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Liquid Nitrogen operated Cooling Systems for Superconducting Power Lines

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AmpaCity – the world`s longest superconducting cable (technological world premiere in Essen)

AmpaCity –
the world`s longest superconducting cable

AMPACITY
Intelligente Netze für die Stadt

A project of RWE Deutschland AG (now: Innogy SE)

<u>in cooperation with:</u>

- Nexans → cable and cryostat
- KIT (Karlsruhe Institute of Technology) → material research / scientific attendance
- PTJ (German federal ministry of research) → public funding
- Messer → cooling unit and LIN-supply

Photo:
Cooling Unit for AmpaCity

Time schedule

• LIN-vessel installation:	09 / 2013
• HTS-cable installation:	10 / 2013
• Cooling unit installation:	11 / 2013
• functional tests:	12 / 2013
• start up:	02 / 2014
• regular operation since	03 / 2014
• full integration into network	03 / 2016

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German Climate and Environment Innovation Award (IKU) 2015 (Federal Ministry of Environment)

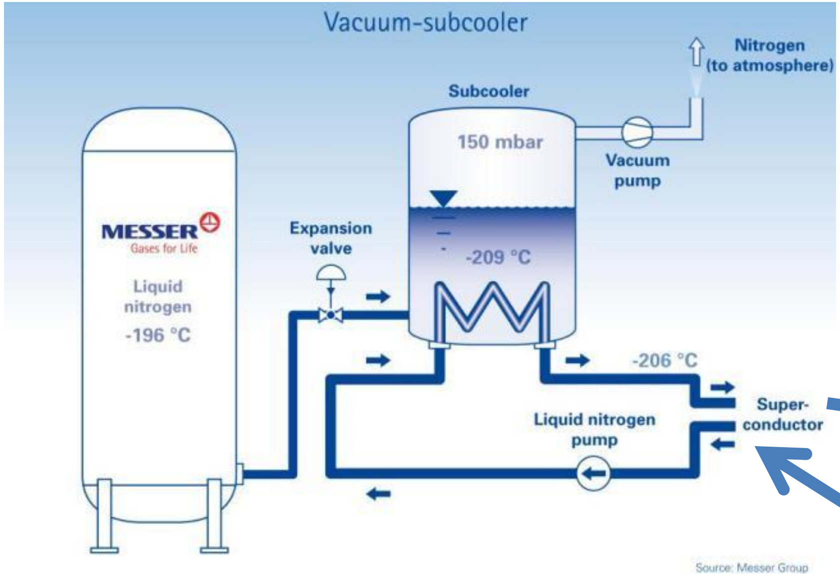
Project data

Place: Essen, Germany

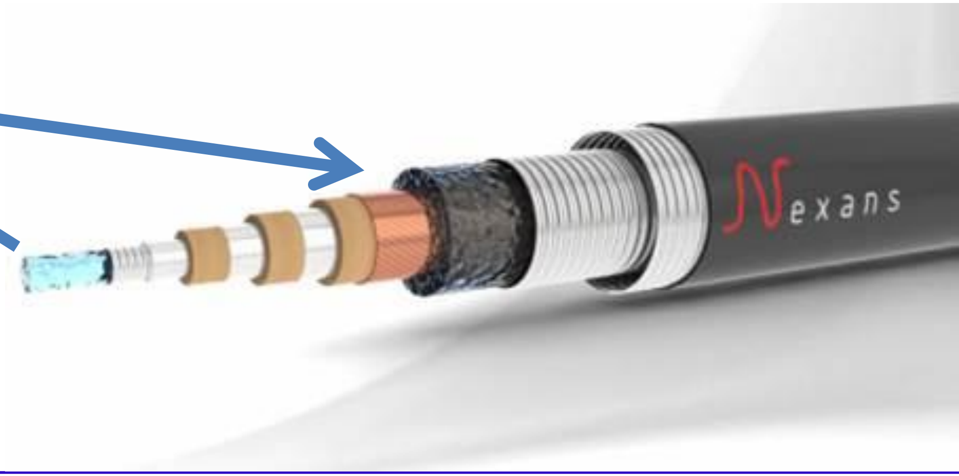
- Cable length: 1,000 m
- Voltage: 10,000 V
- Electrical capacity: 40,000 kW

- Cooling capacity (cable): 4 kW
- Cooling temperature: - 206°C (67 K)

