Nitrogen liquefaction plants

for underground LNGS

Antonio D’Addabbo - 27 Jul 2021

Nitrogen liquefaction

Two needs at underground LNGS

CORRISPONDENZA GAS/LIQUIDO

GAS	m^3 gas a 15°C e 98067 Pa	Litri di liquido a temp. ebolliz. a 101325 Pa	kg
N_2	1 0,7048 0,8716	1,4189 1 1,2367	1,1473 0,8086 1

1 - DarkSide experiment

Provide cooling power from liquid nitrogen (LN) to keep ~700 tons of Argon in liquid phase (LAr) through re-liquefaction of evaporated Argon

2 - LN for uLNGS customers

Install in the LNGS a nitrogen liquefaction facility that could serve for the experimental sites/huts needs in the underground laboratory, other than Dark Side experiment

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1 - DarkSide experiment

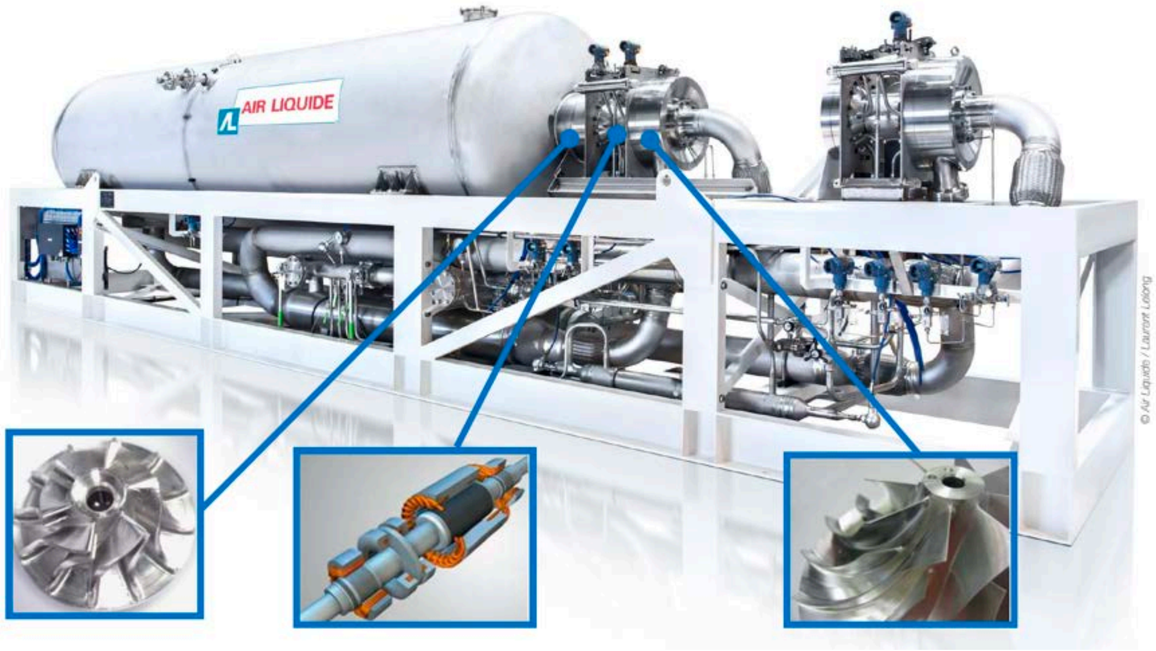
- Requested cooling power:
  - 11 kW @ 87K in normal operation
  - up to ~15 kW @ 87K during initial filling of the Dark Side tank with LAr
- Additional requests:
  - LN2 pumps
  - insulated lines
  - LN2 buffer volume

2 - LN2 for uLNGS customers

- Consumptions:
  - 1 050 000 kg of LN2 in 2020 (472 000 for BOREXINO)
  - ~490 000 kg of LN2 in first half of 2021 (205 000 for BOREXINO)
- Requested liquefaction rate:
  - uLNGS needs: ~105 scm/h (~150 l/h)
  - uLNGS needs without BOREXINO (-43.5%): ~60 scm/h (~85 l/h)
- In alternative we could accept an higher production if the system is modular and does not need to be on continuous operation

