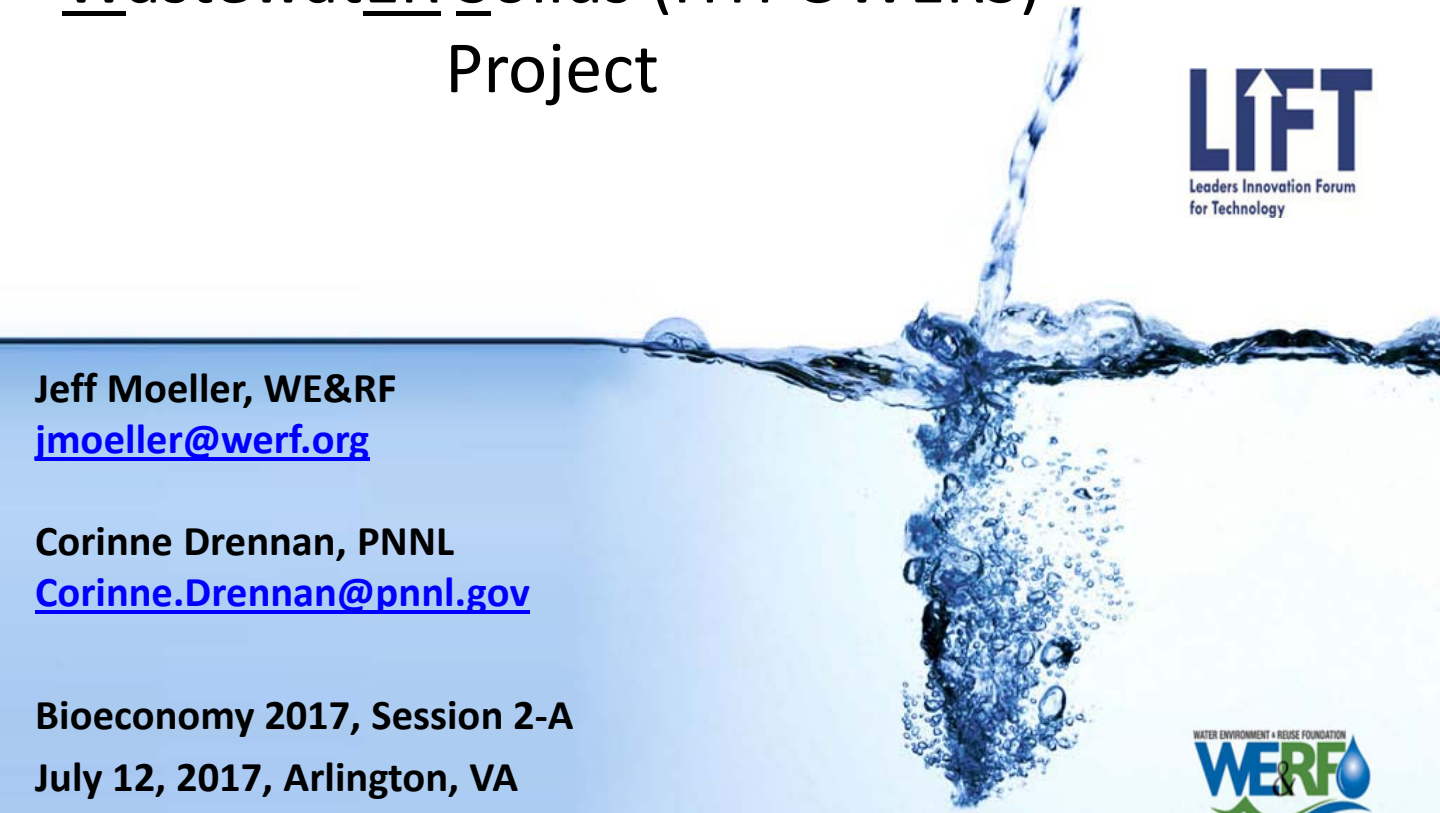
Hydrothermal Processing Of WastewatER Solids (HYPOWERS) Project



