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Systematic design of integrated equipment for “waste-to-energy” processes

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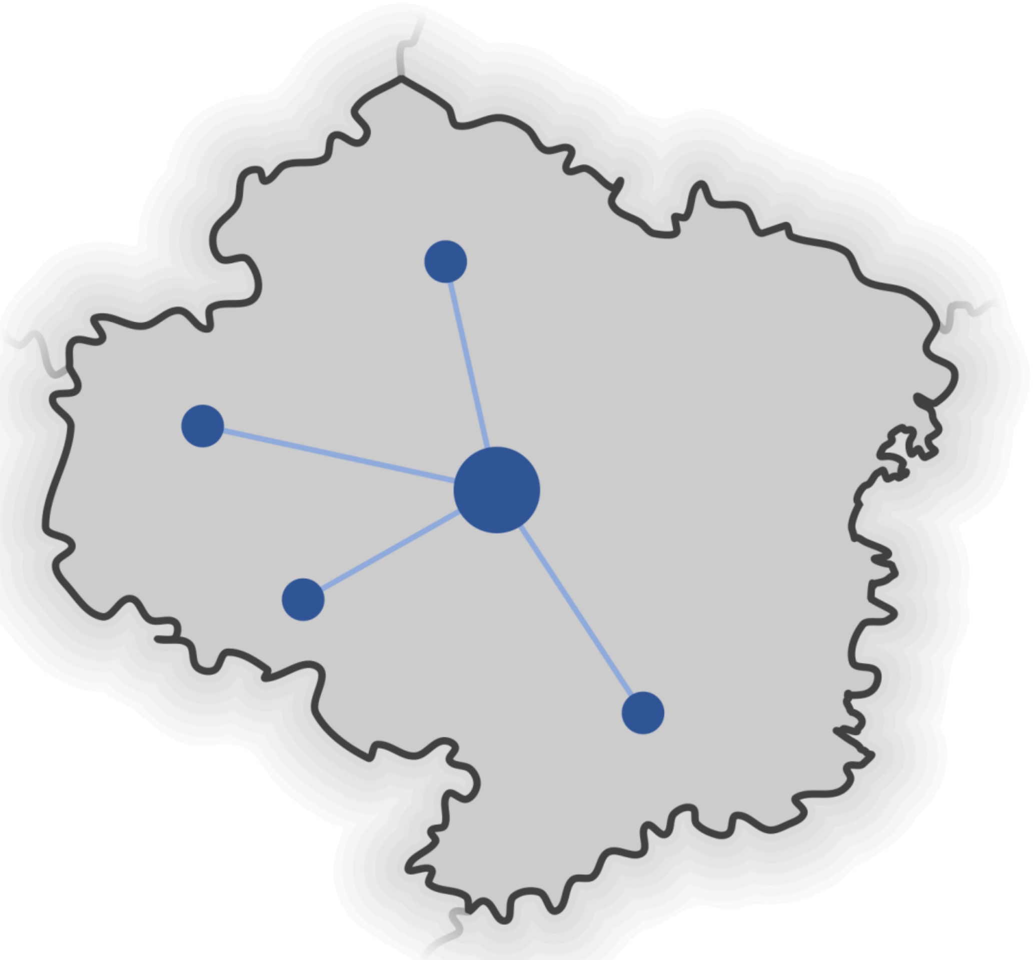
unis

Integration within regions

Both region-wide…

NERUDA*



*Pluskal J., Šomplák R., Nevrlý V., Smejkalová V., Pavlas M. (2021) *Journal of Cleaner Production* **278**, 123359.

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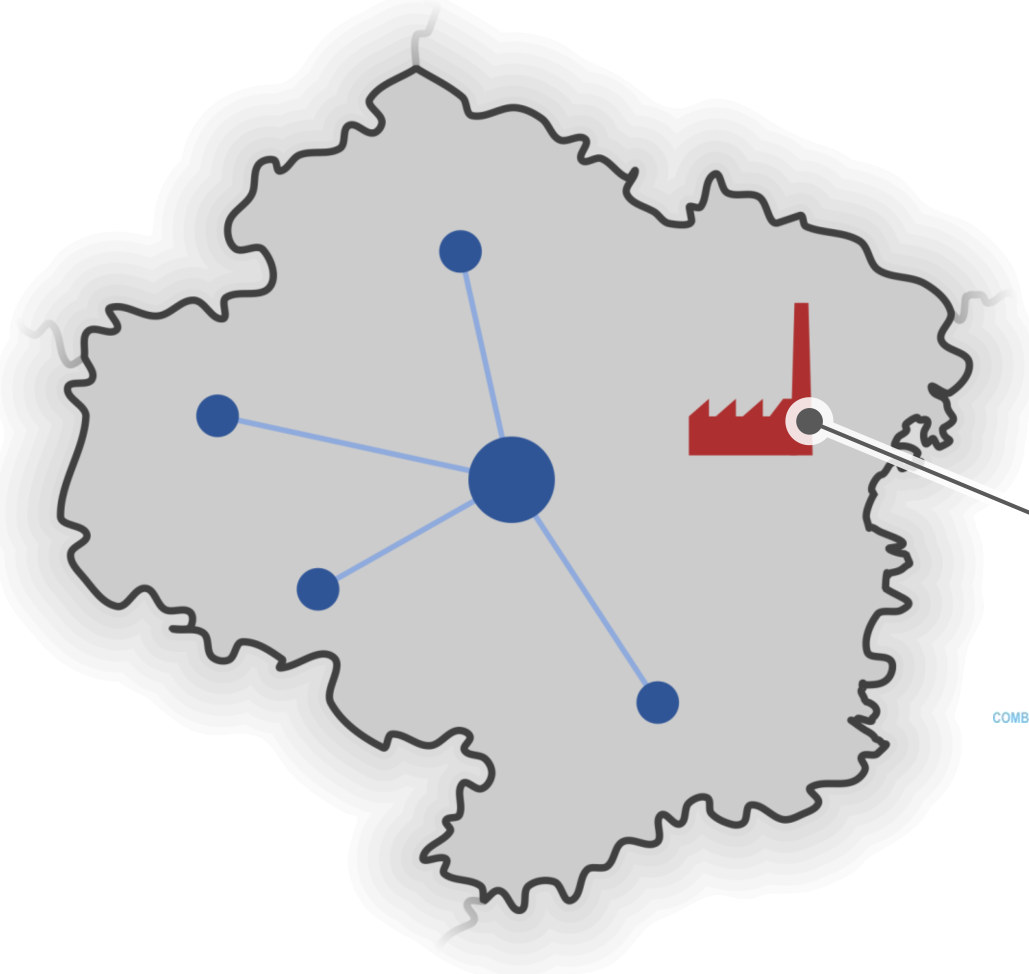
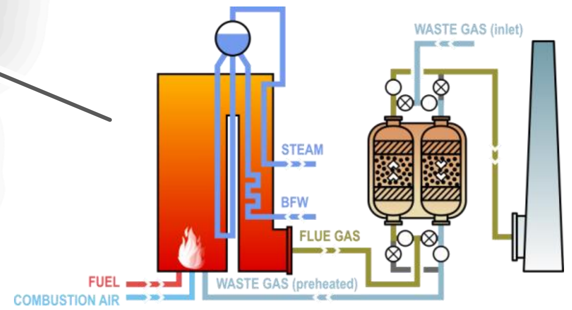


…and local



Tailor-made technology
incl. a heat recovery system

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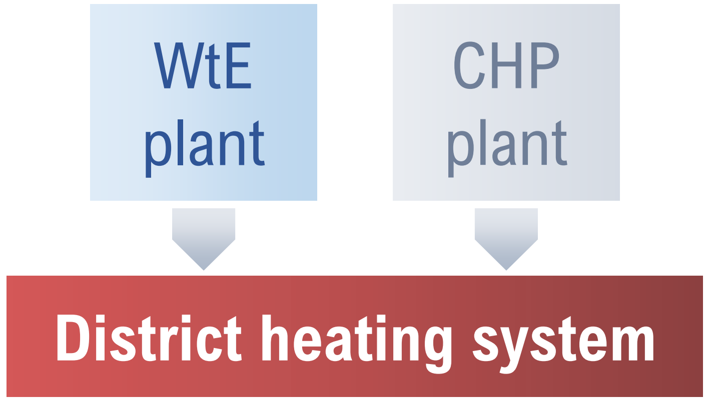
Example: local integration of WtE & CHP plants



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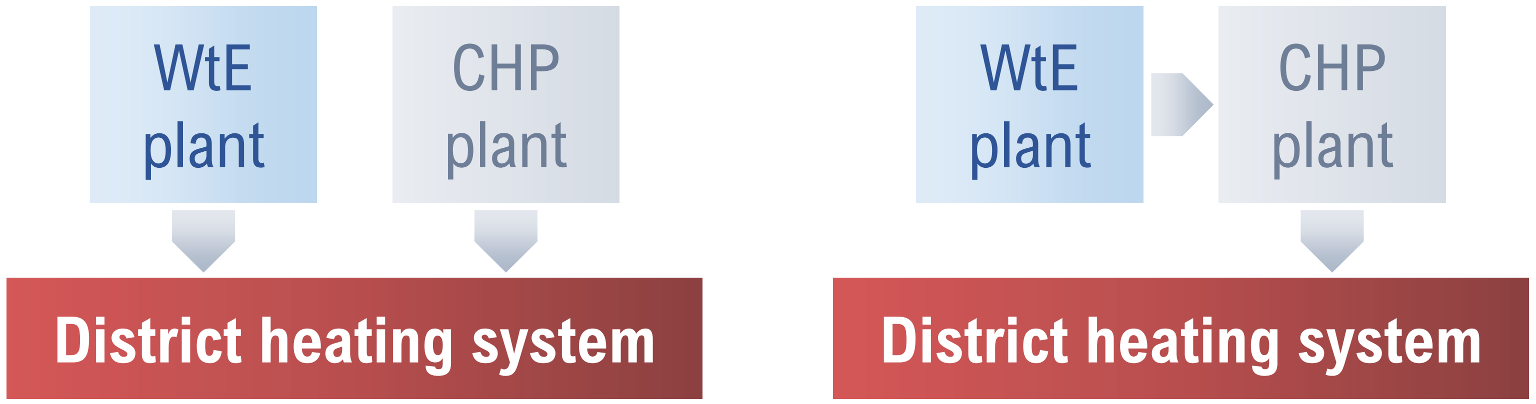

