Future Circular Collider
Technical Infrastructure

Cooling update for FCC

I. Martin Melero (EN/CV)

FCC Week 2025

Outline

- 0. Definitions
- 1. Update on thermal loads
    - 1.1. Cooling towers
    - 1.2. Operation modes
    - 1.3. Chillers
    - 1.4. Demineralised water
- 2. Update on cooling towers
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    - 2.3. Water-air coolers
    - 2.4. CO_2 heat recovery
- 3. Update on water supply
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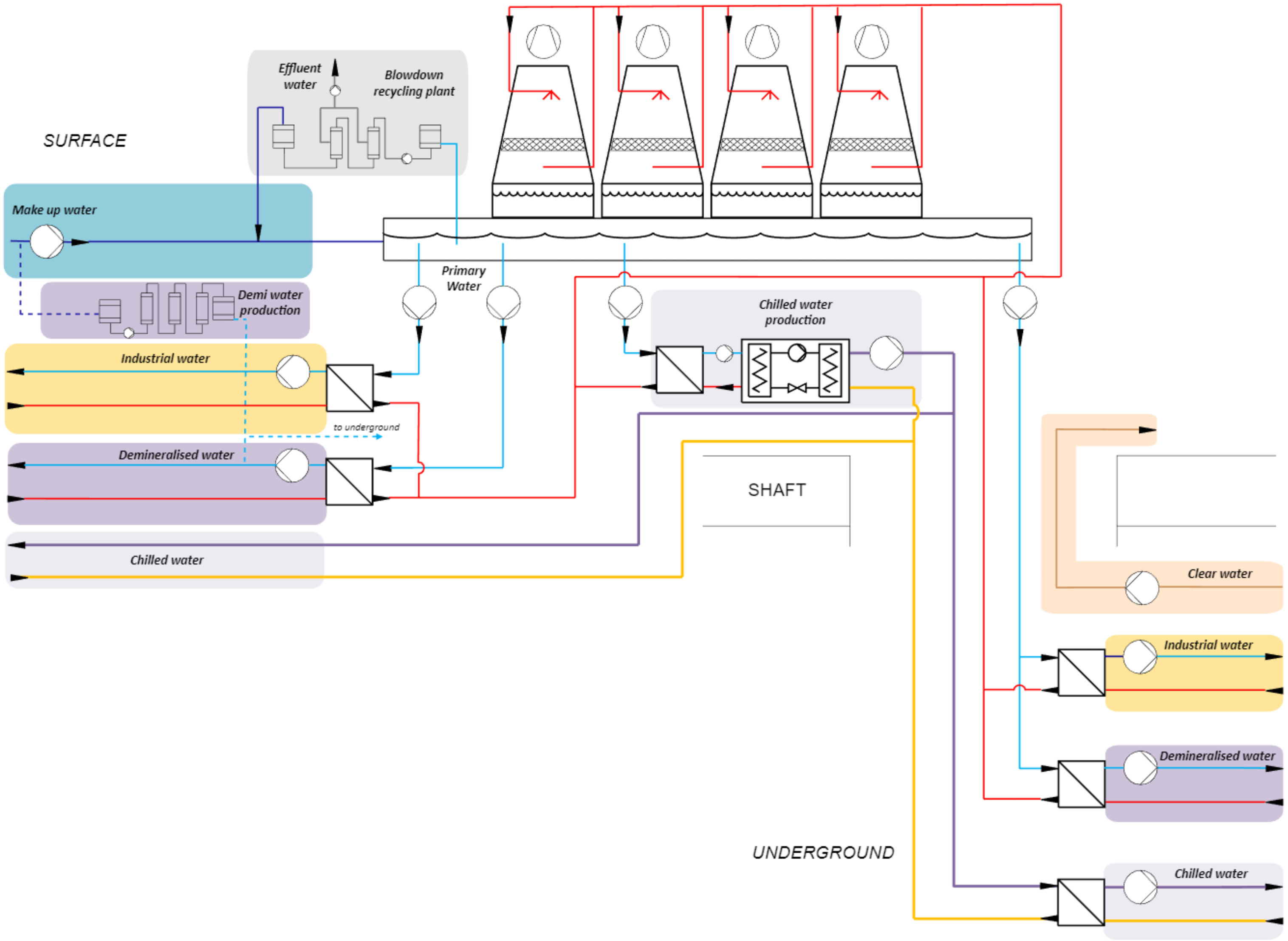
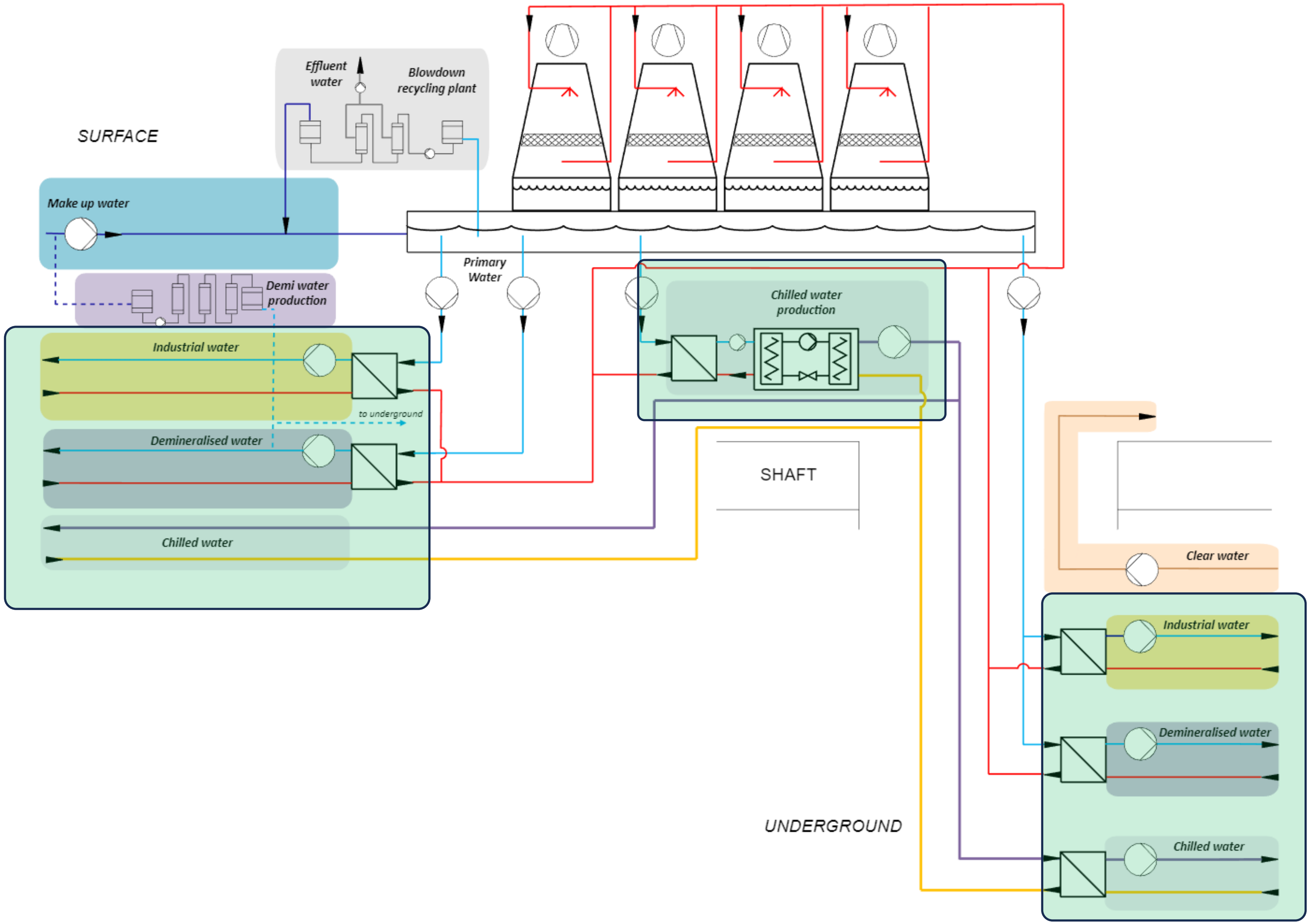
    - 3.2. Synergies
- 4. Update on disposal
    - 4.1. Blowdown recycling
    - 4.2. Effluent centralization
    - 4.3. ZLD technology
- 5. Next steps

0. Definitions



- Primary water → transfers heat load from subcircuits to cooling towers
- Make-up water → compensates losses in cooling towers and is used to produce demineralised water
- Demineralised water → cools sensible equipment like magnets or SR absorbers
    - Chilled water → produced at chillers, dissipates heat load from air in AHUs, fancoils
    - Industrial water → same quality as primary water, cools equipment like cryogenics
    - Clear water → evacuated from infiltrations and drains
    - Effluent water → byproduct of blowdown recycling, high salts concentration

1. Update on thermal loads



1. Update on thermal loads *Cooling towers, ttbar*

Heat loads (MW) at Cooling Towers, FCC-ee ttbar

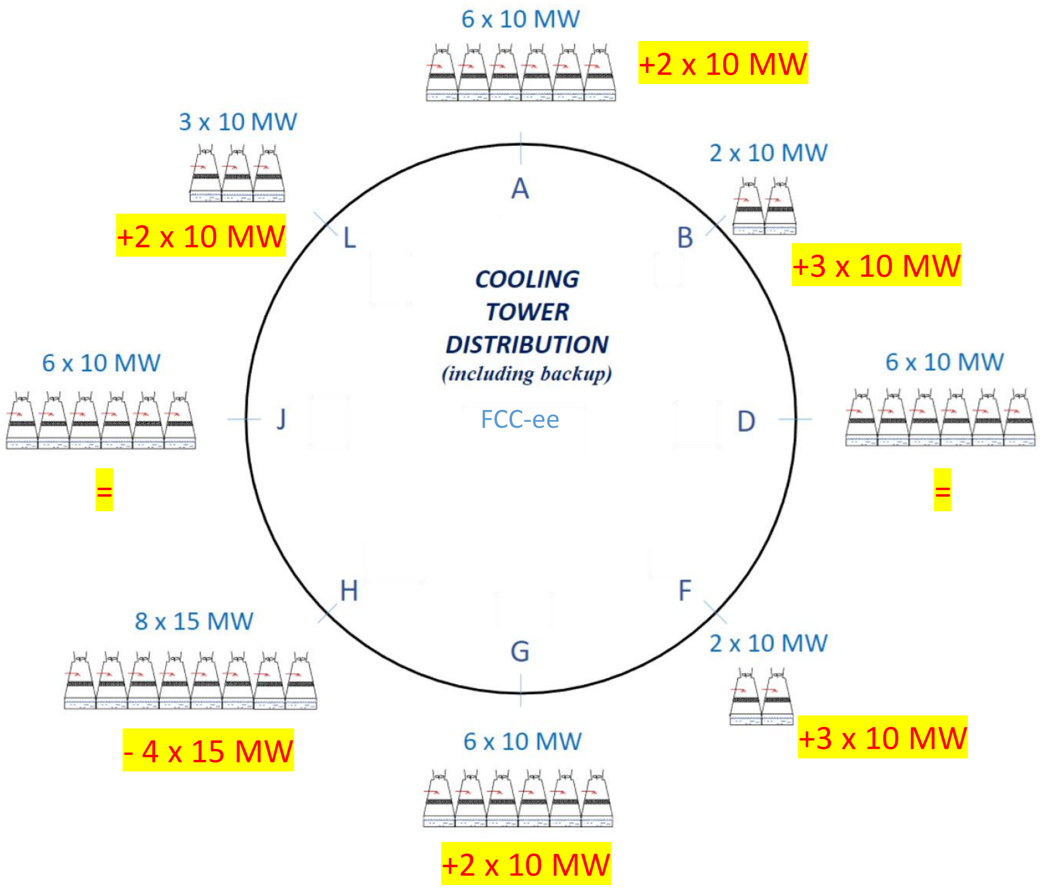
Point	Cryogenics	Experiment	General Services	Power converters RF	Chilled Water	Underground	TOTAL
A	0.35	0.50	2.00		5.87	42.56	**51**
B			2.00		5.18	1.05	**8**
D	0.35	0.50	2.00		5.84	42.56	**51**
F			2.00		5.18	1.05	**8**
G	0.35	0.50	2.00		5.87	42.56	**51**
H	34.00		2.00	4.50	11.24	48.95	**100**
J	0.35	0.50	2.00		5.84	42.56	**51**
L	10.00		2.00	0.07	5.71	2.74	**20**