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Project Background

- DOE FOA Issued May 2016
  - For pilot and demonstration facilities, for “Biofuels, Bioproducts, and Biopower” to advance previous R&D projects to commercialization
  - One topic of interest included “Primary, secondary, tertiary, and post-anaerobic digestion sludge from municipal wastewater treatment systems”
- DOE Selection Notification in Jan 2017
- Kickoff Meeting June 2017

HYPOWERS Project Description

- Phase 1 (ongoing)
  - $2.5 million (50/50 DOE cost share)
  - Validation, planning, and front-end engineering & design (2 yrs)
  - After Phase 1, DOE evaluates plan and may award Phase 2

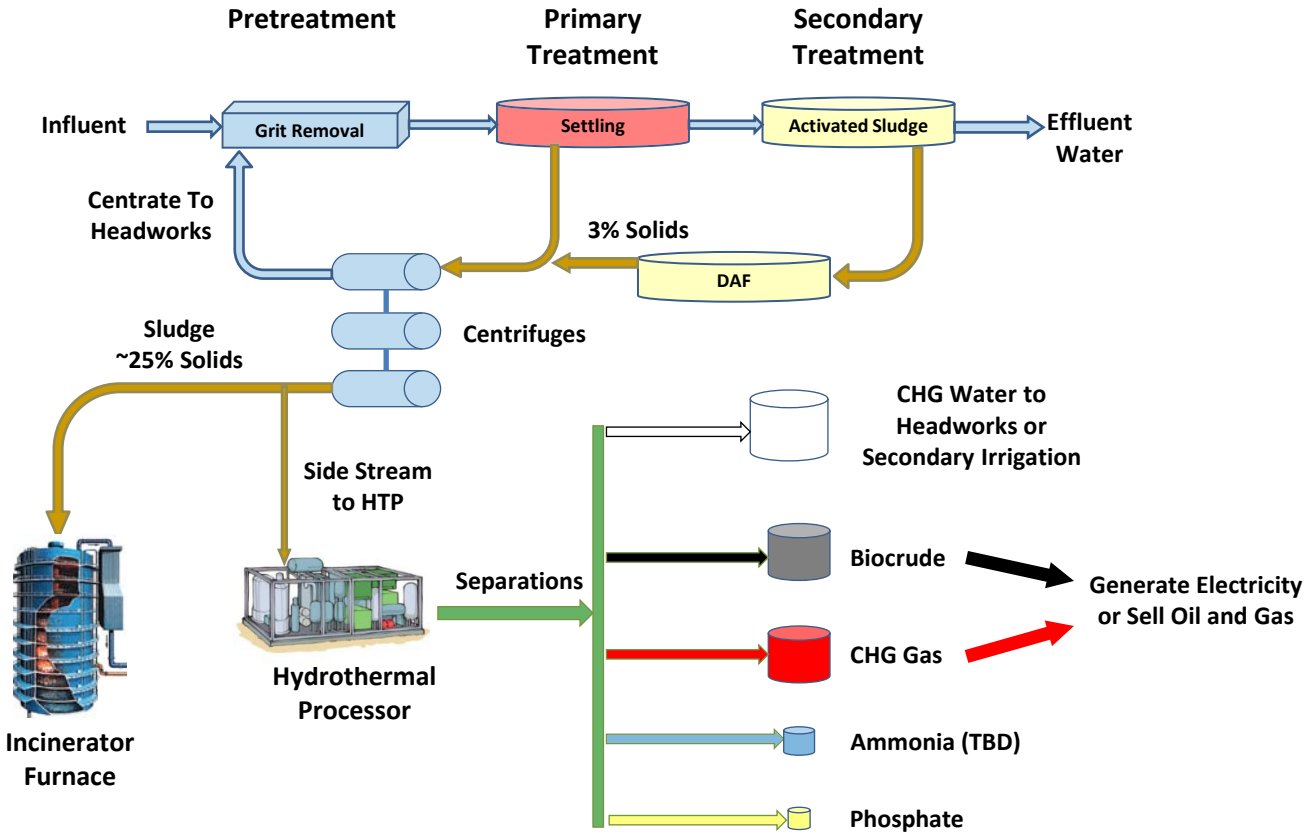
- Phase 2 (planned)
  - Up to $30 million (50/50 DOE cost share)
  - Construction & piloting of an HTP facility at CCCSD (2+ yrs)

HTP Technology

- Hydrothermal processing (HTP) uses water, temperature and pressure to convert wastewater sludge into biocrude oil and natural gas in less than an hour with approximately 99% conversion of the organics.