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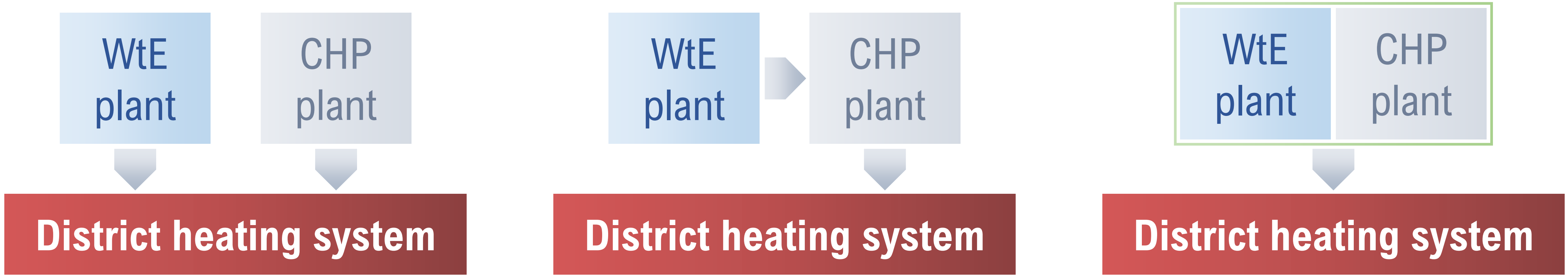

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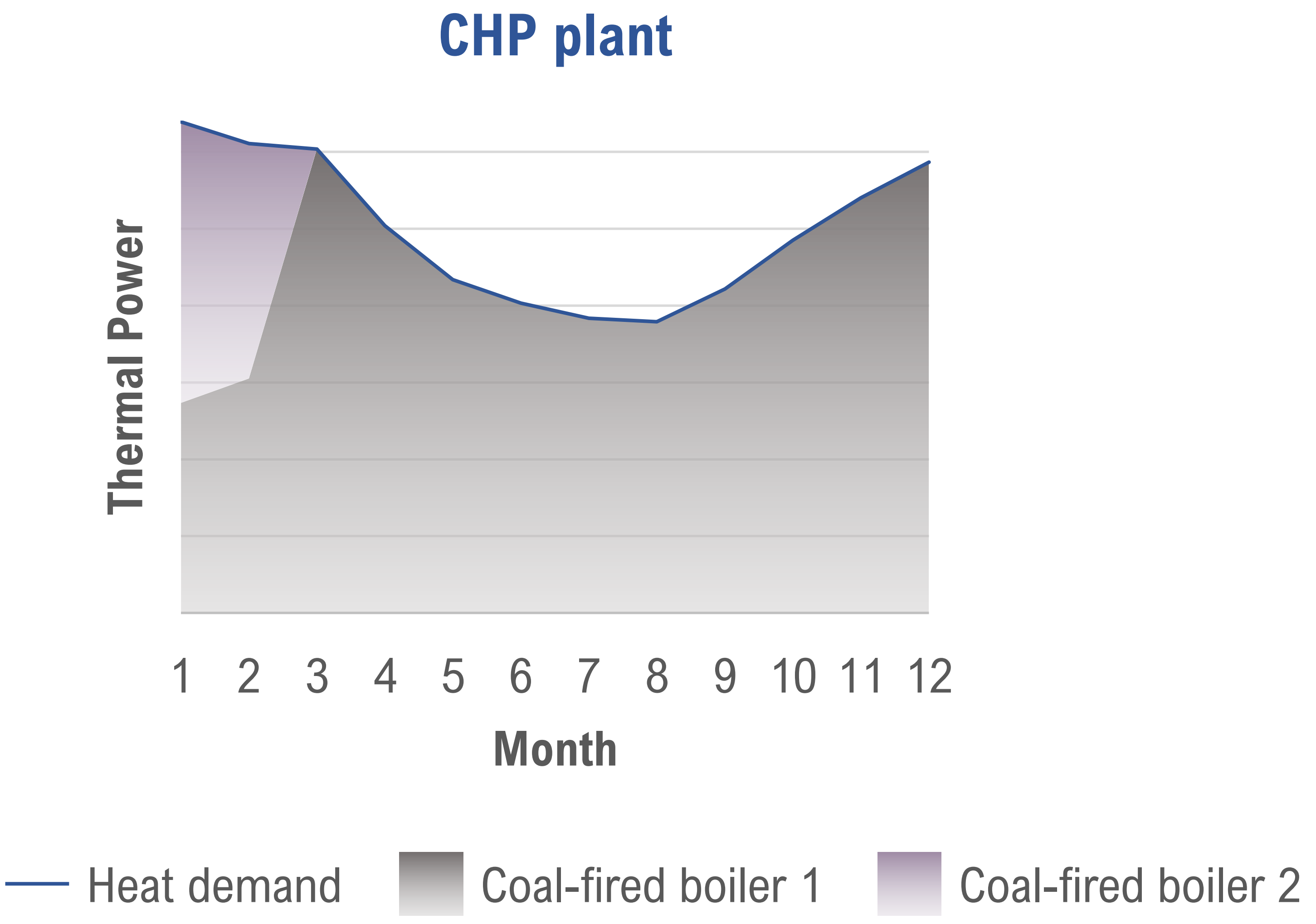

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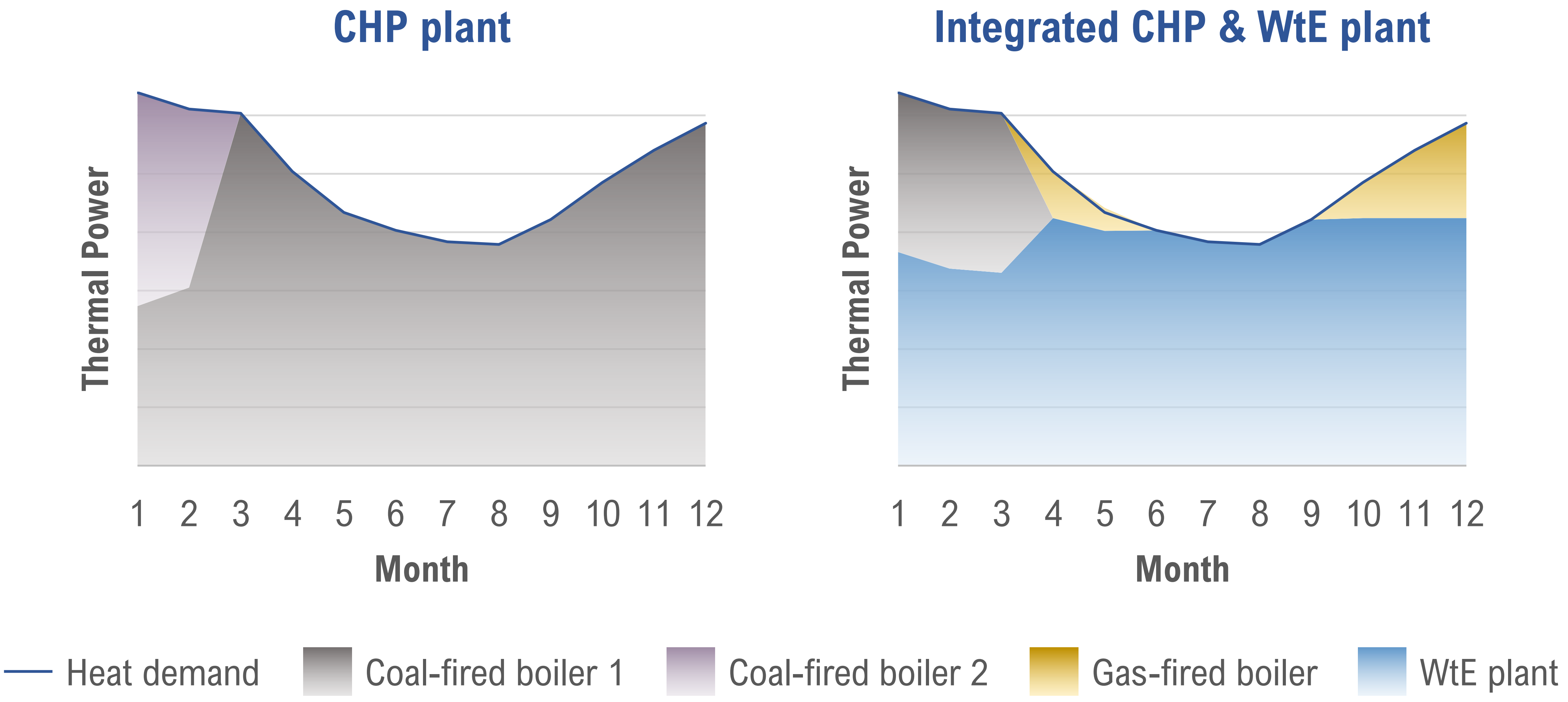

WtE plants require innovative solutions

- Experience: common designs and standardized equipment are often ill-suited

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→ **In many cases, novel/tailor-made designs are the only way to reduce operating problems**

WtE plants require innovative solutions

Integrated processes

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“ Integration^2 ”

Integrated processes

Integrated equipment

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Key factors:

- Heat integration

WtE plants require innovative solutions

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Key factors:

