A Neighborhood Fecal Sludge Treatment System Using Supercritical Water Oxidation

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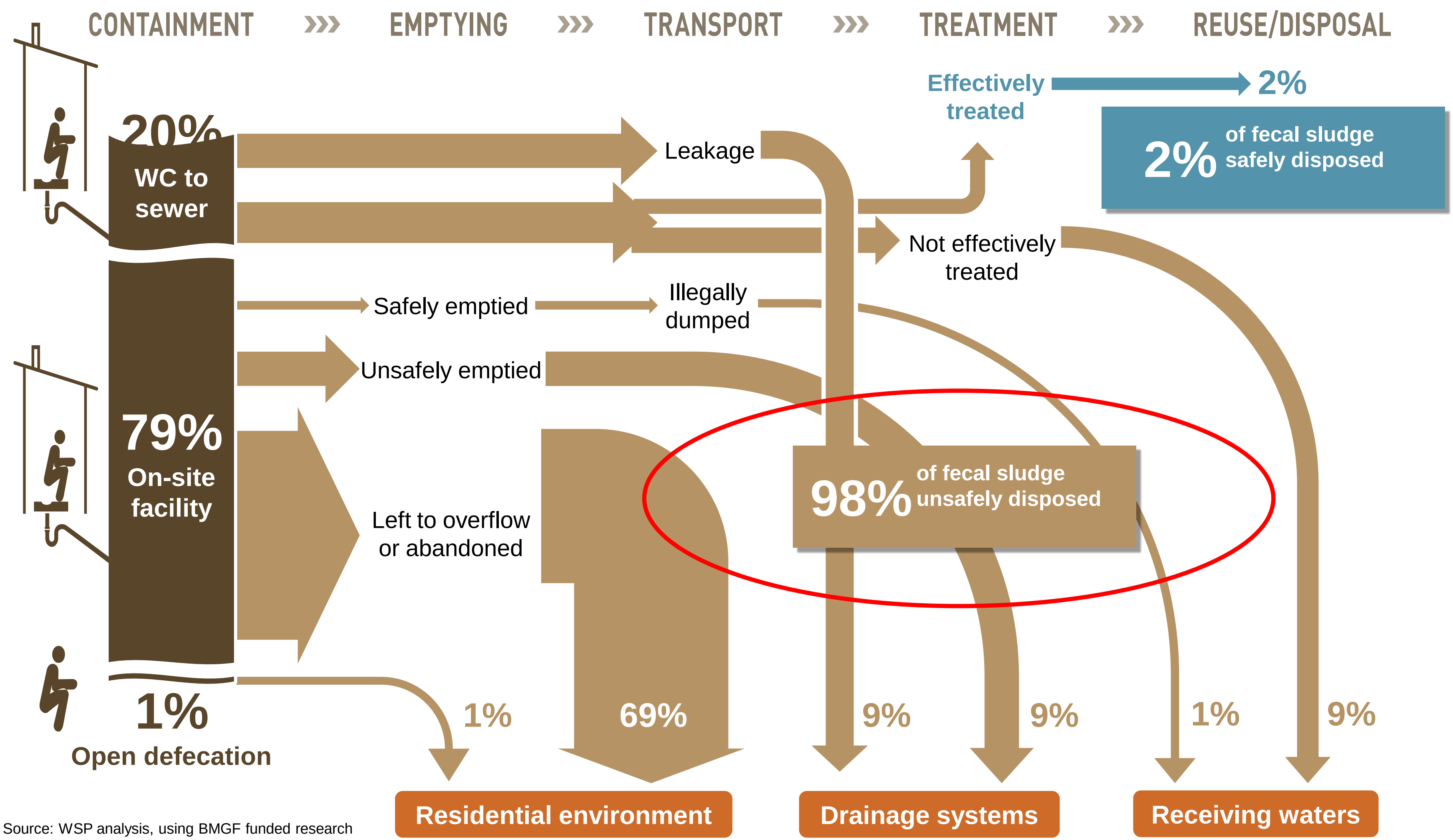
"INSTITUTIONAL" OPEN DEFECATION

Untreated sludge ends in the environment (Dhaka, Bangladesh)