Heat loads (MW) at Cooling Towers, FCC-hh

Point	Cryogenics	Experiment	General Services	Power converters	Chilled Water	Underground	TOTAL
A	42.00	10.50	2.00	0.14	5.87	6.16	**67**
B	29.00		2.00	0.14	5.87	2.00	**39**
D	32.00	6.50	2.00	0.14	5.87	5.46	**52**
F	29.00		2.00	0.14	5.87	2.00	**39**
G	42.00	10.50	2.00	0.14	5.87	6.16	**67**
H	32.00		2.00	0.14	5.87	2.00	**42**
J	32.00	6.50	2.00	0.14	5.87	5.46	**52**
L	29.00		2.00	0.14	5.87	2.00	**39**

Cooling towers for FCC-ee ttbar

Changes for FCC-hh



1. Update on thermal loads *Operation modes*

Total heat loads (MW) at Cooling Towers, FCC-ee, mode of operation

Point	Z	W	H	ttbar
A	31	34	38	51
B	3	4	5	8
D	31	34	38	51
F	3	4	5	8
G	31	34	38	51
H	51	65	69	100
J	31	34	38	51
L	4	8	10	20

Mode Z → 4 years
Mode W → 2 years
Mode H → 3 years
Mode ttbar → 5 years

SD → Shutdown 17 weeks
com → beam commissioning 4 weeks
OP → Operation 20 weeks
DT → Downtime 6 weeks
TS → Technical Stop 2 weeks
MD → Machine Development 3 weeks

Total heat loads (MW) at Cooling Towers, FCC-ee, operation throughout year

Point	Z						W						H						ttbar					
	SD	com	OP	DT	TS	MD	SD	com	OP	DT	TS	MD	SD	com	OP	DT	TS	MD	SD	com	OP	DT	TS	MD
A	2.1	20.4	**31.4**	5.3	5.3	13.6	2.3	23.2	**34.1**	6.2	6.2	16.2	2.3	24.6	**38.9**	7.0	7.0	21.1	2.5	32.6	**51.3**	10.3	10.3	32.1
B	0.0	2.1	**3.2**	1.0	1.0	3.3	0.0	2.8	**3.8**	1.2	1.2	3.8	0.0	3.6	**4.7**	1.9	1.9	4.7	0.2	4.6	**8.2**	3.1	3.1	7.0
D	2.1	20.4	**31.4**	5.3	5.3	13.6	2.3	23.2	**34.1**	6.2	6.2	16.2	2.3	24.6	**38.9**	7.0	7.0	21.1	2.5	32.6	**51.3**	10.3	10.3	32.1
F	0.0	2.1	**3.2**	1.0	1.0	3.3	0.0	2.8	**3.8**	1.2	1.2	3.8	0.0	3.6	**4.7**	1.9	1.9	4.7	0.2	4.6	**8.2**	3.1	3.1	7.0
G	2.1	20.4	**31.4**	5.3	5.3	13.6	2.3	23.2	**34.1**	6.2	6.2	16.2	2.3	24.6	**38.9**	7.0	7.0	21.1	2.5	32.6	**51.3**	10.3	10.3	32.1
H	0.5	33.2	**51.6**	7.9	7.9	22.2	0.5	42.8	**65.8**	21.7	21.7	36.5	0.5	47.3	**69.7**	24.2	24.2	40.3	0.7	66.4	**100.7**	54.6	54.6	72.6
J	2.1	20.4	**31.4**	5.3	5.3	13.6	2.3	23.2	**34.1**	6.2	6.2	16.2	2.3	24.6	**38.9**	7.0	7.0	21.1	2.5	32.6	**51.3**	10.3	10.3	32.1
L	0.2	2.8	**4.3**	3.4	3.4	3.9	0.2	5.8	**8.3**	7.0	7.0	7.8	0.2	6.8	**9.7**	8.0	8.0	9.2	0.3	12.4	**20.5**	15.3	15.3	18.6

1. Update on thermal loads *Chillers*

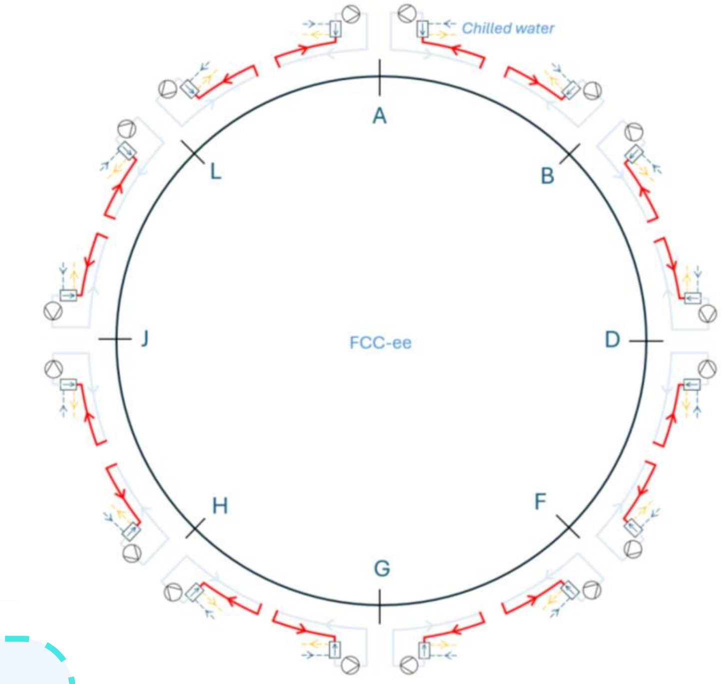
More info:

I. Martin Melero @ Session TIWG 5

Chillers, FCC-ee ttbar

Point	Cooling power (kW)	Flow rate (m^3/h)	Number of chillers	Cooling power / chiller (kW)	TOTAL (kW)
A	4,895	703	6	1,000	**6,000**
B	4,322	620	6	900	**5,400**
D	4,875	700	6	1,000	**6,000**
F	4,322	620	6	900	**5,400**
G	4,895	703	6	1,000	**6,000**
H	9,367	1345	7	1,800	**12,600**
J	4,875	700	6	1,000	**6,000**
L	4,757	683	6	1,000	**6,000**

