Outcome of the engineering studies for the FCC-hh cryoplants

Wednesday 26th of June 2019 – FCCWeek2019

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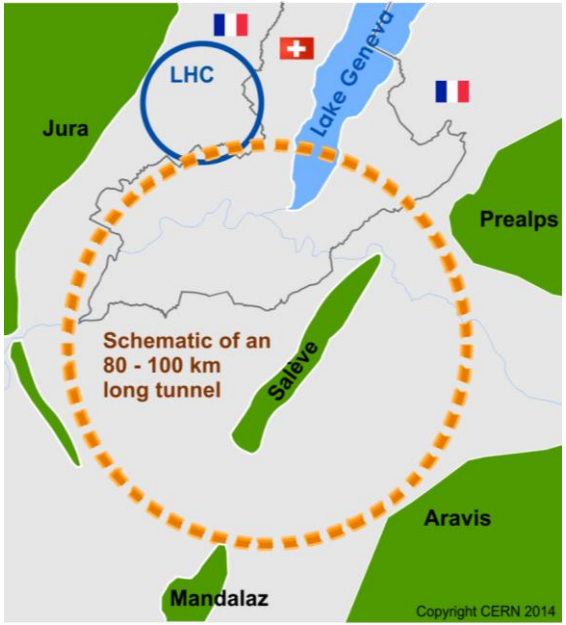
   - FCC study
   - Cryoplant state-of-the-art
   - Industrial study
2. Process concept evaluation & Performances
3. Identified technical adaptation and novel developments
4. Conclusions

Scope of the FCC study

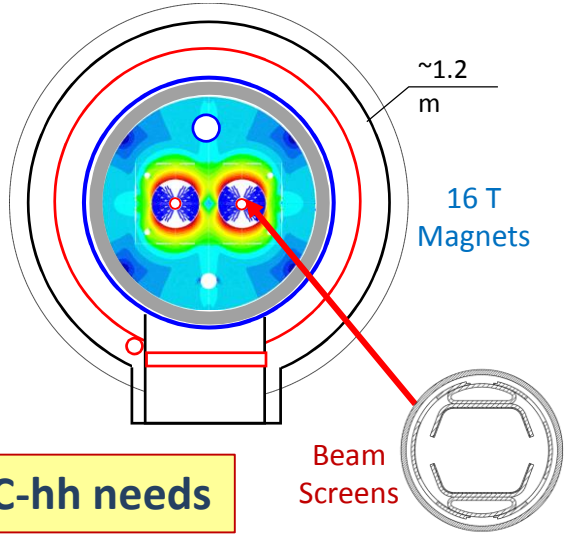


100 km tunnel infrastructure
in Geneva area, site specific

International FCC collaboration (CERN as host lab) to study:

16 T => 100 TeV *pp* in 100 km

- ***pp*-collider (*FCC-hh*)**
  => long-term goal, defining infrastructure requirements
- **e^+e^- collider (*FCC-ee*),**
  as potential first step
- ***p-e* (*FCC-he*) option**
- **HE-LHC** *with FCC-hh technology*

