H-CHP Equipment
-
Development of Prototype of Steam Based CHP

UNIVERSITY OF OULU

Northern Periphery and Arctic Programme
2014–2020

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University of the Highlands and Islands
Lews Castle College
Oilthigh na Gàidhealtachd agus nan Eilean
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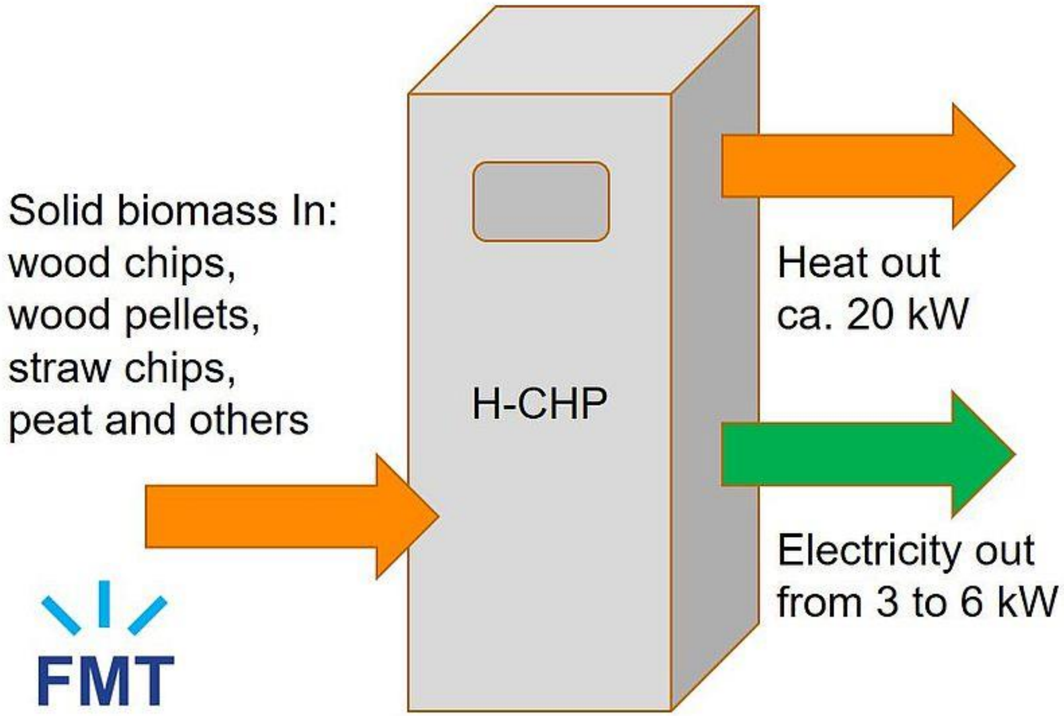
Steam CHP Specifications

- **Service life over 10 years - please😃**
- **Establish *open source community* for further developing of CHP-plants**



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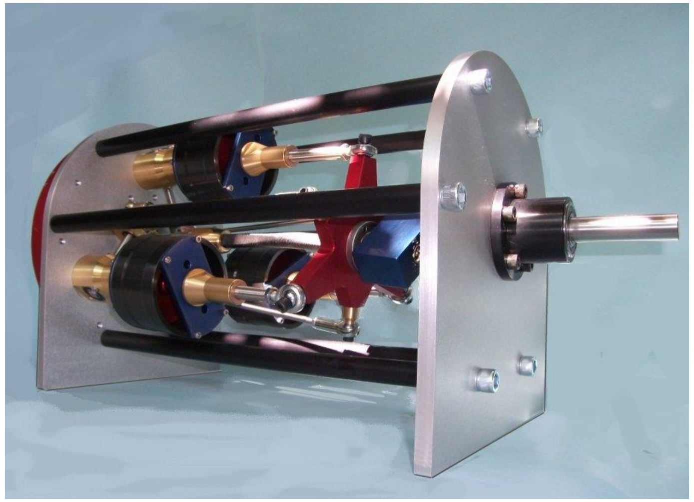
Steam Engine – modern “commercial”

