Resource efficient manufacturing

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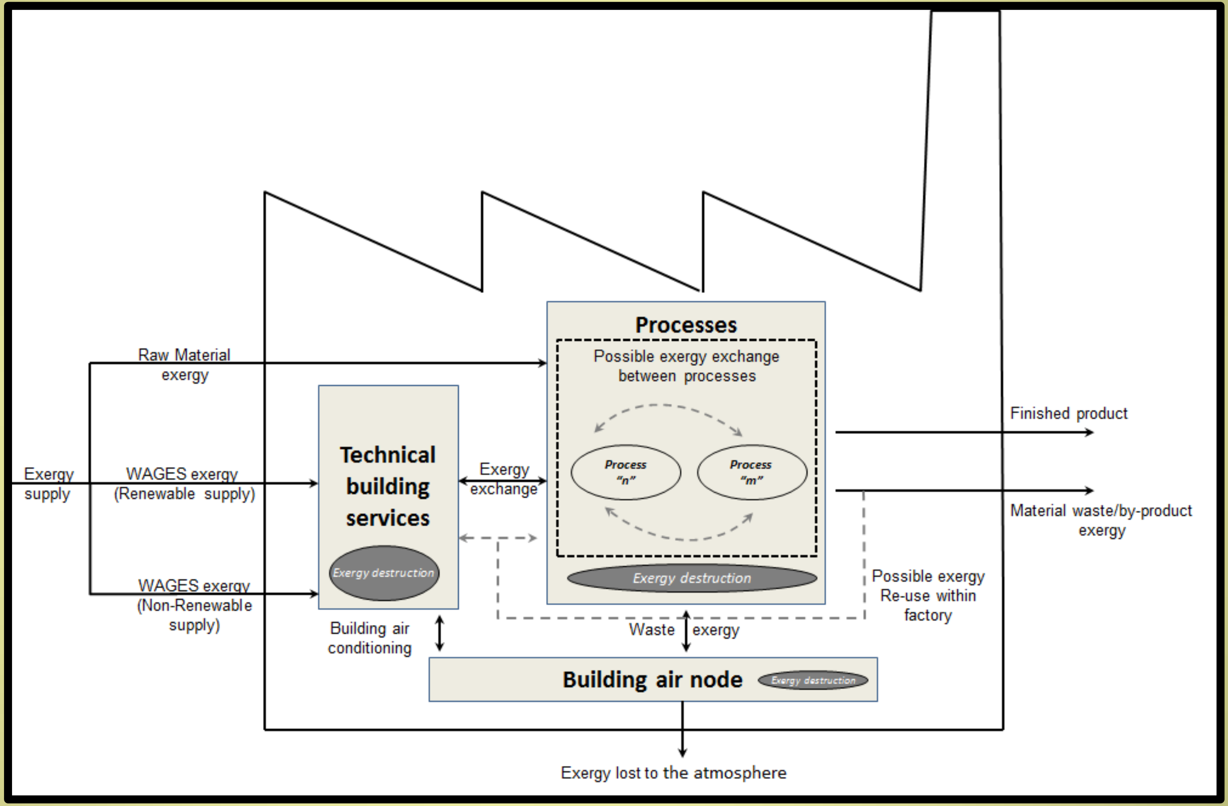
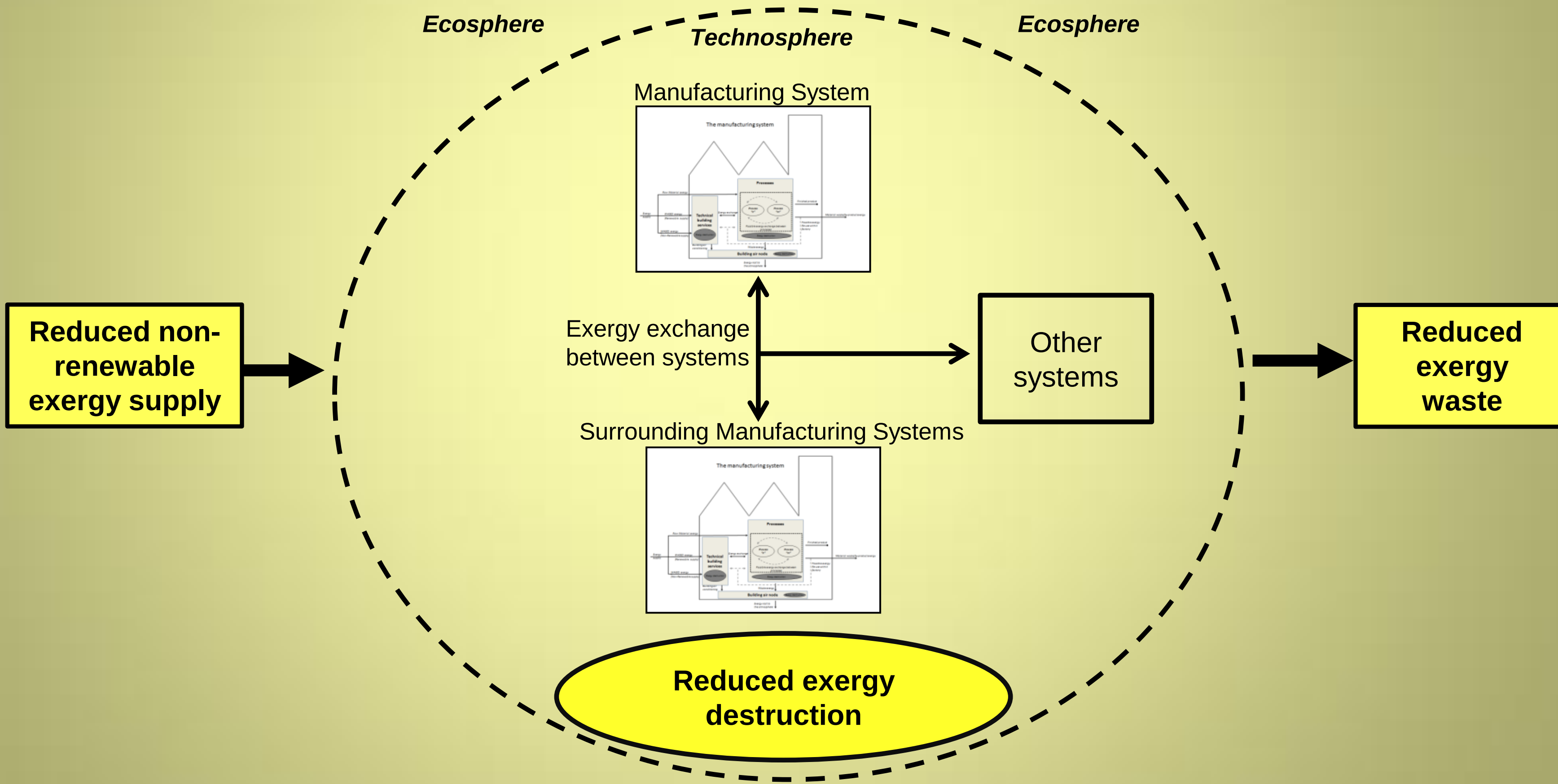