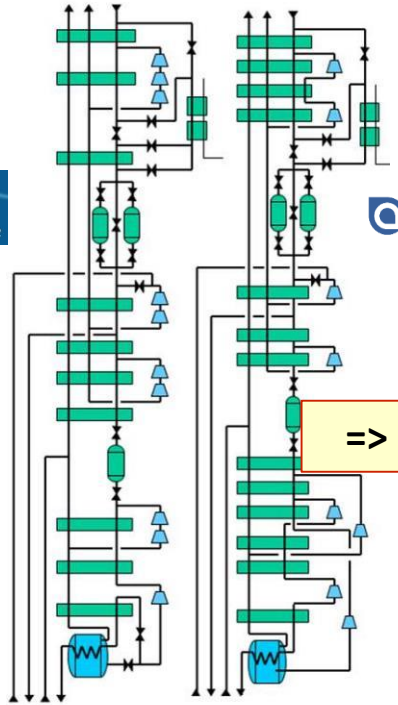


=> Engineering study based on FCC-hh needs

He cryoplant - Existing large-scale 4.5K Refrigerators and Liquefiers

LHC 4.5 K Refrigerators

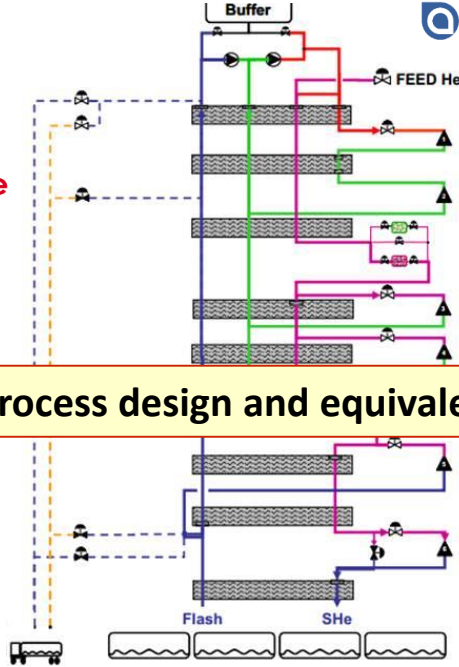
8 modules of 18 kWeq @ 4.5K



U.Wagner/ CERN

Qatar Helium Recovery Unit

20 tons/day - 24 kWeq @ 4.5K



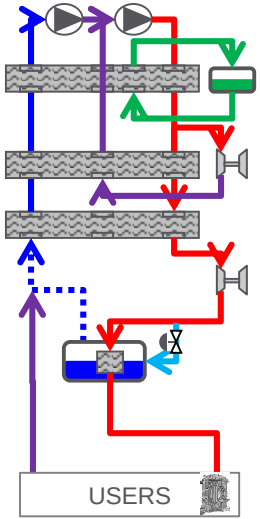
F.Andrieu / ALAT

=> Similar process design and equivalent size

ITER He Plant

3 x 25 kWeq @ 4.5K

3 modules in //



Commissioning soon

Esxisting LN2 liquefiers
250 to 1000 t/d

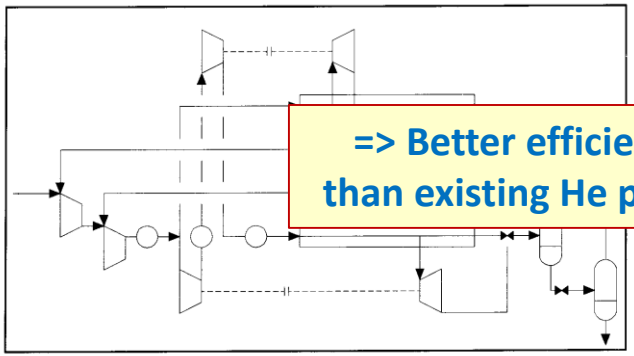
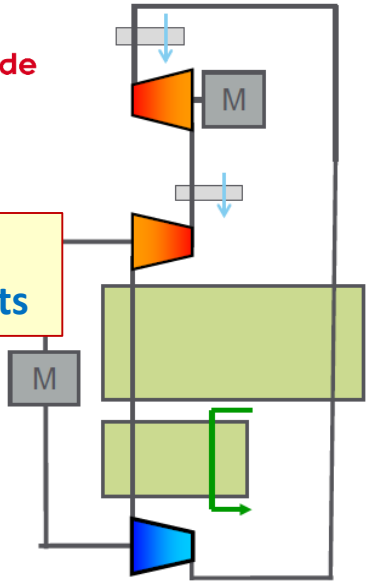


Fig. 5 : Liquéfacteur d'azote à deux turbines

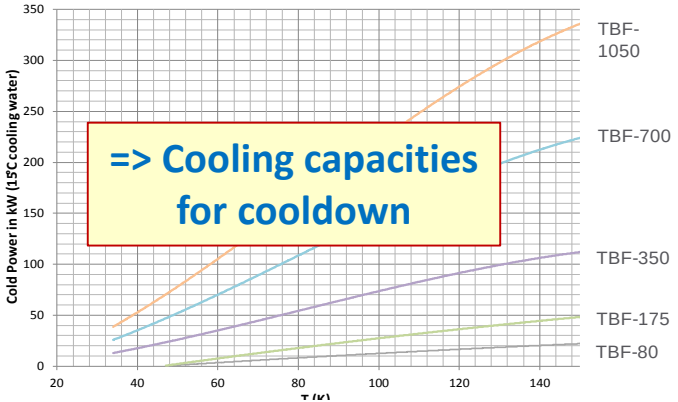
=> Better efficiency than existing He plants

Achieved efficiency > 50% Carnot

Existing Turbo-Brayton Fridges
50 kW@40K



Achieved efficiency 40% Carnot



=> Cooling capacities for cooldown

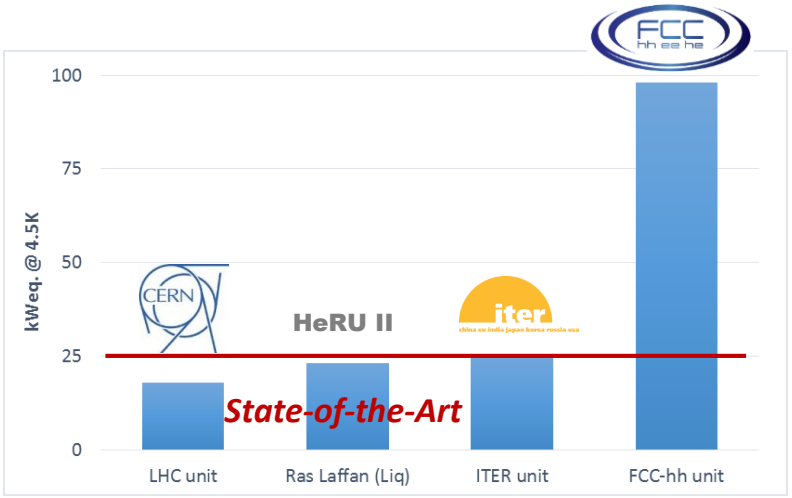
Variable temperature operations (cooldown needs)

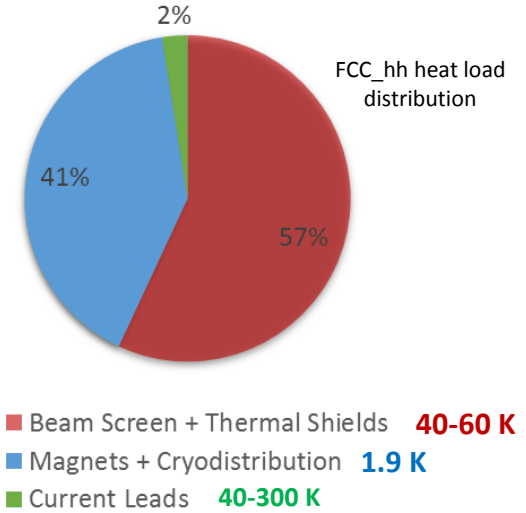
See for reference : Rev. Gen. Froid 1993