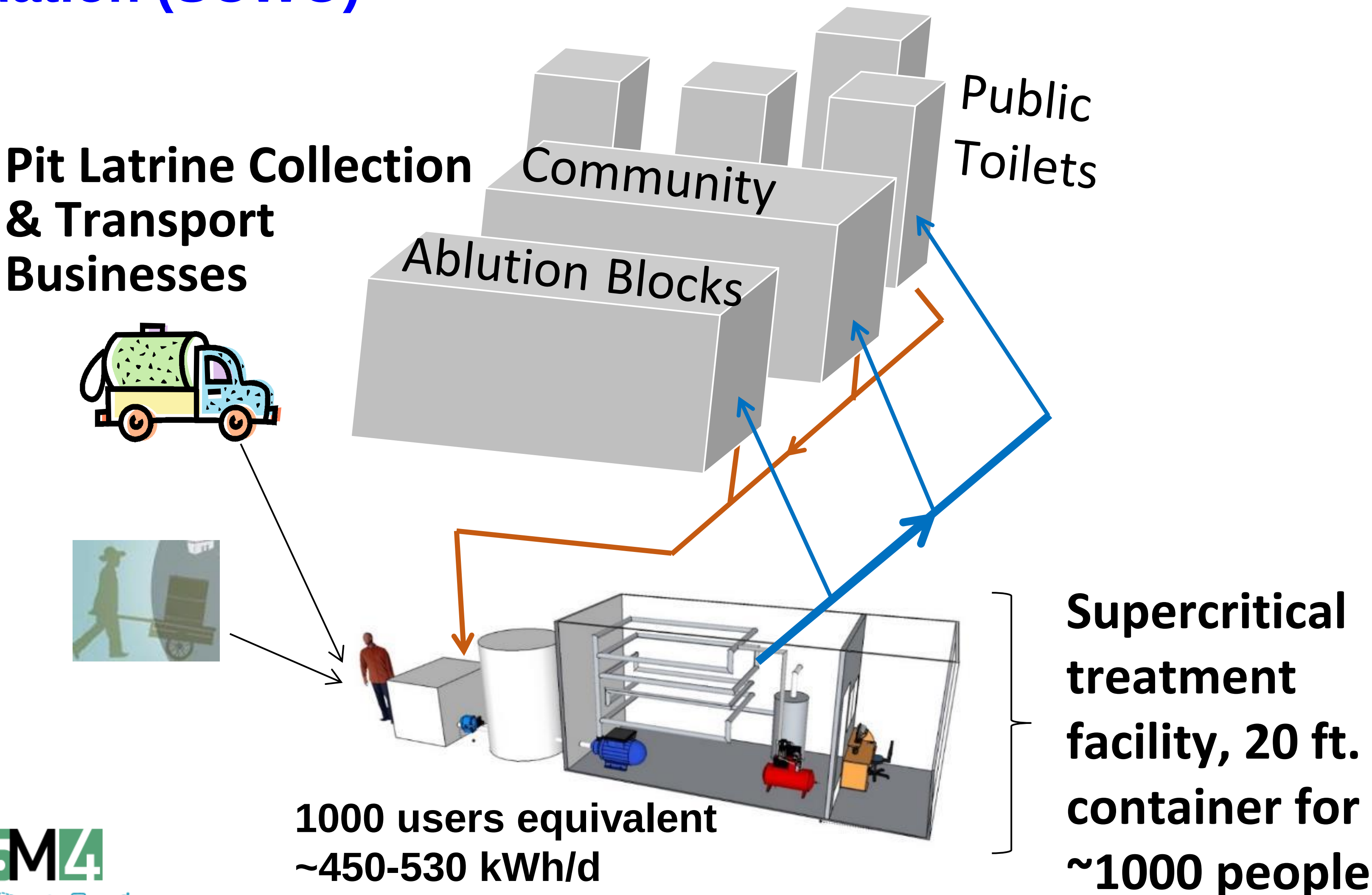


Source: WSP analysis, using BMGF funded research


This is a 87 kWh dump!!!
...a 15 L hot shower ~ 0.4 kWh

Our Vision: Omni Processor for Fecal Waste

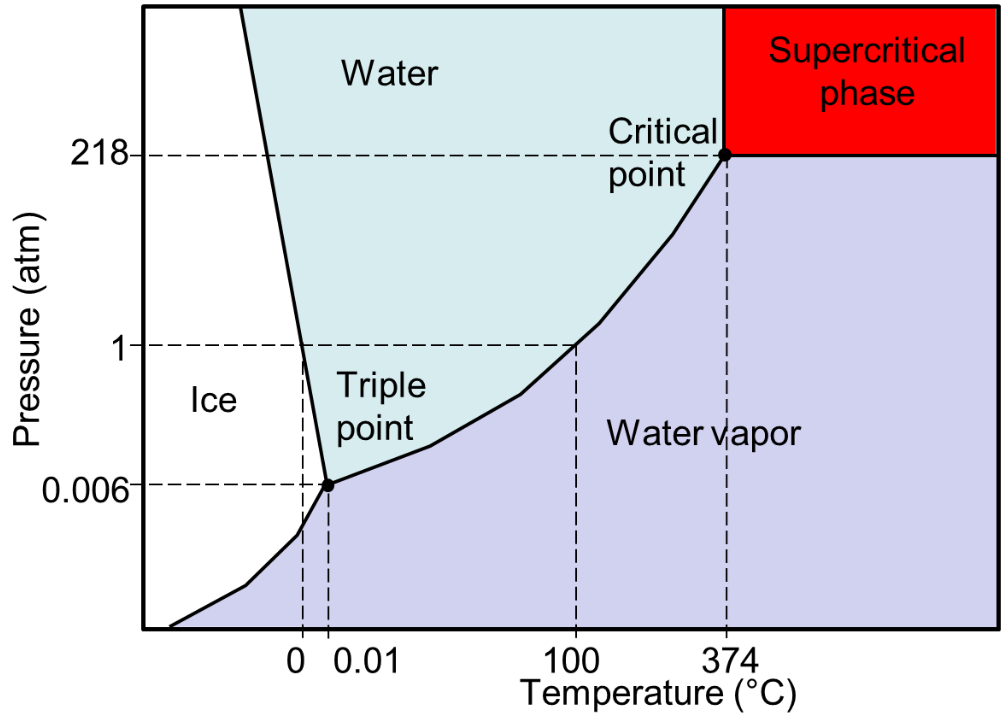
Sanitation for the urban poor using supercritical water oxidation (SCWO)



In supercritical water, organics are rapidly oxidized (in seconds) resulting in heat, and CO_2

Benefits
- Very fast reaction (sec.)
- High conversion to CO_2 + clean water
- No SOx, NOx or odor
- No need to dry waste
- Can co-treat haz. wastes

Technical risks
- Corrosion
- Salts deposition/plugging



Fecal slurry +	Air	T > 375 °C, P > 240 bar →	CO_2 +	H_2O +	N_2 +	ashes +	heat
1 m^3	600 m^3		100 m^3	~1 m^3	20 m^3	20-30 kg	1500 MJ
100 kg solids	160 kg O_2		180 kg				

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Pilot unit at Duke: 1000 p/d

- Heat and energy recovery
- Metallurgy and corrosion
- Process control
- Slurry pumping

System Characteristics

Basic characteristics

- **100-150 kg dry/day**
- **1-2 m^3/day**
- **Feed ~7-20% solids**
- Reactor ID: 19 mm
- Reactor length: 4.0 m
- Heat exchanger: 39 m
- Reaction time = **2.5 to 4.5 s**

