Energy efficiency in the process industry: Learning from nature

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Outline

- Energy efficiency – definitions

- Energy efficiency studies
  - -- process units and natural systems
  - -- four North Sea Oil platform processes

- Conclusions

Horizon2020 Aims

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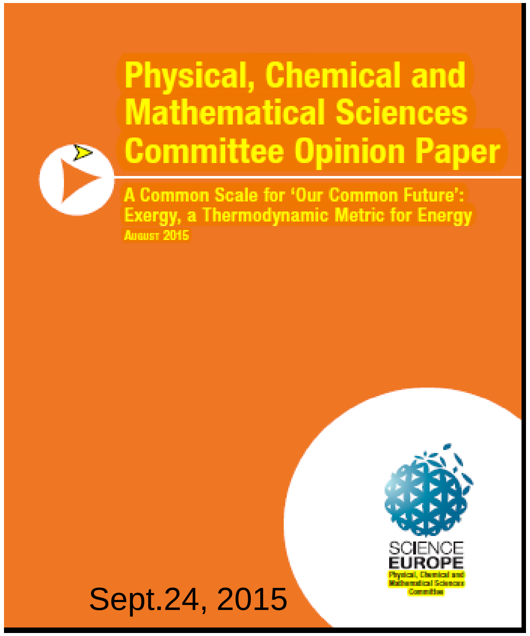
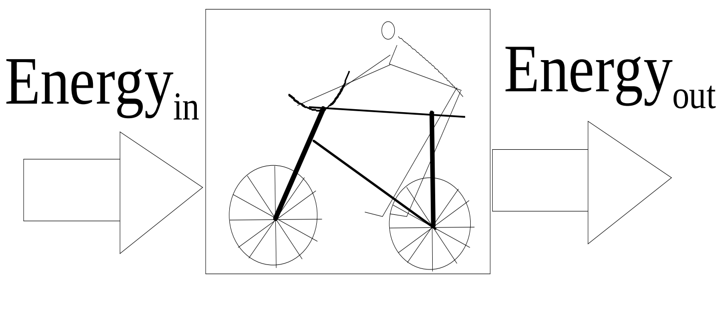
- 2009: Improve energy efficiency by 27%
- 2011: Energy Efficiency Plan
- 2015: Create an integrated, competitive, borderless energy-union (fifth freedom)

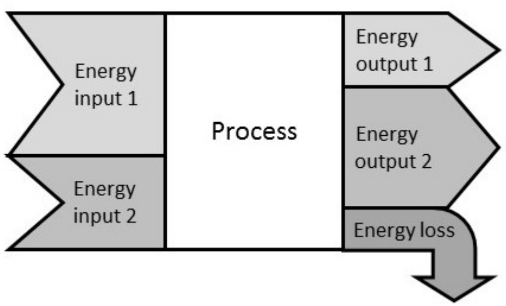


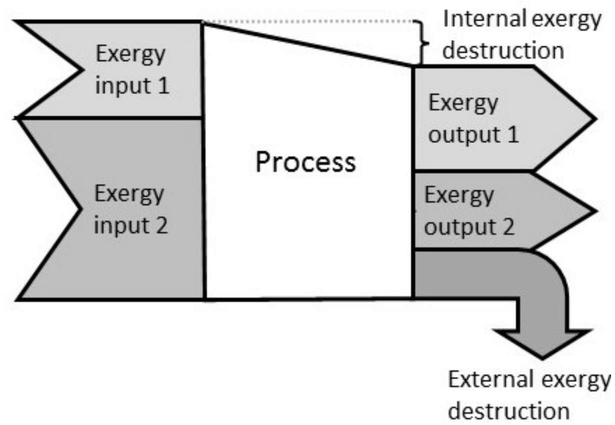
What tools do we have?

Thermodynamic laws

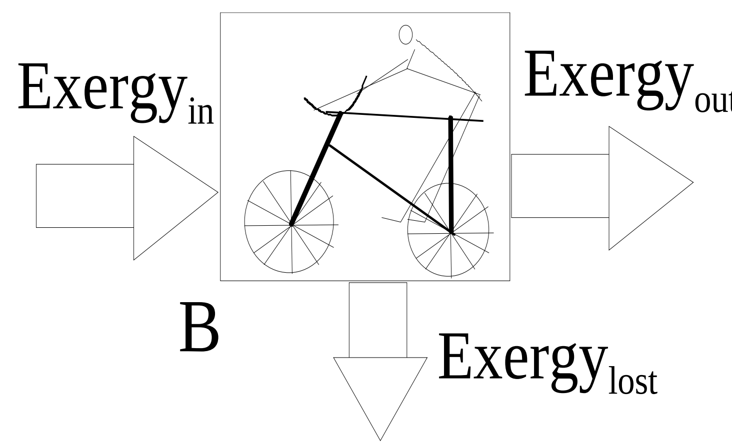
Energy is conserved







Exergy can be used and lost



Definitions

Exergy = The ideal work

$$W = W_{ideal} - W_{lost}$$

The lost exergy should be minimum!

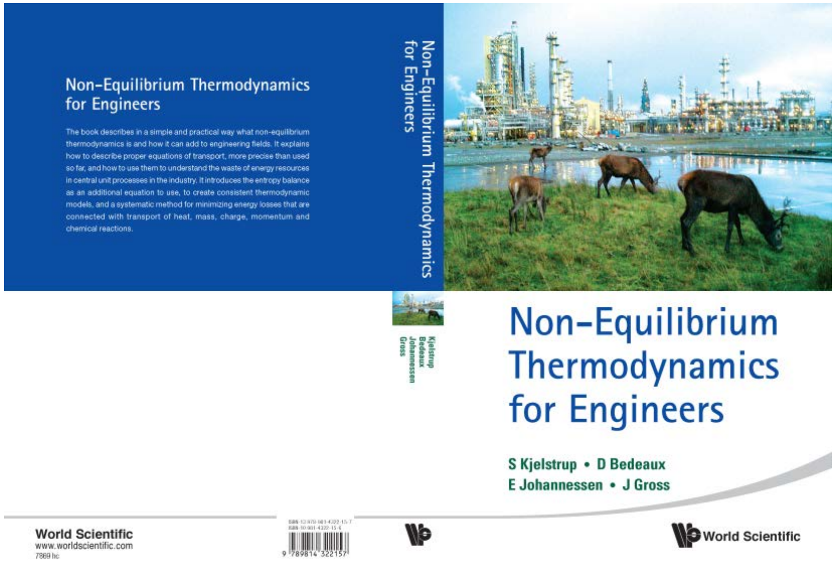
The second law of thermodynamics:

$$dW_{lost} / dt = T_0 (dS_{irr} / dt)$$

$$dS_{irr} / dt > 0$$

$$dS_{irr} / dt = \int_V \sigma dV,$$

$$\sigma = \sum_i J_i X_i \geq 0$$



Case: Optimal heat exchange

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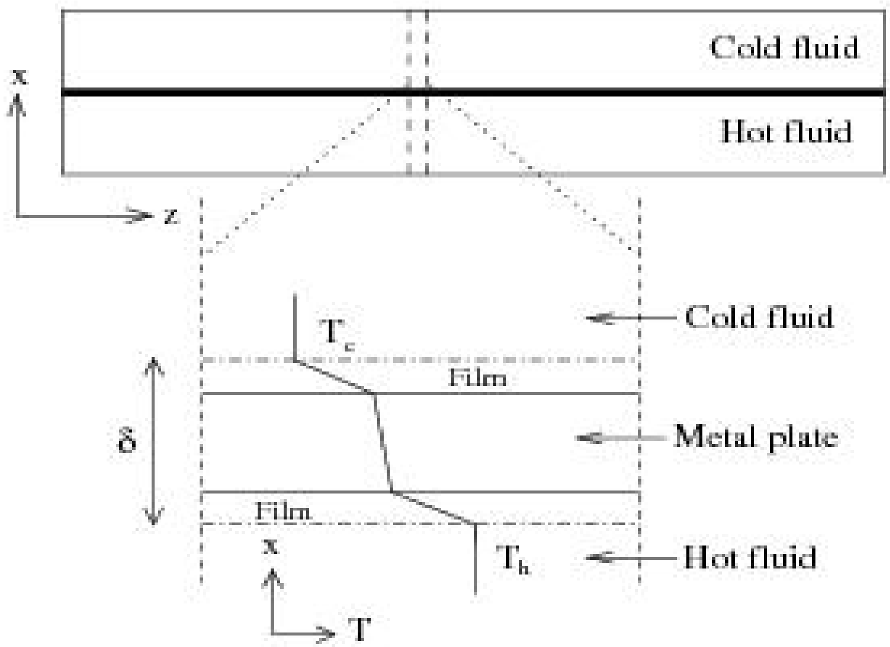
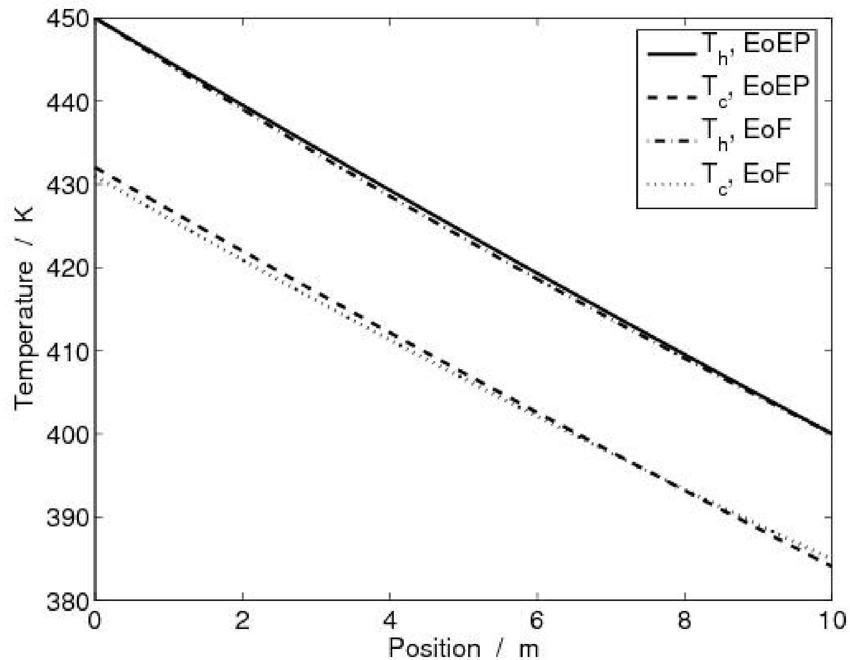
The counter-current heat exchanger





Optimal temperature-profiles obey

Equipartition of Entropy Production (EoEP)

E. Johannessen et al. *International Journal of Heat and Mass Transfer*, 2002

Case: Optimal reformer reactor

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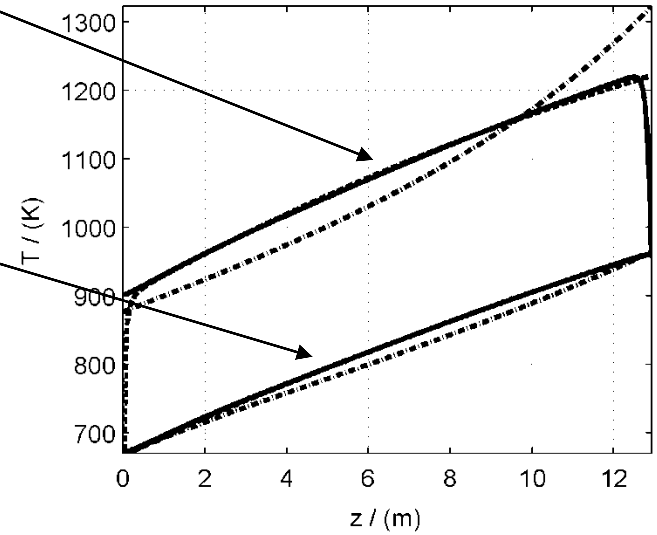
Heating temperature

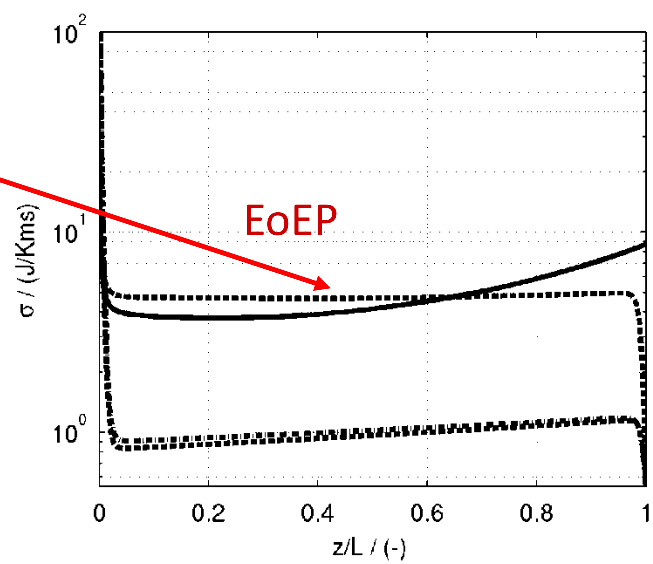
Reactor temperature



--- State-of-the art reactor

— Reactor with min. entropy prod.

Equipartition of entropy production!