- Heat integration
- Selection of heat exchangers

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Key factors:

- Heat integration
- Selection of heat exchangers
- Fouling

WtE plants require innovative solutions

"Integration²"

Integrated processes

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Key factors:

- Heat integration
- Selection of heat exchangers
- Fouling
- Heat and fluid flow distributions

WtE plants require innovative solutions

“ Integration^2 ”

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Integrated equipment

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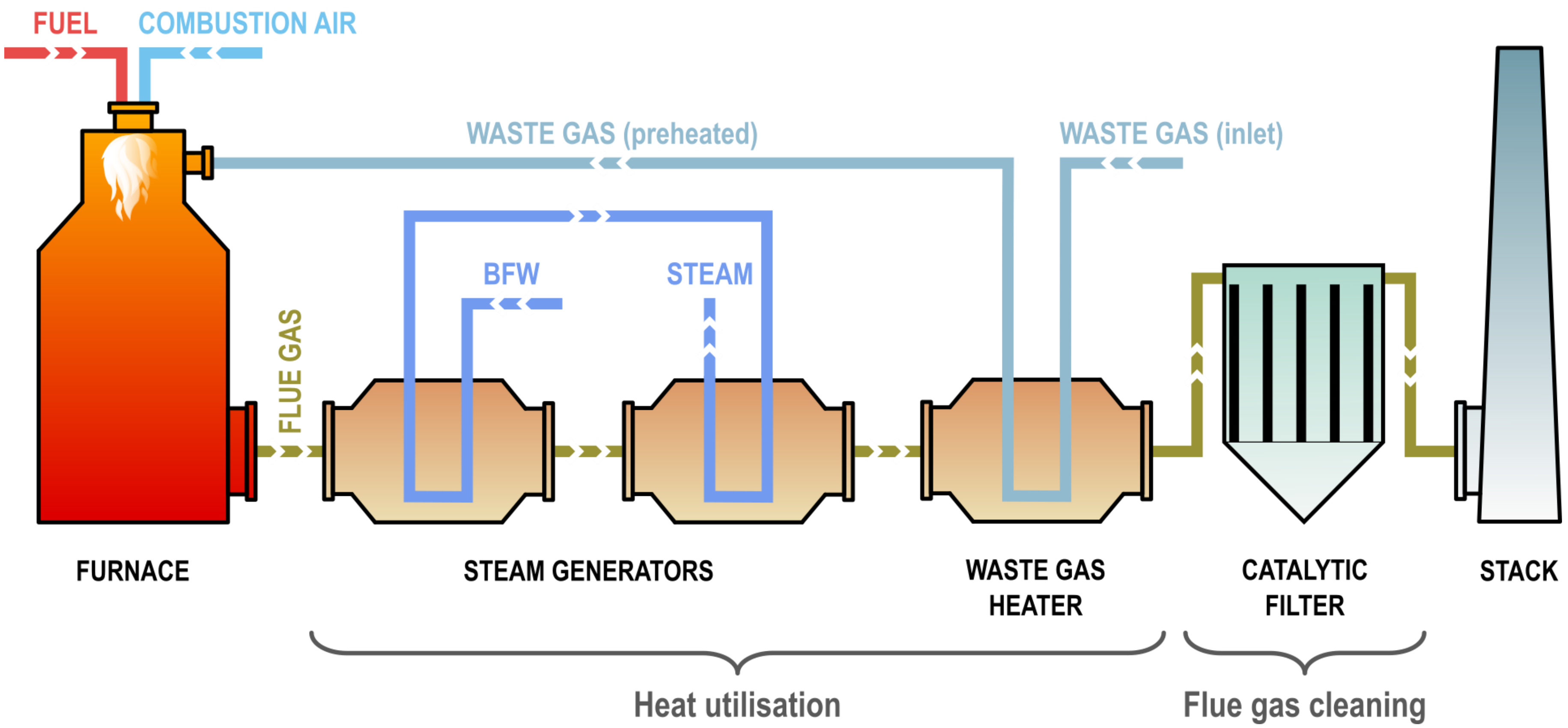
How to proceed? **Combine know-how, experience, and modelling!**