By courtesy C.Gondrand/AL

Development of **large-scale cryogenic infrastructures** with reliable and efficient operations

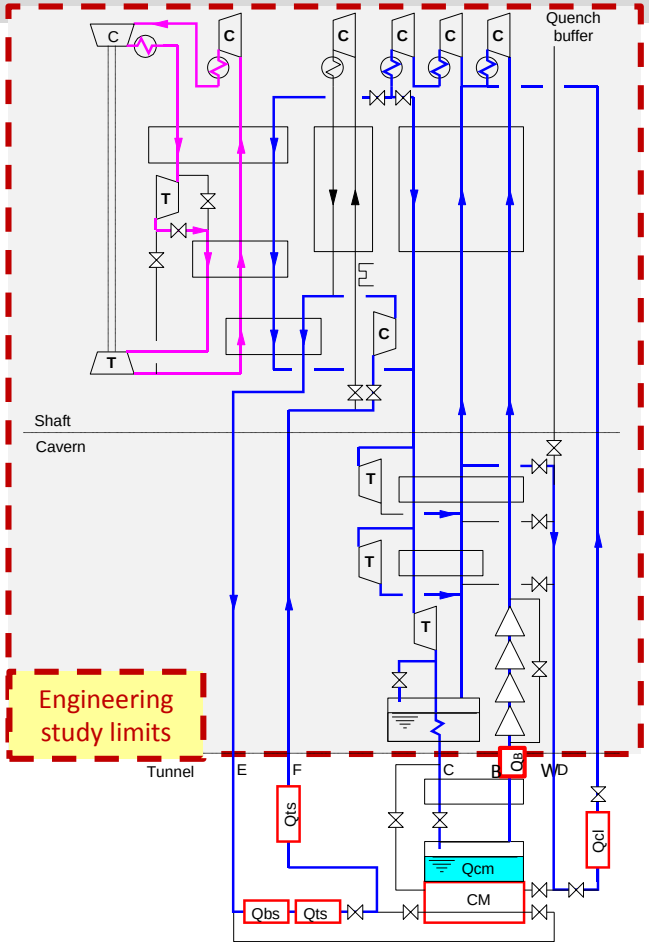
- **Towards 1 MW @ 4.5 K** with 10 units of **100 kW at 4.5K** ***> State-of-the-art***
- **Non-conventional thermal load distribution with large thermal loads > 40K** ***>50%***





Industrial Engineering Study for FCC-hh Cryoplants

FCC_hh cryogenic system with **10 cryoplants**



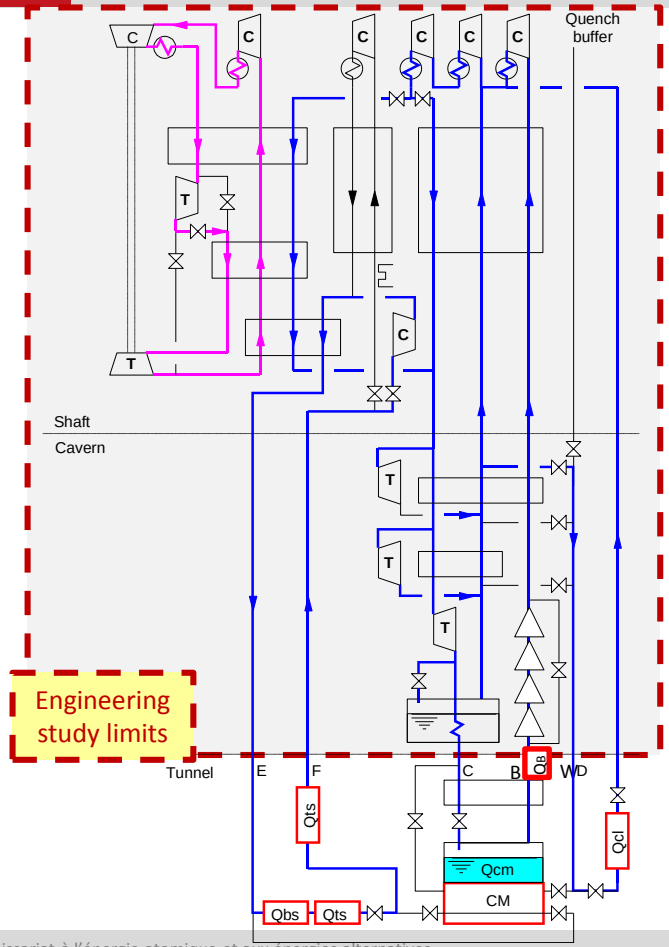
CERN preliminary studies define architecture and requirements for FCC-hh cryoplants

Objectives of the Industrial Engineering Study :

- **Assess the "FCC-hh Cryoplant Solution"**
- **Identify the technical risk items and the innovative technologies for reliable and efficient cryoplants**
- **Estimate the cryoplant dimensions and costs**

