ppm)

Water Quality

Analysis	Regulatory Limit	CHG Effluent
BOD cBOD	< 60 ppm < 15 ppm	√ (< 26 ppm)
Total N	< 2 ppm	X (> 1100 ppm)
Total P	< 0.2	√ (< 1 ppm)

CHG effluent may be capable of meeting regulatory requirements for discharge except for nitrogen

Test Results - CHG Gas

Siloxanes

- Found in biogas; silica formed in combustion is abrasive and insulating
- Analyzed gas effluent for 7 specific siloxanes and 2 precursors by laboratory used by Silicon Valley Clean Water WWTP

Feed	Test	Siloxane Conc.
Primary	HTL	All < 263 ppb
Post-Digester	HTL	All < 2886 ppb
Primary	CHG	All < 22.7 ppb except trimethylsilanol = 43.3 ppb
Secondary	CHG	All < 43 ppb
Post-Digester	CHG	All < 40 ppb

- Gas engine fuel specifications:
  - GE Jenbacher - < 3 ppm
  - MWM Caterpillar - < 800 ppb
- All CHG gas siloxane concentrations met engine specs
- Si partitions mostly into aqueous phase effluent

Test Results - HTL Solids

	Primary	Secondary	Post-digester
Sludge Feed (g/hr)	1541	1499	1570
Sludge Ash (wt%)	7.5	16.2	28.0
HTL Solids (g/hr)	17.4	29.8	88.9
HTL Solids Ash (wt%)	64.4	64.5	73.3
HTL Solids Weight Reduction (%)	99	98	94

- **Post-digester sludge generated the highest amount of solids and %ash**
- **HTL process results in high solids reduction relative to sludge feed weight**

Key Conclusions and Recommendations

- Biocrude and methane successfully generated from all 3 sludge types.
- No difficulties pumping sludge feeds; potential to process at higher concentrations.
- Biocrude quality comparable to that from other biomass feeds (e.g., algae).
- Had > 99% COD reduction in effluent and 94-99% solids reduction relative to feed.
- Siloxane concentrations in the CHG product gas were below engine limits.
- The CHG aqueous effluent is capable of meeting regulatory limits except total N.
- Sulfur poisoning of CHG catalyst occurred.

The overall results of this proof-of-concept test program are sufficiently promising to justify further investigation of the HTL-CHG technology for application to sludge.

- Determine optimal, representative sludge feed concentrations.
- Perform long-term operation tests on a single, integrated HTL-CHG system at pilot-scale that is representative of the equipment and design that would be installed at a WWTP.
- Perform energy balance, site specific economic analysis, and GHG reduction analysis to verify economic viability for installation/operation of a HTL-CHG system at a WWTP.

Acknowledgments

- Jeff Moeller and WE&RF staff
- Members/Organizations of LIFT Project Subcommittee and Steering Committee
- Metro Vancouver
- Silicon Valley Clean Water
- Pacific Northwest National Laboratory
- U.S. Department of Energy
- U.S. Environmental Protection Agency

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Hydrothermal Processing in Wastewater Treatment

