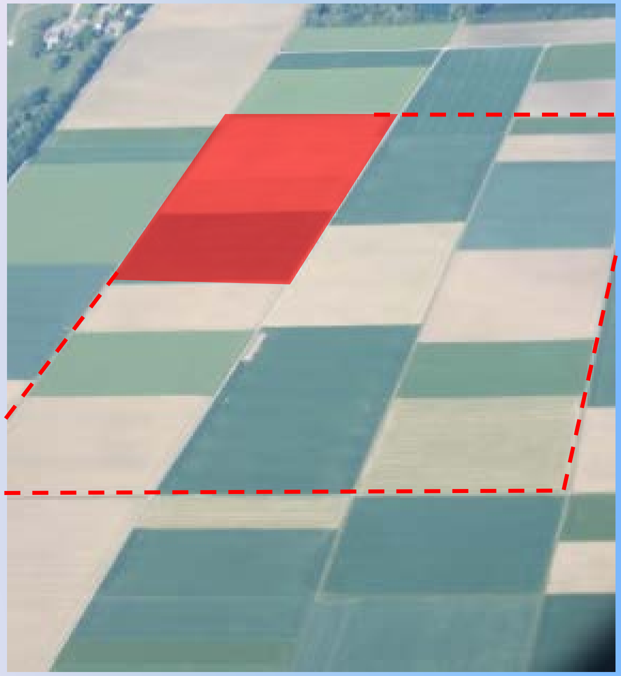
Towards energy sustainable wastewater treatment plants



Facilities footprint
1/10 -1/5

Capital cost
1/3 -1/2

Energy consumption
1/10 – 1/5

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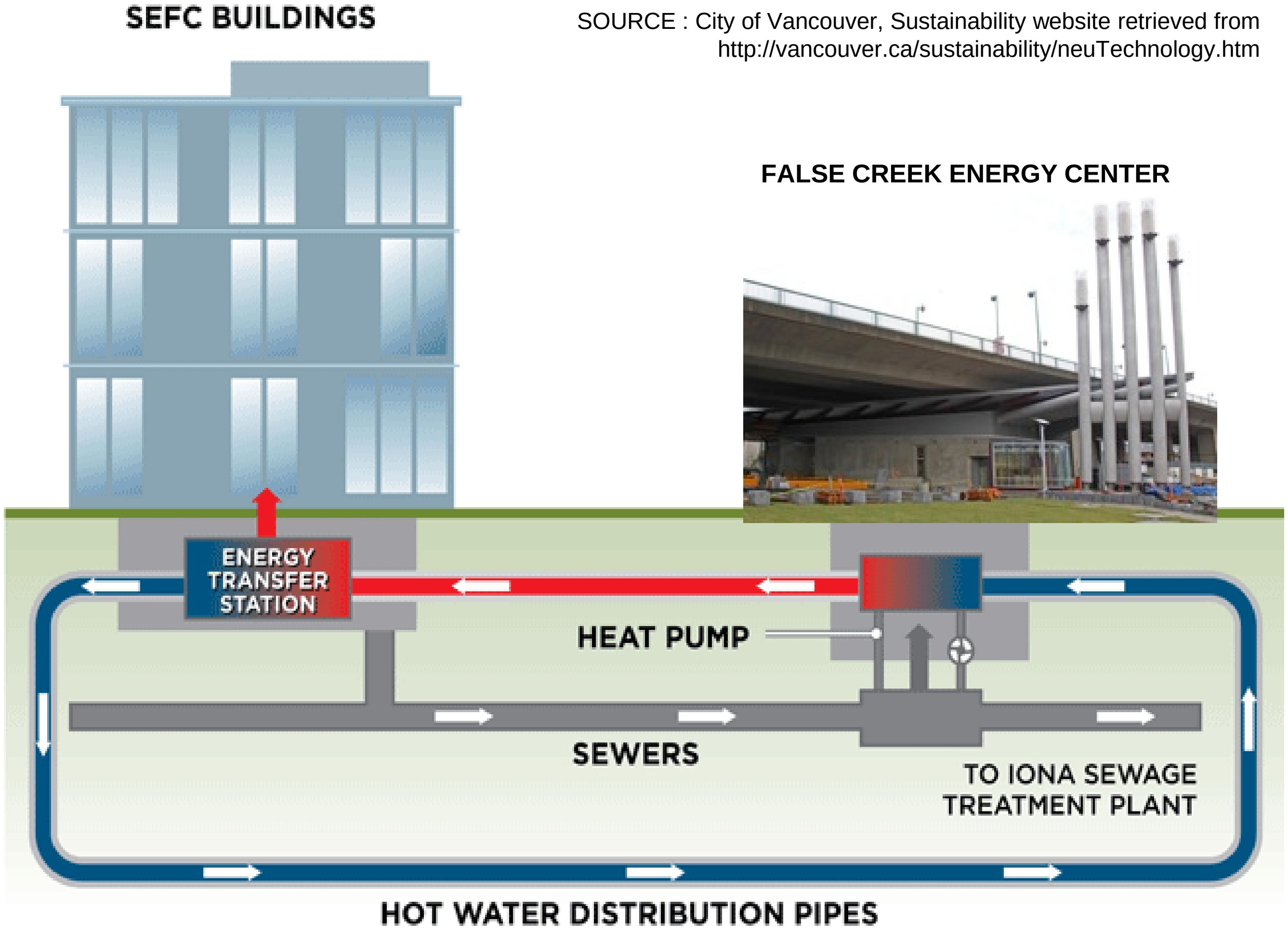
Deficient energy design

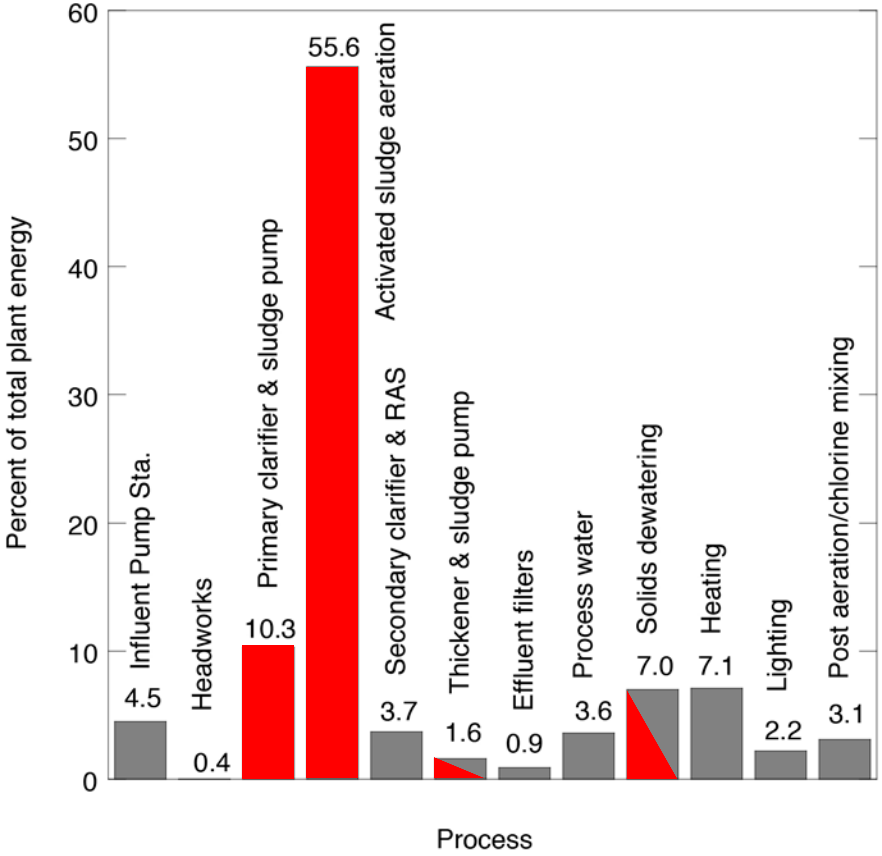
At 0.03 €/kWh energy efficiency was not an issue.
Example: Excessive headloss (energy loss)
at primary sedimentation tank weir

Heat reclamation from sewage

SOURCE : City of Vancouver, Sustainability website retrieved from
http://vancouver.ca/sustainability/neuTechnology.htm



Energy distribution in conventional wastewater treatment plant



>70% of energy is consumed for aeration and primary sludge management

Energy content of wastewater

Heat energy

Specific heat of water = 1.16 Wh/g •ºC, at 20ºC

Chemical oxygen demand (COD)

$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 2H_2O$

(113) 5(32)

Chemical energy (Channiwala,1992)