- **It's an old invention,**
    - the most famous in history in 1784 by James Watt
- Nowadays, those are mainly familiar from jewelled-beauty nostalgic machines on boats, but attempts to bring steam motors to CHP plants have been seen from time to time
- Piston type machines:
    - single cylinder,
    - double cylinder (compound) and
    - three-cylinder (Triple)
- Can be designed as double-acting - a piston is doing work on both directions



https://www.greensteamengine.com/

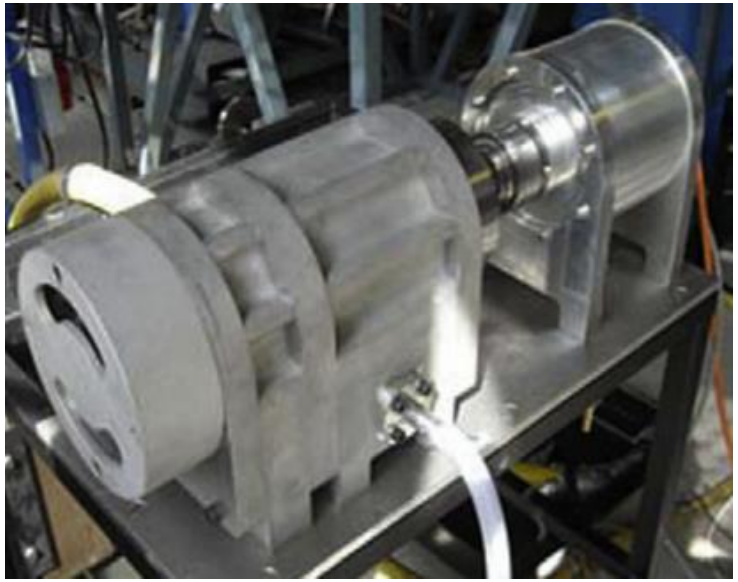
https://cyclonepower.com

Rotary Steam Engine – Novoro Oy 2006

A! Aalto University

Rotary steam engine (RSE)-I

- Developed by Novoro Inc. in collaboration with Aalto University since 2006
- Operational principle:
  - Rankine cycle
- Characteristics:
  - Utilize 150...200 ºC vapor (5-15 bar)
  - Oil free, noiseless, 1000-2000 RPM
  - Compact size, power/weight ratio
  - Connection to generator without gearing
  - Versatile sources of heat (e.g. biofuels or solar energy)
  - Estimated installed cost of a similar magnitude as for micro-CHP plants based on internal combustion engines



- ➢ Boiler 25 kW
- ➢ Electrical efficiency of 9%, thermal efficiency of 77%
- ➢ An overall cogeneration efficiency of 86%

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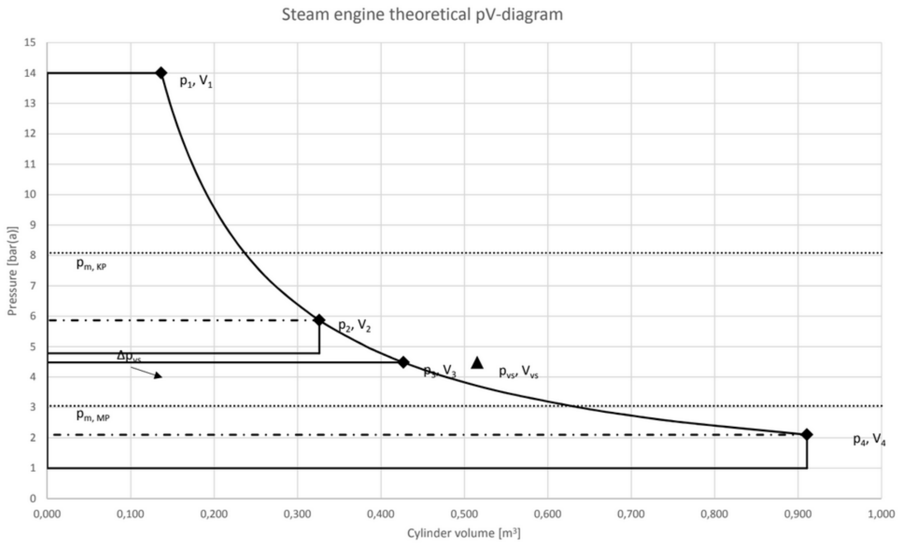
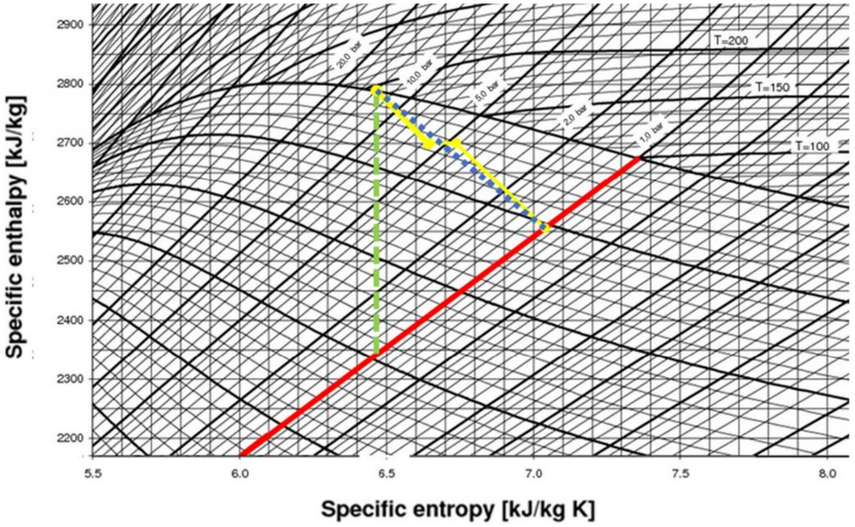
Steam CHP system calculations