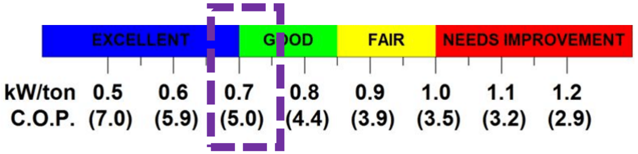
Chilled water requirements

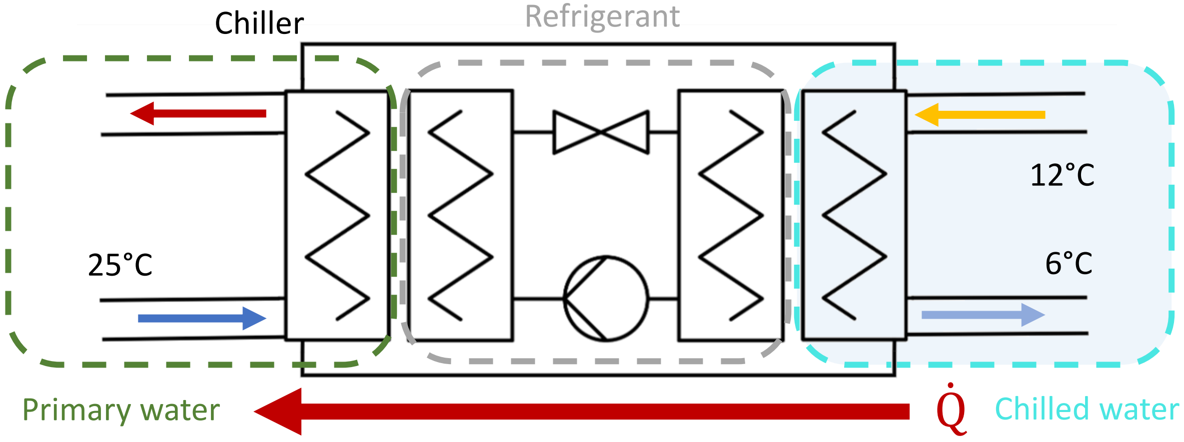


Increase in chillers due to cable load Tunnel

Primary water requirements in Table p. 5

COP ≈ 5



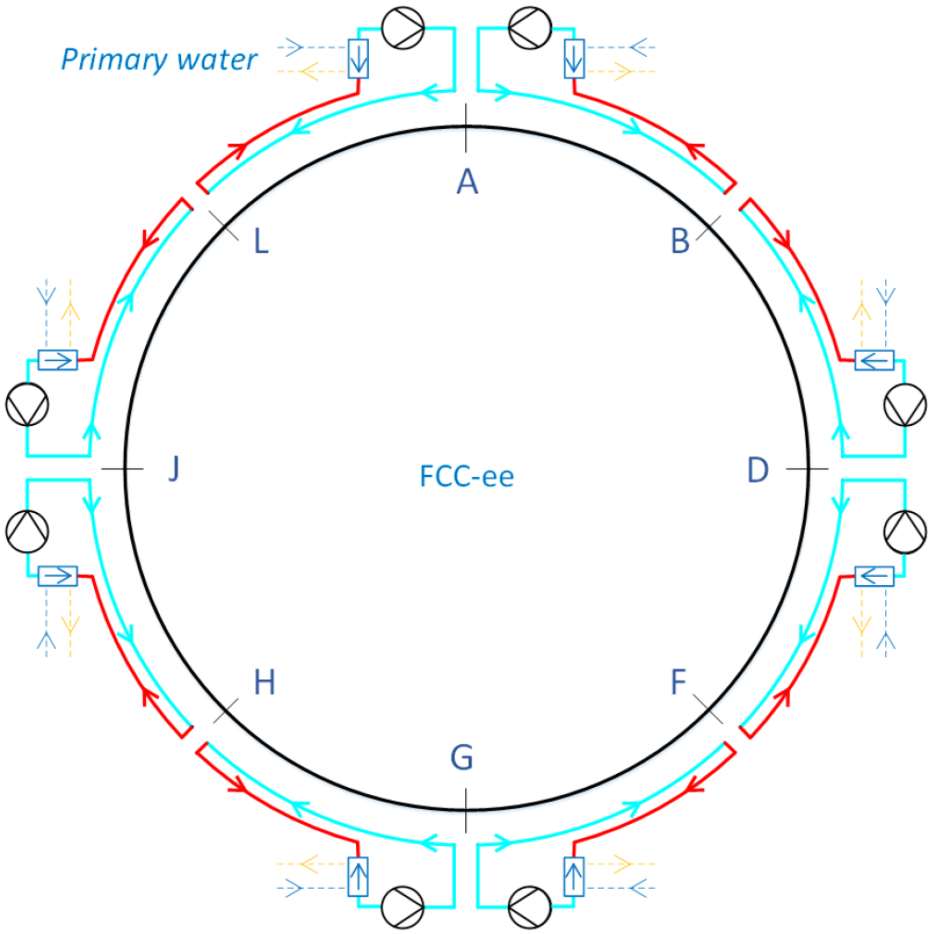


1. Update on thermal loads *Demineralised water*

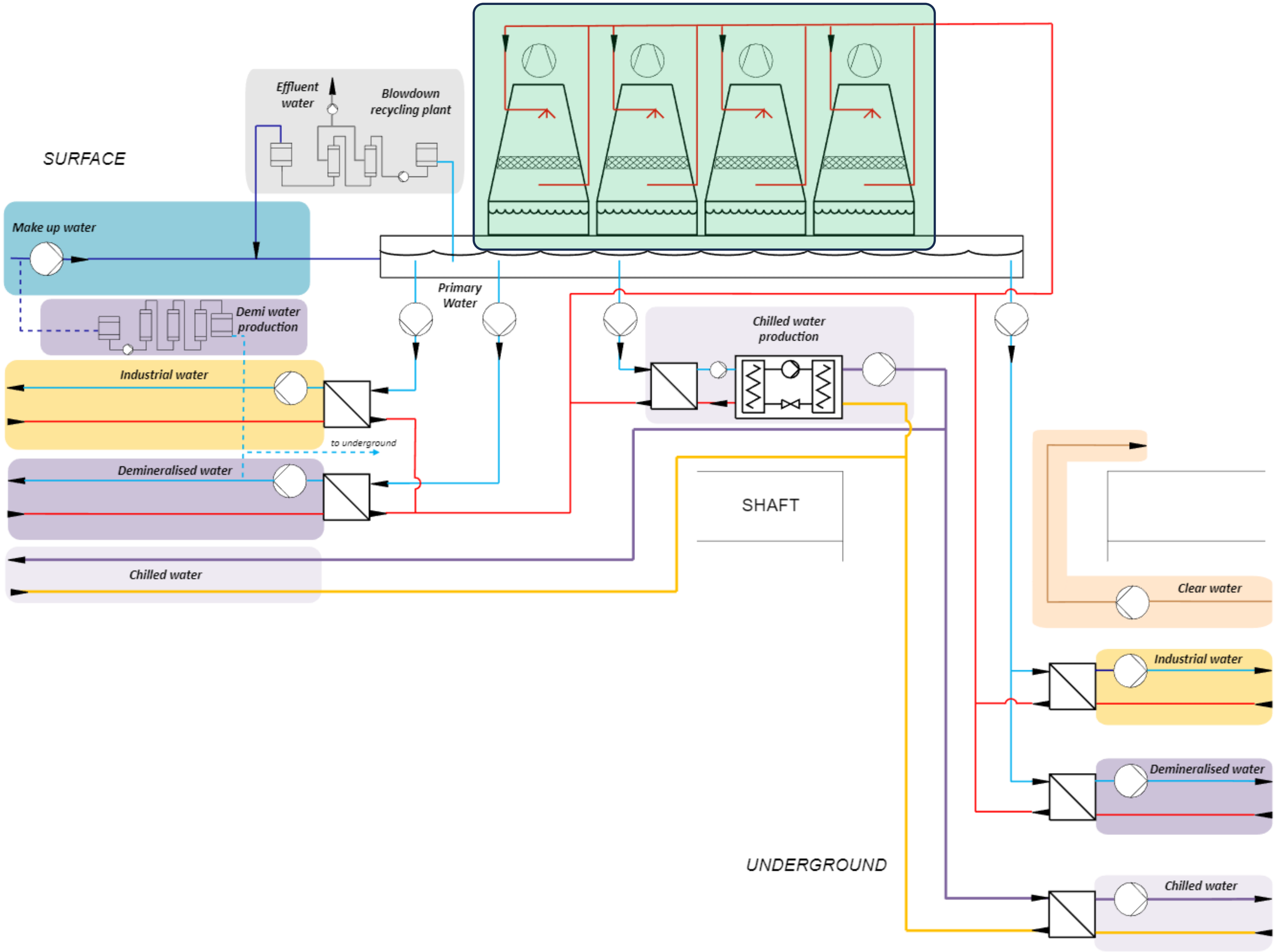
Heat loads (MW) of Demineralised Water, FCC-ee ttbar

Location	Magnets	Alcoves	SR Absorbers	Detectors	Power converters accelerator	RF underground	Cryogenics*	Underground TOTAL
L-A	7.1	0.9	12.5					
A				0.5	1.05		0.01	**42.56**
A-B	7.1	0.9	12.5					
B					1.05			**1.05**
B-D	7.1	0.9	12.5					
D				0.5	1.05		0.01	**42.56**
D-F	7.1	0.9	12.5					
F					1.05			**1.05**
F-G	7.1	0.9	12.5					
G				0.5	1.05		0.01	**42.56**
G-H	7.1	0.9	12.5					
H					1.05	45.7	2.2	**50.95**
H-J	7.1	0.9	12.5					
J				0.5	1.05		0.01	**42.56**
J-L	7.1	0.9	12.5					
L					1.05	0.69	1.0	**2.74**

*Cryogenic equipment is cooled with Industrial water

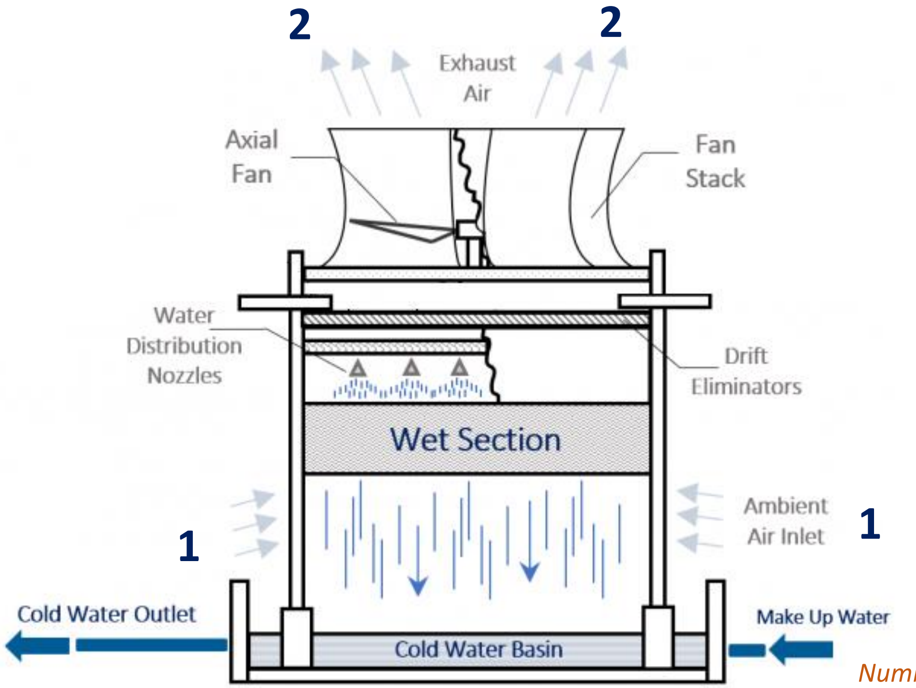


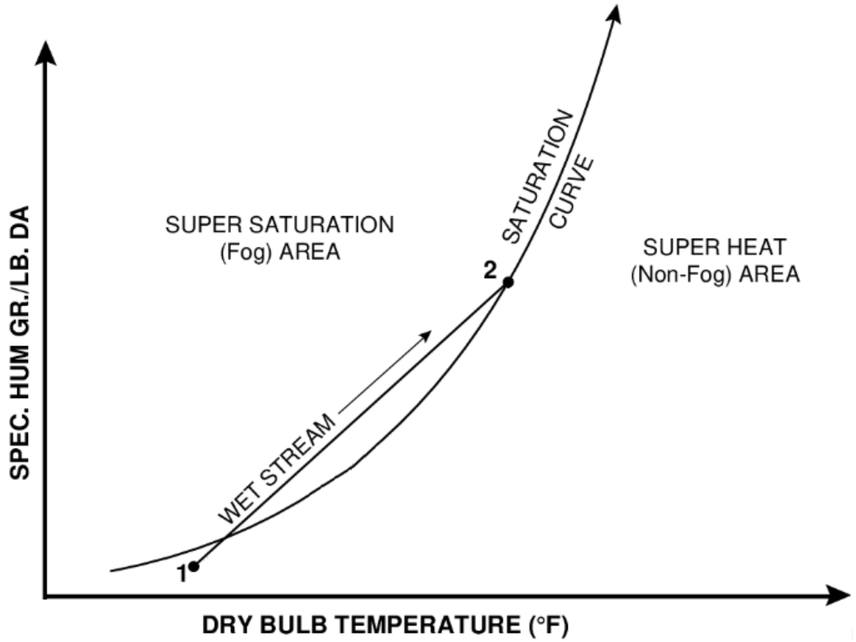
2. Update on cooling towers



2. Update on cooling towers *Wet cooling towers*

Baseline: wet cooling towers





Numbers under study

Point	Make-up water needs (m^3/h)*	Water cost (CHF/y)**	Dimensions (L x W x H)	Construction cost (CHF)
Exp., A	94	307.000	60 x 11 x 12	1.500.000
Tech., B	13	42.000	20 x 11 x 12	300.000
RF, H	192	610.000	104 x 12 x 12	2.600.000
RF, L	36	114.000	30 x 11 x 12	600.000

*For ttbar mode, nominal **Considering annual operation profile, and 0.7 CHF/m^3

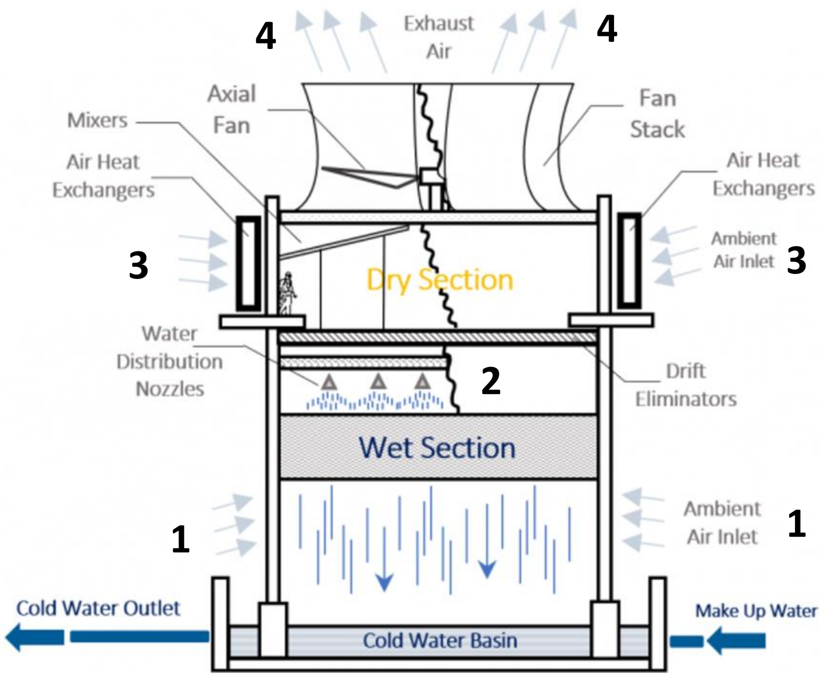
Technically feasible, but…

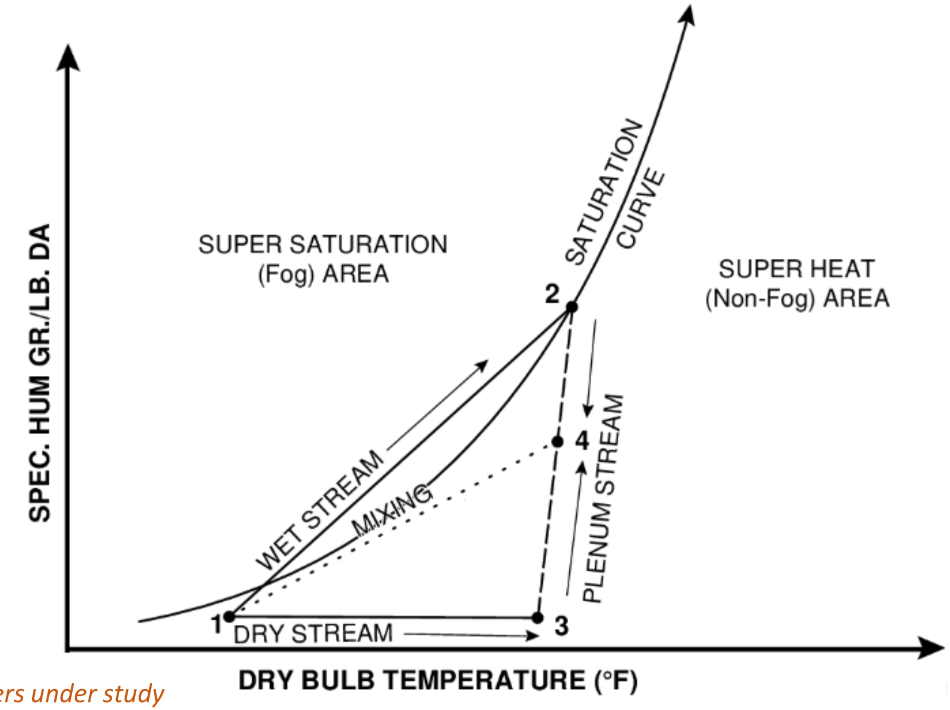
- Visibility of plume → social acceptability
- Higher water consumption → environmental impact

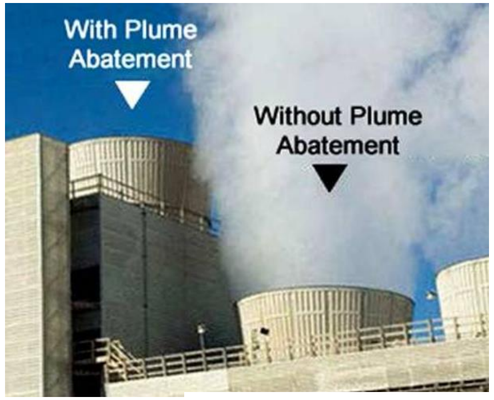
2. Update on cooling towers

Hybrid cooling towers

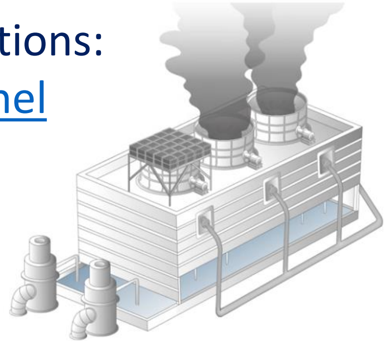
Alternative: hybrid cooling towers







Other options:
WaterPanel



Numbers under study

Point	Make-up water needs (m^3/h)*	Water cost (CHF/y)**	Dimensions (L x W x H)	Construction cost (CHF)
Exp., A	75	248.000	60 x 11 x 15	4.500.000
Tech., B	11	35.000	20 x 11 x 15	1.000.000
RF, H	154	509.000	104 x 12 x 15	7.400.000
RF, L	29	95.000	30 x 11 x 15	1.800.000