- Target size for completed project is 20 wet metric tons of sludge @ 20% solids = 4 metric tons of dry solids
  - May change depending on Phase 2 cost share

Central San Process Flow with HTP



HYPOWERS Project: Phase 1 Objective

- *"Develop a complete design, business plan, and regulatory approach for a pilot-scale hydrothermal processing system at an operating wastewater treatment facility".*
- The design and related documents must meet the definition of "CD-3": Critical Decision-3 means *"Project is ready for implementation and start of construction"*
- Ultimate objective is to demonstrate & commercialize HTP as a new technology for the wastewater industry

Project Participants

Project Team

- WE&RF
- Genifuel Corporation
- PNNL
- Merrick & Company
- MicroBio Engineering
- Cal Poly
- Brown and Caldwell
- SoCal Gas Company
- Tesoro Corporation
- CCCSD
- Metro Vancouver

Utility Advisory Committee

16 Members, including:

- Water utilities in US and Canada
- Private companies
- Water/wastewater holding companies

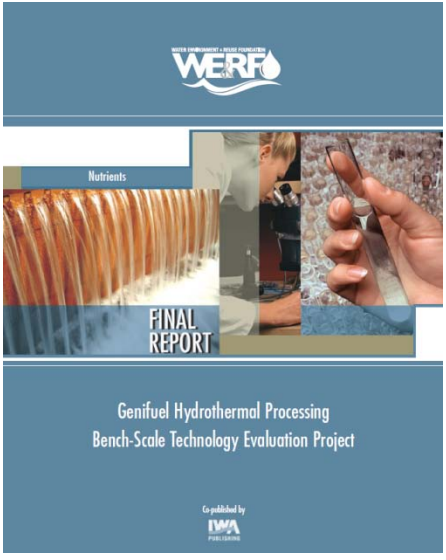
Peer Review Team

- Hazen and Sawyer
- CH2M Hill
- University of Illinois
- ARCADIS

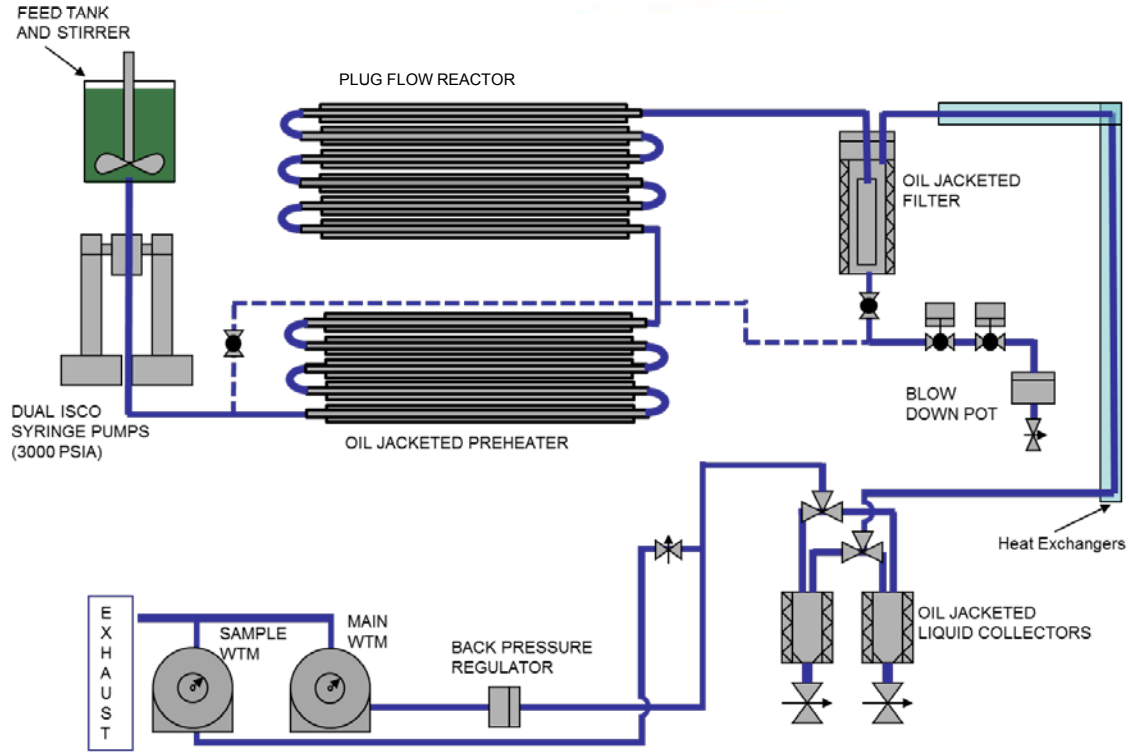
Team Formation & Bench Scale Testing

Started with WE&RF LIFT project:

- Genifuel technology evaluation began in 2014
- Bench Scale Test started in 2015
- Funding from WE&RF, EPA, DOE (in-kind) and 10 utility partners
- Peer review panel
- Final report by third-party firm published in 2016



Hydrothermal Liquefaction Technology



HTL Operating Conditions

- Average T, P: 330-350 C, 2900psig