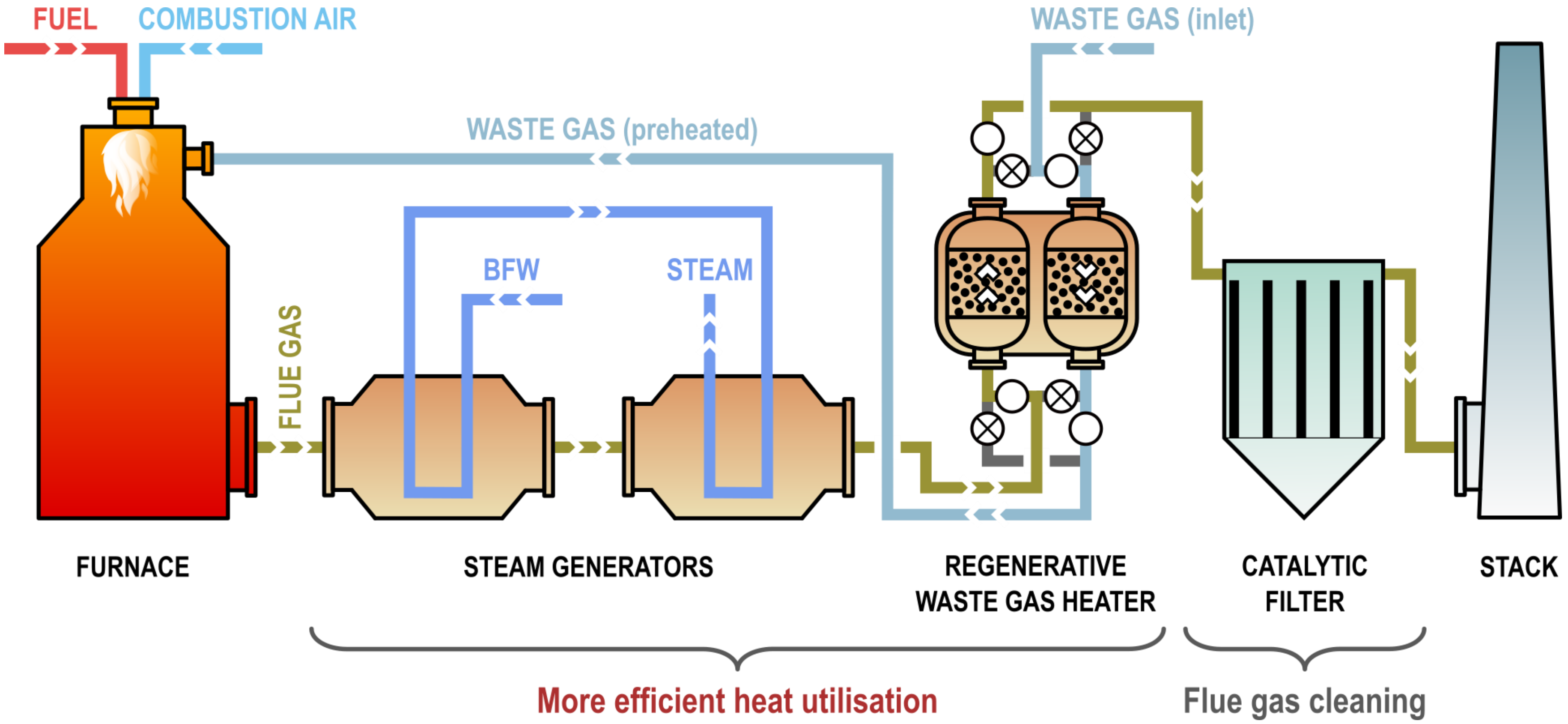
Large industrial WGtE units

Common arrangement



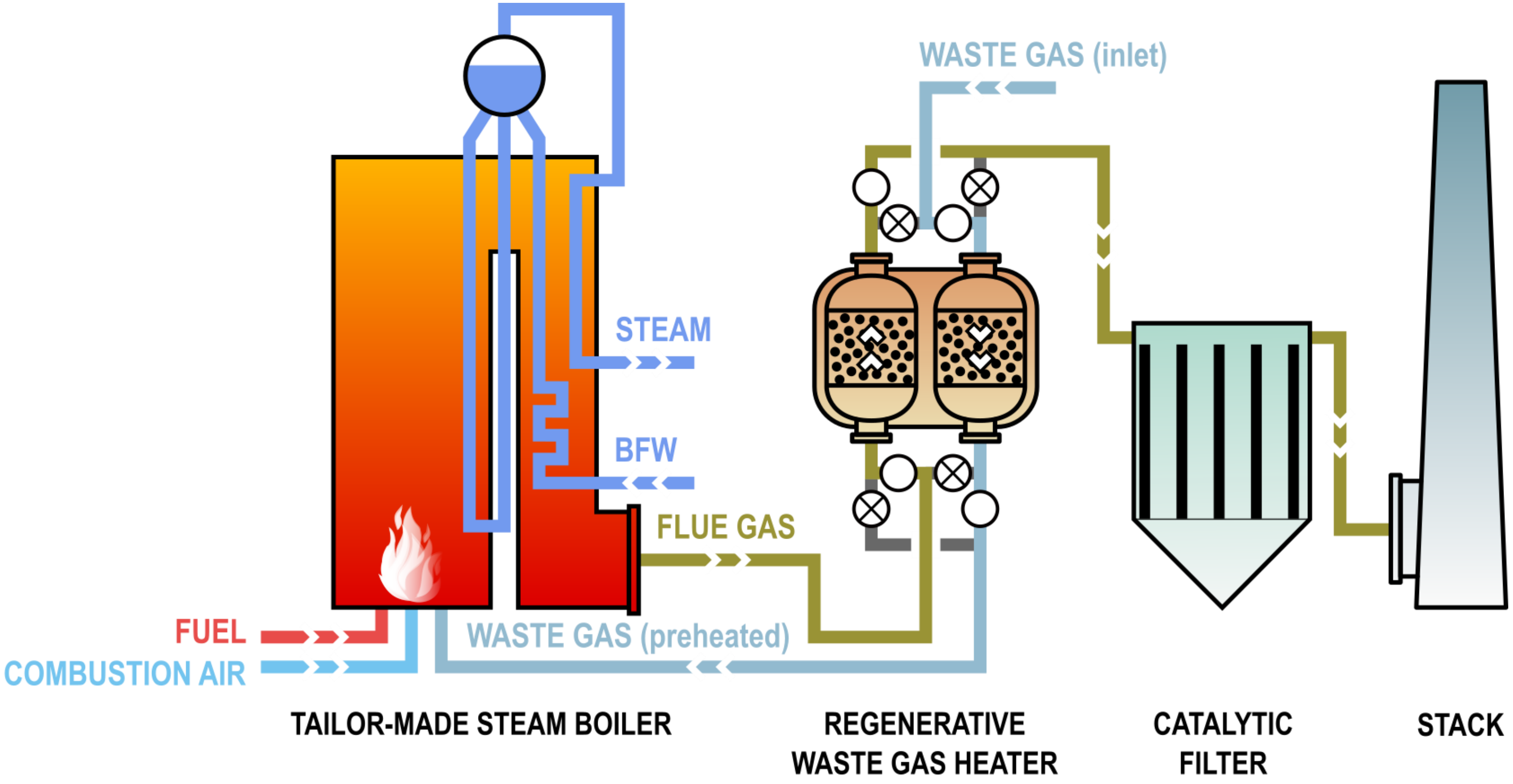
Large industrial WGtE units

Improved integrated arrangement



Large industrial WGtE units

Opportunities presented by modern integrated equipment



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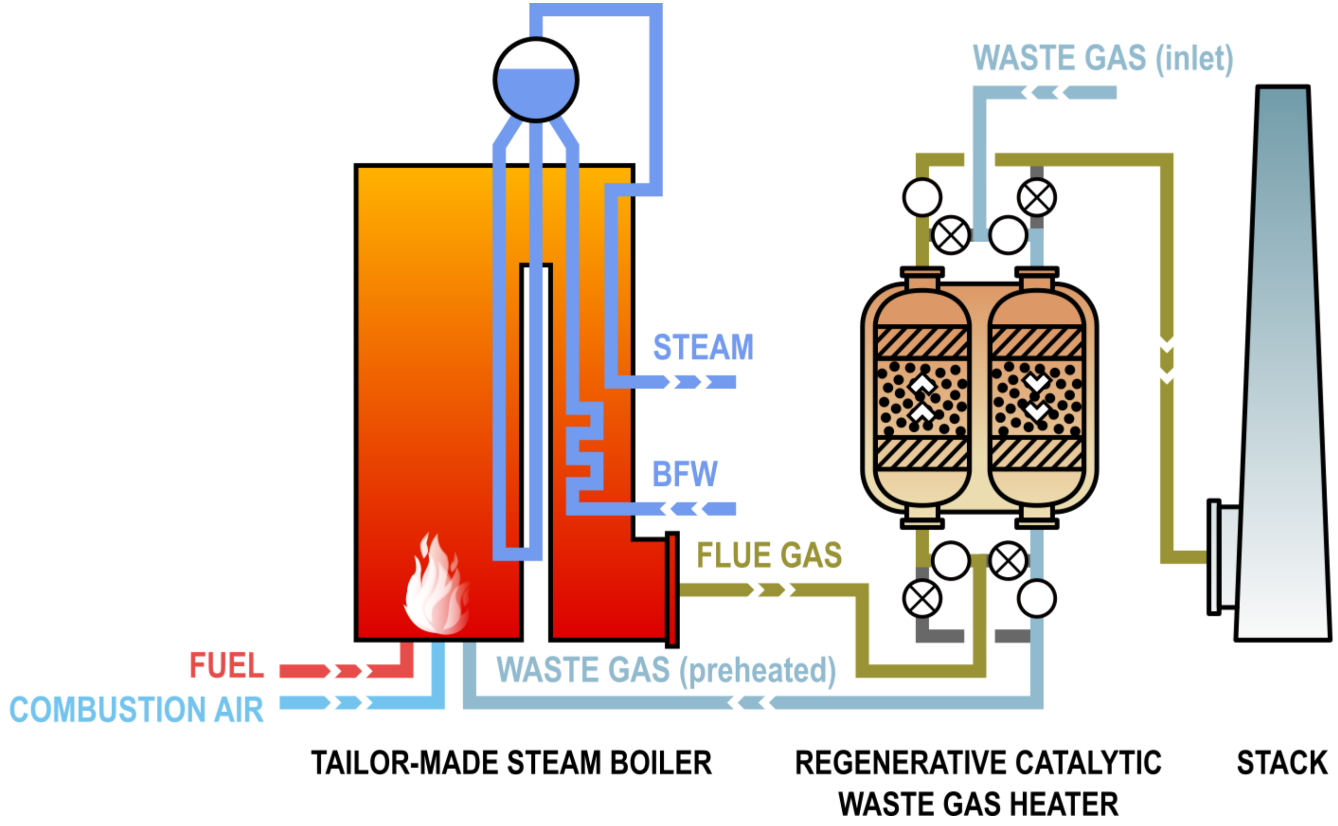


Large industrial WGtE units

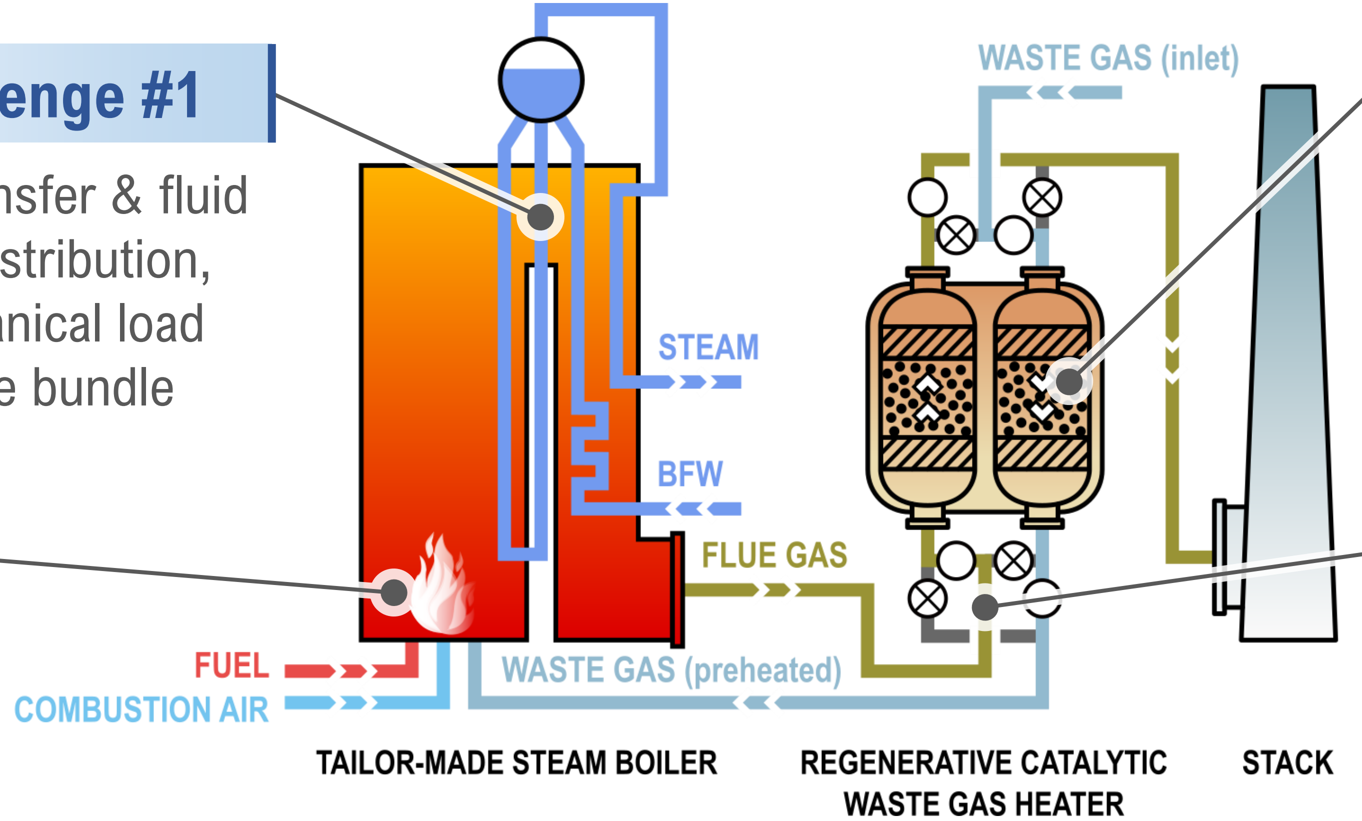
Main challenges in the design of modern integrated equipment