There are plenty of ”free” books available for dimensioning steam engines, but those are rather old.

The boiler pressure is 14 bar





Steam engine sizing

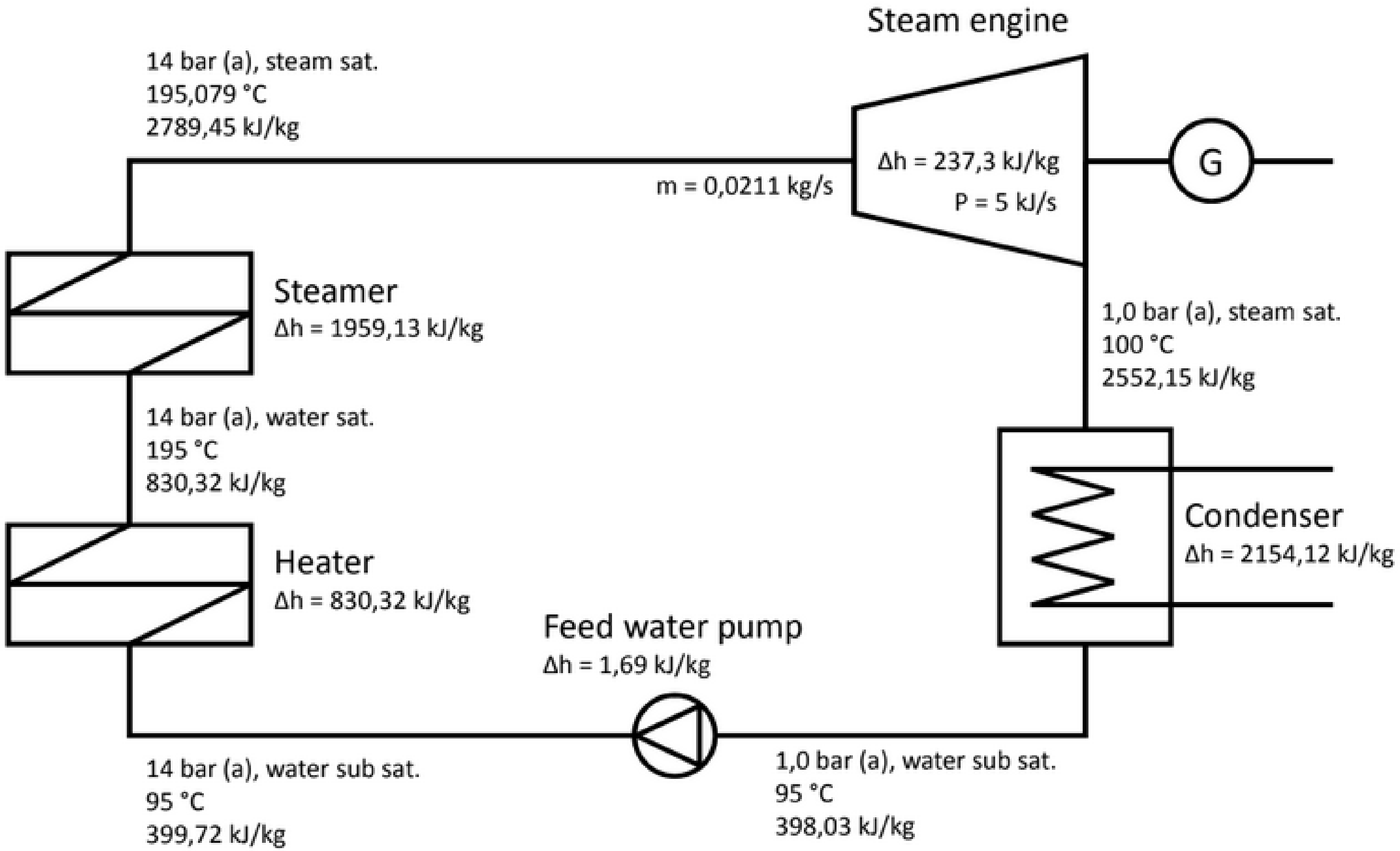
Wanted power	$P =$	5	kW	
Ratio of expansion, whole engine	$1/R =$	0,15		$\frac{1}{R} = \frac{V_1}{V_4} = \frac{p_4}{p_1}$
	$R =$	6,67		$R = \frac{V_4}{V_1}$
Cylinden volume ratio	$r =$	2,65		$r = \frac{V_4}{V_2}$
Overall diagram factor	$f =$	0,6		The actual indicator area
Mechanical efficiency	$\eta_{Mech} =$	0,9		Steam engine mechanical parts
Total efficiency	$\eta_{Tot} =$	0,54		$\eta_{Tot} = f \times \eta_{Mech}$
Rotation speed of engine	$rpm =$	600	r/min	
	$N =$	10	r/s	$N = \frac{rpm}{60\ ^{s}/_{min}}$
Piston speed	$v_m =$	2,50	m/s	Speed should be <5 m/s
Piston stroke length	$l_{stroke} =$	0,125	m	$l_{stroke} = \frac{v_m}{2 \times N}$
	$l_{stroke} =$	125	mm	
HP cut-off volume	$V_1 =$	0,000137	m^3	$V_1 = \frac{P_{engine}}{\langle 100 \times 2 \times f \times N \rangle \times \langle [p_1 \times (1 + lnR)] - (p_b \times R) \rangle \times \eta_{Mech}}$
	$V_1 =$	0,13660	dm^3	
	$V_1 =$	136,60	cm^3	
Steam amount	$V_{Steam} =$	0,002732	m^3/s	10 strokes/s * 2 sides of piston