Ø. Wilhelmsen et al. *International Journal of Hydrogen Energy,* 2010

A curious observation:

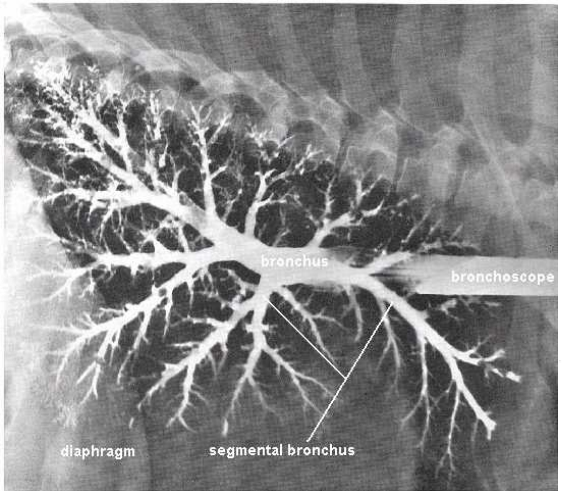
The optimal solution has
(nearly) constant entropy production

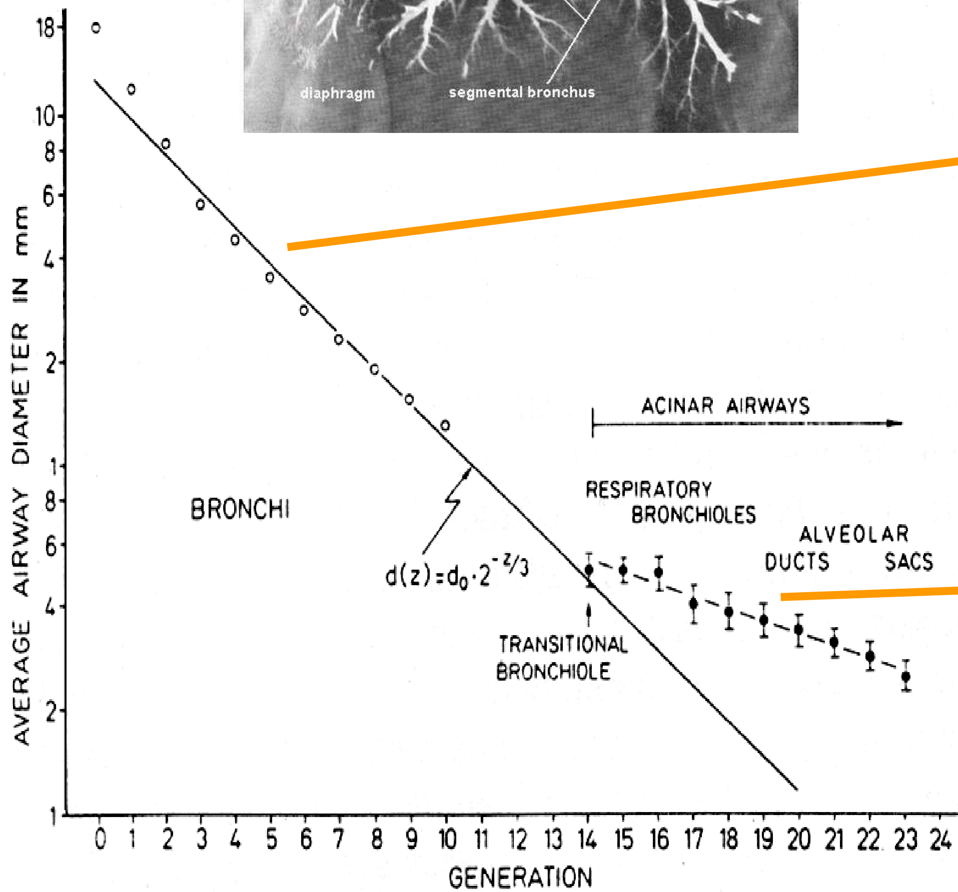
«A highway in state space»

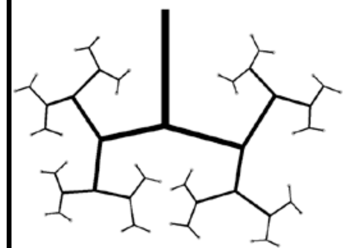
Constant entropy production has been numerically proven for some cases

E. Johannessen et al, *Chemical Engineering Science*, 2005

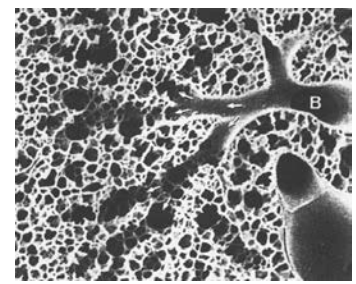
The entropy production in the human lung is constant…







…in the flow regime and…



…in the diffusion regime!

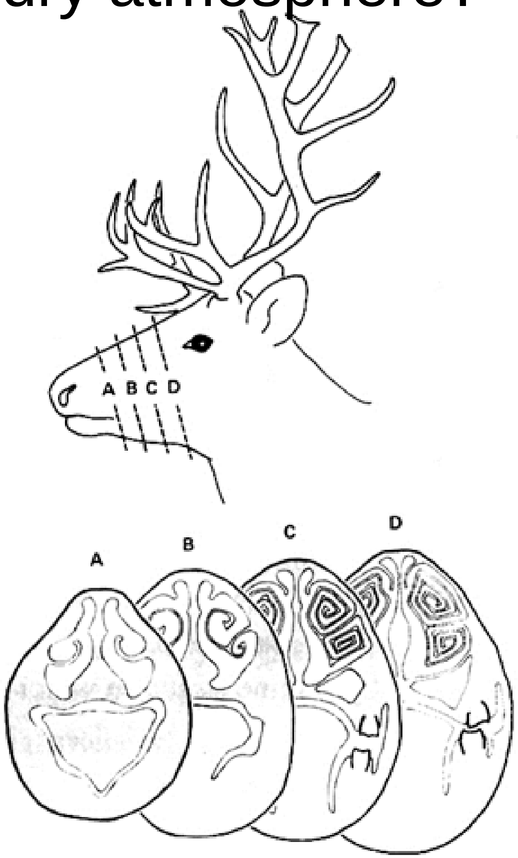
E. R. Weibel, *Americal Journal of Physiology*, 1991
S. Gheorghiu et al. *Fractals in Biology and Medicine,* 2005


Has Nature energy efficient design?

The case of the reindeer nose

How do they manage life below -30 in a dry atmosphere?