Demonstration Project at Metro Vancouver

Paul Kadota
metrovancouver

James Oyler
Genifuel CORPORATION

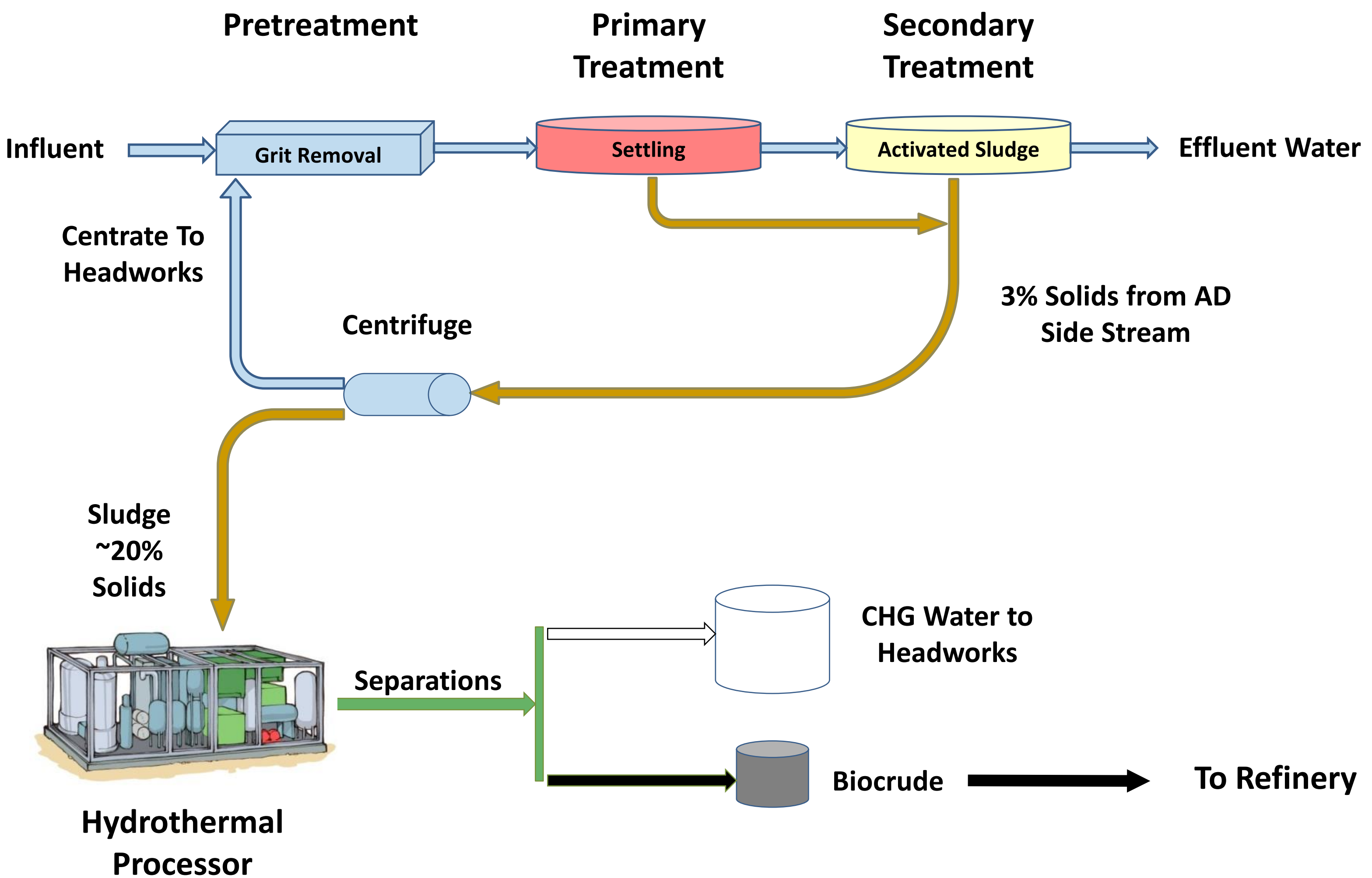
Metro Vancouver's Interest in HTP

- MV sees HTP pilot project as a way to explore solutions to key issues
  - Rising cost of solids management and increasing distance to end-use sites
  - High cost of installing AD at smaller sites
  - New technology for future system upgrades to improve process and reduce cost
  - A pathway to meet environmental goals for lower emissions and greater energy recovery
- The MV system will process wastewater solids equivalent to a population of app. 30,000 people