	$\rho_{Steam} =$	7,1028	kg/m^3	Saturated steam 14 bar(a)
	$m_{Steam} =$	**0,019404**	**kg/s**	
Mean effective pressure	$p_{m,LP} =$	3,05	bar(a)	$p_{m,LP} = f \times \left\{\left[\frac{p_1}{R} \times (1 + lnR)\right] - p_b\right\}$
	$p_{m,HP} =$	8,08	bar(a)	$p_{m,HP} = r \times p_{m,LP}$
High pressure cylinder (HP)	$p_1 =$	14	bar(a)	
	$p_2 =$	5,87	bar(a)	$p_2 = \frac{V_1 \times p_1}{V_4} + \Delta p_{vs}$
	$V_1 =$	0,000137	m^3	
	$V_2 =$	0,000344	m^3	$V_2 = \frac{V_4}{r}$
HP cylinder diameter	$\varnothing_{HP} =$	0,0592	m	$\varnothing_{HP} = 2 \times \sqrt{\frac{V_2}{l_{Stroke} \times \pi}}$
		59,2	**mm**	
Receiver pressure loss	$\Delta p_{res} =$	0,30	bar(a)	
Receiver	$p_{res} =$	4,48	bar(a)	$p_{res} = p_3$
	$V_{res} =$	0,000515	m^3	$V_{res} = 1,5 \times V_2$
Low pressure cylinder (LP)	$p_3 =$	4,48	bar(a)	$p_3 = \frac{p_1 - \Delta p_{res} + (p_b \times r)}{(r+1)}$
	$p_4 =$	2,10	bar(a)	$p_4 = \frac{V_1 \times p_1}{V_4}$
	$V_3 =$	0,000427	m^3	$V_3 = \frac{V_1 \times p_1}{p_3}$
	$V_4 =$	0,000911	m^3	$V_4 = R \times V_1$
LP cylinder diameter	$\varnothing_{LP} =$	0,0963	m	$\varnothing_{LP} = 2 \times \sqrt{\frac{V_4}{l_{Stroke} \times \pi}}$
		96,3	**mm**	
Condenser pressure	$p_b =$	1	bar(a)	