1 - Dark Side experiment

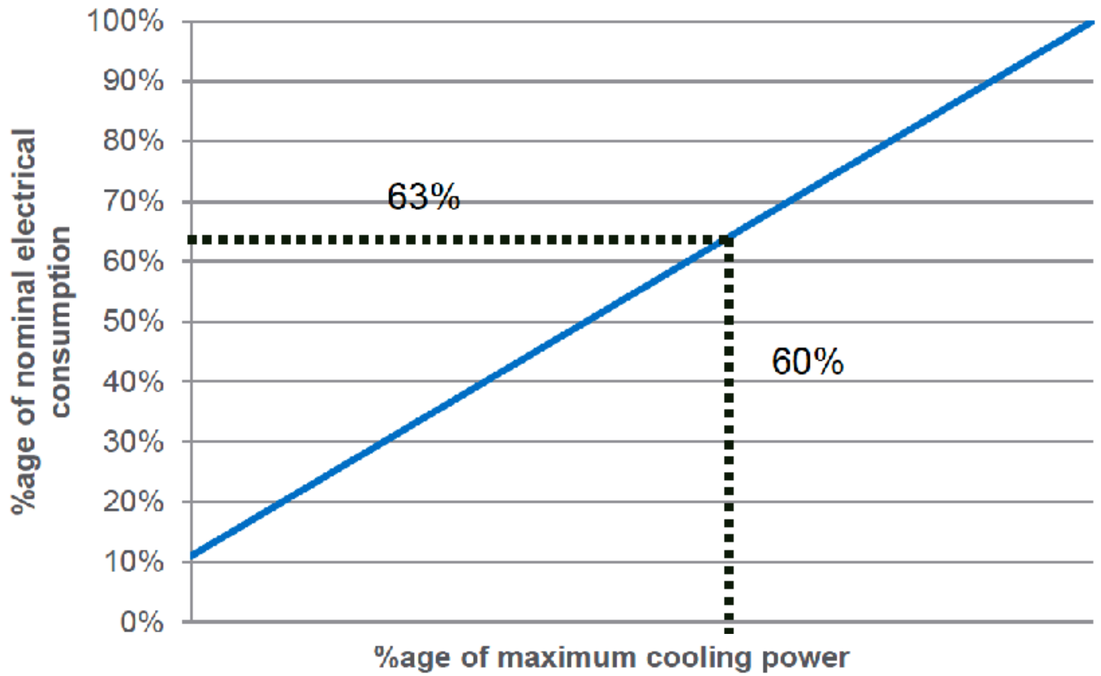
Turbo-Bryton (TBF) systems from Air Liquid

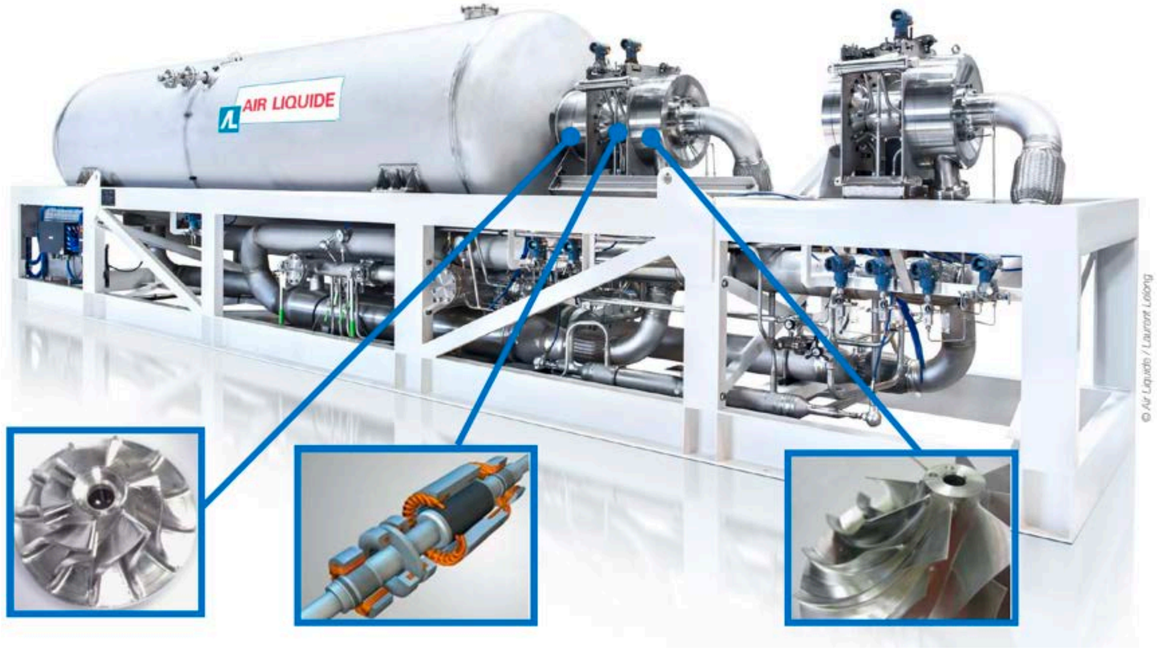


- Easiness of installation and operations (user friendly)
- High efficiency, reliability and lifetime
- Hermetic design
- 100% Oil-free (magnetic bearings)
- Capability of turning the system on/off several times
- It takes 3 hours from ambient temperature to cool-down the Turbo-Braytonand start subcoolingLN2
- Flexibility and modularity: stand-by mode with a low rotation speed (between 5 and 10% of electrical consumption depending on the product), and immediately subcoolLN2 at order

1 - Dark Side experiment

Turbo-Bryton (TBF) systems from Air Liquid





- High efficiency is an advantage for full load, but even more at partial load.
- At 60 % partial load, the overall efficiency of the refrigerator is only decreased by 3 %
- The cold power is automatically adjusted from 0 to 100 % by varying the speed of the motor. No valves nor heater are needed.