Challenge #1

Heat transfer & fluid flow distribution, mechanical load of the bundle

Challenge #4

Development of low-emission burners for WGtE applications



Challenge #2

Thermal behaviour of the catalytic bed, pollutant removal efficacy

Challenge #3

Tightness of bolted flange joints under variable operating conditions

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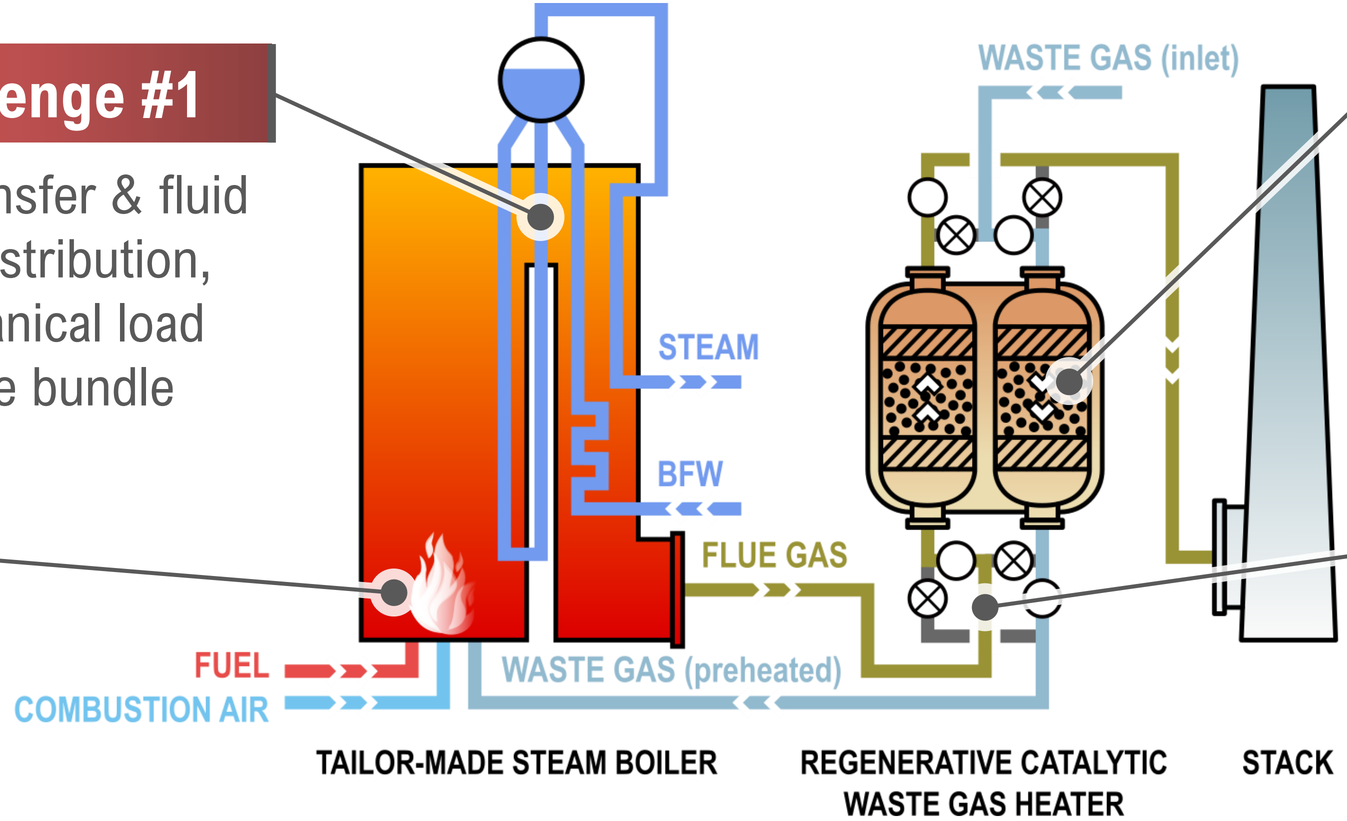

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Not suitable for large equipment

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- CFD-FEM

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Possible solutions (if speed is preferred over accuracy):

- CFD-FEM
- CFD-FVM with a coarse mesh & other simplifications

Option I: CFD-FEM

Intended use case:

Modelling of large, but structurally simple equipment

Option I: CFD-FEM

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Main advantages and disadvantages:

- Lower computational demand

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- Easier to implement

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Intended use case:

Modelling of large, but structurally simple equipment

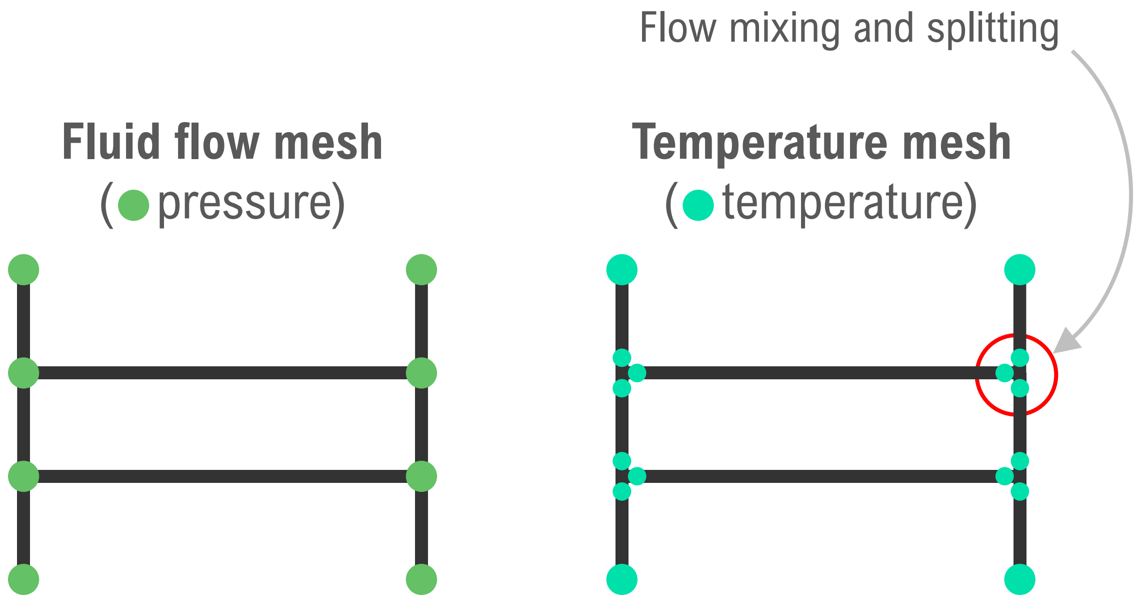
Main advantages and disadvantages:

- Lower computational demand
- Easier to implement
- Difficult to properly include the effect of turbulence

Option I: CFD-FEM

Simplified quasi-1D model*:

- $\dot{m} = k\Delta p$
- Two overlaid meshes consisting of linear, 2-node elements



*Based on Dudar O.I., Dudar E.S. (2017) *IOP Conference Series: Materials Science and Engineering* **262**, 012085.

Option I: CFD-FEM

Procedure:

1) Fluid flow predictor*

For the entire mesh:

$$\mathbf{K}^{(I-1)}\mathbf{p}^{(I)} = \dot{\mathbf{m}}^{(I-1)} \quad \longmapsto \quad \mathbf{p}^{(I)}$$

*Létal T., Turek V., Fialová D. (2019) *Chemical Engineering Transactions* **76**, 157–162.

Option I: CFD-FEM

Procedure:

1) Fluid flow predictor*
2) Fluid flow corrector*

For each mesh edge:

$$k^{(I-1)}\Delta p^{(I)} = \tilde{\dot{m}}^{(I)} \quad \longmapsto \quad \tilde{\dot{m}}^{(I)}$$

$$\mathrm{iter}\left(\Delta p^{(I)}, \dots\right) \quad \longmapsto \quad \dot{m}^{(I)}$$

$$k^{(I)} = k^{(I-1)}\sqrt{\dot{m}^{(I)}/\tilde{\dot{m}}^{(I)}} \quad \longmapsto \quad k^{(I)}$$

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Option I: CFD-FEM

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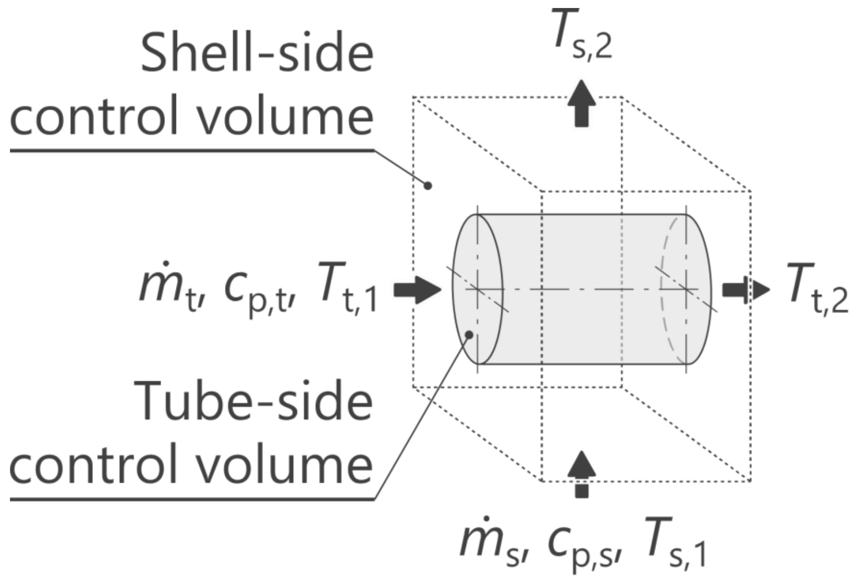
3) Heat transfer†



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Option I: CFD-FEM

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1) Fluid flow predictor*
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4) Mechanical load – *current research focus*