One piston expansion ratio

$r_{1,HP} = \frac{V_2}{V_1} = 2{,}52 \quad r_{2,LP} = \frac{V_4}{V_3} = 2{,}13$

Steam engine theoretical efficiency

	Δh [kJ/kg]	Φ [kW]	
Boiler process	2 389,7	50,35	94 %
Boiler losses	71,7	1,5	3 %
Flue gas losses	71,7	1,5	3 %
Total	**2 533,1**	**53,4**	**100 %**
Steam engine	**237,3**	**5,0**	**9,9 %**
Condenser	**2 154,1**	**45,4**	**90,1 %**



Steam engine – design basics

- Two cylinders – High pressure and low pressure
- Type: Double acting compound (piston doing work on both side)
- Rotation speed 600 rpm
- Stroke 125mm
- High pressure piston dia. selected as 63mm (calculated 59,2mm)
- LP piston dia. selected as 100mm (calculated 96,3mm)
  - This is done due to standard sizes of cylinders
- Valve: rotary type
  - HP valve is kept open 39,8% of stroke then closed and let the steam expand
  - LP valve 46,9% of stroke
- Receiver volume 0,515 liter (overall space between HP valve issue and LP valve entry)

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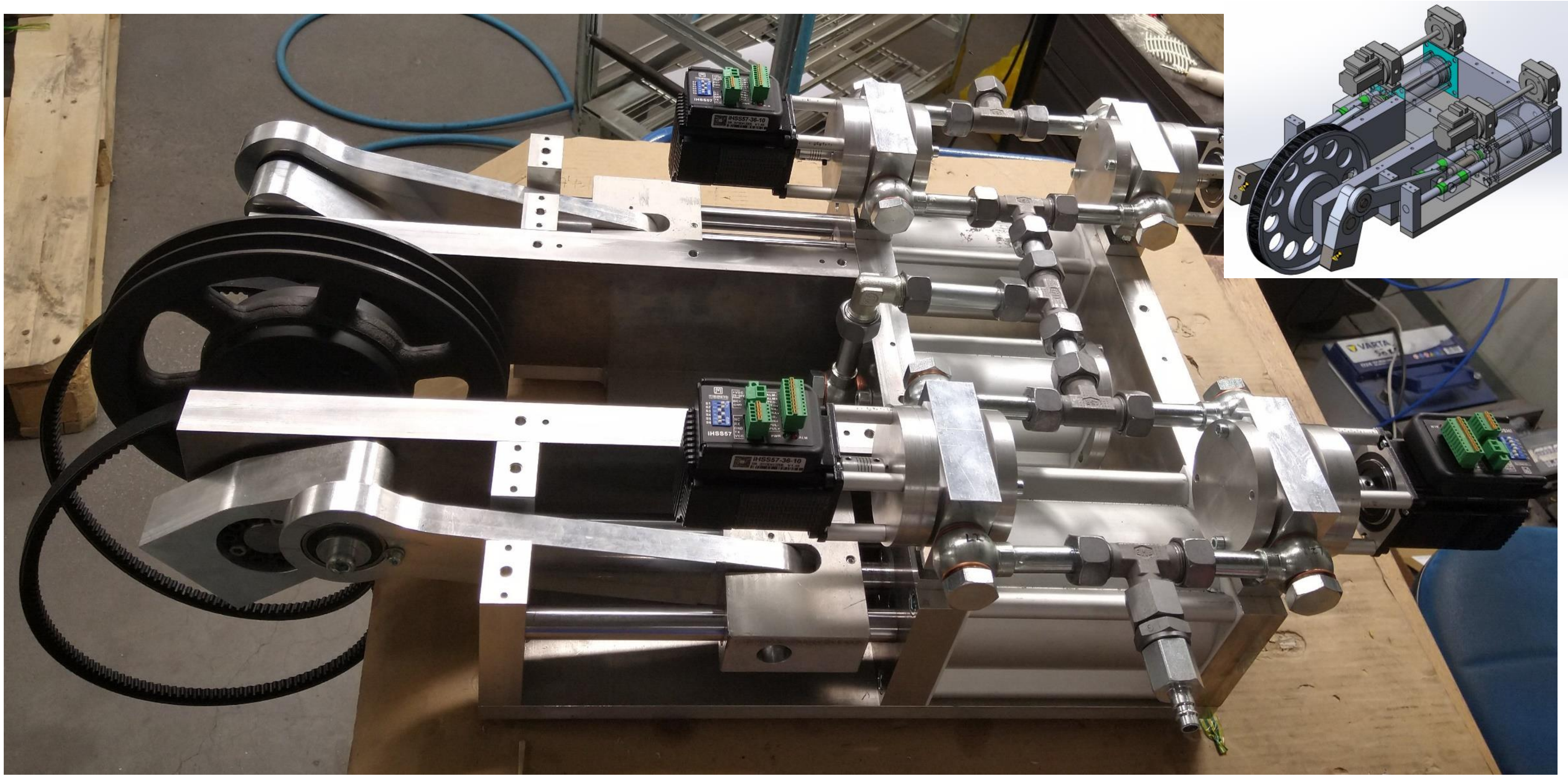
Steam engine