- Thick, well insulating fur
- Short legs
- **Complex nose!**

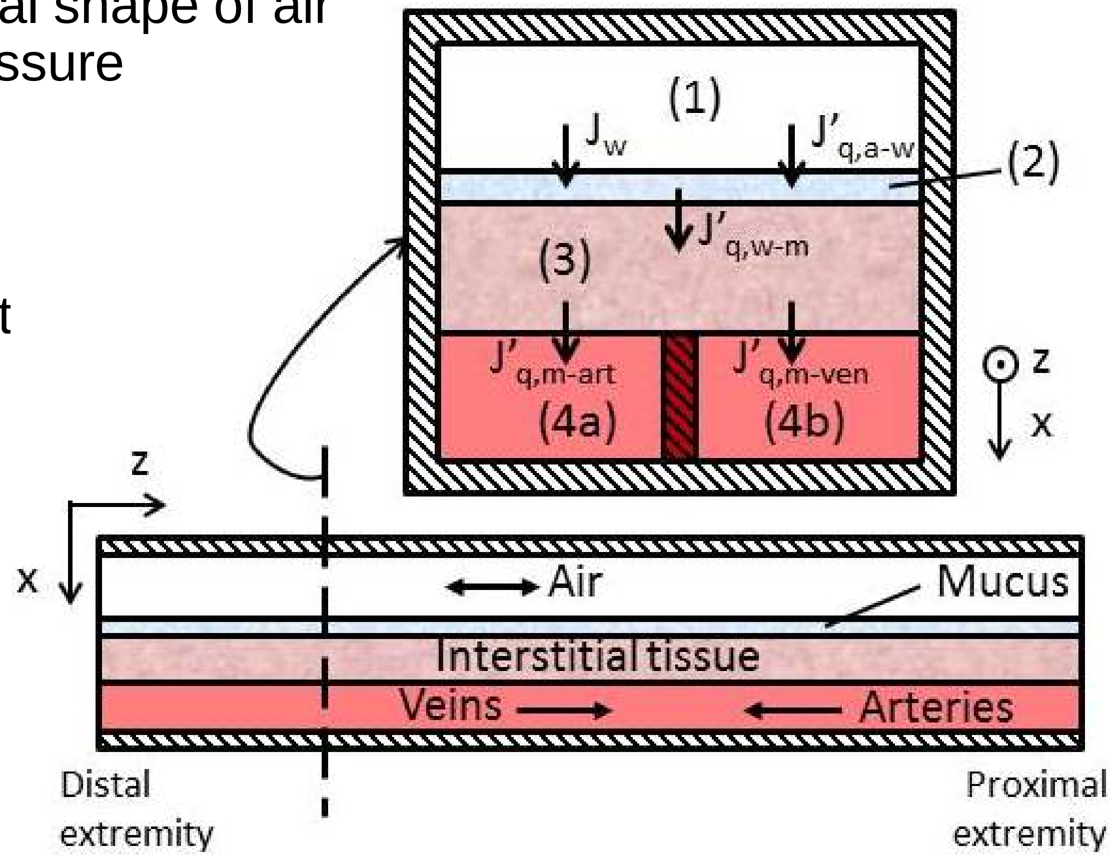


→ this peculiar nose makes us curious…

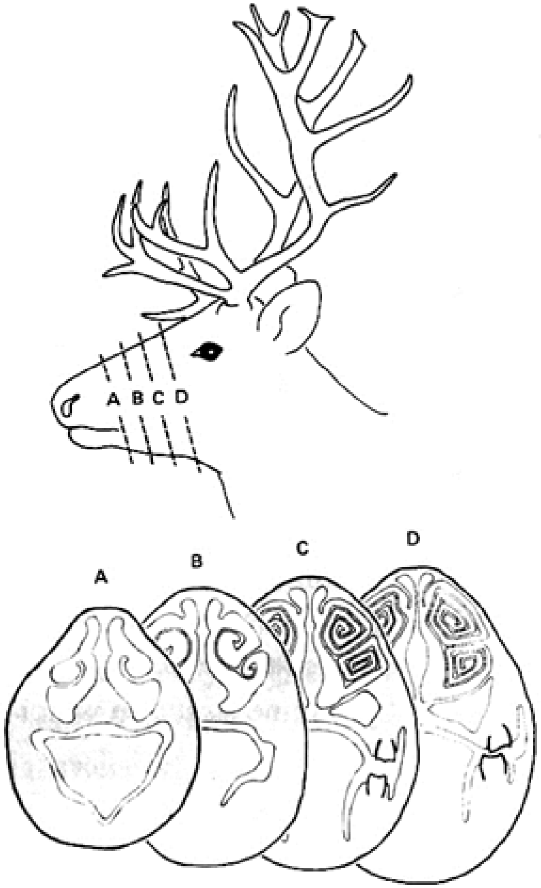
Five sub-systems:

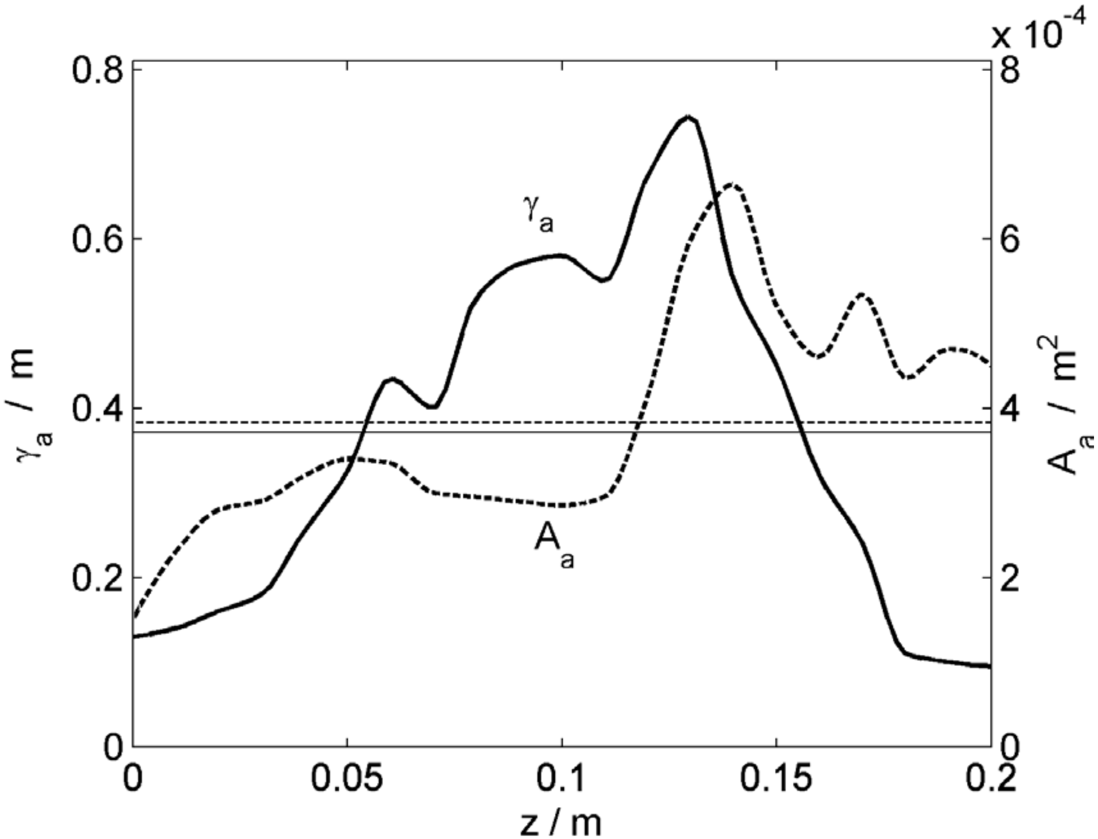
1. Nasal cavity: humid air (fixed dry air composition), sinusoidal shape of air flow rate, constant pressure
2. Mucus (water)
3. Interstitial tissue