1 - Dark Side experiment

Turbo-Bryton (TBF) systems from Air Liquid

Specifications

System name	Electrical consumption	Cooling power @68K	Water cooling	Re-liquefaction capability	Size (LxWxH) (m)	Mass	Cost
TBF-175	200 kW	17 kW	9.3 Kg/s	~0.2 t/h ~174 smc/h	9.5 x 1.7 x 2.65	15 t	2.7 M€
TBF-350	410 kW	40 kW	18.6 Kg/s	~0.45 t/h ~394 smc/h	11 x 1.7 x 2.65	17 t	3 M€

1 - Dark Side experiment

Turbo-Bryton (TBF) systems from Air Liquid

Maintenance, warranty & co.

- Guarantee of 1 year (+ possible extensions)
- Maintenance: one intervention each 5 years, plus an intervention each 8000 hours for the additional LN pumps
- Delivery time is 14 months for the order, independently of the chosen system.
- Possibility of paying a part in advance vinculated to the delivery of the system

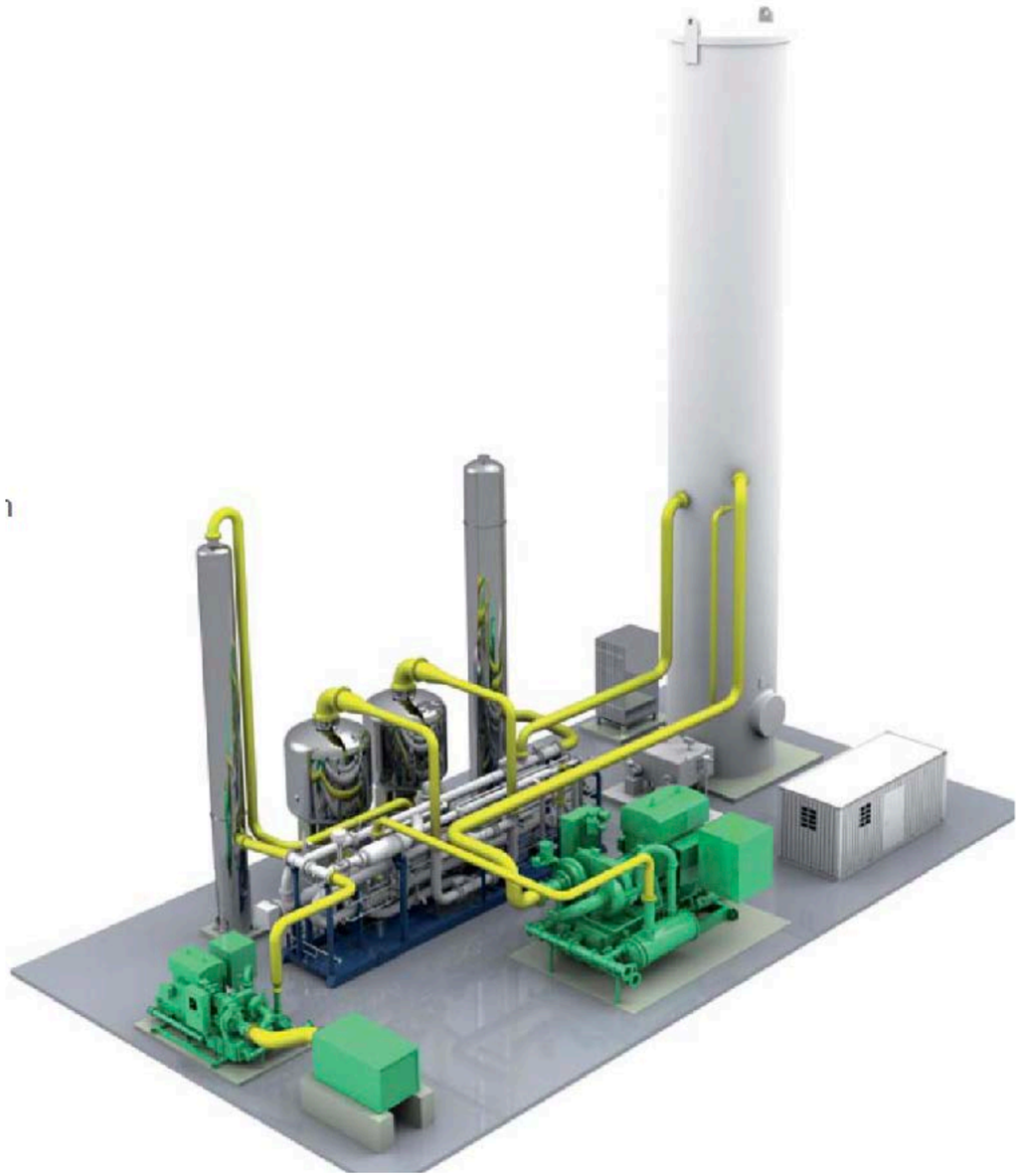
1 - Dark Side experiment

Additional thoughts

- The experimental facility is ~100 metres away from the installation site:
    - This would require installation of pumps on the LN tank. In this regard we should consider putting two identical pumping system such that one could serve as backup of the other, allowing maintenance without turning off the system
    - thermally insulated pipes for LN from the re-liquefaction facility to the experiment (~0.5 k€/m). Can be provided by Air Liquid. Need to take into account additional losses/inefficiencies for the final cooling power budget.