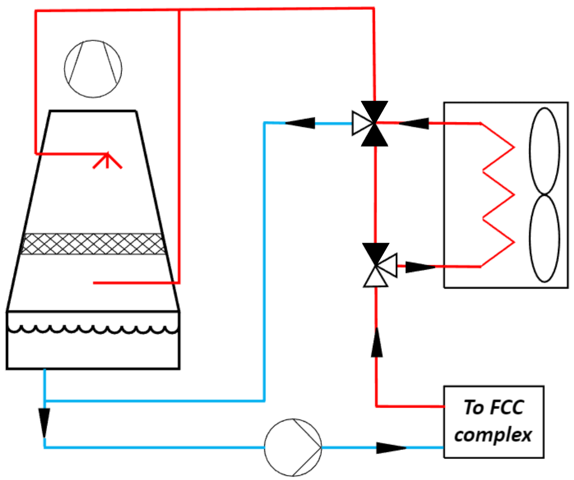
*For ttbar mode, nominal **Considering annual operation profile, and 0.7 CHF/m^3

Design basis → 15% dry section (rejected in air HEX)
Plume abatement
Water needs, water cost ⬇
Dimensions ≈
Construction cost ⬆

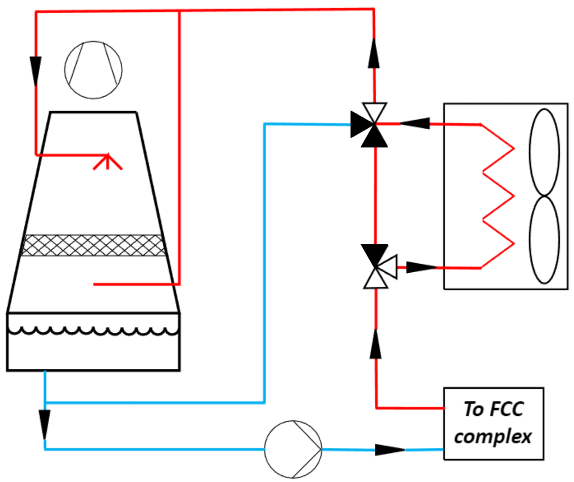
2. Update on cooling towers *Water-air coolers*

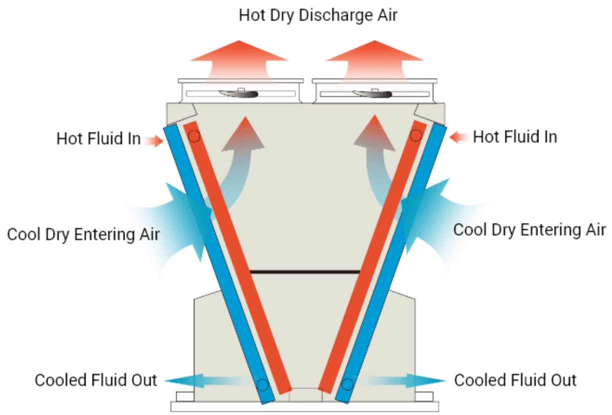
Alternative: water-air coolers

Operation, winter shutdown



Operation, rest of year





Numbers under study

Point	Water savings (CHF/y)*	Dimensions of dry part (L x W x H)	Additional construction cost (CHF)
Exp., A	17.000	32 x 18 x 11	1.120.000
Tech., B	2.000	10 x 8 x 5	210.000
RF, H	4.000	15 x 11 x 7	380.000
RF, L	2.000	6 x 8 x 4	170.000

***For ttbar mode, nominal, considering annual operation profile, and 0.7 CHF/m³**

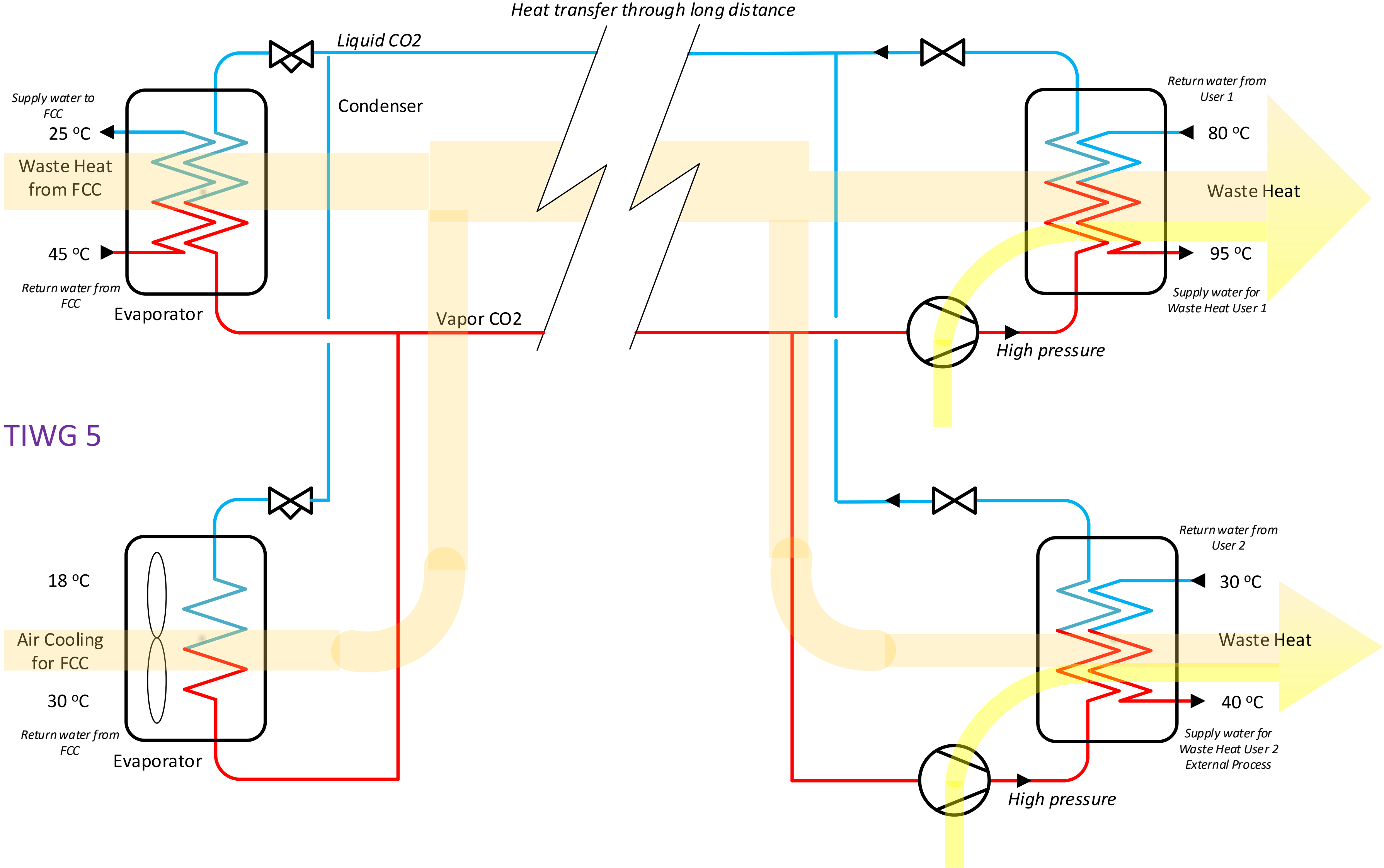
Water-air coolers dimensioned for shutdown winter load

Water needs, water cost ⬇
Winter operation only with dry side → maintenance of cooling towers

Dimensions ⬆
Construction cost ⬆
Electric consumption ⬆
Noise

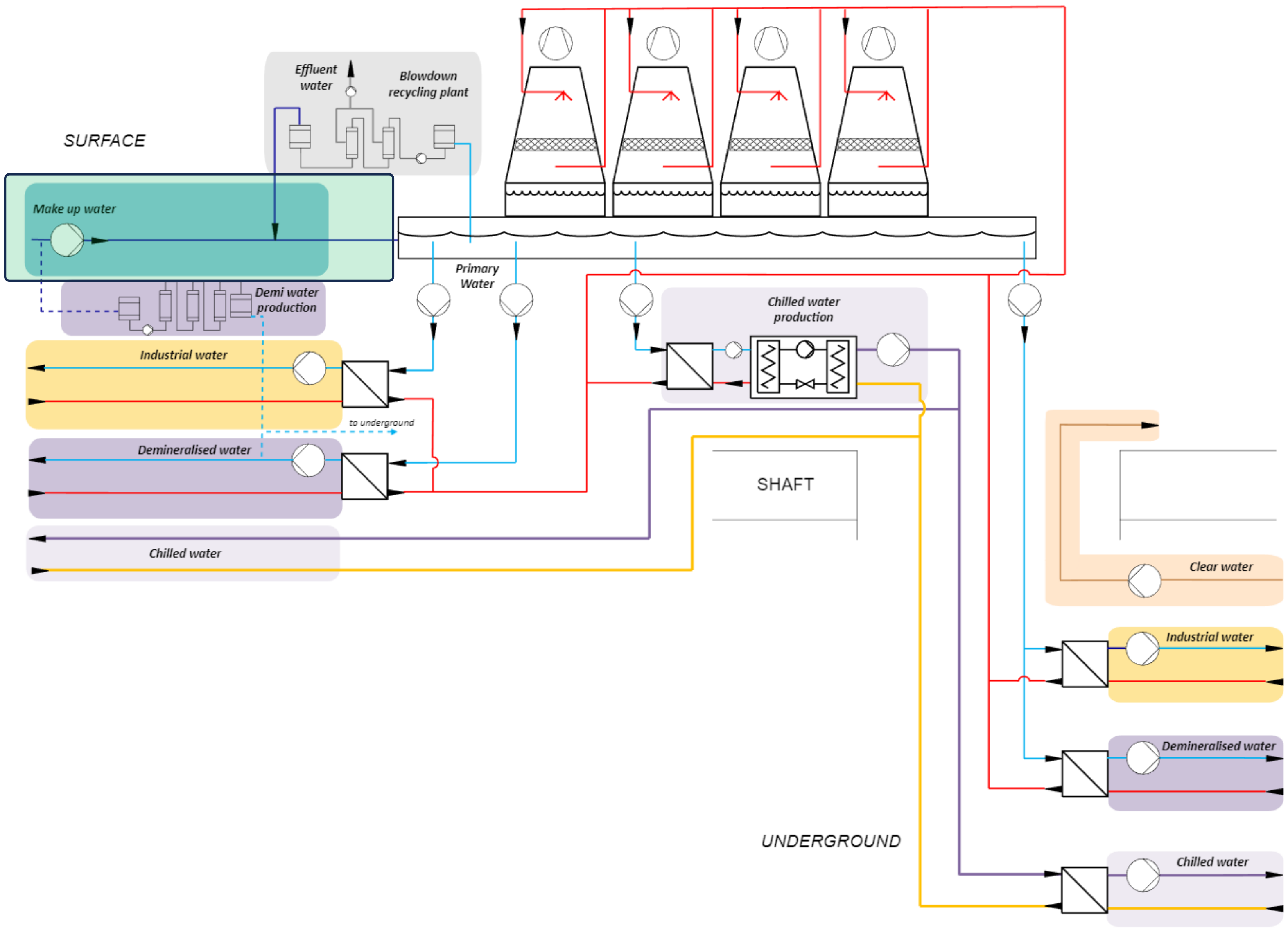
2. Update on cooling towers *CO_2 heat recovery*