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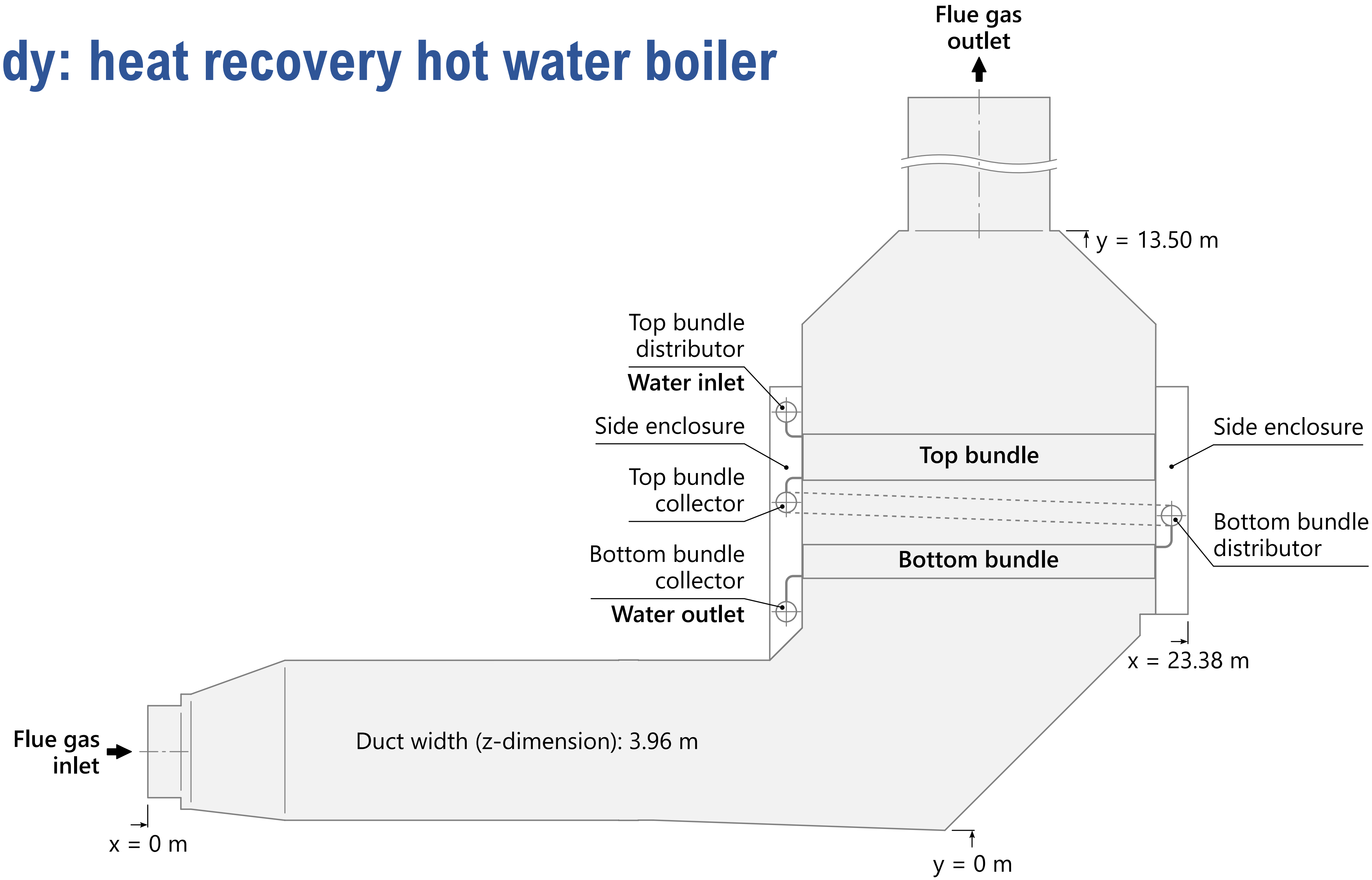
Case study: heat recovery hot water boiler



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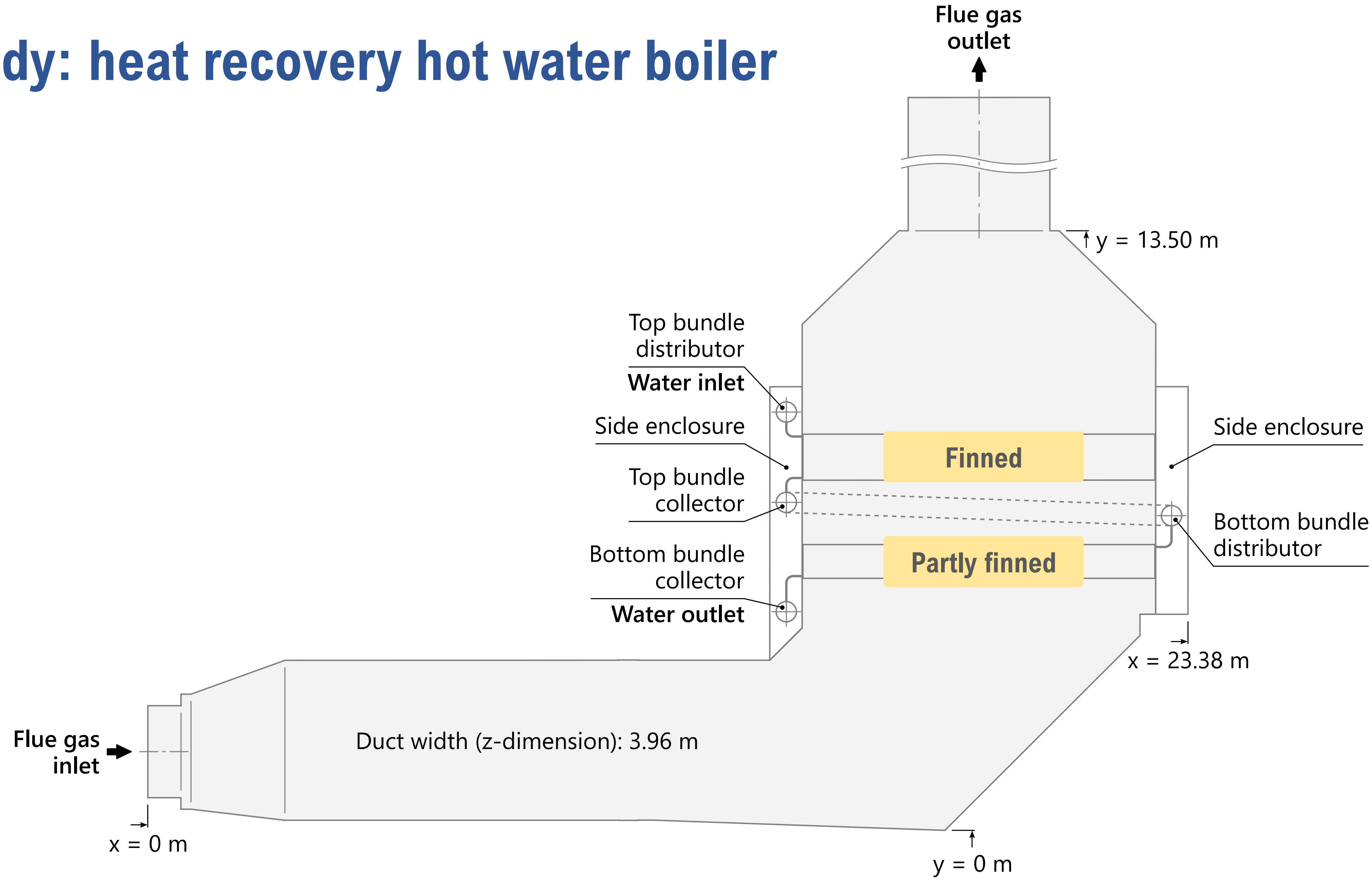