Involve industries at the earliest stage of the FCC project

Technical requirements

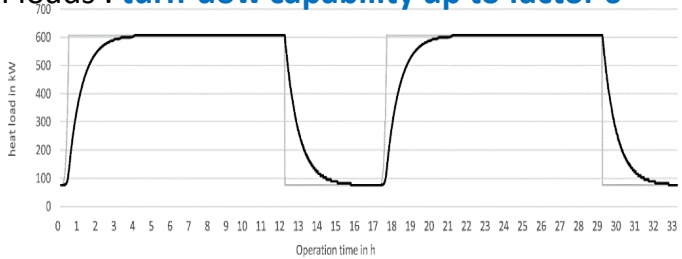


- Main cooling requirements for one FCC-hh sector (one cryoplant)

Loads	Cooling circuit	Temp. range	"High" mode	"Low" mode
Qcm [kW]	SC Magnets	1.9 K	12*	4
Qbs+Qts [kW]	Beam screens & shields	40-60 K	620	90
Qcl [g/s]	HTS Current leads	40-300 K	85	43

** 2017 values for magnets*

- Beam screen loads : **turn-dow capability up to factor 6**



- Magnet loads : **turn-dow capability up to factor 3** *(similar to LHC)*
- Cooldown *(24 000 tons)* in less than 15 days : **>2.5 MW down to 80 K**

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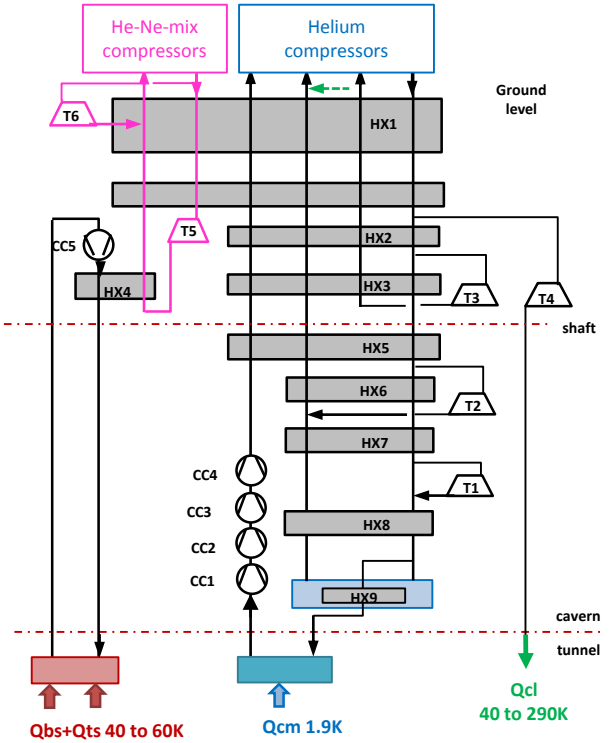
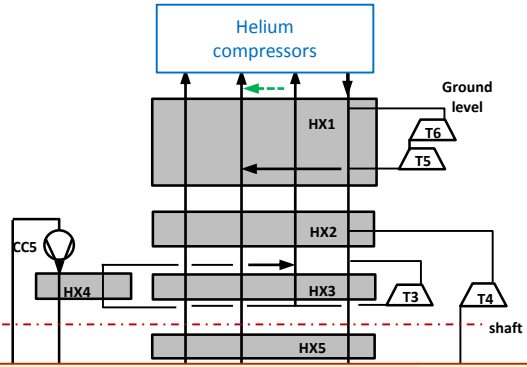
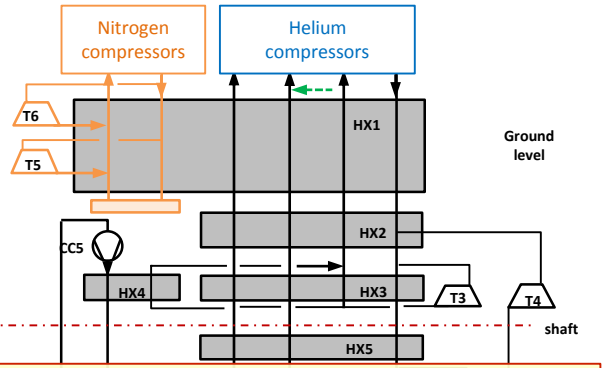
FCC-hh option ?