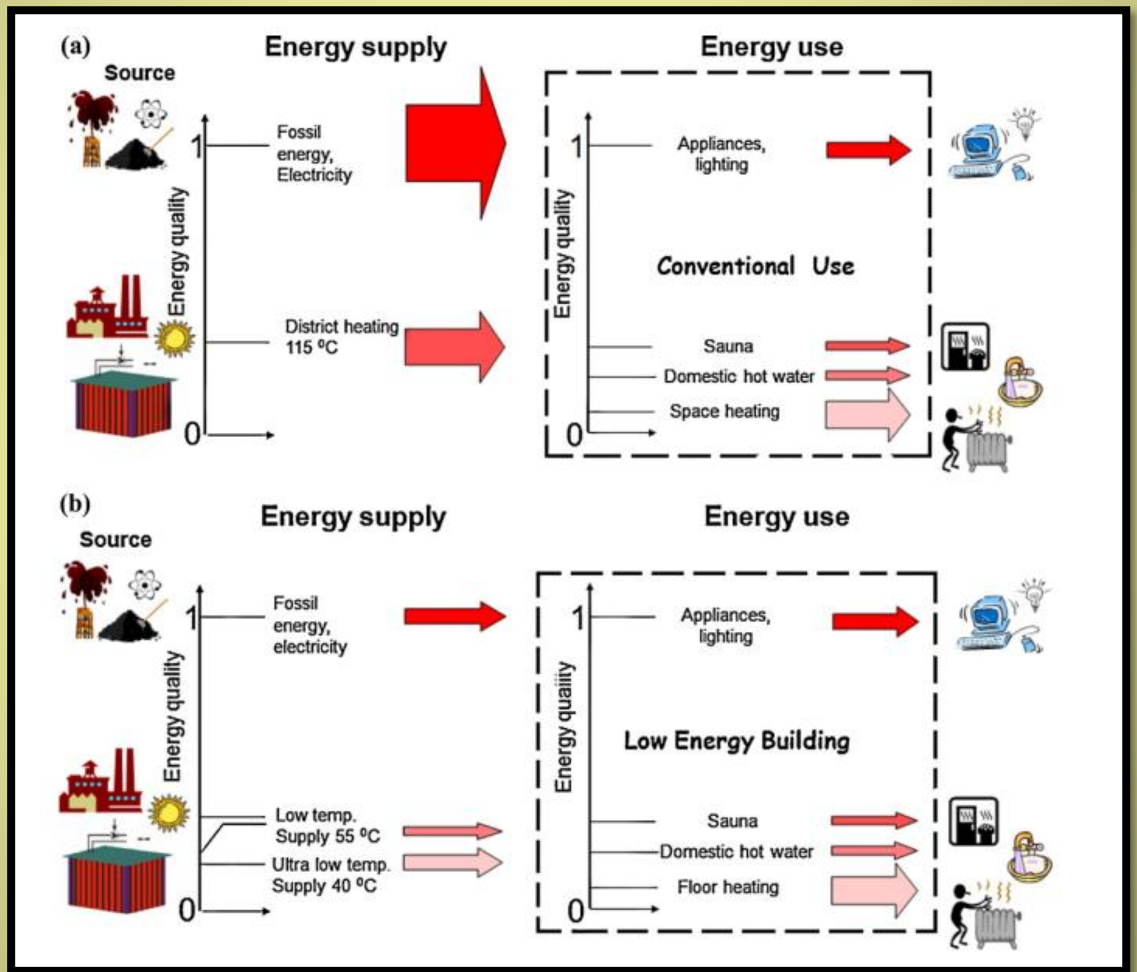
An exergy based conceptual approach to factory analysis