And when all other needed parts installed it looks something like this…

- Generator
- Frame
- Conderser
- Engine pre-heating coil
- Pipes and hoses
- Hi-pressure pump
- Expansion vessels
- Valves (non-return, solenoid, safety)
- Automation
- …

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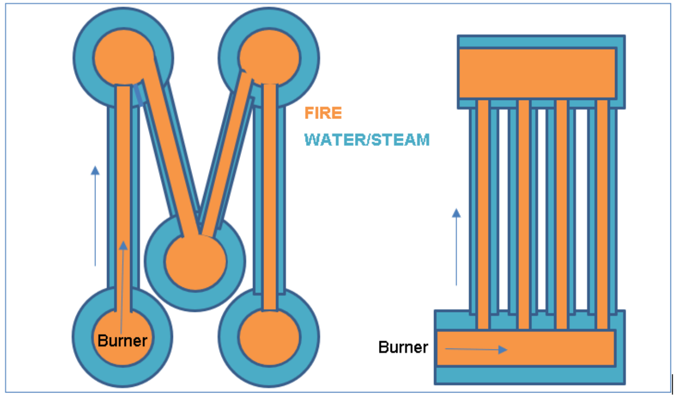
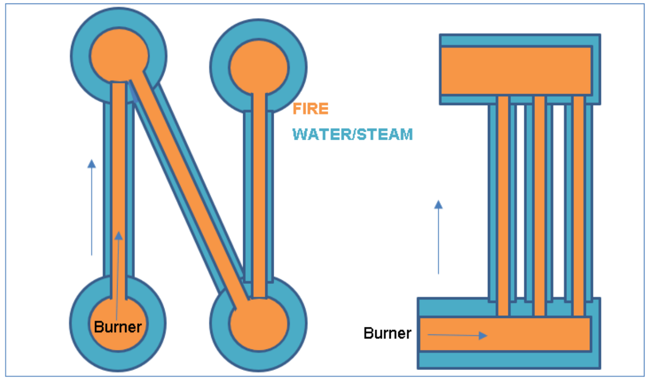
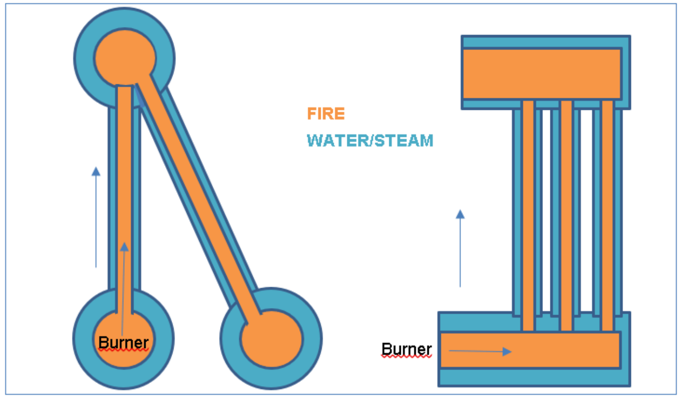
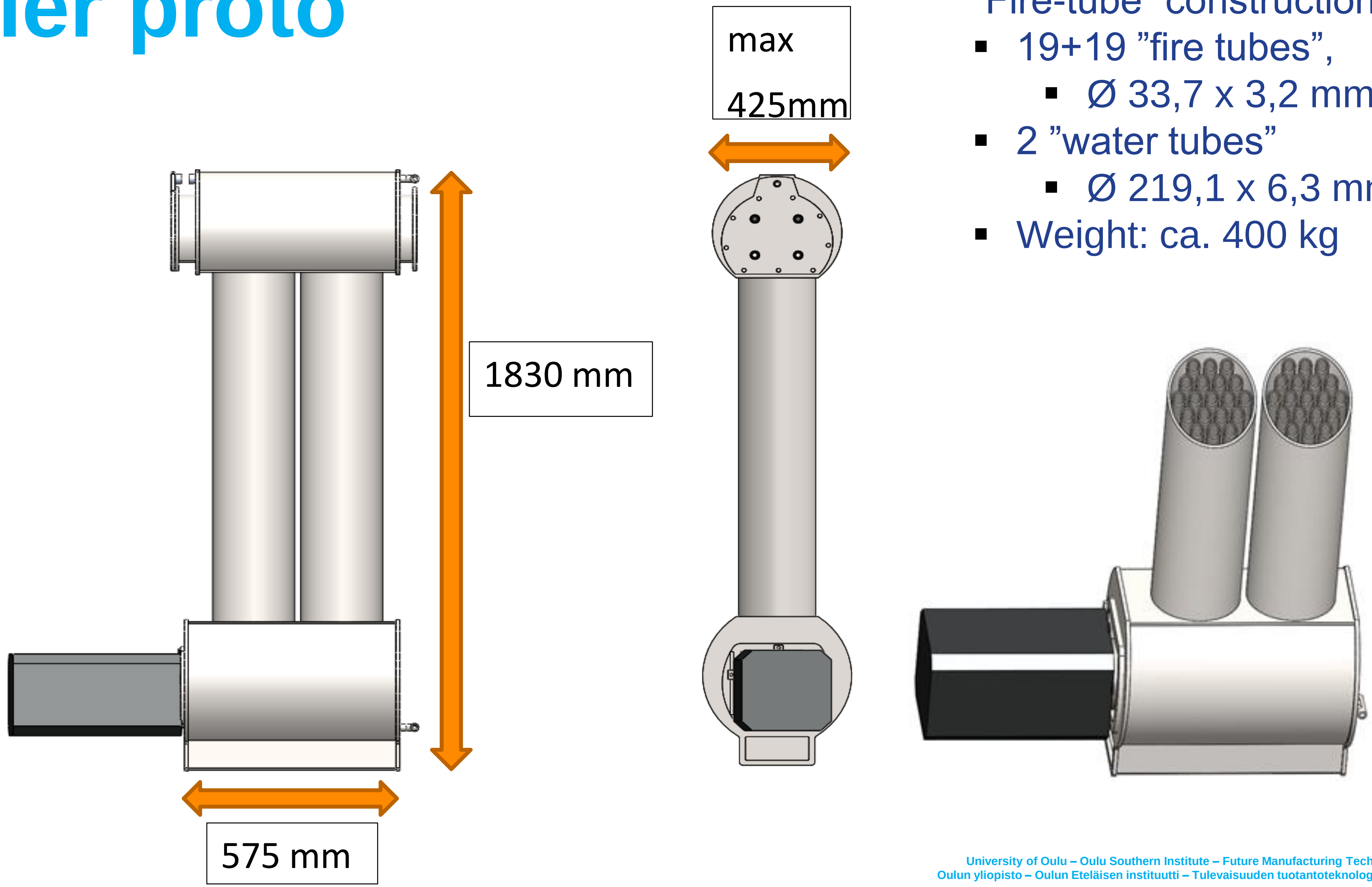
Brainstorming / Concept planning of steam boiler