The most important components



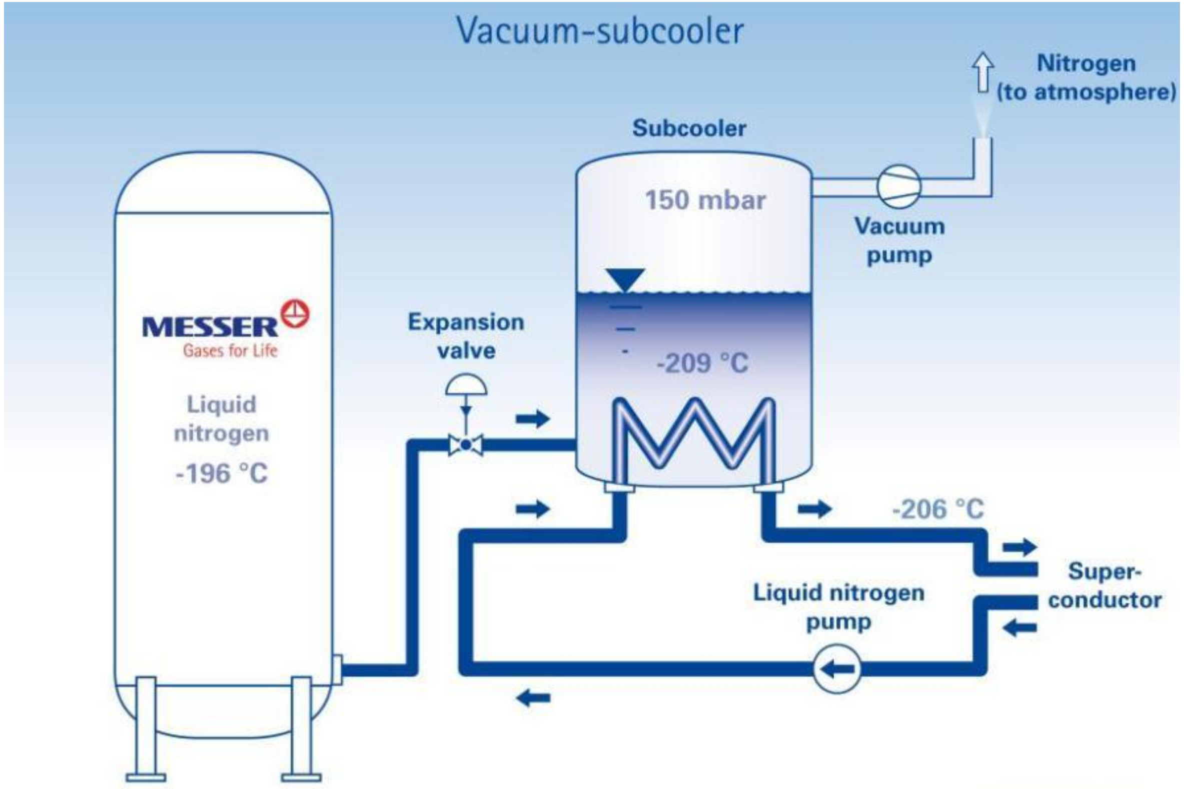
Nexans cable



Messer cooling unit

Basic diagram

- Liquid nitrogen is used
  - as heat transfer medium
  - as cooling agent
- LIN is pumped through the superconducting cable
- LIN is recooled in the subcooler (to -206°C)
- LIN vaporizes at 150 mbar(a)
- LIN temperature decreases to -209°C in expansion valve (LIN becomes solid at -210°C)

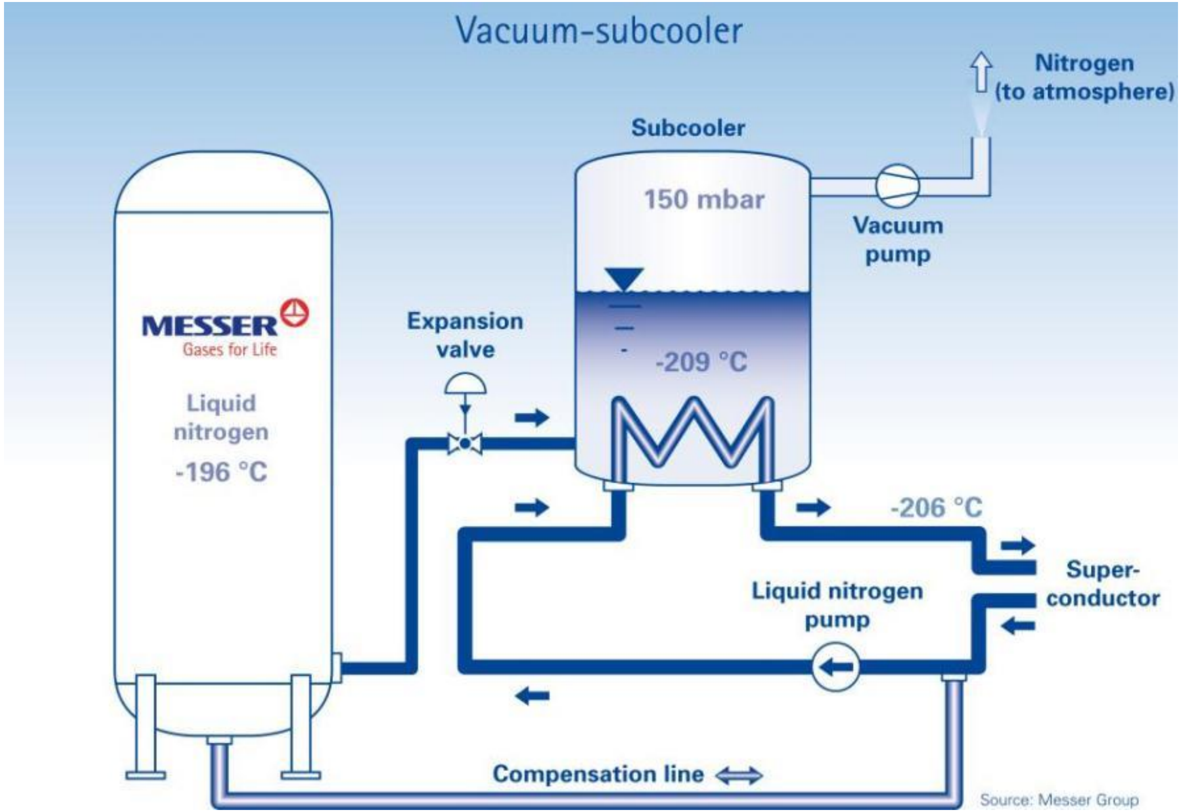


Source: Messer Group

Basic diagram

- Expansion vessel is tricky to design (gas volume collapses in subcooled liquids)
- We use the LIN tank as expansion vessel