Anti corrosion and plugging measures

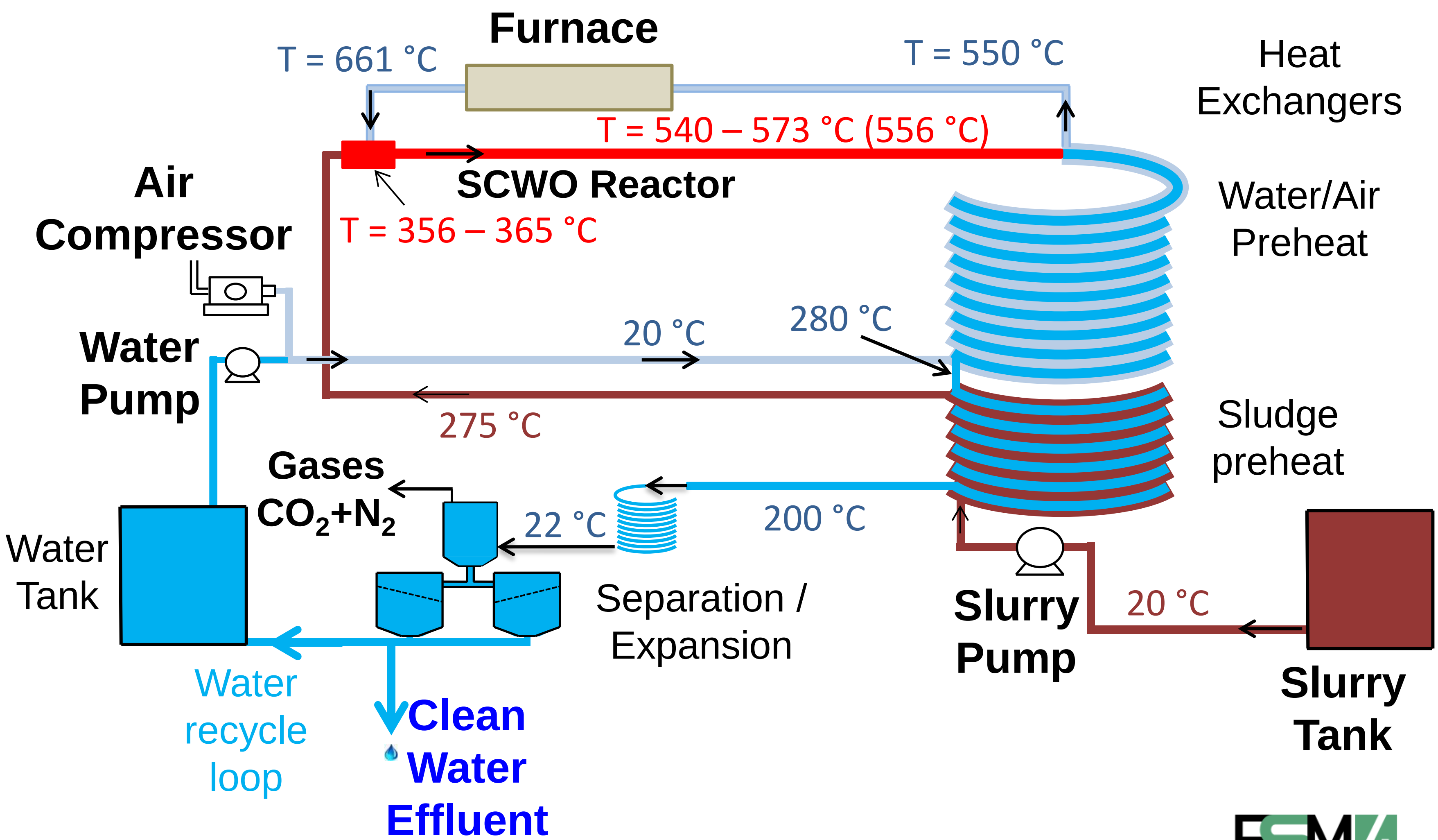
- High Re number, slight down slope
- Minimize transition zones
- Stainless steel and special alloys
- Continuous operation with periodic maintenance

Other

- Startup with isopropyl alcohol (IPA) but any other liquid fuel will work
- **Air** is used as oxidant

Pilot unit construction

Process flowsheet



Waste Processed

Secondary sludge
Dry solids-content ~16%
Ash content: 20-24%
HHV: 15 MJ/kg_{dry}

Dog feces
Dry solids-content 20-30%
Ash content: 27%
HHV: 15.7 MJ/kg_{dry}

- **Used as surrogates for human fecal waste (diluted to 4-10% solids)**
- **Mixed with IPA because of pumping issues**