HHV (MJ/kg) = 34.91C+117.83H -10.34O -1.51N+10.05 S-2.11Ash

Assuming 0.5 gCOD/L and 3.6 MWh/kg-COD → 1.8 kWh/m^3

Energy content of wastewater

Constituent	Unit	Value
Wastewater, heat basis	$kWh/(10^oC \cdot m^3)$	11.6
Wastewater, COD basis	kWh/kg COD	3.3 – 4.2
Primary sludge, dry	kWh/kg TSS	4.2 – 4.4
Secondary biosolids, dry	kWh/kg TSS	3.4 – 3.8

Required and available energy for wastewater treatment, exclusive of heat energy

- Energy required for secondary wastewater treatment (activated sludge)

  0.3 kWh/m^3 (only BOD removal)

  to

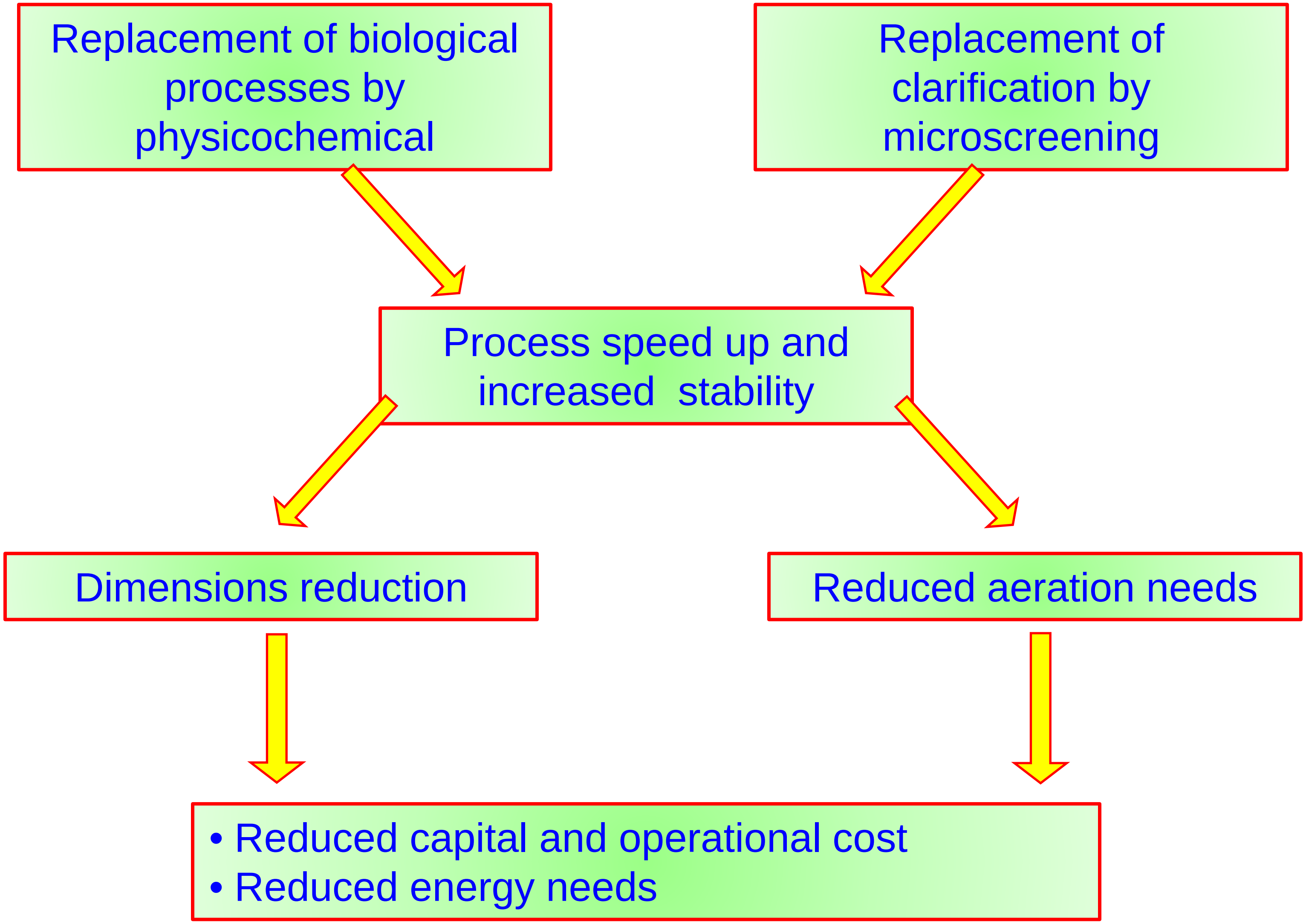
  0.65 kWh/m^3 (BOD and nitrogen removal)

- Energy available in wastewater for treatment (assume COD = 5.0 g/m^3)

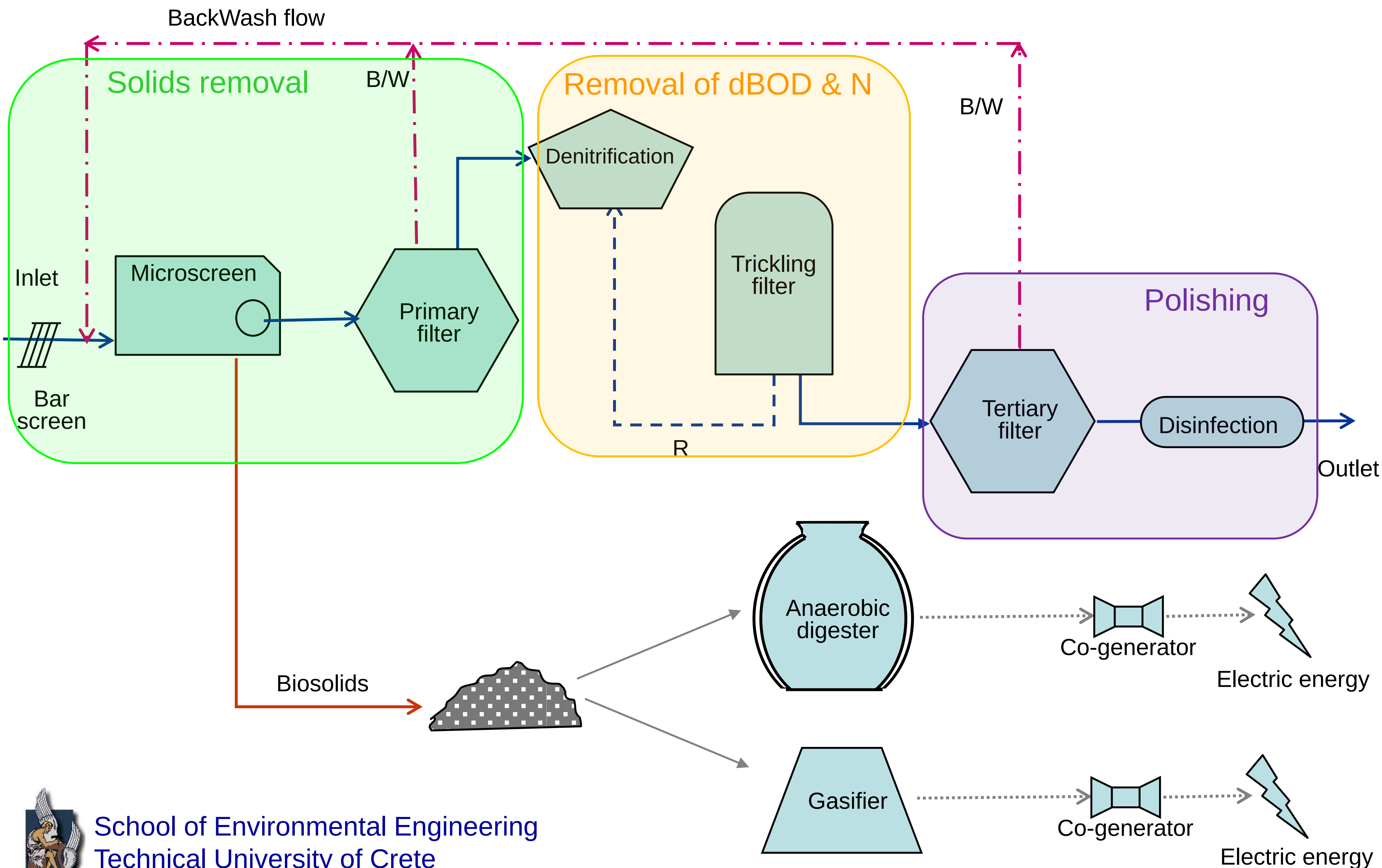
  $E = (0.5\ g\ COD/m^3)\ (3.6\ kWh/gCOD) = 1.8\ kWh/m^3$

- Energy available in wastewater is 3 to 6 times the amount required for treatment