- Slurry feed rate: 1-4 L/h (LHSV=1-6 L/L/h)

Recommendations from LIFT

- Increase feed concentration
- Longer duration test in larger scale system w/single feed
- Test with representative blend (primary & secondary)
- Test with better temperature control
- Produce more biocrude for upgrading
- Perform trace component characterization

Actions from LIFT report: 50/50 sludge mix from LGWA/Detroit

As Received, 32 wt% Solids, autoclaved

Immersion mill

After milling and dilution to 20%

LIFT Feeds Compared to GLWA/Detroit

		GLWA Detroit	Metro Vancouver (LIFT)	
	unit	1:1 Prim:Sec	Primary	Secondary
Total Solids in Feed	wt%	20.3%	11.9%	9.7%
FAMES in Dry Feed	wt%	6.2%	9.8%	4.7%
Ash in Dry Feed	wt%	26.1%	7.5%	16.2%
Ash in Slurry Feed	wt%	5.3%	0.9%	1.6%
AF Solids in Slurry	wt%	15.0%	11.0%	8.1%
Feed density	g/ml @20C	1.065	1.035	0.998
Feed Rate, dry basis	g (AFDB)/h	322 - 641	169	122

Summary of Results

- Throughput and oil yield improved strongly from LIFT to GLWA/Detroit and should remain at higher level in HYPOWERS

	Unit	GLWA/Detroit		Vancouver (LIFT)	
		Prim:Sec 1:1	Prim:Sec 1:1	Primary	Secondary
Ash-Free Solid (Feed)	Wt%	15.0%	15.0%	11.0%	8.1%
LHSV	L/L/h	1.8	3.6	2.1	2.1
Oil Output Rate	**g/h**	**145**	**285**	**64**	**24**
Mass Balance and Yields (Dry, Ash Free, Normalized)					
Mass Balance	%	101%	100%	101%	103%
Oil Yield, Mass (N)	**g_{oil}/g_{fd}**	**45%**	**44%**	**37%**	**25%**
Aqueous Phase					
COD	mgO/L	57,500	61,300	40,800	73,000
Nitrogen	wt%	0.74%	0.77%	0.26%	0.72%
Phosphate	ppm	ND*	ND*	25	710
Sulfate	ppm	140	200	60	160
pH	pH unit	7.7	7.8	6.4	8.0

What about the finished blendstock?