    - On the way back, the evaporated nitrogen should be recollected in gaseous phase by the re-liquefaction system with additional ~100 meter length recovery lines (less stringent needs on thermal insulation).
- The Dark Side experimental facility has a main tank of 700 tons of LAr, the idea would be to keep a buffer volume of LN large enough to serve as a cooling power reservoir in case of problems with the re-liquefaction facility.
    - The approximate amount of LN to keep the system cold would be of the order of 5 tons/day, so that a buffer volume of 10-15 tons would be reasonable
    - An idea would be to make it accessible from outside in emergency, in order to leave the possibility of refilling it with LN from trucks in case of problems on the re-liquefaction facility.

2 - LN for uLNGS users

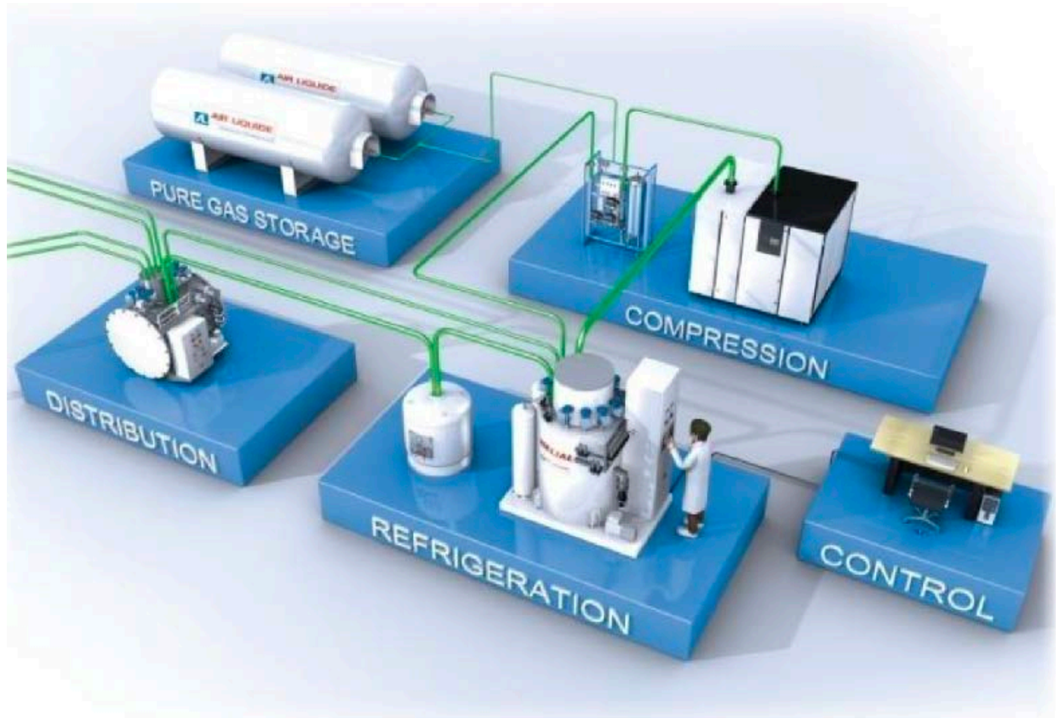
- Solution is not straightforward for uLNGS
  - Nitrogen recovery system at LNGS is not an viable option for the this kind of usage
  - Use bundles of compressed would require too many truck deliveries trucks in the underground
  - Need of insitu nitrogen distillation from air
- Industrial nitrogen liquefaction plants can liquefy nitrogen directly form air, but are over dimensioned for our needs and would require usually high distillation coldboxes (> 20 m height). SIAD is not a possibility, a check with AirLiquid is ongoing
- 2 possibilities:
  - Use the same TBF for both Dark Side and uLNGS needs
  - Disentangle Dark Side and uLNGS needs using two independent systems