Concept A – Ne/He precooling
FCC-hh CDR proposal



Concept B – Pure Helium
LHC-like option



Concept C – LN2 precooling
ITER-like option

*Evaluation of **three precooling options down to 40K** with:*

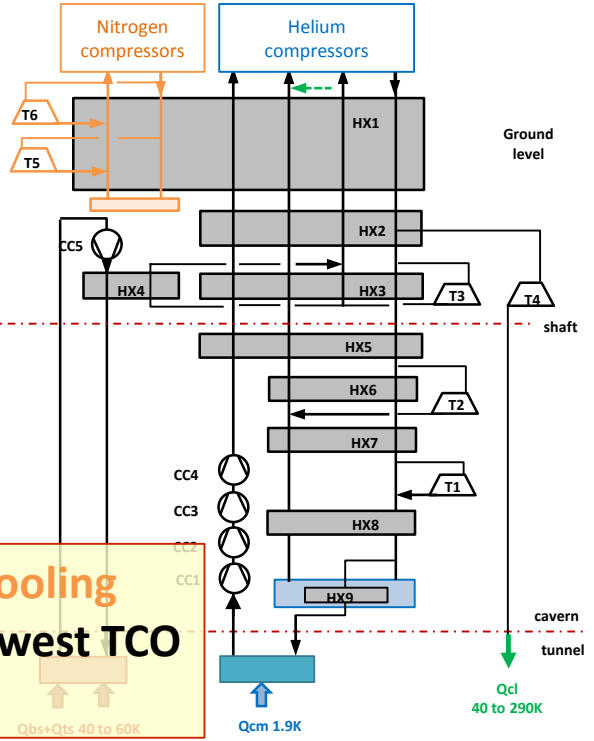
- ***Same interfaces** with FCC-hh tunnel*
- ***Identical cold ends** (up to 40K)*
- ***Fixed equipment efficiencies** for calculations*
  - *85% for turbines*
  - *70 to 80% for centrifugal compressors & circulators*
  - *≤55% for screw compresors*

Comparison of the three FCC-hh cryoplant concepts for technical-economic criteria:

- **Process and equipment design**
- **Technical risks**
- **Technology readiness levels (TRL)**
- **Operation costs (OPEX)**
- **Capital costs (CAPEX)**

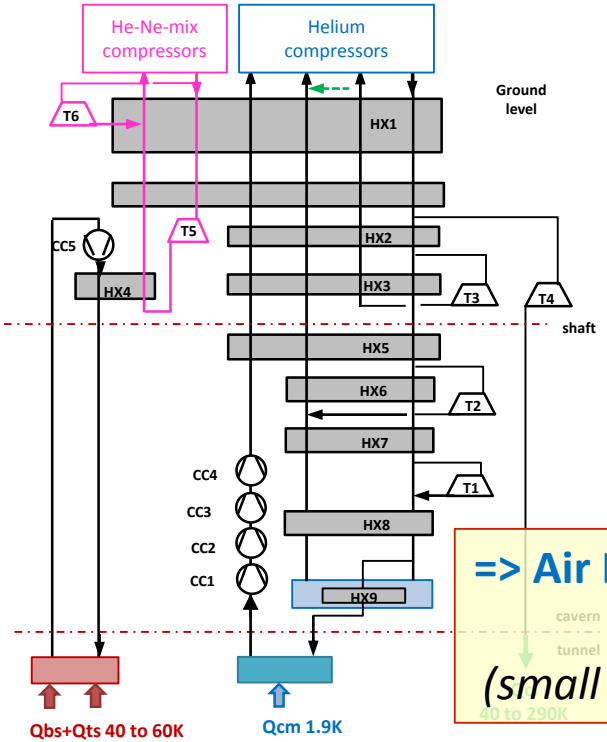
} ***Total Cost of Ownership (TCO) = CAPEX + OPEX***

=> Linde preferred solution = Concept C with LN2 precooling
with **cheaper refrigerant, mature technologies for ASU, lowest TCO**
(small gap with Concept B with Pure Helium)



Concept C – LN2 precooling
ITER-like option

Air Liquide proposal



Concept A – Ne/He precooling

FCC-hh CDR proposal

Comparison of the three FCC-hh cryoplant concepts for technical-economic criteria:

- **Process and equipment design**
- **Technical risks**
- **Technology readiness levels (TRL)**
- **Operation costs (OPEX)**
- **Capital costs (CAPEX)**

Air Liquide creative oxygen

=> Air Liquide preferred solution = Concept A with He/Ne precooling

with **experiences in Turbo-Brayton fridges**

(small gap with Concept B with Pure Helium and Concept C with LN2)

Open issues for rotating machines

❑ Warm compressors :

- **« Conservative » option** with screw compressors for He and centrifugal compressors for He/Ne & N2
- **« Challenging » option** with full centrifugal compressors

❑ Turbo-expanders:

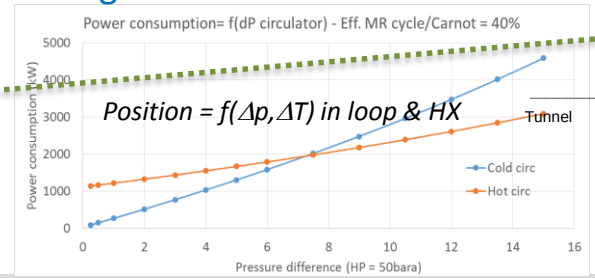
- With **energy recovery** for large-scale turbines