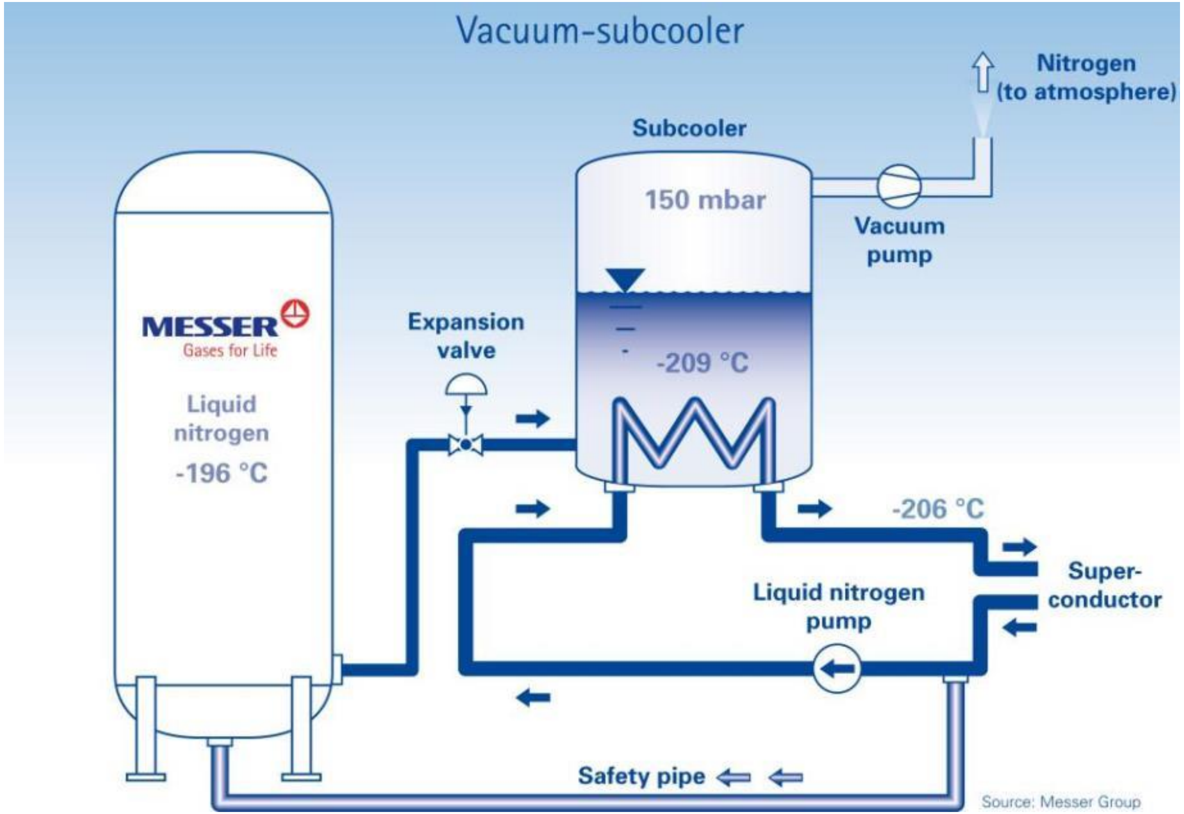
➔ The LIN vessel becomes a <u>functional</u> detail of the cooling circuit !



Basic diagram

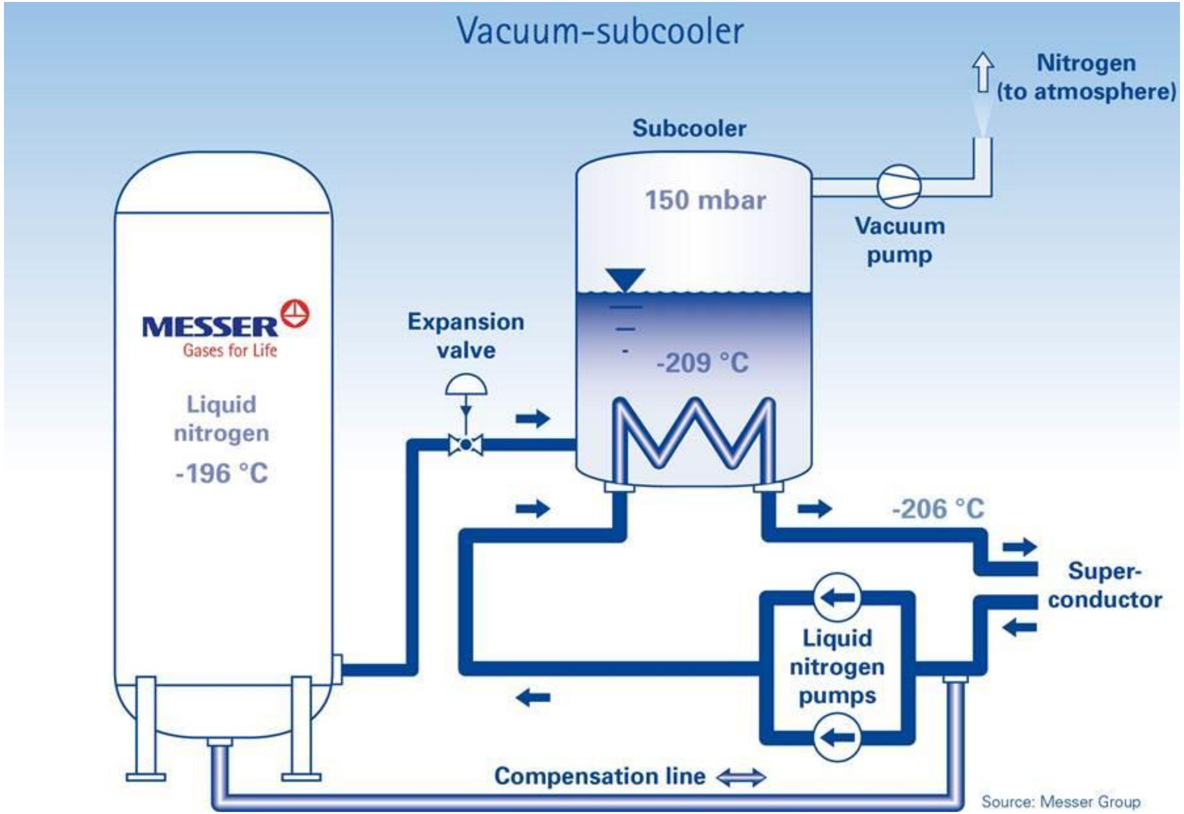
- In case of a serious damage LIN (3.000 l) flows back to the storage vessel
- The LIN vessel additionally has a safety function