2 - LN for uLNGS users

A single TBF for Dark Side and uLNGS needs

- Use part of the cooling power of the same TBFused for Dark Side, to liquefy nitrogen for uLNGS users too
- A TBF used in this way would suffer for a considerable reduction of its efficiency
- AirLiquid answered that liquefy ~100 litres/h of nitrogen could be feasible with a TBF-175 (17 kW @68 K)
- Given that the Dark Side needs would be of additional 13-15 kW @ 87K, a TBF-350 (40 kW @ 68 K) would be more than enough for both the systems



2 - LN for uLNGS users

An independent nitrogen liquefaction plant for uLNGS needs

Possible solutions

- **<u>Air separation + TBF-175 + heat exchange system</u>**
    - Couple a TBF-175 to a nitrogen separation plant that extract gaseous nitrogen (with a given purity) from air without liquefying it directly
    - Considerable loss of efficiency but feasible, the cooling power provided by the TBF-175 should be transferred to the nitrogen to be liquefied through exchangers
- **<u>Air separation + different liquefaction system</u>**
    - Couple a nitrogen separation plant to a direct liquefaction plant
    - Asked a study of feasibility to SIAD (70-80 smc/h, max 100-110 smc/h, evaluation of power and water consumption cooling power @ 77 K, maintenance, size, cost, delivery time, warranty, assistance)
    - SIAD minimum is not less than 500 smc/h. It could still be ok if it does not suffer if operated for few days each 1-2 weeks
- **Air separator types are for example Pressure Swing Adsorber (PSA) systems:**
    - Isocell (see next)
    - Cryotec

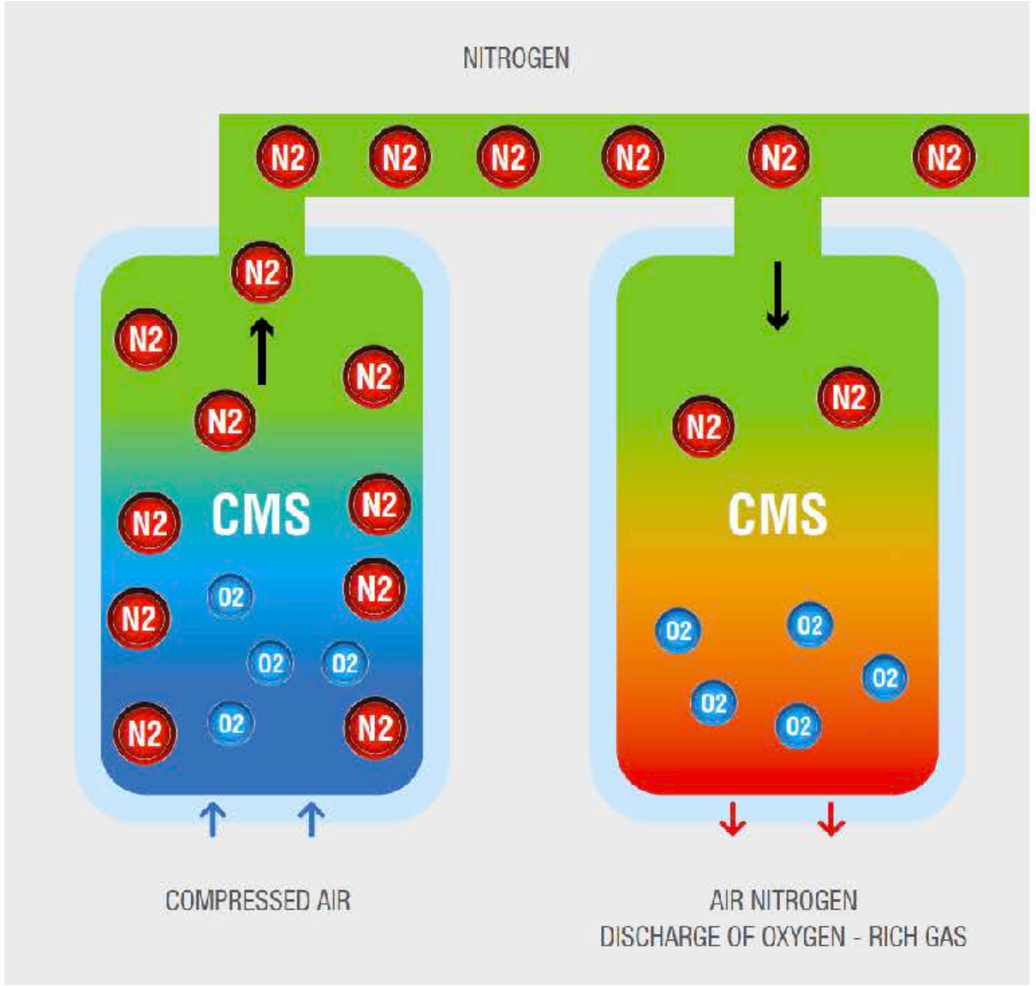
PSA nitrogen generator - Isocell

Working principle

Come funziona un Generatore PSA?