4a/4b. Arterial rete/Venous ret constant blood flow



Nose perimeter, crossectional area

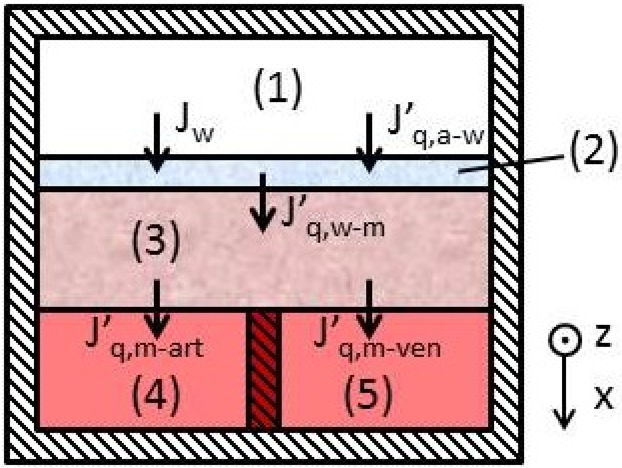


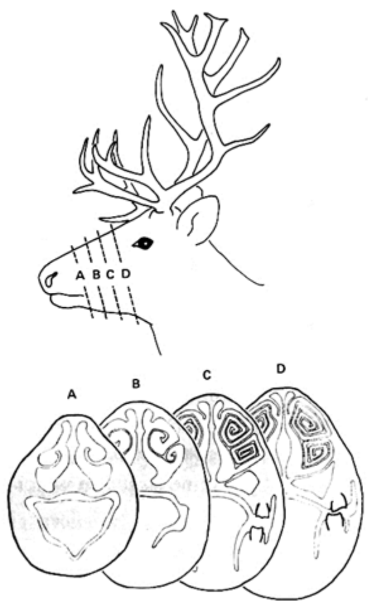


Reindeer nose VS "Pipe" nose

I.L. Casado Barroso, *MSc Thesis*, 2014

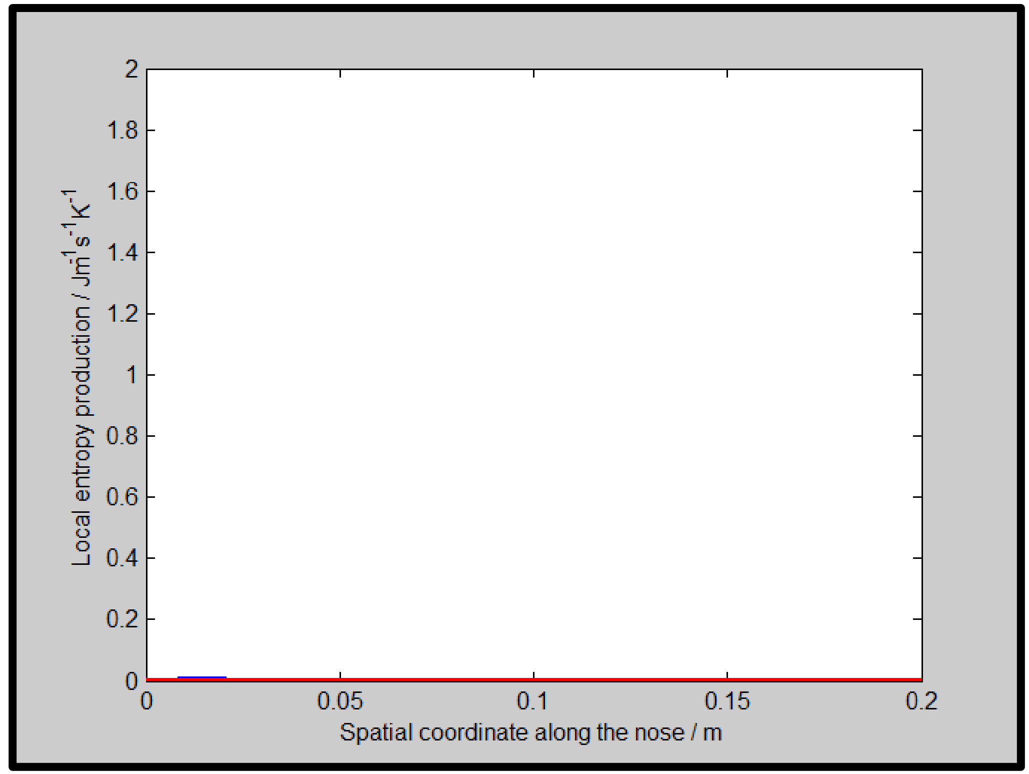
Entropy production





— "pipe" (blue)

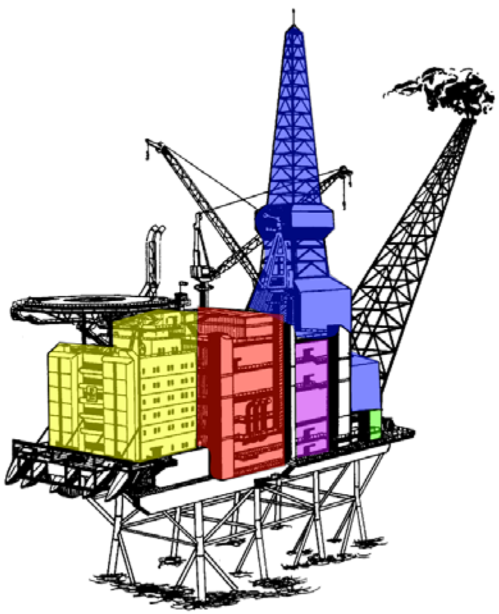
— reindeer (red)



E. Magnanelli et al, *Journal of Non-Equilibrium Thermodynamics*, 2017

Exergy analysis off-shore

M. Voldsund et al, *Energy*, 2013, and Energy 2015



- Total exergy destruction:
  - Utility plant: 62—65%
  - Processing plant: 35—38%