➔ The LIN vessel is an integrated part of the cooling unit



Redundancy (circulation)

- There are installed 2 liquid nitrogen circulation pumps.
- 1 pump is in operation, the other one is in standby.
- Pump maintanance is done without stopping the circuit.
- In case of malfunction there is automatic switchover to the standby pump.

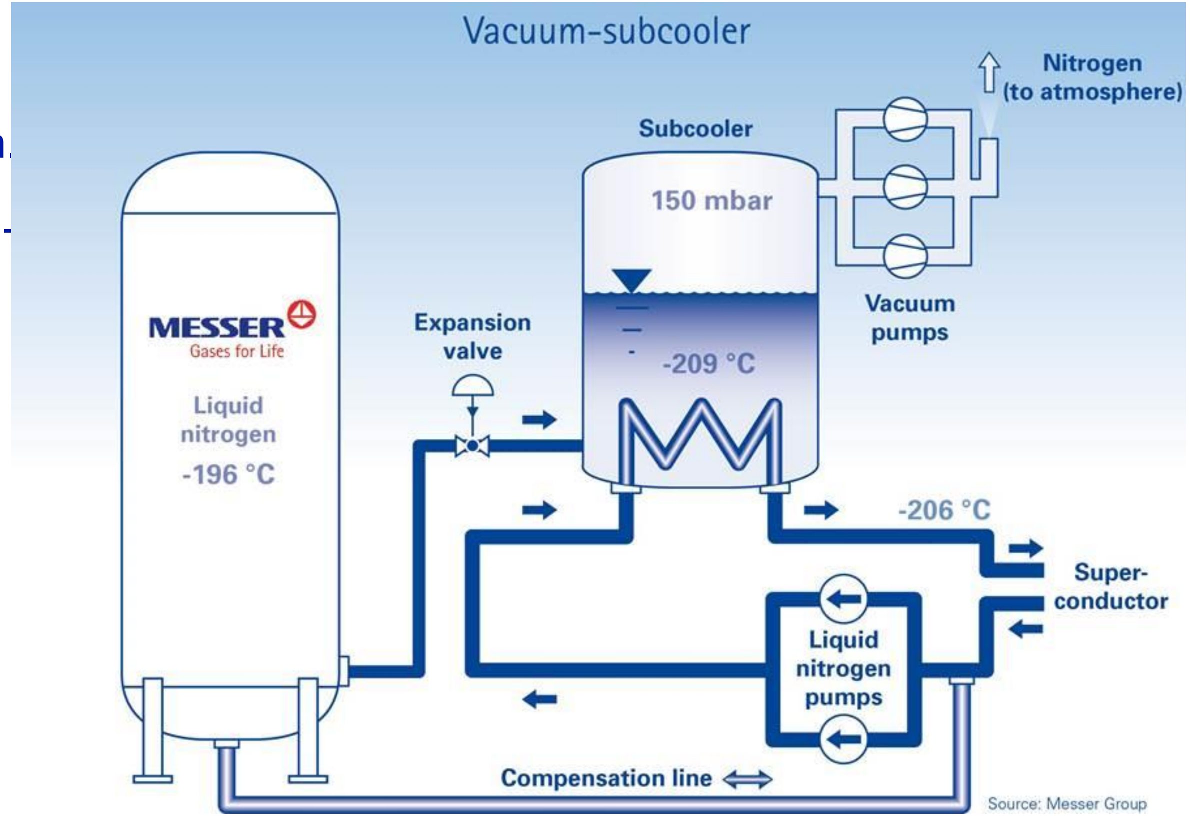


Redundancy (vac. pumps)

- For operation at <u>full capacity</u> 2 vacuum pumps are in operation.
- In case of 1 vacuum pump mal-functioning there is automatic switchover to the 3rd pump.