I nuovi Generatori d'azoto Serie M-S-D sono l'ultima evoluzione dei tradizionali sistemi PSA (pressure swing adsorber) che permettono di produrre Azoto in continuo dall'aria compressa. **I Generatori d'azoto Serie M-S-D sono costituiti da uno o più moduli** di due colonne riempite di setacci molecolari di alta qualità caratterizzati da una porosità molto fine e quindi ad altissime prestazioni e selettività. L'aria compressa, essiccata e filtrata, attraversa una delle due colonne filtranti che ne trattengono ossigeno, residui di vapore acqueo ed di altri gas rari.

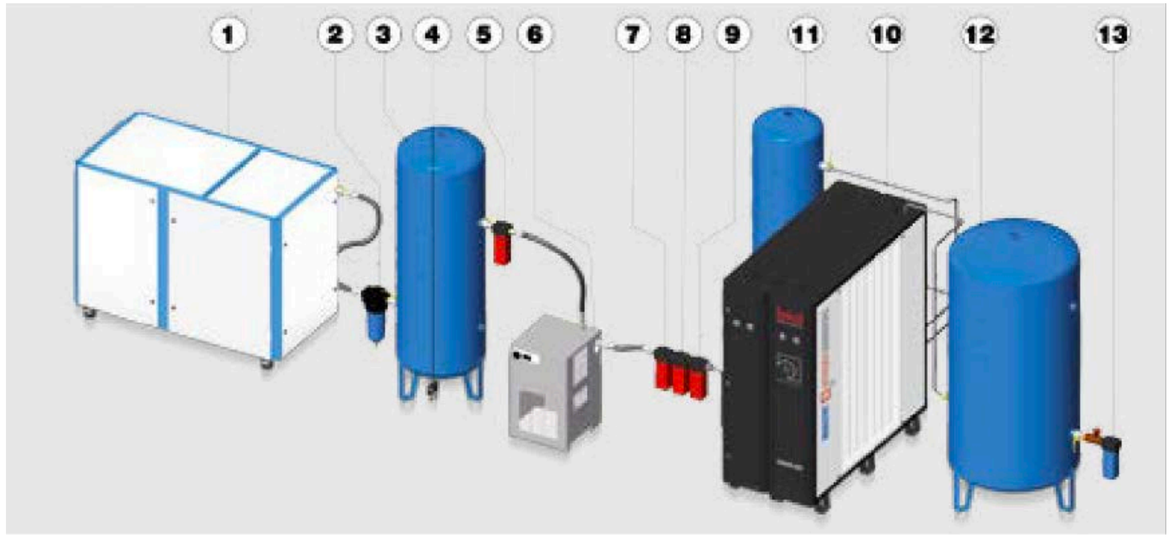
Quando la colonna filtrante si è saturata di ossigeno, viene depressurizzata scaricando l'ossigeno nell'aria. Nello stesso momento l'aria compressa viene deviata nell'altra colonna, cedendo l'ossigeno fino al cambio successivo. Questo ciclo continuerà ininterrotto da prima per riempire un serbatoio di accumulo, che funge da polmone per assorbire eventuali picchi di richiesta e poi per garantire l' erogazione continua di azoto al processo. Quando il serbatoio di accumulo raggiunge la massima pressione di riempimento il Generatore si pone automaticamente nella posizione di stand-by, in attesa di nuova richiesta di gas.



PSA nitrogen generator - Isocell

Series S-D

- Small size
- From few l/h to >1000 m^3/h
- Optimization for “multi banking” systems
- Modularity (adding filters in a single module and/or adding modules after first installation)



1 Compressore
2 Separatore ciclone
3 Serbatoio aria compressa
4 Scaricatore elettronico
5 Filtro universale
6 Essiccatore
7 Filtro fine
8 Micro filtro
9 Filtro a carboni attivi
10 Generatore d'azoto
11 Serbatoio di processo
12 Serbatoio di accumulo azoto
13 Filtro polvere