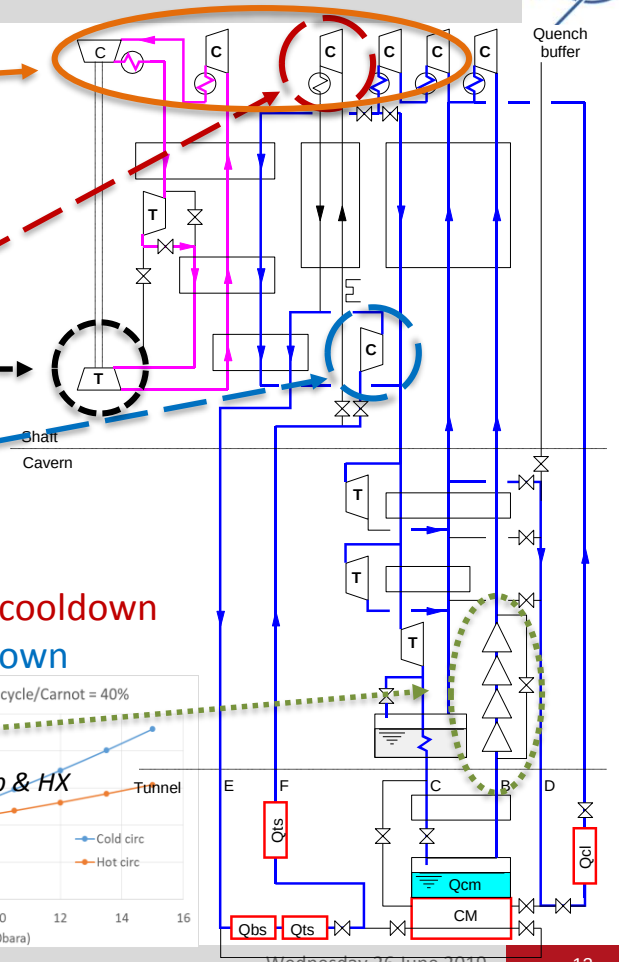
❑ GHe 40-60K loop circulator :

- Air Liquide – warm circulator option with simple configuration for cooldown
- Linde - cold circulator option with complex configuration for cooldown

❑ Cold compressors for 1.8K loop :

- Air Liquide – 3 stages in series
- Linde – 4 stages in series





Linde and Air Liquide engineering studies confirm :

❑ Process cycle pre-design :

- 40-300K stage for beam screens, thermal shields & HTS CLs
- 1.8K stage for magnets

❑ Cryoplant performances :

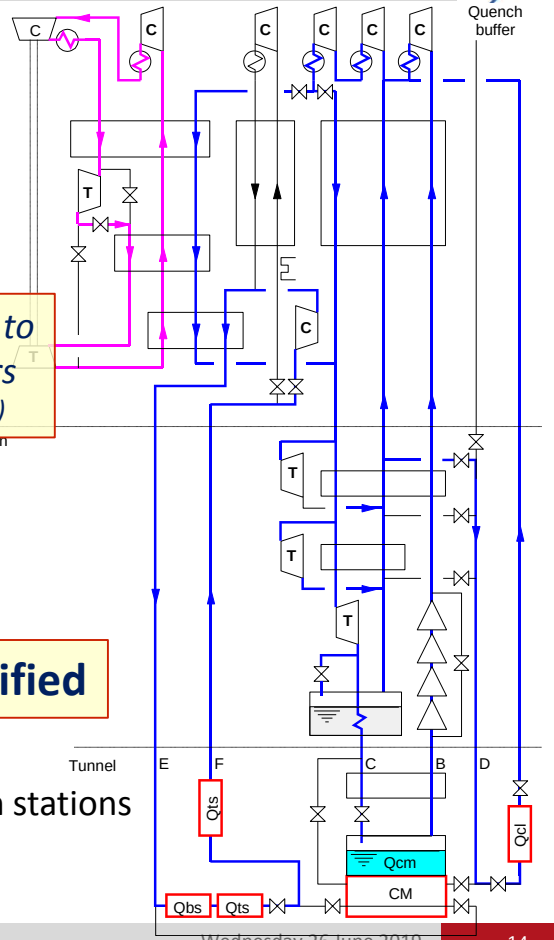
- Electrical consumption in nominal conditions
  - Conventional He screw compressors : 200 MW*
  - Advanced He centrifugal compressors : **160-170 MW***
- Turndown factor for transient operations **> 3 to 6**
- Cooldown capacity **> 2.5MW**

Potential saving : 150 to 200 MCHF in 10 years
(6000hr/yr – 60CHF/MWh)

=> All better than specified

❑ Technical feasibility :

- Pre-design of main equipment (compressors, turbines, HXs)
- Estimation of required footprints for cold boxes and warm compression stations



** With 12kW@1.8K for magnets (2017 values)*

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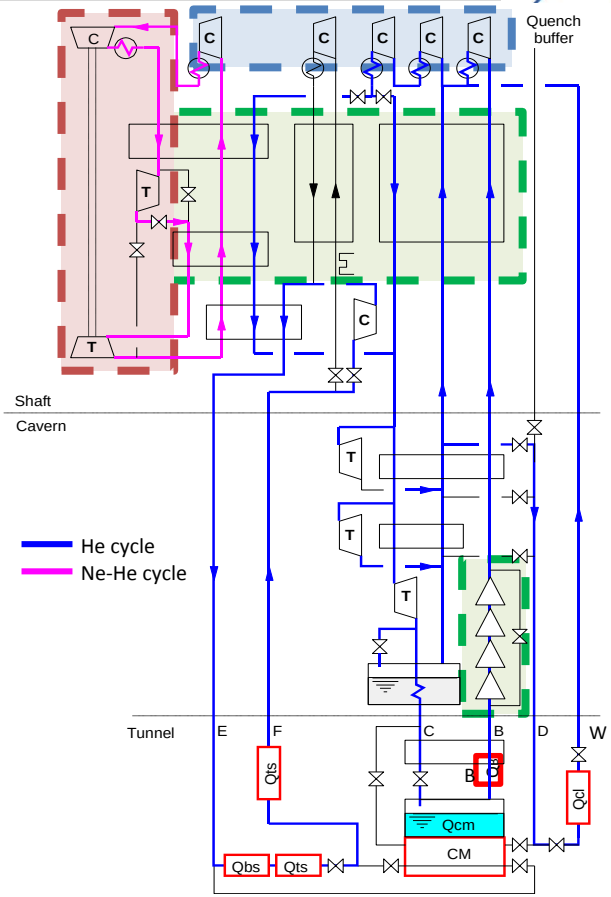
❑ Identified technical adaptations and novel developments :