New concepts in wastewater treatment and reuse management



Upfront solids removal (USR) process



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Biosolids:
Gasification versus anaerobic digestion*

Potential for net electrical energy production

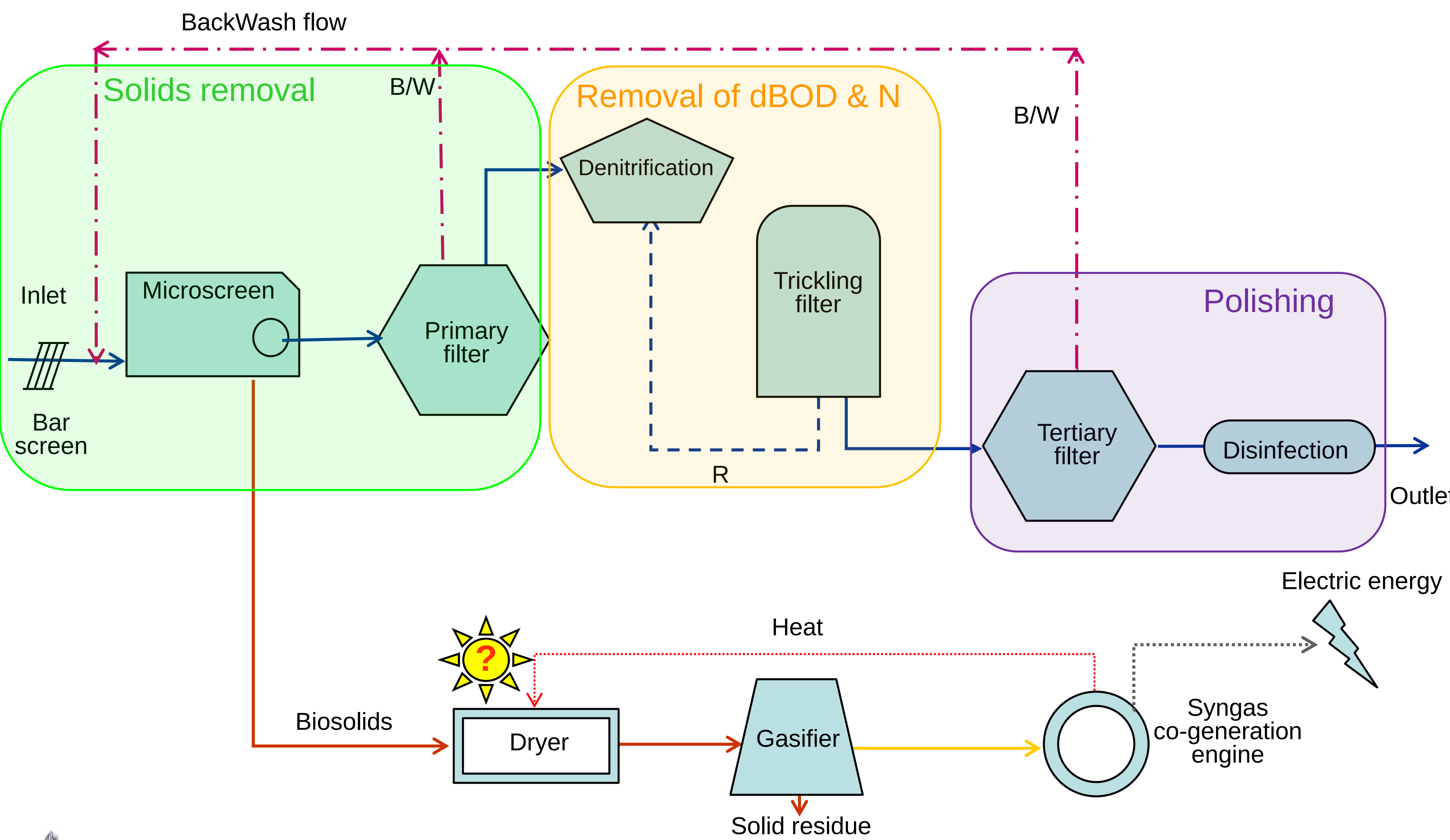
Gasification

Anaerobic digestion

2 : 1

* P. Gikas, 2014, Environmental Technology, 35(17), 2140-2146

Upfront solids removal (USR) process with biosolids gasification



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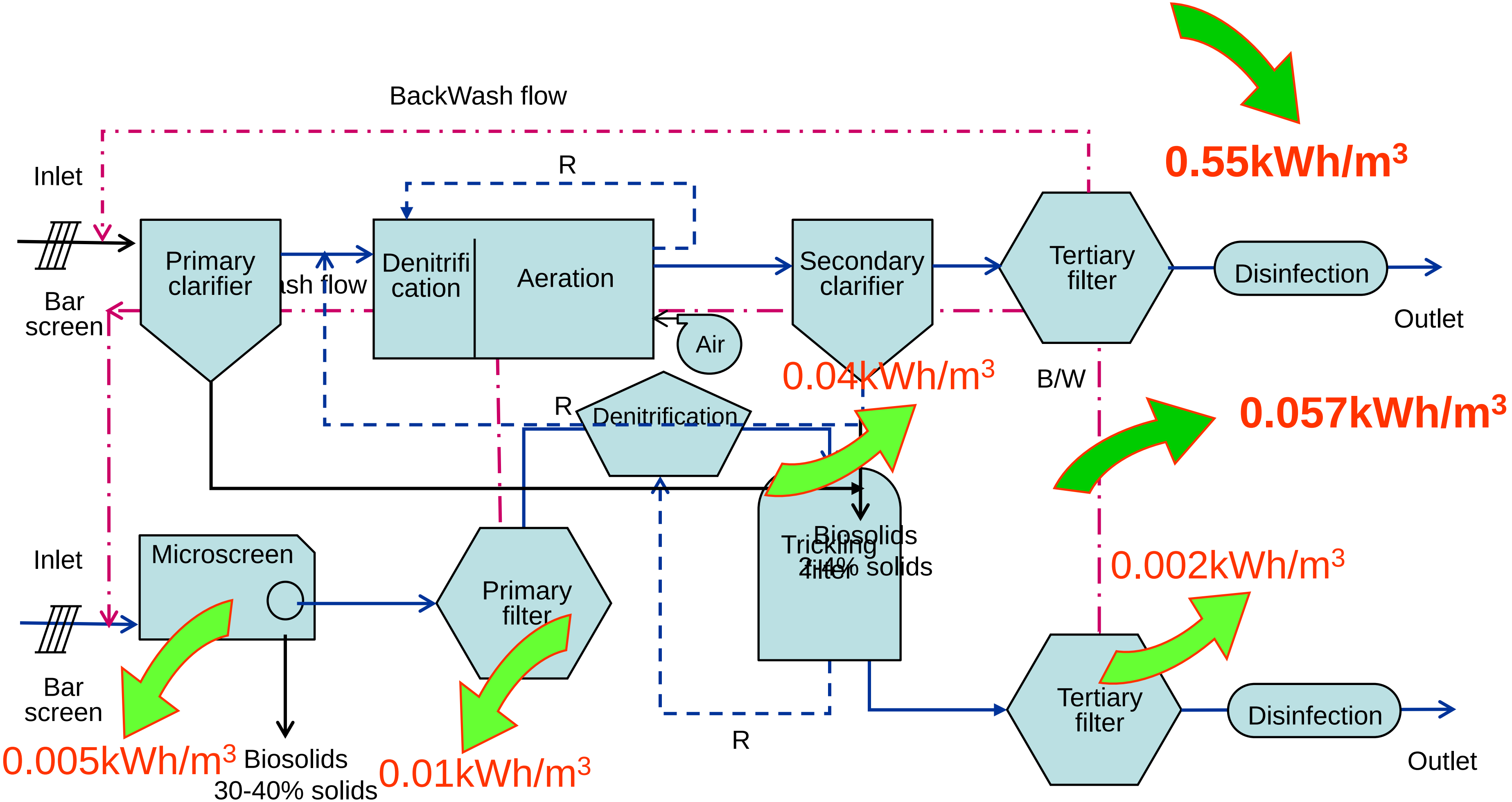
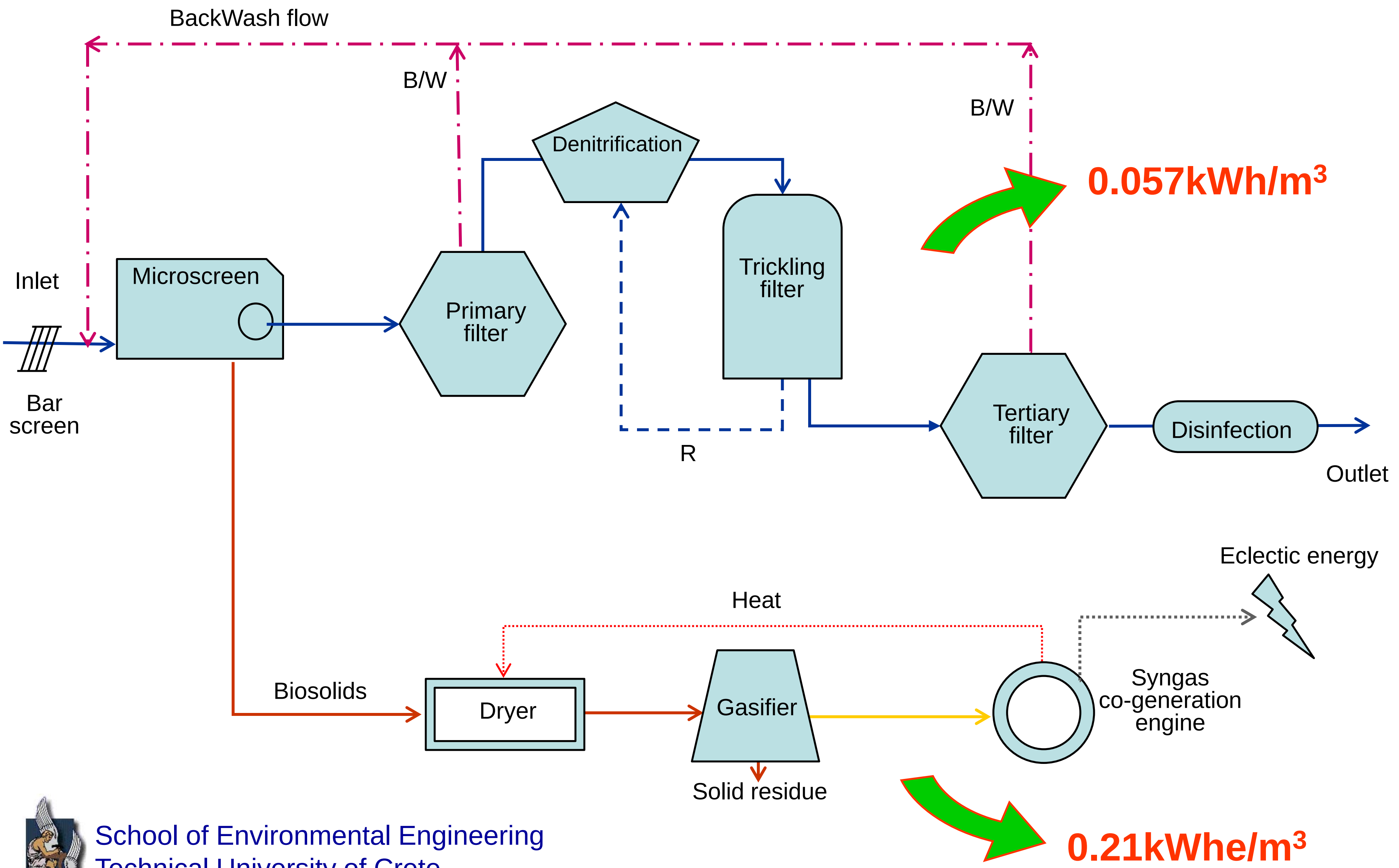
Wastewater treatment process flow diagrams-Energy requirements