- Exergy losses:
  - Exhaust gases
  - Flaring system

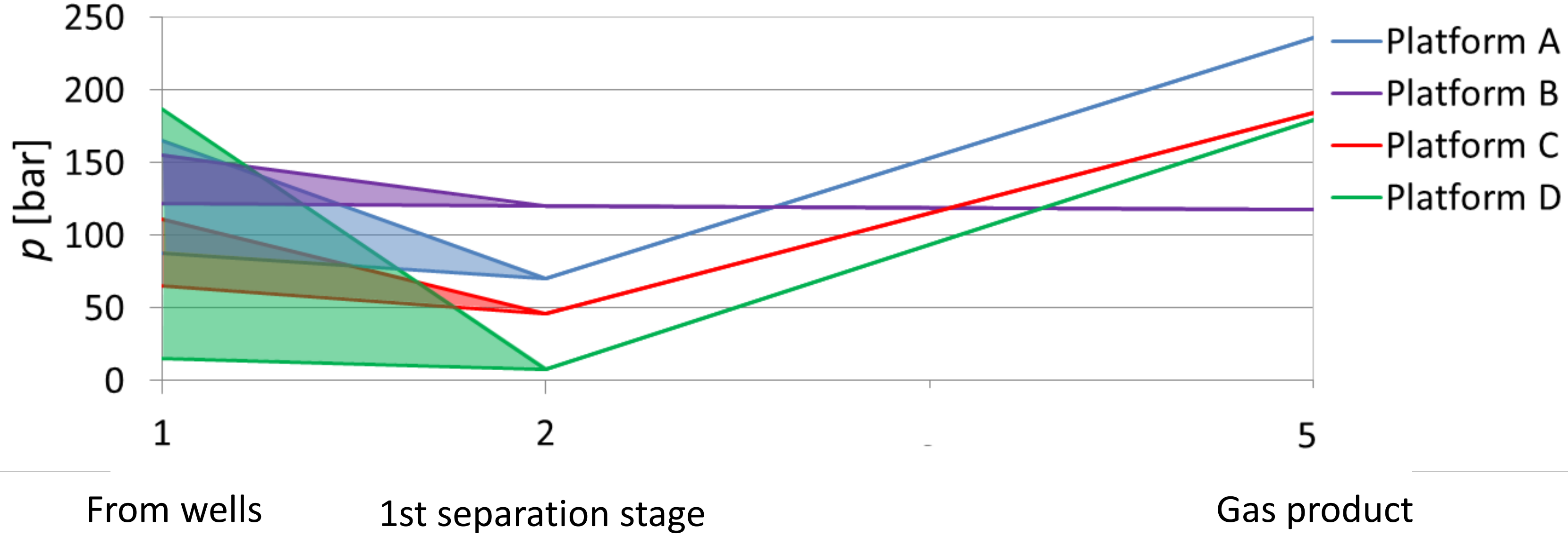
North Sea Platforms A—D input

M. Voldsund et al, *Energy*, 2013, and Energy 2015

Platform	A	B	C	D
Products exported	Oil	Condensate	Oil	Oil and condensate
	Injected gas	Exported gas	Injected gas	Exported gas
			Gas lift	Gas lift
Flow rates				
Oil/condensate [Sm^3/h]	133	267	1094	195
Gas [10^3 Sm^3/h]	369	1001	362	42

North Sea platforms A—D input

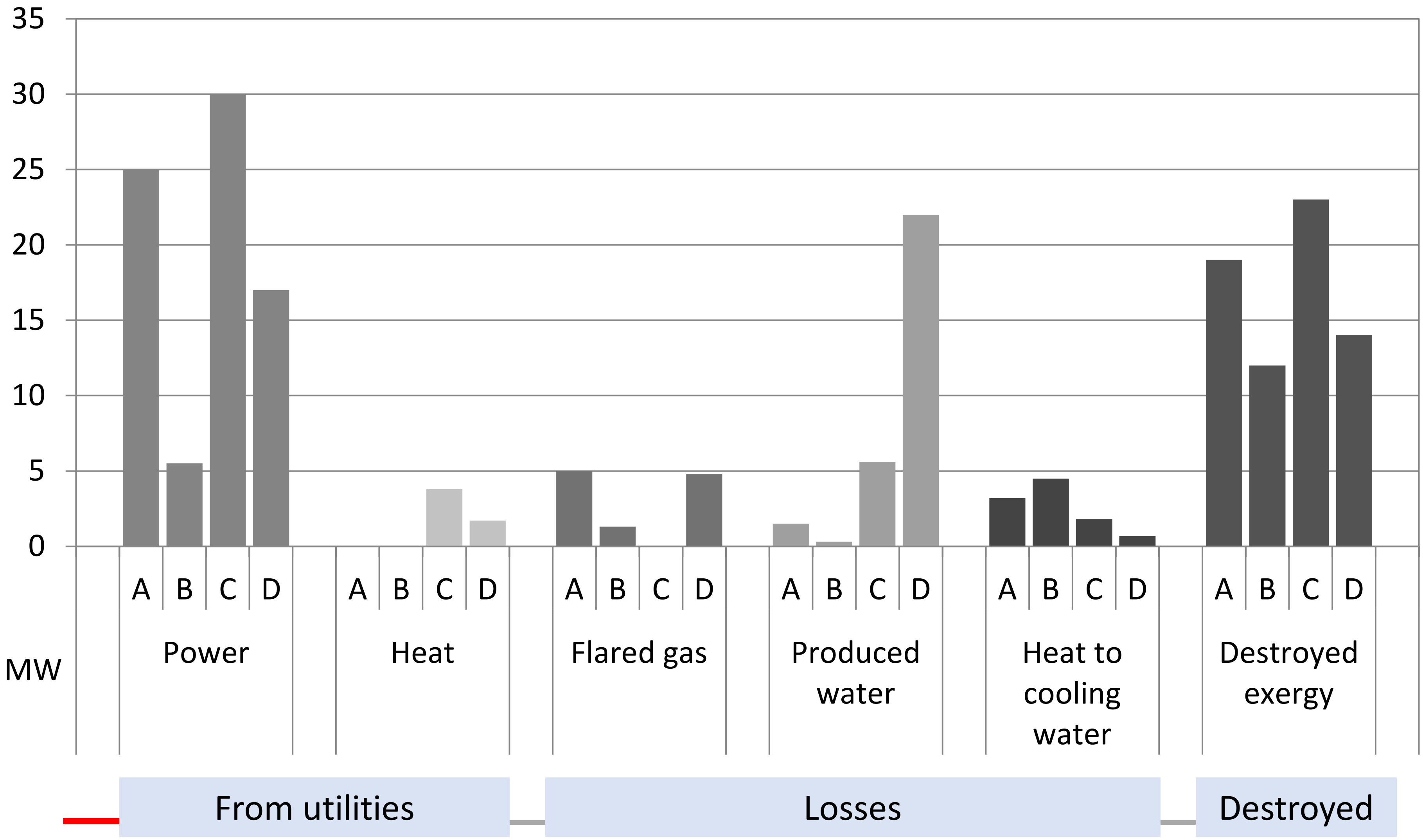
M. Voldsund et al, *Energy*, 2013, and Energy 2015