- An exergy based holistic view of the factory
- Why use exergy? Why take a holistic perspective?


Ecosphere
Technosphere
Ecosphere
Manufacturing System
Reduced non-renewable exergy supply
Exergy exchange between systems
Other systems
Reduced exergy waste
Surrounding Manufacturing Systems
Reduced exergy destruction

Matching energy quality supply and demand in a building

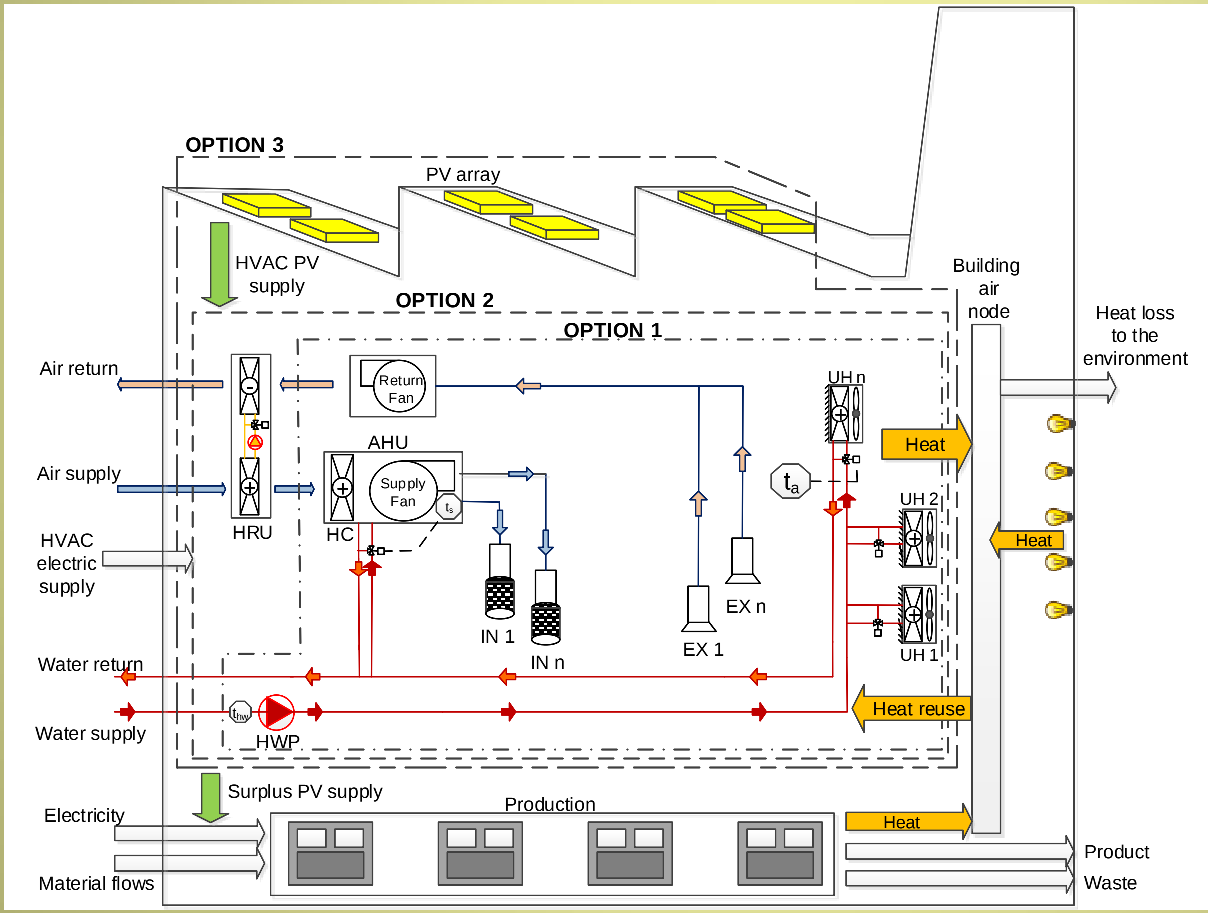


Energy quality schematic (a) conventional use (b) Low energy building with supply and demand quality matching. Source(Hepbasli, 2012)

Case study – Factory heat reuse

- Automotive cylinder head manufacturing line
- The factory HVAC system reuses heat from within the factory space (low grade thermal energy)
- The HVAC system energy and exergy efficiency quantified
- Exergy destruction quantified