Alternative: CO_2 heat recovery



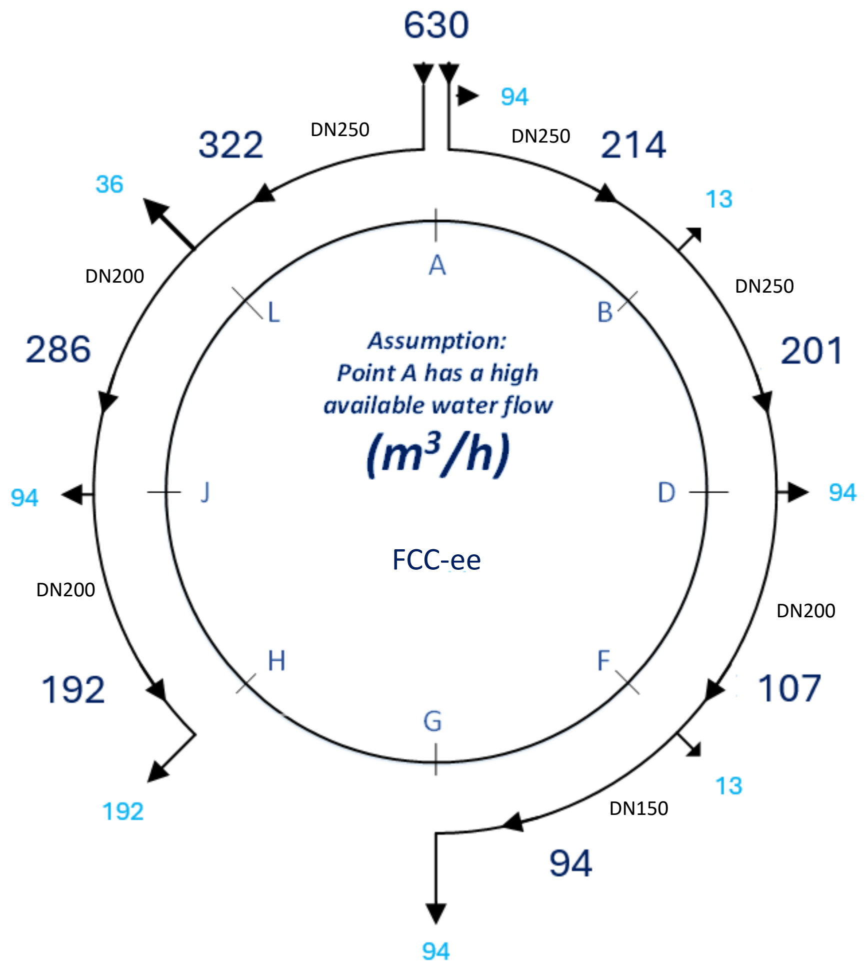
More info:
A. Hafner @ Session TIWG 5

3. Update on water supply

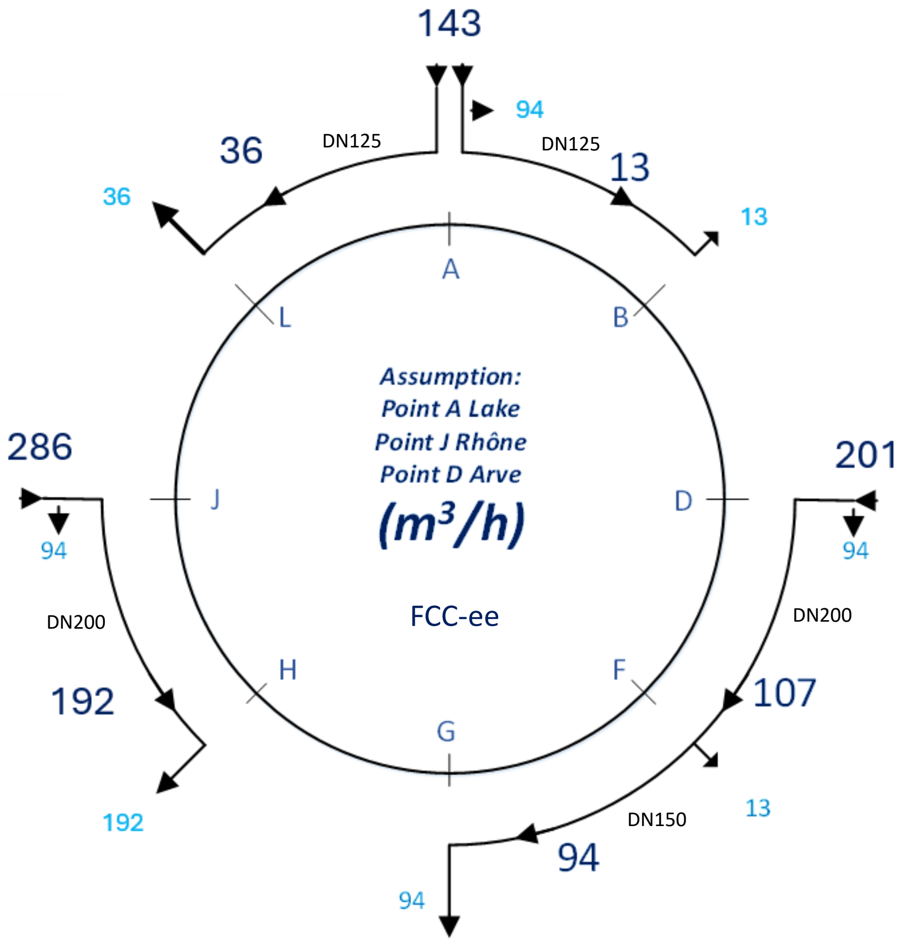


3. Update on water supply *Large water sources*

Baseline



Alternative



SECTORS: SUMMARY TABLE		
Pipe size	**No. of sectors for** ***1 entry point***	**No. of sectors for** ***3 entry points***
DN250	**3**	**0**
DN200	**3**	**2**
DN150	**1**	**1**
DN125	**0**	**2**

Baseline: larger pipes in Tunnel, higher cost of pipes in Tunnel

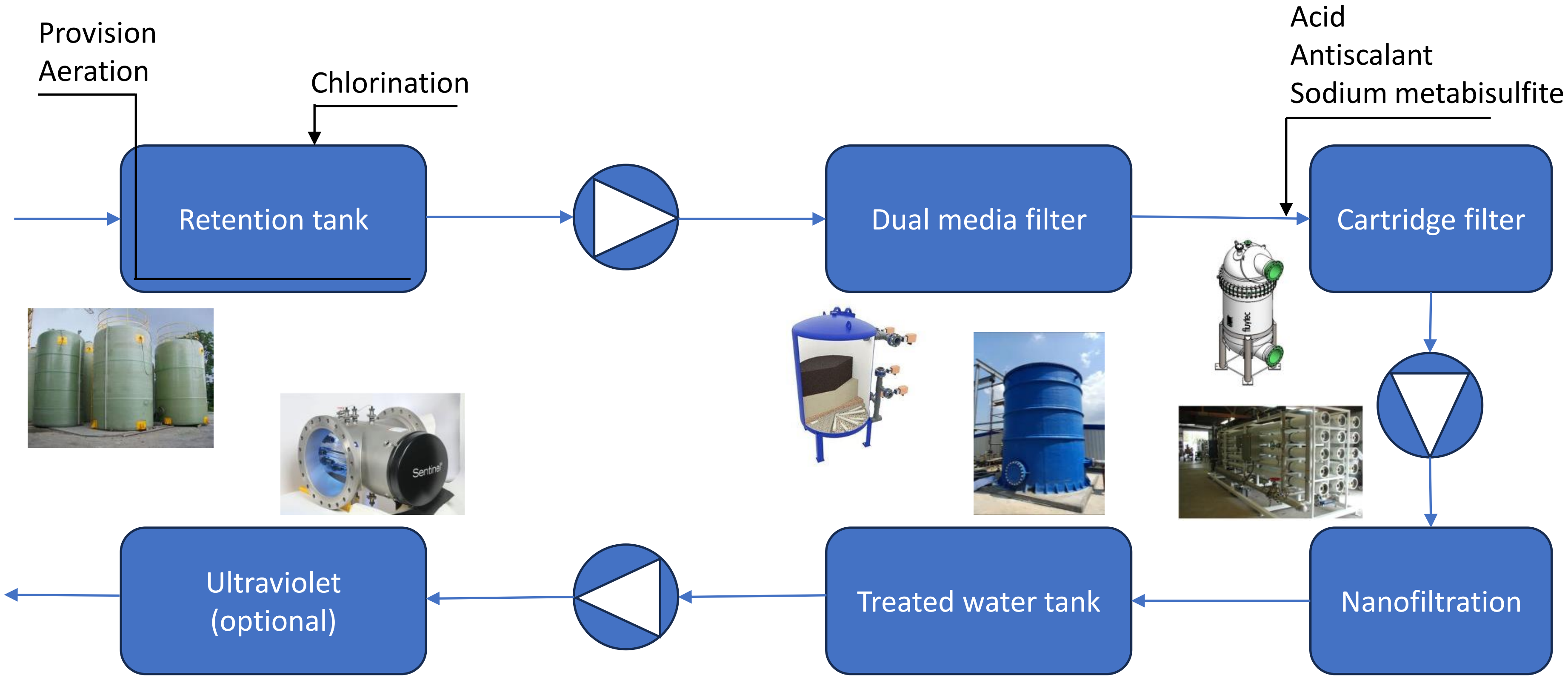
Alternative: smaller pipes in Tunnel, lower cost of pipes in Tunnel, interface between CERN and local water providers

Dimensioning with worst case between FCC-ee and FCC-hh

3. Update on water supply *Synergies*

Alternative: STP recovery at PD

STP Scientrier



Treatments:

Primary: oxidize sulfur, heavy metals and restrict chemical & biochemical oxygen demand growth

Secondary: reduction of total suspended solids (TSS)

Tertiaty: reduction of total dissolved solids (TDS)

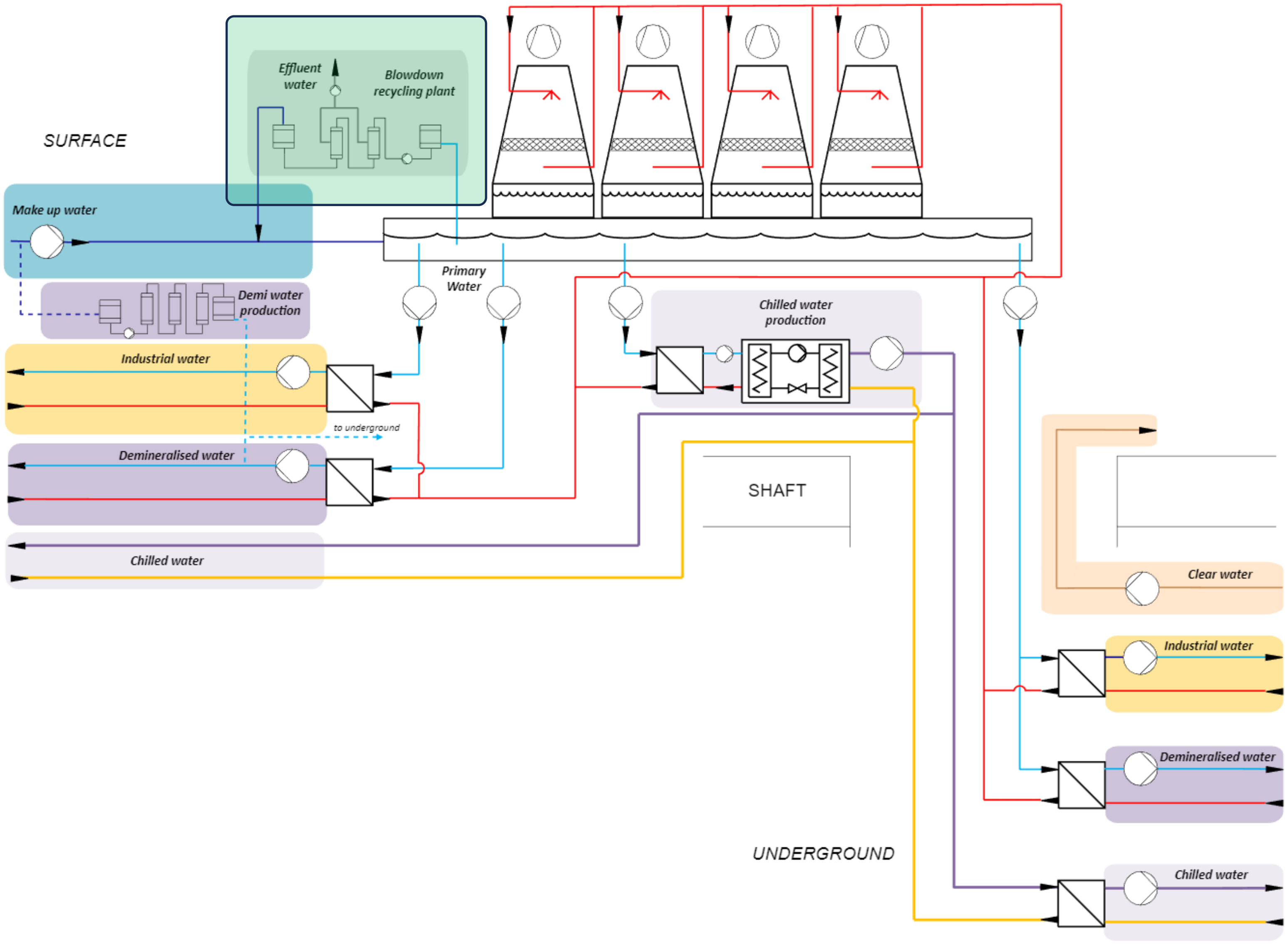
More info:
L. Alix @ Session Environment (I)

Option	Incoming water flow from STP (m^3/h)	Treated water to cooling towers (m^3/h)*	Dimensions (L x W)	Construction cost (CHF)**
1	200	160	39 x 57	1.690.000
2	500	400	60 x 65	3.630.000