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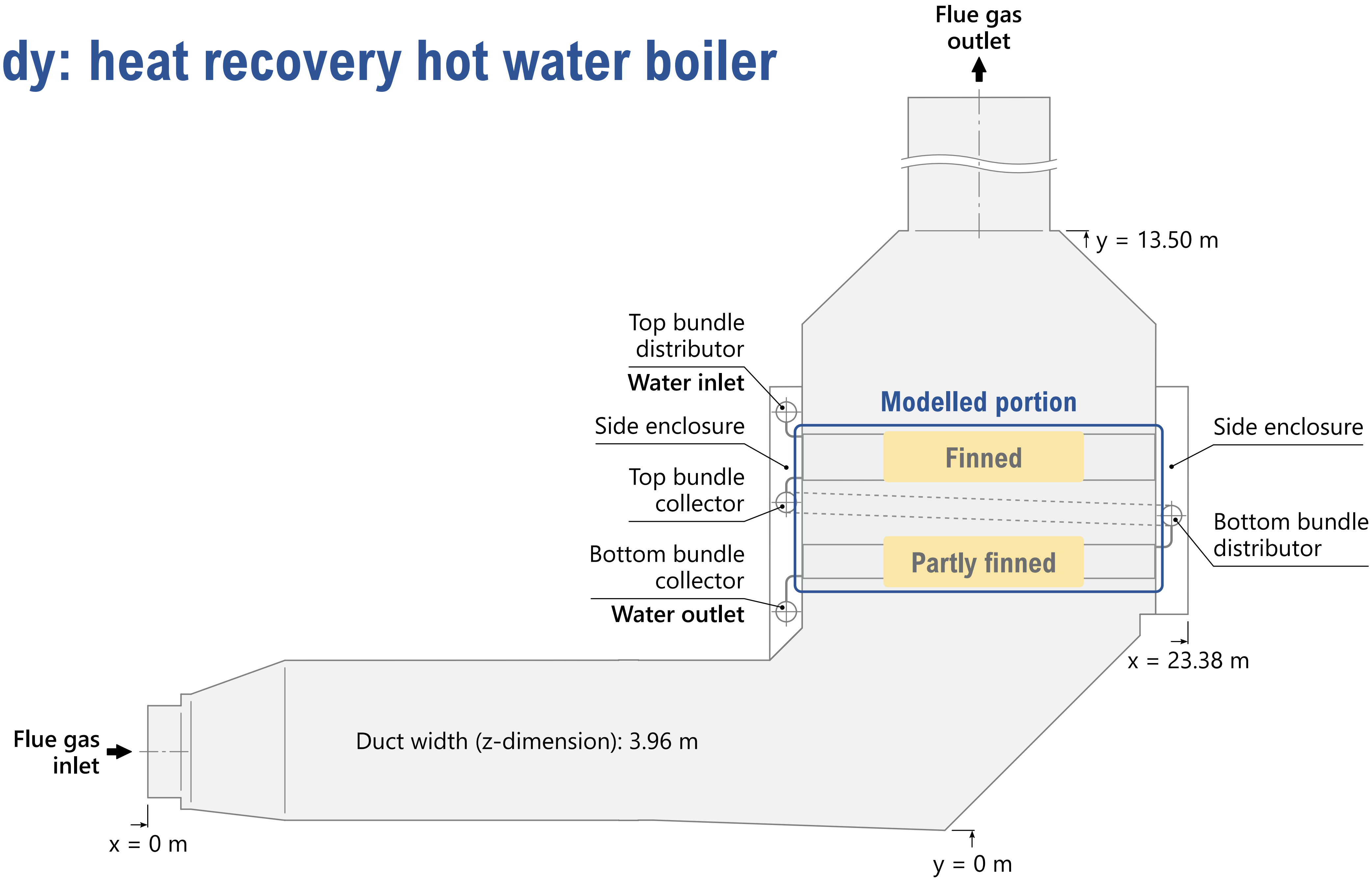
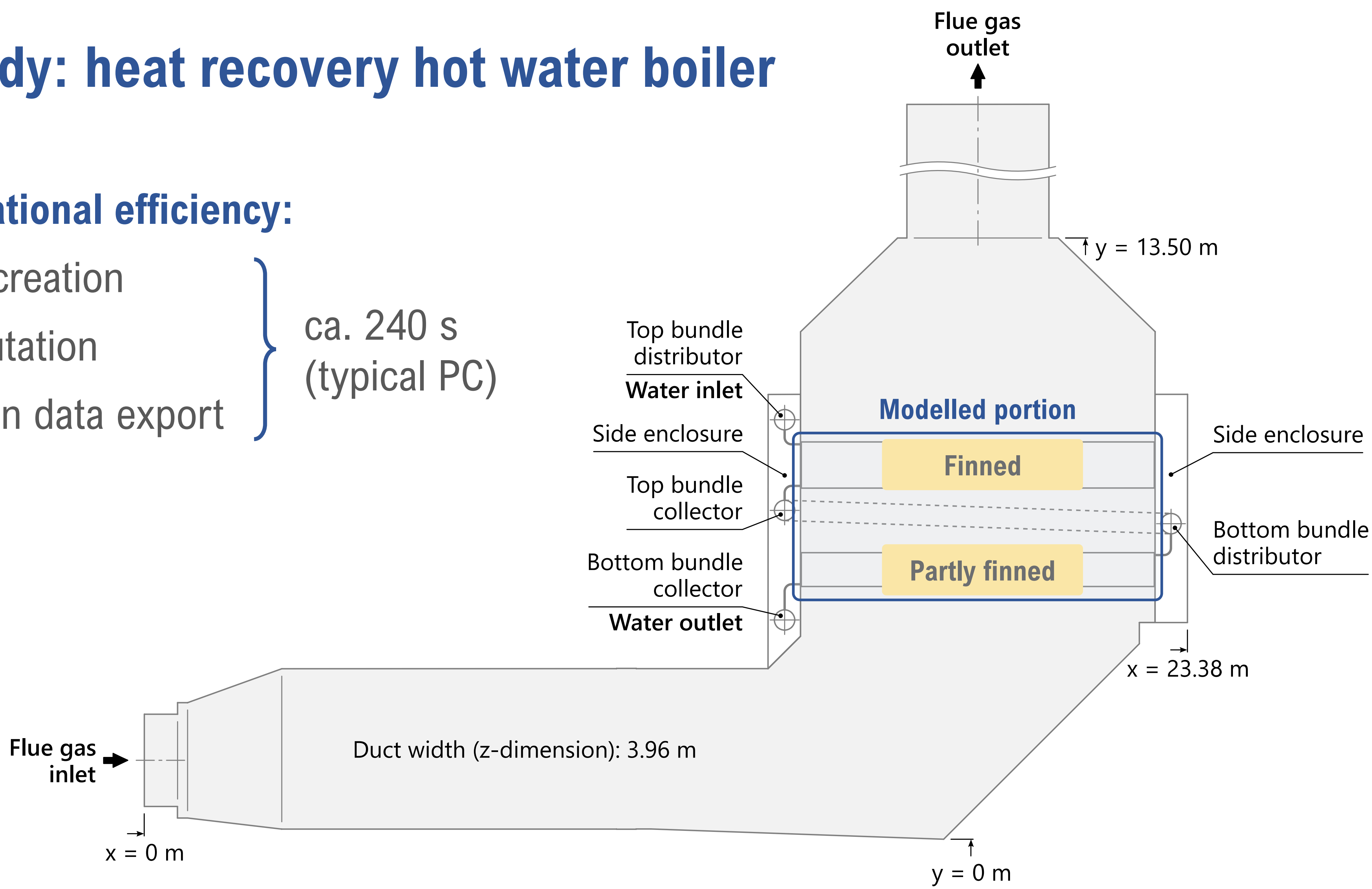


Case study: heat recovery hot water boiler

Computational efficiency:

- Mesh creation
- Computation
- Solution data export

ca. 240 s (typical PC)



Case study: heat recovery hot water boiler

	Operator	FEM-based model	
		Value	Error
Tube side			
Outlet temp., °C	139.3	136.1	–3.2 (–2.3%)
Pressure drop, kPa	32.15	30.33	–1.82 (–5.7%)
Shell side			
Outlet temp., °C	ca. 70*	62.9	ca. –7.1 (–10%)
Pressure drop, kPa	1.61	1.14	–0.47 (–29%)
Heat duty, MW	53.3	52.6	–0.7 (–1.3%)

*Estimated by the operator of the boiler

Case study: heat recovery hot water boiler

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Pressure drop, kPa	32.15	30.33	–1.82 (–5.7%)	32.33	+0.18 (+0.6%)
Shell side					
Outlet temp., °C	ca. 70*	62.9	ca. –7.1 (–10%)	59.3	ca. –10.7 (–15%)
Pressure drop, kPa	1.61	1.14	–0.47 (–29%)	0.93	–0.68 (–42%)
Heat duty, MW	53.3	52.6	–0.7 (–1.3%)	53.1	–0.2 (–0.4%)

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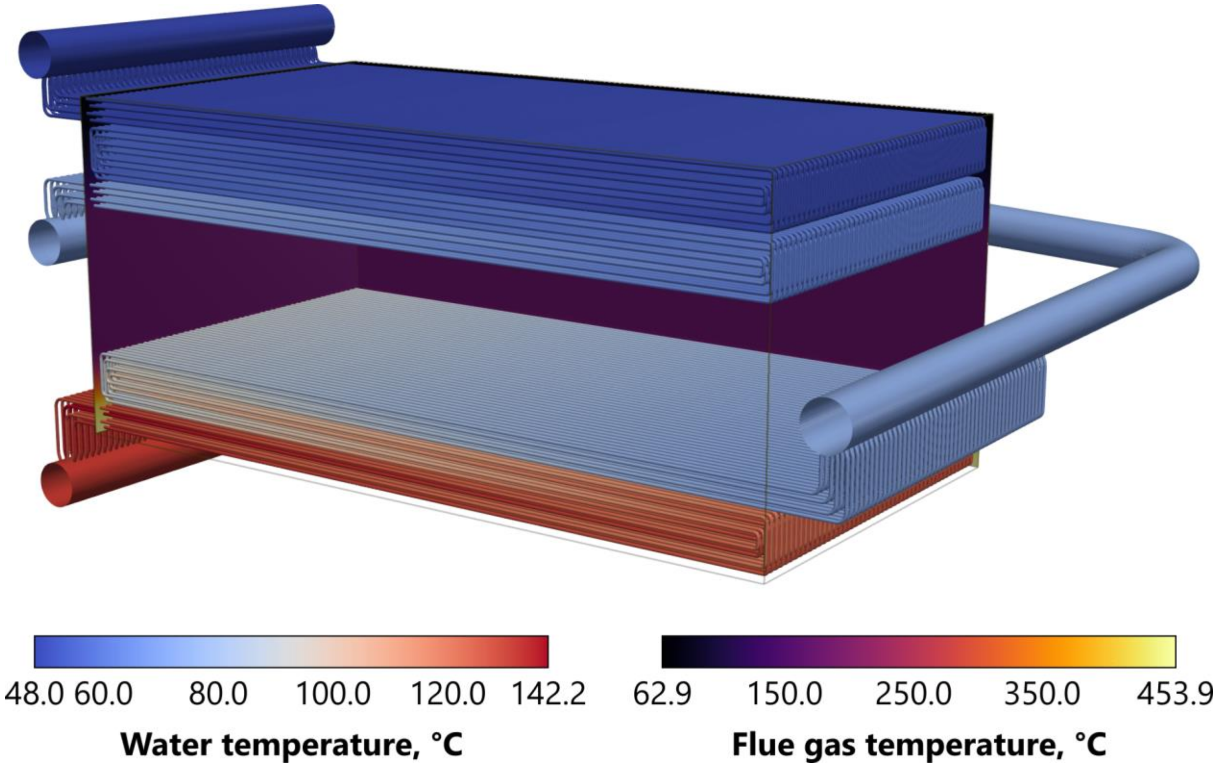
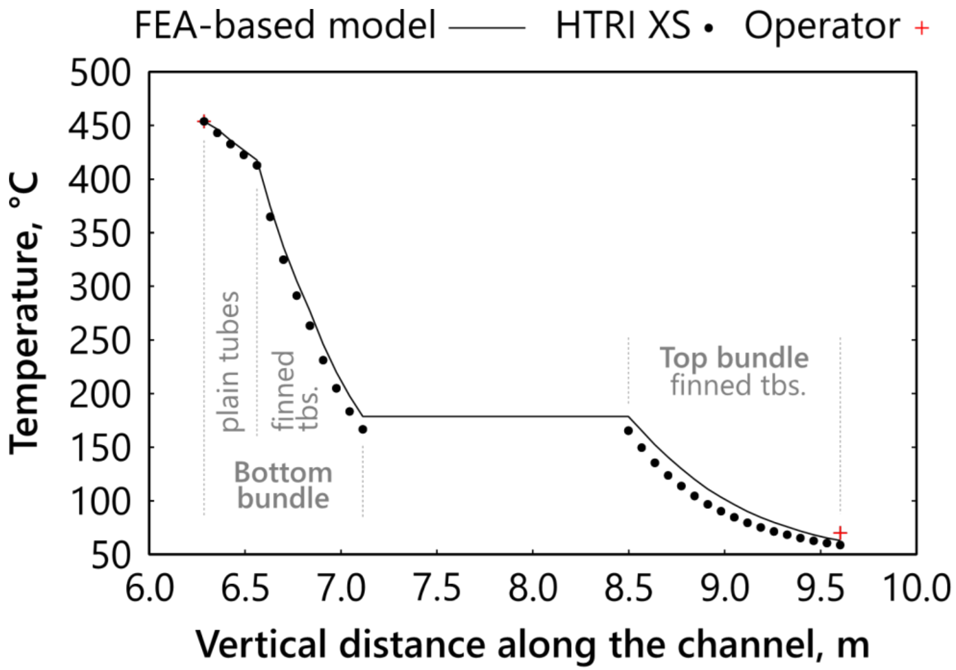
†*De facto* industry standard