Energy balances for USR process with biosolids gasification



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USR process characteristics
(Liquid management part)

Retention time (min)				
Microscreening	Primary filter	Trickling filter and denitrification	Tertiary tratment	Total
0.2-0.6	13-20	15-25	10-20	38-65

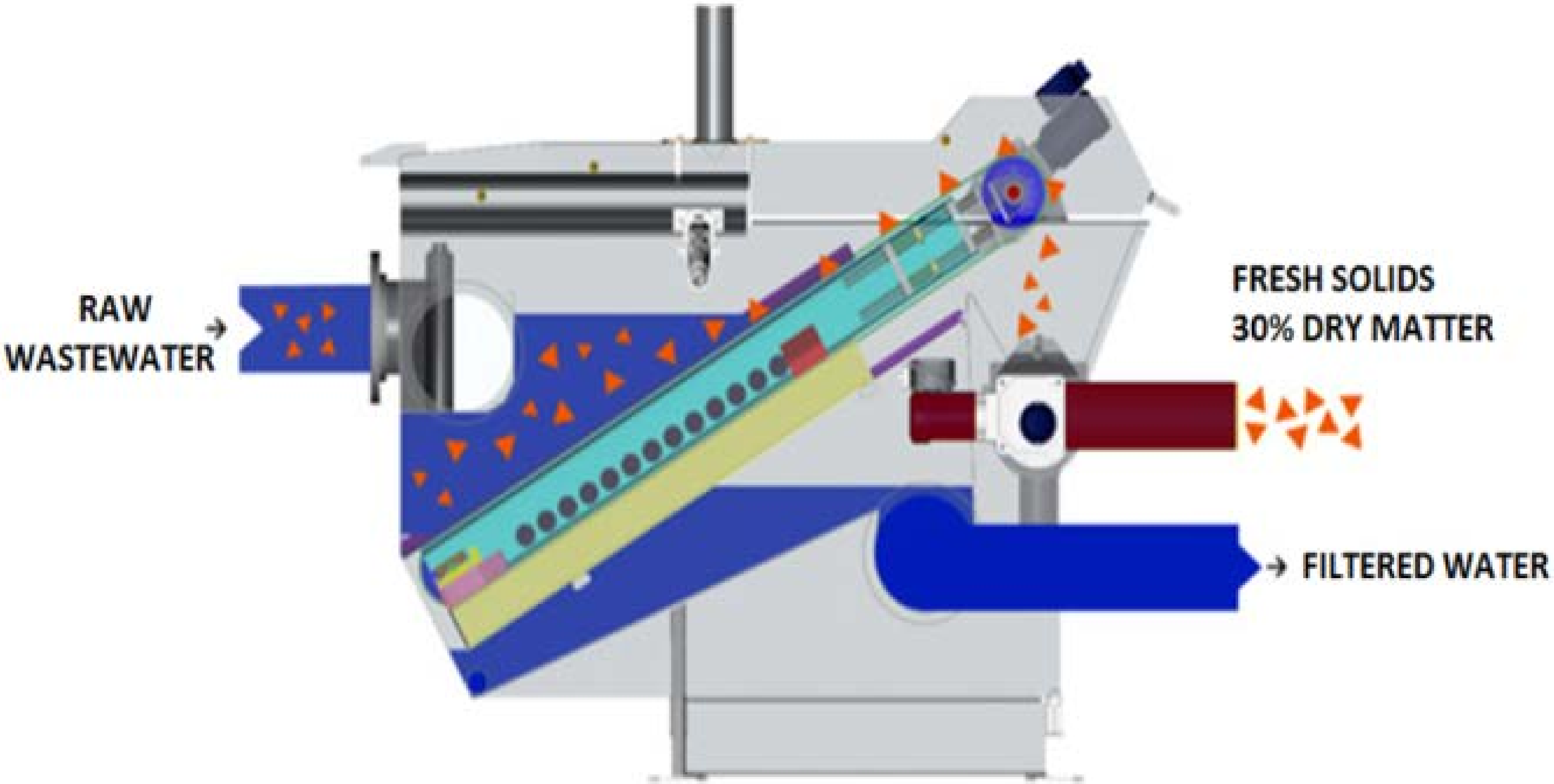
Removal (%)		
Microscreening	Primary Filtration (following microscreening)	Biological treatment (following the previous processes)
TSS: 40-70, BOD_5: 40-60	TSS: 80-95, BOD_5: 70-80	Discharge limits

USR process vs activated sludge process
(Liquid management part)

Retention time (h)	
Upfront solids removal process	Activated sludge process
½ - 1½	**7-15**

Energy requirements (kWh/m^3)	
Upfront solids removal process with nitrogen removal	Activated sludge process with nitrogen removal
0.057	**0.55**