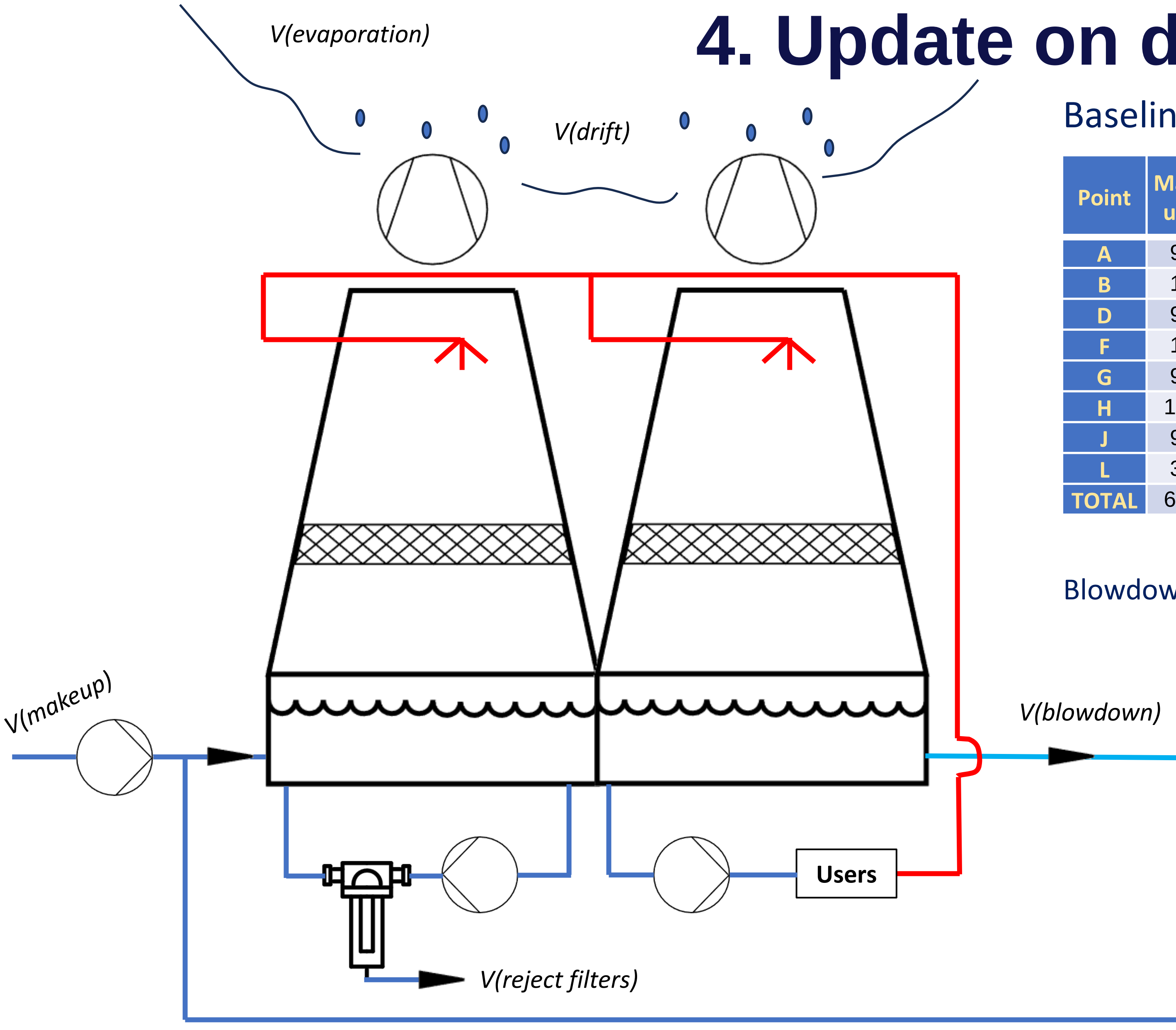
***Assuming a recovery of 80% in Nanofiltration**
****WITHOUT considering the piping between CERN ↔ recovery plant**

Numbers under study

4. Update on disposal



4. Update on disposal *Blowdown recycling*



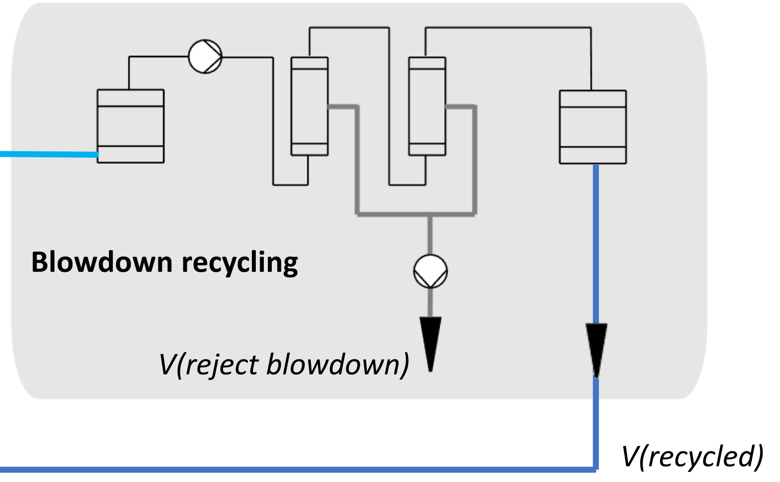
Baseline: Blowdown recycling

Numbers under study

Point	Make up*	Blowdown	Recycled	Reject (from blowdown)	Reject (from filters)	Drift	Evaporation
A	94	22	17	5.5	7.1	0.5	71
B	13	3	2	0.8	1.0	0.1	10
D	94	22	17	5.5	7.1	0.5	71
F	13	3	2	0.8	1.0	0.1	10
G	94	22	17	5.5	7.1	0.5	71
H	192	45	36	11.2	14.5	0.9	144
J	94	22	17	5.5	7.1	0.5	71
L	36	8	7	2.1	2.7	0.2	27
TOTAL	630	147	118	36.8	47.6	3.3	453

* *Including contingency*

Blowdown recycling ↓ Water consumption but… ↑ High TDS reject water



4. Update on disposal *Effluent centralization*

Baseline: Blowdown recycling

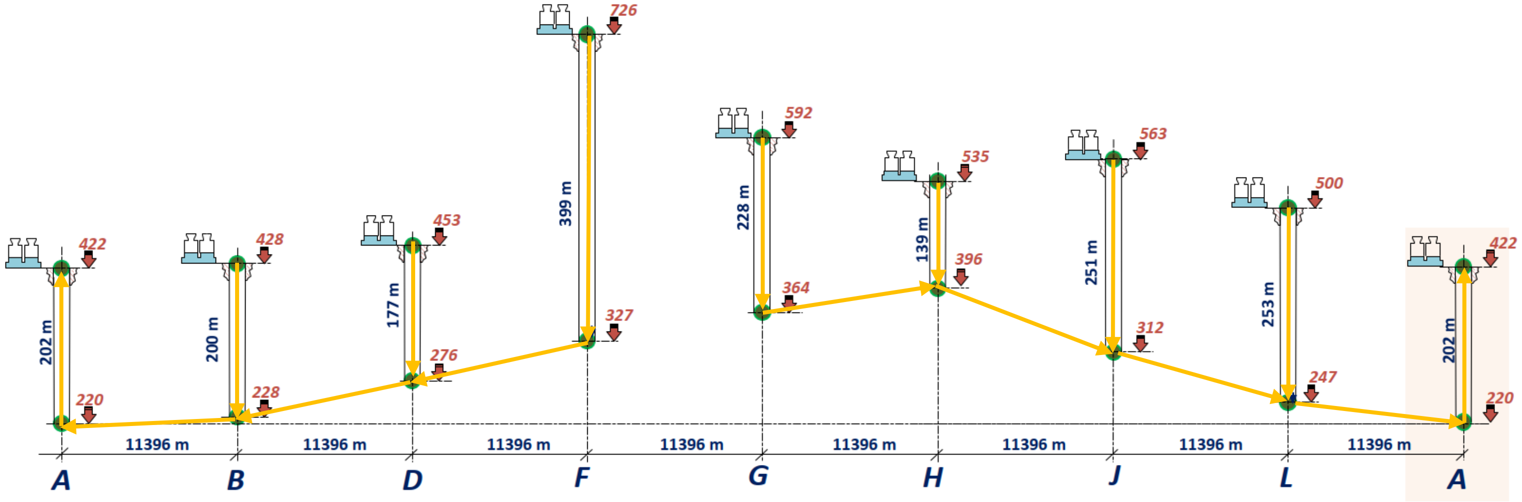
Difficulty of disposing rejects in local networks / water bodies
→ piping system to bring them back to PA

Reject from filters → high in TSS
- Disposal in local networks?
- Minimization through filter technology?

[Bernouilli self-cleaning filters]

- Joint disposal with blowdown recycling? → larger pipes in tunnel
- Specific disposal by trucks?

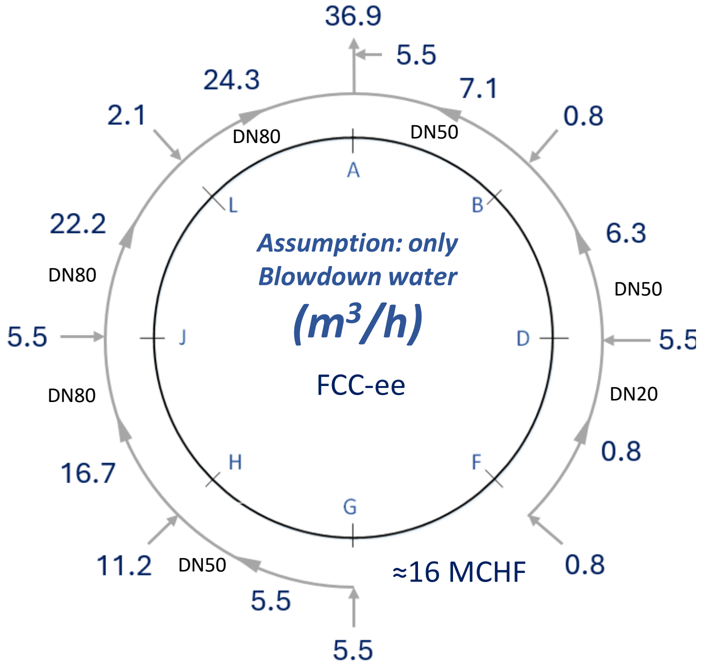
Reject from blowdown recycling → high in TDS
- Centralization of treatment in PA?
- Further concentrating?

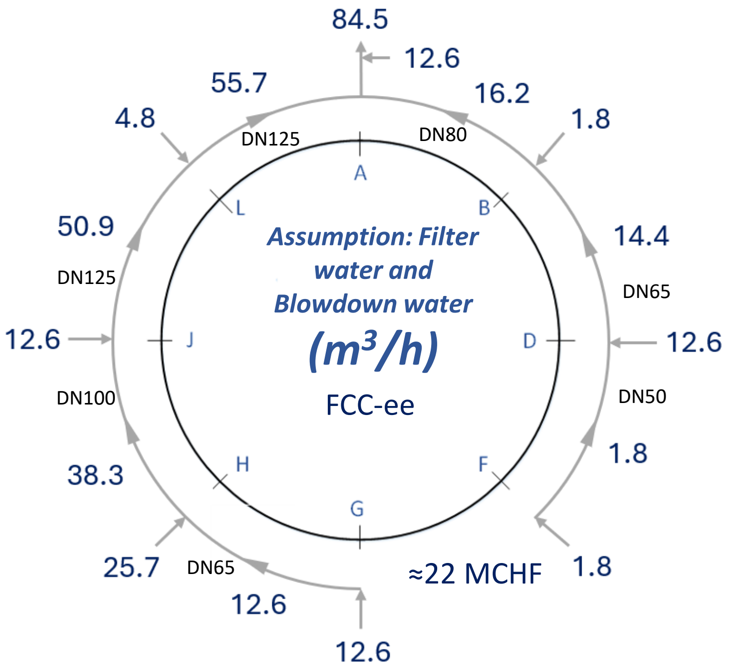


Numbers under study

Point	Dimensions (L x W x H)	Construction cost (CHF)	Chemicals cost (CHF/year)*	Piping cost (CHF)
Exp., A	30 x 10 x 5	580.000	6.000	22.000.000
Tech., B	20 x 10 x 5	100.000	1.000	
RF, H	60 x 15 x 5	1.150.000	12.000	
RF, L	30 x 10 x 5	500.000	5.000	

*Excluding chemicals cost of centralized treatment at PA





4. Update on disposal *ZLD technology*

Alternative: Zero Liquid Discharge

Difficulty of disposing rejects in local networks / water bodies
→ Avoid production of any liquid waste