- **Detailed design of large-scale components** :
  He turbines, cold compressors & heat exchangers
- **Reliable and efficient turbo-compressors**
- **Energy recovery for large turbo-expanders**



Heat exchanger sizing compare to the state-of-the-art

Standard Aluminium Plate-Fin Heat Exchangers (PFHX) = baseline for the engineering study

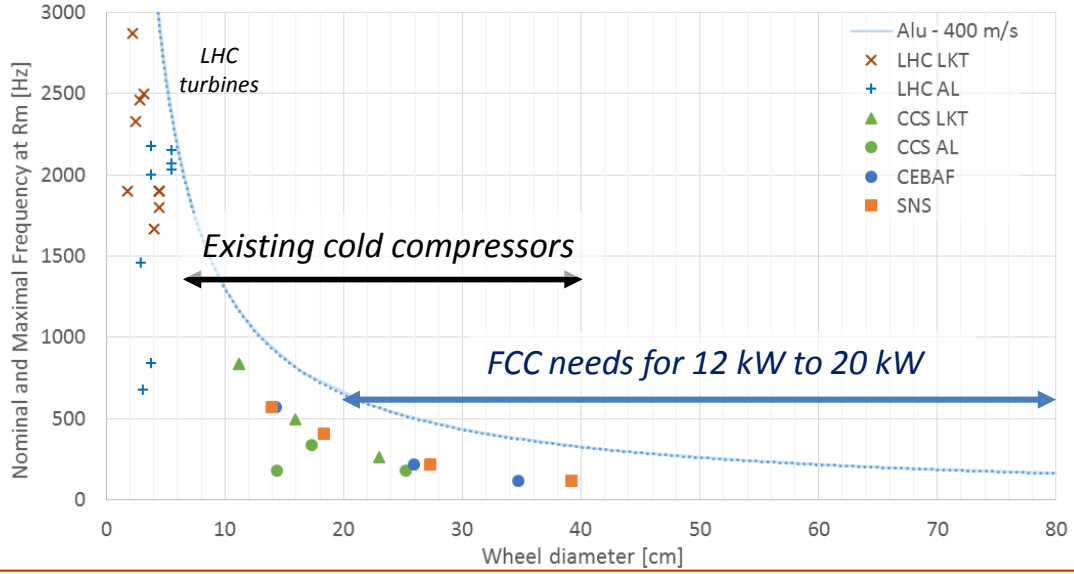
"The dimensions of each PFHX core in the UCB and LCB are below the maximum PFHX dimensions and within the standard of Linde Engineering PFHX."

The maximum feasible dimensions of Linde Engineering plate-fin heat exchangers (PFHX) are up to 8.2 metres in length, 1.5 metres in width and 3.4 metres in height

See for details : Linde Engineering plate-fin heat exchangers

Cold compressors

FCC-hh cold compressors (200 g/s < Qm < 1000 g/s – Eff.> 75%)



Large cold compressors have to be adapted with larger wheels &
special attention to rotor-dynamics with large motors & bearings

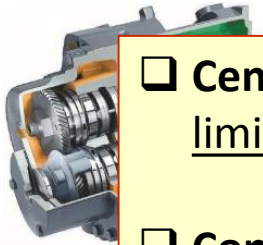
Air Liquide
creative oxygen

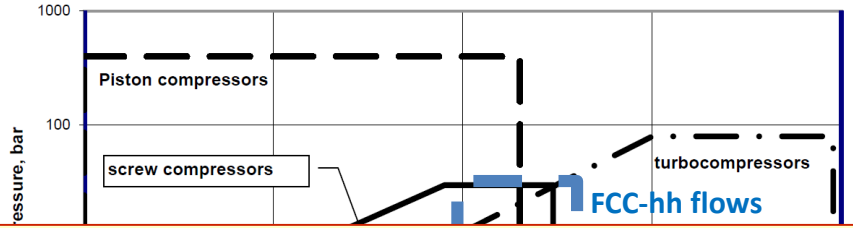
THE LINDE GROUP
Linde

By courtesy LINDE & Air Liquide

Technology for warm compression

Present technology : screw compressors





Proposed alternative : turbo-compressors

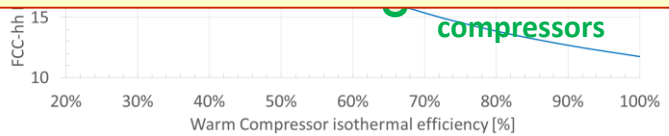
- **Centrifugal warm compressors** offer larger flow capacity, better efficiency and limited pressure ratio per stage requiring numbers of stages in series

whereas

- **Conventional screw compressors** offer larger pressure ratio, lower efficiency and limited flow capacity per stage requiring numbers of stages in //