Microscreen - Operating principle

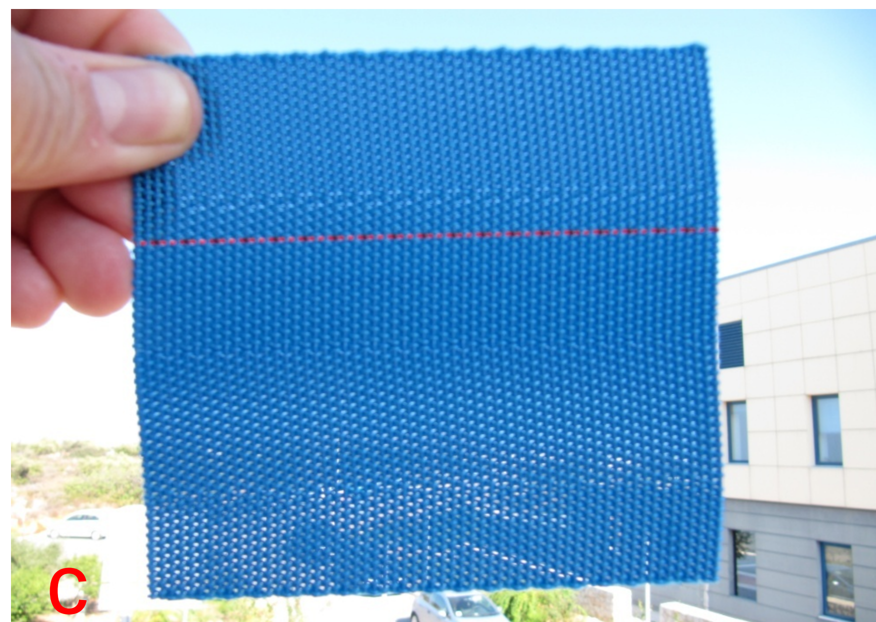


Microscreen

a. Microscreen with open housing

b. Sludge removal (~45% TS)

c. Microscreen cloth (350μm openings)

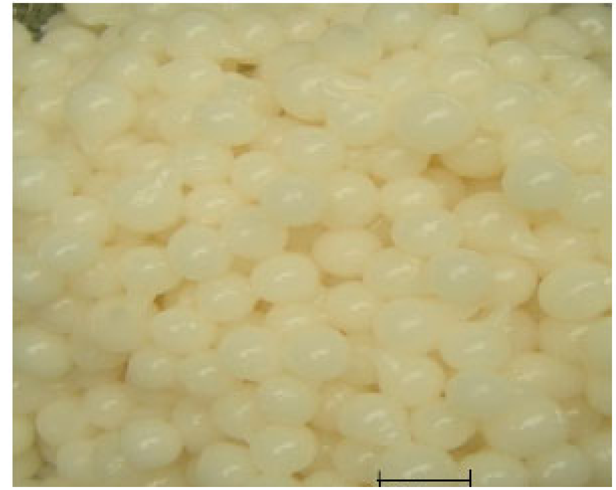


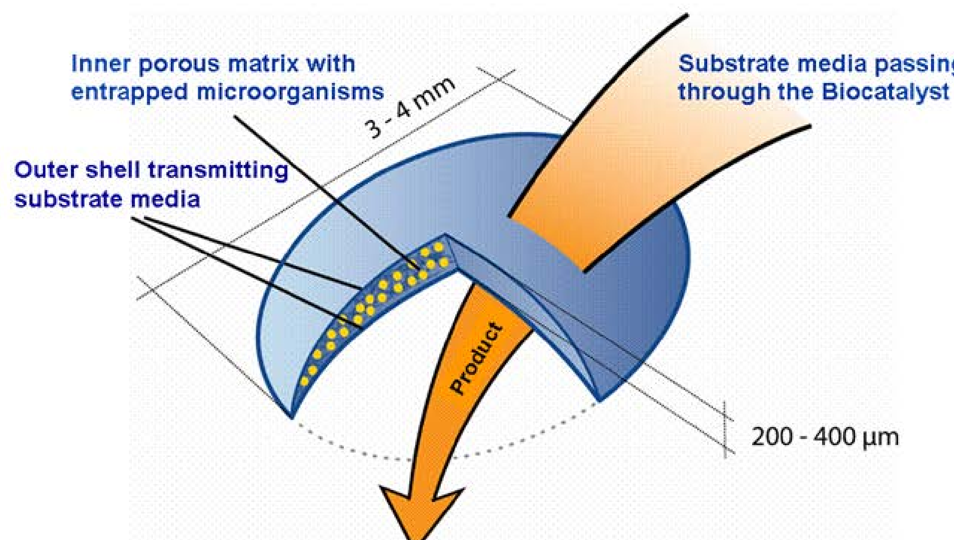
Microscreen (Patra, Greece)


Upflow sand filters, Adelanto, California
(15000 m3/d)