- Pretreatment: Lime softening
- Filtration: Dual media filter
- Membrane filtration: Reverse osmosis
- Evaporation: Mechanical vapor recompression
- Crystallization: Forced circulation crystallizers

Main ZLD plants → Points A, D, G, J, H
Points B, F, L transport mid-product to final treatment in another Point

- From Point B: 21 trucks / year*
- From Point F: 21 trucks / year*
- From Point L: 46 trucks / year*

*Considering nominal run at ttbar during all year (conservative)

24 m^3 truck

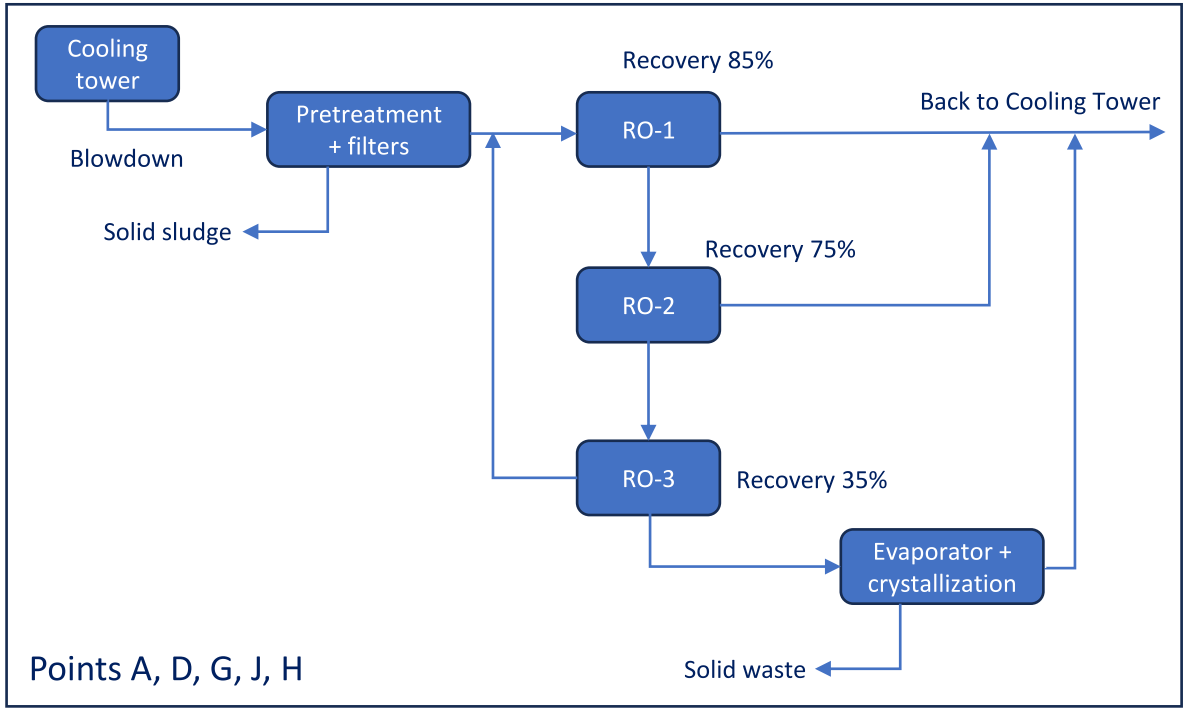
Point	Dimensions (L x W x H)	Construction cost (CHF)	Chemicals cost (CHF/year)
Exp., A	34 x 33 x 5	1.800.000	610.000
Tech., B	35 x 23 x 5	405.000	97.000
RF, H	41 x 36 x 5	2.050.000	1.270.000
RF, L	35 x 23 x 5	440.000	234.000

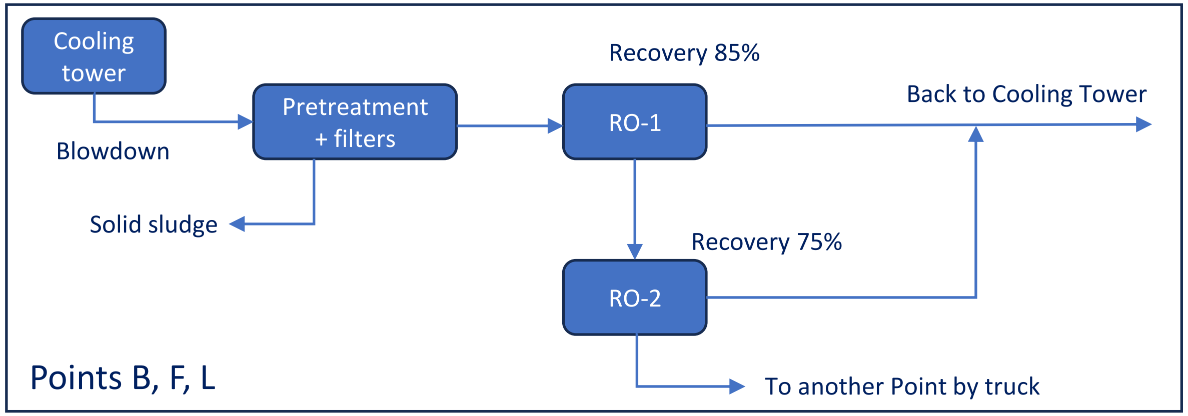
~~Central piping to PA~~

Dimensions ⬆
Construction cost ⬆
Chemical cost ⬆

Numbers under study

Transport of disposal of solid salts?





5. Next steps

- Interact with the rest of departments and exchange information: heat loads, pipes integration, sustainability considerations…
- Further iterate the design level of the cooling circuits
- Decide on the technology of the cooling tower
- Determine the water supply strategy
- Select the disposal option for implementation
- Proceed with the preTDR tasks defined for the cooling part

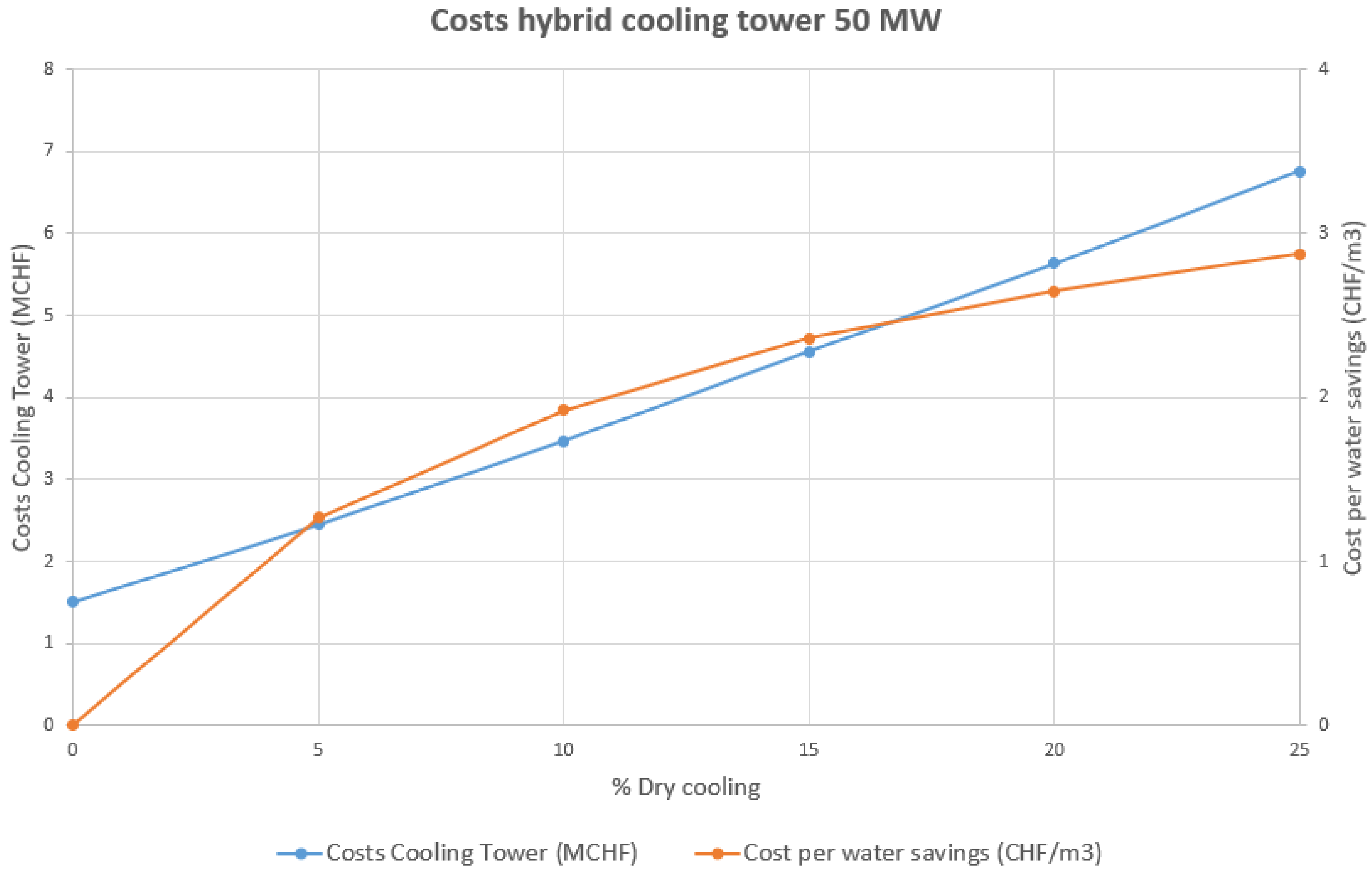
Thank you
for your attention.

SPARES

2. Update on cooling towers *Dry section design*

Alternative: hybrid cooling towers

Why 15% dry section? Optimisation process



Complete plume abatement → ~ 10% heat dissipated in air HEX.

Values for <u>one Experimental Point</u>, 50 MW

% dry section	Make-up water needs (m^3/h)*	Water saved in 15 years (m^3)	Construction cost (CHF)	Visual plume
0	94	0	1.500.000	YES
5	86	740.000	2.400.000	PARTIAL
10	80	1.000.000	3.400.000	NO
15	75	1.300.000	4.500.000	NO
20	71	1.500.000	5.600.000	NO
25	66	1.800.000	6.700.000	NO

Numbers under study

2. Update on cooling towers *Design T_{wb}*

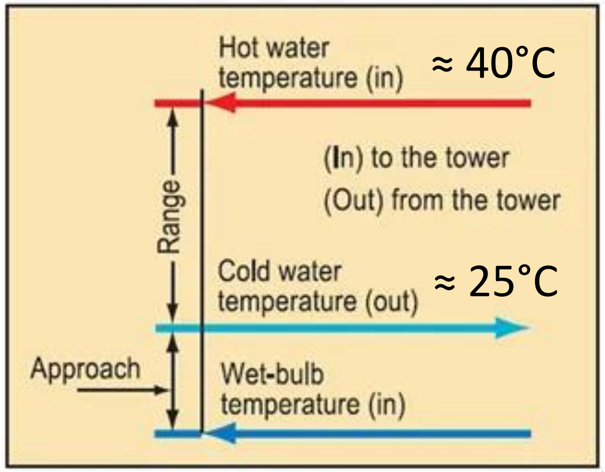
Climate change

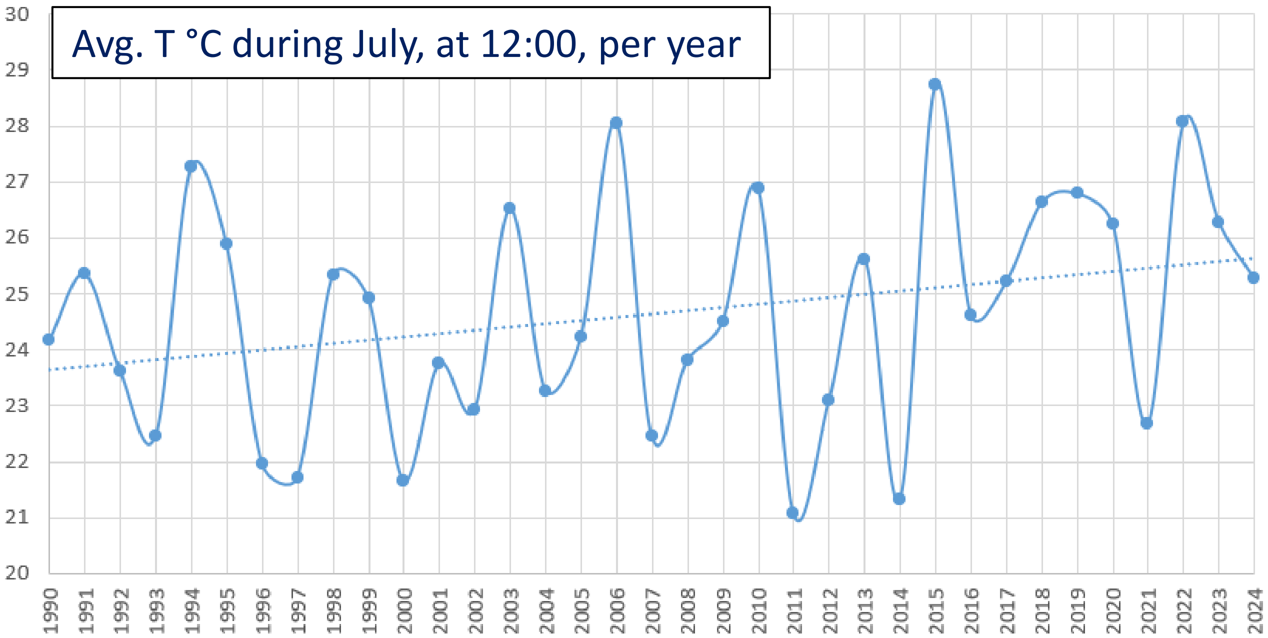
Cooling limit in cooling tower: marked by $\mathbf{T_{wb}}$
Most demanding scenario for cooling towers: summer, with hot & humid air
Design value ASHRAE 2021: 20.7 °C