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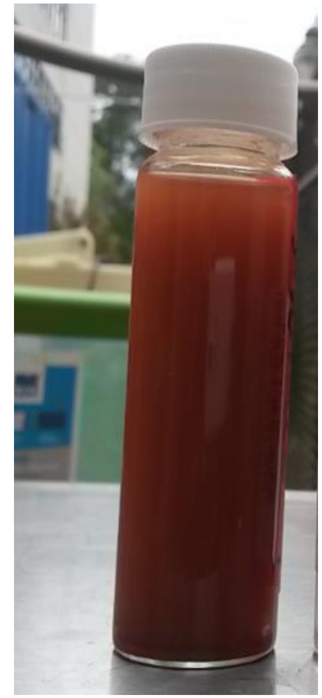
Secondary Sludge Treatment

Biosolids
(14 MJ/kg dry)

Feed



Effluent

Effluent
After settling

Slurry feed:
4.3% biosolids
9% IPA

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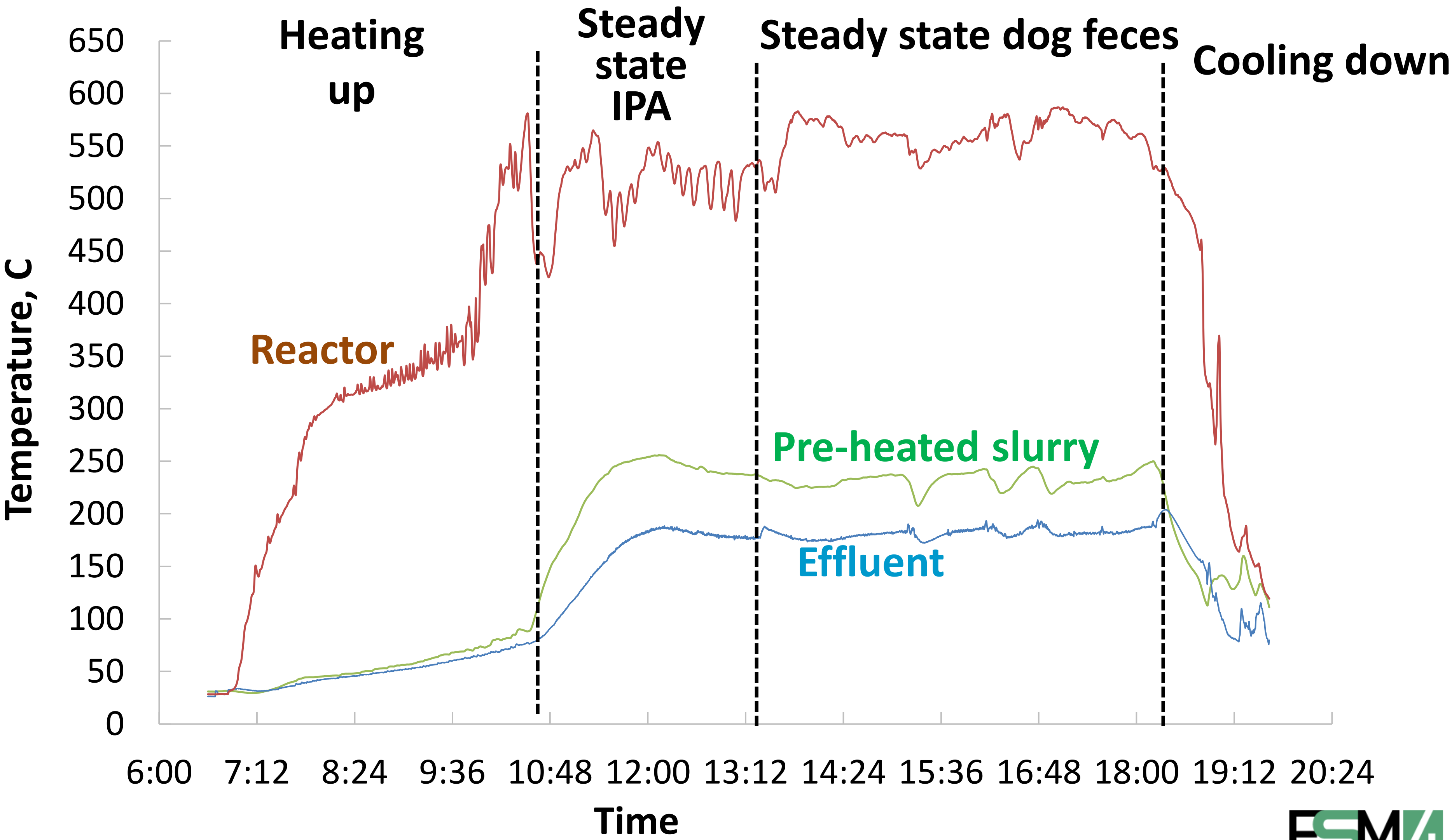
Temperatures During a Typical Run