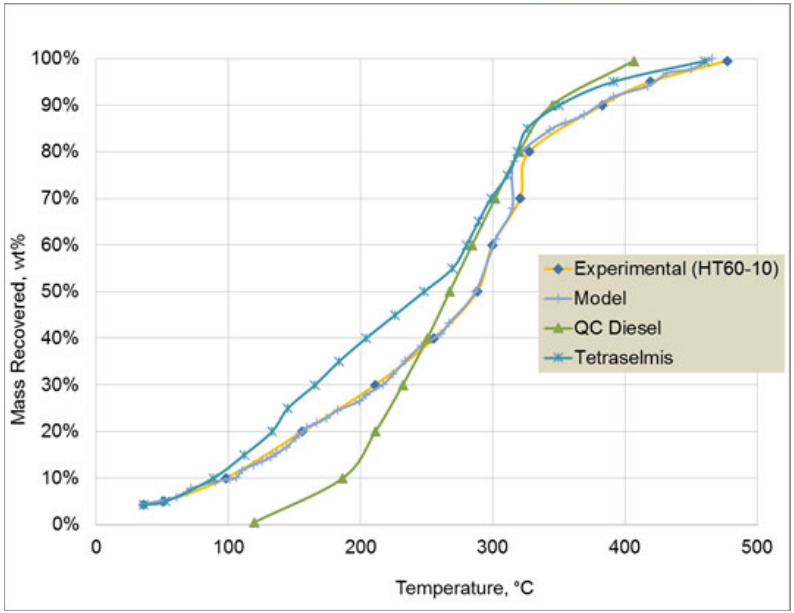
HTL biocrude from WWTP sludge can be upgraded to a light sweet crude in a single stage (unlike fast pyrolysis bio oils)

N, O, S removed with a conventional catalyst

Single stage hydrotreatment:

- T = 400 °C
- P = 1500 psig H_2
- LHSV = 0.25 h^{-1}
- Sulfided $CoMo/Al_2O_3$

Fuel Products from GLWA/Detroit Biocrude



ASTM D2887 Comparison

Distillate Fraction	BP Range, °C	Estimated Yield, mass%
Gasoline	20 - 150	20%
Diesel	150 - 390	70%
Residual (Wax)	< 390	10%

- Biocrude upgrading provides distillate range products as blendstock

HYPOWERS Conclusion and Challenges

- Testing with Detroit sludge addressed remaining questions from LIFT Project and should carry through to HYPOWERS
- Challenge for HYPOWERS is to produce enough biocrude for refining
  - Refinery Integration AOP project (w/NREL) will have sludge-derived co-processing data prior to build phase
  - Alternative: Hydroprocess and fractionate with PNNL's demo-scale reactor and distillation column
- Challenge for HTL aqueous phase
  - Use Catalytic Hydrothermal Gasification to yield gas and clean effluent
  - Alternative: Return to headworks, but nitrogen levels may be too high for this to be a 'standard' model for commercialization