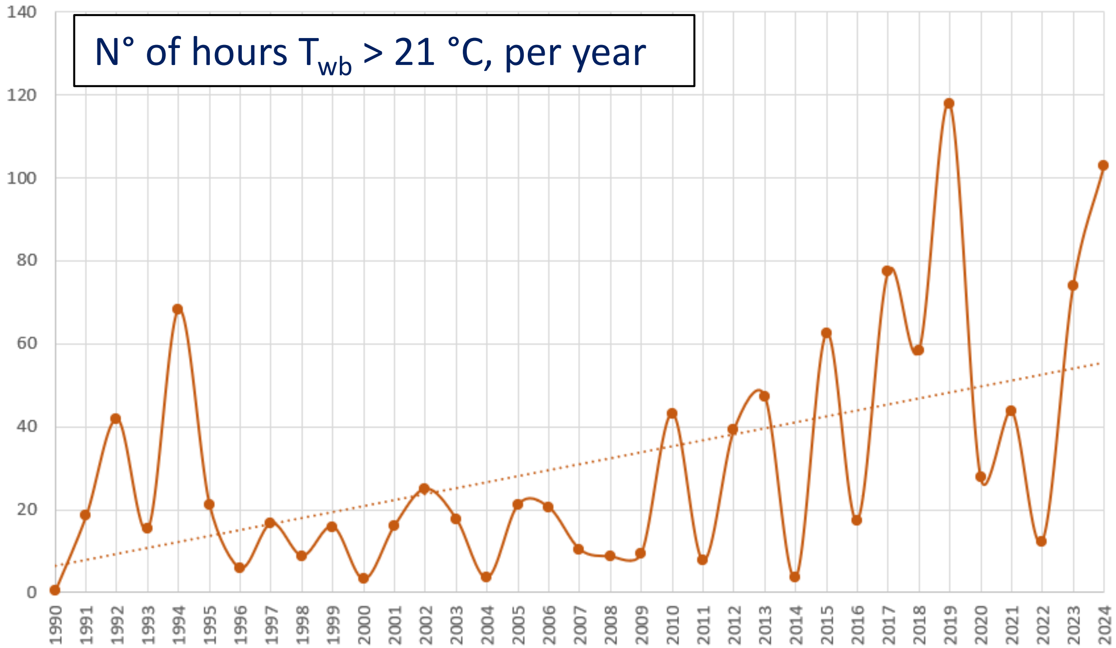
How may this evolve until FCC-hh finishes operation, 2090?

Data from MeteoSwiss

Feasible approaches:
min. ≈ 3 – 4 °C







1. Update on thermal loads

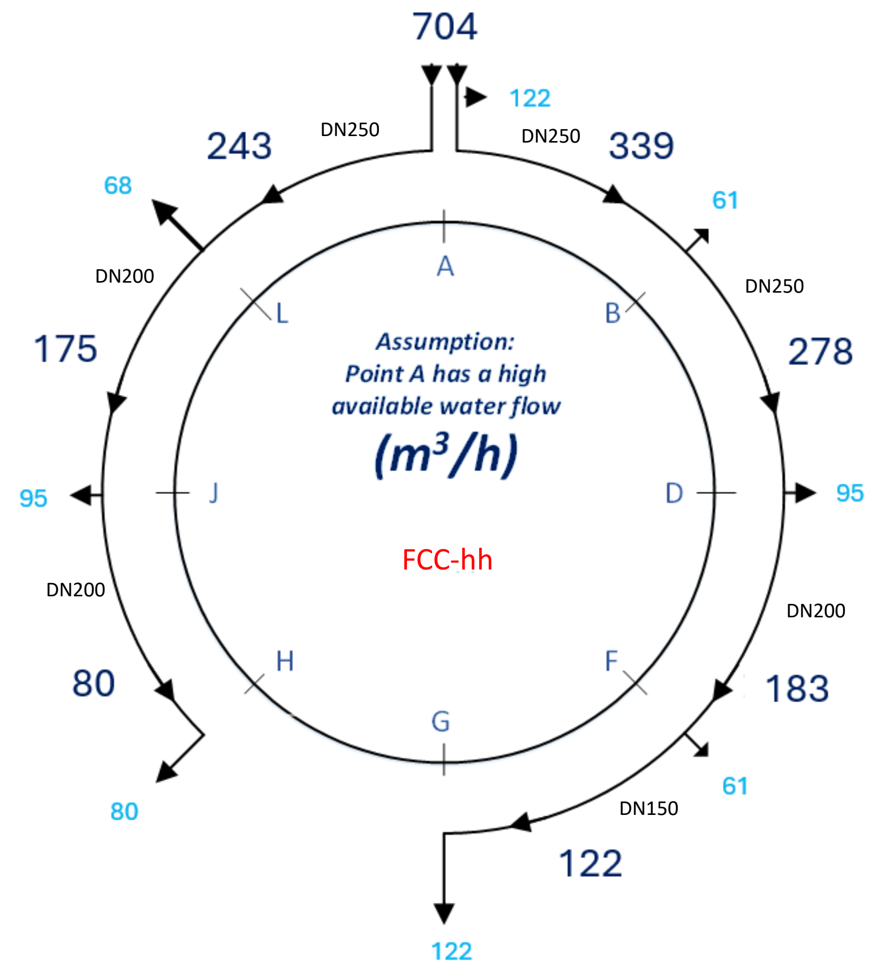
Next Two Years

- The next two years are critical for FCC and the ESPP in general.
- It is well known that there is no consensus in the council for going ahead with FCC and there is not yet consensus in the community.
- The main issue is related to the affordability of the FCC.
- Two critical steps will point to the way forward
  - The results of the feasibility study along with the associated panel reports will be presented to the council in November 2025
  - The council meeting in May 2026 with topic the update of the ESPP.
- Thereafter the ability of the CERN management to attract external collaborators who could provide significant contributions to the FCC project is critical.
- This is closely related to the governance question of the next flagship project of CERN and clearly it involes negotiations between CERN potential contributors which may be states or private entities.
- Throughout this time the CERN council will be closely involved in defining the terms of the negotiations and intervening as needed to express the will of the member states.

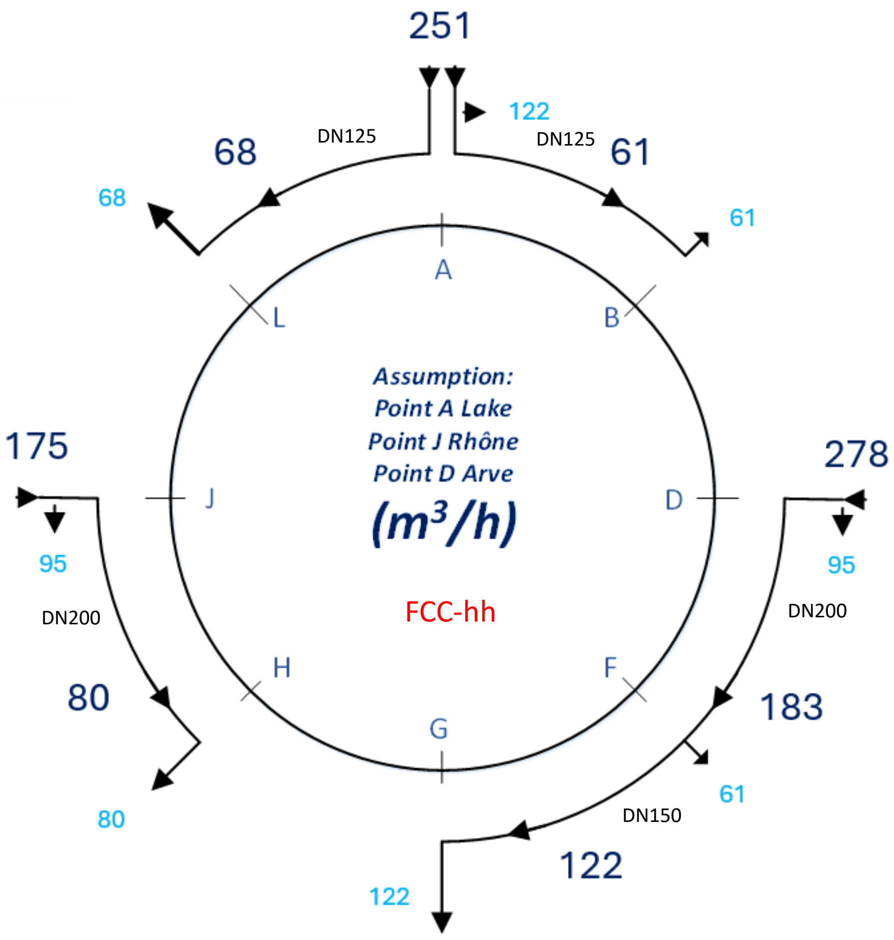
C. Fountas, FCC Week 2025

3. Update on Supply

Baseline



Alternative



SECTORS: SUMMARY TABLE		
Pipe size	**No. of sectors for** *1 entry point*	**No. of sectors for** *3 entry points*
DN250	**3**	**0**
DN200	**3**	**2**
DN150	**1**	**1**
DN125	**0**	**2**

Baseline: larger pipes in Tunnel, higher cost of pipes in Tunnel

Alternative: smaller pipes in Tunnel, lower cost of pipes in Tunnel, interface between CERN and local water providers

Dimensioning with worst case between FCC-ee and FCC-hh

3. Update on Supply

Alternative: STP recovery at PD → Technologies

Primary: oxidize sulfur, heavy metals and restrict chemical & biochemical oxygen demand growth

Aeration system type	Key Feature	Oxygen Transfer Efficiency
Surface Aeration	Mechanical mixing at the water surface	Moderate
Sub-Surface Aeration (Fine Bubble Diffusers)	Small bubbles, high surface area	High
Jet Aerators	High-velocity air-water mixing	Moderate
Conventional Aeration (cascade type)	Gravity-driven, natural aeration	Low

Secondary: reduction of total suspended solids (TSS)

Parameter	Dual Media Filter (DMF)	Ultrafiltration (UF)
Filtration Mechanism	Depth filtration (media layers)	Surface filtration (Membrane)
Pore size	10-50 microns	0.01-0.1 microns
Contaminants Removed	Suspended solids, turbidity	Suspended solids, turbidity, Bacteria, viruses
Pressure Required	Low	Moderate
Fouling Tendency	Lower, easy to clean with backwash	Higher, requires chemical cleaning
Energy Consumption	Low	Moderate
Application	Pretreatment, wastewater, industrial water	Drinking water, wastewater reuse
Cost	Lower capital and maintenance cost	Higher due to membrane maintenance

Tertiaty: reduction of total dissolved solids (TDS)

Parameter	RO (Reverse Osmosis)	NF (Nanofiltration)
Pore size	0.1 nm	0.5-2 nm
Membrane Characteristics	Dense, with no discernible pores. It operates mainly through diffusion rather than filtration.	Less dense than RO, with nano-sized pores that allow the passage of small molecules and ions.
Rejection	Removes around 95-99% of dissolved salts (ions), bacteria, viruses, organics, and other dissolved solids.	Removes 50-90% of dissolved salts. It is selective in rejecting larger divalent ions (e.g., calcium (Ca^{2}+),), but monovalent ions (e.g., sodium (Na+), chloride (Cl-)) pass through more easily. Large organic molecules are rejected too
Operating Pressure	Higher pressure due to the dense membrane structure and small pore size	Lower pressure compared to RO because of the larger pore size (less than half)
Energy Consumption	Higher due to the need for higher operating pressures.	Lower than RO because it operates at lower pressures
Fouling Tendency	High	Low
Application	Desalination, pure water	Water softening, wastewater
Cost	High	Lower