Pressure operating conditions

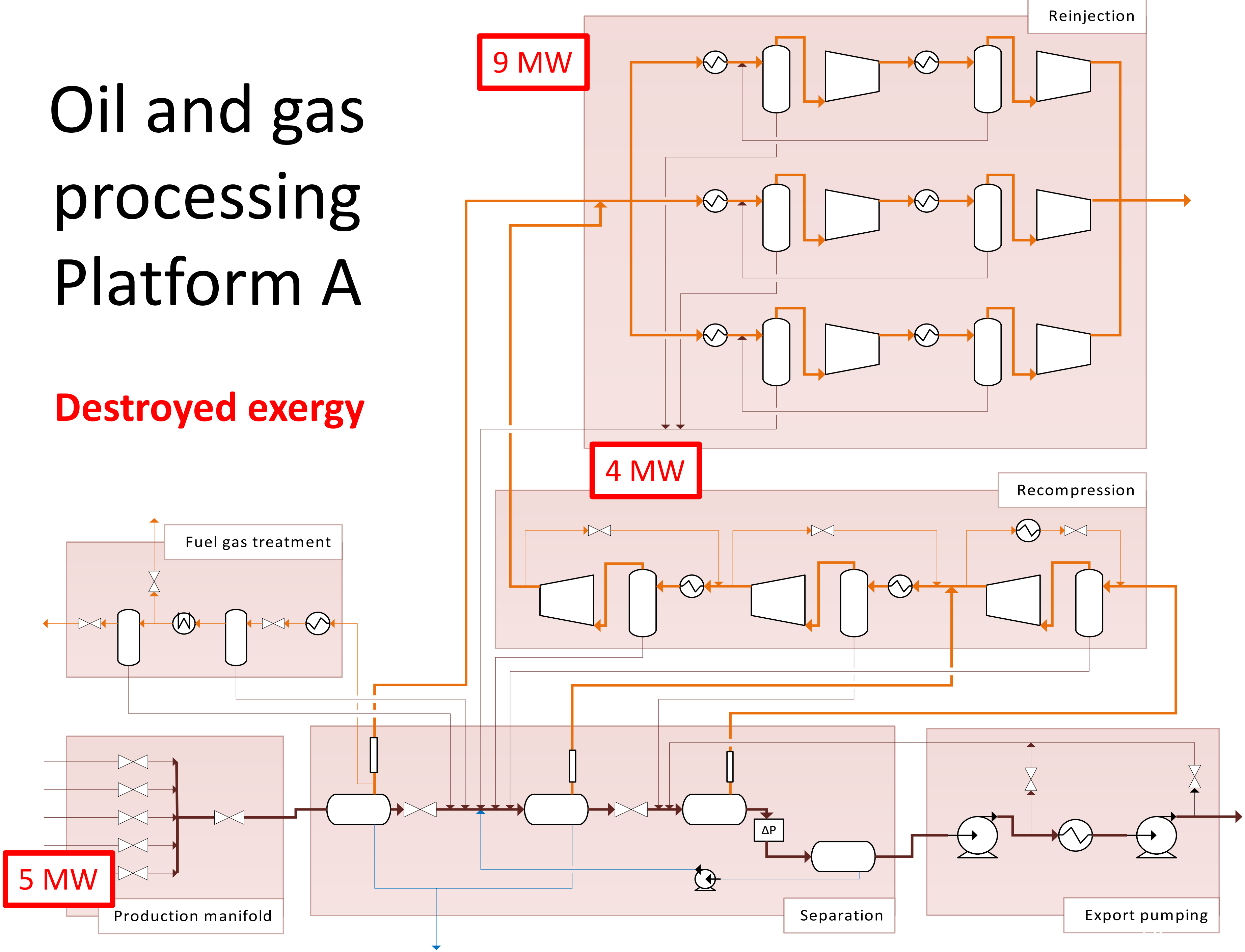
Results: Component exergy flows A - D

M. Voldsund et al, *Energy*, 2013, and Energy 2014

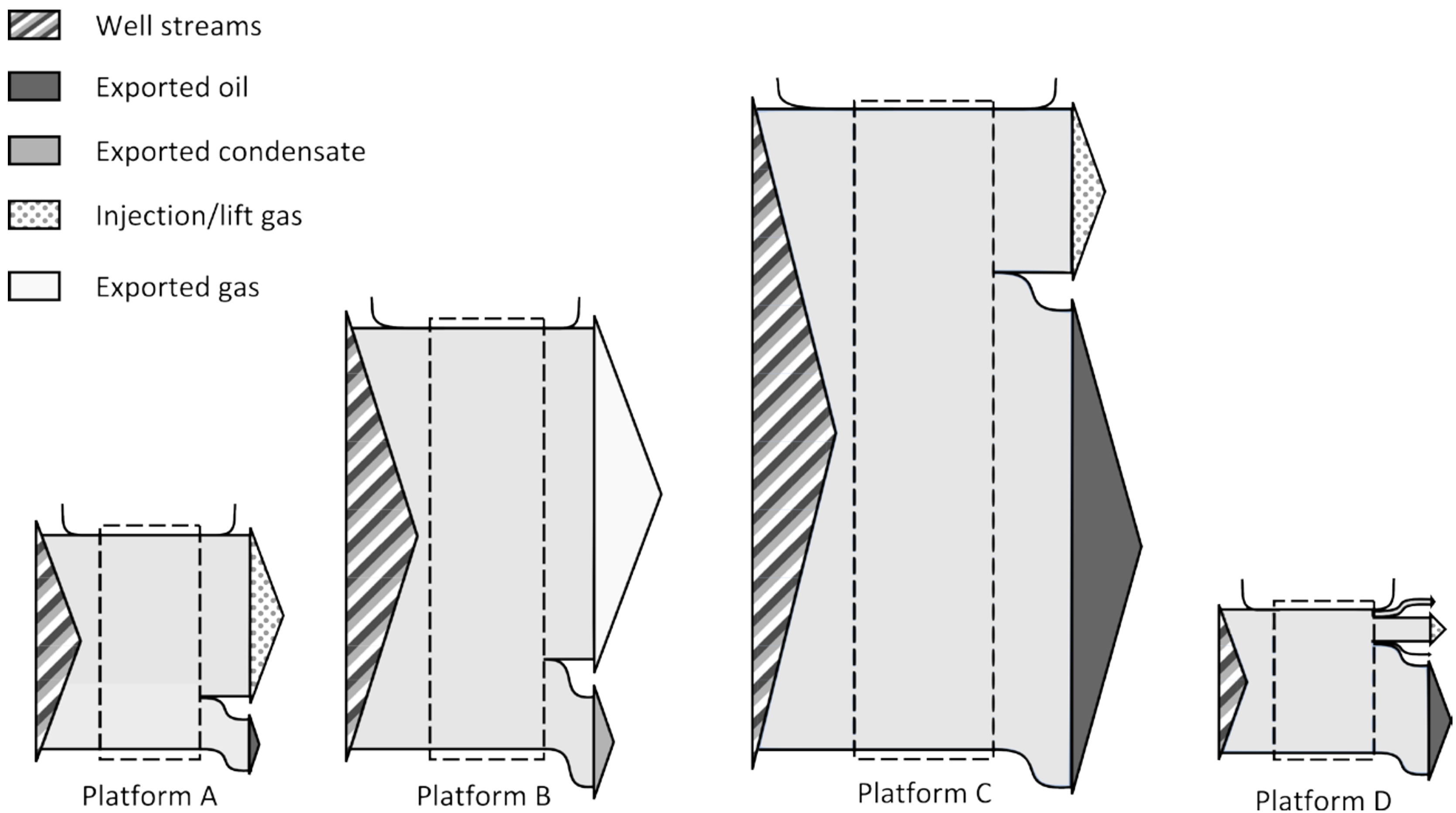


Oil and gas processing Platform A

Destroyed exergy



Overall exergy flows platforms A - D



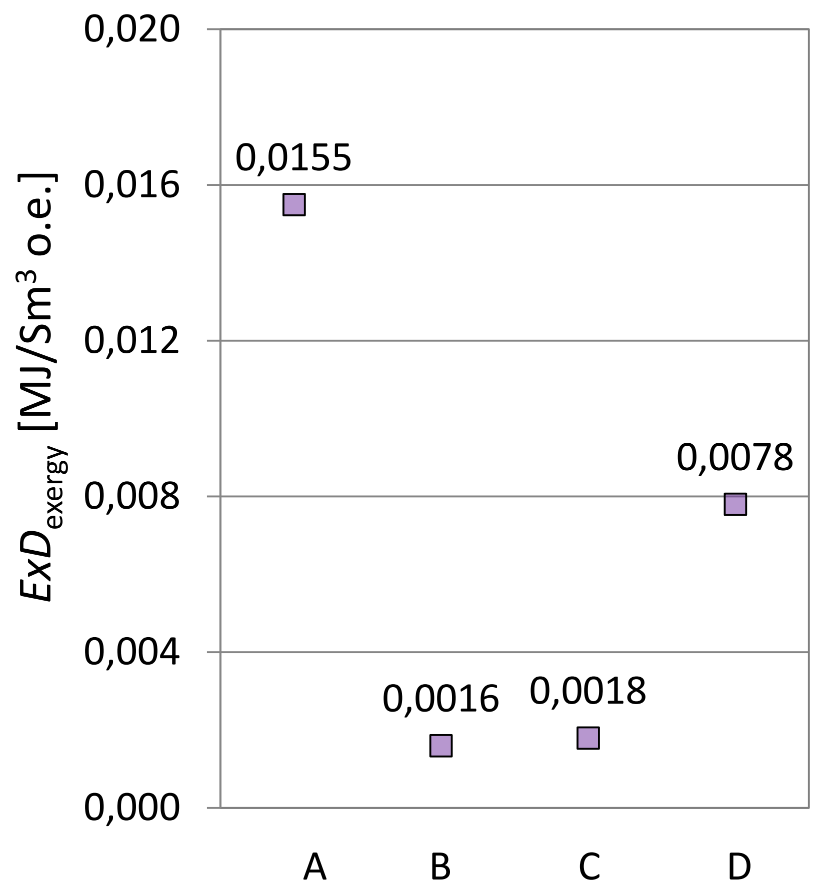
High throughput = high performance?