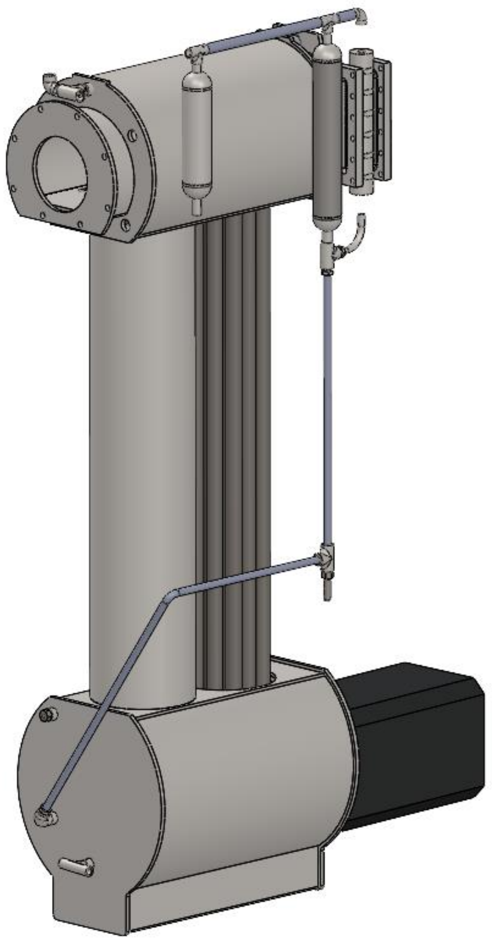
Boiler proto



”Fire-tube” construction

- 19+19 ”fire tubes”,
  - Ø 33,7 x 3,2 mm
- 2 ”water tubes”
  - Ø 219,1 x 6,3 mm
- Weight: ca. 400 kg

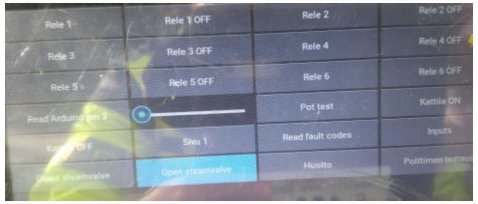
Boiler proto – accessories assembled



- Pellet burner
- Water droplet separator
- Water level regulator and sight glass
- Safety valve
- Chimney

What else is needed for Steam CHP

- **Power electronics**
  - Inverter
  - battery back
- **Control system and user interface**
- **Hot water storage tank (for excess heat)**
- **Fuel silo**



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And of course programming

- The main program is on Raspberry Pi contains…
  - …over 1000 lines of code
  - contains only the user interface and most of the boiler control logic
  - Rasperry also has several monitoring and control sub programs.
- In addition, there are programs on separate microprocessors e.g. for valve control and io control.

```
def kattilan_vedenpinnan_seuranta(a):
        if(read_reserve_water_level(1) != 0):#!= 1
                if "Water reserve too low" not in fault_list:
                        update_fault_codes("Water reserve too low")
                return
        paineakun_paine = read_paineakku_paine(1)
        #print paineakun_paine
        if(paineakun_paine < 16.0):
                print("Adding pressure to paineakku")
                kattila_painepumppu_ON(1)
                #Clock.schedule_once(kattilan_vedenpinnan_seuranta, 0.1)
        elif(paineakun_paine > 18.0):
                kattila_painepumppu_OFF(1)
        if(GPIO.input(kattila_vedenpinta_alarajaPin) == 1):
                relestate[vedenlisays_valve_rele] = 1
        if(GPIO.input(kattila_vedenpinta_ylarajaPin) == 1):
                relestate[vedenlisays_valve_rele] = 0
def start_steam_engine(a):
        if(ce == 0):
                print("Höyrymoottorin käynnistys...")
                if(engine_started == 0):
                        steamvalve_position(50)
                        if(read_steamvalve_position(1) > 48):
```

Thank you for your kind attention!

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