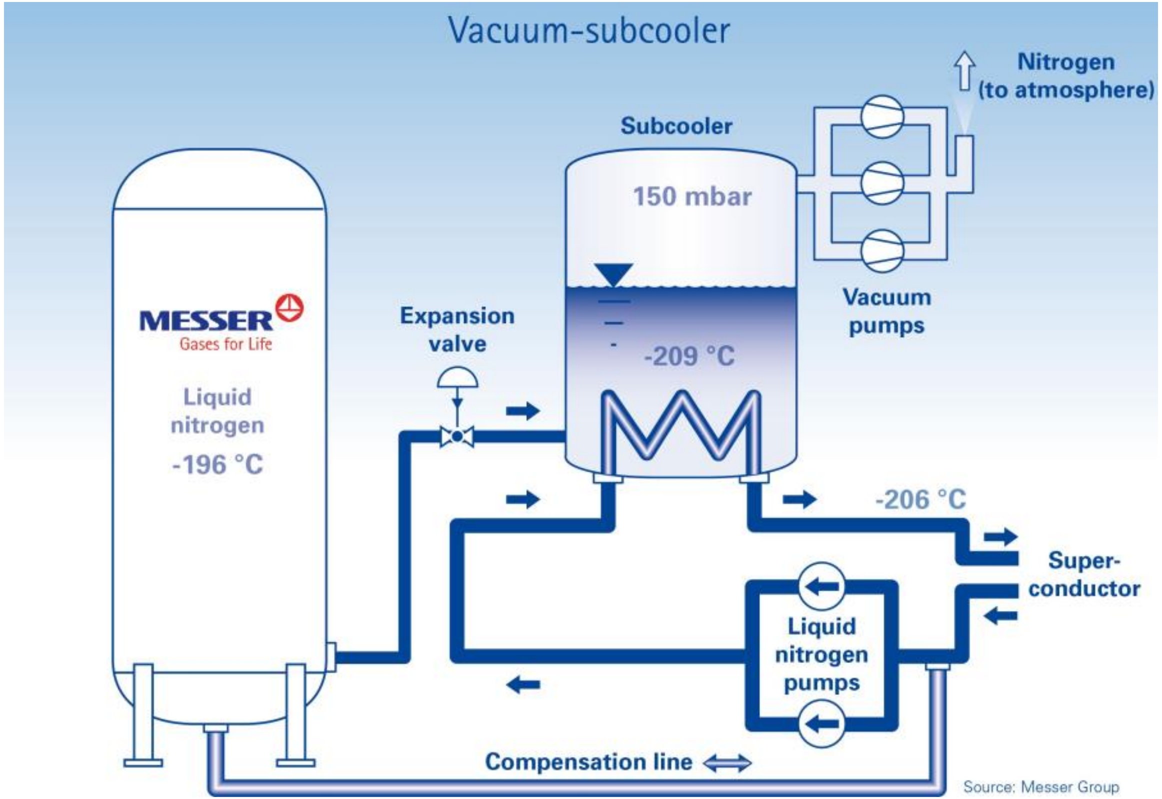
<u>Remark:</u>

Full capacity means
4 kW @ -206°C (for the cable)
plus internal losses of the cooling unit (pumps, insulation)



Redundancy

→ 100% redundancy is available for < 5% additional investment.



liquid nitrogen and electricity consumption

	cooling-demand HTS-cable (total*)	liquid nitrogen consumption	$P_{el.}$ vacuum pumps	$P_{el.}$ other components	$P_{el.}$ total
AmpaCity regular operation	1.8 kW (3.4 kW)	68 kg/h	5 kW	4 kW	9 kW
AmpaCity design	4.0 kW (5.6 kW)	110 kg/h	9 kW		13 kW
future projects scale up	30 kW (36 kW)	710 kg/h	50 kW		54 kW

* total: heat impact from cable + cooling unit (mainly circulation pumps)

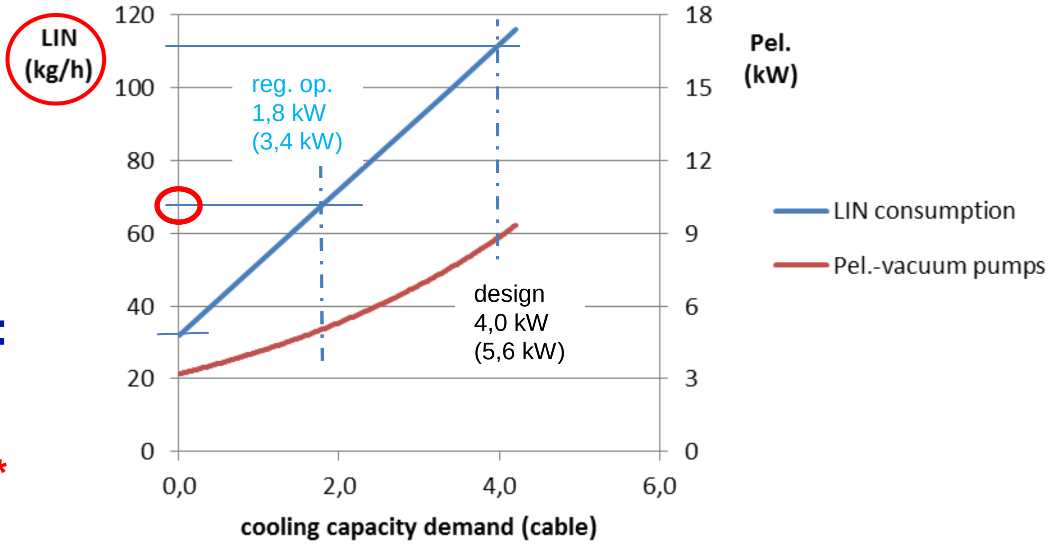
liquid nitrogen and electricity consumption

Cable-cooling demand:

- regular operation 1.8 kW @ 67 K

total-required cooling capacity:

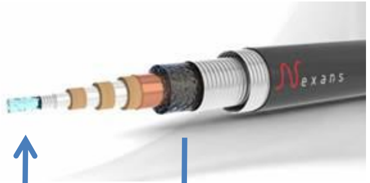
- regular operation (3.4 kW) @ 64 K **



** N2 becomes solid at 63 K (-210°C)

Cooling unit energy- data (regular operation point)