Case study: heat recovery hot water boiler

Tube and shell side temperatures:



Shell side temperature profile:



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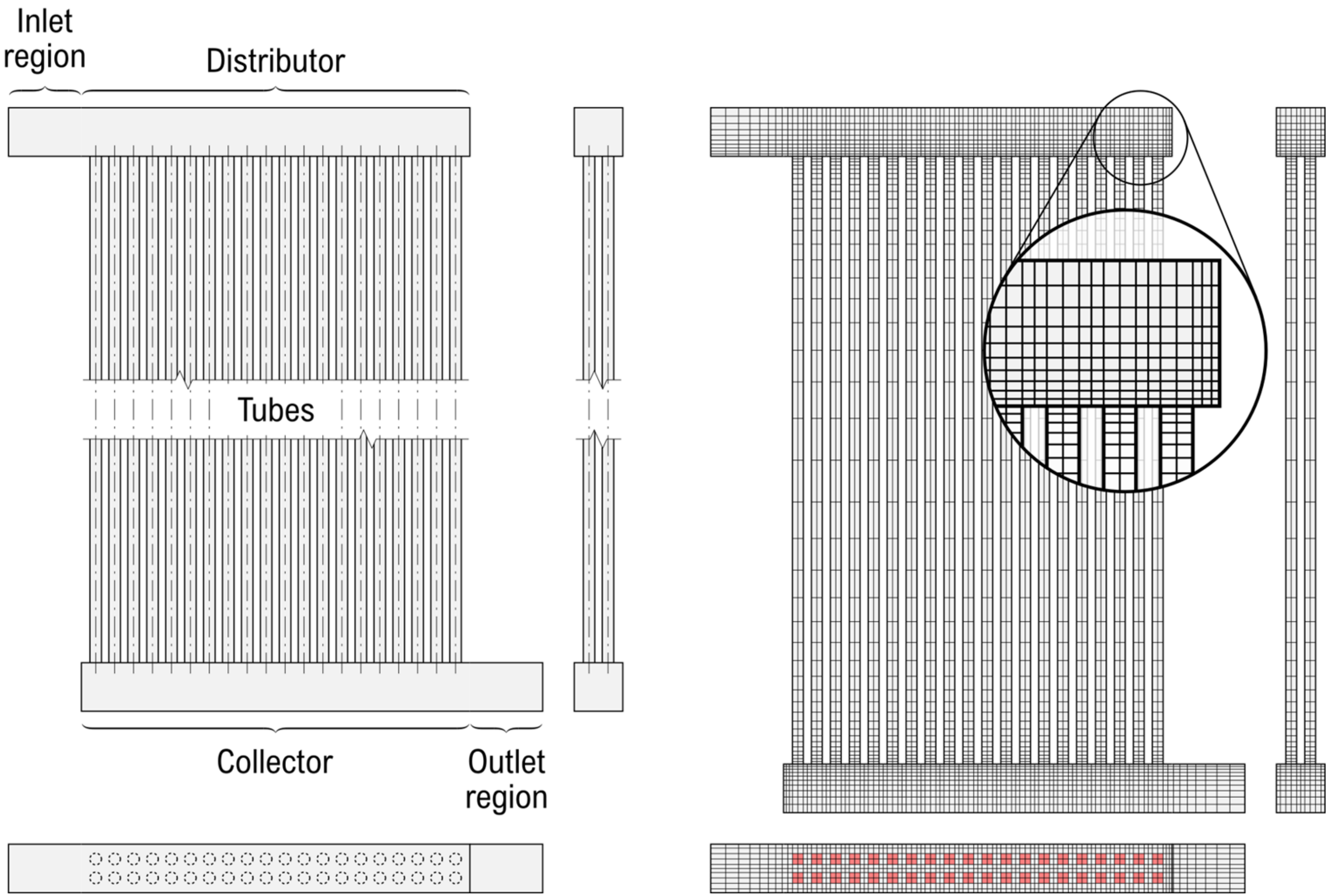

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  → Segregated solver (e.g., SIMPLEC), first-order schemes, CG/BiCGstab + ILU, …

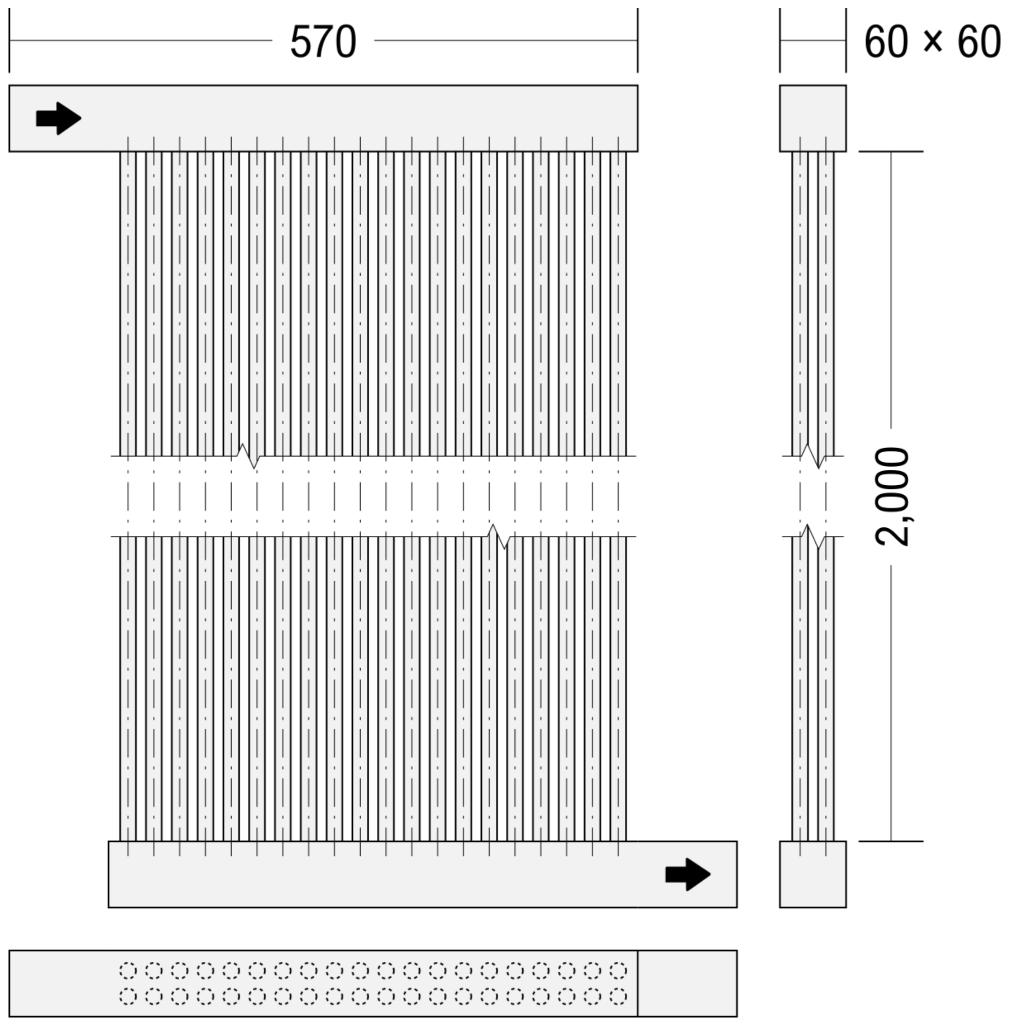
Case study: small cross-flow tube bundle

Fluid:

Water

Average tube Reynolds number:

Ca. 20,000



*All dimensions are in millimetres.

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Model preparation	< 1 min.	Units of hrs.

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→ Using the developed SW makes sense in spite of the mentioned limitations

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Future work

- CFD-FEM model:
  - Shell side: 1D mesh $\rightarrow$ rectangular grid
  - Tube side: additional mesh elements with better support for wider (“2D”) tube sheets
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  - Allowing prism (non-cuboid) cells at the boundary of the domain
  - Would it be better to write a preprocessor for, e.g., OpenFOAM?

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- Properly including the effect of turbulence is problematic if speed is preferred
- As of yet limited applicability (mechanical load submodels are still missing)

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Funding: EU Operational Programme Research, Development and Education; Ministry of Education, Youth and Sports of the Czech Republic

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