Control Volume depicting the factory



Option 1:
No heat recovery

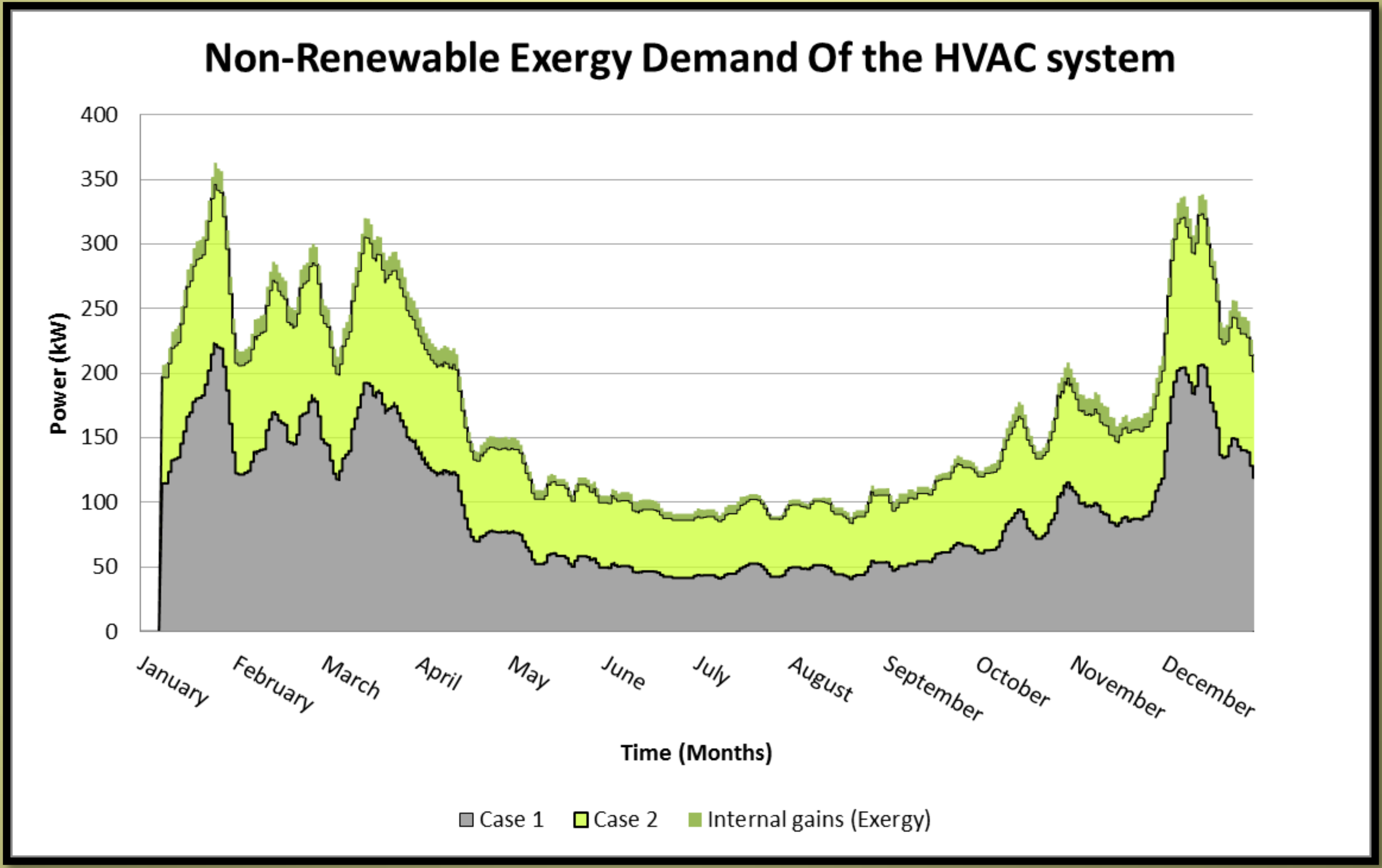
Option 2:
With heat recovery

Option 3:
With heat recovery and renewable supply

Analysis approach

- Factory **with heat reuse** (Actual case) Compared to the factory **without heat reuse** (Simulation, E+)
- Exergy analysis conducted
- Quantifying effect of technology on resource efficiency

Exergy demand comparison



Summary of yearly results

	Non-renewable energy demand (MWh/year)	Non-renewable exergy demand (MWh/year)	Non-renewable exergy destruction (MWh/year)
Option 1 -No heat recovery	2962	851	732
Option 2 – With heat recovery	1329	627	581
Option 3 – With heat recovery and solar power	1118	412	361
Improvement	62.3%	51.6%	49.2 %

Summary

- Low grade heat is reused to reduce usage of a higher grade energy.
- Energy quality supply-demand matching improved.
- The reduction in exergy removal from supply resource quantified.
- No extra data in addition to an energy analysis required!
- Low level of complexity in exergy calculations

Water Reuse – Kettelby Food Factory

- 27/4 Production
- Processes and machinery (Oven, mashing, cleaning washing etc.)
- Energy and water use data, Main concern – water use

Year	Gas (kWh)	Electricity (kWh)	Water (m^3)
2011	913,324		3,302
2012	679,290	224,898	3,335
2013	728,257	224,351	3,542
2014*	737,920	204,434	3,510

**Weekly average based on actual values Jan-Mar*

Energy and water consumption from [1]

Total exergy of a mass flow

$$
\begin{aligned}
b_T(\mathrm{kJ/kg}) = {} & \underbrace{c_{p,\mathrm{H_2O}}\left[T_p - T_0 - T_0 \ln\left(\frac{T_p}{T_0}\right)\right]}_{b_t} + \underbrace{v_{\mathrm{H_2O}}\left(p_p - p_0\right)}_{b_m} \\
& + \underbrace{\left[\sum_i y_i\left(\Delta G_f + \sum_e n_e b_{\mathrm{chne}}\right)_i\right]_p}_{b_{ch}} \\
& + \underbrace{RT_0 \sum x_i \ln\frac{a_i}{a_0}}_{b_c} + \underbrace{\frac{1}{2}\left(\frac{C_p^2 - C_0^2}{1000}\right)}_{b_k} + \underbrace{g\left(z_p - z_0\right)}_{b_z}
\end{aligned}
$$