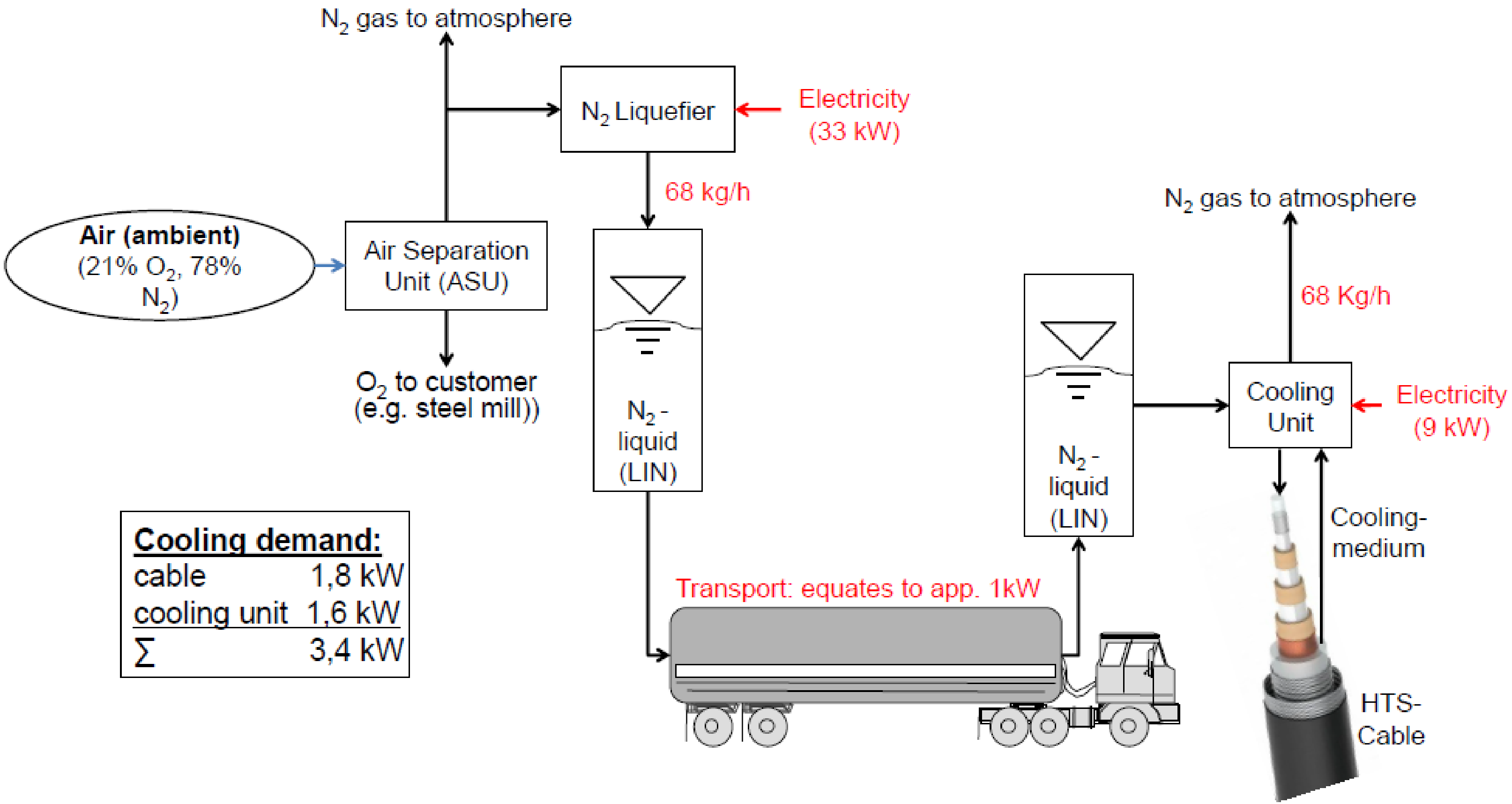
- liquid nitrogen consumption: 68 kg/h
- electricity 9 kW



Liquid nitrogen supply chain (additional losses)

air separation unit (ASU) → transport → tank → cooling unit

HTS – cooling unit: nitrogen and energy balance



Cooling demand:

cable	1,8 kW
cooling unit	1,6 kW
$\sum$	3,4 kW

Energy-data comparison (regular operation point)

- Cable-cooling demand: 1.8 kW (@ 67 K)
- Total required cooling capacity: 3.4 kW (@ 64 K)

- Liquid nitrogen consumption: 68 kg/h

- Required electricity for N2-liquefying: 33 kW
- Exergetic effect LIN transport (130 km): 1 kW
- Pel. (vacuum pumps): 5 kW
- Pel. (other equipment): 4 kW

total: 43 kW

- for comparison:

Pel. for mechanical cooling: 75 to 100 kW

(dependant on the availability of cooling water)

Comparison (1 km cable lenght):	mechanical	liquid N2
• Investment costs (single unit)	high	medium
• Redundancy	+ 100 %	+ 5 %
• Reliability	machines	pumps (only)
• Flexibility (cooling capacity / temperature)	design on the pointlow	oversizing at low costs
• Electricity consumption	app. 100 kW	9 kW
• liquid nitrogen consumption	---	68 kg/h
• total energy consumption (incl. N2 liquefying)	app. 100 kW	43 kW
• Energy consumption at deviation from design	exponential	linear
• additional operational costs for redundancy	yes	no ***