Specific exergy destruction

M. Voldsund et al, *Oil and Gas Facilities, 2014, T. Nguyen et al. Energy, 2014*

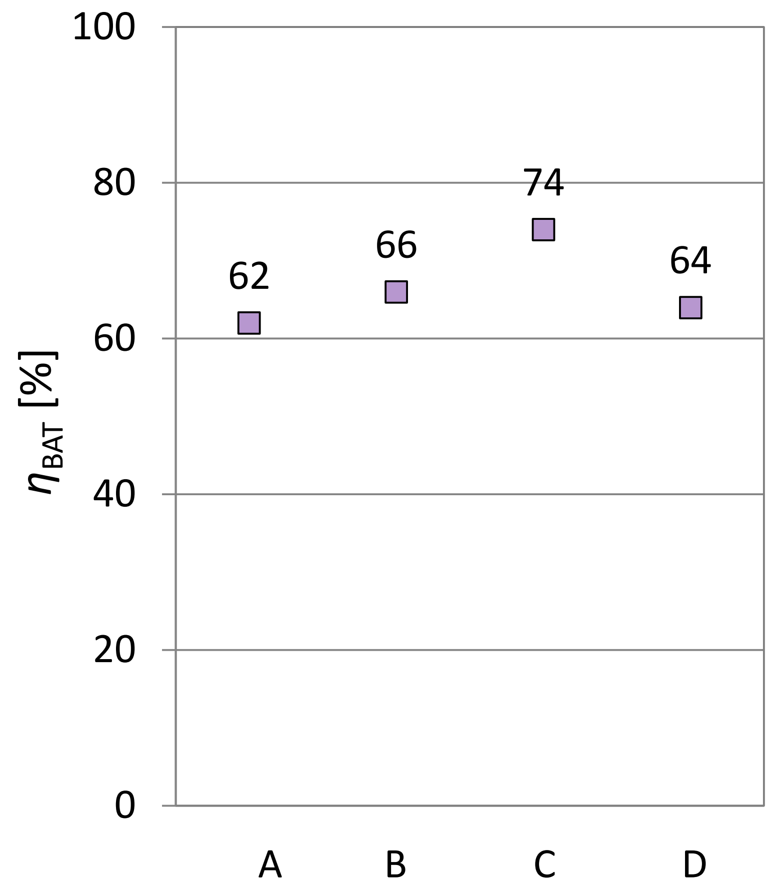
$$ExD_{\mathrm{exergy}} = \frac{E_{\mathrm{D}}}{E_{\mathrm{export}}}$$

This indicator evaluates the total destruction of resources



Best available technology (BAT) efficiency

$$\eta_{\mathrm{BAT}} = \frac{E_{\mathrm{W,BAT}} + E_{\mathrm{Q,BAT}}}{E_{\mathrm{W}} + E_{\mathrm{Q}}}$$

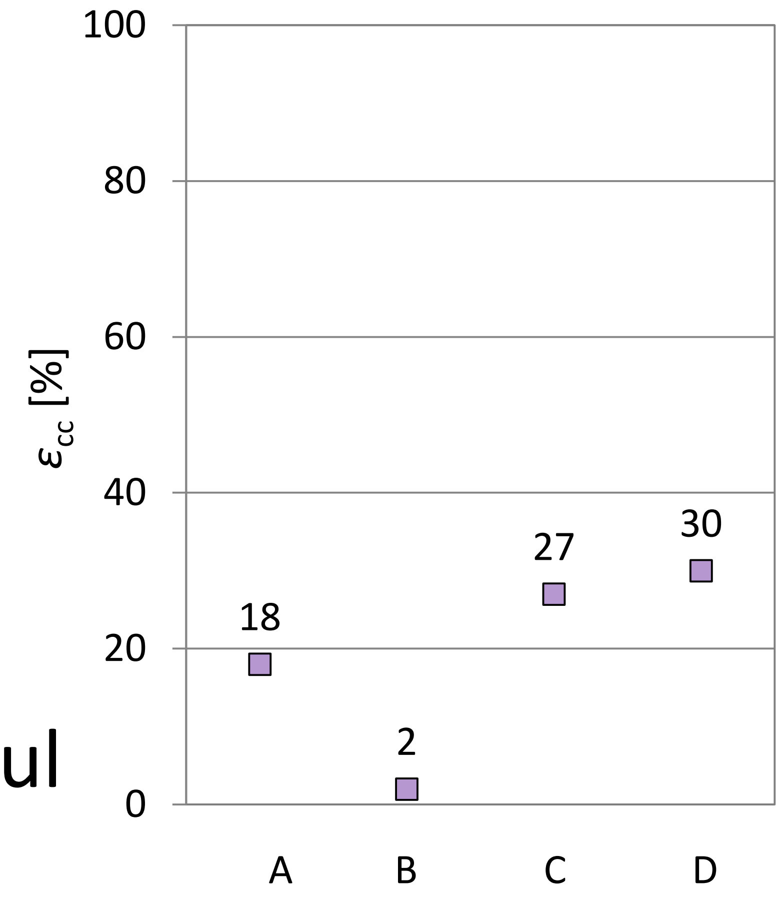


This indicator evaluates how we use presently technical achievable solutions

Component-by-component efficiency

M. Voldsund et al, *Oil and Gas Facilities, 2014, T. Nguyen et al. Energy, 2014*

$$\varepsilon_{\mathrm{cc}} = \frac{\Delta_{+}E^{\mathrm{ph}} + \Delta E^{\mathrm{ch}}}{\Delta_{-}E^{\mathrm{ph}} + E_{\mathrm{W}} + E_{\mathrm{Q}}}$$



This indicator may be useful for comparing platforms

Conclusions

- Cases of exergy (= entropy production) analyses have been presented, including of North Sea platforms

- Results indicate potential for improvements e.g. in:
  - Compression efficiency
  - Production manifolds
  - Flaring

- Entropy production reduction can be done using equipartition.

- Suitable indicators help us monitor the efficiency

Thanks to

You, for the attention!

Questions?