Trickling filtration & Nitrogen removal

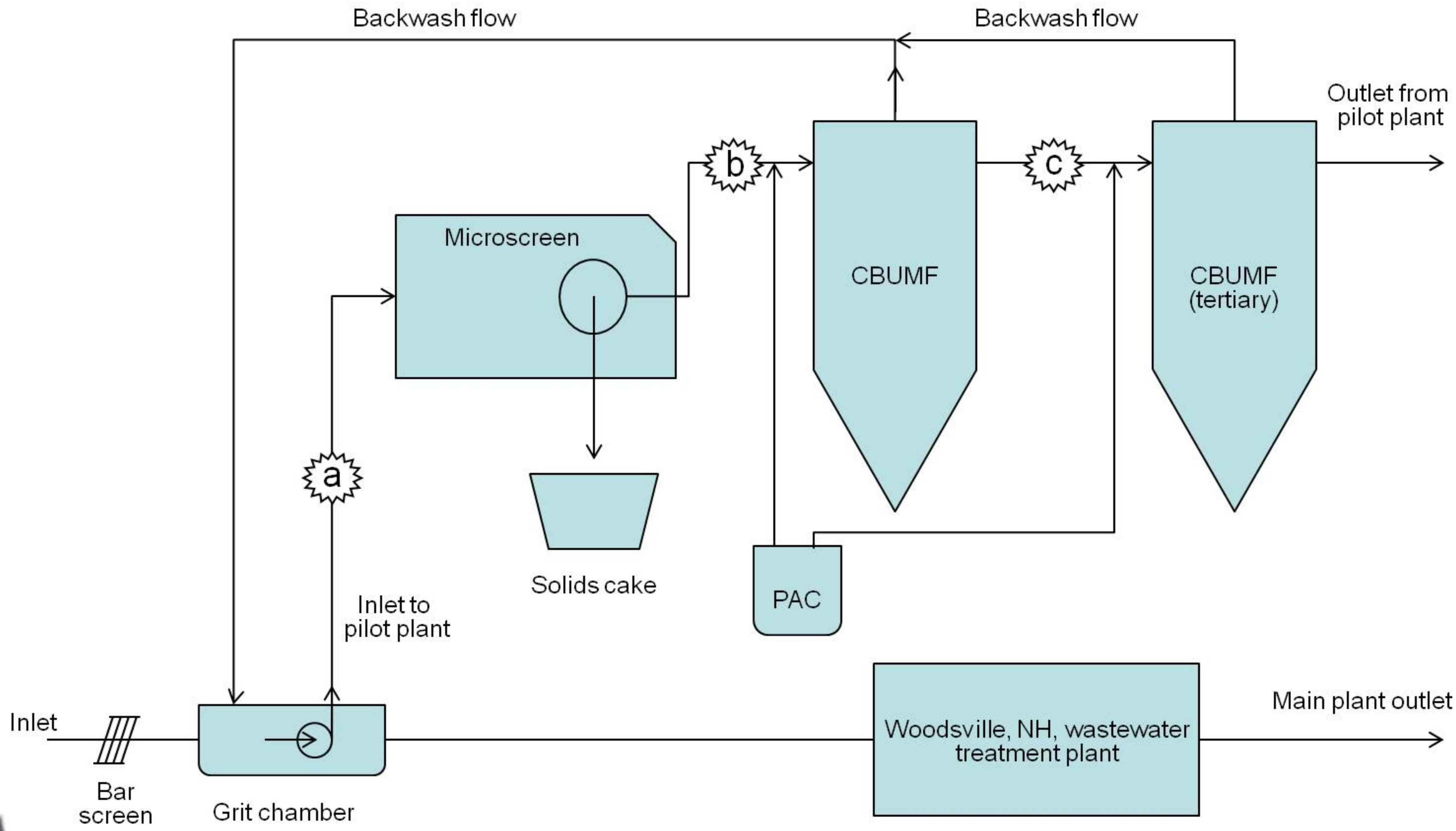
Small pilot trickling filters





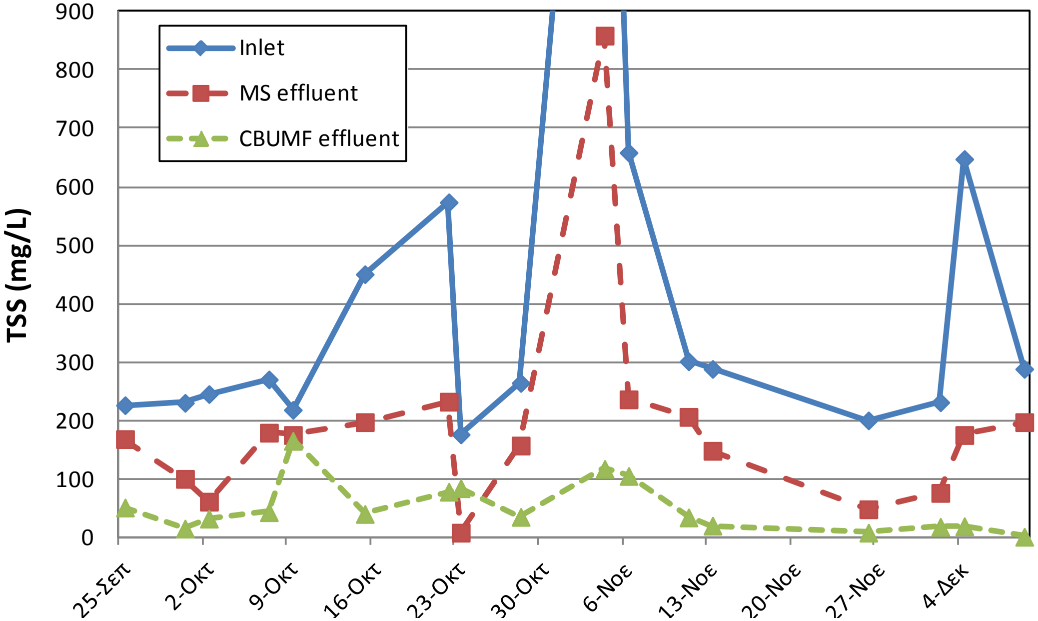
Lens shape encapsulated denitrifiers

Experimental pilot facility (Woodsville, CN, USA)

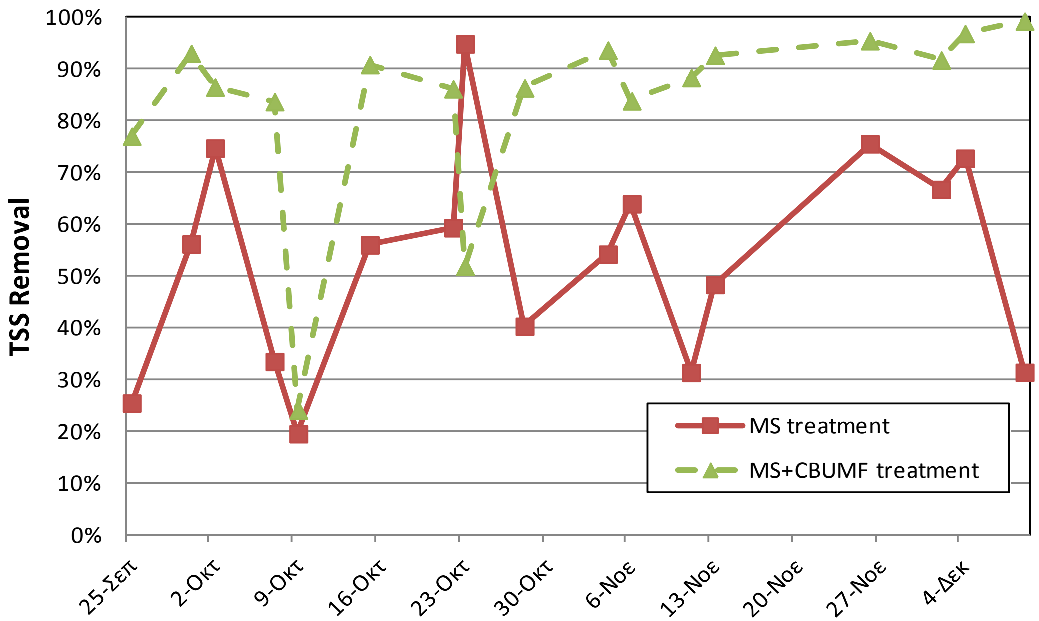



Polishing filter
Biological filter
Sand filter
Microscreen
T1 - V2
T1 - V1
Experimental pilot facility (Woodsville, CN, USA)

TSS removal



TSS values in various stages of the process



TSS percentage removal

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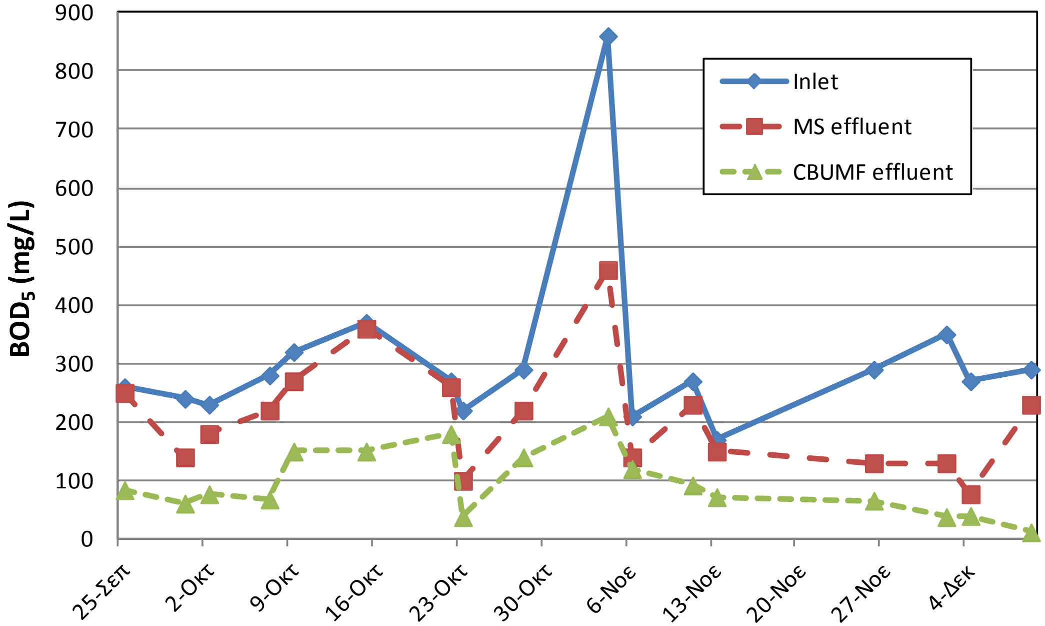
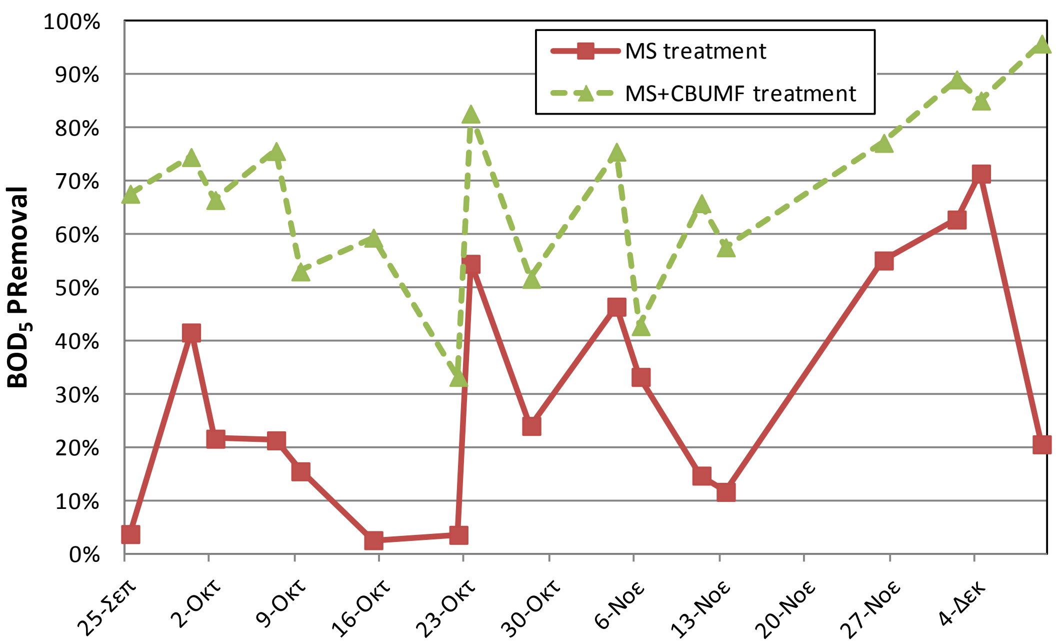
BOD removal



BOD values in various stages of the process



BOD percentage removal

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Biosolids management for energy production

BIOSOLIDS

Anaerobic digestion

- Converts only a fraction of carbon to methane
- Produces sludge as byproduct
- Bioprocess, and thus susceptible to instability
- Well received by the public