Chemical formation reaction exergy

Concentration exergy

Method of Chemical Exergy Calculation for the water sample

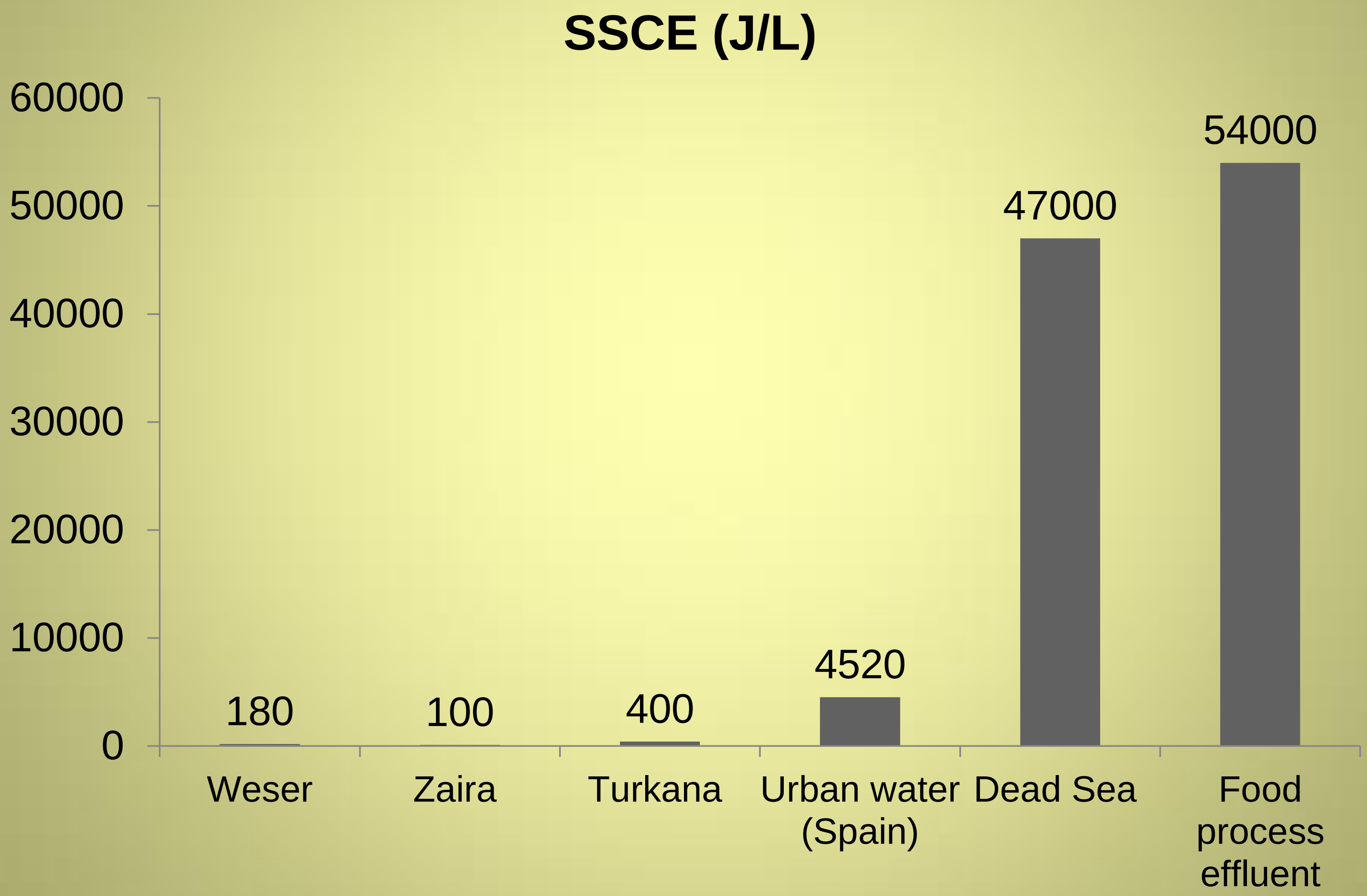
- Inorganic and Organic substances present.
- Different methods for organics calculation.
- Tests conducted :
  - Electrical conductivity
  - COD (Oxygen demand)
  - TDS (Total dissolved solids)
  - Anions/ Cations breakdown

Chemical analysis of effluent water sample and exergy calculation

Substance	Measurement	Molar fraction	Type of calculation	Exergy (kJ/L)
Chloride	330 mg Cl/L	0.000139218	Concentration Exergy	0.13079153
Sulphate	1.5 mg SO4/L	2.33551E-07	Concentration Exergy	0.00125579
Calcium	68 mg Ca/L	2.53755E-05	Concentration Exergy	0.09647113
Sodium	340 mg Na/L	0.116909961	Concentration Exergy	0.179371
Magnesium	16 mg Mg/L	0.005815136	Concentration Exergy	0.989158
Potassium	82 mg K/L	0.047953934	Concentration Exergy	0.12735
Organics	3870mg O2/L		Formation exergy: Method 1	52.632
			Formation exergy: Method 2	66.7575
			Formation exergy: Method 3	54.438
Total				**54.1 kJ/L**

Results sensitive to the reference environment selection!