MV is 5x Larger Than Previous HTP System

Will Be Located at Annacis Island Plant

MV Will Process Undigested Solids Into Biocrude Oil



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Benefits of HTP

- Economical compared to Anaerobic Digestion
- Eliminates sludge and related management costs
- Process is complete in 45 minutes; short retention time means small size
- Substantial reduction in greenhouse gas emissions
- Destroys organics such as pesticides, pharmaceuticals, flame retardants, etc.
- Phosphorus can be recovered as by-product
- Biocrude oil can be sold to refinery to produce gasoline, kerosene, and diesel

Conclusions

- Pilot project follows recommendation from LIFT project
- Pilot will provide valuable data and experience with hydrothermal processing
- Successful project can form basis of large scale commercial implementation
- A potentially disruptive technology for the wastewater industry

Utility Partner Perspectives

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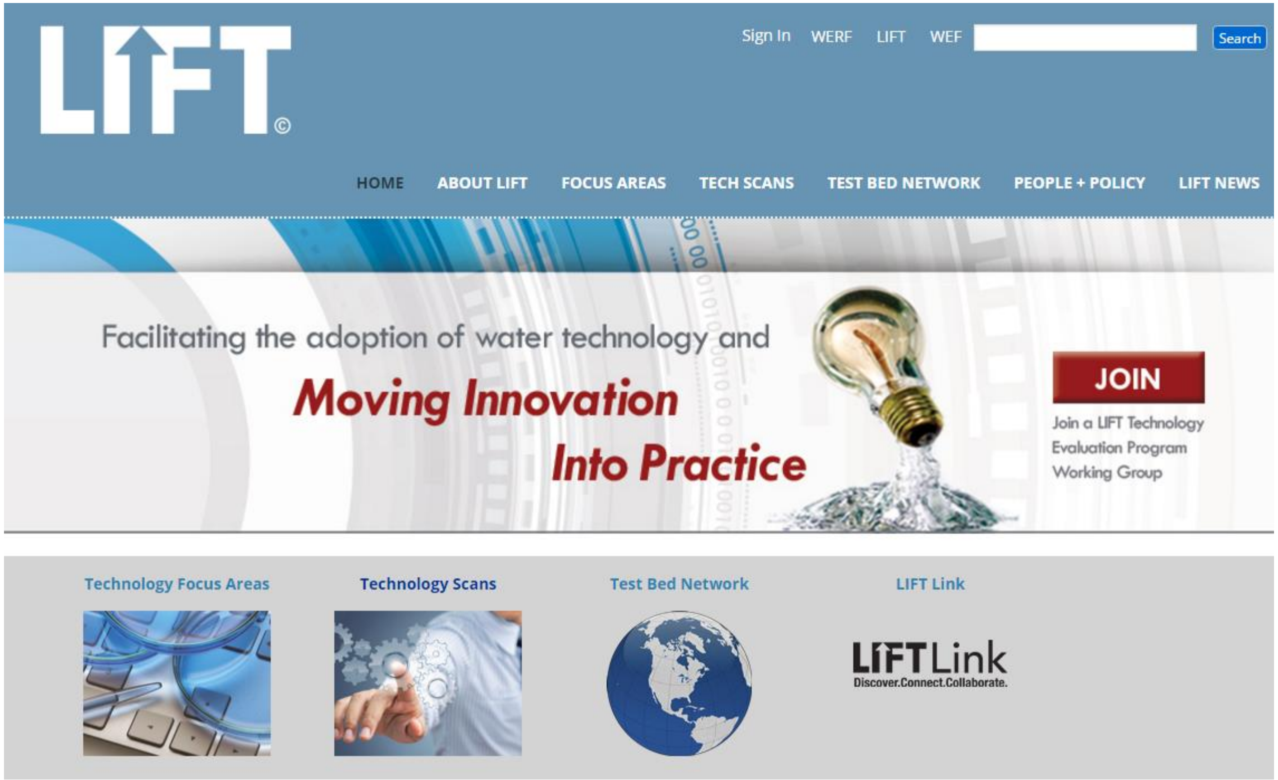
Thank You!



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