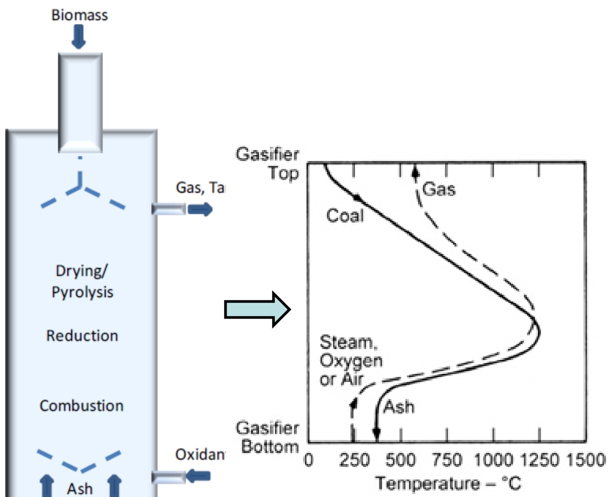
Direct combustion

- May produce harmful byproducts
- Production of solid residue (with tar)
- Incomplete conversion of carbon to gaseous species
- Not well received by the public

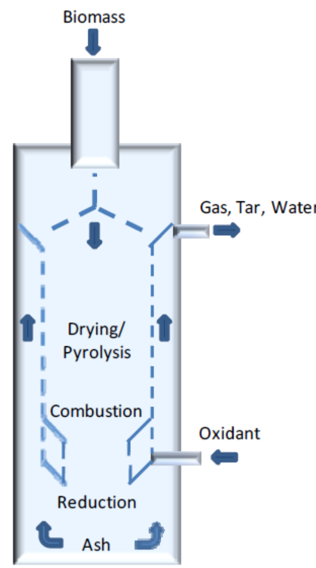
Gasification

- Production of clean combustible gas
- Production of solid residue (no tar)
- Technology still under development
- Complete conversion of carbon to gaseous species
- Confused with combustion by the public