Comparison with water bodies around the world



Main contributor to the high value of exergy

Substance	Reference Environment [1]	Urban Waste Water [3]	River sample [4]	Food Process Effluent	Remarks
COD test result (mg/L)	N/A	7.6	4.56	3870	- 500 times Urban waste water - 848 times river water

Water treatment through AD(anaerobic digestion)

A typical AD process [5]

Effluent water

Electricity

Treatment chemicals

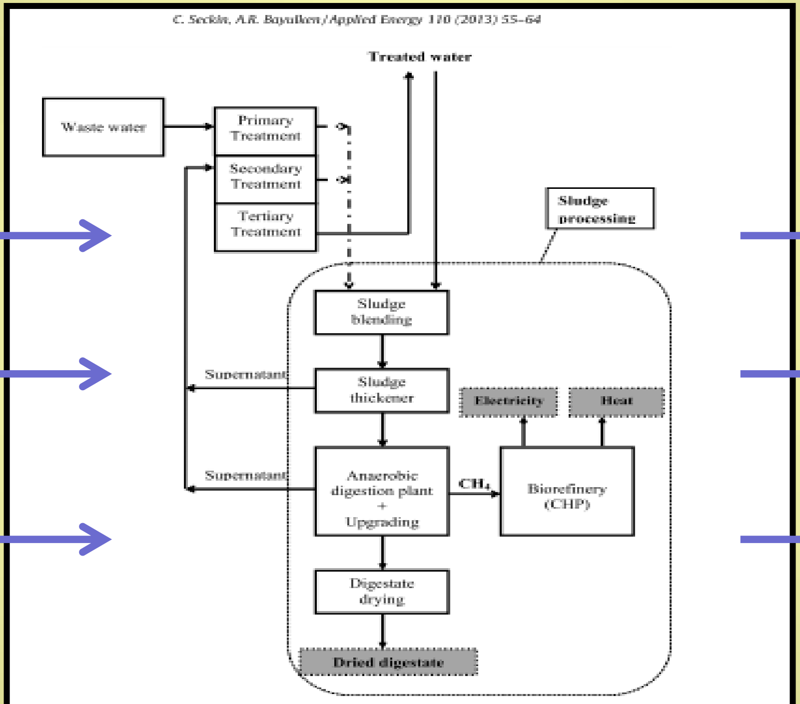


Fig. 2. Flowchart of wastewater treatment process chain.

Clear water

Methane gas

Fertilizer

- Exergy efficiency of such a process is 97-98% [6] !
- Methane gas exergy produced is almost equal to the electricity used

References

- [1] Fuentes, P. S. (2014)“Opportunities for energy efficiency in food manufacturing. A building modelling and energy simulation approach“ MSc thesis. De Montfort University
- [2] Ref:Chen, G. Q., and Xi Ji. "Chemical exergy based evaluation of water quality."*Ecological Modelling* 200.1 (2007): 259-268.
- [3] Armando, Gallegos-Muñoz, A. A. Zaleta, and R. H. V. Hugo. "On an exergy efficiency definition of a wastewater treatment plant." *International Journal of Thermodynamics* 6 (2003): 169-176
- [4] Martínez, Amaya, and Javier Uche. "Chemical exergy assessment of organic matter in a water flow." *Energy* 35.1 (2010): 77-84.
- [5] Seckin, Candeniz, and Ahmet R. Bayulken. "Extended Exergy Accounting (EEA) analysis of municipal wastewater treatment–Determination of environmental remediation cost for municipal wastewater." *Applied Energy*110 (2013): 55-64.
- [6] Mora, C. H., and S. Oliveira. "Environmental exergy analysis of wastewater treatment plants." *Therm. Eng* 5 (2006): 24-29.