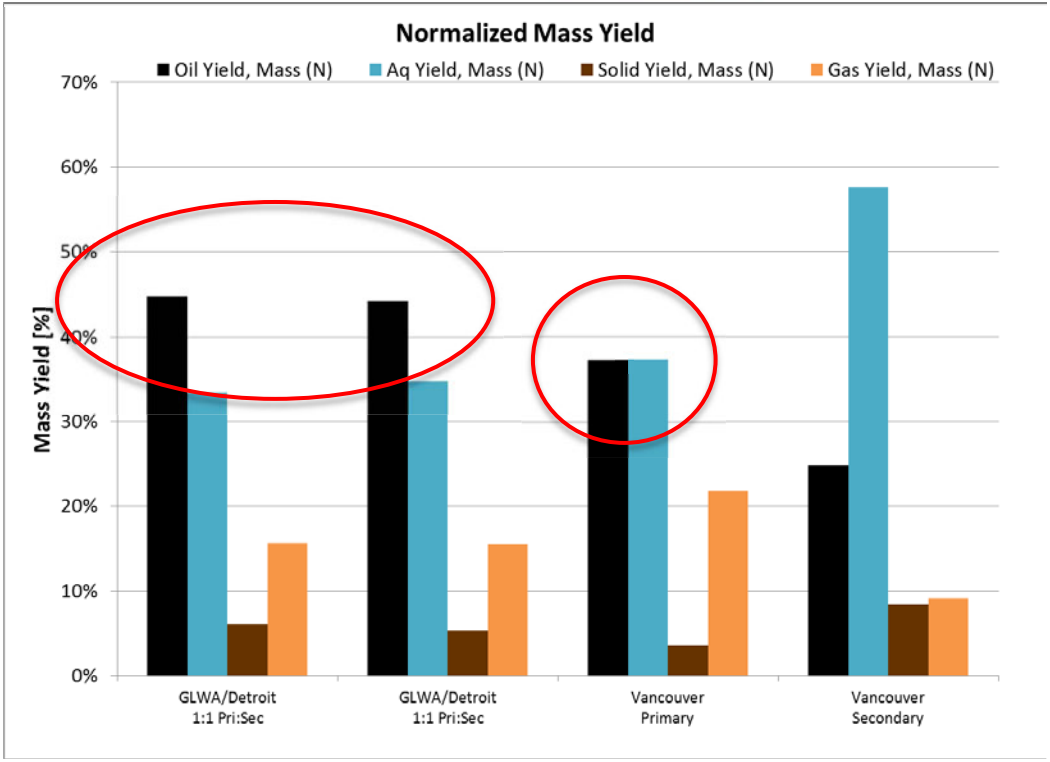
Extra Slides

Technology Impact

- **Project's Key Idea/Takeaway:** Transform wastewater treatment to eliminate wastewater solids while profitably producing renewable hydrocarbon fuels using existing infrastructure, offsetting fossil fuels, and reducing greenhouse gas emissions.

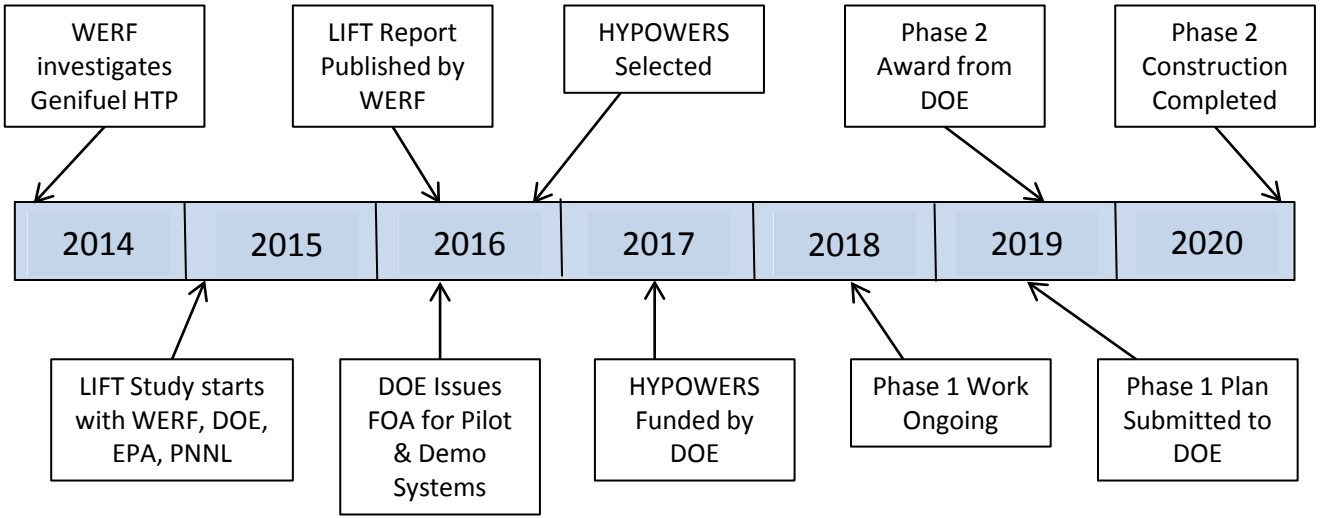
- **Technology Impact:** Wastewater treatment produces over 12 million metric tons (dry weight) of solids in the US annually. Converting these solids with HTP will produce the equivalent of 41 million barrels of oil per year and save $2.2 billion in solids disposal costs.

Normalized mass yields



Mass yield to biocrude for GLWA was 44% - vs.- 37% yield from primary sludge from Metro Vancouver

Schedule of HYPOWERS Project



Project Roles