(redundant pumps not in operation) ***

Tank Installation

- 19.09.2013
- Transport
- Erection
- Installation and piping

People at work

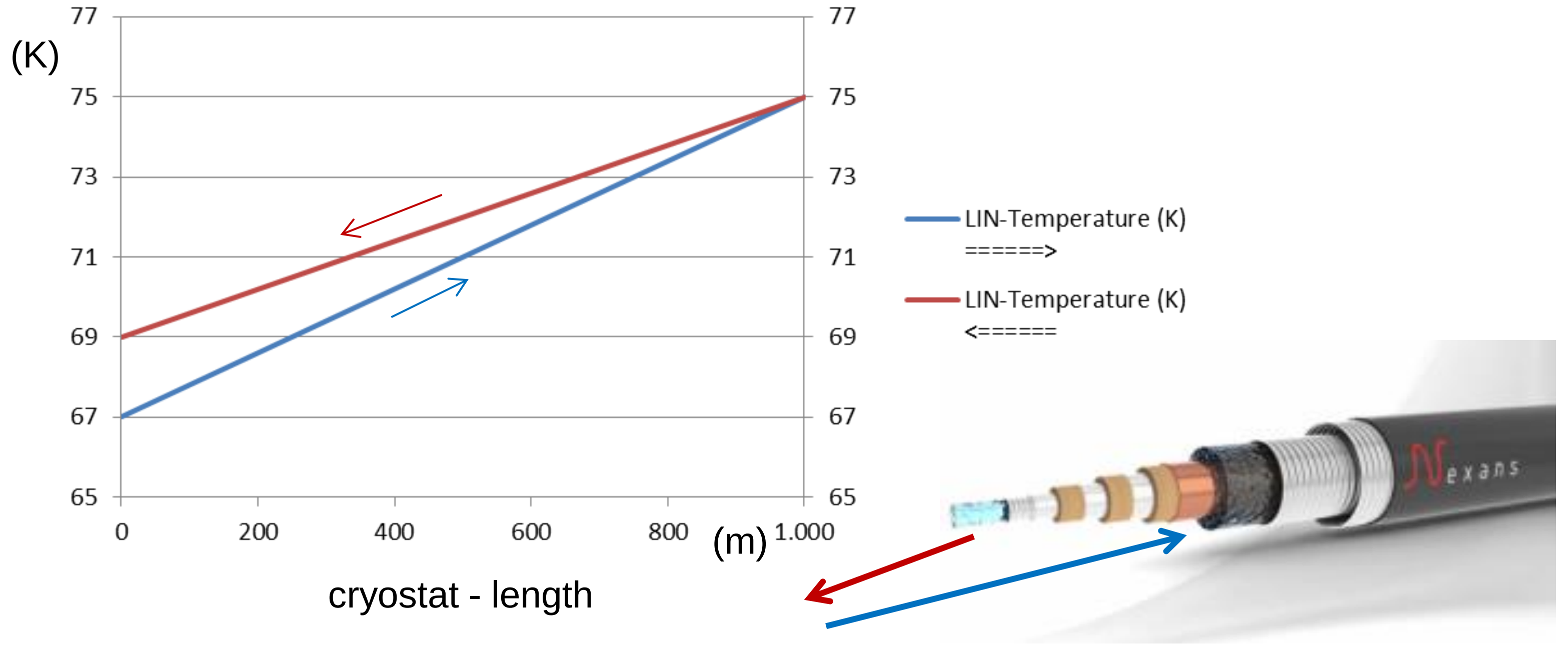
<u>Installation of:</u>

Cooling unit

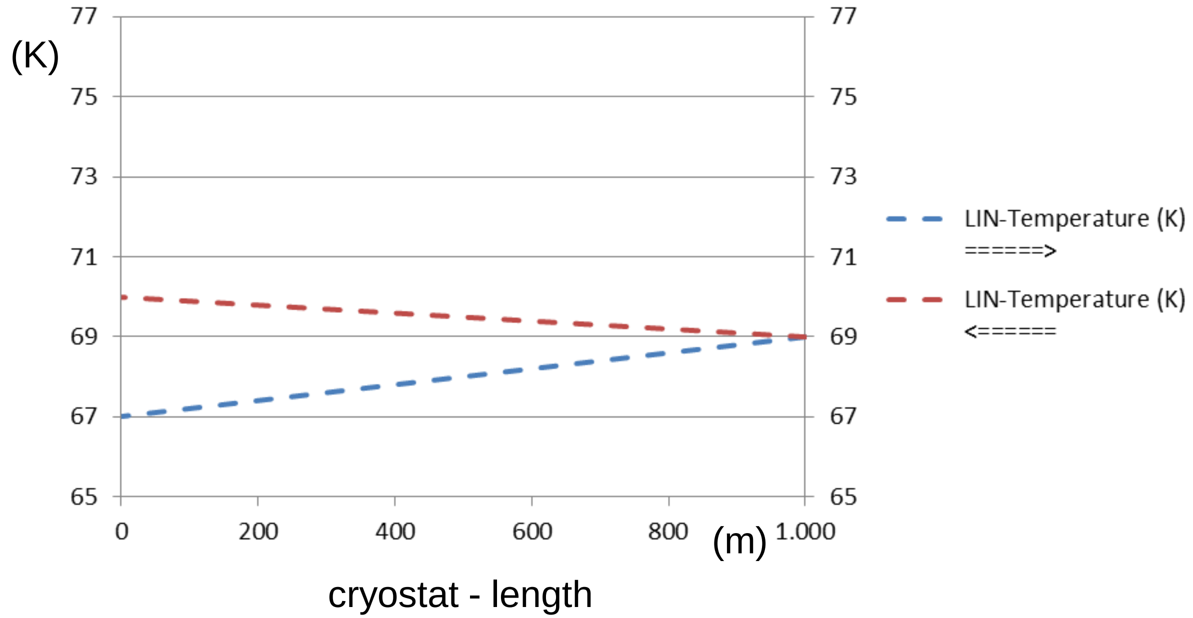
LIN-vessel

HTS-cable

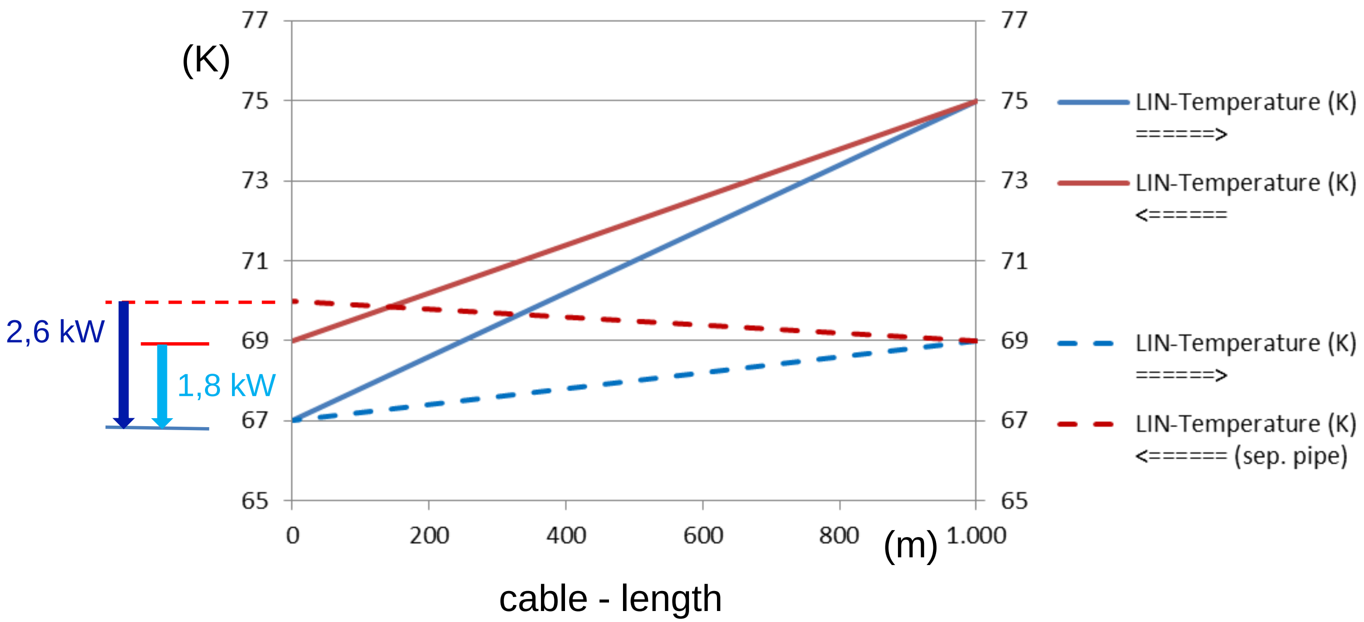
Liquid Nitrogen Temperature inside the Cable-Cryostat



Liquid Nitrogen Temperature Profile with separate return Pipe



Temperature Profile Comparison: concentric cable / cable with sep. return pipe



Electrical Energy Transfer

<u>typical lenght</u>

- 10 kV - cable: 5.000 m
- High current bus bar: 500 m

➔ lower heat impact through cryostat

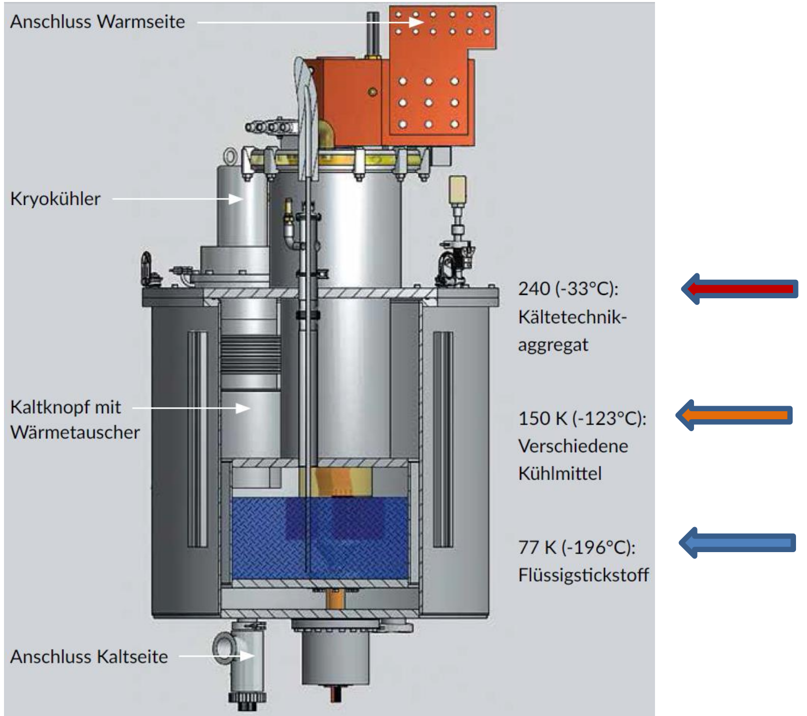
<u>typical current</u>

- 10 kV - cable: 2.000 A
- High current bus bar: 200.000 A

➔ add. heat impact through current leads

high current bus bar (e.g. for aluminium smelters)

Current Lead: ICE®LINK – Sytem from VESC (Vision Electric Super Conductors)



cooling system	required cooling capacity	temp.	P (el.) / P (req.)	P (el.)	for comparison
cryocooler (mech.)	4.250 kW	77 K	22	93.500 kW	100%
ICE LINK (VESC)	2.700 kW	240 K	1	2.700 kW	
	2.800 kW	150 K	6	16.800 kW	
	1.750 kW	77 K	22	38.500 kW	
			sum:	**58.000 kW**	62%
ICE LINK (VESC) with liquid nitrogen cooling	2.700 kW	240 K	1	2.700 kW	
	2.800 kW	150 K	6	16.800 kW	
	1.750 kW	77 K	10	17.500 kW	
			sum:	**37.000 kW**	40%

Conclusion

- AmpaCity is in regular opertion since 3 ½ years with great success.
- Operating data evaluation gives us the chance to design upscaled units very accuratly with quite precise forcasts of operating costs and reliability.
- Installations for typical distances of power distribution cables in urban areas (3 to 6 km) are easily feasable.
- Major advantage for urban installations are low space requirements for the installation.
- Major advantage for high current industrial installations are energy savings.

Thank you

IWC Workshop Karlsruhe 2017