=> Centrifugal warm compressors : a promising solution for FCC

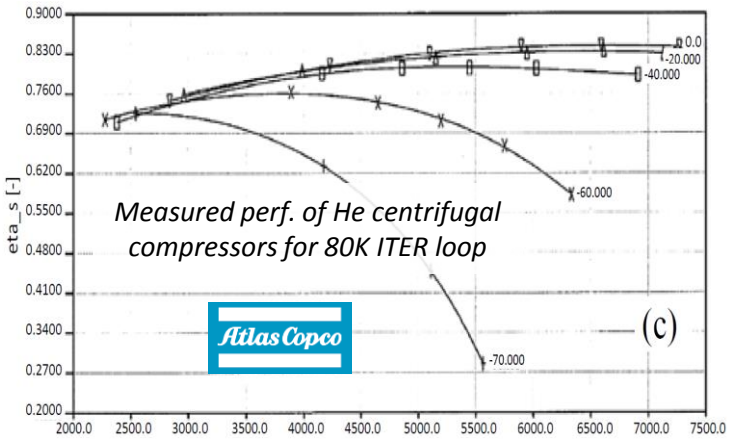
already for precooling plants and potentially for He plants

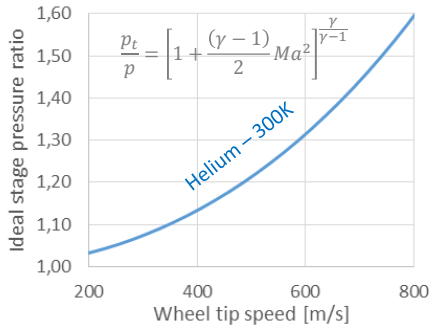


Alekseev (2013) – Cardella (2017)

Warm Turbo-Compressors

(Kouzmenko – 2018)





- ❑ Reliable and efficient products
  - Oil free
  - Active Magnetic Bearings
  - Compact design
- ❑ Already commercially available for natural gas and air separation.
- ❑ **Feasibility for He already confirmed in single stage.**
- ❑ **However developments required for light gases**

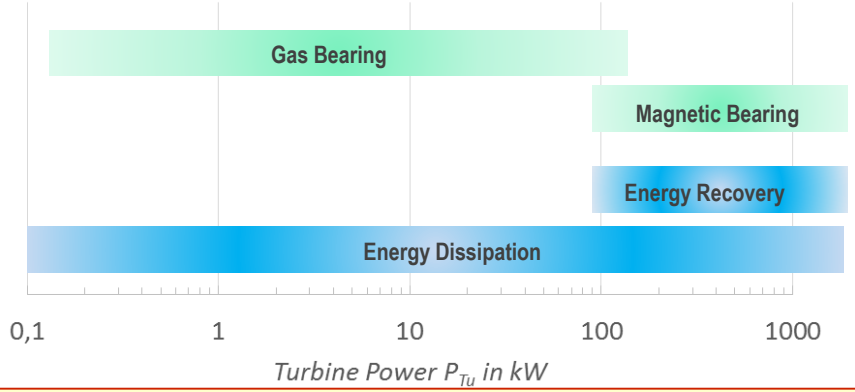
More reliable components (oil free, AMBs)

+ Expected gain for FCC-hh : 15 to 25% of Pelec

*Potential saving : **100 to 150 MCHF** in 10 yrs*
(6000hr/yr, 60CHF/MWh)

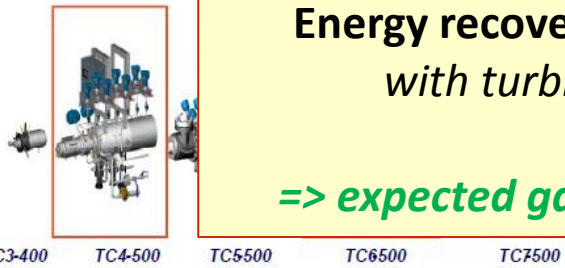
Turbo-expanders

FCC-hh turbines (5 kW < Pw < 1 MW – Eff. > 80%)



Large turbo-expanders for Ne-He and He have to be developed
including
Energy recovery already existing for turbines > ~100 kW
with turbine-generators or turbine-compressors

=> expected gain for FCC > 1 MW/cryoplant = 7% of Pelec



Potential saving :
40 MCHF in 10 yrs
(6000hr/yr, 60CHF/MWh)

By courtesy LINDE & Air Liquide + *Cardella U et al. Aspects of hydrogen liquefier scale-up – Process and equipment design. Proceedings of the 14th CRYOGENICS 2017 IIR International Conference, Dresden, 2017*

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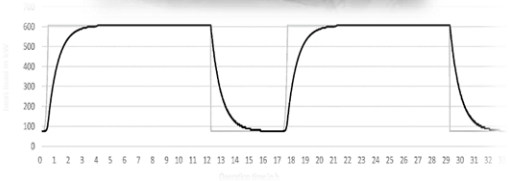
❑ Technical feasibility confirmed for the 100kW@4.5K plants

=> No showstopper identified by industries !

- **Confirmation of process cycle options and performances**
  (up to 40% of Carnot eff. with He turbo-compressors)
- **Identification of required adaptations and R&D actions**
  to supply more reliable & energy-efficient cryoplants
  (warm & cold centrifugal compressors, energy recovery)



Next steps ? Cryoplant consolidation, dynamic simulations, component R&D ?

See EASITrain Presentations & Posters on FCC-hh cryogenic system & turbo-compressor development

Thank you for your attention

Questions ?