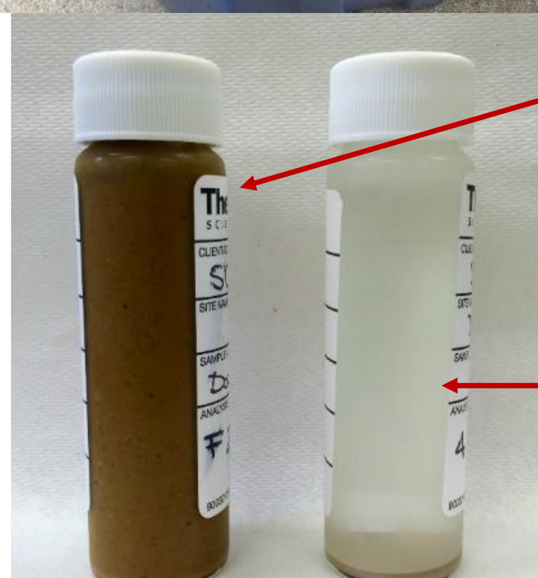


Secondary Sludge Treatment Summary

Analysis	Influent (3% sludge + 9% IPA)	Effluent Steady State	Removal (%)
COD (mg/L)	214,000	70 →	**99.97**
Total N (mg/L)	10,875	200 →	**98.12**
NH_3 (mg/L)	443	17.6	
NO_3^- (mg/L)	183	15.9	
NO_2^- (mg/L)	14.9	0.4	
PO_4^{-3} (mg/L)	4930	67.9 →	**98.60**
pH	6.8	7.02	
Conductivity (µS/cm)	2560	659	

Dog Feces Treatment

Slurry feed pre-processing:
14% solids (15.7 MJ/kg dry)



Feed
10% solids
+ 4% IPA

Effluent

Fresh Dog Feces Treatment Summary

Analysis	Influent (10% feces + 4% IPA)	Effluent Steady State	Removal (%)
COD (mg/L)	192,000	65-280 →	**99.97-99.85**
Total N (mg/L)	4704	220-420 →	**95.32-91.70**
NH_3 (mg/L)	627	185-325	
NO_3^- (mg/L)	98	0.3-0.8	
NO_2^- (mg/L)	22.5	0.04-0.54	
PO_4^{-3} (mg/L)	14,500	13.4-63.9 →	**99.91-99.56**
pH	5.95	-	
Conductivity (µS/cm)	4500	-	

Fate of Metals and Other Elements

Dog Feces Run

Element	Conc. dry feces (mg/kg dry)	Conc. liquid feed (mg/L)	Conc. liq. effluent (mg/L)	Conc. dry ashes (g/kg dry)
Ca	75,400	2,932	27.50	298
S	6,180	240	49.70	1.55
P	4,040	157	2.92	25.2
K	2,580	100	28.60	2.26
Fe	1,820	70.8	< 0.05	10.1
Zn	1,000	38.9	0.04	4.32
Al	450	17.5	< 0.05	4.44
Cu	93.6	3.64	0.16	0.23
Cr	83.2	3.24	< 0.01	0.32
Ni	57.2	2.22	0.20	0.21

Treatment of Micro-Pollutants

Experimental Approach

- Spiked trace contaminants during a run
- Used high concentrations of Triclosan, Acetaminophen, and Ibuprofen
- Run with spiked IPA first, then spiked dog feces and IPA

Results

- Ibuprofen and acetaminophen (10 mg/L each) – not analyzed yet

- Triclosan:

Relevant concentration: 0.5 – 1 µg/L
Concentration spiked: 100 µg/L
Concentration in effluent (IPA treatment): ND at < 0.1 µg/L
Concentration in effluent (dog feces + IPA treatment): < 0.1 µg/L
Removal > 99.99%