PSA nitrogen generator - Isocell

Flow rates

		LOW PURITY - LP [1]					HIGH PURITY - HP [2]				
Nitrogen purity rate		95 %	97 %	98 %	99 %	99,5 %	99,9 %	99,95 %	99,99 %	99,995 %	99,999 %
Residual oxygen		5 %	3 %	2 %	1 %	0,5 %	0,1 %	500 PPM	100 PPM	50 PPM	10 PPM
M1	Flow nm³/h (1)	8,6	6,9	5,9	4,7	3,8	2,5	2,1	1,4	1,2	0,8
M2	Flow nm³/h (1)	17,2	13,7	11,8	9,4	7,7	5,0	4,2	2,8	2,4	1,6
M3	Flow nm³/h (1)	25,8	20,6	17,7	14,1	11,6	7,6	6,4	4,3	3,6	2,4
M4	Flow nm³/h (1)	34,4	27,5	23,7	18,9	15,4	10,1	8,5	5,7	4,8	3,2
S2	Flow nm³/h (1)	34,4	27,5	23,7	18,9	15,4	10,1	8,5	5,7	4,8	3,2
S3	Flow nm³/h (1)	51,8	41,4	35,5	28,3	23,2	15,2	12,8	8,6	7,2	4,8
S4	Flow nm³/h (1)	69,2	55,3	47,5	37,9	31,0	20,3	17,1	11,4	9,6	6,5
S5	Flow nm³/h (1)	86,6	69,3	59,5	47,4	38,8	25,4	21,4	14,3	12,1	8,1
S6	Flow nm³/h (1)	104,2	83,3	71,5	57,0	46,7	30,6	25,7	17,2	14,5	9,7

Flow rates at standard atmospheric conditions (20°C / 1000 mbar / 0% RH)

[1] Accessory recommended: low purity sensor (electrochemical or zirconium)

[2] Accessory recommended: high purity sensor (zirconium)

PSA nitrogen generator - Isocell

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		LOW PURITY - LP [1]					HIGH PURITY - HP [2]				
Nitrogen purity rate		95 %	97 %	98 %	99 %	99,5 %	99,9 %	99,95 %	99,99 %	99,995 %	99,999 %
Residual oxygen		5 %	3 %	2 %	1 %	0,5 %	0,1 %	500 PPM	100 PPM	50 PPM	10 PPM
S7	Flow nm³/h [1]	121,8	97,4	83,6	66,7	54,6	35,8	30,0	20,1	16,9	11,4
S8	Flow nm³/h [1]	139,4	111,5	95,8	76,3	62,5	41,0	34,4	23,0	19,4	13,0
S9	Flow nm³/h [1]	157,2	125,7	107,9	86,0	70,4	46,2	38,8	26,0	21,9	14,7
S10	Flow nm³/h [1]	175,0	140,0	120,2	95,8	78,4	51,4	43,2	28,9	24,3	16,3
D6	Flow nm³/h [1]	209,2	167,3	143,6	114,5	93,7	61,4	51,6	34,6	29,1	19,5
D7	Flow nm³/h [1]	243,1	194,4	166,9	133,0	108,9	71,4	60,0	40,2	33,8	22,7
D8	Flow nm³/h [1]	276,7	221,3	190,0	151,4	124,0	81,3	68,3	45,7	38,5	25,8
D9	Flow nm³/h [1]	310,0	247,9	212,9	169,7	138,9	91,1	76,5	51,2	43,1	28,9
D10	Flow nm³/h [1]	343,0	274,4	235,5	187,8	153,7	100,8	84,6	56,7	47,7	32,0

Flow rates at standard atmospheric conditions (20°C / 1000 mbar / 0% RH)

[1] Accessory recommended: low purity sensor (electrochemical or zirconium)

[2] Accessory recommended: high purity sensor (zirconium)

PSA nitrogen generator - Isocell

Specifications

(2) Increased compressor flow rate in order to compensate evt. Compressor performance tolerance and ambient temperature fluctuations.

(3) Dew point at atmospheric pressure.

(4) Necessary for guarantee performance of the nitrogen generator (integrated).

(5) Standard for PSA NL M On Request for PSA S e D

Quality:	Class 1-4-1 ISO 8573.1 Solid < 0,1 µm Dew point < +3°C Oil < 0,01 mg/m³
Pressure:	6 - 10 bar (g)
Temperature:	0 ..... +45°C
Compressor Fad Flow rate: (2)	1,2 X Air Cons.

Outlet pressure:	0-9 bar(g)
Dew point: (3)	< 40°C

Power Requirements

Power Supply:	230 V / 50 - 60 Hz
Power Consumption:	max. 0,5 kW

● = standard equipment
○ = on request

Control panel	
4 line display	●
Purity monitoring and control	
O_2 Electrochemical Sensor 0-25 %	○
O_2 Zirconium Sensor 0-25 %	○
O_2 Zirconium Sensor 10-1000 ppm	○
Dew point sensor with indication on display	○
Flow meter with indication on display	○
Valves and accessories	
Back pressure control valve kit (5)	○ ●
Compressed air pressure sensor	○
Nitrogen buffer pressure sensor	●
Process tank pressure sensor	○
Exhaust silencer	●
Super exhaust silencer extern mounted	○

Logging and data handling	
Analog output 4-20mA (O_2 level)	●
Modbus RTU	●
Modbus RS485/USB serial converter	○
Profibus connection convert	○
Canbus connection convert	○
Ewon (webserver + sms alarm + data logging)	○
Digital remote control	●
Extern alarm digital input	●
Necessary accessory (4)	
Process tank with all accessories	○