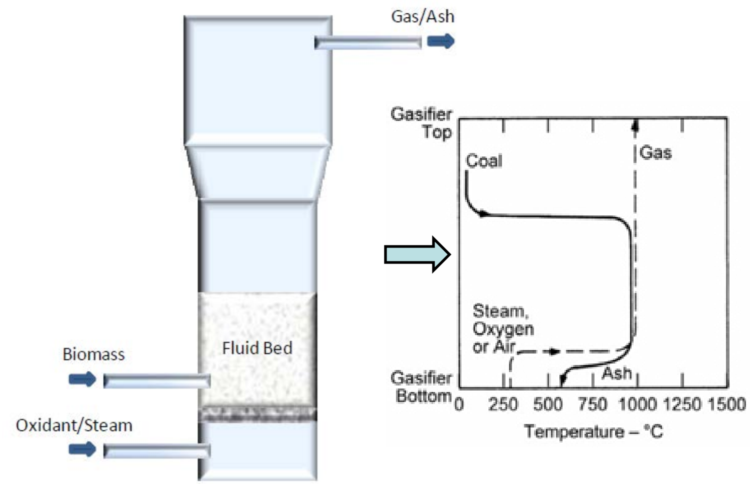
Main types of gasifiers



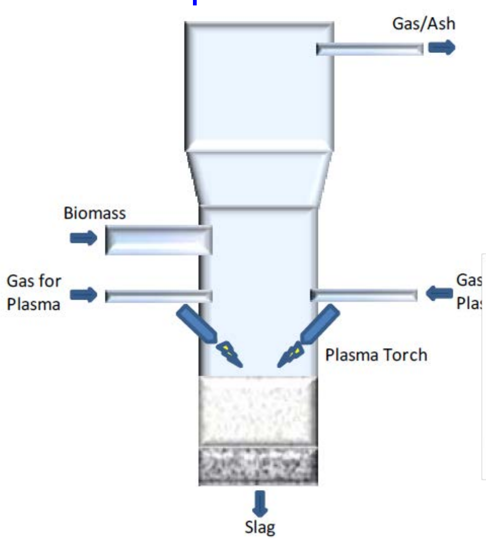
Updraft



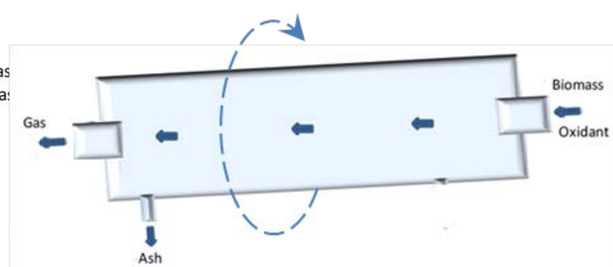
Downdraft



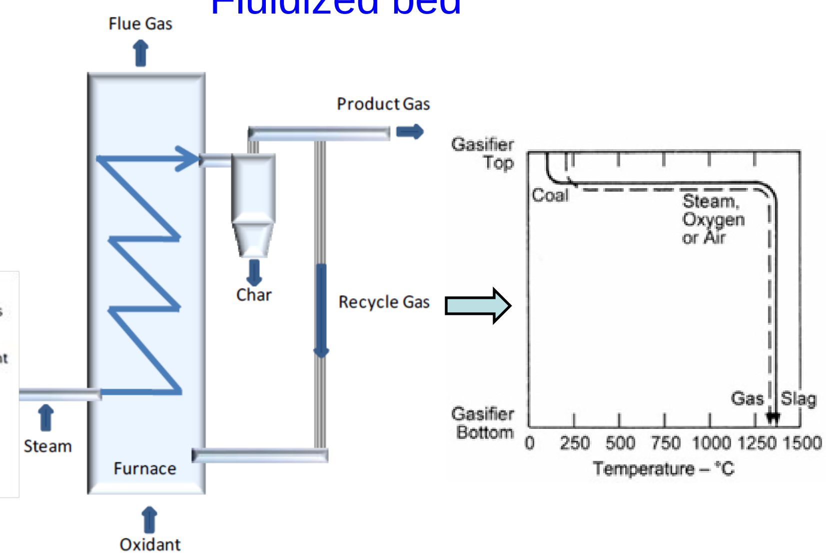
Fluidized bed



Arc plasma



Rotary drum



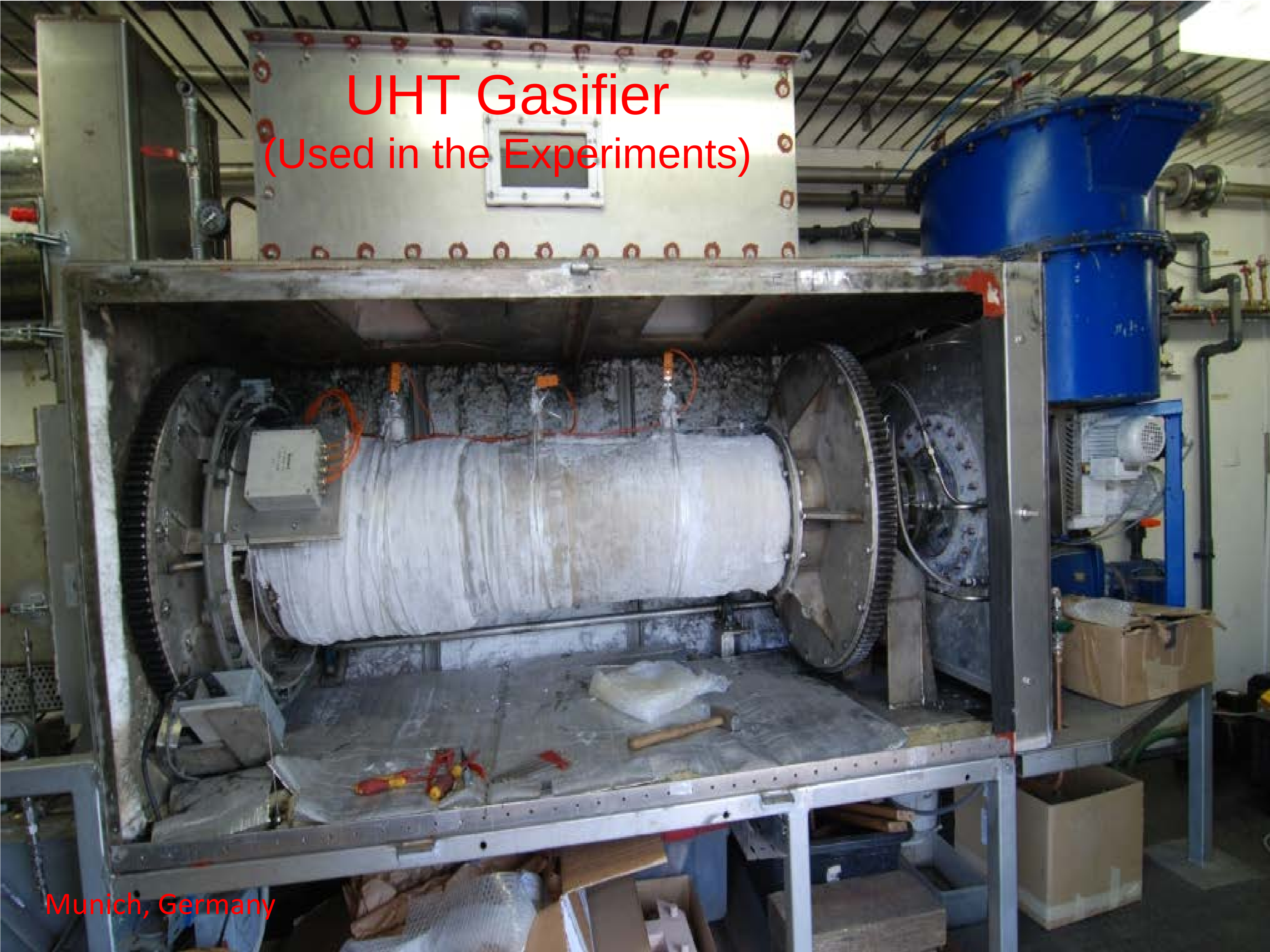
Entrained flow

The “ideal” gasifier

- Low capital cost
- Low operational and maintenance cost
- Low operational risk
- High syngas yield
- Appropriate syngas composition and temperature
- Low emissions
- Minimal requirements for feedstock pretreatment
- Feedstock diversity
- Non-complicated start up / shut down processes
- Proven technology

Ultra High Temperature (UHT) Gasification

- Standard sizes: 5 tpd or25 tpd
- Rotating cylindrical nickel-chromium or molybdenum alloy reactor with impregnated heat resistant coating and proprietary electric heating element
- Operating temperatures of 1100˚C to 1500˚C
- Air tight operation to prevent nitrogen dilution (zero emissions gasifier)
- Complete thermal decomposition of all organic matter into syngas, typically 62% H_2 and 31% CO (depending upon feedstock and reactor temperature range)


UHT Gasifier
(Used in the Experiments)
Munich, Germany

Feedstock

a. Microscreen removed solids (partially dried)

b. Microscreen removed solids (after size reduction)

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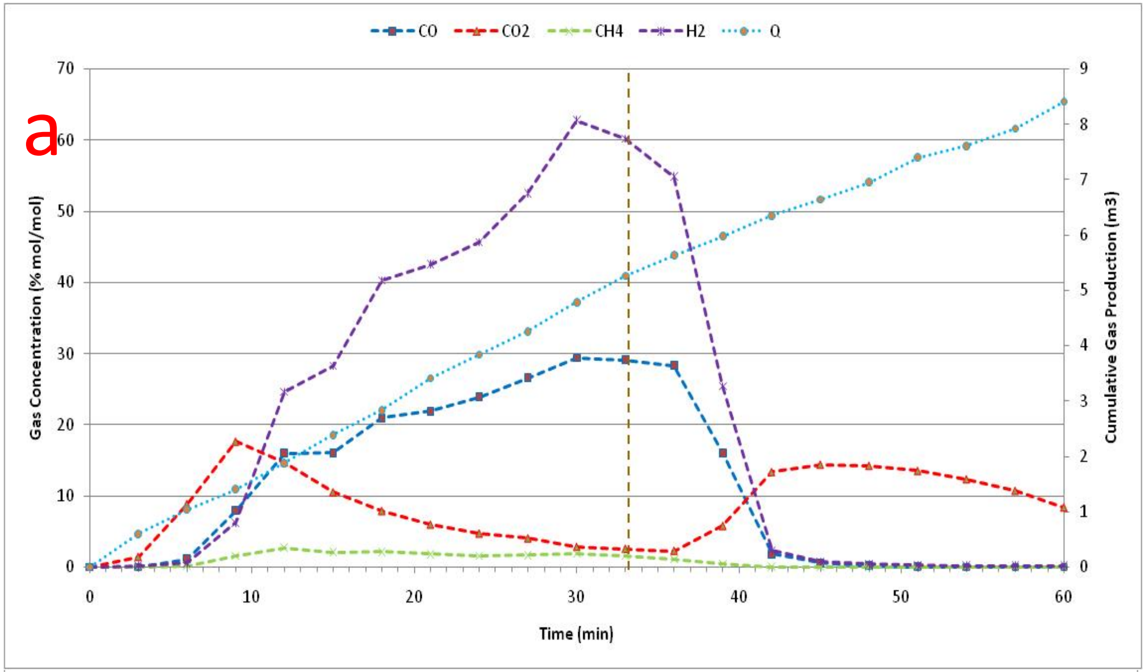
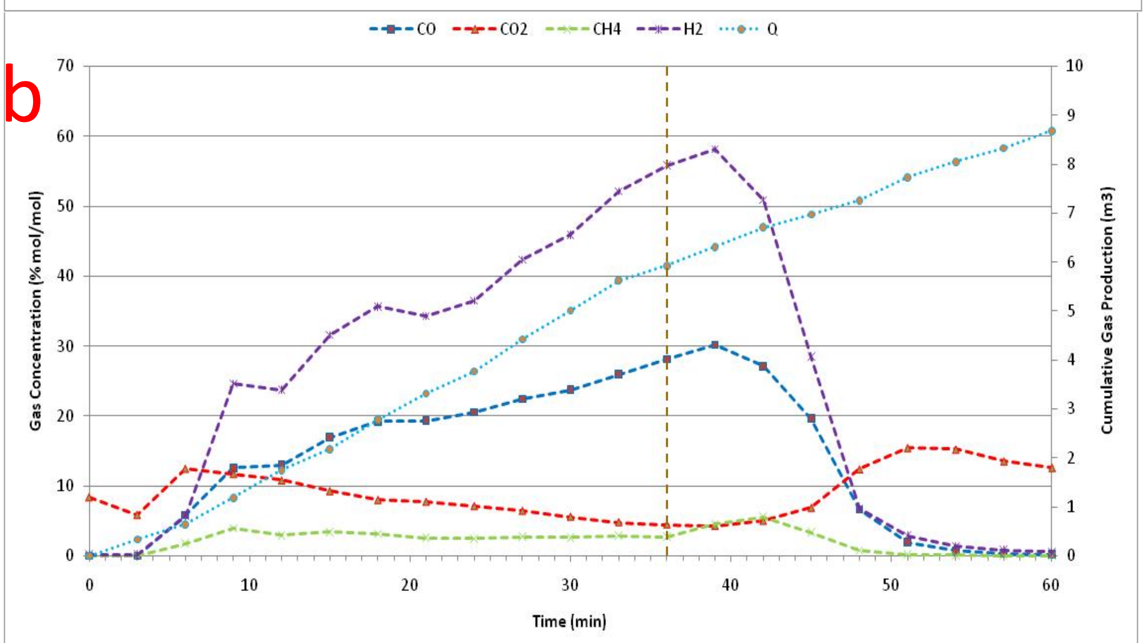
Syngas composition and production rate



a. Run 1: Maximum temperature = 1050 °C



b. Run 1: Maximum temperature = 950 °C

Gasification solid residue

Overall inlet and outlet from the gasifier

Run No	USR proc solids (kg)	Moisture (%)	Temp. (˚C)	CO (%)	CO_2 (%)	CH_4 (%)	H_2 (%)	Other gases (%)	Ash (kg)
Run1	8.15[a]	17	1050	29.87	2.63	1.79	62.96	2.75	0.52[b]
Run2	8.15[a]	17	950	29.86	4.14	2.92	62.18	0.90	0.52[b]

a: Combined weight of infeed charge for Run1 and Run2
b: Total measured weight of ash from both Run1 and Run2 combined

Syngas production → 1.56 m^3 / kg solids (17% H_2O)

Gross energy production → 19.7 MJ / kg solids (17% H_2O)

Electric energy consumption → 8.12 MJ / kg solids (17% H_2O)

Net energy production → 12.63 MJ / kg solids (17% H_2O)

Pilot plant under installation at Chania, Greece wastewater treatment plant

Conclusions

- The Upfront solids removal (USR) process my successfully replace conventional activated sludge treatment process
- Retention time in USR process is 90% lower than in activated sludge process
- Energy consumption in USR process is 90-80% lower compared to activated sludge process
- Biosolids gasification produces approximately double electric energy compared to anaerobic digestion
- Wastewater treatment process should be redesigned taking into account recent technological achievements and the needs of the modern society

Thank you for your attention

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