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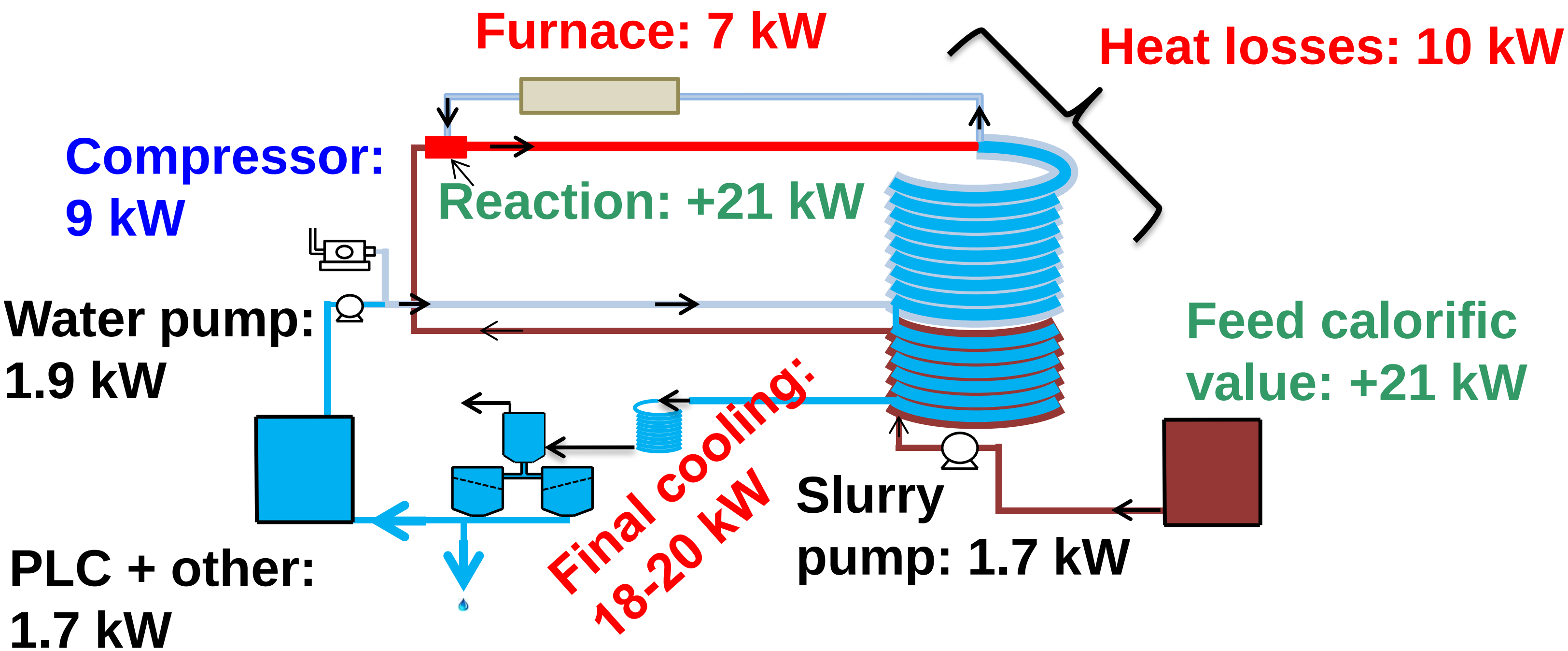
Energy Balances – 1000 users/day



- Compressor = biggest draw
- Losses + final cooling → not autothermal

Optimized design:

- Turn of furnace (autothermal)
- Recover energy from gas expansion (3-6 kW)
- **Expected draw = 6-10 kW   (this is 6-10 W/p)**
- **Produce 5-10 kW has heat**

Current and future activities

- Modify current prototype for greater energy efficiency
- New slurry pump to allow operation with high solids content and larger particles
- Techno-economic analysis, sensitivity of CAPEX and OPEX to size
- Design of an optimized and manufacturable product

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Conclusions

- SCWO can turn fecal waste into clean water and heat really fast without odor, SOx, or NOx emissions…
- All pathogens are killed
- SCWO can even co-treat hazardous wastes
- Selling "high value added" by products can be a driver

- But many challenges remain…

Acknowledgments

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