PRO & CONS

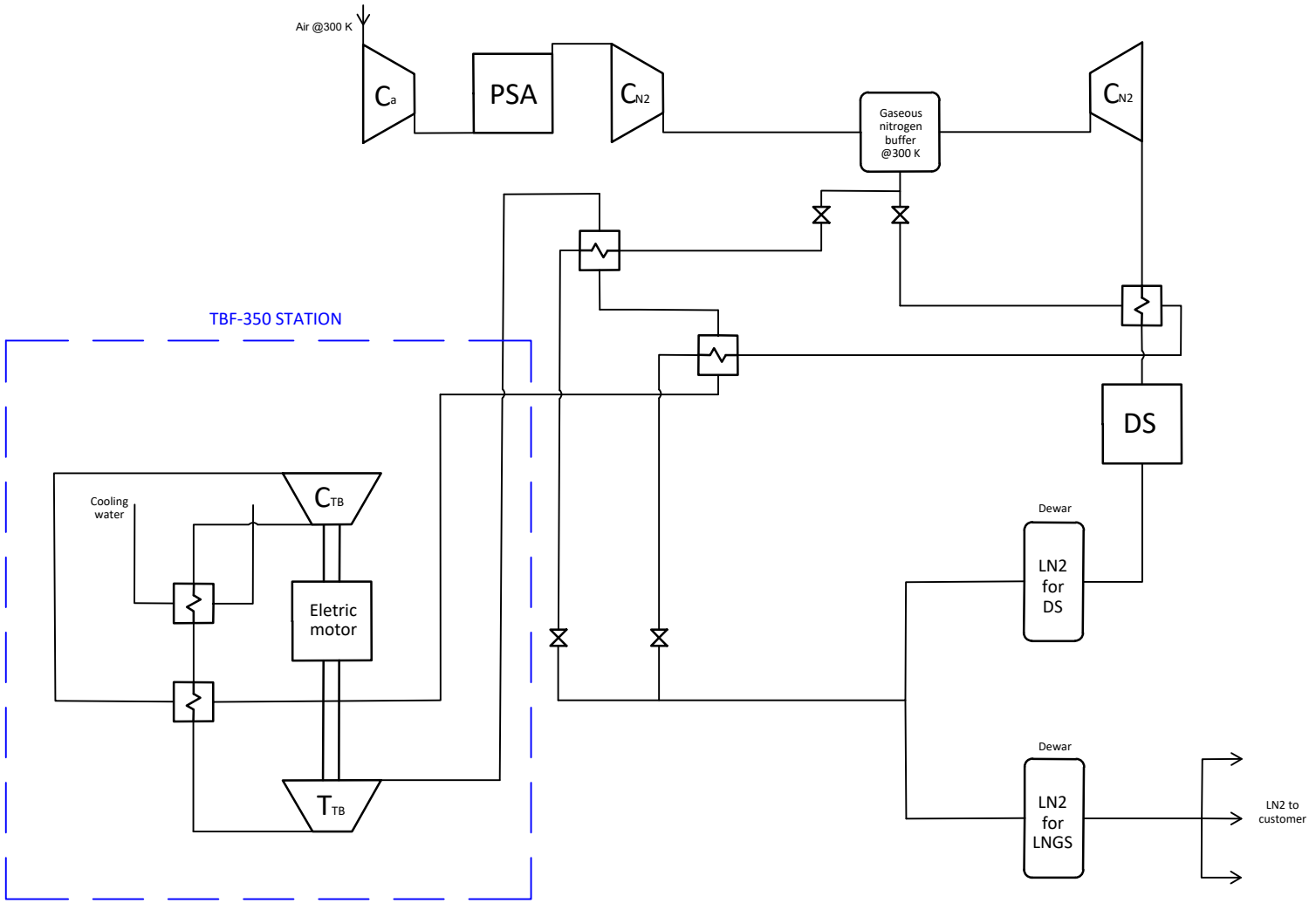
A single TBF for Dark Side and uLNGS needs

PROs

- Optimization of costs
- Modularity (tuneable cooling power)
- Flexibility (does not suffer for ON/OFF cycles)
- Can be started immediately after the installation for 2.
- …

CONs

- Two interconnected systems with very different needs
- Loss of efficiency (for 2.)
- Custom designed system
- Investigate deeper the feasibility with Air Liquid
- …



PLANT TITLE

Nitrogen Liquefier

Laboratori Nazionali del Gran Sasso - INFN

LEGEND					
	Ca Air compressor		Heat exchanger		Turbo-Brayton F-350 Station
	CN2 Nitrogen compressor	DS	DarkSide experiment	CTB	Turbo-Brayton compressor
	PSA Pressure Swing Adsorber		Valve	TTB	Turbo-Brayton expander

INFN LNGS

DATE 10/02/2022

SIZE A4